

# FULL ABSTRACT CITATIONS

## Acosta, J.C. • Medrano, J.

A platform for automatically characterizing network layer attacks in tactical and strategic networks.

## Ahrens, A. • Jefferson, S. • Tovar, A.

Material recycling in 3D printing/material sustainability in additive manufacturing.

Plastics experience degradation resulting from environmental exposure including oxidation, heat, and ultraviolet light. The effects of environmental exposure manifest in two ways: polymer chain segmentation and polymer chain crosslink. These can either increase or decrease the molecular weight of the polymer chains. As a result, physical properties such as melting point, tensile strength, and hardness can change due to the change in the molecular structure. The changed material properties can pose major challenges for the recovery and reuse of plastics, especially in additive manufacturing. Currently, the use of recycled plastic in additive manufacturing is hindered by process difficulties (e.g., clogging) and property loss (e.g., brittleness). The objective of this project is to identify the optimal recycling process parameters to reclaim plastics and make them available in additive manufacturing. The focus of this work is on the fused deposition modeling (FDM) additive manufacturing technology. The plastic blends explored in this work include Acrylonitrile butadiene styrene (ABS)—most common material used in FDM—and High-density polyethylene (HDPE)—the most ubiquitous plastic in industry. The project has three phases. The initial phase provides data to demonstrate the need to reclaim material for FDM. The second phase demonstrates the challenges of material recovery by utilizing mechanical reclamation, i.e., sort, shred, grind, extrude and reuse. The second phase also provides test data to confirm the extent of material property loss by the “mechanical” reclamation process. The third phase of the project focuses on introducing additives (antioxidants) to the process, which improves the viscosity and flexibility, thus improved 3D printing process, as well as the properties of final product. The project opens up an opportunity to combine a mechanical process (3D printing) with material science and nanotechnologies to create a practical approach to improve the sustainability of material use in additive manufacturing.

## Akinwande, D.

Graphene electronic tattoos for imperceptible human monitoring and human-system interfaces.

Electronic tattoo sensors made from atomic nanomaterial, graphene, have been developed and can be seamlessly integrated onto any part of the skin for applications ranging from human physiological health sensing/monitoring to human-machine interfaces for remote and gesture control. These tattoos have several attractive features including invisibility, imperceptibility and conformability onto human skin without the need for any adhesive tapes typically used in other types of electronic tattoos. Once laminated onto the skin, the tattoos can sensor a variety of human electrophysiological signals including EEG,

ECG, EMG and EOG. Moreover, body temperature and hydration can also be monitored. A major challenge for the further development of these atomic electronic tattoos is the full integration of a wireless interface for data and power. Finally, we demonstrate prototype graphene electronic tattoos for mobile health monitoring and for wireless gesture control of a drone.

## Ali, A. • Chandra, N. • Hanna, M.J. • Kleinberger, M. • Pfister, B.

Variability in human head surrogate data with changes to boundary conditions in blunt and blast trauma.

Purpose: The objective of our research is to determine the biomechanical link between the traumatic brain injury (TBI) event (blunt, blast, etc) and damage to the brain. Damage to the brain has been directly correlated to the degree of brain deformation. Since the mechanical behavior of biological materials is time-dependent (viscoelastic), it is likely that physical contact (lasting in the range of milliseconds) and blast exposure (no physical contact with a shock wave passing through head in microseconds) will illicit different responses. To elucidate these differences, we developed custom-made head surrogate models to record deformations occurring in the brain during different injury scenarios with high speed photography. Sagittal sections of the surrogate model were cut for real-time viewing of damage during replicated head injury events. Our objective is to characterize the mechanical behavior of the brain during various injury scenarios, as seen through the surrogate model’s window. Theme: According to the Defense and Veterans Brain Injury Center, “no cognitive differences have been identified between blunt and blast induced concussions” and “since most evidence suggests that blast and blunt TBI are very similar, there’s no difference in the treatment.” Our data suggests otherwise, with clear differences seen in the deformation patterns of the surrogate brain. TBI pathology begins with a mechanical insult, also known as the primary injury. Characterizing its effects in various injurious scenarios may help to improve warfighter TBI diagnosis, treatment, and prevention. Design/Methodology/Approach: Physical head models consisting of a skull, brain, and neck were constructed. The skull materials tested include PVC (Anatomy Warehouse), ABS (Stratasys), and Veroclear (Stratasys). The skulls were cut at different offsets from the midsagittal line creating ½, ¾, and “full” skulls. Brain materials tested include 5%, 10%, and 20% ballistics gelatin (Clear Ballistics). The neck used was the Hybrid III 50th Percentile Male. One surrogate iteration attempted to model cerebrospinal fluid (CSF) as a fluid-filled (water) space between the brain and skull. Some models also included strain gauges on the skull surface. Blunt injury scenarios were replicated with a uniaxial impact machine. Tests were done with a ~10lb metal impactor, the approximate weight of a human head. Impactor speeds were controlled to make contact at 3 or 5 miles per hour. The surrogate heads were oriented to be impacted at either the crown or forehead. A shock tube was used to generate shock waves similar to those generated with high-order explosives and deliver the energy to the head models. Head surrogates were set at

a neutral orientation, that of a standing person, and exposed to 70kPa overpressures. All tests were recorded with a high speed camera at either 2000 (blunt) or 5000 (blast) frames per second. Visual markers within brain surrogates were used to motion track deformations and extract strains (principal tension, principal compression, max shear). The movement of a selected grid of markers on the brain surface were captured using motion capture software ProAnalyst and exported into MATLAB. A custom algorithm was written to analyze the data. Findings: Maximum principal shear strains (~21-25%) in the brain during crown and forehead impacts were near the point of impact, but during forehead impacts the contrecoup region of the brain also experienced similarly large strains. Regions of the brain surrogate with increased strains remained elevated regardless of the ballistics gelatin percentage (at 20%, 10%, or 5%) or of injury modality (blunt or blast). However, the distribution of strain values shifted toward larger values as the gel became less stiff and the regions of increased strain had larger peak values. Reducing the amount of skull flexion in the surrogates during blunt impacts also reduced the brain deformations. Inclusion of CSF changed the deformation pattern in the brain during blast, however enough data has not yet been collected to quantify this effect further. Practical Applications: Brain deformation is what initiates damage to the brain. Mapping the spatial and temporal brain deformation due to specific head injury cases will provide insight into where injuries are likely to originate. This data can also be used to develop more precise tissue models of TBI. This approach is also being used to scale between models such as human to pig (a common TBI model). Finally, the methods used can be used as a platform for validating finite element modelling to further the research.

## Anglin, D. • Major, J.

Advanced Combat Engine (ACE): opposed piston advantages.

The OP Engine eliminates the cylinder heads so it has a reduced surface area to volume ratio of the combustion chamber (i.e. less surface area relative to the volume) for reduced heat transfer and heat rejection. This has numerous benefits: Less heat is wasted through the cooling system, enabling more of the fuel energy to be used for useful work; reduced heat transfer enables earlier and more efficient combustion; and reduced heat rejection to coolant enables reduced cooling system and radiator size resulting in reduced armor opening sizes and reduced under-armor volume required for powertrain components. The OP Engine takes advantage of the inherent power density of a two-stroke cycle by reducing displacement (reducing the size, mass, and cost of the engine). The OP Engine has efficient, uniflow scavenging that decouples the pumping work from the engine speed. At low loads, the engine can retain a high proportion of exhaust gases by reducing the supercharger work, which improves efficiency. The combustion system developed by Achatés Power uses diametrically opposed dual injectors with proprietary piston shapes to provide excellent fuel and air mixing, resulting in low soot combustion and reduced heat transfer to the combustion chamber walls.

**Asher, D.E. • Barton, S.L. • wPerelman, B. • Schaffer, J. • Waytowich, N.R.**

### **ALLIES: Agent Learning Leveraging Intelligent Engagement with Soldiers.**

Utilizing learning agents in the field requires the development of collaborative, adaptive, human-aware systems that learn to take actions based on the dynamic activity in the local environment and their human counterparts, acting effectively as teammates rather than tools. We propose that a novel ensemble of 1) deep reinforcement learning (RL), 2) multi-agent RL, and 3) human-guided RL is a candidate for effective, adaptive computational teammates. Our work explores a three-armed approach towards the development of computational teammates that leverages state-of-the-art advances in RL to discover the emergence of intelligent engagement with Soldiers via collaboration. Modern Soldiers need increasing capabilities to provide overmatch in the multi-domain battlespace. In many situations, these capabilities will involve Soldiers collaborating with intelligent systems to successfully complete their missions, utilizing adaptive collaborative technologies that will be expressed in the next generation of combat vehicles. Classic human factors research has shown that optimal strategies and behaviors do not necessarily lead to successful collaboration. Non-effective teaming can result if the autonomous system implements optimality instead of prioritizing collaboration with the Soldier. Therefore, the next generation of autonomous combat vehicles will need to leverage learning agents that engage intelligently with Soldiers across different Military Occupational Specialty (MOS) codes having diverse capabilities, aptitudes, preferences, and most importantly, performance. Our work focuses on creating a general collaborative agent as an effective teammate for any Soldier. Our three-armed approach provides a systematic assembly of a framework designed to generate collaborative computational teammates in problem domains that have shared objectives. First, the limitations of RL are ameliorated with multi-agent deep learning, which permits solutions to problems with greater complexity. Second, human reward-shaping can constrain agent exploration of the action space and speed up the discovery of effective behaviors and strategies. Third, human behavioral profiles or parametrization of human capabilities derived from surveys of work-interest variables and human-human teaming experiments associated with MOS codes can help tailor agent behavior to the needs, duties, and capabilities of different Soldiers. This approach addresses the problem of computational teammates at three critical levels: 1) the necessary computational framework, 2) the learning paradigm needed to discover and optimize team behavior, and 3) the human dimension that contextualizes behavior. Producing collaborative computational agents is not a trivial problem. It requires a means for agents to sense the actions, intentions, and needs of human partners in a robust and online fashion. We suggest that collaborative agents may be thought of as a narrow AI problem that does not require solutions to the open questions of general AI. Rather than seeking to define the computational principles of intelligent engagement

with Soldiers (i.e., collaboration) explicitly, we aim to leverage human intelligence by creating agents capable of learning collaboration continuously via human interaction. Achieving collaboration, and to a broader degree teamwork, between humans and computational agents requires engendering agents with an ability to adaptively respond to the actions and needs of their human partners. Human-guided RL research provides a powerful set of algorithms that can learn complex behaviors from experiences with the human partner. Ultimately, the output of any RL procedure is a function (exact or approximate) that maps states of the environment into actions taken by the agent. While RL procedures are capable of producing a tabular or discrete mapping from states to actions, such mappings quickly become computationally (and conceptually) unwieldy as the complexity of the environment and the agent's action choices grow. Thus, the combination of deep neural networks with RL to learn virtually any mapping from states to actions solely through experience, is an incredibly powerful theoretical concept for creating collaborative computational agents that can operate in dynamic environments. Mapping complex states to actions also provides a mechanism for computational agents to learn through interacting with human partners, which has improved upon state-of-the-art algorithms by reducing 4 days of training to 15 minutes in at least one case. The goal of our three-armed approach for developing collaborative agents is to create a framework that trains agents to help complete the mission, enhance Soldier capabilities, and perform with intelligence to ensure overmatch. We view these agents as teammates that augment Soldier performance based on their innate behaviors.

**Avera, M.**

### **High fidelity VTOL flight simulator for UAS platform assessment.**

The purpose of this research is to develop a virtual vertical takeoff and landing (VTOL) platform assessment capability for manned and unmanned aerial system (UAS) platforms by integrating high-fidelity flight dynamics and the latest in 3D graphics engines. In a single simulation environment, a selectable fidelity model of a VTOL concept's flight mechanics and performance is directly controlled by an optional navigation controller. The result is a tool to test autonomous control algorithms such as path planning, trajectory following, localization, and more along with flight characteristics and handling quality assessment of novel VTOL aircraft. This capability has applications to the Future Vertical Lift and Soldier Lethality Chief of Staff of the Army Modernization Priorities. The simulator consists of 3 core components: the 3D graphical environment, the aircraft flight dynamics model, and the optional navigation controller. Aircraft motion is simulated using Flightlab, a rotorcraft flight dynamics code with real time-simulation capability. The vehicle's material, geometric, and aerodynamic properties and stability flight controller are used to simulate the aircraft's motion from prescribed control inputs. Data about the vehicle's state is sent to the 3D graphical environment which is built using the Unity3D engine. The graphical environment serves two

purposes, to provide a visual 3D representation of the scenery which the vehicle moves through, and to simulate sensors on board the vehicle such as cameras, LIDAR, and altimeter. Virtual scenery including buildings, vehicles, and terrain can be constructed to a high level of graphical detail. The quality of objects in the scene is important to mimic the performance of on board sensors, especially visual based sensors. The physical appearance and shape of the virtual objects will be reflected in the sensor data such as camera images or LIDAR point maps. Sensors are modeled in the graphics engine by various techniques such as ray casting with applied noise, distance limits, and time delays to mimic LIDAR or depth sensors. These virtual sensors provide data to the navigation controller. The navigation controller will leverage existing intelligent control techniques and algorithms to provide path planning, trajectory following, and localization capabilities. It will incorporate the Robot Operating System (ROS) to receive sensor data from the graphical environment. The use of ROS allows for the implementation of many open-source and research oriented tools to accomplish many important UAS tasks such as simultaneous localization and mapping (SLAM), visual perception, and obstacle avoidance. This data can inform AI-based controllers which make higher level decisions about navigating the environment. This effort is early in the development process. As it sits today, only piloted operation available with or without viewing from a HTC Vive virtual reality headset. The current progress is focused on closing the data transfer loop to enable autonomous operations. Once completed, the flight simulator has a number of applications which include simulations for training AI-based decision making algorithms in wide variety of mission scenarios, testing of AI-based flight controllers, and assessing mission performance impact of VTOL platform and configuration modifications.

**Behler, K.D. • LaSalvia, J.C. • Marvel, C.J. • Shoulders, W.T. • Vargas-Gonzalez, L.R.**

### **Advanced ceramics for future soldier protection technologies.**

During the past 75 years, the U.S. Army has been driven by the need for increased Soldier survivability and mobility to continually develop lighter weight protection technologies. This was enabled through the use of ever lower density materials specially processed to tailor their properties to meet specific threat and mobility requirements. During approximately the last thirty years, body armor for the dismounted Soldier has been based on ceramic "strike-face" plates bonded to polymer composite backer (or "catcher") plates. Thirty years ago, the ceramic and polymer composite were based on alumina and Kevlar, respectively. Today, the ceramic is either monolithic silicon carbide or a silicon carbide/boron carbide composite blend bonded to high-molecular weight polyethylene. Today's body armors are not only lighter than these legacy systems (15% lower in areal weight), but also provide significantly improved levels of protection. For Future Modernization, the U.S. Army has set the goal of at least 15% lighter than

today's systems. To achieve these lightweight armor goals, new material technologies will need to be developed, to include new ceramic and polymer materials or current materials processed in new ways thereby achieving new structures that mitigate current material deficiencies related to their ballistic effectiveness. This presentation will give examples of on-going ceramics' research projects that are exploring both paths: the development of armor-grade boron suboxide and hierarchically-structured boron carbide/silicon carbide composite blends. Monolithic boron carbide has been very successfully used in previous body armor technologies. However, new performance requirements have precluded the development of lighter weight body armor technologies based on traditional monolithic boron carbide. This is believed to be due to the discovery that boron carbide can undergo stress-induced amorphization when impacted at stresses above its Hugoniot Elastic Limit which appears to facilitate fracture and fragmentation. A new ceramic material, which is considered an alternative to boron carbide, is boron suboxide. It is of interest not only because it is considered to be harder, but also because it appears to be less prone to the negative effects of stress-induced amorphization. The two primary challenges to developing boron suboxide for body armor applications are achieving both full density and increased fracture resistance. Because of low self-diffusion and decomposition reactions above 1750 oC, boron suboxide is most easily densified using pressure-assisted sintering methods such as hot-pressing with the use of sintering additives. At ARL, the effects of sintering additives and hot-pressing temperature on the densification and microstructure of boron suboxide were investigated. Overall, it was found that silica and silica - rare-earth oxide additives, with contents between 1 - 5 vol.%, were most effective in achieving full densification and controlling microstructure. For certain additive chemistries and hot-pressing temperatures, abnormal grain growth was observed, resulting in a self-reinforced microstructure believed to possess increased fracture resistance. Improvements in densification behavior and changes in microstructure are believed due to changes in the chemistry and structure of grain boundaries in these materials as shown by aberration-corrected scanning/transmission electron microscopy. This project demonstrates that the development of fully dense boron suboxide bodies possessing increased fracture resistance is possible by effectively engineering their interfacial boundaries at the atomic and nanometer length-scales. The silicon carbide/boron carbide composite blends used in some of today's body armors represent success stories of structurally engineering the ceramic plate at the micro-scale to achieve lightweight requirements. Each manufacturer has undergone its own path to optimization. However, performance-dictating aspects of these complex materials, such as residual stress, micro-cracking, and an overall more complete description of the microstructure, fall outside the typical interest of an industrial R&D operation. In our view, further investigation of these details is necessary to reach the next generation of lightweight armor ceramics. A better understanding of ceramic composite armor performance is achieved by examining hot-pressed, particulate reinforced blends over the entire composition range from pure silicon carbide to pure boron carbide in 10 wt.% increments. Observations in the cracking behavior during micro-indentation tests, residual

stress measurements using x-ray diffraction and Raman spectroscopy, and quantitative stereology of optical and electron micrographs are used to gain insight into the performance of silicon carbide/boron carbide composite blends. Experimental procedures and detailed findings will be presented and discussed.

**Benard, W. • Clark, S. • Kott, N. • South, J. • Zunino, J.**

**Army additive manufacturing: expediting material to materiel.**

The Army Research and Development enterprise has invested significant resources in Additive Manufacturing (AM) over the last several years to advance the Army's ability to produce parts on-demand and by-design. The focus has been on developing new materials for AM, developing process expertise to improve materials properties once printed, and investigating the expanded design space AM has to offer. In addition, user experiments (for example R-FAB) have been executed, to get AM in the hands of the warfighter to better understand the application space and learn about the benefits and challenges of pushing capabilities into the theater. Coordination and collaboration across the R&D enterprise has been coordinated through the RDECOM AM Community of Practice (CoP) to provide a comprehensive capability supporting modernization. The Army has unique materials needs due to the challenging environment in which our ground forces operate. AM material sets are processed in different ways, with widely varying facilities needs. For example, conventional metal processing requires temperature and humidity control, and consumes significant power. Polymer processing on the other hand, can be relatively simple and energy efficient; however, the resultant materials properties limit the potential uses. The Army is strategically developing new AM materials for deploy-ability, structural properties, complex function and energetics. Closely-coupled with the Materials development is process development. The properties of a material are only of interest as-printed. Significant effort is being invested in the development of processes to deliver high performance materials, as well as to drive toward broad process windows for robust processing. Additionally, efforts to instrument and model AM processing, are providing insight into build limitations and help identify failures early on for early termination or repair. The ultimate goal for the process models is to tune the materials properties for function within a part. For instance, a lever arm may have a high-hardness surface for advanced wear properties, while the bulk may have require strength balanced with ductility for load. The ability of AM to place material almost arbitrarily within a volume opens a design space almost impossible to achieve via conventional manufacturing approaches. The design space is further expanded by the ability to mix materials within a build. The relaxation of design constraints has significant potential for realizing fundamentally new classes of high performance material across a wide range of applications, but is extraordinarily complex. Consequently a new class of design tools is in development to access this space, and the integrated circuit model of parameterized designs is being applied to offer tailored but verified design spaces for application specific performance. An open-architecture topology optimization engine has demonstrated the ability to be rapidly adapted to and solve complex Army specific design challenges.

Additionally, parameterized UAV designs are rapidly instanced to meet a given mission profile, and custom parts are printed using AM to complete the assembly.

**Besaw, L.E. • Allmen, M.**

Dismount following by an unmanned autonomous ground vehicle.

**Besaw, L.E. • Lupo, J. • Sgroi, A.**

**Generative adversarial networks for thermal imagery data augmentation.**

Introduction: Automatic Target Recognition (ATR) technologies are used in critical C4ISR aspects the Air Force, Army and Navy. ATR operates across a wide range of sensor modalities, including seismics, acoustics, sonar, and all exploited regions of the electromagnetic spectrum (electro-optics, infrared as well as airborne and ground-based radar). Currently the US Army's ground-based thermal sensing and ATR systems are used to detect enemy troops and vehicles in low/no light conditions. The US Army Night Vision Lab (NVL) is looking to continue developing develop thermal sensing and ATR technologies with high probability of detection (Pd) and low the false positive rate (FPR). Machine Learning (ML) and Artificial Intelligence (AI) technologies are increasingly being used as the backbone of ATR systems. Deep Learning (DL), a recently emerging division of ML and AI, demonstrates human-comparable performance in many complex recognition tasks, including object recognition in images and video. DL has been successful in ATR software because it learns important features, data representations and discriminant functions directly from large, annotated training datasets. As a result, acquiring high-quality training data is more critical than ever before. Unfortunately, collecting and annotating training datasets large enough for DL and ATR technologies is very slow, labor intensive and expensive. Purpose: With support of NVL, ARA/Neya is researching a state-of-the-art approach that may revolutionize the way ATR algorithms are developed. We are researching the use of Generative Adversarial Networks (GANs) to model complex patterns in thermal imagery and generate new imagery that is indistinguishable from real imagery. GANs are an unsupervised learning approach capable of generating color imagery that looks photo-realistic to the point that it can fool human evaluators in to thinking the imagery is real. We are researching the use of GANs to generate photo-realistic thermal imagery to augment existing thermal imagery datasets which will aid thermal ATR systems. Theme: This research relates to several focus areas of the symposium. GANs are a specific DL approach within general AI and intelligence systems. AI technologies are transforming the ways in which soldiers operate within the C4ISR chain as human capabilities are continually being improved with human-machine interaction. Our research may significantly improve thermal sensing and ATR systems, providing Warfighters greater situational awareness in low/no light battle filed environments. This will have significant impact on the C4ISR chain in future military operations and increase the lethality of our soldiers by optimizing and enhancing their existing performance. Design/Methodology/Approach: Our approach followed traditional AI development paradigms. We extracted imagery from a large corpus of thermal videos collected and annotated by NVL.

These videos contained a number of specific targets and natural scenes at different locations and times throughout the diurnal cycle. We sampled this very large dataset and conducted detailed analysis to ensure the extracted imagery was of sufficient quality for GAN training. We developed a number of GAN architectures to learn the latent image distributions. We experimented with many GAN parameters and optimized the photo-realism of generated imagery using Nvidia GPUs to accelerate the training process. GPU-accelerated computing reduced training time from days to hours. We developed novel scoring metrics to evaluate the photo-realism of our GAN-generated imagery. Findings: Our research demonstrates that GANs can generate large volumes of photo-realistic thermal imagery. This imagery looks realistic based on our derived scoring metrics as well as when evaluated by humans. Practical Applications: Our GAN thermal imagery will be used to further train and refine existing ML-based ATR systems. By generating large volumes of realistic background scenes, ATR algorithms will be able to significantly lower their FPR. Our effort may also lower the overall cost of data collection efforts, enabling more efficient use of fewer resources. GANs may also be able to generate target imagery and even “un-mask” partially obscured targets in order to improve the Pd performance of ATR algorithms. These technologies may also be extended to other ATR sensing modalities (seismic, acoustics, sonar and radar). Original Value: This is the first application of GANs to thermal image generation for military applications. By generating photo-realistic data, GANs can significantly increase the impact of a number of existing datasets and make the collection of additional datasets less expensive. The potential of this technology is “invaluable” as described by NVL personnel who are familiar with the excessive costs associated with collecting and annotating these types of datasets.

**Birdwell, A.G. • Ivanov, T.G. • Neupane, M.R. • Shah, P.B. • Weil, J.**

#### Diamond RF electronics for long-range precision fires.

Subsystems for long-range precision fires that enable navigation and guidance, fuzing, and target seeking abilities could benefit significantly from radio frequency (RF) power transistors that fundamentally advances thermal and output power capabilities. This is due to the ever increasing demands placed on the subsystems' control electronics by harsh thermal environments and output power requirements of the microwave sources. As a result, next generation electronics for Army RF systems could be diamond-based due to the superior thermal performance of diamond over current semiconductor technologies, e.g., gallium nitride. Additionally, other fundamental material parameters suggest diamond will outperform all other established materials for RF power devices. As a result, the Army Research Laboratory (ARL) has an in-house program to develop RF field-effect transistors (FETs) on hydrogen-terminated diamond surfaces. These devices are fabricated on single-crystal diamond substrates, and employ both atmospheric adsorbates and molybdenum trioxide (MoO<sub>3</sub>) as the transfer-doping electron acceptor layer leading to a free-hole current channel.[1] In this work, we present an overview of ARL's device fabrication process together with the DC and RF characterization results for FETs fabricated with gate lengths ranging from 4  $\mu$ m to sub-

100nm. This demonstrated technology compares favorably with reported state-of-the-art results, in terms of DC and small signal performance. [2,3] Such outcomes are paving the way to the development of a diamond semiconductor technology for the next revolution in RF power transistors. This advancement could have a substantial impact on the overall capabilities of long-range precision fires, and to help meet the on-going demands by cause of continued force modernizations by near-peer adversaries.

**Boteler, L. • Berman, M.**

#### Co-design and transient thermal mitigation for high performance power electronics packaging in Army vehicles.

Across the battlefield, military technology is becoming more electric from vehicles to ISR capabilities and even survivability and lethality system. There are many challenges with the move to more electric drive platforms including high temperature and high frequency operation, high currents and voltages, and storage. As this shift occurs in military vehicles, there is a continual need for power electronics modules with increased power densities and capabilities to enable future capabilities in Army platforms. Currently, packaging and thermal management limits the power density improvement. Two areas in which significant progress is being made to improve the SWaP of vehicle power electronics is through improved designs using co-design methods and techniques to mitigate thermal transients. Co-design methods have the potential to significantly advance the state of the art in power electronics packaging. A co-designed approach moves away from a sequential design approach (electrical layout, then a mechanical design, and finally thermal management) and replaces it with an approach where the electrical, thermal, and mechanical domains are simultaneously considered during the design. This requires the electrical engineer, mechanical/packaging engineer and the thermal engineer to work together during the initial design phase to understand the requirements and opportunities for improvement across the domains. Furthermore, in order to create an optimized fully integrated package, multi-functional design must be utilized. To achieve an optimized solution the co-design technique relies on two key aspects (1) multi-functional components (MFCs) and (2) quick parametric analysis. Multi-functional components (MFCs) are package parts that eliminate single function elements that only perform a single primary function. A heat sink, for example, is a SFC because in most modules the only function it performs is to remove heat (thermal domain). The Army Research Laboratory (ARL) has demonstrated a >10X reduction in size when using the MFCs. The second aspect of a co-designed module is a parametric study of potential geometries to understand their impact on the electrical, thermal and mechanical domains. This parametric analysis is performed using a tool that was co-developed by the ARL and the Naval Academy called ParaPower. ParaPower allows fast parametric multi-modal design analysis on most rectilinear module designs using a 3D thermal resistance network to quickly calculate temperatures and stresses in a generic module structure. When compared to standard finite element analysis (FEA) this tool varied less than <5C and varied <30% in stress with >100X faster solution times. This work presents an easy to use approach that quickly estimates the device

temperatures and thermal stresses in a generic power module. This method eliminates computer aided drawings (CAD) in favor of numerical parameters that can be easily and quickly varied over a wide range of chip dimensions, number of devices, chip layout, material types, board layers, cooling solutions, etc. The ability to quickly assess a wide variety of power module design parameters with reasonable results significantly improves design speed and the optimization of the final module. In addition to co-design methods, transient thermal mitigation is a key enabler to improve the SWaP of power modules. Typical thermal solutions provide continuous cooling to address the peak thermal load as if it were a steady-state condition. Such a conservative approach satisfies operation at 100% duty cycle, but it results in significant cooling overdesign in proportion to the actual duty cycle. This overdesign has direct negative impacts on system size, weight, and cost, with negative impacts to meeting platform size constraints. Alternatively, ARL is investigating methods to reduce system size and weight without sacrificing platform performance by developing a transient cooling system. By implementing a cooling system that is capable of providing sufficient cooling capacity during the pulsed load and dissipating that heat prior to onset of another thermal event, the system can be designed for a capacity closer to the average thermal power level rather than the peak. To achieve this, ARL is investigating phase change materials (PCMs) incorporated into the module and in direct contact with the heat dissipating die. During thermal transients the PCM melts, greatly increasing energy absorption and then re-solidifies as it cools. Significant temperature reduction (>60C) has been achieved through simply replacing existing encapsulant materials with a metallic PCM. ARL's work on improving power electronics modules has the potential to significantly reduce SWaP for Army systems. A holistic, iterative approach that understands and improves on all aspects of the design is necessary to allow significant improvement in next generation electronics modules and Army vehicles.

**Brawner, K.**

#### Adaptive, policy-driven, after action review in the generalized intelligent framework for tutoring.

‘The best instruction is from a subject matter expert who is also an expert in tutoring, in a one-on-one session, and represents the ideal arrangement for learning – improving student outcomes on between one and two standard deviations. However, this is clearly not feasible for the vast majority of instruction, as a “one tutor per Soldier” model is not sustainable. However, one way to attaining similar goals is through the use of technology such as Intelligent Tutoring Systems (ITS) – computer systems which can take expert-created content and tutor it with built-in instructional expertise. Such systems combine the two areas of expertise – subject expertise and instructional expertise. Systems such as the Generalized Intelligent Framework for Tutoring (GIFT) allow for the creation and configuration of this type of tutoring systems, marrying content from the expert and instruction from a configured system. Human tutors, as opposed to most computer tutors, are not statically defined and unchanging – they learn over time. They are able to select key content which focuses on desired learning objectives, and to improve

their selections over time after observations of effectiveness – they do what they observe to work. ITSs should mimic this functionality, by tracking which content sequences teach effectively, improving both content selection and ordering over time. Further, this feedback should be presented in After Action Review (AAR) – immediate feedback upon student actions after the student takes them. This work uses artificial intelligent and machine learning (AI/ML) in order to customize instruction for the purpose of human performance enhancement/optimization (HPE/O). An Adaptive AAR (A-AAR) system was developed which modeled the problem as a Partially Observable Markov Decision Process (POMDP). The basic POMDP modeled {state} as expertise on three levels, available content as possible {actions}, a Gibbs sampling probability distribution as the {transition function}, resultant student assessments as {observations}, and the encoded sum of the {observations} as the {reward}. Thusly, a POMDP policy was learned via traditional Bellman Update as the {update function} on a small sample of pilot study data from real students experiencing random system choices; this represents a sparse exploration of the space. This dataset was used to make a much larger dataset of simulated students to explore the opportunities for adaptive policies. The developed policies were tested against simulated students with favorable results, suggesting that live trials would be effective. Live trials were performed as a randomized controlled trial with the Adaptive After Action Review (A-AAR) policy used as the independent variable, while control subjects received randomly selected feedback. The 31 experimental subjects were shown to complete tasks an average of 40% faster in equivalent training time. Exact performance times on the three tasks and significance levels decreased by 24% ( $p=0.098$ ), 47% ( $p=0.016^*$ ), and 44% ( $p=0.023^*$ ). Although one of the results is not statistically significant at the  $p=0.05$  level, there is reason to believe that it would be with greater than 31 subjects, as ~60 participants are needed to detect, for significance, the observed Cohen's D effect size of 0.6 on that task. An average 40% improvement (average Cohen's D of 0.78) without subsequent increase in training or authoring time makes a case for the relevance of the technology. The above study made use of existing content, with existing feedback, but with changing the order and reviews to be relevant based on observed data. Further, the policies developed with a small number of students (and a larger number of simulated students) can be further refined based on the system observations of actual students. It is possible that the discovered policies on 1000 simulated students are not the global maximum policies and more real student data can further improve the policies. This technology was implemented within GIFT, a modular architecture for ITS, so it can be readily applied across a large number of domains; GIFT has tutored >50 different instructional domains at the time of writing. As such, it is a relevant implementation of AI/ML for HPE/O tasks. This is especially relevant within the context of the upcoming Synthetic Training Environment (STE), one of the Army's six modernization priorities.

**Brou, R.J. • Normand, S. • Stallings, G.**

Scenario-based, free response assessments of interpersonal leadership skills. Army leaders must be more than tactical/

technical experts. They must possess, project, and inspire Army values and the interpersonal skills required to reach and lead Soldiers in their units. To develop leaders who can meet these demands, the Army must not leave the assessment and training of those values and skills to chance. Rather, leadership skills must be systematically assessed, trained, and refined over time, just as any technical skill is developed. Unfortunately, there are few systematic assessment methodologies that can gauge an individual Army leader's aptitude on such dimensions. Assessment techniques for 'soft skills' or interpersonal attributes tend to fall into two categories: 1) self-report surveys that ask the individuals to rate their own aptitude, and 2) live assessments conducted in field training exercises or other scripted events. Many self-report surveys suffer from shortcomings such as subjective personal bias in the interpretation of one's own strengths and weaknesses, lack of standardized baselines from which to judge one's self in comparison to others, and/or the influence of 'test taking' skills. Live assessments suffer from a lack of scalability due to time and/or resource costs (e.g., trained role-players). Acknowledging these limitations, the Army Human Dimension Strategy (2015) specifically highlighted a set of Key Tasks that included: "Incorporate research-based techniques in the assessment, training, education, and development of future leaders," and "Leverage scientific research to provide unbiased and relevant feedback on the baselines, leadership attributes, and actions of individuals in order to enable continuous improvement." The current research offers a novel, third option for assessment that aligns with these Key Tasks: scenario-based, free-response assessments (SBFRAs). SBFRAs use natural language processing (NLP) algorithms to interpret leaders' responses to evolving scenarios that model practical, real-world problems leaders may face. For example, a leader may be presented with a virtual Soldier who is gossiping about other members of the unit. As the Soldier verbalizes the increasingly unprofessional observations he has made to the leader in a real-time conversation, the leader can respond at any time by typing what he/she would like to say. The response made by the leader will be interpreted via NLP algorithms and will alter the virtual Soldier's behavior according to the type of response made. If the leader chooses to reprimand the Soldier, he will cease his gossiping. If the leader chooses to remain silent, or to ask for more details, the Soldier will continue with the behavior more and more enthusiastically. The leader is never overtly prompted to reply by the SBFRA, rather he/she must decide when/if to engage in the conversation and in what manner. This approach has several advantages. First, by modeling real-world situations and giving no overt prompts (e.g., multiple choice options) for response, the SBFRA is less subject to the weaknesses of self-report assessments. That is, it provokes a realistic, unguided response as opposed to a cued response based on fixed response options. Second, because the SBFRA is computer-based, it can be scaled to assess many leaders using a fraction of the time/resource cost of live assessments. For the current research, 3 SBFRAs were developed each containing 4 to 7 related conversations/interactions with virtual Soldiers or civilians. The SBFRAs were administered to approximately 200 Officer Candidates (OCs) completing Officer Candidate School (OCS) at Fort Benning. OC responses were preprocessed

to account for spelling errors, idiomatic phrases, etc., then matched to a set of language 'libraries' associated with various 'branches' for each interaction. The NLP algorithms reached an 80% successful match rate with OCs' free response inputs. Further, systematic behavioral differences were detected across OCs which correlated with their OCS instructors' ratings of their interpersonal leadership skills across a variety of graded activities. These findings suggest that SBFRAs have high potential to provide a systematic means of assessing the Army values and interpersonal skills leaders must develop to be successful. Future research will refine the development of SBFRAs. Specifically, developing methods to allow for nonlinear conversations and tracking the disposition of virtual characters across multiple interactions will allow for more robust assessments. The current work represents an important, unique first step towards enabling the scalable, objective assessment of important Soldier attributes to support human performance optimization and enhancement. As success in dynamic and complex areas of operation (e.g., megacities) is increasingly driven by interpersonal skills, the ability to assess and train those skills systematically will only grow more vital.

**Burguess, V.**

Friction stir welded aluminum hull structure material fatigue analysis.

**Canavan, S.J. • Fabiano, D.**

Human emotion recognition using fused physiological signals.

This research relates to the theme of Empowering a Soldier's Success using artificial intelligence and intelligent systems by monitoring the emotional state of soldiers. It allows for real-time feedback from them giving vital information that has the potential to increase the soldier lethality and save lives. The purpose is to recognize human emotion using physiological signals including heart rate, blood pressure, respiration rate, and skin conductivity (EDA). Using a new fusion-based method we can represent emotions as new signals that contains these modalities. The fused signals can be used as input to machine learning classifiers to recognize 10 different emotions including happiness, surprise, sadness, startled, skepticism, embarrassment, fear, pain, anger, and disgust. We developed a new method to fuse each of the signals into a new physiological signal that retains the important information for each. We tested on 140 subjects each having sequences of 10 emotions, each with 8 different physiological signals. Using these signals, we want to retain relevant temporal information. To do this, we first normalized all training data to the same units of time (5000 frames). This allows us to make direct comparisons between each of the signals. Once the signals are normalized, we then fuse them into one signal that represents each emotion. This is done for each subject and emotion for a total of 1400 newly fused signals (140 subjects \* 10 emotions) compared to the original 11,200 signals (140 subject \* 10 emotions \* 8 signals). To fuse the signals, we keep the signals (out of the original 8), that display the most important information. We hypothesized that signals with low variance will not significantly contribute to an overall emotion recognition rate. To study this, we calculated the variance for each signal, which is then normalized between [0,1] where 0 is the lowest variance and 1 is the highest. This normalized variance is then

used to weight each signal's importance. Each signal frame is multiplied by the weight, and then each signal is summed together to create our new fused signal. Again, this is done for each subject and each emotion. Our fusion technique retains the most variance for all the signals. Given the 1400 signals we next hypothesized that each emotion can be represented by one signal (compared to 140). To do this, we took the average value for each emotion across time to create 10 fused signals. Each of these signals can accurately represent the displayed emotion, allowing for accurate emotion recognition. To test this, we hypothesized that the signals vs. time can be used as features to recognize emotion (i.e. each frame of time in the signal can be used as 1 feature). Based on this hypothesis, we conducted the following experiments. First, we used 10-fold cross validation to randomly split the data into training and testing sets where 90% of the data was used for training and 10% for testing. We then trained random forest, SVM, and naïve Bayes classifiers. We achieved a correct classification rate of 86%, 88%, 86% respectively. For our next experiment, we then split each signal into training and testing data where the first 2500 frames were used for training a random forest and the last 2500 were used for testing. This gave us 25000 frames for training and testing (2500\*10 emotions). Using this experimental design, we correctly recognized 97.8% of the instances across 10 emotions. These encouraging results show the potential to predict emotion as the data was split based on time. We are also interested in how accurate pain can be recognized compared to the other emotions. To test this, we split the data into 2 classes of pain and no pain. We conducted the same 10-fold cross-validation experiments using random forest, SVM, and naïve Bayes classifiers. Using this design, we correctly identified 100% of all pain emotions compared to no pain for all three classifiers. These experiments show our fused signals can accurately represent the differences found in each emotion, especially when recognizing pain vs. non-pain. This research has practical applications in predicting soldiers' emotional state, most importantly pain. Using a wearable sensor, real-time feedback can be retrieved from the soldier. This feedback can include stress, if the soldiers have been wounded, and the general emotional state of how they are handling the current mission. This information can be useful to adjust the mission as needed or retrieve them from the battlefield. This data is also useful in training scenarios. It would allow the instructors to gain insight into the state of the soldier and see if the training is eliciting the desired response. A new way to recognize human emotions in a real-time setting is conveyed through this research. This is facilitated by a new method of fusing physiological data into one signal by using the signal variance to weight each and sum them together.

### **Cavanagh, J.W. • DeRocco, E.S.**

#### **MakerMinded—creating the next generation of manufacturing leaders.**

Lightweight Innovations for Tomorrow (LIFT), a founding member of the Manufacturing USA National Network for Manufacturing Innovation, is pleased to submit this abstract to the National Defense Industry Association for consideration for inclusion in the 2018 Army Science and Technology Symposium. MakerMinded was launched in 2016 to achieve four main goals: 1. Expand K-12 students' awareness and access

to transformational STEM and advanced manufacturing learning opportunities that prepare them for careers in advanced manufacturing; 2. Provide all students with opportunities to gain 21st century technical and employability skills; 3. Directly connect students to the manufacturing industry through employer-based programs; and 4. Galvanize disconnected STEM learning programs around a pro-manufacturing campaign and create a "MakerMinded" culture among middle and high schools. Over the next decade, nearly 3.5 million manufacturing jobs likely will need to be filled, and the skills gap could result in 2 million of these jobs going wanting. Today's K-12 students will have to be this future workforce if the U.S. wants to "home grow" talent and maintain its Defense industrial base. The students in classrooms today will have to transform into the tech-savvy, adaptable workforce driving innovation in tomorrow's advanced manufacturing economy. Students start to formulate career interests as early as the eighth grade and make critical decisions about their future by the end of high school. But, only 16 percent of American high school seniors are proficient in mathematics or interested in a STEM career. One main source of this problem is a lack of awareness and access to learning opportunities that provide early exposure and skills development, causing students to miss critical connections to careers in advanced manufacturing. MakerMinded is changing this reality and rewriting the future of the next generation advanced manufacturing workforce. MakerMinded brings together actionable information and the power of competition and campaign communications in a digital platform that provides students with widespread access to a curated portfolio of market-leading STEM and manufacturing education experiences. Students compete with other schools in a statewide MakerMinded campaign, as points for completing activities are tallied and tracked through a real-time leader board, resulting in an end-of-year, high-visibility recognition event. The MakerMinded activity portfolio is guided by three key principles: 1) Quality: the programs result in rigorous, relevant learning outcomes for students; 2) Diversity: the portfolio includes a range of programs to meet the individual needs and interests of students and schools; and 3) Equity: the range of programs level the playing field for schools of varying sizes and resource capacity. The MakerMinded platform offers activities that represent multiple STEM and advanced manufacturing disciplines, delivery methods and outcomes. The portfolio provides students with alternative options to gain foundational STEM skills and experiences with an emphasis on work-based, project-based and experiential learning. Other key components of these program options include the use of cutting-edge technology, relevant "real-world" content, and industry partnerships that provide mentorship, subject matter expertise, and other learning experiences. Each activity or program has a unique set of performance requirements and learning outcomes aligned to industry's needs. Through MakerMinded programs, students gain foundational, technical and employability skills and essential experiences core to understanding and being prepared for STEM and advanced manufacturing careers. Competition inspires action. Through MakerMinded, we are raising STEM and advanced manufacturing learning to the level of athletic competition. Most importantly, MakerMinded shows employers and other stakeholders that the United States has its future workforce in today's students; today, we just don't

do enough to cultivate, celebrate and reward them for their technical and STEM skills. LIFT's initial investment enabled rollout of MakerMinded in middle and high schools across Tennessee and Kentucky in October 2016, with Ohio launching a campaign in August 2017, and Detroit launching in January 2018. To date, over 4600 students and teachers from over 375 schools are active on the platform. Over 50 local manufacturing companies created specific MakerMinded student activities to connect with students in their communities—many for the first time. The demonstrated increased rate of student engagement in STEM and advanced manufacturing has created a firm foundation from which to build a national campaign and movement. This August 2019, LIFT will launch three additional MakerMinded campaigns in Indiana, and two states to be determined in June.

### **Cheeseman, B. • Lynch, M.**

#### **Materials and manufacturing advancements to demonstrate objective underbody protection.**

Historically, aluminum hulled combat vehicles have proven vulnerable to underbody blast events. Both the M113 Armored Personnel Carrier (APC) and the M551 Airborne Reconnaissance Assault Vehicle, both fielded in the 1960s, were required to be air-droppable, thus restricting their weight and corresponding aluminum armor thicknesses. Neither was developed with an underbody capable of withstanding anti-tank mines. When these vehicles were deployed to Vietnam, their vulnerability to underbody blast was soon exposed, and expedient kits were developed to mitigate casualties. The currently fielded M2/M3 Bradley Infantry Fighting Vehicle (IFV) features a lower hull similar in design and armor thickness as the M113 APC. It, too, proved vulnerable to underbody Improvised Explosive Devices (IEDs) in Operation Iraqi Freedom (OIF). As in Vietnam, an expedient Add-on-Armor (AoA) kit was developed for the vehicle and fielded into theater. However, when this kit was evaluated against an operationally-relevant threat by the Office of the Secretary of Defense (OSD) during Live Fire Test and Evaluation (LFT&E), results indicated that severe vulnerabilities still existed against underbody blast. The US Army Affordable Protection from Objective Threats (APOT) Manufacturing Technology (ManTech) effort was thus initiated to mature three different aluminum hull manufacturing methods – forging, forming, and advanced welding – to produce lower hulls that would not only demonstrate the ready defeat of threats exemplified by those used in the OSD LFT&E tests, but that would provide protection from underbody blast threats having multiple times that amount of explosive (Objective level). While the APOT effort matured lower hull manufacturing techniques, the alignment of this effort with a number of Department of Defense projects enabled not just the manufacture of the lower hulls, but the subsequent fabrication of a number of them into notional 50-ton combat vehicle ballistic hull and turrets (BH&Ts). The BH&Ts were outfitted with energy absorbing and impulse mitigating technologies and tested at Objective levels. This paper will present the materials and manufacturing advancements that were developed with the government-industry research team. From the aluminum armor alloy selections, to the thermomechanical process parameters for the manufacturing processes, the team rapidly matured and demonstrated three distinct manufacturing paths that achieved

Objective level blast resistant hulls. A discussion of the relative performance of each will be presented along with the transition of some technology developments to the Armored Multi-purpose Vehicle program.

**Chu, K. • Atwater, T.B. • Howarth, Y.J.**

**Comparing various capacitor types for high power applications.**

The increasing power and energy demands of Army equipment, from something as small as a radio to as large as a generator starter, have created a need for newer and better power solutions than what is currently provided by the traditional battery. Although batteries, particularly lithium-ion batteries, have traditionally been the main power source for a variety of Army systems, they have varying limitations when it comes to power, cycle life, and performance at extreme temperatures. The emergence of lithium-ion hybrid capacitors and the increasing development of supercapacitors – both of which are lighter, offer better cyclability, and have higher power densities than a battery – provide viable alternatives as power sources. Although supercapacitors are already being applied in systems such as power tools, electric vehicles, elevators, as well as serving as an uninterrupted power supply to places like hospitals, and lithium-ion hybrid capacitors are being used as auxiliary power devices or in electric vehicles, neither supercapacitors nor lithium-ion capacitors are extensively used for military applications. While similar in many ways, there are a few key characteristic differences between supercapacitors and lithium-ion capacitors that cause them to behave in subtle, yet vastly different ways. On one hand, supercapacitors electrostatically store their charge on the surface of the electrode, while batteries store their charge in the bulk of the electrode. Supercapacitors, usually composed of two electrodes made of the same material, have extremely high power density, capable of safely delivering over 5kW/kg. Because supercapacitors lack high energy density, they need to be utilized in conjunction with another power source if the application is used for an extended period of time. On the other hand, lithium-ion capacitors apply an asymmetric electrode system, meaning they will have two different types of electrodes. One electrode stores charge electrostatically – typically a graphite anode – while the other electrode stores its charge in a faradaic manner – usually using a lithium-doped activated carbon cathode. Because this asymmetric electrode system uses a positive electrode that stores its charge in the bulk of the electrode itself, the energy of the system is up to ten times higher than that of a supercapacitor system. Additionally, since rate capability – and therefore power density – of a lithium-ion capacitor is determined by the anode, the anode can be tailored to be more energy dense or more power dense depending on the application. This paper will study two different lithium-ion capacitor cells – one more energy dense and the other more power dense – and compare them to a supercapacitor. The goal is to analyze the respective capabilities of the systems to meet requirements for various applications.

**Clausen, J. • Dorvee, J. • Morris, B. • Newman, S. • Williams, C.**

**Soil and meteorological properties affecting thermal IR sensor performance for mine/IED detection.**

The environmental phenomenological properties responsible for the thermal variability evident in the use of thermal infra-red (IR) sensor systems is not well understood. This lack of understanding is manifested in a poor probability of detection (PD) and elevated false alarm rate (FAR) when using thermal IR for mine/improvised explosive device (IED) detection. High performing sensor systems are necessary to support the operational needs of the warfighter to avoid mines and IEDs. Increased understanding of the environmental impacts and confidence in the PD of thermal IR could also allow the warfighter to shape the battlefield by identify locations where to place mines that are not detectable due the background noise. Several highly instrumented field test plots were designed and constructed at the ERDC-CRREL facility and monitored continuously for several months. In addition to the acquisition of continuous soil and meteorological variables both electro-optical and thermal IR data were acquired with and without buried objects. The presentation will discuss the environmental variables contributing to thermal spatial and temporal variance and associated impact on IR signature detection. Preliminary results indicate the surface thermal IR spatial pattern is a function of incoming solar radiation, air temperature, subsurface soil temperatures, moisture, and hill shading (surface aspect, slope). Temporal analysis reveals windows of opportunity for mine/IED detection and the variables affecting the optimum thermal window. An unique finding is that temporal comparisons of data from two different points in time allows identification of buried objects not apparent in single snapshot events. This research has application to the warfighter on the applicability thermal IR sensor technology for detecting mines and IEDs and the limitations.

**Collins, P.D.**

**Army Research Laboratory HBCU/MI design challenge.**

The Army Research Laboratory (ARL) is developing plans to conduct its first-ever university design challenge for HBCU/MI participation. Using statutory authorities provided to conduct prize competitions and to promote outreach to minority institutions the ARL's competition will enlist student teams from HBCUs/MIs to compete in a two-phase competition focused on Army-relevant technology challenges. The challenge is modeled on similar DoD challenges (DARPA's Grand Challenges, MIT/USMA Soldier Design Competition) and winning teams will receive recognition and possibly cash awards. A panel of Army leaders will judge and determine the winners in each phase. The challenge has a potential participation base of 1,752 eligible institutions. The ARL HBCU/MI Design Challenge has several goals and anticipated outcomes. The challenge will introduce HBCU/MI students to Army research and technical challenges. It will engage students with the Army's technical and operational communities. The challenge will leverage ARL's extended campuses and associated partnerships and it will stimulate innovation and entrepreneurship. Lastly, the design challenge is

consistent with the Army's strategy to strengthen engagement with the Nation's HBCUs/MIs. Although the HBCU/MI design challenge is in the early stages of the planning and approval process, several activities are underway to enable the ARL to conduct a successful competition. Potential topics intended to focus the contestants' entries are being evaluated. The current challenge structure is centered on a two-phase competition. Phase I will solicit concept papers in which participants can describe their ideas. Winners from Phase I will be invited to develop models and prototypes for a final competition. Phase I will be conducted during the fall and Phase II will occur over the spring months. The specific elements of each phase as well as judging criteria for each phase are undergoing further development and details will be announced as soon as available. The ARL is also considering partnerships with industry and academic consortia to facilitate the competition and to enhance the outreach and participation.

**Cox, G.**

**Scatterable Collaborative Remote Electronic Warfare System (SCREWS).**

Our near-peer adversaries have developed advanced capabilities associated with integrated air defense (IADS) and other electronic warfare systems. These capabilities have extended the A2AD environment well past 100km in many cases. There is a significant concern for the survivability of our helicopters, aircraft, UAVs, guided weapons, and even ground based systems in such an environment. Textron Systems in conjunction with our partner Mercury Defense Systems are developing what we call SCREWS (Scatterable Collaborative Remote Electronic Warfare System) that offers a disruptive and potentially paradigm shifting approach to these problems. The SCREWS concept leverages Textron's Supervised Smart Munition (SSM), developed for the US Army's Family of Scatterable Mines (FASCAM) replacement program-of-record, together with recent breakthroughs in micro-DRFM technology (Digital Radio Frequency Memory) developed by Mercury. Rather than trying to defeat enemy radar and communications from a standoff EW platform, low-cost SCREWS nodes are dispensed in the enemy's backyard and operate together at close range to spoof, disrupt, and deceive enemy systems including communications and radar. Moreover, SCREWS continues to work on the ground, under remote control, thus can function persistently for many hours or even days. This would potentially allow entry of US Forces into such areas with dramatically less risk. Other potential applications include: 1) Masking blue force communications from enemy SIGINT and Cyber attacks, 2) Access enemy LANs for our own Cyber attacks, 3) Disrupt enemy ground control station downlink for Counter-UAS, 4) Jam/spoof enemy satellite navigation 5)PNT.

**Crone, J.C. • Boothe, D.L. • Franaszczuk, P.J. • Oie, K.S. • Yu, A.B.**

**Modelling complex neuronal dynamics across network scales.**

Purpose: The goal of this work is to advance the computational algorithms and models employed to simulate neuronal networks. Here we present techniques to maintain biofidelity and complexity

across scales in neuronal simulations. Our results have implications for future artificial intelligence (AI) algorithms by identifying the necessary properties and network scales to achieve more “brain-like” functionality. Many of the challenges to simulating large, complex neuronal networks will carry over to the implementation of complex AI neural networks on low power neuromorphic computing architecture. Therefore, this work also serves to identify many of the limitations and constraints to implementing reliable AI on neuromorphic devices. Theme: The development of robust and adaptable AI is crucial for achieving the current vision for empowering a Soldier’s success on the future battlefield. However, even the most advanced AI algorithms are no match for the robustness and adaptability exhibited by the brain. While AI has borrowed heavily from neuroscience in using neural networks, current AI algorithms do not incorporate the complexity in dynamics or connectivity that is observed in the brain. Incorporating this complexity in low power neuromorphic AI will require understanding which features of neuronal activity need to be represented to produce reliable computation. Approach: The tasks for work are two-fold: improve the computational tractability of large scale simulation and improve the biofidelity of neuronal models. To improve the computational tractability, algorithmic improvements were made to an existing neuronal simulator, the GENEral NEural Simulation System (GENESIS). These improvements enabled large scale simulations of neuronal networks through efficient utilization of HPC resources at the DoD Supercomputing Resource Centers (DSRC). Developments to the neuronal model were focused on the neocortex, which is the part of the brain involved sensory perception, cognition, generation of motor commands, spatial reasoning, and language. Each of these tasks are critical to current and future AI capabilities. Findings: High fidelity neuronal networks require simulating neurons with multiple compartments and complex dynamics. The computational cost of realistic neural models is high. Challenges in scalability and memory usage were encountered due to the large number of connections between neurons. Our algorithmic improvements, coupled with HPC resources, enabled us to perform simulations of over 340,000 neurons with over 8 billion synaptic connections. Work is ongoing to further increase the tractable simulation size. Large scale simulations also revealed unexpected numerical challenges that are not observed at small scales. Specifically, the sensitivity to the timing of the neurons’ fast, all-or-none behavior or “spikes” increases as the total number of neurons increases. Due to the complex nonlinear behavior of neuronal networks, even small differences in time integration can lead to large, unpredictable errors in the dynamics. This can lead to qualitatively different behavior. To make simulations consistent across scales, one needs to be particularly careful in testing convergence with respect to numerical parameters in both large and small scale simulations. We expect for neuromorphic implementations of next generation AI to exhibit similar sensitivities between the timing properties imposed by hardware and the underlying neuronal nonlinearities that impact model dynamics. Practical Applications: It is critical that the numerical challenges inherent to biophysically neuronal simulations are thoroughly understood and controllable before more complex dynamics can be incorporated into AI algorithms and implemented on neuromorphic computing

architectures. Our results suggest that naively scaling models and computing resources will lead to “unpredictable errors.” This could compromise the functional behaviors of the models and the future AI systems built upon them. Original Value: Through simulation of complex neuronal networks, we aim to identify properties of both the neurons’ dynamics and the network connectivity that lead to the rich behavior of the brain. These properties may inform and constrain the organization and functional mechanisms of next generation AI, to provide algorithms with unprecedented performance and reliability. This work may also serve as a roadmap for navigating the challenges of implementing large neural networks on low power neuromorphic computing architectures.

**Darvish, K. • Assari, S. • Langford, D. • Tierney, R. • Wright, W.G.**

#### Brain tissue mechanics in blast loading.

Purpose: The brain tissue mechanical behavior at loading rates that approach those that occur during blast-induced neurotrauma (BINT) is not clearly understood. In order to better define forces that impact the brains of military personnel, we use modeling whereby these loading conditions can be assessed to better protect the brain. Our rat TBI models show that in blast loading conditions, the cerebrovascular pressure changes occur at rates of 0.5 to 1.5 kHz. As a result, for such applications, brain tissue needs to be tested with loading duration as small as 0.5 ms, which is equivalent to shear strain rates as high as 1000 1/s. The aim of this study was to characterize the material behavior of brain tissue in large shear deformations and high strain rates relevant to BINT to allow for improved protective material generation. Theme: This research relates to Soldier Lethality and Neuroscience. Repetitive sub-concussive or concussive head traumas can occur in many types of standard military training as well as in battlefield conditions. Blast exposure events involve forces due to the shock wave from the explosion, which include primary, secondary and tertiary forces. There are a multitude of jobs in the military that involve blast exposure events, which require the service member to be near an explosive weapon or device, e.g. breachers, anti-tank missile crew, special operators, machine gunner, riflemen, infantry. Assessing the effects of BINT in an animal brain tissue model, may provide insight into their effects on military personnel who may experience such conditions either in training or in battlefield conditions. Methods: A novel shear test setup was designed and built capable of applying strain rates ranging from 300 to 1000 1/s. In this setup, a 2-in diameter shock tube was utilized to drive a linear actuator with accelerations in the range of 200 to 1000 g and velocities of 3 to 14 m/s to deform the brain tissue samples in a parallel plate shear configuration. At the fixed end, the shear force was measured. Our approach allowed achieving high signal to noise ratio in the force measurement, which due to vibration of the system, is a major challenge in such high acceleration impact tests. The samples (n=20) were cylindrical shape (10 mm diameter, 10 mm height) excised from the corona radiata of 2 fresh bovine brains. The sample deformation was determined via high-speed imaging of small markers painted along the sample at the rate of 10k fps. Temple IACUC and ACURO approved this protocol. Results: The velocity of propagation of shear wave along the sample was measured by two methods namely, tracking the shock wave front and the delay in the rise of force at the fixed

end. The results of the two methods were in close agreement (2.5 m/s). The brain instantaneous shear modulus was determined from this velocity. The results showed that the measured shear modulus (6 kPa) was more than 3 times higher than the values generally reported in the literature. Practical Applications: A long-term goal of our team is to develop a computational finite element (FE) model of human head that can predict the type and severity of brain injury as a result of BINT. The results of this study will enhance the injury prediction of such FE model. Taken together these data will be used to engineer improved protective gear. Original Value: To predict the type and extent of brain injury using computational tools in blast loading conditions.

**Dogaru, T. • Le, C. • Sullivan, A.**

#### Forward Looking Synthetic Aperture Radar (FLSAR) concept for landing in Degraded Visual Environments (DVE).

The development of sensors to assist helicopter landing in degraded visual environment (DVE) is currently an important Army requirement, addressing the Survivability of Future Vertical Lift Platforms as one of the Army modernization priorities. Over the past three decades, dozens of rotary-wing aircraft crashes have been responsible for a large number of casualties to US and coalition forces in different parts of the world. Out of these crashes, at least 75% have occurred in brownout conditions, where dirt or dust is stirred up and re-circulated by the rotor blades, created low- or no-visibility environment for the aircraft pilot. R&D efforts to mitigate this issue starting in the early 2000’s recommended several possible solutions based on optical (LIDAR), infrared (IR) and radar sensors. Unfortunately, most of these solutions proved either ineffective or involved unacceptable size, weight, power and/or cost (SWAP-C), leaving the Army with a capability gap needing to be filled. The sensor solution proposed by the Army Research Laboratory (ARL) is based on millimeter-wave (MMW) imaging radar technology. The main idea behind this sensor is to combine a linear antenna array with the radar platform motion in order to obtain a high-resolution three-dimensional (3-D) terrain map of the landing zone. This information would be passed to the aircraft pilot via helmet mounted display to assist in deciding whether the landing zone is safe. Several previous efforts in developing similar sensors, based on passive or active MMW technology, have focused heavily on two-dimensional antenna arrays working in scanning mode to obtain a terrain map. These efforts generally produced devices which proved either too expensive, unreliable and/or inaccurate for the required task. The ARL proposed solution leverages advanced radar imaging methodology, together with the current boom in commercial MMW RF technology (driven by developments in autonomous car navigation and 5-G wireless communications), to produce a reliable, low SWAP-C sensor prototype addressing this requirement. MMW frequencies, linear antenna arrays and the forward looking synthetic aperture radar (FLSAR) concept are the 3 radar technologies enabling this sensor to achieve the stated goals. MMW are the best choice in terms of radio frequencies, allowing development of small size, low power and high resolution sensors. At the same time, their propagation characteristics through dust, clouds, snow and other less-than-ideal atmospheric conditions are vastly superior to electromagnetic waves at optical/IR



frequencies, which is key for this application. In terms of radar imaging, the ARL team is leveraging 20+ of experience with FLSAR technology. A multiple-input, multiple-output (MIMO) linear antenna array mounted on the rotorcraft's front end will provide the required cross-range resolution, while the transmitted signal bandwidth (up to 1 GHz) will provide down-range resolution. To achieve resolution in elevation, the radar will exploit small altitude deviations in the helicopter flight path, which naturally occur when the pilot is preparing for landing. This idea is equivalent to the FLSAR sensing modality which has been successfully demonstrated by ARL researchers in counter-IED applications, from a vehicle-borne platform. Overall, our radar sensor concept represents a significant shift in implementation from a hardware-heavy solution to an emphasis on signal processing and computational power, with large potential cost savings and performance improvements. In this paper, we present results obtained so far by computer modeling of the radar operation and performance in a hypothetical but realistic helicopter landing scenario. This scenario includes a patch of terrain featuring rocks, soil irregularities, a tree and a power line. 3-D images obtained through simulations in different MMW frequencies bands allow us to assess the accuracy of the radar images in rendering the salient terrain features. These model predictions provide essential information to the radar developers in terms of expected performance and system design parameter choice, such as frequency, bandwidth, array geometry, and polarization. They also allow us to experiment with innovative signal processing algorithms for real-time 3-D scene imaging, as well as clutter suppression. An additional Army application we envision for this MMW radar sensor is targeting military vehicles placed in an open field. By using the vertical motion of the rotorcraft platform, the radar can acquire high-resolution 3-D images of the target, using a principle similar to that of the FLSAR. These high quality images can greatly assist automatic target recognition (ATR) algorithms and eventually pass this information to fire control sensors for accurate targeting.

### **Don, M. • Hamaoui, M.**

#### **Localization technologies for swarming munitions.**

The US Army Research Laboratory is investigating the advantages of group swarming behavior over a comparable group of solitary agents. One advantage is the ability for swarm agents to localize relative to the group, using spatial relationships between many agents to achieve accurate relative attitude and position information. This is particularly important in GPS (Global Positioning System) denied environments where there are limited options for absolute positioning. In these cases, only one agent with absolute localization is needed to grant absolute localization to the entire swarm. Applications also exist for relative positioning alone, such as collision avoidance, formation flying, and patterned weapon delivery. This research investigates the feasibility of two localization technologies for swarming munitions, radio direction finding (RDF) and RF (radio frequency) two-way ranging (TWR). Compared with other technologies, RF TWR products have many benefits including: available low-cost commercial products, low power, small size, and accuracy comparable to GPS. Disadvantages include susceptibility to jamming and interference as

well as antenna integration difficulties on small munitions. However, considering that a swarm will likely already possess wireless networking capabilities, there is no reason not to use the RF signals for ranging as well as communications. RF TWR products generally fall into two categories, ultra-wideband (UWB) and narrowband (NB). UWB products are more accurate, but due to transmit power limitations, have shorter ranges. NB products are less accurate but have longer ranges that can be extended even further through external amplification. In addition, frequency hopping to mitigate jamming and interference is theoretically easier with NB ranging because of the greater number of available frequency slots. Thus the Nanotron Swarm BEE LE, a NB TWR product, is chosen for evaluation. Unlike many typical applications, swarming munitions have unique range, accuracy, and sample rate requirements which are characterized in both laboratory and field experiments. A networking scheme for swarm localization is developed leading to a successful demonstration of relative localization among 6 agents. Unlike RF TWR, a suitable commercial off-the-shelf RDF device for swarms of small agents does not exist. Larger systems for search and rescue and radar cannot be easily adapted to small agents, while smaller automotive radar systems have limited range. Instead of using the preferred phase interferometry approach, many systems use time difference of arrival or received-signal-strength-indication methods that do not achieve high accuracy. Phase interferometry using antenna arrays can be difficult to implement because antenna characteristics and multipath effects can significantly degrade performance. Despite these problems, literature suggests that a reliable RDF system could be designed for swarm-relative localization. There are three significant reasons why swarms of munitions present fewer design challenges than other RDF applications. First, high-altitude swarms will not be significantly affected by multipath. Secondly, many swarms can have antenna arrays attached to the agents in a repeatable manner, simplifying antenna characterization issues. Contrast this with a device such as a cell phone, whose possible orientation and proximity to other objects makes assumptions about antenna performance problematic. Third, unlike many RDF applications, there is complete control over both the transmitter and receiver systems which can be exploited during system design. RDF is demonstrated here using a simple 2-element antenna array with a small standalone software-defined radio (SDR). A novel technique is developed to resolve integer ambiguities and the RDF performance of modulated signals is evaluated. An RDF laboratory experiment is designed and executed, demonstrating the feasibility of RDF for swarm localization.

### **Douglas, J. • Latorre, P. • Berka, D. • Hurley, C. • Thompson, R.**

Advances in Li/CFx non-rechargeable batteries for portable electronic systems.

### **Dowling, J.P.**

#### **Schrödinger's web — race to build the quantum internet.**

Over the past 20 years bright sources of entangled photons have led to a renaissance in quantum optical interferometry. These photon sources have been used to test the foundations

of quantum mechanics and implement some of the spooky ideas associated with quantum entanglement such as quantum teleportation, quantum cryptography, quantum lithography, quantum computing logic gates, and sub-shot-noise optical interferometers. I will discuss some of these advances and the unification of optical quantum imaging, sensing, and information processing. I will end with quantum communications and networks and highlight advances particularly the quantum space satellite network built in China.

### **Drost, R.J. • Arslan, C.H. • Dagefu, F.T. • Verma, G.**

#### **Ultraviolet communications and networking.**

Due to increasingly complex, congested, and contested tactical communication environments, the Army has keen interest in exploring alternative communication modalities. Augmenting Army networks with alternative communication capabilities has the potential to increase network resiliency, enabling connectivity even when conventional systems are inappropriate or ineffective. One such alternative modality involves the use of deep-ultraviolet (UV) light (wavelengths of 200–300 nm) for communication. At these wavelengths, increased atmospheric scattering of transmitted (signal) radiation and the increased atmospheric absorption of solar (noise) radiation enables the use of extremely sensitive photon-counting receivers (i.e., photomultiplier tubes) to establish novel non-line-of-sight optical links through the atmospheric scattering channel. While the substantial loss associated with this channel potentially limits its use to short-range low-rate applications (such as voice communications over a couple hundred meters), the channel loss also limits the ability for an adversary to detect or jam a UV communications (UVC) link at range. The unique features of this modality and channel have sparked significant research effort in recent years. Much of the existing literature has focused on point-to-point links and, in particular, understanding and modeling the point-to-point communication channel. Of the proposed modeling approaches, the most general involves the Monte Carlo simulation of photon propagation through the atmosphere. Combining path loss estimates from such a model with a Poisson counting noise model allows one to explore a variety of point-to-point system design issues. Experimental measurement systems have been used for validation of this prior research, though it should be noted that experimental challenges have often limited measurement precision and, therefore, the quality of such validation. Lacking from the existing literature is a deep understanding of the multiuser UVC scenario, such as a network of UVC systems operating in the same vicinity. To enhance throughput in a multiuser environment, the atmospheric channel can be spatially multiplexed so that different regions of the sky are predominately utilized by different communication links. Using spatial multiplexing, the optimization of the pointing direction (i.e., the azimuth and elevation angles) of each transmitter and receiver becomes crucial to proper operation, since even a single transmitter pointing suboptimally (perhaps in a greedy attempt to optimize the particular link that it is trying to establish) has the potential to inject an unacceptable level of noise into many of the other network links, resulting in their disconnection and, possibly, complete network failure. Here, we present our recent efforts in advancing

the state of the art in UV communications and networking. In particular, we discuss four research facets. First, the theoretical study of UV networking requires low-complexity channel modeling to enable rapid evaluation of the channel loss associated with every pair of nodes in the network. Our approach considers the use of high-performance computing for the precomputation of the effects of the steering of the transmitters and receivers, combined with a range-correction factor based on prior theoretical channel modeling results. The second research avenue that we highlight investigates the mitigation of a receiver-saturation effect, called dead time, that can degrade the performance of photon-counting receivers. In particular, we describe a method for impulse-response estimation from dead-time-limited data. Third, we discuss our recent development of an experimentation system designed to enable high-fidelity validation of UV networking research. This system features precision steering, temperature-controlled high-power light-emitting-diode transmitters, photon-multiplier-tube detectors, and an interface that makes use of a National Instruments data acquisition device for a high degree of reprogrammability. The construction of multiple such systems is enabling the measurement, exploration, and validation of multi-node UV networking modeling and optimization. Finally, recognizing that UVC has rate/range limitations, we describe efforts to develop networking models amenable to the integration of extremely diverse communication modalities. Such modeling can enable networks that leverage and adapt multiple communication technologies (such as UVC and conventional RF) heterogeneously throughout the network as appropriate for the particular communication environment and mission requirements associated with each node.

**Dubinskii, M. • Fromzel, V. • Luo, C. • Yin, S. • Zhang, J.**

**Lasers for DEW based on fully crystalline fibers.** Fiber lasers have been recognized as part of laser architecture capable of delivering high power with nearly diffraction limited beam quality. The multi-kilowatt silica-glass based single-mode fiber lasers/amplifiers have been reported, but further increase of fiber laser power to the multi-ten-kilowatt level while maintaining near diffraction limited beam quality is required. This development is facing fundamental physical limitations, including the thermal - due to the low thermal conductivity of the silica-glass material ( $\sim 1 \text{ W/m}^2\text{K}$ ), the onset of the stimulated Brillouin scattering (SBS) - due to the relatively high SBS gain coefficient of the silica-glass ( $\sim 5 \times 10^{-11} \text{ m/W}$ ), the onset of the transverse mode instability (TMI), and the photo-darkening effects. In search for paths towards further power scaling out of a single fiber aperture, and in order to overcome the above limitations, there have been some efforts toward fiber lasers based on non-silica crystalline materials. They have shown that lasers based on fibers made entirely from crystalline materials (fully-crystalline fibers) would have the potential for achieving multi-ten-kilowatt output power out of a single fiber aperture, even for the single-frequency fiber laser/amplifier. Fibers based on single-crystalline materials are also likely to exhibit much higher TMI thresholds. Fabrication of double-clad, fully-crystalline fibers ('crystalline-core/crystalline-cladding' design - CCCC, or C4), was found to be a major challenge. Since recently, in order to realize fully-crystalline, 'crystalline-

core/crystalline-clad' (C4) fibers, a variety of techniques were implemented to grow crystalline claddings around the LHPG-grown crystalline fiber cores. Despite the reported successes in cladding deposition, no laser results have been demonstrated from these efforts so far. An alternative liquid solution growth method, which can be used for crystalline cladding deposition over the LHPG-grown fiber (used as a seed) - a liquid phase epitaxy (LPE), has been recently developed, and very encouraging first laser results based on the (LHPG+LPE)-derived C4 fiber have been demonstrated by ARL. Presented research is aiming to demonstrate the realism of laser power scaling out of a single fiber aperture which exceeds current State of the Art (SoA) fiber laser power scaling potential by at least a factor of 10. This research is directly addressing the Air and Missile Defense Capabilities (Directed Energy). Reported here are the advanced techniques used for further development of high quality growth of the fully-crystalline C4 fibers as well as characterization results of the key properties of the grown C4 fibers, including the crystalline structure, material composition, and propagation loss. Research objective, a proof-of-concept, has been achieved through innovative fully crystalline fiber fabrication technique and a proper laser design. We have demonstrated that high efficiency diode-cladding-pumped laser operation can be realized with the low-loss fully-crystalline C4 fiber as the gain medium. This essentially provides a proof-of-concept for the innovative path to highly power scalable fiber laser development. In the Q-CW regime  $\sim 50 \text{ W}$  of Q-CW Yb-laser power at 1030 nm has been achieved with the optical-to-optical laser efficiency (versus the launched pump power) approaching the 70% mark. Experimental results nearly perfectly agreed with the numerical simulation of the laser performance. Practical applications of our research are in DEW development (power scaling of a "master laser"). After further development significant SWAP reduction of the DEW system can be achieved.

**England, M.**

Citadel defense company: clearing the skies.

**Felton, M.A. • Booth, D.L. • Franaszczuk, P.J. • Oie, K.S. • Yu, A.B.**

**Phase-modulated power of dendro-somatic current transmissions in a neocortical layer 5 pyramidal neuron model.**

Approach: To assess the subthreshold interaction between the soma and distal apical regions, we first characterized the resonance properties of a biophysically-realistic compartmental model of a neocortical layer 5 pyramidal neuron. Consistent with recently published theoretical and empirical findings, our model was configured to have a "hot zone" in distal apical dendrite and apical tuft where both high- and low-threshold  $\text{Ca}^{2+}$  ionic conductances had densities 1-2 orders of magnitude higher than anywhere else in the apical dendrite. This type of configuration has been shown to faithfully reproduce the distal apical dynamics that are necessary for the coupling of the soma and distal apical regions of layer 5b pyramidal neurons. We simulated injection of broad spectrum sinusoidal currents with linearly increasing frequency to calculate the transfer impedance between the soma and distal apical dendrite/tuft, and a dimensionless term we

introduce called resonance quality. We used the insights from transfer resonance analysis to demonstrate phase-locking of somatic frequency preference for distal apical input to a somatic modulating signal. Specifically, we simulated injection of a slow sinusoidal modulating signal into the soma while simultaneously simulating injection of multiple sine waves, each at a different frequency determined from transfer resonance analysis, into distal apical compartments. In addition, to observe which conditions are conducive to multi-frequency coupling on the single neuron level, we simulated injections of slower currents in distal apical tuft while faster currents were injected into the soma and dendrites close to the soma. Simultaneously, a slow, large amplitude modulating current was injected into the soma. Findings: We show that when the soma was hyperpolarized below its resting membrane potential, it was most sensitive to distal apical input at roughly 7 Hz. On the other hand, when the soma was depolarized close to the membrane potential for action potential initiation, it was most sensitive to 15 Hz distal input. We therefore demonstrate a form of phase modulation of power where the amplitude of the faster signals transmitted from distal apical compartments to the soma is varied as a function of the phase of the slower somatic modulating signal. This type of process may underlie phase-amplitude coupling observed in EEG data. Furthermore, when a slow current ( $< 10 \text{ Hz}$ ) is injected into distal apical tuft while a faster current ( $> 20 \text{ Hz}$ ) is injected into dendrites close to the soma, multi-frequency coupling is more readily observed in the soma when it is at or below its resting membrane potential. Interestingly, multi-frequency coupling arising from slow current injections in distal apical regions and fast current injections close to the soma persists across a wide range of membrane potentials for compartments comprising middle apical dendrite. These compartments do not display the same "on-off" toggling of multi-frequency coupling with high-amplitude modulation of local membrane potentials like the soma and compartments close to the soma, and the fast current injected into compartments close to the soma do not propagate into distal apical dendrite and apical tuft to generate sufficient coupling with local slow current injections. These results are consistent with the belief that the apical dendrite is the primary generator of the current observed through EEG and suggests that multi-frequency coupling has a stable signature in middle apical dendrite as long as there is slow distal oscillatory input in conjunction with fast oscillatory input closer to the soma. Practical Applications: This type of detailed analyses of a model neuron that possesses much more of the complexity of real neurons reveals behaviors that are not observed in the simple artificial neurons used in today's AI systems. This analyses also suggests potential ways to control a system's adaptive behaviors through functional mechanisms that depend on having model neurons with adequate complexity. Original Value: The findings of this research serve as promising examples of how the use of model neurons that are more realistic may one day enable more robust encoding, plasticity, and adaptation in AI and machine learning algorithms.

**Folkes, P.A. • Decoster, G. • Nichols, B. • Taylor, P.J. • Vail, O**

**Topological materials for energy-efficient electronics.**

This research is aimed at the discovery of fundamental properties and novel applications of topological materials in future Army energy-efficient electronics. The use of energy-efficient electronics in future Army sensors and autonomous systems will enable the use of intelligent energy-aware maneuvers and thereby empower a soldier's success. We experimentally investigated the molecular beam epitaxy (MBE) growth of PbSnTe, thin layers of semiconductor tin ( $\beta$ -Sn), and a monolayer of Sn (stanene) and verification that they are a topological crystalline insulator (TCI), a three-dimensional (3D) topological insulator (TI), and a two-dimensional (2D) TI, respectively. A collaboration between ARL researchers and the University of Maryland Physics department has led to the world's first observation of proximity induced superconductivity in many mesoscopic Josephson-Junction devices (JJ) that were fabricated using Pb<sub>1-x</sub>Sn<sub>x</sub>Te topological crystalline insulators that were grown by MBE at ARL. Fabrication and characterization of the mesoscopic JJ devices were carried out by Prof. Williams' group at Univ. of Maryland. Measurements of these junctions, demonstrate that a supercurrent is observed in the device and the show the response of the supercurrent to an applied perpendicular magnetic field. The demonstration of proximity induced superconductivity in Pb<sub>1-x</sub>Sn<sub>x</sub>Te is groundbreaking, and was enabled by ARL's high quality MBE materials and the near-perfect interface with superconductors. ARL has perfected MBE growth technology for semiconductor Sn, which is a metastable phase of tin that is a topological insulator under certain conditions. Semiconductor Sn is a topological insulator with a bulk energy gap that could enable room-temperature operation. Further, semiconductor Sn offers rich opportunity for simplicity because it is an elemental topological insulator. Thin layers of epitaxial semiconductor tin having diamond-cubic structure ( $\beta$ -Sn) were grown by molecular beam epitaxy (MBE) on (111) CdTe substrates. X-ray diffraction and Raman scattering measurements confirm that the thin layers of  $\beta$ -Sn are single-crystal and slightly strained. Resistivity and magnetoresistance measurements as a function of temperature on the  $\beta$ -Sn layers show the existence of a thin disordered metallic layer at the  $\beta$ -Sn layer/CdTe substrate interface. The disordered metallic layer exhibits increasing resistivity as the temperature decreases over the range 4 K – 75 K and becomes superconducting at a critical temperature  $T_c = 4$  K. X-ray diffraction data suggests that the disordered metallic layer at the  $\beta$ -Sn/CdTe interface is an interdiffused, compensated Sn:SnTe:CdTe alloy layer formed at the initial stages of MBE growth. Theoretical calculations of the effects of quantum confinement, orientation and strain on the topological characteristics of  $\beta$ -Sn/CdTe show the occurrence of several topological phase transitions. Magnetotransport measurements will be carried out to observe these and measure the transport characteristics. Our results show that ARL's high-quality topological materials can be used for energy-efficient electronics. For example, the realization of theoretically proposed energy-efficient magnetic switching devices [1] is crucially dependent on

strong interfacial proximity induced magnetic coupling between the topological insulator (topological crystalline insulator) and the ferromagnetic (antiferromagnetic) insulator. Pb<sub>1-x</sub>Sn<sub>x</sub>Te is an excellent platform to begin the study of other proximity-induced phenomena such as the proximity-induced ferromagnetism using MBE growth of topological insulator (topological crystalline insulator) interfaces with EuS ferromagnetic material and EuTe antiferromagnetic material. To maintain a pristine and perfect interface between the topological and ferromagnetic materials, these materials will be epitaxially grown within the same MBE chamber in sequence. Fortunately, those two europium chalcogenides share the "rocksalt" crystal structure with Pb<sub>1-x</sub>Sn<sub>x</sub>Te materials. In addition, the Pb<sub>1-x</sub>Sn<sub>x</sub>Te and EuS/EuTe materials are known to be closely lattice-matched, and entirely compatible. In addition, we plan to experimentally investigate molecular-beam-epitaxy-grown interfaces between topological insulators semiconductor Sn and ferromagnetic (antiferromagnetic) insulator to determine the interface with the strongest interfacial proximity induced magnetic coupling. We will investigate the 4 K – 300 K temperature dependence and the penetration depth of the magnetic anisotropy of the interface magnetization in ungated interfaces using ARL's Superconducting Quantum Interference Device instrument. We will experimentally investigate gate voltage controlled rotation of the ferromagnetic insulator interface magnetization.

**Foster, L.A. • Niggemeyer, D.**

**Biologically-inspired processor for ultra-low power video surveillance applications.**

Many surveillance tasks require continuous and long-term processing of video. The data needs to be classified and evaluated for content-of-interest. Over the last few years, convolution-based neural network algorithms have been successfully implemented with digital logic or on standard processors. Two main issues arise from this approach: (1) the power consumption is generally too high for any battery-powered applications, and (2) enormous amounts of specific training data are required for the learning phase of the neural networks before they can be deployed. The current top-performing neural network algorithms are powerful; however, their approach can only be described as brute-force processing. In contrast, the topology and connectivity of the mammalian brain efficiently operates with much lower power to perform simple image identification and classification tasks. As a simple example, the driver of a car has to constantly surveil the traffic situation to determine how to react to control the automobile through the environment. The driver's brain constantly processes his collected imagery to identify the path and objects to avoid. And his brain does this with a fraction of power required from conventional processors implementing complex image recognition software. EWA Government Systems Inc. was awarded and successfully completed an Army Small Business Innovative Research (SBIR) Phase 1 and 2 project to develop a bio-inspired neural processor design. There were several biological characteristics we employed in our design. We employ memristors to adjust the neurological weighting of signals between neurons that sum up in a neural synapse junction. We developed biologically-inspired spiking neurons which mimic how the brain receives and processes information from the

input of our body sensors, such as eyes and ears for sensed input. Spiking neurons significantly lower the overall power consumption since the information is communicated between neurons as small units of charge instead of conventional processors with constant voltages of binary number value. Finally, the neural network circuit can operate in synchronization with additional digital processors, so that these processing components can split the workload when appropriate. In the SBIR project, we also had to consider the limitations required for fabrication on a silicon chip substrate. For example, biological neural networks are three-dimensional and feature millions of neurons and synapses. For our prototype design, we developed a network of neurons with minimal connectivity that permits the implementation in a two-dimensional integrated circuit layout. We also explored how to use electronic chip components to create electronic circuit analogs that mimic the operation of biological neurons. We designed all of the circuitry building blocks of this revolutionary processor, tested the blocks in simulation, and developed an analytical simulation of the neural network processor array using the limitations of the circuit building blocks for mathematical accuracy. Furthermore, we developed a software application to train the neural network to apply the appropriate weights of information between neurons. We then assessed the performance of the neural processor to recognize images and determined an estimate of power consumption. What we found was that our neural processor design uses one-thousandth the power compared to a similar software application running on a state-of-the-art computer. We also found that the processor was capable of scanning digital imagery downloaded from the internet and find objects with a 90% probability of detecting target images. We can leverage biology to inspire a revolutionary next generation processor. With efficient processing, we can transform dumb video cameras into smart sensors that recognize the images they collect with negligible power. We can develop image processing servers that utilize a fraction of power to scan imagery and video for objects of interest. We assembled a team of engineers and a chip fabrication research facility that can develop a first prototype spiking neural network processor core. We look forward one day to have a chance to create a revolutionary neural processor to

**Foulis, S. • Hughes, J.M. • Procter, S.P. • Taylor, K.M.**

**Overview of the ARIEM Reduction in Musculoskeletal Injury (ARMI) Study.**

Musculoskeletal injuries (MSKIs) are a threat to Soldier performance and lethality. Due to the unique multi-stressor environment of Army basic combat training (BCT), MSKIs are common in recruits (27-62% in females and 14-42% in males). MSKIs interfere with training and prevent recruits from achieving their peak physical performance, frequently resulting in recruit recycling and attrition. Despite the high incidence and profound effects of MSKIs on Soldier health and performance, comprehensive, longitudinal evaluations of the most influential risk factors for MSKIs, as well as evidence-based recommendations for prevention practices are lacking. Identification of recruits at high risk for MSKIs and the development of effective prevention practices require comprehensive scientific evaluation of modifiable (e.g. medication

use, nutritional status, sleep) and non-modifiable (e.g. race/ethnicity, sex, age) risk factors for MSKIs. The overarching goal of this study is to develop an optimized predictive model of risk factors for MSKI. In addition to development of a predictive model of MSKI, the study aims to develop evidence-based, actionable recommendations to Army leadership to reduce musculoskeletal injuries in recruits without reducing training standards. Included in the study objectives will be an assessment of the Occupational Performance Assessment Test (OPAT) initiative as a screening metric predictive of physical performance to high physical demands tasks required by Soldiers and determination of the effectiveness of ongoing injury prevention programs such as the Performance Readiness Bar (calcium and vitamin D supplement). To accomplish these objectives, this study is a collaborative effort with the Army Research Institute of Environmental Medicine, Army Public Health Center, Training and Doctrine Command: Center for Initial Military Training, and a number of academic institutions. The study includes approximately 4000 (2000 male and 2000 female) recruits undergoing BCT and being tracked throughout and following BCT (for two years after) to examine MSKI outcomes, lost training time, and critical risk factors for injury. Recruits consenting to participate are asked to complete surveys (e.g. personal background, physical activity, health information, sleep, and psychological characteristics), anthropometric and body composition measurements, state-of-the-art high resolution peripheral quantitative computed topography (HRpQCT) scans to assess bone and muscle microarchitecture, brief series of physical exercise tasks, and a blood draw. These assessments are being completed at both the beginning and the end of BCT. Recruits will be given a weekly survey during BCT to capture injury status, missed training events, and medication usage. Recruits are also asked for consent to obtain accession and training record data as well as medical records to obtain MSKI and related information for the 2 years following Army BCT graduation. The approach of employing novel muscle and bone scanning technology, examining modifiable and non-modifiable risk factors, and tracking injury and related outcomes in a large cohort of recruits during BCT allows us to determine who is at greatest risk for MSKI, identify novel risk factors, and determine underlying mechanisms of injury. Data will provide information on traditional and emerging risk factors for MSKIs that can be utilized to develop solutions that optimize Warfighter health readiness, lethality, and performance. The views expressed in this abstract are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

**Gallmeyer, T. • Dahal, J. • Neuchterlein, J. • Stebner, A. • Thyagarajan, R.**

Systematic development of framework for validation and performance quantification of Additively Manufactured (AM) replacement parts for structural steel applications. In this paper, we will present an Integrated Computational Materials Engineering (ICME) framework that consists of statistical modeling of pre-existing data, finite element modeling, and targeted, small numbers of experimental

validation tests as a means to systematically validate additively manufactured (AM) steel replacement parts and quantify their performance versus the production legacy part. Being able to produce AM parts at the point of need in theater, and adequately quantifying its performance is critical to empowering the warfighter and ensuring mission success. Specifically, the following steps represent the primary methodology approach to achieve our research objectives: (1) A Random Forest algorithm was used to model the statistical performance of pre-existing additively manufactured steel data. The yield strength (units are ksi) model validation is shown in Figure 1. (2) Those statistics were then used to inform a finite element (FE) based "design for additive" process (Figure 2) for a currently cold-rolled and cast steel door hinge assembly of a MAXXPRO Mine-Resistant Ambush protected (MRAP) vehicle (Figure 3) (3) The FE model was used to optimize the AM builds of the hinge parts, which were made from 17-4 Argon-atomized, precipitation hardened, stainless steel powder (Figure 4). An EOS M-290 direct metal laser sintering (DMLS) 3D printer, which was also equipped with a melt-pool monitoring camera system, was used. (4) Validation was performed by testing coupons extracted from each legacy replacement parts (Figure 5), as well as the new additively manufactured replacement parts. Destructive full hinge assembly tests were also performed. Additionally, combined tension-torsion fatigue and resonant modal testing of the appropriate parts were also undertaken as part of the experimental characterization. (5) Tests were performed in both "as-printed" and "H900 heat-treated" states to evaluate the need and effectiveness for post heat treatment operations. We will present the findings comparing both the legacy part performance vs. the AM replacement part performance, as well as the FE model predictions of the AM parts vs. the actual part performance. We will conclude by discussing the improvements in statistical certainty of the model that were gained by updating the database with the new test data, demonstrating the ability for "sequential" or "active" machine learning. This project is designed to give the Army a continuously improving framework for designing and quantifying the performances of additively manufactured replacement parts. The practical application of this research is to develop a method that can be used to quantify the ability of AM replacement parts to substitute for the original design. While it would be ideal if the AM part met or even exceeded the performance of the legacy part, in reality, simply knowing what percentage of the legacy part performance can be achieved by the AM part is extremely useful in determining how best to use it. This is what we mean by performance quantification and describes the uniqueness of this research approach. The goal is to be able to execute this accurately using minimal physical testing of specimens either cut out of the AM parts (Figure 5), or alternatively from specimens made specifically for this purpose (Figure 4), aka witness specimens, from the same build as the AM parts. The comparative performance of AM vs legacy parts, even when manufactured using the same machine with the same processing parameters and out of the same material, will differ from case to case, depending on the actual part and the loading scenario. It is therefore the overarching objective of this research to define a simple and general methodology that will reliably quantify the performance of the AM part.

**Gans, E. • Bennett, M.D. • Roberts, D.C.**

Development and testing of Augmented Reality Command Control Communicate Coordinate (ARC4) for enhanced battlefield situational awareness.

Purpose: This research includes methods and processes for providing heads-up situational awareness with data from the tactical network presented to the operator on fielded display systems. The paper/presentation shall describe how information is presented to the warfighter and the associated value provided by the geo-registered symbology (i.e., Augmented Reality). In addition, we discuss how computer vision techniques and 3D terrain models can be used for geo-location, precision surveillance, and targeting including in GPS-challenged/denied environments. Theme: Advanced situational awareness technologies such as AR are specifically designed to assist the operator by providing mission critical information heads-up, on-the-move. With the proliferation of wearable computer systems such as the Nett Warrior End User Device (EUD), the operator is often checking their smartphone for mission critical information which requires 'heads down' viewing that reduces awareness of the surrounding environment. ARA's ARC4 technology is designed to be intuitive and unobstructed, providing critical mission information in fielded displays such as Enhanced Night Vision Goggles (ENVGs). By maintaining real-time SA, critical information from the tactical network can be received and presented to the operator in a non-obtrusive fashion. This includes symbology for waypoints, friendly forces, and potential threats, among others that ultimately aims to improve Soldier lethality, survivability, and mobility. Design/Methodology/Approach: ARA worked side-by-side with experienced military operators in developing our situational awareness tools and associated user interface. Specifically for our user interface we followed a four (4) step approach of: Identifying Cognitive Challenges; Defining Information Requirements, Develop Design Concepts, and finally, Testing, Evaluating and Refining the System. This process was iterated numerous times to produce an intuitive and modular user interface that 'blends' into the surrounding environment with low cognitive burden. Findings/Results: ARA has performed extensive outdoor testing to validate the performance of our AR systems. This includes a variety of locations including urban and remote areas with considerable natural terrain. Verification testing includes surveying the test environment to determine the physical location (i.e., ground truth) of features in the environment such as buildings, mountaintops etc. that can be 'marked' by the AR system to generate a symbol that is "locked" to the object or structure's physical location. We validate performance by having the user execute a variety of dynamic activities typical for a dismounted operator while viewing the ground truth to determine the consistency of the AR symbology to remain fixed on/over the real-world counterpart. For more precision and quantitative testing, ARA employs custom test fixtures that allow for input of specific motion profiles. Recent testing has shown that better than 5 mRad accuracy is achieved for symbology using our computer vision techniques to supplement commercial-grade MEMS Inertial Measurement Units. Practical Applications: ARA's technology is compatible with fielded military systems including the Enhanced Night Vision

Goggle (ENVG) and the Nett Warrior EUD, among others. Our situational awareness technology, called ARC4 (Augmented Reality Command, Control, Communicate, Coordinate), runs natively on a variety of operating systems including Windows, Linux and Android. All symbology is MIL-STD-2525 compliant. By providing two-way information sharing, operators can not only identify potential threats in the environment, but also 'mark' them for dissemination across the tactical network. This ultimately helps to realize the concept of a "Soldier as a Sensor" allowing the operator to rapidly share actionable intelligence across their squad and to higher command. Ultimately, heads-up SA provides overmatch capability and increased survivability to the infantry squad. Original Value/Conclusion: ARA's ARC4 technology delivers effective and intuitive situational awareness and is compatible with fielded military equipment. By leveraging systems such as the ENVG and Far Target Locators in combination with the Nett Warrior EUD (i.e., Android-based smartphone), ARA provides enhanced capabilities using organic assets. Our system is fully customizable, allowing the operator to fine tune the user interface for both overall layout as well as quantity and form of information presented in the heads up display. Recent field tests showed the ARC4 system is highly effective for navigation and route planning, allowing operators to adjust trajectory on the fly while not losing sight of the next critical waypoint or other object of interest, even when out of the operator's field of view due to obstruction.

#### **George, M.C.**

Army science and technology to support long range precision fires modernization.

#### **Germane, K.L. • Perisin, M.A. • Sund, C.J.**

##### **Microbial reactors - indigenous feed stocks to functional materials.**

The Army needs to be more adaptive, expeditionary, and have a near-zero logistic demand to enable soldier lethality in the deep future operational environment. The challenges to meet such needs will require manufacturing from inconsistent indigenous resource and waste streams. Current processing technologies are not amenable to complex inputs, nor are they capable of creating high value products or precise hierarchical materials. To lower expeditionary operation burdens and cost, synthesis of complex precision materials can be performed by biological systems using reclaimed, renewable, and indigenous resources and waste materials. Microbial systems are capable of utilizing a wide variety of feedstocks and their metabolic outputs can be directed to useful chemicals by genetic manipulation or by ecological interactions with neighboring microbes in complex consortia. The Army is developing these two approaches to create agile and expedient microbial reactors for manufacturing at the point of need. Genetic manipulation of microbial chemical output involves the introduction of exogenous DNA to alter metabolic pathways. *Clostridium acetobutylicum*, a ubiquitous soil microbe, was selected for further study due its ability to convert a wide range of substrates to useful outputs. These complex metabolic capabilities decrease the extent of genetic manipulation required to produce desired chemicals. Previous characterization of carbohydrate metabolism in *C. acetobutylicum* by

the Army, as well as recent advances in genetic manipulation, will allow for precision control of desired chemical production through modification of feedstock composition and metabolic pathway regulation. Some of the current chemical targets include alkanes, lactones, and polymer as well as energetic precursors. Certain chemicals of interest, not capable of being produced through genetic manipulation, will be targeted by designed microbial consortia. Constituents of the human gut microbiome, that are already adapted to a food waste stream, could be repurposed for useful chemical production. Computational models predict that combinations of gut microbes will enable increased and emergent production of useful chemicals. These microbes produce a variety of organic acids and alcohols that could feed into additive manufacturing platforms. Furthermore, fundamental understanding of gut microbes will enable nutritional and probiotic strategies to enhance soldier performance, a clear transition to the Natick Soldier Research and Development Center. Overall, these systems biology approaches will result in microbial reactors that are flexible to non-homogenous feedstocks and reconfigurable to produce chemicals of interest. Microorganism and consortia engineering will both enable agile expedient manufacturing energy generation and sustainment, thus increasing soldier lethality.

#### **Getnet, D. • Gautam, A. • Hammamieh, R. A. • Jett, M. • Marmar, C. • Yang, R.**

A pilot study to characterize the epigenomic status of the US OEF/OIF war veterans with PTSD.

#### **Goerz, M.H. • Kasevich, M.A. • Kunz, P.D. • Malinovsky, V.S.**

##### **Optimal pulse schemes for high-precision atom interferometry.**

Recent advances in atomic interferometry such as the ten meter atomic fountain interferometer (AFI) built in the group of Mark Kasevich at Stanford University have opened up new pathways to high precision gravitational quantum sensing. Analogously to an optical interferometer, a cloud of ultracold atoms is launched into a free fall while being split into a quantum superposition of two pathways that are later recombined. The gravitational field experienced by the falling atoms is imprinted on the resulting interference pattern of the quantum wave function. The fundamental limitation in this interferometer is the realization of high-fidelity, robust atom beamsplitters and mirrors. These must be realized through carefully tuned laser pulses manipulating the atomic momentum states. The purpose of our research is to develop numerical optimal control theory to design suitable pulse sequences to improve the efficiency of the device. The research is part of the Army Research Lab's overall drive for quantum enhanced sensing. Our methodology relies on the computer simulation of the interferometer's full quantum dynamics. As a first step, we then test the efficacy of a proposed pulse schemes using adiabatic passage with frequency-chirped pulses that are highly robust with respect to variations in the laser amplitude. We then apply well-established methods of quantum optimal control that allow to compress the control pulses to the shortest possible duration. Preliminary findings show that through optimal control, analytical pulses sequences can be compressed by more

than an order of magnitude, while also bringing nonadiabatic errors arbitrarily close to zero. We will discuss how the resulting scheme may also be made robust with respect to both quantum and classical noise sources. It will be possible to directly test our new proposed pulse schemes in Stanford's AFI experiment. Altogether, the use of adiabatic passage and advanced optimal control techniques are expected to facilitate an increase in the signal contrast, an enhancement of detector sensitivity, and a reduction in the size and weight of future AFIs. Ultimately, this will allow for the miniaturization of the device, and its use for mission-critical tasks such as remote sub-surface monitoring, e.g. the satellite-based detection of underground structures.

#### **Golt, M. • Ashkin, D. • Campbell, J. • Palicka, R.**

##### **Automating science to rapidly discover higher performing armor ceramics for readiness today.**

With the new era of Army modernization and a Futures Command, there will be increasing reliance on S&Es to deliver innovative and high-impact technologies to prevent the Soldier from fighting with legacy technologies in an evolving battlefield. To meet this challenge at the basic research level, new experimentation technologies can be developed that increase the discovery rate of superior performing materials and systems, while simultaneously increasing that scientific understanding that enables revolutionary advances in performance. The rate of scientific discovery and understanding is limited to the pace of experimental data collection. For most research efforts, data generation is a serial effort of process ? characterize ? analyze ? adjust ? repeat. This slow, methodical approach has been acceptable for academic works when knowledge is the product and a literature publication is the measure of success. However, when the measure of success is winning wars, the rate of obtaining knowledge and making discoveries must outpace our adversaries. Going forward, scientific discovery will accelerate through the automation of high-throughput experimentation capabilities. These capabilities will tend to include four main components: 1) Combinatorial, high-volume processing, 2) High-throughput structure/composition characterization, 3) High-throughput property/performance characterization, and 4) Computational informatics that is used to link parts 1-3 to obtain scientific understanding. These components form the basis for a machine that requires all components to operate with high-throughput to effectively increase the rate of scientific discovery. To that end, automation of- and within these components is essential. A high-throughput experimental approach is a very reasonable opportunity that more laboratories are beginning to embrace. These experimentation technologies begin at the bench level and can quickly result in exceptional, high TRL materials and systems for the PM. Discussed is an example of a high-throughput experimental approach that has recently been demonstrated at the Army Research Laboratory (ARL) to accelerate armor ceramic development. CoorsTek, an industrial manufacturing partner provided high-volume, combinatorial processing of 500+ armor ceramic specimens over a range of processing and ingredient combinations (#1). ARL developed a crucial technology to automate the non-destructive microstructure characterization of the samples by measuring their electrical properties (#2), as well as developed an efficient,

information-based ballistic testing method (#3). ARL then applied material informatics algorithms (#4) that determined the key processing parameters which resulted in superior performing microstructures. Validation testing showed that this method can be used to reduce the lot variability and raise the average protection level. This increased minimum level of protection can alternatively be exchanged for a reduction in weight. Since these discoveries are obtained on a production-level industrial process, the material is ready to be manufactured in high volumes for immediate use. In addition, these technologies are being transitioned to further improve ceramic armor R&D on novel ceramic systems, provide insights into successful microstructure designs and failure mechanisms, and utilized as a tool for quality control of production runs to minimize performance variability. This model shows how automation of high-throughput experimentation made in partnership with industry manufacturing can yield immediate and compelling products from a research effort.

### **Gregorczyk, K.N. • O'Donovan, M.P.**

#### **Exoskeletons for soldier augmentation: current research perspectives.**

**Purpose** - The intent of this talk is to summarize the current state of the art in Exoskeleton technologies, the near term applications for the military, and to identify the critical research areas that must be pursued for these systems to be able to provide close combat overmatch. **Theme** - Exoskeletons for enhanced human performance in close combat environments directly addresses the overall symposium theme, "Army Science & Technology - Empowering a Soldier's Success," as well as the focus area of Soldier Lethality: Human Performance Optimization and Enhancement. **Design/Methodology/Approach** - In April, 2018, in conjunction with the Office of the Under Secretary of Defense for Research and Engineering (OUSD R&E), the U.S. Army Natick Soldier Research Development and Engineering Center (NSRDEC) hosted a DoD Exoskeleton Interchange Meeting. The purpose of the meeting was to bring together representatives from industry, academia, and DoD to discuss user needs, DoD investment areas, developer technologies, and current state of the science. This talk summarizes the outcomes of that meeting with a focus on the state of exoskeleton systems currently in use or being developed for medical, industrial, and military sectors. Additionally, future areas of research were identified and will be presented as critical to further advance these systems for use in close combat scenarios where exo-human symbiosis is an absolute necessity. **Findings** - Commercial exoskeleton technologies have matured rapidly and are currently in use at the New York Veterans Association (VA) Rehabilitation, Research & Development Center for rehabilitation of spinal-chord injury as well as on production lines for aerospace and automotive manufacturers as a way to decrease ergonomic risk to their workforces. Specifically, Boeing, Toyota, and Ford have all begun to pilot test the use of commercial exoskeletons for specific manufacturing tasks including overhead tool handling and lift assistance. While there have been encouraging outcomes associated with the use of exoskeletons for rehabilitation including positive gains in lean tissue mass, fat loss, and improved bowel and bladder function, these medical systems are limited by slow walking speeds, non-standardized training protocols, and widely varying adaptation

responses across individuals. There have also been positive indications for use of commercial exoskeletons in industrial settings including reduced muscle activity and reductions in ergonomic risk. However, systems are typically task specific (i.e. can only be used for a specific type of manufacturing task or motion) and long term data on the health benefit provided to workers is still non-existent and needs further exploration. With that said, these types of systems have the near-term potential to positively impact the Military Occupation Specialties with similar logistical requirements as the automotive and aerospace industry spaces. The Army's adoption and utilization of these devices has the potential to reduce acute and overuse musculoskeletal injuries and should be explored. However, these devices are limited in their application to highly variable environments such as combat. In order to accelerate the development of exoskeleton systems to accommodate the incredibly complex, demanding, and varied tasks associated with close quarters combat, several research areas were identified. These areas include: Increased human-exoskeleton fluency and interaction, human variability and responses to adaptation and training, increased experimental throughput, and human-in-the-loop controls development. Only by targeted resourcing and support to research areas that will advance the design of exoskeleton controls, increase the communication between the human and the system, and increase the understanding of the roles of training and adaptation, will the vision of Soldier physical augmentation through exoskeletons be realized. **Practical Applications** - If the areas of research outlined here are pursued, it could lead to the development of advanced systems and controls for exoskeleton systems to augment Soldier physical performance and significantly increase Soldier lethality in close quarters combat. **Original Value** - The areas of research outlined here are all novel and of high value for the development and design of advanced exoskeleton systems and controls. This talk seeks to provide information to the Army S&T community on the current state of applicable technologies as well as the current research needs of the exoskeleton community.

### **Gutstein, S. • Bohannon, A. • Lawhern, V. • Slayback, D.T. • Waytowich, N.**

**HAIL:** a human-autonomy crowdsourcing approach to image classification.

### **Haile, M.A.**

**Risk-adaptive maneuver for enduring operation.** We introduce a new operational construct, called Risk-Adaptive Maneuver for Enduring Operation (RAMEO), for extending the maintenance-free operating period (MFOP) of future Army aircrafts. The over-arching goal is to establish a new risk-based operational paradigm that enables the future force, including Future Vertical Lift, to operate in highly austere and denial-of-service environments with minimum maintenance and logistics support. RAMEO is an operational construct in which maneuver profiles are manipulated to maximize the maintenance-free operating period of an aircraft without exceeding the operational risk threshold. RAMEO enable vehicle operations in degraded or damaged states with the implied assumption that, temporary and controlled performance suboptimality is conditionally acceptable in order to gain

additional MFOP hrs. As an operational construct, RAMEO is primarily concerned with service damage. Hence, damage is cumulative in that it initiates at time  $t_0$ , monotonically grows large enough to be detected at time  $t_1$  and reaches a critical threshold at time  $t_2$ . The health or damage state of a system during  $[t_1 t_2]$  is probabilistically estimated from sensor measurements and physics models using a Bayesian framework. A physics model requires initial state, usage data and model uncertainty. A sensor measurement depends on the characteristics of the diagnostics system (such as probability of detection) and a calibration model. The future state of a system after the completion of a series of flight (or operational) maneuvers. For a given current state and maneuver profile, a future damage state is obtained using probabilistic state transition models. Since the future state is an estimate, it entails a great deal of uncertainty and risk. The operational risk (or the risk of operating the vehicle) during the MFOP is obtained using probabilistic risk assessment where the probability of failure of each component and associated severity (cost of failure) are quantified using Bayesian inference. The latter is numerically solved using Markov Chain Monte Carlo (MCMC) and Subset Simulation (SS). MFOP-Vulnerability (MFOP-V), is the probability that a vehicle fails to survive for the duration of the MFOP due to excessive system degradation. Ideally, an aircraft will be serviced as soon as MFOP-V exceeds a certain threshold, however, in certain conditions (future force) the vehicle must stay operational for additional  $\Delta t_{(MFOP)}$  flight hours without the necessary corrective actions. This extra  $+t_{(MFOP)}$  carries an increased risk, such as a high probability of failure, which must be quantified and mitigated. The increase in risk is related to the maneuver profile of the aircraft. The maneuver profile, which is a description of the aircraft's flight path and in-flight activities (speed, load, geometry...), is composed of several flight regimes. Each flight regime  $I_{[j]}$  adds a finite amount of degradation (in a cumulative sense) to components depending on regime parameters such as load at main rotor-shaft, tail rotor-shaft, etc. Cumulative damage and risk can be mitigated by adapting maneuver regimes and parameters based on knowledge of failure modes and mechanisms of the aircraft systems. The adaptation process involves: (1) identifying the modes of failure, such as fatigue crack, wear, corrosion, etc, of critical systems, (2) eliminating avoidable maneuver regimes that significantly contribute to failure mechanism (such as excessive bending, vibration, shear, temperature, etc) and (3) tuning the flight parameters of unavoidable maneuver regimes. The three steps outlined here invariably require tradeoffs with performance of the vehicle. As such, the vehicle will be allowed to perform below its design capability until at least the next window of opportunity for maintenance and repair. Mathematically, RAM is implemented as a probabilistic optimization routine where maneuver regimes are permuted so as to minimize the risk  $R$  or MFOP-V of a mission profile. For complex aircraft systems the optimization routine problem can only be solved using Bayesian Networks (BN). Bayesian networks capture structural and numeric probabilistic relationships among random variables in terms of a directed acyclic graph and conditional probability tables. In this paper, we report methods for implementing BN for approximating MFOP-V and risk  $R$  for finite

discrete sets of maneuver parameters.

### Hall, C.M.

#### Physics and Chemistry Explorations in STEM.

The purpose of the US Army Research Laboratory (ARL) ARL K-12 STEM Outreach Program is to inspire and motivate students to seek STEM based higher education, by providing Army science-based, innovative, hands-on activities and experiences; designed to enhance formal classroom training. Physics and Chemistry Explorations in STEM, (PACES) is a unique STEM outreach program developed collaboratively by ARL and Harford County Public Schools (HCPS), designed to inspire the next generation of scientists and engineers. PACES provides every 8th grade student in HCPS the opportunity to take part in an immersive, hands-on laboratory experience featuring aspects of chemistry, physics, mathematics and engineering. Cellular phone technology serves as the overarching theme of the experience, with labs that focus on batteries and speakers. As students participate in the electro-chemistry battery lab they learn about the importance of providing power for Soldiers and associated challenges such as weight, portability, durability etc. lending insight to relevant Army research. As students use principals of engineering design to build and test speakers they learn about sound waves and energy, hearing protection/loss and bone conduction transmission. They explore the importance of Soldier focused research efforts and gain insight into Soldiers' need for hearing protection that provides situational awareness. FY17 student survey data results following participation in PACES: Increased interest in taking high school STEM courses – 46%. Continued interest (no change) in taking high school STEM courses – 47%. Less or minimal interest in taking high school STEM courses – 7%. Increased interest in a STEM career – 50%. Continued interest (no change) in a STEM career – 46%. Less or minimal interest in a STEM career – 4%. PACES reaches students at an important age as they begin to consider their own education pathway. A key element of PACES includes interactive brown bag discussions with Army scientists and engineers who discuss their personal STEM education path and career. During these sessions, students gain an awareness of STEM pathways and potential opportunities available to them in

### Hansberger, J.T.

Virtual reality interfaces for exploited media analysis.

### Hart, R.J.

#### Development of computational models for composite structures to accelerate the design of lightweight next generation combat vehicles.

This research relates to the development of lightweight Next Generation Combat Vehicle architectures. Historically, the Army has made significant investments in developing demonstrators that show the advantages of using composite materials to create lightweight combat vehicles (i.e. Composite Infantry Fighting Vehicle, Composite Armored Vehicle). Despite these successful demonstrations, composite structures have struggled to cross through the “valley of death” into a program of record. While there are multiple barriers impeding

the widespread use of composite materials in ground combat vehicles, one barrier is the high cost to test heterogeneous composite materials compared to more homogenous metal alloys. This research aims to reduce the scope and cost of testing by creating novel material models and finite element methods that accelerate the design of lightweight interior structures for the Next Generation Combat Vehicles. A finite element (FE) material study has been completed in Abaqus/Standard to understand the influence of several different parameters on the impact response of fiber-reinforced polymer (FRP) composites. A single common epoxy matrix material (SC-15) was utilized for all specimens in the study. SC-15 is a toughened epoxy resin commonly used for military ground vehicle applications and is compatible with fiberglass, aramid, and carbon fibers, which were the fiber materials considered in this study. The composite laminates in this study included unidirectional or plain weave fabric plies laminated in cross-ply [0/90]s configuration. The material properties of the composites were calculated in a custom Matlab code using a widely accepted composite material theory called the rule of mixtures. The material properties from Matlab were then inserted into a finite element model where the material was subjected to a low-velocity blunt impact. Overall, this study was able to demonstrate that the Matlab code could generate reasonable material properties to be used in the finite element models. Generally, the composite laminates with unidirectional plies experienced higher peak impact loads, lower deflection, faster impact response, and steeper load vs deflection curves compared to the plain weave fabric ply laminates. This research is intended to be used as a practical tool for a design engineer that has limited experience in designing using composite materials. All the designer would need are material property datasheets from the manufacturers of the fibers and resins. The code takes these material properties and combines them to generate the equivalent material properties of a composite lamina with the desired fiber content, fabric weave, and orientation. The material model can then be used in finite element simulations so that the designer can decide which material(s) are preferred for the given application. The methods can be easily adapted for optimization purposes. The use of computational models narrows down the quantity (cost) of unique materials that must be tested before deciding on a final material selection. This research is unique in that the material model code automatically generates material properties of any composite material based on datasheet properties. Many software packages have built-in material models for some common composite materials, however these materials are almost always aerospace grade composites. In order to add a new material to the code, the user must have experimental data in hand, which may not be feasible for early design studies. This research is geared specifically to reduce the effort and testing burden for developing composite material models for designing lightweight Next Generation Combat Vehicles.

### Heintz, A.M. • Colachis, M. • Ganzer, P. • Shqau, K.

#### Enhancing warfighter performance with non-invasive neurostimulation enabled by dry skin electrodes.

Comfortable, efficient wearable devices will

be key to enabling the new wave of warfighter technologies and electrotherapeutics. For these devices to realize their full potential, they need stable and continuous electrical contact with the person. The key limitation to establishing stable and continuous electrical contact is the interface between the electrode and the person. The state of the art is to use a hydrogel to couple the electrode to the skin. However, such systems can change with time, temperature, and humidity, and their performance can change as the person moves due to squeeze out and other factors. The goal of our research is to develop a comfortable, conductive, non-invasive, dry electrode that will broaden the realm of materials utilized in wearable devices, focusing first on transcutaneous electrical nerve or neuromuscular electrical stimulation (TENS, NMES). Our research aims to create new platform materials that can enhance warfighter performance, particularly through wearable devices that are used for neurostimulation. To overcome the deficiencies of hydrogel-based systems, we have developed a new type of electrode based on mixed-ionic-electronic conductor (MIECs). The MIECs are an interconnected network of electrical and ionic conductors in an elastomeric matrix that provides: (1) high surface area for efficient capacitive charged discharge; (2) high ionic conductivity for low interfacial resistance; (3) low ohmic resistance; and (4) excellent flexibility and toughness. Carbon nanotubes (CNTs) are the electrical conductors in the MIEC and hyaluronic acid (HA), along with moisture and ions, is the ionic conductor. This system exhibits good mechanical properties, high conductivity and high ion mobility, leading to facile electrode kinetics. The performance of the flexible MIEC electrode was evaluated in terms of extent of the ionic charge transfer resistance on ionic block electrode changes, as a function of moisture, sodium and hyaluronic acid content. Electroimpedance (EIS) spectroscopy was carried out with a skin simulant to characterize the effect of formulation variables on the interfacial charge transfer characteristics, using a Randle circuit model. The biocompatible materials were incorporated into sleeve, which was used for transcutaneous muscular stimulation in able-bodied humans. Finally, the electrodes were used in preclinical tests for non-invasive nerve stimulation. The results indicate that the conductivity of the flexible electrode is well maintained with extension over repeated cycling. It is possible to independently tune the double layer capacitance and interfacial resistance elements by choosing the right configuration. This provides more efficient coupling with the skin, indicating that devices configured with such an electrode would consume less power. Our results from able-bodied testing, under AC stimulation, show that MIEC has a lower impedance than state-of-the-art hydrogel electrodes with stainless steel current collectors. Results from preclinical testing suggest the ability to use for enhancing cardiopulmonary function non-invasively. Non-invasive stimulation is being explored for reducing stress and fatigue and enhancing cognition and mood, with the end goal of improving warfighter awareness, memory and focus. Typically such devices use a hydrogel electrode interface, which is not stable; the performance can change as the person moves due to squeeze out and other factors. Devices made with this MIEC minimize the power needed to stimulate because the electrode has low losses at the skin. It is also lightweight and has excellent flexibility,

so does not disrupt warfighter mobility. We estimate our power advantage is at least 10-15% better than a hydrogel. The preclinical devices could be readily adapted. The performance of a novel dry electrode for non-invasive nerve stimulation in both human and animal models was demonstrated.

**Holthoff, E.L. • Bickford, J.R. • Cho, P. • Pellegrino, P.M.**

#### Chip-scale optical phased arrays to enable reliable communications.

In the emerging contested and constrained electromagnetic (EM) battlefield, the Warfighter can no longer rely on conventional communication and networking approaches. Indeed, a key gap identified involves alternative dynamic communications approaches capable of operating in such environments. This gap is critical in that failure to close it jeopardizes conventional Warfighting operations. Despite the robustness of conventional-RF systems, it is imperative in the future fight that the Warfighter be equipped with technologies that exploit all available resources, employing unconventional spectrum, channels, devices, and networking modalities. Highly miniature optical phased arrays can provide a directional networking capability that enables stealth and anti-jam characteristics, empowering a soldier's success. Photonic integrated circuits (PICs), systems of light/electron interaction components in chip form, are the key enabler of such arrays. We are developing rapidly steerable optical phased array (OPA) PICs to serve as the basis for a directional communication system in the near-infrared (NIR) (where PIC technology is sufficiently mature). Chip-scale OPAs can offer solid-state optical beam steering, beam shaping, and MIMO-like multiple simultaneous beam emission, establishing robust free-space communication links that can be rapidly reconfigured (potentially within tens of milliseconds) to ping or track remote transceivers or enable micro-UAV intra-swarm short-range high-bandwidth ranging/imaging/communications, avoiding the use of bulky mechanical gimbaling. This can, for example, enable very high-speed (potentially >25 Gbps) stealthy and anti-jam optical links on mobile platforms and micro-UAVs. We are developing an OPA optical communication link model to study link-performance tradeoffs. This model will elucidate the technical hurdles needed to realize a robust low SWaP-C link. While fabrication of NIR PIC components is well understood, the arrangement of and composition of PIC components working together as an OPA system is not. OPA transmitter system concepts are being designed, fabricated, and characterized to enhance our fundamental understanding. Insights gained from this research will inform exploration and development of novel network protocols that will serve to realize the potential of this technology in tactical environments. We will present the progress of our design exploration of these structures, including our recent demonstration of passive one-dimensional edge emitter array steering and also two-dimensional planar emitter array beam steering on a probe station. Exploiting the advantages of PICs to develop OPAs that enable ad hoc free-space optical communication can provide a complimentary high-bandwidth, low probability of detection communication alternative for the Warfighter and supports the Army Network Modernization Priority.

**Huisman, T.**

#### Immersive training: using sound as a training tool.

We perceive our world and surroundings through sound first, giving us a true 360 degree field of 'view' on our environment. Sound is a key differentiator on where to focus our visual system and an integral part of the decision making process. It is the only real information carrier between humans. The recognition of these factors and the value it can provide for the quality of training is an important first step in developing the same standards that exist for the visual counter part. The right solutions and content will truly transfer the trainee into the virtual world and therefore increasing the quality of the training outcome. The question is therefore how to take sound beyond notifications and truly make training immersive? Immersion as a keyword encompasses a broad range of qualities that are vital to the outcome of training in virtual environments. Emerging technologies in VR, AR, MR and traditional visualization change what is possible to train in a virtual environment. But one key element to achieve sensory immersion is left behind in number of fields like standardization, program requirements, recognition of tactical relevance etc. Building on the developments in COTS technologies I would like to stimulate the debate on how to bring these factors for sound into the simulation world to improve the quality and open-up new possibilities in this area.

**Jayakumar, P. • Choi, K. • Funk, M. • Gaul, N. • Wasfy, T.**

#### Development of a stochastic mobility map for next generation NATO reference mobility model.

In the current NATO Reference Mobility Model (NRMM), only the deterministic values the terrain property variables and terramechanics simulation models are used in the development of off-road mobility maps. The developed deterministic mobility maps would not be reliable and thus cannot be used effectively in mission planning of NATO forces under different terrain scenarios and for selection of capable Next Generation Combat Vehicles. To support the Next Generation NRMM, a framework for generation of reliability-based stochastic off-road mobility maps is developed in this paper using full stochastic knowledge of terrain properties and modern terramechanics modeling and simulation capabilities. The framework that needs to be developed is uncertainty propagation and reliability assessment for Speed Made Good and GO/NO-GO decision based on the variabilities of the terrain condition. For modeling terrain condition variability, the elevation raster data was obtained from the Shuttle Radar Topography Mission. A simple toolbox was created in ArcGIS that calculates the slope from an elevation raster data. For variability of the slope at given point, realizations of the elevation raster are generated using the normal distribution. For the soil property parameters, a geotechnical database provided two tables, one for soil cohesion values and the other for friction angle values. Using the min and max values of the soil property, the distribution type was assumed a normal distribution with a 99% confidence value range; and the distributions for the soil parameters for each of the soil types were constructed. Similarly, bulk density distributions were constructed for different soil types using bulk density measurements. With all of these soil variability information gathered, each

soil type now has its own distribution for each of the soil properties: friction, cohesion, and bulk density. For the framework, we need to identify ranges of the terrain elevation and soil properties that will cover the regions of interest. Within these ranges of terramechanics input parameters, a Dynamic Kriging (DKG) surrogate model of the Speed Made Good is generated using the terramechanics model runs at the design of experiment points. This DKG model generation is a compute intensive process and likely require the use of high performance computing (HPC). However, once generated, the surrogate model of the vehicle and terrain can be reused to generate reliability-based stochastic mobility map for any regions of interest efficiently. Using the DKG surrogate model, the propagation of variabilities from elevation and soil properties into mobility can be calculated by carrying out inverse reliability analysis. The inverse reliability analysis results is used for generation of reliability-based stochastic mobility map across the selected region of interest. To generate reliability-based stochastic mobility map, we need no less than 1000 Monte Carlo Simulation samples at each location of the pixel. Thus, depending on the size of the region of interest, it could be tens of million pixels. However, using the DKG surrogate model of the Speed Made Good, this process can be carried out efficiently. This will allow quicker generation of the stochastic mobility map without requiring the use of HPC. For a prototype demonstration of the developed framework, Monterey, CA is selected as the region of interest. For the vehicle model, the Nevada Automotive Test Center Wheeled Vehicle Platform is used. The inverse reliability analysis is carried out to create the reliability-based stochastic mobility maps of Monterey, CA. In the map, e.g., 90% Speed Made Good map means that there is 90% probability that the maximum obtainable speed is greater than or equal to the value shown on the map. It is found that the deterministic map is somewhere between the 20% and 30% reliability maps, meaning the deterministic map only has probability of approximately 25% to achieve the indicated speed. This demonstrates the need for taking into account the variability so that accurate Speed Made Good maps can be generated and have a given reliability or confidence associated with them, in order to provide reliable information to the decision maker of the next generation combat vehicle mobility. The same DKG surrogate model and the uncertainty quantification tool can be used to generate the reliability-based GO/NO-GO maps. For GO/NO-GO maps, the cut-off speed is 5 miles/hour. In this map, the green color means GO, the red color means NO-GO and the blue color means water. Thus, the green color in 90% GO/NO-GO map means that there is 90% probability that the vehicle can move with at least 5 miles/hour speed. It is found that, for up to 40% reliability, the NO-GO region does not seem to be significantly appearing. However, starting at 50% reliability, the NO-GO region is beginning to show up. It is found that the deterministic GO/NO-GO map appears to be similar to the 60% GO/NO-GO map.

**Jayakumar, P. • Marple, G.R. • Mehergui, D. • Veerapaneni, S. • Wasfy, T.**

A novel active learning approach for constructing high-fidelity mobility maps. Accurate predictions of vehicle mobility are vital



to combat operations. A mobility map predicts the maximum speed an off-road vehicle will be able to obtain for the various soil conditions in their theater of operations. In the past, empirical and semi-empirical techniques, such as the NATO Reference Mobility Model (NRMM), were used to predict mobility maps on off-road terrains. Because of its empirical nature, new vehicle designs containing advanced technologies, such as lightweight robotic vehicles, have mobility capabilities that are not easily predicted by simply extrapolating the NRMM method. Therefore, it is imperative that new techniques for predicting mobility are developed. A mobility map depends on a variety of parameters, such as terrain topology, soil type (mud, snow, sand, etc.), vegetation, obstacles, weather conditions, and vehicle type and characteristics. The map is created by discretizing a terrain map onto a Cartesian grid. Each cell on the grid represents a certain geographical area with a specific topology and soil type. A mobility measure is then superimposed on each cell. A mobility measure that is commonly used is the speed-made-good which is an estimated maximum vehicle speed at a steady-state. In order to more accurately predict mobility, the NATO Next Generation NRMM Team has suggested that physics-based methods, such as the discrete element method (DEM), should be used. While physics-based modeling has been shown to be a good predictor of vehicle mobility, its use in generating mobility maps has caused some difficulties. For example, in order to simulate the complex behaviors of the various soil types, each simulation has to keep track of millions of soil particles and their interactions. This means that these physics-based simulations require a great deal of computing resources. In addition, since each cell on the mobility map may have slightly different topology and soil conditions, generating a mobility map for a single ground vehicle can easily require tens of thousands of simulations. As a result, a mobility map can take several weeks to generate, even with the help of high performance computing. A recent approach was able to reduce the time needed to generate mobility maps by using techniques from machine learning. The idea was to train a machine learning classifier, such as a support vector machine (SVM) or a neural net, to predict the speed-made-good using data generated by running a large number of physics-based simulations. Once a classifier is trained, it can be used to quickly generate a mobility map. Unfortunately, this approach has several difficulties. According to probably approximately correct learning (PAC learning) theory, a data distribution that can be perfectly separated by a classifier is expected to require  $O(1/\epsilon)$  randomly selected points in order to train the classifier with error  $\epsilon$ . This means that increasing the accuracy of a classifier from 95% to 99% would require up to 5 times the number of simulations. In addition, as more features are incorporated into the model, the number of simulations will increase again. In order to address this problem, we developed a sampling technique that can substantially reduce the number of simulations that are needed to train a classifier. Our approach uses techniques from active learning, which is a special case of semi-supervised learning. Active learning is generally useful when a large amount of unlabeled data is available but labeling that data is expensive or time consuming. This is exactly the situation that arises when data from computationally intensive simulations is used to train classifiers. Active learning reduces the number of labeled data

points by interactively choosing more informative points to label. In fact, active learning techniques can, in some cases, train classifiers using only  $O(\log(1/\epsilon))$  data points, which is an exponential improvement over random sampling. We evaluated the effectiveness of our approach by constructing a test function using data from 528 physics-based simulations. By leveraging uncertainty sampling, query-by-committee, and error reduction techniques, we discovered that high accuracies could be obtained using less than a third of the number of data points that would be needed if the data points were uniformly or randomly sampled. We found that a neural net, that was trained using 300 data points that were carefully chosen by our sampling technique, was able to predict the test function with over 99% accuracy. To test the robustness of our approach, we used our sampling technique to train a neural network on data that was incorrectly labeled 10% of the time. We demonstrate that high accuracies can be achieved even in this context of data being noisy.

### Jiang, R. • Tran, D.T.

#### In situ hydrogen generation and hydrogen fuel cell for future soldier power system.

A highly efficient compact electric power source plays a key role for soldiers to win a war in a battlefield because automatic weapons, telecommunication devices, night vision goggles, sensors and portable computers all need electric powers. Currently, power sources for short-term army missions is provided by batteries. However, the Army dismounted soldiers require lightweight, high power, high energy electric power sources for long term operation safely and reliably. Fuel cells have demonstrated promise for providing clean electric power to automobiles, unmanned aerial vehicles (UAVs), submarines, and consumer electronics. A fuel cell must use gaseous hydrogen as fuel. Hydrogen generation, containerization, and transportation are great concerns, which have hindered fuel cells as power sources for various army applications. Addressing the hydrogen source concern, we have invented a power-free device for hydrogen generation. When an alcohol water solution is filled into this device, hydrogen gas is continuously generated at room temperature. The yield of alcohol conversion to hydrogen with methanol is determined, up to 90% with this apparatus. Theoretically, 100g methanol can generate 18.75g hydrogen. Furthermore, addressing the challenges of hydrogen containerization and transportation, we have designed a fuel cell system containing an in situ hydrogen generator, which has no need to carry on a hydrogen gas tank. The hydrogen gas is in situ generated and used simultaneously in this device. This device is called A/C junction fuel cell. A prototype of A/C junction fuel cell has been designed, demonstrated, and tested. When using methanol for hydrogen generation to fill the hydrogen/air fuel cell, about 1300 Wh/kg power density has been achieved. Because of these achievements, we have received two patent issues. Focusing on high efficiency hydrogen generator and high performing fuel cell system, we have overcome various technical barriers. In this presentation we will report the science of nano materials research; the technologies of micro electrode structures design, the assembly of prototypes of hydrogen generator and fuel cell system; as well as a possible scale up of this device. Here, the single fuel cells are scaled up to a fuel cell stack, and the single hydrogen

generators are scaled up to a hydrogen generator stack. The estimated fuel energy efficiency and hydrogen generator's power density are calculated by assuming a 20W H<sub>2</sub>/Air fuel cell stack for 72 hours operation, containing 16 single cells, each cell having 16 cm<sup>2</sup> electrode area, with graphite bipolar plates as electrodes, 200 mA/cm<sup>2</sup>, filling with 2M methanol at 60 °C. The estimated fuel energy density with methanol is 3166 Wh/kg or 2532 Wh/L [1, 5], and the estimated hydrogen generator's power density is 172 W/Kg, or 196W/L, respectively. Conclusion: Our research has demonstrated that methanol can be used as an alternative of "Liquid Hydrogen" to feed a hydrogen/air fuel cell. Theoretically, 100g methanol is able to generate 18.75g hydrogen. The actual conversion number is dependent on the fuel cell design methods, operating temperature, electrolyte type, and catalysts, etc. Our method is possible to be scaled up to a future soldier power system. In order to realize this goal, we must develop better nano catalysts for the hydrogen evolution reaction (HER), oxygen reduction reaction (OER), and alcohol oxidation reaction (AOR); as well as increase the operating temperature of HER to reduce the over potential to as low as 0.1V.

### Johnson, T. • Bigdely-Shamlo, N. • Kellihan, B. • Robbins, K. • Touryan, J.

#### Standardized annotated neurophysiological data repository for the assessment of cognitive state.

Soldier performance assessment, long a key component of U.S. Army research, will continue as a critical element of the Soldier lethality priority within the Army modernization strategy. Measuring and evaluating Soldier physical and cognitive performance in real-world conditions has been historically difficult. However, recent efforts within the U.S. Army Research Laboratory's (ARL) Cognition and Neuroergonomics Collaborative Technology Alliance (CaN CTA) program have produced a valuable resource for identifying neurocognitive state information of research subjects performing militarily relevant tasks, such as driving and target detection. ARL's Standardized Annotated Neurophysiological Data Repository (SANDR) is an archive of EEG study data featuring fourteen hundred hours of EEG recordings collected from over one thousand research participants across several different studies. SANDR serves dual purposes: 1) to standardize the representation of EEG data for analytical use, thereby facilitating reuse of tools for evaluating and visualizing EEG research data, and 2) supporting Big Data analytics for EEG data via the extensive collection of diverse datasets that have been standardized. The immediate value of the repository has been as a mechanism to support the development and testing of large-scale EEG analytics. Heretofore, EEG analyses have been based on modest numbers of subjects. However, the ARL CaN CTA program provided a unique opportunity to leverage the output from several independent studies to create a consolidated standardized data repository. The increased scope of the data offers a robust platform for exploring individual differences, as well as potentially revealing trends in the data that could not be found using homogenous datasets. The datasets have also been used to support Brain-Computer Interaction (BCI) model development for other ARL research. Additional value has been realized in having data

in a central repository on a single server platform. Locating datasets from among various computer systems or external drives is no longer an issue, and data backups are simplified. Furthermore, the standardization techniques allow for common data analysis and visualization tools. This benefit is derived from the repository design, which ensures that common file formats and naming conventions are utilized. The SANDR design includes several open source standards and associated tools that were developed or extended as part of the CaN CTA program, including 1) the Hierarchical Event Descriptor (HED), 2) the EEG Study Schema (ESS), and 3) the EEG Pre-Processing (PREP) pipeline. This series of tools represent ARL's Big EEG Pipeline, which produces standardized EEG datasets ready for analysis using a common set of applications. At the core of the architecture is a "Community Tagging" methodology, which features HED as the common, managed vocabulary for identifying events of interest. Event tags are defined in the form of a hierarchy, with properties inherited from the top down. A tangential goal of the research is for the tools and methods to become formal or de facto standards for the specification and handling of EEG data through transitions to other organizations. Another feature of the data repository design is the CaN CTA Consortium Data Server (C3DS), which is comprised of a hardware platform for storing repository data and a user interface that serves as a searchable public online data catalog with ARL-controlled access to data from the various studies. The C3DS is still under development, with future planned capabilities to identify and retrieve epochs of EEG data based on user-specified criteria. The findings of a recent Big Data EEG analytics project using representational similarity analysis (RSA) on a group of several SANDR datasets confirmed the hypothesis that events sharing similar HED tags have more similar EEG dynamics than unrelated events. In addition to the encouraging large-scale analysis results, the data were also used successfully in several one-off EEG analysis efforts for which publications were done. Finally, two datasets were transitioned to DARPA for a challenge. The level of organization and the scope of SANDR make it a unique resource with applications beyond large-scale analysis support. For example, SANDR can facilitate the development of new algorithms for analyzing EEG data without the need to perform a new data collection. The datasets are well documented, with study-specific information available in data downloads, as well as a summary document that describes the HED tagging methodology, event types for each study, and a list of publications related to each dataset.

### Jones, E.M. • Ryan, K.J.

#### Tactical augmented reality, precisely where you need it: bringing registered AR to the field.

As the Army continues to invest in advanced mobile technology for its soldiers, there is growing interest in harnessing the benefits of rapidly advancing Augmented Reality (AR) capabilities. AR overlays digital objects (augmentations) on a view of the real world, as seen through a display carried or worn by the user. There are two primary classes of AR: that in which digital elements are placed regardless of the real world (called 'unregistered'), and 'registered' AR, in which that placement with the respect to the real world is critical. The potential of AR comes from its ability to blend the real and digital worlds, but it is only when augmentations are registered

that this potential is realized. Registered AR is able to provide soldiers and other users tactically relevant information, fused with other data, in formats that reduce distractions and improve operational performance. When information is in view, the user is not required to shift their attention to multiple platforms and data sources, reducing cognitive strain. Digital augmentations display the data streams and information in visually rich presentations that are easier to interpret and translate into actions. As a result, workload is reduced because it is easier to access and interpret information. When tasks take less time to learn and perform, fewer errors are made and performance gains are achieved faster. And when users remain engaged in real-world tasks, Situational Awareness (SA) is maintained with less effort. Although the benefits of AR are encouraging, the constraints of existing solutions limit their adoption and usage. The value of registered AR depends on the accuracy with which augmentations are placed, and today's AR technology only maintains accuracy in limited, instrumented areas. AR systems must know where you are and how you are oriented to accurately overlay graphics on your view of the real world; i.e., they need to maintain 'pose alignment.' To do this, many AR applications rely on known reference points in the scene (fiducials) which are often added to the environment. However, because a fiducial must always be in view, this approach does not easily scale to large, cluttered areas of operation. In addition, a fiducial-only approach is brittle: if a reference point is moved or visually blocked (as is expected in dynamic, deployed settings), a new one must be established to continue operating in that area. Some systems use Simultaneous Localization and Mapping (SLAM) and shine infrared light into the environment to create a map of the world. These solutions work well in areas where lighting is controlled, but they do not work well outside in sunlight. Furthermore, active sensing is not an option during missions which require stealth. SLAM solutions are also computationally intensive, as well as brittle to changes in the environment because they depend on static features for localization. To overcome the challenges of fielding registered AR, Draper is building on its 80-year legacy in delivering guidance, navigation, and control systems by developing a software/hardware system which maintains pose alignment when fiducials are not in view and without employing SLAM. This system, called Monarch (TM), uses camera imagery and inertial measurements to calculate changes in position and orientation as the unit moves (also referred to as 'vision-aided navigation'). As a result, accurate registration is maintained across large, dynamic areas without any prior knowledge of where or how the system will be used. Draper has been developing vision-aided nav. systems for 10+ years, having built solutions for tactical UAVs, precision airdrop systems, ground vehicles, dismounted warfighters, and astronauts. Monarch's capability has been demonstrated in an end-to-end proof-of-concept. Leveraging mature-COTS hardware, the prototype provides pose information to a tablet-based AR app. In real-time while seamlessly taking advantage of existing, fiducial-based tracking methods to reduce error in the calculated vision-aided nav. solution. To better serve the needs of warfighters, Monarch-enabled AR is being integrated with the government-owned Android Tactical Assault Kit (ATAK). ATAK is built as a tactical map-based SA tool designed to operate on COTS Android

devices. The ATAK app. provides a built-in map engine, enabling display of overhead imagery and geo-located overlays and map annotations (points, shapes, routes, heat maps). In past work, Draper has employed its human-centered engineering and design process to improve upon the existing ATAK software suite. By leveraging the nav. technology underlying Monarch, ATAK is able to display operators' real-time positions without using GPS. In addition, as operators interact with the AR environment, representations of those digital augmentations are also displayed to ultimately enhance team SA (for example, leaving a virtual "sign-post" indicating an area of a building or a room has been cleared).

### Kaplan, L. • Jadbabaie, A.

#### Social learning theory with uncertain models.

Situational awareness in contested urban environments require fusion of sensor observations across the battlespace. However, network connectivity can be intermittent with limited bandwidths. Agents can make sense of this environment by sharing beliefs formed by their own sensor observations with those of their neighbors. Eventually, the agent can obtain a global belief representing knowledge of all the observations across the battlespace in space and time. Social learning theory (SLT) is able to demonstrate the conditions when and when not the updated belief of an agent is able to learn the ground truth. Specifically, an agent must form a belief in one of K possible hypotheses by tabulating the likelihood of these hypotheses based upon its own observations and those of the other agents. The current theory assumes that that observation likelihoods, i.e., the probability of the observations conditioned on each possible hypothesis, are known precisely. However, these probabilities are obtained via a machine learning (more precisely a parameter estimation) process using training data. In military operations, the training data can be very sparse, and as a result, knowledge of the probabilities to form the likelihoods are known only within a second order probability distribution. This work extends SLT for this case when the likelihoods are not known precisely. If an agent collects and integrates all the observational likelihoods collected from each agent over time while maintaining the entire history, it is easy to see that as time goes to infinity, the most likely hypotheses will correspond to the ground truth. This is the well-known Bayesian solution that requires all the likelihoods to be communicated to each agent. To save network resources, agents can share beliefs with neighbors. SLT considers different learning rules describing how beliefs are shared and then updated at each agent. Recent results demonstrate how the log-curvature dictates whether or not the agents will converge to the ground truth. The theory, however, assumes the likelihoods are known precisely. This work considers subjective logic where the likelihoods are characterized by a Dirichlet distribution. This implies that an effective number of instantiations of the observations were collected as samples of a multinomial distribution. In other words, the observations can be viewed as rolling a weighted die and using the instantiations of these observations to gain knowledge about the probabilities of the outcomes. The Dirichlet distribution is the conjugate prior for the multinomial distribution; thus, its usage to represent uncertain likelihoods in this work. In light of these uncertain likelihoods,

this work introduces the expected likelihood ratio as a test to evaluate each hypothesis. More precisely, this ratio is the expected likelihood of the hypothesis in light of second order probabilities divided by the expected likelihood given vacuous knowledge of the probabilities, i.e., the probabilities are uniformly distributed. In the absence of precise knowledge of the conditional probabilities, one cannot compare an expected likelihood ratio for a given hypothesis against the ratio for another hypothesis. This is because the value of the ratio is limited by the number of effective training observations to determine the Dirichlet distributions. Nevertheless, the expected likelihood ratio for each hypothesis can be evaluated on its own as shown in this research. Specifically, values much larger than one provides evidence that the observations are consistent with the hypothesis, which indicates that the hypothesis can be accepted as true. Likewise, values much less than one mean the observations indicate that the hypothesis is false. At the extremes, as the ratio goes to infinity, the hypothesis appears to be true, and as the ratio goes to zero, the hypothesis is proven to be false. When the ratio is close to one, one is very uncertain to accept or reject the hypothesis due to lack of evidence. Overall, when the agents share uncertain likelihoods with each other, the overall expected likelihood ratio represents the full Bayesian result. This work extends SLT to show that when  $N$  agents only incrementally share uncertain beliefs using the log-linear learning rule where the weights form a doubly stochastic and irreducible adjacency matrix, then the beliefs converge to the  $N$ -th root of the full Bayesian results. This result does not hold for DeGroot learning. Nevertheless, the log-linear and DeGroot uncertain beliefs appear to be correlated based upon empirical results. At the extreme case where the conditional probabilities become precisely known, then one can prove that both log-linear and DeGroot learning is able to precisely accept the ground truth hypotheses and reject the other hypotheses. Overall, the newly extended SLT demonstrate how agents can share uncertain belief and reason under uncertainty.

**Kaplan, L. • Chen, F. • Cho, J. • Sensoy, M. • Sullivan, P.**

#### Uncertainty-aware artificial intelligence for more effective decision making.

Many information processing systems have been proposed to provide situational awareness (SA) for a decision making based upon observations from physical sensors and/or human generated reports. Advancement of such systems are crucial for the Army's modernization plans. For instance, next generation combat vehicles (NGCVs) will rely on SA to decide when it is necessary to engage their active protection systems or when to alter routes to avoid unnecessary (but possible) kinetic engagements. All of these automated information processing systems are designed to work under certain conditions, and the algorithm developers do not necessarily understand the bounds of the operational space outside of which these systems cannot perform reliably. It is crucial for an information processing system to express its degree of confidence on its reported information about the area of interest so that the decision maker can digest this report with his/her own observations to form a proper SA picture. If the information system provides wrong information instead of stating that it does have enough evidence to reliably make an

inference, the decision maker can easily make a fatal mistake. Many of information processing systems exploit artificial intelligence and machine learning (ML) technologies to understand how to interpret patterns in the observations. A common approach is for observations to feed into ML algorithms such as (deep) neural networks (NNs) to detect and classify objects in the scenes. Then, a higher level reasoning system such as a Bayesian network (BN) can be used to fuse these detections and classifications into a threat assessment. The NNs must be trained to learn the values for its weights to effectively classify and detect objects. Likewise, the BN requires past evidence to determine the conditional probabilities that characterize the network. This historical evidence can come from either 1) a domain expert who uses his past experiences or 2) historical data to formulate the probabilities. In the military domain, the past evidence about a particular area of interest is usually very sparse. Therefore, the parameters describing the NNs and BN models cannot be determined precisely. This lack of precision affects the outputs of the information processing systems that are inferred by the observables and the trained models, and it becomes crucial to characterize the uncertainty of these outputs. This work builds upon subjective logic to establish the theoretical foundation to realize uncertainty aware processing components of the information processing systems. Subjective logic is a framework for probabilistic reasoning under uncertainty. It connects belief mass assignments to second-order distribution knowledge of probabilities. Specifically, the beliefs and uncertainty values, which constitutes a subjective opinion in subjective logic, map to the parameters of a Dirichlet distribution. This work summarizes our recent efforts to probabilistically reason over uncertain probabilistic graphical models where knowledge of the parameters for the modes are expressed as subjective opinions, i.e., uncertain probabilities. This includes subjective BNs where uncertain knowledge of the conditional probabilities is represented as subjective opinions. We have developed an efficient method to infer subjective opinions for latent variable conditioned on the values of the observed variables. Similarly, collective subjective logic expands probabilistic soft logic (PSL) with uncertain reasoning. We have developed the inference method for subjective opinions of latent variables in light of the opinions of observed variables and the set of probabilistic first order logical rules inherent in PSL. Finally, we are currently training uncertainty-aware NNs by developing loss functions that interpret the output layers as the parameters of a Dirichlet distribution. We can evaluate the utility of uncertainty-aware information processing in terms of how well the uncertainty characterizes the disparity between an expected inference and ground truth. Specifically, we report the divergence of the desired confidence bounds for the higher-level reasoning methods, i.e., subjective BNs and collective subjective logic. The uncertainty-aware NNs are evaluated based upon how uncertainty values change as the test data is extracted from similar or different sets in relation to the training data. We also demonstrate that on the testing set, classification performance increases as more uncertain test samples are pruned. Currently, all the real data for quantifiable evaluations are common ML datasets that are not necessarily military relevant. We will use a military relevant vignette for route planning of a NGCV to show how an end to end uncertainty-aware information

processing system is able to exhibit confident inferring when the observations are normal but indicate high uncertainty once the observations do not represent the training cases.

**Kapteyn, H.C. • Murnane, M.**

Bright tabletop source of coherent x-rays: new directions in materials and biological science.

**Kilic, O. • Fathy, A.E. • Plaku, E.**

#### Drones with reconfigurable phased array antennas for manned-unmanned teaming operations.

Theme: We present a distributed adaptive antenna swarm on drones to enhance soldiers' mission on ground by empowering them with autonomous reconnaissance and surveillance. The multi-domain battle concept based on manned-unmanned teaming (MUM-T) is an updated vision of how army handles future conflicts, and fills the gap evolved after the recent retirement of OH-58 Kiowa used in association with Apache attack helicopter. Unmanned aerial systems provide the best technology for this purpose. Design/Methodology/Approach: We present concepts of building an Autonomous, UAV-Swarm-Distributed, 3D-Reconfigurable Antenna System (ASDR3A) for remote reconnaissance and surveillance operations. The ability to remotely sense, image, or monitor any activity or a particular property of an environment using microwave remote sensing (MRS) is exceptionally strategic due to its many inherent advantages over conventional camera-based systems. In particular, microwaves penetrate barriers, walls, fires and other clutter. Another advantage is the robustness of MRS with respect to weather and daylight conditions, which render camera-based systems ineffective. ASDR3A system uses a swarm of collaborative, autonomous, low-cost UAVs. Each UAV carries a small, low-gain, lightweight antenna element and its RF circuitry. This distributed system conforms in 3-D space to any geometry, and the UAVs can be strategically positioned so that the on-the-fly reconfigurable array can dynamically adapt itself to achieve desired beam coverage over a region. Furthermore, ASDR3A is a completely dynamic system, which not only reconfigures the array geometry but also modifies the number of antenna elements in the swarm, as elements can be added and removed on demand. This freedom of motion of each element allows for a "mechanical" steering of the collective beam pattern by modifying the relative spacing between elements to achieve a physical phase shifting mechanism. Also, equipping each element with an electronic phase shifter creates an "effective relative motion" without physically moving the element, which enhances this mechanical steering. This combined electro-mechanical phase shifting concept in 3D is used to optimize the motion planning for the swarm, while adaptively generating desired beam patterns over the scene. Multi-robot motion planners, which can enable UAVs to monitor, cover, or inspect large, complex, scenes are employed for the ASDR3A system concept. Definitely, an easy-to-use interface can be developed where soldiers in the field can specify the overall mission, including time bounds, monitor the UAV-swarm progress, add or remove UAVs from the swarm, or make other modifications as needed. Findings: We optimize ASDR3A system for its performance in terms of directivity and radiation characteristics, such as side lobe levels (SLL) and beam shape. We model

the UAVs' formation in flight using 3D non-uniform antenna arrays, considering the optimization of the positions of the antenna elements. The electronic phase shifting, hence virtual motion of each element is utilized to aid the motion-planning stage to reduce the utilized energy for motion. Practical Applications: Given that an Apache is fully digitized, it can locally control the flight path and payloads of unmanned aircraft systems like drones. The possibilities are endless including receiving live sensor imagery, taking control of the sensor and weapons payloads instead of depending on remote control. ASDR3A can run ahead of the Apache to provide "triggers for targeting" and allowing the helicopter pilots to see anything coming down range to provide a decision point to go to one place or another depending on where threats are—as expressed by Col. Paul Cravey, the Army Training and Doctrine Command Capability Manager. Drones are at advantage point upon flying at the operations levels and at large heights and can be paired together to build ad-hoc reconfigurable phased array antenna, a cluster for wideband communication link, or a forward looking into a denied environment and could protect each other. Original Value: For many of these applications, current MRS systems require a fine sampling of the region under observation using high-gain antennas, which dictate a large aperture that radiates the available energy into space. To gain mobility, conventionally, the entire antenna is mounted on a single UAV. To improve coverage, multiple UAVs are used in parallel, each carrying a single high-gain antenna. However, as high-gain antennas are often large, mounting the entire antenna on a single UAV considerably limits the applicability and flexibility of the system, as it requires UAVs capable of carrying heavy loads. Moreover, such UAVs have difficulty maneuvering in cluttered environments or residential areas, which further limits the applicability of the system. ASDR3A system addresses these challenges.

## Kim, C.

### Machine reasoning for determination of threat level in irregular warfare.

Irregular warfare (IW) campaigns depend on not just military prowess but also understanding of social dynamics. Therefore IW or counterinsurgency cannot be conducted without understanding the human terrain. The objective of the research is development of a machine-reasoning based decision-assist system for determining and predicting threats for field commanders in irregular warfare utilizing diverse datasets of local populace environment and other sources for the other parts of the world. The machine reasoning system aims to answer the following question: With the present information, what is the threat probability of the region of interest and how certain is the probability itself? Provision of quantitative threat level given diverse datasets and information requires an intelligent system which extracts dominant contributors and learns and updates as new data is added to the datasets. The machine reasoning system keeps, upon existing and updated datasets, extracting dominant contributory HT attributes, generating rules for threat level determination with the attributes, and producing the certainty level of the rules themselves. The main theory behind dominant attribute discovery and decision rule extraction from datasets is the information entropy minimum principle. "Information measure" (I) is defined as proportional to the negative of the

logarithm of probability (p), with k a constant:  $I = -k \cdot \ln(p)$ . Information entropy (S) is defined as the expected value of information:  $S = -k \cdot \sum p \cdot \ln(p)$ . In the entropy minimum state, all of the information has been extracted, and there is no information gain, leading to maximum certainty. The first step in determining the dominant attribute is to convert all analog-valued sample data to binary valued data. The "binarization" is performed by threshold calculation. The calculated threshold value with minimum conditional entropy optimizes the separation of two outcomes, Threat (T) and No-Threat (F). The conditional entropy  $S(x)$ , which, for a chosen value x, is defined with conditional probabilities of two outcomes, T and F, under 2 conditions (one for a sample value lower (x-) than a certain threshold value x and the other greater (x+) than that) as,  $S(x) = -p(x-) [p(T|x-)\ln(p(T|x-)) + p(F|x-)\ln(p(F|x-))] - p(x+) [p(T|x+)\ln(p(T|x+)) + p(F|x+)\ln(p(F|x+))]$ . A binarized sample data is obtained after converting the analog data into binary values, 1 for sample values above the threshold, 0 for below the threshold. The same conditional entropy can be applied to determine dominant attributes in correlating an attribute to the outcomes. A conditional entropy equation for the ith attribute,  $S_i$ , for T or F under 0 or 1 attribute value is as follows:  $S_i = -\pi_i(0) [\pi_i(T|0)\ln(\pi_i(T|0)) + \pi_i(F|0)\ln(\pi_i(F|0))] - \pi_i(1) [\pi_i(T|1)\ln(\pi_i(T|1)) + \pi_i(F|1)\ln(\pi_i(F|1))]$ . After applying the conditional entropy to all m attributes, a certain attribute  $A_k$  which produces the minimum conditional entropy will be the best attribute in correlating the sample data to the outcomes. Then the decision rule,  $R_k$  for the attribute k, can be drawn from the best (highest) conditional probability from the set of four:  $p_k(T|1)$ ,  $p_k(F|1)$ ,  $p_k(T|0)$ , and  $p_k(F|0)$ . If, for example,  $p_k(T|1)$  is the highest from the set, then the decision rule is formed as follows:  $R_k: \text{IF } (A_k = 1), \text{ THEN } (T)$ . In this step, the probability (or certainty) of this decision rule itself is generated from the maximum entropy based Bayes estimate by  $\langle p(O) \rangle = \frac{\{x + 1\}}{\{n + 2\}}$ , where, x is the total number of samples satisfying the condition (T|1), and n is the total number of samples satisfying the attribute condition. Also, the margin of error of the drawn probability is obtained by  $e(O) = \{ \langle p(O) \rangle^* (1 - \langle p(O) \rangle) \} / \{n + 2\}$ . Usually, not all samples can be directly linked to a single decision rule. Therefore, we apply step-wise approximation by which, after the first attribute and its corresponding decision rule are found, we remove all the samples which match the decision from the binarized dataset and we repeat the conditional entropy minimum process for the remaining data samples. We tested the implemented machine reasoning system with an example dataset which has a total of 31 samples, 21 Threat and 10 No-Threat samples, with 7 attributes. The reason produced 3 steps of rules with a satisfactory result. For practical applications, the decision assist platform would be configured around a client-server based secure network. The machine reasoning algorithm resides in a server and the data would be loaded to the server from client computers in the network. A client representing a field command console for threat level monitoring would also be connected to the network. The machine reasoning system would provide the forces in the field with operationally-relevant decision assistant for determining threat in global context.

## Kim, K. • Clerkin, P. • Kruger, K. • Kweon, C.M. • Szedlmayer, M.

### Assessment of a turbocharger performance and reliability in a UAV engine.

Diesel engines are widely used for various unmanned aerial vehicles (UAVs) with its high power density, fuel efficiency and reliability. Such vehicles provide invaluable intelligence, surveillance, target acquisition, and reconnaissance to the warfighter. Turbochargers are widely used in diesel engines to supply compressed air to the engine to produce higher power and improved thermal efficiency when compared to similarly sized engines. Turbochargers in UAVs play an even greater critical role due to the need to provide sufficient power to meet mission requirement at high altitude conditions, where air density at 7,620 m (25,000 feet) is as thin as one third of the value at sea level. An airborne diesel applications cannot operate without boosted pressure at altitude conditions higher than 3,657 m (12,000 feet), which is the reason why turbocharger for UAVs should be robust and reliable. However, existing boost technology, such as turbochargers and superchargers are mostly developed and optimized from the automotive industry and becomes a single point failure when operated at altitude conditions. While turbochargers used in ground systems operate mostly at transient conditions, aircraft operate significantly different. For aircraft applications, turbocharger may dwell at fixed operating conditions for periods of time and at higher shaft speeds exceeding their design criteria. Operation of a turbocharger with resonant modes in the shaft and blades can be unsafe due to consequential blade deflections, which can lead to high cycle fatigue and failure of a turbocharger. The objective of this research is to investigate performance and reliability of a turbocharger used in a UAV engine at altitude conditions. The study was conducted using an in-line multi-cylinder direct-injection high-speed diesel engine installed at the Small Engine Altitude Research Facility at the Army Research Laboratory at Aberdeen Proving Ground. The facility was designed to independently vary the pressure and temperature inside of the chamber to simulate altitude conditions of up to 9,144 m (30,000 feet). The engine was operated from sea level to 7,620 m (25,000 feet), where the outside air temperature was controlled independently from -37 to 30 °C. Two 3-axis accelerometers were installed at compressor housing of the turbocharger to measure vibration of the turbocharger at resolution of 100 kHz. An eddy current blade counting system was installed in the compressor scroll housing to measure rotational speed of the turbocharger. A power spectral density (PSD) analysis was performed on acquired accelerometer signals to identify frequency and amplitude of compressor housing vibration. A significantly high amplitude of vibration, which correlates with 1st and 2nd mode of vibration was identified from the PSD analysis with the turbocharger speed exceeding its design criteria at certain altitude conditions. To enhance understanding of turbocharger operation with a UAV engine, the US Army Research Laboratory is developing a new turbocharger test bench with the capabilities of testing turbocharger at various inlet and altitude conditions using non-intrusive stress measurement systems to measure blade displacement and vibration, and analyze high-cycle fatigue in turbochargers.

**Klett, J.W. • Greiner, N.**

**Phase change material filled graphite for electronics cooling in transient environments.**  
 The purpose of this research was to develop an enhanced heat sink that can be retrofitted or used with OEM designs to dramatically enhance endurance of electronics during airborne missions. The focus of this project was the electronics of unmanned air vehicles that can loiter on the tarmac in a very hot climate, where the electronics were not designed to operate. This loiter time could eventually lead to the electronics overheating and a scrubbed mission before it even takes off. Our goal is to demonstrate that by utilizing a unique graphite foam/phase change material heat sink, the heat while loitering on the tarmac can be absorbed a significant duration, thus allowing ample time for the vehicle to get airborne and begin experiencing cold air which can provide the proper cooling to the electronics. This research relates to the theme and focus area of Future Technologies/Materials Science. ORNL has developed a novel lightweight material with very high thermal conductivity and high porosity. This is known as high conductivity graphite foam. Because of these unique properties, graphite foam has the potential to improve the performance of a phase change material (PCM) in the use of cooling electronics. The ligaments of the foam exhibit a thermal conductivity over 1700 W/m·K, compared to only 400 for pure copper. Thus, if the pores of the foam are filled with the PCM, the heat can move very rapidly through the ligaments of the foam to the surfaces of the PCM within the pores, thus being adsorbed more rapidly than a block of PCM. Recent work at ORNL [1] showed that there is a balance between the volume of pores and the volume of solid foam to balance the amount of PCM available for energy storage and the rate of heat transfer into the body. This research expanded the work of Trammel [1] to model the foam/PCM concept in a heat sink design where the foam/PCM is used between the hot source (IC chip) and the finned sink. Using Star CCM+, we can model the foam porosity, ligament conductivity, overall conductivity, PCM volume fraction, PCM physical properties (heat capacity, latent heat, etc.) and other parameters of the heat sink. We will use the model to simulate various expected thermal conditions on a hypothetical heat sink on an air frame. These simulations will be used to generate expected performance for different conditions, with the anticipation that the results will show that the system will absorb the heat sufficiently to allow the system to continue running while on the ground, and cool effectively after liftoff. Using the results of the CFD model, we designed an experimental system to validate the computer simulation results. The paper will correlate the results of experimental testing to that of the model to validate the CFD model. PCM/GF can extend missions significantly. We showed that the PCM can absorb energy for nearly 80 minutes in our tests prior to liftoff of a UAV. After liftoff, the cooling air is colder and can provide sufficient cooling needs of the electronics. These results show that with proper engineering and design, Graphite foam/PCM systems can be used to absorb (or deliver) heat rapidly in transient systems, not just electronics. There are many applications that can utilize this concept of graphite foam/PCM cooling. These range from the obvious in electronics components used in areas where there is a transient in the cooling or the heating to cooling of Batteries when access to

cooling may not be afforded. In addition, directed energy systems, engines, and other applications where high heat loads can be seen with reduced area for cooling are applicable. For the most part, anywhere that experiences either large transient in cooling capacities or large transients in heat generation would find this technology beneficial. These can range from helicopters to UAVs to man wearable systems and even to missiles. We will present original data (both modeling and experimental) on PCM/GF heat transfer with electronics in transient climate cooling situations. We will demonstrate enhanced and even enabling performance as a heat sink in aircraft electronics, for both OEM and retrofit applications.

**Koditschek, D.E.**

**Science of embodied innovation, learning and control.**

**Approach/Methodology:** A robot's mobility depends on its capacity to move energy from a store to its mass center along the right degrees of freedom at the right time by actuating appendages toward the periphery where it meets the environment. Because there is a premium on getting this work done quickly, power (the rate at which actuators can move Joules) is a first scarce resource. The information required to direct these outward flows appropriately must also be generated from some prior memory combined with feedback decisions made using real time streams. Moreover, since the purposes of mobility are inevitably linked to the robot's knowledge about the environment as well as the task, its ability to bring information from the periphery inward to the core at adequate rates inevitably presents a challenge simultaneous with and dual to its management of outward power flows. Our approach integrates a multidisciplinary team from biology, engineering and mathematics to coordinate research addressing these dual problems of information-energy flow. The role of morphology – the nature of limbs and body and their endowment with actuation and perceptual resources – to promote effective interaction between energy and information streams over contrasting scales of length and time represents the design-time focus of our project. The discovery of how to evolve, use and revise this endowment to achieve goal-directed mobility and create new solutions to sensorimotor limitations and challenges represents the execution-time focus. **Original Value/Unique Aims:** Our research aims to discover: (RCA1) universal physical constraints on rates of energy-information exchange that can expose design implications at key points of interest along the vast spatiotemporal scales; (RCA2) the endowment of animal body plans and materials with actuation and perceptual resources as the foundation of learning to engage the physical environment at evolutionary, developmental, and behavioral timescales in the face of these fundamental constraints; and (RCA3) the implications of such organismal innovation within these physical limits for robot design and deployment. RCA1 aims for new fundamental insights into limits on the mathematical structures and information thermodynamic mechanisms underlying the algorithms and supporting physical design of purposive mechanical work. The identification of a new universal limit bearing on sensorimotor systems opens the way for a host of assays that the DoD service labs' bench scientists and engineers can then develop for measuring the efficacy of existing or proposed

designs. RCA2 takes a complementary step, distinct from the contemporary AI focus on deep learning, to gain new inspiration from the mammalian hippocampus. Formalizing the neuromechanical basis of animals' abilities to innovate promises DoD new, computationally tractable representations for higher order learning that could be joined to rapidly advancing reinforcement learning technologies. Finally, because models of unstructured (e.g., gravel-strewn, broken-sloped, icy or leaf-littered) substrates are so incomplete, we require physical experiments with robots in natural terrain to test our hypotheses. To benefit from animal designs and pursue fundamental tradeoffs demands far more controlled and rational materials use than can be found in commercial robot designs. Thus, RCA3 focuses on novel materials for distributed sensorimotor structures in robotics, directly impacting DoD capabilities through the development of new robots with unparalleled mechanical competence and autonomy. **Findings/ Practical Applications:** As an empirical testament to the practical efficacy of this research, our Y5 goal is to field a squirrel-inspired (likely ~20 cm length scale, likely tailed, quadrupedal) robot with unprecedented agility and insight into how its body can exploit available surfaces to rapidly negotiate complex terrain. The robot's unparalleled capabilities will benefit from an entirely novel structural integrity developed from cut-out sheets of compliance- and damping-tuned materials animated by a carefully distributed electro-chemo-mechanical sensorimotor suite. We aim to demonstrate at Y5 that this platform's "embodied insights" enable it to display a degree of "creativity" in exploiting its surroundings that has heretofore been entirely absent in any robot.

**Kravitz, A.**

**Large virtual aperture hyper-spectral NANO-SAT formations for operationally responsive space-based identification and tracking of fuel vapors, lethal gasses, and other hyperspectral applications.**

These swarms are formed from a pattern of independently operating Nanosats launched from a canister to form a scanning line array. Each Nanosats has both a full color imaging context camera for calibration and pointing registration, and a spectrometer. A Deployment Canister with sufficient NANOSATS allows for the formation to be refreshed to allow for limited battery life and cube mortality. Canisters allow for continuous coverage of a target by spacing the formations along the same orbit, and simultaneously using multiple swarms. To guarantee coverage of at least 2 visits per day 24 hrs must be a harmonic of the orbital periods. Replacing a damaged or destroyed Satellite with a rapid-reaction Nanosat-formation provides gap coverage where and when needed. The flexibility of a short-lived Nanosat reduces cost by utilizing commercially available but appropriate industrial and commercial components. Rapid reaction Tactical Nanosat formations provide theater commanders and forward operating bases with hyperspectral imagery for; Disaster relief, intelligence in a crisis, and ready replacement coverage if National assets are damaged or destroyed. The formations orbit is set based on the altitude resolution and number of cubes. 10 cube formations with a 1/8th deg FOV and an orbit of 278Km has a ground resolution of 202m (1/3 pixel sub pixel approximation). The canister can be deployed

from a prepositioned asset such as the phantom express or other asset. Several imaging Nanosats are deployed sequentially with the same force and time spacing, to match the ground resolution. The orbital cube spacing is set to the without sub pixel approximation. In the case mentioned previously it works out to 606m. The Imagers are a spectrometer and a full motion video context camera. The canister contains numerous Nanosats which it deploys in pairs in opposite directions to balance impulse reaction on the canister. The ground segment communicates with each Nanosats and the canister. The Ground segment is used to command, control, monitor the satellites, receive and process the down link and serve as the first point of processing and field exploitation of the data. Each Nanosat acts as a single Pixel. The Nanosats are spaced to form 2 formations that act as 2 large aperture line array's. The scenery overlap is minimized but sufficient to allow image stitching to form a larger gap free image, and line to line sub pixel approximation is used to increase resolution by a factor of 3. The independent Nanosats work together as if they were a single hyperspectral imager producing a sequence of hyper cube images of a ground swath. Each cube has a spectrometer and a context camera. A single high-resolution VIS, context camera with a FOV covering numerous cubes provides a high-resolution reference image of the Hyperspectral imagery for understanding, calibration, and ground processing to allow for a lower performing attitude control system, and to determine the individual Nanosat pointing errors so the hyperspectral image can be corrected on the ground. To maximize mission life each Nanosats has an energy management capability. The Field programmable processor in each Nanosats transition between modes. These modes include; sleep mode, mission mode which includes imaging, communications with the ground station, and data down load of recorded data or diagnostics and maintenance mode, which allows the ground station to monitor swarm health and allows the processors FPGA to reconfigure itself to heal after a single event upset, and quarantine from use its damaged gates. If the imaging, and communications event is scheduled for about 10 minutes per orbit and the rest of the time the Nanosats is in a sleep mode, then a swarm mission can last up to 6 weeks before running out of power and having to be refreshed by deploying a new swarm. Each Nanosats contains 3 orthogonal gyro-pairs for attitude control, a battery pack and power management sufficient to provide 4 hrs. of on target imaging, processing, and down link. Processing and data collection is provided by an FPGA based processing board, a scientific instrument and the necessary firmware and software for operation. The instrument is a production commercial industrial or scientific spectrometer and a visible band Full motion video imaging camera with sufficient FOV to see imagery in multiple cubes. These context camera imagery is stitched to provide high resolution large swath imagery for additional mission functionality. If the context camera is set to cover the width of the array such that for 1/8 degrees for 10 cube formations then the stitched context imagery would have a 8 degree FOV, and the 2 formations deployed from the cube would have a 16 degree FOV. A 20 Cube formation would have a 32-degree FOV.

**Lee, M. • Edwards, S. • Hyatt, J.S. • Kirk, K. • Mark, E.**

#### **Deep learning for future Army systems.**

Recent advances in machine learning, including deep learning with convolutional neural networks (CNNs), have enabled breakthrough performance in artificial intelligence tasks such as image and speech recognition, natural language translation, and complex game playing. With an eye towards Army-specific challenges, our research team has been exploring the utility of these new technologies in diverse contexts such as condition-based maintenance, cyber intrusion detection, and additive manufacturing. In this work, we demonstrate two applications of CNNs: crack damage detection and cyber intrusion detection. In the first case, we have used CNNs to estimate the extent of material crack damage from ultrasound evaluation. Our collaborators in the Vehicle Technology Directorate supplied us with data from experiments where pitch-catch sensors were placed on opposite ends of a material coupon, whereby a total 9 paths and 8 frequencies per path are recorded via the catch sensors in short intervals as the material was being stressed. A total of 72, 8000-sample, channel outputs were trained into a multi-layer convolutional network with the intent of estimating the time remaining to total crack failure. The net result of this study was that we were able to correctly predict crack progress in experiments that were not part of the training set. We also illustrate how we used a similar CNN topology to classify the function of CPU opcode sequences towards the goal of automatically filtering out malware. In this case, we tried to classify five different program types (compression, two implementations of cryptographic hashing, memory operations, and decryption.) The outcome of this preliminary work was that we could distinguish each function class. Our future plans in this area are training on a much wider range of computer program space. Finally, we explain why we believe CNNs can augment many other Army-relevant technologies going forward. In additive manufacturing, for example, CNN-based image recognition will provide continuous video monitoring of the build process with the possibility of automatic self-correction and generation of important evidence for the certification process. In the realm of autonomous vehicles, CNNs will provide perception not only of the intended future path but also an annotation of the wider environment for the purpose of improved situational awareness. Similarly, we expect CNNs will play a vital role in condensing and interpreting the ever-expanding flow of data from sensors in the battle space.

**Linder, K.**

#### **Multimedia topic modeling for threat actor identification.**

This abstract describes ongoing research to automatically filter online multimedia artifacts (pictures/videos) to perform enhanced non-cooperative identification of threat actors. The research implements artificial intelligence (deep learning) to classify online multimedia artifacts (pictures/videos) by relevance and topic using contextual features extracted from associated text (e.g. chatroom comments, blogs). The current process of identifying relevant threat actors in online multimedia artifacts is limited to keyword searches and evaluating metadata tags created by the individual social media users or content providers. However, the process requires

significant computational power and processing time. Several tag clustering approaches have been proposed but are hindered by the sparsity of metadata tags and the variability of tag meanings (e.g. is #AustinRocks a person, location or organization?), resulting in an abundance of artifacts with little relevance. To overcome these limitations, Orbis implements clustering models to group relevant artifacts and labelling that enables automated sorting. Latent dirichlet allocation (LDA) is chosen for clustering because of its proven accuracy. Orbis uses a semi-supervised classification approach whereby the LDA model clusters the videos based on the associated text and human annotators manually label the clusters. The labels are used for identifying high value clusters that may warrant additional processing (e.g. parsing individual faces from the video frames, face matching to government watch lists). The labelled videos are also used for training deep learning models, involving Recurrent Neural Networks (RNNs), to enable automatic classification [6]. Orbis displays the results in a dynamic user interface that ingests videos, displays the videos in topic clusters and generates accuracy measurements of the likelihood to contain threat actors. An initial clustering experiment evaluated multimedia artifacts from the Muqawamah terrorist website ([www.muqawamah.net](http://www.muqawamah.net)). The LDA model identified five clusters based on the associated chatroom text. Upon manual inspection of the text from each cluster, the topics were manually labelled as "ISIS Speeches", "Destruction/Killing", "Prayers/Ground Reports", "Palestinian Grief/Religious Questions" and "Palestinian Speech/Islamic Definitions". The initial evaluation of topic assignments using LDA is encouraging, with almost half of the videos obtaining high topic assignment correlation strength (>70%). Results from automatic classification using RNNs will be discussed at the symposium. The payoff of Orbis research is to provide a user-friendly application that significantly reduces the computing time required to process large volumes of multimedia artifacts for threat actor identification and ultimately enhances the ability to provide actionable intelligence for decision makers.

**Long, L.N. • Kelley, T.D.**

#### **Implementing emotions in cognitive robots.**

Emotions and temperament are crucial for animal survival (including humans). Emotions allow rapid behavior adjustments to changing circumstances. Also, group survival is enhanced by having a mixture of temperaments. Temperament (or personality traits) and emotions are not the same thing. Temperaments are traits that an individual animal possesses that are innate and typically fixed for that animal's life. Emotions vary continuously, sometimes on small time scales. In animals (including humans), temperament and emotion (and variations across groups) are as important to survival as cognition. They would make robots more effective also. Emotions and temperament would also be useful in human-robot interactions. The literature on emotions is extensive and growing rapidly every year. A lot of these papers and books relate to humans, and we still do not understand the complexity of the human mind. Instead of trying to use this model to predict human behavior, it should be viewed as a means of making a robot more effective and survivable by rapidly changing its behavior in different situations. The particular emotions and temperaments discussed herein do relate

to humans, but for robots we might use different emotions and temperaments, depending on the goals of the project. We are not trying to model human behavior or psychology here, although this model might eventually be useful for that. When we design and build autonomous robots (for air, land, sea, or space) we do not generally think of behaviors varying across the group, but a heterogeneous mix of traits in a group will make the group more successful. In addition, unlike in biology where these traits are relatively fixed over the life of the organism, these could be varied in intelligent mobile robots. It might be extremely valuable if we could quickly change a group of robots from docile to aggressive, for example. Damasio refers to emotions as automated programs for action that have been created through evolution. Emotions are related to reward, punishment, drives, perceptions, expectations, and motivations. There are typically negative and positive emotions, and they are tied to reinforcers (rewards, punishments, lack of reward, and lack of punishments), see papers by Gray and Rolls. Ortony et al discuss the activations and valences of emotions. While many investigators have studied affective computing in robots, there are very few studies which quantitatively define temperament and emotions or incorporate them into mobile robots. And the ones that do exist, do not properly distinguish temperament from emotions. Gray discusses the connection between emotions and cognition. An interesting anecdote relates to the well-known robot soccer competition. One of the researchers remarked that the robots play in the same manner at the start of the game as at the end, whereas a human would play very differently in the last few minutes of the game, especially if they were losing. The model presented here could allow the robots to change their behavior depending on the circumstances. Another example is group behavior. In nature there are many examples of groups (ants, fish, rats, humans, etc.) that are very effective, and the groups usually include a wide variety of personality types. Robots with emotions and temperaments will also allow better interactions with humans. If the robot could understand the humans emotional state, and the robot behavior could change accordingly, that would be very interesting. Likewise, it would be useful if the human could sense the robot's emotional state. In addition, teams of animals (including humans) are more effective when the groups have a mix of temperaments. This has been shown true for robots, cockroaches, fish, ants, spiders, humans, sheep, and other animals. Also, Eskridge and Schlupp state: The combination of different personalities within a group and the associated roles assumed by different members have been found to improve the overall success of the group. Studies have shown that these personality differences can be stable and maintained over time. This model is well suited to coupling to a cognitive architecture or other rule-based system. Using IF-THEN rules one can manage the values of the reinforcers. For example, if the robot sees something dangerous (e.g. a gun). There would be a set of rules needed to activate the positive and negate reinforcers. There would also need to be rules to handle the emotions. For example, one could determine which emotion has the highest value and then have some rules to handle it, e.g. if robot is afraid then run and hide. The above model has been implemented on cognitive robots and with the ARL's SS-RICS software. It worked extremely well. As it roamed the building it could recognize objects such as guns, food, etc. These

objects would act as reinforcers to the emotion engine. Its behavior would then change depending on its emotional state.

**Malinovsky, V.S. • Jiang, L. • Monroe, C. • Muralidharan, S. • Santra, S. • Soderberg, K.**

Optimal rates of quantum repeaters based on two species trapped ions.

**Malinovsky, V.S. • Birdwell, G. • Budker, D. • Hawasli, S. • Ivanov, T. • Jarmola, A.**

Quantum gyro for assured positioning, navigation and timing.

Inertial sensors are essential for navigation systems in both military and civilian applications. Gyroscopes based on the Sagnac effect in large-area ( $\sim m^2$ ) ring lasers, cold atom interferometry, and noble-gas nuclear spins have yielded or are projected to have a sensitivity on the order of  $10^{-10}$  rad/s/Hz $^{1/2}$ . These sensors rely on large volumes or enclosed areas. Compact solid-state gyroscopes based on vibrating microelectromechanical systems (MEMS) are commercially available, but can only achieve sensitivities of  $10^{-4}$  rad/s/Hz $^{1/2}$ . Compact inertial sensors with sensitivities in the range of  $10^{-5}$  rad/s/Hz $^{1/2}$  or better can greatly enhance the inertial navigation capability when GPS is not available to soldiers. This project aims to develop solid-state gyroscopes based on ensembles of negatively charged nitrogen-vacancy (NV-) centers in diamond. The NV center is a defect formed in diamond by one substitutional nitrogen atom and an adjacent vacancy. The NV- center features a ground state with electronic spin  $S = 1$  which can be initialized, manipulated, and detected via convenient optical and microwave transitions. Rotation of the NV symmetry axis induces Berry-phase shifts in the NV electronic ground state as well as the  $^{14}N$  nuclear sublevels. The Berry-phase shifts are proportional to the solid angle subtended by the symmetry axis and can be measured with a Ramsey scheme as well as more sophisticated pulse protocols. Such a quantum gyroscope based on NV in diamond has been projected to have a sensitivity in the range of  $10^{-5}$  rad/s/Hz $^{1/2}$ , an order of magnitude improvement over other compact solid-state gyroscopes such as commercially available vibrating MEMS. Furthermore, operation as a three-axis sensor may be possible by monitoring coherences in NV-centers with different orientations with respect to the host lattice. The goal of this work is: Develop a theoretical model of geometrical Berry-phase shift of rotating spin system in diamond; Analyze the excitation-pulse sequence and Berry-phase measurement schemes for electronic and nuclear spins; Determine the ultimate limit of inertial quantum sensors based on color centers in diamond. Here we report some new results demonstrating coherent Rabi oscillations on electronic and nuclear spin transitions. The design layout and simulation results of microcoils arrange in a Helmholtz configuration to achieve homogeneity of magnetic field across diamond sample will also be discussed.

**Manser, M. • Giardini, S. • Okamoto, M.T. • Osgood, R.M.**

Nano-enhanced thin-film solar metadvice with large broadband absorption augmentation.

**McClure, S. • Jarosova, R. • Swain, G.M.**

Boron-doped diamond carbon paste electrodes. This research project is focused on evaluating the electrochemical properties of carbon paste electrodes formed with glassy carbon powder and glassy carbon powder modified with an overlayer of boron-doped ultrananocrystalline diamond. This was accomplished by studying the electrochemical response of the different powders using different redox systems in aqueous and ionic liquid media. The presentation will report on the designs of the different paste electrode architectures, cyclic voltammetric studies of the different redox system behavior, Raman spectroscopy to investigate the carbon powder microstructure and SEM to determine the powder morphology. The boron-doped ultrananocrystalline diamond overlayer is formed by subjecting the glassy carbon powder to a microwave plasma consisting of 1% CH $_4$ /Ar plus 10 ppm B for doping. The core-shell approach imparts the unique properties of diamond (wide potential window, excellent microstructural stability, and weak molecular adsorption) to the substrate powder. Furthermore, the advantages and disadvantages of each material and each proposed electrode body will be addressed. This can be accomplished by looking at the large-scale application of boron-doped diamond carbon paste electrodes.

**McCormick, S. • Adler, E. • Gamizina, D.**

Non-lethal protection concept development for next generation combat vehicle consideration. This is a technology concept overview for non-lethal Directed Energy (DE) protection for Next Generation Combat Vehicle (NGCV) consideration using Active Denial (AD) phenomenology. The technology development focuses on optimizing size, weight, and power (SWaP) to reduce the burden on the NGCV and maximize DE coverage. AD requires a sufficient average power density at range to achieve effects, and so the combined millimeter wave (MMW) source output and antenna gain must be large. Additionally, power losses must be kept low. Choices for MMW amplifiers include vacuum electronic (VE) devices, such as a klystron or gyrotron, and solid state (SS) devices. Both amplifier choices have respective challenges, but to date, no single SS amplifier has been shown to achieve the needed power level. Multiple SS amplifiers would need to be combined. What would be preferred is a single amplifier which can be done using VE devices, but to date, no MMW VE amplifier has been demonstrated at the desired power level, efficiency, and weight class (< 25 lbs). Research by the SLAC National Accelerator Laboratory has shown that it is entirely feasible to build a low-voltage, ultra-compact RF amplifier based on state-of-the-art VE technology that optimizes SWaP. The RF amplifier is designed to dimensions of (length x diameter) 12 in. x 3 in. and a weight of less than 10 lbs at 40% efficiency, with further opportunities for weight and size reductions. The fundamental design is based on the demonstrated

10-50 kW W-band sheet beam klystron developed at UC Davis and originally conceived at SLAC. The new ultra-compact device delivers over 2 kW of CW RF power and operates at a low voltage of 35 kV. Low voltage operation will allow for integration with an ultra-compact prime power supply for a high RF power density solution. The device incorporates high current density cathodes based on the nano-composite scandate tungsten technology ensuring fast turn on without a sacrifice in system lifetime. A sheet electron beam with high aspect ratio and beam current density of about 40 A/cm<sup>2</sup> in combination with a four-stage depressed collector is employed to achieve high efficiency. A quadrupole magnet tuned periodic cusped magnetic confinement system ensures that over 97% beam transmission is achieved in a compact package. The interaction structure consists of eight RF cavities with WR-10 input and output waveguides featuring nanoscale surface roughness to minimize ohmic losses. The high heat flux environment is addressed by a CVD diamond based thermal management system. To maximize DE coverage and handle the average source power, the radiator is chosen to be a linear broad wall slot array in thin walled (< 0.01 in.) WR-10 waveguide. The advantage of the slot radiator over others is that its 3 dB beam width is 90° in the plane orthogonal to the slot length. The array has 256 slots to meet the required gain, which makes the total length 22 in. The slots are oriented longitudinally as shunt slots so that the broad DE coverage is across the waveguide width. The slot lengths and widths are on the order of 0.06 in. by 0.005 in. and each are displaced from the broad wall centerline by 0.0026 in. The array was designed using standard circuit model equations found in the literature and full wave Electromagnetic simulations using the finite-element boundary-integral method and the method of moments with the fast multipole method. The combination of small features in a very large waveguide makes manufacturing the array significantly challenging. Electric Discharge Machining (EDM) was tested as a potential method on a smaller array with 5 slots, but comparisons of the measured and simulated reflection coefficients show that EDM cannot meet the needed tolerances. High resolution images and measurements show significant variations in slot dimensions and rounded corners with large radii of curvature. Alternatively, metal additive manufacturing (MAM), electroforming, and others are potential solutions for manufacturing, but, the contrast in feature sizes means that current methods may be stressed. Successful demonstration of non-traditional manufacturing methods for the array would help to drive development of such processes as applied to multi-scale parts. Additionally, evaluating effects of surface roughness and accuracy when printing small parts could further improve future MAM methodologies should that method be chosen for this array.

**McNair, O. • Piland, S. • Wiggins, J.**  
Pneumatic cushions for warfighter protection and enhanced performance.

**Merkle, L. • Dubinskii, M.**  
New process for efficient laser pumping: three-for-one cross-relaxation.  
Lasers operating at mid-infrared (mid-IR) wavelengths can be useful in many sectors. Army applications include, among others, infrared

countermeasures for the protection of Future Vertical Lift platforms and other airborne assets to increase survivability. It is important that mid-IR lasers for such applications be small, lightweight and efficient. This favors the use of a solid-state laser, and pumping (supplying the energy needed to emit laser light) with semiconductor diode lasers, which are more efficient than other pump sources. Trivalent rare-earth ions, introduced into a crystal as deliberate impurities, have properties well suited to be the laser light-emitting species. Several of the rare earth ions have energy levels spaced by the right energies to enable emission of light at the desired wavelengths (approximately the 3-5- $\mu$ m range). In the study reported here, we have focused on Pr<sup>3+</sup>. It can be excited at any wavelength near 1.5  $\mu$ m, a region in which diode lasers are reasonably efficient, and its lower-lying energy manifolds are spaced such as to allow three different fluorescence transitions in the 3-5  $\mu$ m region. For operation at such long wavelengths, the crystal that hosts the Pr<sup>3+</sup> impurities must be chosen to minimize the nonradiative decay of excited states before they can emit light. This deleterious process becomes weaker if the maximum phonon (quantum of vibrational energy) is reduced. It is therefore important to choose host materials that have only rather low-energy phonons. In the current study we focus on RbPb<sub>2</sub>Cl<sub>5</sub> (RPC), whose maximum phonon energy is only about 203 cm<sup>-1</sup> (about 25 meV). Thus, we have studied the laser-related spectroscopic properties of Pr:RPC (the RPC crystal with Pr<sup>3+</sup> ions deliberately incorporated), to evaluate its potential as an efficient mid-IR laser material. We have measured its optical absorption and fluorescence spectra and the rate of decay of its excited states, not only at the wavelengths needed for excitation and mid-IR emission, but over a wide range of wavelengths when needed to understand the material. We have also measured these properties over a range of temperatures, which proved very important for interpreting the material's behavior. We observed that excitation at 1.53  $\mu$ m by a diode laser results in fluorescence in several wavelength bands, as anticipated, but that at room temperature a surprisingly large fraction of all observed fluorescence occurred in the wavelength range 3.6-5.5  $\mu$ m, thus strongly overlapping the most favorable wavelength range for Army applications. Also, the "lifetime" of that fluorescence band is long enough at room temperature to be practical for pumping by laser diodes. These are very encouraging potential laser characteristics. It is important to understand why these behaviors occurred, to determine how they might be optimized further. We found that the standard processes for decay of an excited state to lower states in the same ion could not explain the observed combination of strong mid-IR fluorescence, variation of that strength with temperature, and the changes of all upper states' lifetimes with temperature. The mid-IR fluorescence is too strong by a factor of several to be explained by intra-ionic processes. However, when we included certain interactions that can occur between nearby Pr<sup>3+</sup> ions, the situation changed dramatically. If a Pr<sup>3+</sup> excited by the diode laser sits near enough an unexcited Pr<sup>3+</sup> so that the process known as cross-relaxation can transfer about one-third of that excitation energy to the unexcited ion, both are left in intermediate energy levels. If another unexcited Pr<sup>3+</sup> is sufficiently nearby, a different cross-relaxation process transfers another one-third of the original excitation energy to that ion, leaving all three in the excited state that emits the 3.5-5.5

$\mu$ m fluorescence band. Thus, the two cross-relaxation steps combine to give a "three-for-one" effect, in which one initially excited ion gives rise to three ions in the state emitting the desired fluorescence. This combination of processes required a rather complicated set of equations for their description, but they showed that the model including the cross-relaxation steps can explain the observed strong mid-IR fluorescence, whereas exclusion of those steps cannot. This is a potentially important observation for the development of efficient mid-IR lasers for Army applications. We are now seeking sources of RPC crystals grown with different concentrations of Pr and other Pr-containing crystals, to optimize the cross-relaxation and to see how widely it can be applied. With further optimization, this previously unobserved phenomenon may lead to significantly more efficient mid-IR lasers, providing the soldier with the needed output power with low enough size and weight to be practical for successful protection of the Future Vertical Lift aircraft and other platforms.

### **Michaelis, J.R.**

Enabling semantics within IoT services: extensions to the SPF IoT middleware.

Towards facilitating data querying and discovery, both Semantic Web technologies and knowledge encoding methods offer many potential complements to the current Internet of Things (IoT) landscape [1]. Graph-based data, which underpins the Semantic Web, enables versatile representation and linking of information concerning IoT devices, the data they generate, and their usage patterns. In prior IoT research efforts, application of the Semantic Web has been assessed in the domains of dynamic service discovery [2], pervasive computing infrastructures [3], and context-aware asset search [4]. Successes in these areas indicate strong potential for usage of the Semantic Web in facilitating distributed analytics over IoT infrastructures, as well as device scheduling and content dissemination driven by Value of Information (VoI) to particular consumers. A core challenge to wider adoption of Semantic Web technology in IoT systems concerns managing both storage and processing of potentially large knowledge collections. Many approaches to IoT information management proposed so far, based on the collection of IoT-generated raw data for storage and processing in the Cloud, place a significant burden on both communications and computational resources, and are known to introduce significant latency. An alternate vision to IoT information management centers on shifting of data processing to network edge, paired with smart dissemination solutions to deliver the processed information to consumers. While such approaches (e.g., Fog Computing) offer promise for use in resource-constrained environments, corresponding methods for maintaining Semantic Web data collections remain largely unexplored. To advance the state of the art, this talk explores novel extensions for the Sieve, Process, and Forward (SPF) IoT middleware [5], to support both storage and querying over Semantic Web repositories. Fundamentally, SPF provides an SDN approach that extends the reference Open Networking Foundation (ONF) architecture, replacing the Data Plane with an Information Processing and Dissemination Plane. A key design feature of SPF involves usage of programmable information processors at the network edge, termed Programmable IoT



Gateways (PIGs), which in-turn are managed through one or more Controllers. SPF IoT applications, hosted on PIGs, provide consumer services based on available IoT data (e.g., a service for gauging neighborhood traffic levels in an urban area could be defined to use both video and image feeds). Each SPF application defines methods to facilitate IoT data filtering (the Sieve phase), information extraction from filtered data (the Process phase), and dissemination (the Forward phase) of information via available channels (e.g., Wifi, 4G/LTE, D2D). Likewise, SPF Controllers facilitate the definition of IoT applications by developers, their deployment to PIGs, as well as management and forwarding of client-side application requests to appropriate PIGs. Finally, to aid IoT application developers, SPF includes a dedicated Domain Specific Language (DSL) that allows for rapid development and configuration of IoT applications and services. To enable SPF's integration with the Semantic Web, a series of design extensions are proposed to enable both hosting and communication of SPF Controllers and PIGs with Semantic Web repositories. The paper will conclude with a survey of future research challenges corresponding to usage of Semantic Web repositories and supporting tools within SPF and similar IoT middleware.

### Miller, C.

#### Resilient communications with hybrid adaptive networking.

Our research examines Army C4ISR Satcom mobile and expeditionary networking in context of the DoD's enduring mission "to provide combat-credible military forces needed to deter war and protect the security of our nation. Should deterrence fail, the Joint Force is prepared to win." Space and cyberspace superiority are essential enablers to this enduring mission. US Army and DoD leadership is rightfully challenging current satellite communication procurement and deployment practices to accelerate adoption of emerging technologies to fight cohesively in any environment including environments where electromagnetic spectrum is denied or degraded. Purpose: Analyze the alternate approaches to achieve a cohesive Army Satcom Network with hardware, software, and infrastructure, sufficiently mobile and expeditionary for the Army to fight cohesively in any environment where the electromagnetic spectrum is denied or degraded. Theme: Our research determined a layered Satcom networking architecture is essential to Army multi-domain operations enabling order-of-magnitude improvements in Army warfighter C4ISR performance in the presence of current and emerging threats by state competitors and non-state actors. Design/Methodology/Approach: Leading private sector, or commercial, Satellite Service Providers are offering Satcom services with advanced protections against electromagnetic spectrum interference while also significantly increasing overall C4ISR data capacity within an operational theater, vastly increasing warfighter end-user terminal data rates, lowering cost of operations, and embedding active artificial intelligent (AI) learning into Cyber security defenses. The DoD and USAF are defining a Space Enterprise Vision/Space Warfighter Construct (SEV/SWC) that is also offering Satcom services with protections against electromagnetic spectrum interference. Our research characterized the performance of the current Army/DoD systems, the planned

DoD SEV/SWC systems, and the private sector offerings establishing both a protection and resilience metric and an operational theater capacity metric for detailed comparative analysis. The research examined the potential to blend elements of all three approaches, current Army/DoD, DoD SEV/SWC, and private sector into a cohesive architecture based on an overall Operational Availability (Ao) metric. The analysis showed layered or Hybrid Adaptive Network architecture can assure individual warfighter data rates and operational theater capacity even in congested and contested areas of operations where multiple warfighter assets must be supported simultaneously in the presence of: All Weather conditions; Teleport outages regardless of cause; Fiber outages regardless of cause; Cyber outages caused by previously known or NSA/DHS government-furnished-information (GFI) signatures; Interference or jamming within an operational range to the jammer (i.e. 25, 50, 100 nautical miles). Finally the research established a recommendation for an Army layered networking architecture that can fight cohesively in any environment including when electromagnetic spectrum is denied or degraded. Findings: The analysis shows that the Army and DoD are currently employing the least protected, least resilient, and most expensive Satcom services. In contrast, the private sector Satcom services are advancing significantly beyond the protection and resilience capabilities that the Army and DoD are employing and the DoD SEV/SWC is targeting when operating against both current and emerging threats. The analysis also shows that the private sector will conservatively add 100-fold more Satcom data capacity, by 2022, than the DoD requires by 2030, enabling the DoD to adopt a layered networking architecture that seamlessly leverages and roams across multiple DoD purpose-built and private sector systems. This layered networking architecture will dramatically improve protections, resilience and deterrence while imposing new costs and denying disruptive effects on adversaries. Practical Applications: This novel seamless multipath layering network architecture facilitates procuring Satcom-as-a-Service, thereby increasing warfighter lethality, increasing protections and resilience in all environments, increasing Army and DoD productivity, reducing life-cycle Satcom expense, and enabling the continuous adoption of rapidly emerging Satcom capabilities. Original Value: A means to evaluate and understand the protection and resilience capabilities of Satcom services, including current Army/DoD, future SEV/SWC DoD, and private sector. Thus, enabling the selection of an enterprise network architecture and warfighter terminal architecture, sufficiently mobile and expeditionary, for the Army to fight cohesively in any environment, even in environments where the electromagnetic spectrum is denied or degraded.

### Mitchell, G. • Hedden, A. • Galanos, D. • Anthony, T. • McElrone, B.

Agile and reconfigurable digital radar technology for air and missile defense.

### Moore, T. • Cho, J.

Designing resilient networks using software diversity.

Monoculture software is recognized as one of the critical vulnerabilities that make a network at risk

to catastrophic epidemic failures deriving from, for example, malware spreading. An attacker can take advantage of the network system's homogeneity to efficiently exploit a known or learned software flaw. As a consequence, the notion of polyculture software is emerging as a moving target defense approach to increase security in the network system. Strategies for distributing or assigning software, which is known to be an NP-complete problem, have been investigated to determine their effectiveness and efficiency. We propose a metric to measure the software diversity within a system in order to make first-time adaptive decisions for minimizing vulnerability and improving the security or the network resilience. The metric is inspired by the notions of eigenvector centrality and considers the diversity of the software of other nodes in its local k-hop neighborhood relative to its current software assignment. Hence, a node can be vulnerable if it shares the same or similar software version to its neighboring nodes and if it resides in a neighborhood with many nodes with low software diversity, i.e., a vulnerable neighborhood. This latter possibility captures the notion that the node has potentially greater exposure to attack because its neighbors are epidemic-vulnerable, even if the node's own software is distinct from its immediate neighbors. The proactive adaptations to resist attacks involve modifying the network topology via link rewiring in the following two ways: (1) the removal of a link between two nodes due to the use of the same software version, and (2) the addition (or restoration) of a link between nodes that do not share the same software version and, thus, would have limited security vulnerability. Reactive adaptations to model the response of an intrusion detection system also modify the network topology by the removal of all edges connected to a node that is found to be compromised. These processes leverage from the concepts in percolation theory [5] to develop the proposed software diversity-based adaptation (SDA) method. We conduct extensive simulations comparing the proposed scheme against comparable approaches and a baseline non-adaptive approach, with and without a simple limited software shuffling strategy, on network models and real networks. We model the spread of compromised nodes using the Susceptible-Infected-Removed (SIR) model, which is a common model for studying spreading or epidemics over networks in many contexts [6]. We study how the network density, attacker density, and number of available software versions affect the network connectivity and the adaptation cost given a specified software availability with limited correlation between versions. Our key findings from our extensive simulation experiments include: (1) the SDA metric is well-matched with the size of the giant component (a simplistic measure of network service availability) under epidemic attacks; (2) SDA-based strategies perform better under dense networks and poorer under sparse networks in comparison with the baseline; (3) SDA-based strategies are more effective and efficient than the limited software shuffling strategy by itself; (4) this shuffling strategy, however, performs better in sparser networks compared with dense networks; and (5) the SDA-based strategies perform the best under an optimal threshold criteria that, if set too low, eliminate the benefits of the approach compared to the baseline.

## **Nair, A.S.**

### **Engineering bacterial guanylate cyclase for optogenetic applications.**

Optogenetics is a technique that uses light to regulate genes that control a variety of biological process in cells and organisms. It is based on genetically engineered proteins that are activated by light. Red light, specifically, the Near Infrared Window (NIRW) of the visible light spectrum, can effectively penetrate through layers of tissue and is ideal for optogenetic applications. Bacteriophytochromes (BphP) are bacterial photoreceptors that absorb NIRW light. BphP uses biliverdin IX? (BV) as a chromophore (light absorbing molecule). BV is a product of heme degradation, by heme oxygenase in humans. Genes encoding BphP can be linked to human genes using genetic engineering and the expression of this synthetic bacterial-human module can be controlled by NIRW light. Guanylate cyclase (GC), the enzymatic domain, uses the ubiquitous substrate guanosine triphosphate (GTP) to create cyclic guanosine monophosphate (cGMP). cGMP is a second messenger that regulates a variety of biological processes. It is a small molecule and has a high signal-amplification capacity. The length and number of amino acids composing the ?-helical linker connecting BphP to the enzymatic domain is critical for successful production of cGMP. Based on this background, the aim of this project was to design a light-responsive system to activate human guanylate cyclase and to determine the optimal linker length connecting the photosensory module to the GC gene. Efficient and precise medical care is critical for the survival of soldiers. A major limitation of drug-based treatment is that they can cause undesirable adverse-effects. This is due to the diffusible nature of chemicals, causing them to affect the entire body. Optogenetics allows for high spatial-temporal resolution (controlling the “when” and “where” of treatment) and therefore provides a method for localized treatment, eliminating non-target effects. Using a flashlight to activate endogenous pathways that can aid in the treatment of casualties among combat soldiers in an effective and innovative strategy. The research presented provides synthesis of a photosensory module that provides proof-of-principle for such approach. E. Coli cells containing the Dr BphP\_MA plasmid were inoculated in ampicillin-containing LB media for 18 hours at 37 oC . The plasmid was extracted and digested with HindIII and SacI to separate the vector backbone, which was subsequently purified by gel extraction. The human GC gene was obtained from Thermo Fisher Scientific and was cloned to an ?-helical linker with the amino acid sequence RAELAE or sequential deletions of the linker (Fusion 0-Fusion 7) using polymerase chain reaction. Eight different forward primers and one reverse primer were used to amplify different linkers with the GC insert. The vector backbone, human GC gene with different ?-helical linkers, and BV generating module were cloned at 50 oC using Gibson Cloning. The plasmid obtained in the step above was transformed into bacterial cells by electroporation transformation. The transformed bacteria were grown in agar plates containing ampicillin. The DNA was then isolated from the bacteria and sequenced to verify the product. The lacZ blue/white screen was used to test the ability of the newly designed bacterial-human GC construct to produce cGMP in a light-dependent manner. A light-responsive system that uses a bacterial phytochrome to activate human GC

was successfully constructed. Among the eight constructs designed, five were active. Of these, three exhibited constitutive activity (F0, F2 and F5). The other two constructs showed activity in response to NIRW light (F1 and F3). Since F1 and F3 demonstrated NIRW-activity at 37°C, these constructs have the potential to be used in human optogenetic applications. Optogenetics holds the future of medicine. The optogenetic system could potentially be used to treat a number of disease including cardiovascular and neurodegenerative disease. To this end, the GC gene can be replaced with other genes that are involved in the specific disease process. The use of optogenetics would help in in precision medicine by targeting therapy and rendering it more effective without adverse effects. This is the first time that a red-light activating guanylate cyclase system has successfully designed and evaluated. This system would serve as a template for future design of systems for specific diseases and conditions.

## **Nakano, V.M. • Ramesh, K.T.**

### **Developing the materials-by-design workforce at the Hopkins Extreme Materials Institute.**

The next generation of materials workforce must have a broader set of skills if they are to continue to advance Army science and technology. Whether they work in a government laboratory, industry or academia, there is a critical need for individuals who have the depth of knowledge in multiple disciplines with the agility to flow between them. This is especially true when designing materials for extreme military environments such as blast and ballistic events. Johns Hopkins University (JHU) established the Hopkins Extreme Materials Institute (HEMI) to address this critical need. Through the Materials in Extreme Dynamic Environments (MEDE) program, HEMI is educating students in the science of materials-by-design. MEDE is the Army’s largest basic research program on protection materials with applications for lightweight vehicle and soldier armor. It includes 15 university partners working in close collaboration with the Army Research Laboratory (ARL). The program’s core elements include: advanced experimental techniques, modeling and simulation, bridging the scales, material characteristics and properties at multiple scales, and synthesis and processing. MEDE utilizes a materials-by-design strategy that synchronizes experimental, modeling and processing research activities across the program. This strategy is reinforced to the principal investigators and the doctoral graduate students who are conducting the research. They work together to see the mechanisms during the extreme dynamic event, to understand them through multiscale models, and to control them through synthesis and processing. They must understand materials in terms of the simultaneous coupling of the core aspects of experiments, modeling and processing with respect to the application space. Graduate students have traditionally focused their research in a single discipline. In MEDE, the students are expected to work in multiple disciplines simultaneously. MEDE students are referred to as “Pi-shaped,” symbolic of the Greek letter ?. The two vertical legs represent knowledge and depth in two disciplines, linked together with a horizontal segment showing the student’s agility to move between the two. In addition, these students learn how to collaborate effectively with other university partners and scientists at ARL. In concert with MEDE, HEMI has extended the materials-by-design strategy into its internship programs. Most

of these programs are included in the portfolio of the Army Educational Outreach Programs (AEOP), demonstrating the strong connection with the U.S. Army. For the high school students in underserved STEM populations, HEMI hosts the AEOP’s Research and Engineering Apprenticeship Program (REAP). REAP students are matched with a faculty member and a mentor (usually a graduate student or postdoctoral fellow) for an intense, summer internship. This research experience with a dedicated mentor significantly motivates the student to consider majoring in a STEM field. At the undergraduate level, HEMI manages multiple university sites for AEOP’s Undergraduate Research and Apprenticeship Program (URAP). Similar to REAP, URAP students are exposed to the materials-by-design strategy through participation in MEDE research activities. Additionally, HEMI works closely with Morgan State University, a local, historically black college/university. Morgan State students are matched with faculty hosts at various MEDE universities for a similar URAP research experience. Finally, JHU is a destination location for a number of Department of Defense (DoD) civilians are earning their doctorates through AEOP’s DoD SMART scholars program. JHU’s proximity to the Army Research Laboratory makes it a convenient location with the added benefit of working on Army relevant research such as the MEDE program. The materials-by-design strategy for workforce development has been successful. Of the 35 doctoral students who have graduated from the MEDE program, 22% went onto a National or DoD laboratory, 22% to academia and 56% went to industry. Industry partners want Pi-shaped individuals. A major materials company remarked, “An employee who can work in both experiments and computational modeling is a tremendous asset.” Undergraduates who participated in HEMI programs have gone onto graduate studies in STEM fields as well as to jobs in the defense industry. Developing a materials-by-design workforce is critical to the Army’s modernization priorities. The MEDE program’s research will directly impact the future survivability capabilities for the Next Generation Combat Vehicle, Soldier Lethality and the Future Vertical Lift. With an aging science and technology workforce, it is imperative that programs are in place now. The Hopkins Extreme Materials Institute has built a strategy to educate and develop the next generation materials workforce and encourage other institutions to address this challenge as well.

## **Nguyen, A. • Lashbrook, K.R. • Donahue, K. • Gilmer, G.**

### **Synthetic data for deep computer vision.**

High capacity models such as deep neural networks are prone to overfitting and as a result require sizable amounts of training data to properly fit. Additionally, in order for a model to generalize well, the training data needs to capture and represent every facet of the intended task. Obtaining large amounts of representative data is not always feasible, limiting the application of state of the art machine learning. The focus of this research is to leverage advances in the field of computer graphics to enable the application of deep computer vision to data scarce problems. In particular, this research involves investigating the feasibility of using generated synthetic data to train deep object detection models when there is insufficient real training data to otherwise train the models. The enablement of high capacity modeling in low and zero data contexts allows

for intelligent automation in the processing and exploitation of image data for a wider variety of tasks than previously possible. The expanded application of deep computer vision will enable the warfighter to receive more timely and comprehensive information about changing conditions, emerging threats, and hidden patterns, ensuring success on the battlefield. Computer graphics rendering methods such as path tracing allow for the generation of highly realistic images from 3D models. In the context of object detection, we first represent a human operator's knowledge about the objects of interest in the form of 3D models. We then combine the 3D models with high dynamic range background images to sample synthetic images. To determine the efficacy of synthetic data, we evaluated the performance of a deep computer vision architecture on a detection task when trained on three separate data sets: a data set consisting of a limited number of real images, a data set consisting of a large number of synthetic images, and a data set combining the first two data sets. NVIDIA's DetectNet object detection architecture was used, with the network's fully convolutional subnetwork initialized using pre-trained weights from an ImageNet-trained GoogLeNet. The intuition behind the use of synthetic data is as follows. Two common approaches to preventing overfitting are regularization in the context of optimization and priors in the context of Bayesian inference. In particular, regularization and priors help to prevent overfitting by introducing additional information that nudges the inference process towards a subset of possible solutions such as sparse solutions. Bayesian priors are especially powerful in how they allow for rich and specific information about a system to be encoded via informative priors. In other words, human operators can incorporate their domain knowledge by specifying an informative prior that represents their beliefs in a manner compatible with the model and inference process. As a result, strong informative priors lend themselves well to data scarce problems. The specification of a strong informative prior on model parameters is difficult for deep computer vision because of the black box nature of neural networks. It is unrealistic for a human operator to encode specific knowledge into a deep learning model by placing a distribution over the model parameters. We note however that the posterior computed with a first batch of data is the prior for the next batch of data. This suggests that it is possible to encode specific human knowledge into a model by updating model beliefs using synthetic data designed to represent human knowledge, avoiding the need to specify informative distributions over individual model parameters. The addition of synthetic data improves performance. In particular, the range and the points of view of accurate detection are increased. The improvements are likely due to the fact that we can generate more varied synthetic data with different scales, angles, contexts, and views, leading to a more representative and balanced training set. Our successful use of synthetic data to train a deep computer vision algorithm suggests many practical applications. Synthetic data will allow for the use of machine learning for tasks previously not automatable due to a lack of a large, representative training set. Additionally, synthetic training data will allow for the faster deployment of algorithms by shortcutting the data collection and labeling process. In particular, situations where training data are improperly collected or labeled can be avoided. With

synthetic data generation, any data issues can easily and rapidly be corrected. Overall, we have demonstrated the effective use of synthetic data in a military use case. Synthetic data will allow the US military to apply deep computer vision to an expanded set of tasks in support of the warfighter.

**Nusca, M. • McQuaid, M.J.  
• Schmidt, J.R.**

#### **Modeling and simulation of gun and rocket propulsion systems for Army tactical weapons.**

Research directed toward the US Army's Long Range Precision Fires (LRPF) program for Integrated Fires includes high-fidelity, physics-based modeling and simulation (M&S) of armament launched from large-caliber guns to supersonic speeds and then augmented by post-launch propulsion packages to hypervelocity. Successful design and gun launch of smart, long-range projectiles from solid propellant guns with integrated on-board propulsion (solid propellant rockets or ramjets) employs M&S as an adjunct to test and evaluation (T&E). We have developed reacting-flow multi-phase combustion M&S tools that predict ignition and flamespreading of solid propellant gun charges as well as the operation of solid rocket-motors (SRM) and solid fuel ramjets (SFRJ). These analyses provide the necessary foundation to the LRPF design cycle in that new and novel gun ignition systems for high-loading density gun charges, propellant thermochemistry for SRMs, and flame-holding techniques for SFRJs can each be explored and refined before test designs are finalized. The Army's research program in the development of state-of-the-art gun and rocket engine Interior Ballistics (IB) models using multidimensional, multiphase, Computational Fluid Dynamics (CFD) is active and has been productive over a wide range of physical fidelity and weapon scales. Significant gains in our understanding of multiphase physics as it relates to ignition and combustion in high-density propellant charges have been made in order to answer specific challenges in Army weapon research. ARL research has yielded a suite of IB M&S tools that aid in this research. In addition, lab-scale ballistic simulators serve to generate model validate the M&S. Lumped-parameter, single-phase, 0D models simulate gas generation from a well-stirred mixture of the energetic components comprising a gun charge. These models simulate shot start and bullet travel through the gun barrel, rapidly predicting gun chamber and gun muzzle pressure as well as bullet velocity. Two-phase (Eulerian), 1D (axial) models simulate primer function (tabular), propellant ignition, flame spreading, and axial pressure wave generation, predicting the gas-solid phase IB cycle and gun muzzle properties. Two-phase (Eulerian-Lagrangian), 2D models simulate the primer configuration explicitly, multi-component charge ignition, flame spreading, charge packaging breakup, and axial-radial pressure wave generation. Substantial research has enabled application of these models to 105/155 mm indirect-fire cannon, 120mm direct fire weapons, mortars, small-caliber weapons as well as muzzle blast/flash and insensitive munitions scenarios. For Army tactical missiles, the objective of this research program is to obtain chemical and mechanistic insights into minimum-smoke and composite solid rocket propellants that can be used as a basis for proposing new formulations and grain designs that will improve the performance of solid propellant-fueled tactical rocket motors. Range extension and

reduced time-of-flight are the performance metrics and Army missile systems include Hellfire, MLRS, Javelin, LC-TERM, and KEAPS. For the composite propellants (CSPs), the primary focus of the program has been developing models for simulating the deflagration of ammonium perchlorate-hydroxyl terminated poly-butadiene (AP-HTPB) propellants. Heterogeneous mixtures composed primarily of AP and HTPB are widely employed as rocket motor propellants. As such, there is a desire to gain insight into the mechanisms that control/limit their performance and thereby identify approaches for improving it. Of particular interest are the mechanisms that dictate the burning rate ( $r$ ) of such propellants as a function of pressure ( $P$ ). Typically represented by the expression  $r = A \cdot P^n$ , where the pre-exponential ( $A$ ) and exponent ( $n$ ) are constants, burning rates at pressures less than 4,000 psi have  $n = 0.25$  (approx), while for pressures greater than 4,000 psi,  $n > 1$ . Since burning rates with  $n > 1$  have the potential to produce combustion instabilities in rocket motors, operating pressures must be kept well below the pressure at which the exponent "breaks". Given that motor efficiency/performance improves as the pressure increases (500 psi increase : 6% range extension), an understanding of the mechanism that underlies exponent breaks has the potential to spawn ideas for formulations for which it will occur at higher pressures. Several research objectives have recently been achieved: 1) completion and publication of a new gas-phase finite-rate chemical kinetics mechanism applicable for modeling the combustion of AP-HTPB composite propellants, 2) adding an AP surface cracking submodel to our 2D laminate CFD model with application to predicting burn rate exponent break, and 3) adding a AP-HTPB surface definition submodel to our 2D laminate CFD model with application to predicting the effect of AP particle size on overall burn rate. Recently, our models have been used to revisit air-breathing propulsion systems for Army projectile such as the SFRJ.

**Oie, K.S. • Boothe, D.L. • Crone, J. • Felton, Jr. • M.A. • Franaszczuk, P.J.**

#### **Taking new concepts for systems design and control from neuroscience to accelerate innovation in artificial intelligence.**

Purpose: Present a discursive analysis of the proposition that, to accelerate innovation, renewing ties with neuroscience could speed development of new concepts for AI system design and control by allowing them to become more "brain-like." Theme: Current visions to empower a Soldier's success require AI capabilities that do not yet exist. However, there is concern that the current approaches may not be able to fully achieve what we need. If so, the time when AI can be fully brought to bear to meet Army needs may still be quite far off. Alternatives are needed to accelerate innovation. Approach: We conducted a focused review and synthesis of the current state-of-the-art at the intersection between AI and neuroscience. We considered how computational modeling could inform the future AI capabilities the Army will need. Findings: The techniques of AI quickly diverged from their neuroscience beginnings. The brain's high complexity underlies its remarkable capabilities, but makes modeling the brain's functions extremely difficult. This is particularly so for its higher, most adaptive functions, such as decision making under uncertainty, generalizing

learned skills to new tasks, or long-term strategic planning. At the same time, early limits on computation forced the use of highly simplified abstractions that traded off biological fidelity for computational tractability. These early trade-offs are still reflected today: Outside of a few key features, such as their characteristic “all-or-none” or “spiking” behavior, the artificial neurons used in today’s AI capture little of the complexity of the biological neurons that were their inspiration. Though they have shown many successes – for example, in classifying pictures into distinct categories (e.g., dogs vs. sailboats) – it is also clear that today’s AI systems are not organized like the brain. In traditional AI, groups of neurons are arranged hierarchically into distinct layers. The neuron in one layer are usually connected to every other neuron in the layer above. There are no “recurrent” connections from neurons in higher layers back to lower layers. The real brain, however, is not strictly hierarchical, and most neurons make few connections when compared to the possible connections they could make. There is also massive recurrent connectivity. Recurrent connections allow behaviors that are extended in time, and AI models based on “recurrent neural networks” (RNNs) can perform sequential tasks. The biological brain performs these kind of tasks relatively easily. By contrast, more traditional AI techniques have found sequential tasks to be largely intractable. The development of RNNs has led to improvements in AI capabilities, such as improved speech recognition or text-to-speech generation, which are critical parts of commercially-successful virtual assistant products, such as Amazon’s Echo or Google Assistant. The successes of RNNs suggest that becoming more brain-like may enable AI to move beyond its current limitations. How can this be accomplished? Analytical modeling and empirical approaches in the neurosciences currently lack the size and measurement fidelity to go much beyond mere inspiration. We suggest that computational neuroscience can. Recent Army research utilizing models that are more biophysically faithful to real neurons and brains provides evidence: First, detailed analyses of model neurons that capture more of the complexity of real neurons demonstrated behaviors not observed in simple artificial neurons, and suggested potential ways to control a system’s adaptive behaviors through mechanisms that depend on model neurons with adequate complexity. Second, large-scale simulations explored more biologically-plausible principles of organization, and showed that relatively small changes can lead to dysfunctional behaviors. This involved systematically altering the patterns of neuronal connections, which cannot be practically done experimentally. Finally, scaling the size of these models also revealed dramatic and unpredictable effects on the model’s behavior. These may be related to nonlinear effects, such as spike timing or thresholds, which become more complex with larger numbers of neurons, with significant implications for the implementation of future AI models. Practical Applications: Large-scale computational neuroscience models could radically change the way we organize and implement AI models to emulate the brain’s functional capabilities. These models better reflect our current knowledge of the brain than today’s AI techniques. Making AI models more brain-like would speed the development of new concepts for AI system design and control, while also guiding their implementation, to accelerate realization of the

capabilities Army AI-based systems will need to emulate. Original Value: This analysis highlights the potentially critical role that computational neuroscience could have in enabling the future AI capabilities that the Army will need.

**Orlicki, J. • Bartucci, M.A. • Flanagan, D.P. • Lenhart, J.L. • Radzinski, S.C.**

#### Catechol-functionalized bioinspired synthetic adhesives: probing interfacial control to improve adhesive properties.

This program seeks to improve adhesive performance by gaining insight and ultimately control of the adhesive-substrate interface, which is typically the site of initiation of failure due to the accumulation of defects or moisture. Catechol functional groups, inspired by the bio-adhesive proteins employed by marine mussels, have been incorporated into a library of synthetic polymers to probe structure/property relationships to explore the adhesive-substrate interactions. This research aligns with the Next Generation Ground Combat Vehicle and Future Vertical Lift thrusts; and broadly impacts systems incorporating composites and adhesive bonding. Most commercial adhesive performance degrades under wet and dirty environments, while several biological systems (e.g. mussel foot proteins) have been optimized for these conditions. Sequencing the interfacial protein residues has revealed that nearly a third of the repeat units consist of 3,4-dihydroxyphenylalanine (DOPA) which exhibit pendent catechols. The versatile chemistry exhibited by catechols (e.g. covalent cross-linking, metal chelating) has led to a number of groups exploring the incorporation of catechol functionality into synthetic backbones. We have synthesized a library of both poly(acrylate) and poly(meth)acrylate-co-1-[2-(3,4-dihydroxyphenyl)ethyl]-maleimides (PAMs) that vary in their aliphatic side-chain length and comonomer composition. This yielded a range in glass transition temperatures that spanned ~ 70 °C, from ~129 °C to 67 °C. The adhesive characteristics were probed using lap-shear test coupons bonded to aluminum substrates, which provided a baseline test to evaluate the library of PAMs. The adhesive performance of these materials was largely unaffected by the T<sub>g</sub>, and exhibited modest adhesion in the 3-5 MPa range. In addition, the catechol moiety was found to promote the uptake of water in the polymer, which plasticized the backbone and reduced the effective range of T<sub>g</sub> variation. However, the plasticized polymer exhibited similar adhesive performance, indicating little impact on the target properties. The modest adhesive performance garnered by the library may provide fundamental insight for the coupling of established adhesive chemistries with novel bioinspired approaches, allowing for the rational design of improved interfacial adhesion in adverse environments. In addition, the impact of small molecule adducts and specific PAM candidates has been evaluated when used in conjunction with model epoxy systems. The PAM was found to substantially improve the epoxy performance when applied to an un-primed aluminum substrate, especially under hot-wet testing conditions. This result is promising, as it may provide new capabilities for in-field repair of composite structures.

**Osteen, P. • Owens, J.L. • St. Amant, R.**

#### Temporal world models for embodied systems.

Future Army systems will need to intelligently adapt and react to unforeseen conditions on the ground. In order to operate effectively in uncertain situations, systems will need to be highly flexible, drawing from both a priori knowledge as well as learned models to make appropriate decisions. A system for storing knowledge along with facilities for accessing information on demand via reasoning, which we call a world model, is a key enabler to such intelligent systems. Three types of reasoning we identify as critical are semantic, spatial, and temporal reasoning. We have developed a world model (the Agent World Model, or AWM), whose goal is to achieve this level of reasoning in the context of human-agent or multi-agent teams. We believe the development of the AWM and similar knowledge storage systems is relevant to supporting online learning algorithms, mission context for planning, and improved human-agent communication. The AWM is based on the concept of immutable storage, allowing a full historical record of the state of a system at any given time. Unless explicitly instructed, the AWM will not overwrite any entry in its underlying database. Such immutability preserves the state of the system at any given point in time, which facilitates temporal reasoning as well as after action reviews. The AWM loads prior knowledge about the expected classes, individuals, and properties in the world using a pre-defined ontology, with runtime perception algorithms associating objects in the environment to the entities defined in the ontology. Queries to the AWM are resolved using concepts from Description Logic such as individual entities (e.g., ‘My Jetta TDI’) and general categories (e.g., ‘Vehicle’, ‘Volkswagen’), as well as the relationships between them (e.g. ‘My Jetta is a Volkswagen’, ‘All Volkswagen are vehicles’). The AWM is exposed as a service that supports instantiation, update, query, or notification requests from clients, using a message passing library that supports various languages and operating systems. A query is formatted by a client as a sequence of conditions that are used to find the appropriate entities in the underlying database, including the histories of entities over requested periods of time. For this study, we test the ability of the AWM to detect spatiotemporal relationships between objects in the environment. In particular, the events of interest are those for which pairs of moving objects interact together over time. This includes objects that move together as described by the Gestalt principle of common fate, as well as objects that have been observed to either pick up or drop other objects. Individual objects are observed moving over time, and upon request, a spatial transform tree is constructed that includes all objects that are relevant to the request. The tree is used to maintain the poses of the objects during a given time period, and provides the relative transform between any pair of objects at any time instant. Using this tree, objects are said to be exhibiting common fate if they are both moving and have approximately the same relative transform over time. Preliminary laboratory studies using a research platform show the ability of the world model to identify instances of common fate as well as instances of people picking up or dropping particular objects. A simple test ontology was created, consisting of various entities including People, Containers, and Cones. Fiducial markers

are used by perception algorithms in place of general object detectors, providing an upper bound performance baseline for common fate detection. The platform is either static or moving in the environment, and observes people picking up, dropping, or carrying other objects. The tests show that even on a dynamic platform, the world model can correctly identify the relevant common fate events to within one second of human-labeled ground truth. Performance evaluations also establish the runtimes of the current implementation, with full common fate response runtimes of about one second for a scenario with one thousand perception updates. Issues with full database immutability are observed as the runtime increases after about six thousand updates to be about 0.2 seconds for object updates alone. We see this as an argument for coupling immutability with a form of information compression; for example, pose updates for static objects do not yield new information and should be compressed for storage efficiency. Further work on the AWM will focus on more advanced semantic reasoning including probabilistic reasoning, as well as reasoning using spatial prepositions.

### **Paranthaman, M.P.**

#### **Extrusion based additively printed magnets outperforming traditional injection molded magnets.**

The aim of this research is to additively print Nd<sub>2</sub>Fe<sub>14</sub>B (NdFeB) based permanent magnets and reduce the overall cost by minimizing the critical materials wastage. One of the ways in which one can achieve this goal is by using extrusion based additive manufacturing techniques to create different shapes and complex geometries of magnets without the need for tooling. Additive manufacturing techniques are also good for rapid prototyping. However, traditional injection molded magnets need tooling or dies to make parts and loading of magnet powders in a binder is also limited. Isotropic bonded magnets with a high loading fraction of 70 vol.% NdFeB are fabricated via Big Area Additive Manufacturing (BAAM) System that enables rapid production of large parts. The density of the printed magnet is 5.2 g/cm<sup>3</sup>. The room temperature magnetic properties are: intrinsic coercivity H<sub>ci</sub> = 8.9 kOe (708.2 kA/m), remanence Br = 5.8 kG (0.58 Tesla), and energy product (BH)<sub>max</sub> = 7.3 MGOe (58.1 kJ/m<sup>3</sup>). The magnetic properties of additively printed magnets outperformed that of injection molded magnets. This demonstration shows great promise for producing high performance magnets more cheaply with additive printing. The unique findings of processing, microstructure and property of additively printed bonded magnets will be conveyed in detail. Additively printed magnets can be used in next generation combat vehicles, motors, sensors, transducers, vertical lift platforms, and communication devices. This work was supported by the Critical Materials Institute, an Energy Innovation Hub funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office.

### **Patil, A.**

#### **Towards dynamic heterogeneous living materials: a comprehensive systems-level framework for global identification of novel molecular interactions and genome-scale modeling of multicellular ecosystems.**

Microorganisms and cells engage in sophisticated interdependent interactions while forming complex community-based networks, and microbial consortia are ubiquitous in the natural world. Characterization of inter-species molecular interactions allows for novel developments in numerous areas including oncology, host-pathogen interactions, soil biology, fermented food, detection of and biofilms – natural cellular communities play a role in nearly every aspect of life on earth. Through this research, we aim to present a new paradigm for understanding how heterogeneous and diverse collections of cells interact – both to understand native behavior and repurpose them for novel applications – through a new pipeline for genome-scale metabolic modeling and molecular interaction studies. By presenting this dual molecular and systems level approach in such a comprehensive framework, we aim to spread a shift in perspective and supply the tools for a new era of multicellular bioengineering and synthetic biology research. The main goal is to demonstrate the applications it possesses in developing bio-inspired chimeric devices, detection-based biosensors, self-repairing armor systems, and a new future for soldiers both on and off the battlefield. Advances in an array of fields are impeded by the lack of data and computational tools permitting understanding of molecular interactions in multicellular ecosystems. Current pipelines take years to produce biologically relevant models, necessitating a more accurate and efficient alternative. We designed an end-to-end multi-omics pipeline combining multiple sources of biological data (gene expression levels, epigenetic factors, genomic sequences, and cellular growth profiles) to create stoichiometric genome-wide metabolic network models of intercellular interactions and processes. Our framework uses Flux Balance Analysis and linear programming to analyze molecular interactions in situ through single-gene perturbations and genome-wide scans, and integrates computational methods with experimental analysis (e.g. High Performance Liquid Chromatography and growth curve assays). This platform is applied to characterize molecular mechanisms of interaction between *E. coli*-*S. cerevisiae* populations in co-cultures, successfully identifying new, experimentally supported molecular interactions, several related to amino acid catabolism. We apply our framework to gain insights into metabolic functions of acute myeloid leukemia by creating the first network models of human hematopoietic stem cells, demonstrating its potential to characterize the molecular behavior of cancer and to provide a deeper understanding of the human microbiome, with respect to how non-self cells influence holistic health and disease. Technological innovation has reached its next frontier: engineering biology. With regards to tool development, nature has no competition: its designs have been tested over millions and thousands of years of pressure and diversity, the culmination of the great process of natural selection. Therefore, it is necessary to look to the biological sciences and learn to construct and engineering complex systems comprised of different species and cells working in unison to better soldier lethality, defense

capabilities, protection, and detection. Our new, generic framework is broadly applicable in guiding biological discovery, aiding creation of new models of immunological regulation and disease along with bio-inspired devices and living materials with embedded reprogrammed cells. Examining weaponizable applications along with those pertinent to the US Army, it is evident that there are numerous scenarios in which our novel perspective and tools are of use. For example, many bacteria develop a protective protein coat that acts as a form of armor: our technologies would allow understanding of what environmental factors trigger these processes, allowing for embedded use in devices for creations such as self-repairing soldier armor that responds to external cues. Filamentous fungi could be engineered to develop mycotecture with unique properties, allowing for on-site development of heat and stress-resistant building material. Better understanding and engineering the gut microbiome could allow for bacteria that detect concentrations of different compounds and biomarkers, and soldier health could be assessed from something as simple as the color of a stool sample. Finally, materials could be created that both detect and protect against threats of biological warfare and terrorism: topics of higher importance as open access to genetic engineering increases. This fundamental tool provides a new paradigm of designing and manipulating biological systems, opening the gateway into realizing such discoveries and many more.

### **Patterson, M. • Mosier, M.**

#### **Use of RF spectrum monitoring assets for 3D geolocation and drone detection.**

**Purpose:** Describe how a distributed RF monitoring system can be used to passively detect aircraft and drones in a tactical environment. Theme: Detection of drones in a tactical environment is a growing and urgent need. The solution must be cost effective and not increase the SWAP of equipment that is already fielded to support a wide variety of needs including providing RF situational awareness. Techniques are now available, by processing information already being collected to support drone detection and tracking as well as integration into active countermeasure systems. **Design/Methodology/Approach:** The technology and applications to be described have been under development for several years and are now available as a high TRL COTS system. Actual test data against airborne targets will be presented using field assets that can also be used to provide RF environment situational awareness. **Findings:** The described system has demonstrated in field testing the ability to locate and track airborne targets with accuracy that is similar to that of ground to air radar systems. Air vehicles have been tracked from near stationary to supersonic speeds, at ranges over 400km, and altitudes from near the surface to 50,000 feet. For Counter Drone applications, the system can be used to detect Video Downlink and control communications of smaller drones. Once detected and tracked the system can provide automated hand-off to integrated active countermeasure systems. The same system can be used to locate ground based drone controllers. RF detection can overcome some of the limitations of radar and Electro-optic sensors. The system can also operate in conjunction with these systems to improve overall system performance. **Practical Applications:** Army Signal Units can deploy this capability with limited

additional hardware and software requirements. SIGINT teams and EW teams can share the data collected for real-time analysis and integration into Electronic countermeasure systems. The data collection can be distributed in real time to the Brigade Combat teams, Division assets or other teams for further action, analysis or archiving. This would give a much broader and more accurate picture of the RF Spectrum and use across the battlefield as well as the detecting and tracking of hostile drones. Current operations have these teams working in siloes and having a more unified system would not only increase intelligence across the battlefield but also enable quicker and more effective responses whether that be within the same team or other assets, Air Force, Navy or Marine or other Allies. Original Value: The technology described can improve utility and value of existing field assets by allowing it to be used for multiple purposes. The same equipment can be used to provide RF situational awareness, emitter geolocation, as well as drone detection and tracking. This would be a valuable addition to the SIGINT and EW capabilities within a unit.

### **Patton, C. • Johnston, J. • Napier, S.**

#### **Improving accuracy of human behavior modeling for enhanced soldier performance.**

In 2017, the US Army Warfighting Challenges raised many human-centered questions which indicated that human-engineering must be involved early in the process of designing tasks and equipment. Development of equipment was focused on the abilities of the product, while the limitations of Soldiers and the way they interact with their equipment on tasks was not considered in depth. Requirements, specifications and designs lacked critical information that resulted in wasted resources, insufficient requirements and decreased performance. These concerns warranted research to find a way to incorporate the Soldiers and tasks into early equipment development. New technology couldn't empower a Soldier's success if they couldn't use it. One possible solution was to incorporate models of Soldier, equipment, and tasks early in the system engineering process. Integrating these pieces required up front knowledge of the Soldiers, tasks and equipment, as well as a methodology to collect and organize it. This research created such a methodology by use of Human View (HV), a scenario based training event to collect human behaviors, the Systematic Team Assessment of Readiness Training (START) tool and Human Abilities (HA). Human View was selected to collect and organize the data. It was developed as a part of the Department of Defense Architecture Framework to represent the human part of a system. It organized upfront human-based data that provided conditions/context, identified human tasks and classified their roles, as well as suggested potential gaps in the training. It was broken into categories to define what type of data should be collected. Populating these categories with human data provided structured information to systems engineers when they were designing equipment. To populate HV, a training event, START, and HA were used. The START tool was developed to determine criticalities of tasks and capabilities of simulators with the goal of determining how to better simulation-based training. START began with a Mission Essential Task list and then assigned attributes of the task. Then Subject Matter Experts rated criticality of the attributes to the components. This methodology was adjusted in this project

to apply to the tasks in the training event. This provided much of the information necessary to fill in the categories of HV. The remaining gaps in HV were filled in using HA. HA were 52 innate aptitudes and trained skills that influenced performance on tasks. They were grouped into four categories: cognitive, physical, sensory and psychomotor. Using the context of the scenario allowed researchers to determine more precisely the HA needed to complete tasks within a realistic environment. While the skills were more cognitive in nature, they took place in a physical environment and thus the full complement of HA were used. Based on the information gathered using the training event, this methodology allowed more complete models of Soldiers, tasks and equipment interactions. The training event was able to provide mission and environment context, tasks, roles and human network categories of HV. HA were able to fill in gaps in the human constraints. The START methodology helped refine the data, especially in roles and tasks categories. Combining HA and START in a scenario gave insights into places where cognitive or physical loads may be too high. This data can be used to create a model to compare potential changes in a system to the current system. The change might impact a work process, roles associated with the task, the number of people assigned to a task, new needs for training or help design better equipment or improve training. Future work can be focused on better integration of the Soldier in the systems engineering process. HA can be integrated into engineering diagrams to give more detail of the human in a scenario and be incorporated into modeling tools to better model performance. Many current models do not hold in a real scenario because the HA and attributes are missing. Task outcomes can now be modeled in a way that reflects what happens if different patterns of cues are missed or misinterpreted. These can be compared to the actual scenarios for validation purposes. There is also the ability to correlate with physiological data to determine stress and HA relationships. Future work will look at these relationships and continue to incorporate the Soldier with the equipment and task. This data sets the stage for further analysis of current and future systems. Until now, there has not been a model that incorporates the human factor early in the design process. Now, it provides a way for systems engineers to design better and more efficient technology using fewer resources. The results of this study are valuable because they will allow Soldiers to perform optimally while using few resources.

### **Payne, R.L.**

#### **Analysis of muscle-tendon dynamics in kangaroo rats.**

Kangaroo rats are efficient hoppers and jumpers, largely due to the physiology and function of their calf muscles. The lateral gastrocnemius, medial gastrocnemius, and plantaris are three muscles connected to the Achilles' tendon that experience force-sharing. In situ direct measurement of musculotendon properties are desirable to better understand data gathered from video cameras and sonometric crystals during behavioral tests including hopping and jumping. The purpose of the research conducted was to determine muscle-tendon properties in maximum activation jumping and cyclic jumping motions, which can be utilized for computer simulations and eventually robotic actuation. Sonometric crystals are small sensors that are surgically implanted along a

single muscle fascicle. The distance between the crystals changes as muscles contract. Data from a sensor is used to estimate length changes for a single muscle, which can be used in conjunction with physiological parameters to determine how each of the three calf muscles contributes to the force in the tendon as well as how each muscle experiences strain. Research that was conducted involved developing a computer model in Matlab that predicts strain in individual muscles during isometric contractions, as well as developing a method to analyze data from the sonometric crystals describing length changes of the muscles. The findings of this research allows users of the program to reliably predict muscle force and length, and to figure out how force is distributed in the three muscles, in order to mimic the efficient, spring-like behavior that these kangaroo rats exhibit. Hill equation constants describing dynamic motion were determined through experimental data and their accuracy was shown with the completed model. Practical applications for the research relate to other bipedal hopping animals in prediction of muscle-tendon interactions. This relates to disruptive technologies that allow for system-modeling of muscle-tendon behavior to benefit future implementations for the most efficient robotic programming that will allow for hopping across rough terrain.

### **Perkins, E. • Barnes, E. • Pilkiewicz, K. • Poda, A. • Warner, C.**

#### **Production of tunable nanomaterials using assembled bacteriophage droplets.**

### **Prothero, J.**

#### **Empowering the warfighter with spiral modulation.**

Astrapi's SM is based on a new generalization of Euler's formula, the underlying mathematics for the telecommunications industry. Existing telecommunications theory and practice implicitly assumes that the spectrum is stationary over each symbol time. The purpose of the research is to demonstrate that spiral modulation, unlike all other approaches, has the game-changing capability to exploit a continuously nonstationary spectrum opening the potential for dramatically higher spectral efficiency than was previously thought possible. Improved spectral efficiency is among the most critical technologies for empowering soldiers. Mission success is often dependent upon communication link integrity. Existing communications channels are capacity and power constrained, and susceptible to increasing amounts of interference. Satellite transponder space is limited, expensive and susceptible to interference and latency constraints. Terrestrial Line-of-Sight is often not optimal given environmental constraints. Beyond-Line-of-Sight has similar challenges. Compromised communication links increase the odds of mission failure. Adversaries are rapidly increasing their ability to develop innovative capabilities. Emerging solutions generally increase the number of nodes while offering only incremental improvements in channel throughput, power optimization and the ability to mitigate interference or jamming. Extending mission life is often dependent upon more power, which increases the weight carried (batteries). And the demand for high throughput images, streaming video, and data

are growing. All require more power. Very little attention is given to physical layer innovation. Astrapi's novel approach lies in how we make use of the waveform design space to meet these challenges and improve the tradeoffs among occupied bandwidth, interference mitigation and power optimization. This directly empowers soldiers leading to mission success. Fundamental problems require fundamental solutions. Low spectral efficiency is a fundamental problem facing soldier communication. Incremental advancement is not making this problem go away. A fundamental solution requires going to the core of telecommunications theory and making a change at the physical layer of the communications stack. We approached the problem by generalizing the underlying mathematics for the telecommunications industry, which is Euler's formula. This gave us, for the first time, the ability to describe how to fully exploit a continuously nonstationary spectrum for information transmission. Since classical communication theory implicitly assumes the spectrum is stationary, it also allows us, in principle, to drive spectral efficiency much higher than was previously thought possible. (More technically, to exceed the Shannon upper bound.) We began with mathematical research, which we extended to software (MATLAB) simulations, and are now pushing down into hardware design. Our work is backed by \$2.3m in private investment and \$924k from two rounds of National Science Foundation (NSF) funding. Key Astrapi findings include: 1. The potential exists to dramatically exceed the spectral efficiency of all deployed and proposed communication systems. 2. Doing so requires exploiting a "loophole" in classical communication theory, which is that it does not cover a continuously nonstationary spectrum. 3. Signal design should use complex spirals (rather than the traditional complex circles), in a particular way. 4. Software simulation shows an initial design with an approximately 4X power advantage over traditional Quadrature Amplitude Modulation (QAM) with matched data throughput. 5. Measuring the occupied bandwidth of a nonstationary spectrum is challenging but doable. 6. There is a clear path to hardware prototype and beyond. Since SM is a foundational innovation at the physical layer of communication, it has widespread and profound implications across multiple defense and civilian applications. It can address essentially any communication problem that is limited by data throughput, signal power, available spectrum, or certain kinds of latency. Use cases range from the terrestrial radio and Beyond-Line-of-Sight to enhanced UAV capability and optimizing satellite transponders. SM requires changes to the radio design to support a new type of signal modulation. Depending on application requirements, the change may be relatively small (affecting only how transmission waveforms are constructed); or, to achieve higher performance, more extensive enhancements may be necessary. Astrapi has developed initial relationships with several defense prime contractors and other key stakeholders to help define technology transition pathways. The ability to dramatically improve communication performance through foundational innovation. SM is currently in the TRL-3 stage. A successful project will demonstrate Astrapi spiral modulation in a hardware prototype (TRL-6) that is suitable for initial network testing.

**Pusey, J. • Brown, J. • Carbiener, C. • Clark, J. • Nicholson, J.**

#### Fore-aft leg specialization controller for a dynamic quadruped.

Many running animals, unlike their robotic counterparts, have distinct morphologies and functional roles for their front and rear legs. We present a new control approach for a 5kg autonomous dynamic quadruped that explicitly encodes separate roles for each contralateral pair of legs. This controller utilizes a functional dynamic decomposition similar to Raibert's three part control law, but focuses on fore-aft leg specialization to regulate the robot's performance. The velocity of this controller, which exceeds 5 body lengths per sec, is compared with an improved trajectory based controller and shown to be significantly more robust to changes in environment. This new fore-aft leg specialization controller (LSC) has produced the highest velocities in terms of body lengths per second of any platform over 5kg and significantly more robust to changes in terrain and changing payload.

**Quraishi, S. • Hannegan, J. • Siverns, J.**

#### Army Research Laboratory, wavelength tunable photons from a trapped ion via quantum frequency conversion.

Purpose: Quantum simulation and networking is a focus of cutting-edge research in quantum science. These efforts are relevant to the DoD's Mission as they impact future communications platforms, networking quantum systems for distributed computation and will serve as toolkits for complex simulations for tactical decision making. The most pristine source of quantum information is derived from trapped ions, providing an advantage over competing approaches. Much research has been done working with a single trapped ion node and in connecting two nodes, however, the range between nodes has been limited to a few meters. In this work, we overcome challenges to extending the connection range of trapped ion nodes via optical fibers. Prior approaches to networking are severely limited in the distance between nodes because of photonic attenuation in optical fiber (approximately 30 dB/km in optical fiber for 493 nm photons). To overcome this challenge, we use quantum frequency conversion to convert the photon into the near-infrared (3 dB/km attenuation in optical fiber), O-band telecom and C-band telecom (0.2 dB/km attenuation in optical fiber). Our approach uses a fiber coupled periodically-poled lithium niobate (PPLN) crystal and is versatile for implementation in other trapped ion setups or quantum memories to improve connectivity to optical fibers. This work is part of the Army Research Program's Mission in quantum networking and quantum information sciences. Beyond networking individual ions, our work is relevant for scaling up quantum simulators. Theme: Our work relates to the Army theme of Future Technologies, in the area of Quantum Communications and Sensing. Work in quantum networking maintains our adversarial advantage and supremacy in quantum information sciences, which is relevant for quantum simulation and quantum computing. Approach: Quantum networking with photonic interconnects allows for entanglement between remotely situated quantum memories. Trapped ion systems

have many desirable properties for quantum networking including long-lived memories, on-site processing and flying qubits, with entanglement and teleportation demonstrated. To extend the range between nodes of the network requires the conversion of the ion's photon to longer wavelengths with improved fiber propagation properties. We show a one-stage frequency conversion process of photons from a  $138\text{Ba}^+$  ion with 493 nm converted to 780 nm. A second stage, currently in progress, will convert from 780 nm to 1530 nm photons. We observe strong signatures of quantum statistics of the converted photons. These efforts significantly help to extend the range between nodes of a quantum network and offer a path to hybrid quantum networking. Findings: We use difference frequency generation (DFG) between  $\text{Ba}^+$  photons at 493 nm and a pump at 1343 nm to produce near-infrared light at 780 nm. Using a second DFG stage, we are working to translate this 780 nm photon into the C-band at 1530 nm. Note that the same pump laser can also perform DFG with 650 nm photons from  $\text{Ba}^+$  to produce O-band light at 1259 nm. In  $138\text{Ba}^+$  we showed that 493 nm photons can be used as polarization qubits for entanglement distribution, whereas the 650 nm conversion process requires only a single stage to get to telecom wavelengths, however is not ideal for ion-photon entanglement. We observe end-to-end quantum efficiencies for DFG from 493 nm to 780 nm to be 20% as well as tuning to the  $87\text{Rb D2}$  resonance. Conversion with  $\text{Ca}^+$  has also recently been shown. Practical Applications: Although our research is focused on 6.1 efforts, we have taken an approach to networking using modular components and are currently working with collaborators in academia and industry to future streamline the experimental setup. Original Value: Considering the remarkable results in quantum information science with trapped ions our results are significant as we demonstrate an approach to significantly increase the distance between trapped ion nodes. This work is relevant to the Army goals in future technologies aimed at quantum communication. Given the new investments in academia, industry and government in quantum science, particularly trapped ions, our work directly impacts the ability to connect two nodes together offering a testbed to extend the range of quantum information processing. Our modular approach is advantageous since it maintains low SWAP-c while effectively enabling the increase in the baseline between quantum nodes.

**Racicot, K.**

#### Where food science meets nutritional biochemistry: performance nutrition efforts in combat feeding.

Purpose - What is the aim of the research to be presented in the technical session or poster presentation? At the nexus of food product development, nutrient stabilization, and nutrition biochemistry is the need to ensure that the warfighter is provided scientifically validated ration components that will optimize physical and/or cognitive performance. Ongoing research activities in collaboration with MRMC focus on conducting nutritional intervention studies to assess which bioactive can be efficaciously incorporated into ration systems to achieve warfighter readiness. Theme - How does the research relate to your designated focus area/ topic AND the theme of the symposium which is: "Army Science & Technology – Empowering a

Solder's Success"? CSA GEN Mark Mileys intent is clearly outlined in his 03Oct2017 Modernization Priorities memo. The Army's modernization strategy has one simple focus: make Soldiers and units more lethal. It is through basic research in human biology couples with food science and collaborative nutritional intervention studies that we intend to support and optimize human performance efforts throughout the Army's research labs. A high performing Soldier is a more lethal Soldier. Design/Methodology/ Approach - How were the research objectives achieved? Include a discussion on the research analysis and the primary methodology used. Discussed here will be overview of major recent areas of research between the Combat Feeding Directorate and MRMC partners, each with their own design methodology. In our understanding of muscle inflammation and immune cell recruitment the approach is to establish in vitro models and assess the influence of exercise induced muscle damage and repair mechanisms. In topic area ketone supplementation, the approach and methodology were centered on market studies, assessments of state-of-the science, and SME interviews. For the effects of gut microbiome and performance, the approach and methodology is primarily focused on characterizing the effects of military relevant stressors clinically, with some supporting applied research. Overall research findings vary according to research technical area which will be highlighted during the poster presentation. In short, ketone supplementation as it relates to performance/endurance is compelling but inconclusive and can be considered in a watch mode. Recent data on ketone supplementation will be highlighted. Characterization of gut microbiome and performance has been shown to have consistencies in the effect of military relevant stressors on gut permeability and systemic inflammation. The applied research is showing that gut community dynamics are altered with new clues as to what those changes mean to functional changes of the microbiome and effect on human host. New evidence is showing that high dose polyphenols may mitigate effects of exercise induced muscle damage. Practical Applications - What are the practical applications of the research? What changes to existing practice might be made as a result of this research? There are multiple immediate and future practical application to performance nutrition research. Immediate applications include working with dieticians and clinicians to augment and assist in educating and informing the military customer on eating habits. Midterm applications include informing ongoing and planned clinical research. Using the data gained will help shape the protocols and experimental design for future clinical research. Long term applications include changing or adjusting field feeding policies which will lead to changes in combat ration platforms. New discoveries in molecular nutrition and clinical nutrition will help uncover areas to improve feeding and warfighter health.

**Ren, F. • Chabi, S. • Dikin, D. • Percec, S. • Zhang, Z.**

Understanding and tailoring the micro- and nano-mechanical behavior of high-strength fibers for ballistic fabrics.

Purpose: High-strength polymers such as poly(p-phenylene terephthalamide) (PPTA) and ultra-high molecular weight polyethylene (UHMWPE) are among the state-of-the-art materials for

manufacturing body armors. The mechanical behavior of these materials dictates their anti-ballistic performance. This is closely related to the intrinsic structural properties of the constituent fibers at micro- and nano- level, and to the fiber-to-fiber interactions. The aims of this study are to obtain a better understanding of the mechanical behavior of these high-strength fibers at the micro- and nano-scale, and to enhance their mechanical properties through surface structure modification. Theme: Future Technologies/ Materials Science: The goal of this work is to advance the material design and manufacturing of high-strength fibers for ballistic applications. This will be achieved with assistance from understanding the effects of material engineering on the fiber microstructure and the mechanical properties. Design/Methodology/Approach: In this work, mechanical properties of PPTA single fibers (Kevlar® K-29) and UHMWPE single fibers are investigated using nanoindentation and micro-tensile testing techniques. Surface treatment of PPTA fibers is conducted by coating with UHMWPE, silica nanoparticle, and other nanoparticles. Findings: Stress relaxation is observed under compression (indentation) loading conditions in the transverse direction and tensile loading conditions along the fiber direction. In both cases, the stress relaxation behavior can be well described by the general Maxwell relaxation model. Meanwhile, the dynamic nanoindentation test assessing the viscoelastic behavior of the PPTA fiber as a function of loading frequency indicates that when the frequency increases, the storage modulus increases also. This implies that the viscoelasticity of the fiber is reduced at higher frequencies. On the other hand, as demonstrated by the micro-tensile testing, repeated loading and unloading also reduces the viscoelasticity of PPTA fibers and increases the ultimate tensile strength and elongation at failure. On the other hand, it is shown that the UHMWPE coating improves the elastic modulus of PPTA fibers in the transverse direction, and introduction of silica nanoparticles increases its wear resistance. Practical Applications: Knowledge of the mechanical behavior and its correlation to microstructure can be used to design and optimize fiber-based body armors against ballistic impact. Meanwhile, surface treatment technologies being developed in this project can be utilized to modify and enhance the performance of high-strength polymer fibers. Original Value: This study explores the time-dependent and dynamic mechanical properties at micro- and nano-scale, which is relatively sparse for single fibers of high-strength polymers. This information can provide novel insights into the structure-property relationship of ballistic fibers, which is essential for the design of next-generation body armor systems.

**Repanshek, J. • Dawidowicz, K.**

Warrior Performance Platform (WP2™) for U.S. Navy: leveraging best-of-breed human performance tracking and analytics technology to enhance Navy's physical fitness, wellness, and nutrition capabilities.

The field of human performance has exploded in the last several years. With the ubiquity of mobile devices and the dramatic increase in "wearables" and other performance tracking devices and gadgets, there are now more sources of valuable performance data than ever before. Along with the growth in the wearable device market, there has been mounting interest in

developing platforms to aggregate and display information to identify trends, support learning and enrichment, and dynamically generate personalized recommendations. The Navy has acknowledged these trends and is investing in tools and technologies that provide human performance-related capabilities to assist in improving force readiness. As is the reality with many of the DoD's forces, the Navy has an atypical set of requirements to consider considering the limited network bandwidth constraints that are unique to a deployed surface force. While many "human performance" software packages and platforms exist on the commercial market, none are currently capable of supporting a full suite of human performance focus areas (wellness, physical training, nutrition) within the austere conditions presented by the Navy's use-cases. Furthermore, the Navy wishes to leverage existing IT investments through custom integrations with several featured platforms, including the Naval Operational Fuel & Fitness System (NOFFS), United States Department of Agriculture's (USDA) MyPlate, and the DoD's Go for Green program. The intent is to embed this application functionality into a physical, touch screen kiosk that meets the ruggedization, power, and connectivity requirements of the deployment environment; the resultant solution now known as the Human Performance Self-Service Kiosk & Application (HPSSK&A). The Informatics Applications Group, Inc. (tiag), in partnership with CoachMePlus, has embarked on Phase II of Small Business Innovation Research (SBIR) Topic #N171-079, "Human Performance Self-Service Kiosk and Application," sponsored by the US Naval Supply Systems Command (NAVSUP). The HPSSK&A project represents a tremendous opportunity to bring state-of-the-art human performance technology to the U.S. Navy in a form and format that meets the Navy's very specific requirements. In support of this mission, tiag and CoachMePlus have leveraged their Warrior Performance Platform (WP2™) solution, which is based on the same commercial CoachMePlus software currently in use by over 220 professional and college sports teams. This platform provides thousands of elite athletes with real-time, interactive assessments of their performance, while leveraging an array of wearable and wireless technologies. We are applying these same capabilities and experiences to provide the Navy with an interactive, touch screen HPSSK&A solution that displays both human performance information and serves as an individualized educational platform for users ashore and at sea. Using the same methodology we apply to the assessment elite professional and college athletes, we are developing HPSSK&A to display and share human performance information that includes a Sailor's nutrition, physical training, and wellness. Just as the flagship CoachMePlus platform integrates an array of team inputs, HPSSK&A supports a platform that permits an individualized, tailored Sailor interface and user choice with an array of options, including the integration of commercially available personal electronic devices, such as phones, tablets, and other touch screen and physical activity tracking devices. The overarching goal of this effort is to assess the viability of the human performance tracking and applied sports science capabilities of the WP2™ platform to enable physical fitness, wellness, and nutrition-tracking capabilities in the unique afloat and ashore environments in the U.S. Navy's unique use-cases. Through the Phase I period of the SBIR effort, which commenced in



June of 2017, the results of initial research, design, and prototyping efforts have been extremely encouraging. Preliminary system architecture and communication strategies have been developed and validated, and the core software platform has been shown to support many of the proposed functional requirements with very limited customization required. As part of Phase II activities, additional findings will be available as we further prototype the solution and test it in real and/or simulated operational environments. The potential benefits of the HPSSK&A research and development effort are immense. The ability to centrally track and monitor the health, fitness, and overall wellness of military personnel both ashore and, more uniquely, afloat will present leadership with visibility into the performance and readiness of a relevant population not previously available. While there are clear and present opportunities for the wide deployment of this capability within the Navy setting, we contemplate many additional applications in other DoD and Federal communities with similar or overlapping requirements to enhance the force readiness of our nations warfighters.

### **Sadler, B.M. • Pham, T.**

#### **Artificial intelligence and intelligent systems: Army challenges.**

Artificial intelligence (AI) research develops tools and theories to describe “intelligent” human-like behavior, and informs the design of intelligent machines and systems. AI encompasses a broad set of tools and theories, including machine learning (ML), and deep learning (DL), a dominant subset of ML. AI is impacting virtually all Army science and technology (S&T), and AI enabled systems will fundamentally transform and empower a soldier’s success in a variety of Army operations. The Army has unique challenges that will strongly benefit from the application of AI tools, on problems that will not be solved by commercial industry. Broad Army S&T areas where AI will play an important role include ISR and analytics, autonomy and robotics, tactical networking, and human-machine teaming. To varying degrees, these all will rely on foundational AI components including reasoning (problem solving), knowledge representation (knowledge bases), planning, learning, natural language processing, perception, motion and manipulation, and social intelligence. This component list comprises a taxonomy of AI, and advances in the components will have impact across multiple S&T areas. For example, perception is fundamental to both ISR and autonomous mobility, and knowledge representation is fundamental to both networking and human-machine teaming. More broadly, learning, reasoning, and planning are critical for all areas. AI has exploded into a variety of commercial applications since 2010. Basic DL paradigms and artificial neural networks (ANNs) date to the 1980s, and computing and data collection advances enabled their emergence. Through trial and error, it has become apparent that the best AI performance could require millions of training examples. However, it is clear that Army AI will require unique data sets, and it is also clear that Army systems must operate in environments without a priori access and so must not rely solely on big data. Driven by recent commercial AI success (especially ANNs), a wave of computing devices is now emerging, evolving from graphical processing units that were designed for gaming. The large commercial investment in chip development

(\$100M’s) will, in turn, enable further exploration of learning architectures and accelerate a cycle of theory–experiment R&D. AI will rapidly become embedded everywhere there are electronics (i.e., everywhere), as the devices achieve commodity pricing and low power operation. Army S&T will exploit these devices to embed low power AI into a large variety of platforms and applications. AI and traditional computing will be integrated. AI will expand to include dynamical inputs such as video streams integrated into control architectures such as robotics and enabled to collaborate via integrated autonomous networking. This future wave of technology convergence will have dramatic implications beyond autonomy, robotics, decision aids, and other areas of current research. When AI devices become omnipresent and embedded, hundreds to thousands of these may be combined into complex and dynamic architectures. The rich combination of global and local embedding of AI into sensors, robotics, and networks will enable autonomous physical agents that team with Soldiers. These will establish self-healing wireless networks that dynamically defend and utilize infrastructure as available and operate in the cyber and physical domains simultaneously. Intelligent agents will be able to sense and secure areas before Soldiers physically enter them, including the ability to detect and map the presence of life, energy sources, and biological agents. Soldiers will also engage with agents to provide directed kinetics in rapid coordinated attacks and defend against such attacks. A variety of challenges must be addressed to make this vision a reality. AI requires new tools for test and evaluation, system safety, redundancy, resistance to adversarial attacks, and explainability. While autonomous navigation is largely a solved problem in the air and undersea, the ability to navigate and maneuver using ground robotics is far less advanced because of the complexity of the environment and the current lack of AI for physical reasoning. Technology convergence has produced a large assortment of new networking techniques (e.g., dynamic spectrum access, MIMO, cognitive radio), but these have outpaced our ability to manage them in a wireless tactical network setting. AI learning methods, such as reinforcement learning, may lead to network management and control policies which are robust, distributed, and adapt to operational conditions, resulting in highly redundant and resilient networks. Central to the development and application of AI is the ability to rapidly transition algorithms to practice, especially in the face of a sophisticated peer adversary. This may require new S&T business practices, tightly coupling R&D with feedback that spans the AI researcher to the soldier.

### **Salavani, R. • Moheisen, R.**

#### **Energy efficient “shelter in shelter” concept for large expeditionary structures application.**

Purpose - The US DoD has a goal of reducing field consumption of fossil fuels in order to improve energy efficiency and operational resiliency. The intent of expeditionary shelters is to provide accommodation and protection for personnel or equipment, but designs are typically focused on transportability and ease of set-up, and these structures are inherently inefficient in respect to energy use (environmental heating and cooling). The Shelter in Shelter (SiS) concept allows strategic and reconfigurable work areas within large military structures, and localized environmental cooling (or heating)

without the energy burden and associated cost of conditioning a large volume space. The concept could be applicable to any scale of expeditionary shelter, but is likely to realize the most cost-effective impact on large deployed military shelters such as Large Area Maintenance Shelters (LAMS). (For reference, the LAMS aviation shelter dimension is 192’ long, 75’ wide, and 31’ high). Design/Methodology/Approach - Prototype SiS configurations were tested and compared against a baseline shelter for potential energy savings. These evaluations occurred at the AFCEC test site at Tyndall AFB, FL. A small energy efficient gable-style shelter was installed inside a medium shelter (30’ wide x 52’ long). A portable air conditioner (A/C) was used in the evaluation however, this can be replaced with a conventional environmental control unit (ECU) if connected to the existing air plenum inside the shelter, and routed into the interior of the SiS. Findings - During the testing phase, energy savings of 49-75% were achieved compared to the baseline, depending upon environmental conditions and ambient temperature. As expected, when the outdoor temperatures were higher, greater savings were achieved. Cumulative average energy savings were ~65% over a 24hr period, with average daytime savings of 74% (at average ambient conditions of 85°F). Practical Applications - The DoD has a goal of reducing consumption of fossil fuels. Energy saving of expeditionary shelters, particularly large expeditionary shelters are notoriously difficult and cost-prohibitive. The idea of having a “shelter in shelter” configuration is to confine the conditioned space to a smaller area rather than to condition the whole shelter, which in turn reduces energy consumption. The design is modular, scalable, and can be retrofitted as an add-on to existing expeditionary structures. Original Value - Over the past decade, AFCEC has executed a joint Army/Air Force program to maximize energy saving, security, resiliency, and efficiency for expeditionary shelters, with particular emphasis on reducing energy (and fuel) consumption associated with soft-wall shelters. The result was identification of a range of technologies that reduced energy demand by up to 50% versus current concept of operations. The successful energy efficient configurations were demonstrated on small-scale shelters, but energy savings did not scale linearly to medium, and large-scale shelters. LAMS, for example, would require connection to multiple Environmental Control Units (ECUs) for effective air conditioning. If heating and/or cooling are required, there is currently no choice but to condition the entire space, which for LAMS is costly in respect to energy consumption. The only approach that provided energy efficiency of >50% for medium-scale shelters was achieved by positioning a smaller modular structure inside a larger structure, and conditioning only the small work zone, instead of the total space. The SiS provides a workspace that can be relocated to provide a heated/cooled environment where and when needed (i.e. for fabrication shops, servicing and test areas, or office/administration areas).

### **Samavedi, S.H.**

#### **Designing a thermostable cellobiohydrolase; a novel approach to sustainable ethanol production.**

The annual global consumption of petroleum by the transport sector is 36 billion barrels. This leads to increasing concentration of atmospheric CO2 contributing to global warming. These

hydrocarbons can be replaced by renewable biofuels. The most promising source of biofuel is cellulose. Annually over 150 billion tons of cellulose is produced by plants and trees through photosynthesis. In nature, cellulose is converted to glucose by different enzymes, one of which is Cellobiohydrolase. It breaks cellulose polymers into 2-carbon sugars called cellobiose. Cellobiohydrolase however does not catalyze this reaction at a commercially viable rate. The goal of this project is to design a modified fungal Cellobiohydrolase with increased thermal stability which will degrade cellulose at a higher rate and a higher temperature. The enzyme chosen for this study is Cellobiohydrolase Cel7a from *Hypocrea jecorina*. This research project has the potential to revolutionize the use of biofuels in transportation and enable the use of synthetic biological materials to fuel the next generation of military combat vehicles. It is a disruptive technology that can dramatically decrease the use of fossil fuels with geopolitical and environmental benefits on a global scale. The baseline thermal stability of Cellobiohydrolase was measured by testing the catalytic activity of the enzyme at different temperatures. This data was plotted on a graph to determine the optimal temperature for Cellobiohydrolase and quantify the rate of cellobiose production per unit enzyme. Using protein modelling software, I-TASSER 5.0 and CHIMERA 1.2, a 3-D model of the enzyme was built and 3D printed for reference. Using UGENE 1.25, multiple Cellobiohydrolase FASTA sequences were compared to identify and map out conserved domains and active sites. Using this information, the amino acid sequence of Cellobiohydrolase was modified using site directed mutagenesis at 16 selected locations to increase the thermal stability without modifying the conserved domains and the overall 3D structure of the protein. The change in the internal structure from each amino acid substitution was studied to identify the changes in the bond structures, particularly the changes in hydrogen bonds, salt bridges, cation- $\pi$  interactions and disulfide bonds. Amino acid substitutions were chosen to increase the number of these bonds as they are known to increase the thermal stability of the protein. The newly created protein was further analyzed with STRUM, and a  $\Delta\Delta G$  score or the change in thermal stability due to each amino acid substitution was calculated. A positive  $\Delta\Delta G$  score will correspond to increased thermal stability. The sixteen modifications that were chosen led to a total calculated  $\Delta\Delta G$  of +13.77 Kcal/mol. This was achieved by decreasing the total volume of the engineered molecule by over 3%. This leads to smaller distances between the atoms and stronger bonding energies including increased van der Waals and London Dispersion forces. The number of disulfide bonds increase by 3, hydrogen bonds including Main Chain – Main Chain, Main Chain – Side Chain and Side Chain – Side Chain bonds increased by 8. The number of ion pairs including salt bridges and partial charge pairs in the engineered protein increased by 7. These internal bonds are known to make a significant contribution to the thermal stability of the protein. This new modified Cellobiohydrolase protein was modeled using I-TASSER and UCSF Chimera, the model was 3D printed and compared with the 3D model of the wild protein to verify that the structure and shape was preserved. This modified protein is more thermostable and should retain its enzymatic activity as its shape is well preserved. The chemical breakdown of cellulose will be much faster as the reaction can now occur

at a much higher temperature. The impact of this innovative research to modify and increase the thermostability of cellobiohydrolase will be a much more efficient and cost-effective production of ethanol from cellulose. Because cellulose is widely available, ethanol can be produced and used locally and eliminate the need to transport fuels over long distances. By eliminating the need for fossil fuels for transportation this innovation can decrease greenhouse gas emissions by up to 70%. The innovative aspect of this research project is the use of emerging bioinformatics technologies like whole genome sequencing, translation of genetic sequences into amino acid sequences, using machine learning technologies like Monte Carlo simulations and gradient boosted regression analysis to accurately model protein structure and calculate its thermal stability. I apply these to address a real-world issue of the harmful consequences of continued fossil fuel use and create a cutting-edge solution in the form of a custom designed protein that will maximize the efficiency of cellulose breakdown that is the critical step in leading us to a greener sustainable future.

### **Sampath, A. • Wijewarnasuriya, P.S.**

Development of nanostructured antireflection coatings for electro-optics infrared systems.

### **Santhanagopalan, S. • Babu, V. • Chen, Y. • Ding, Y. • Yang, C.**

Dynamic response of lithium-ion batteries subjected to mechanical failure under high-velocity impact.

As part of the Advanced Vehicle Power and Technology (AVPTA) Alliance, a partnership between U.S. Department of Army (DA) and U.S. Department of Energy (DOE), to explore solutions for increasing fuel efficiency, enhancing the Nation's energy security infrastructure and supporting the power generation capabilities for the next generation combat vehicle, the U.S. Army's Tank Automotive Research, Development and Engineering Center (TARDEC) and DOE's Vehicle Technologies Office (VTO) collaborated to develop Battery Computer Aided Engineering Tools for Vehicles. This presentation highlights the use of advanced mathematical models to concurrently simulate multiple failure modes in lithium-ion batteries subjected to high-strain rate mechanical deformations, and the implication for the safe design of battery modules. Under the Computer Aided Engineering of Batteries (CAEBAT) umbrella of projects, the DOE's National Renewable Energy Laboratory (NREL) teamed with TARDEC and developed physics-based mathematical models that comprehensively simulate mechanical failure of battery components, relating mechanical properties of cell components, and packaging material for the module. The majority of previous mechanical abuse studies focused on quasi-static and low-velocity impact analyses, which do not represent the extreme loading conditions that are characteristic of military applications. Here we report a combined experimental and computational study on the dynamic response of lithium-ion pouch cells subjected to high-velocity (200 m/s to 1000 m/s) impact. Dynamic simulations were performed using an explicit finite element method, to study onset of failure in a pouch-format lithium ion cell, and subsequent propagation within the module. Specifically, we

studied the effect of cell orientation and physical configuration of the cells within the module (e.g., location of the contact lugs or bus-bars) on the evolution of subsequent failure events, given a single-cell failure event. Initial results indicate that the interfaces among the cell components, and between the cells and packaging material (e.g., heat sink plates or brackets) have a pronounced impact on dissipation of energy accumulated during the initial impact. We also studied the effect of modifying the impactor velocity by suitable design of module container. The velocity profiles under different initial impact velocities offer the ballistic limit for the pouch cell and its implications for safety at the module or pack level. Controlling the duration of direct interaction between the impactor and the cell boundaries leads to disruptive changes in the residual velocity (and thus subsequent damage of adjacent cells in the module). Mechanical failure of batteries is further complicated by the interplay of multiple physical phenomena. For example, an electrical short circuit across the different cell components follows mechanical failure of the insulating material. The severity of the electrical failure is in turn determined by factors such as the residual velocity of the impactor and duration across which the contact is realized. Depending on the nature of the electrical short circuit, the thermal response of the battery module and the propensity for propagation of thermal events vary considerably. Some parameters such as the thermal mass of the module are critical in controlling the failure event. Other factors such as the far-field boundary conditions and/or ambient temperature have limited impact on the safety of the battery module. The presentation includes detailed case-studies outlining the effect of different parameters for each physical domain (mechanical, electric and thermal) on the safety of the module. We use the 6T module design as the benchmark for our studies. We will discuss implications for selection and orientation of cells for a given module design under extreme loading conditions.

### **Santra, S. • Jiang, L. • Malinovsky, V.S.**

High-rate entanglement generation using real quantum memories.

Secure communication using quantum networks can provide physical-level security over and above that possible classically. For this application one needs high rates of entanglement generation which is a resource to achieve distributed information processing in tasks such as cryptography, communication, interferometry and sensing. However, real quantum memories necessary for quantum networking decohere and reduce the quality of the remote entangled states obtained through swapping. We propose a novel schedule for entanglement swapping which mitigates the effects of real memory decoherence and allows two orders of magnitude increase in long-distance entanglement generation rate using current state-of-art quantum memories. Specifically, our optimized schedule maximizes the rate of generation of distillable entanglement for given network parameters: charging success probability and memory lifetime. In our proposal, swapping occurs within a finite waiting-time window after which the memories are reset to mitigate the decoherence in imperfect quantum memories. We show that such a schedule yields a many-fold increase of distillable entanglement rates as compared to expected entanglement generation

rates particularly for the technologically relevant parameters. We show that the optimal size of the waiting-time window depends on the operating point in parameter space. For a quantum network architecture comprised of many nesting levels our results suggest that an adaptive scheme, where the higher nesting levels swap progressively slower relative to lower levels that swap rapidly, can lead to high rates of long-distance entanglement generation.

**Savage, S. • Foulke, S. • McHenry, R**

Tactical short-range radar for personnel tracking with split brain autoencoders.

**Sharp, M.A. • Canino, M.C. • Cohen, B.S. • Foulis, S.A. • Hauret, K.**

Longitudinal validation of the Occupational Physical Assessment Test (OPAT).

The Occupational Physical Assessment Test (OPAT) is a physical performance test designed to screen recruits readiness for a physically demanding military occupational specialty (MOS). The purpose of this study was to conduct a predictive validation study of the OPAT in Army recruits, which is relevant to human performance optimization and enhancement. If Soldiers are physically prepared for their assigned MOS they are more likely to complete training on-time and less likely to become injured. Pre-employment screening is currently used to select qualified people for physically demanding jobs by the U.S. Air Force, Marines and several NATO nations. Army-wide OPAT testing began in January 2017. The U.S. Army Research Institute of Environmental Medicine (USARIEM) was tasked by the Training and Doctrine Command (TRADOC) to develop a criterion-based physical testing procedure for entry into seven physically demanding combat arms MOSs. TRADOC utilized subject matter experts (SMEs) to compile a list of the most critical physically demanding tasks (PDTs) performed by combat arms Soldiers. These included tasks such as a casualty drag and tactical foot movement. SMEs identified a minimum acceptable performance standard (MAPS) for each PDT. USARIEM then conducted the Physical Demands Study (PDS) that included: 1) a job analysis to identify and measure the physiological requirements of the PDTs; 2) identification of the most demanding PDTs; 3) standardization of criterion measure task simulations (CMTS) of the PDTs; and 4) development and concurrent validation of the OPAT predictor test to screen recruits for combat arms MOSs. TRADOC set cut-scores for each OPAT event. Recruits must meet the cut-score on each event to begin MOS training. Since the standards are based solely on the task requirements, all standards are independent of sex and age. While fully-trained Soldiers were used to develop the OPAT, it is intended for use with recruits. To ensure the OPAT would correctly identify recruits with the potential to perform the physically demanding tasks of their MOS, an additional study was conducted to longitudinally validate the OPAT in recruits. The four-event OPAT test was administered to recruits at the start of initial entry training (IET) and the CMTSs were performed near the end of IET. A total of 1,181 recruits (948 men, 233 women) completed the OPAT within the first two weeks of starting IET and 741 (608 men, 133 women) returned to perform the CMTSs near the end of IET. Men were training for

one of seven combat arms MOSs, while women were recruited from other physically demanding MOSs. The four OPAT tests are the long jump, seated power throw, deadlift, and beep test. The CMTSs were road march, casualty drag, casualty evacuation, sandbag carry, and move under fire, load a Field Artillery ammunition supply vehicle, load a tank, and load the main gun on a tank. Regression analyses were conducted to predict performance on the CMTSs from the four OPAT event scores. Regression analyses resulted in validity coefficients (R<sup>2</sup>) of the OPAT's ability to predict job performance scores of 0.70 for the average job performance score of all seven MOSs combined (p<0.01 for all). Based on a sex-moderated regression analysis for the full sample, there was no significant difference between men and women in the OPAT's ability to predict performance of PDTs (p=0.08). The OPAT scores for recruits who graduated with their class were higher than the scores of recruits who did not. Men scored higher than women on all OPAT events as well as on all CMTSs (p<0.01 for all). The ability to meet the MAPS on the CMTSs ranged from 100% of men and women on the foot march, sandbag carry, and move under fire, to as low as 13% of women loading a Field Artillery ammunition supply vehicle. The OPAT scores needed to qualify for a combat arms MOS were used to determine the number of Soldiers correctly identified as passing or failing the MAPS for the PDTs of their MOS. Correct identification of passing/failing Soldiers was 76% for all MOS groups combined. The four-event OPAT test battery correctly identified 76% of recruits who were able to perform the physically demanding tasks of their combat arms MOS by the end of IET, accounting for over 62% of the variance in CMTS performance. Recruits who pass the OPAT appear to be more physically prepared to begin training and more likely to graduate on-time; thus, the OPAT may reduce the human and financial cost of attrition in IET. This research demonstrates the predictive validity of the OPAT in the population for which it was intended and that the OPAT serves as a practical pre-employment screening tool to optimize and enhance Soldier performance. The views expressed in this abstract are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

**Shaw, A.P.**

A titanium-based igniter system for hand grenade fuzes.

The A-1A and TPP igniter compositions have been used in hand grenade fuzes for many years. However, it has proven challenging to produce or source A-1A of acceptable quality, and TPP contains potassium perchlorate which has been targeted for removal from pyrotechnics by the Department of Defense. In hand grenade fuzes, an input charge is often used to ignite the delay composition. After a period of time the delay composition typically ignites an output charge, causing hot gases, incandescent combustion products, and titanium sparks to be ejected. Conventional pyrotechnic wisdom has called for a nearly-gasless input charge (A-1A) and an explosive output charge (TPP). Surprisingly, we have discovered that a ternary mixture of titanium, manganese dioxide, and polytetrafluoroethylene (PTFE) can fulfill both purposes. Here, the PTFE serves as a gas generator, lubricant, and dry binder. Pressed layers of the new titanium-based igniter possess adequate mechanical strength

and effectively retain delay increments that do not contain any binder. Importantly, as an input charge, the new igniter does not prematurely rupture fuze cases or eject percussion primers. Yet, as an output charge, it produces a brilliant burst of sparks similar to that produced by TPP.

**Sheng, J. • Jalali-Mousavi, M. • White, A.**

Development of flexible wrinkle-free optical stress sensor for studying cell substrate interactions.

With the new era of Army modernization and a Futures Command, there will be increasing reliance on S&Es to deliver innovative and high-impact technologies to prevent the Soldier from fighting with legacy technologies in an evolving battlefield. To meet this challenge at the basic research level, new experimentation technologies can be developed that increase the discovery rate of superior performing materials and systems, while simultaneously increasing that scientific understanding that enables revolutionary advances in performance. The rate of scientific discovery and understanding is limited to the pace of experimental data collection. For most research efforts, data generation is a serial effort of process ? characterize ? analyze ? adjust ? repeat. This slow, methodical approach has been acceptable for academic works when knowledge is the product and a literature publication is the measure of success. However, when the measure of success is winning wars, the rate of obtaining knowledge and making discoveries must outpace our adversaries. Going forward, scientific discovery will accelerate through the automation of high-throughput experimentation capabilities. These capabilities will tend to include four main components: 1) Combinatorial, high-volume processing, 2) High-throughput structure/composition characterization, 3) High-throughput property/performance characterization, and 4) Computational informatics that is used to link parts 1-3 to obtain scientific understanding. These components form the basis for a machine that requires all components to operate with high-throughput to effectively increase the rate of scientific discovery. To that end, automation of- and within these components is essential. A high-throughput experimental approach is a very reasonable opportunity that more laboratories are beginning to embrace. These experimentation technologies begin at the bench level and can quickly result in exceptional, high TRL materials and systems for the PM. Discussed is an example of a high-throughput experimental approach that has recently been demonstrated at the Army Research Laboratory (ARL) to accelerate armor ceramic development. CoorsTek, an industrial manufacturing partner provided high-volume, combinatorial processing of 500+ armor ceramic specimens over a range of processing and ingredient combinations (#1). ARL developed a crucial technology to automate the non-destructive microstructure characterization of the samples by measuring their electrical properties (#2), as well as developed an efficient, information-based ballistic testing method (#3). ARL then applied material informatics algorithms (#4) that determined the key processing parameters which resulted in superior performing microstructures. Validation testing showed that this method can be used to reduce the lot variability and raise the average protection level. This increased minimum level of protection can

alternatively be exchanged for a reduction in weight. Since these discoveries are obtained on a production-level industrial process, the material is ready to be manufactured in high volumes for immediate use. In addition, these technologies are being transitioned to further improve ceramic armor R&D on novel ceramic systems, provide insights into successful microstructure designs and failure mechanisms, and utilized as a tool for quality control of production runs to minimize performance variability. This model shows how automation of high-throughput experimentation made in partnership with industry manufacturing can yield immediate and compelling products from a research effort.

## **Shirley, S.**

### **Finding a cure for amyotrophic lateral sclerosis: identification of crocin derivative as an inhibitor of protein aggregation.**

Amyotrophic Lateral Sclerosis (ALS), characterized by the gradual deterioration of motor neurons throughout the body causes muscle weakness and atrophy. ALS is characterized by aggregation of insoluble protein in affected motor neurons, which contributes to its toxicity and loss of function. Currently, there is no effective treatment to reverse the progression of ALS. Therefore, the aim of this study is to identify a novel compound that can suppress ubiquitous protein aggregation in ALS. Crocin is notable its solubility and anti-proliferative activity in cancer. Mutation in Profilin-1 (PFN1) gene induces ALS and mutant PFN1 protein forms aggregates in ALS neuronal culture and in mouse model. HEK293 cells were transfected with the mutated ALS profilin-1 variant (G118V) and treated with different concentrations of crocin (10  $\mu$ M, 50  $\mu$ M, 100  $\mu$ M). Western blot analysis was then conducted to analyze the expression of insoluble protein aggregates. Crocin treatment reduced insoluble protein concentrations, identifying Crocin as a novel candidate for the treatment of Amyotrophic Lateral Sclerosis. Astrocytes, which are implicated in ALS pathogenesis, are known to exacerbate toxicity would therefore form profilin-1 aggregates. If these aggregates form, then treatment with crocin would be further tested on if it would suppress the level of insoluble protein aggregations. T98G cells differentiated into astrocyte-like morphology were transfected with mutated PFN1 ALS gene. Western blot analysis was then conducted to observe expression of insoluble and soluble protein aggregations. Despite high transfection efficiency, mutated T98G cells did not form insoluble PFN1 proteins in comparison to the wild-type and control.

## **Shivers, B.L. • Brozoski, F.T.**

- **Chancey, V.C.**
- **Estep, P.N.**
- **Madison, A.M.**

### **Preliminary characterization of head-supported mass exposure in a simulated dismounted operating environment.**

Purpose: The aim of the research to be presented is to initiate characterization of the exposures Soldiers experience at the head/helmet during typical dismounted maneuvers. Theme: Helmets serve a vital role in protecting Soldiers in combat and non-combat environments, providing critical blunt impact and ballistic protection as well as serving as a mounting platform for operational capability-enhancing technologies. A cost of protection and operational capability is increased

head-supported mass (HSM), positioned away from the head's center of mass (COM), which has been linked to increased neck pain, acute/chronic cervical spine injury, and performance decrements. As technologies continue to evolve to optimize/enhance operational performance, it is vital that clear guidelines be identified for mass and mass distribution of HSM to mitigate neck pain/injury and optimize operational capability. Existing Army HSM guidelines (U.S. Army Aeromedical Research Laboratory [USAARL] Performance Decrement and Acute Injury Risk Curves) were developed based on aviation helmet systems and injuries sustained in helicopter crashes and vibration exposures inherent to an aviation operating environment. While many of the same conventions can be applied to non-aviation environments, there are clear differences in the functional movements and operational exposures unique to dismounted, ground-mounted, or airborne operations; however, the actual exposures are largely unknown. Commanders, materiel developers, and the medical community established a need for specific guidelines for HSM worn in non-aviation operating environments. USAARL researchers used the Load Effects Assessment Program-Army (LEAP-A) to simulate a dismounted operating environment as part of a multi-faceted research effort to develop dismounted HSM guidelines. Selected kinematic data presented in this abstract will address a crucial first step in guideline development: characterization of the operating environment and exposures incurred at the head. Design/Methodology/Approach: An IRB-approved volunteer study was conducted at Fort Benning, GA using subjects from the Experimental Forces Battalion and TRADOC Soldiers in a non-medical holdover status. Subjects completed the LEAP-A course wearing body armor (rifleman configuration) and simulated HSM configurations. The HSM configurations were outfitted with a six degree of freedom instrumentation package (three linear accelerometers, three angular rate sensors, and an inertia cube) to record the head kinematics during course navigation. Data were synced with video to associate data with specific obstacles. Data were captured at a 2500 Hz sampling frequency. Data are presented for subjects wearing a helmet weighing 2.5 kg with a COM located 4 cm forward of the trignon notch; this HSM configuration is similar to one of the most burdensome currently-fielded dismounted Soldier HSM configurations (helmet with enhanced night vision goggles). Resultant linear helmet accelerations were calculated from the linear accelerometer data collected during two selected obstacles: dive to prone (DtP) and high wall (HW). Findings: Twenty-seven subjects completed testing. Four datasets were excluded due to instrumentation concerns. Data were included for 23 subjects for the HW and DtP obstacles. The mean peak resultant acceleration (Ar) was 5.4 G (range: 1.9 - 9.9 G) for the HW and 2.6 G (range: 1.6 - 5.2 G) for the DtP. Overall, subjects spent an average of 95% (range: 86% - 98.9%) of total obstacle time below 1.5 G Ar for DtP and 97.6 % (range: 95.6% - 99.7%) below 1.5 G for HW. Mean percentage of total obstacle time spent at greater than 50% of an individual's peak Ar was 1.4% for the HW and 14% for DtP. Practical Applications: Characterization of head acceleration exposures is critical to identifying risks unique to the dismounted operating environment. While the majority of the time on each obstacle (>95%) showed an Ar of less than 2 G, there were peak accelerations of nearly 10 G recorded on the HW

and 5 G on the DtP. The data from the selected obstacles show that different maneuvers may result in a wide range of accelerations with varying durations of exposure (1.4% vs 14% time spent above 50% of each individual's peak Ar; DtP and HW, respectively). Guidelines for performance decrement may be more heavily influenced by the more constant exposures; however, guidelines developed to assess acute injury risk should take into consideration the less frequent but more extreme exposures. Original Value: Lack of operating environment characterization was identified as the number one research gap during a HSM Expert Panel Working Group in 2016. This preliminary analysis is the first step toward an inclusive characterization of the operational exposures our dismounted Soldiers are experiencing at the head and the role HSM plays in mission capability, performance, and Soldier health.

## **Shurin, S.**

### **Challenges in military ground vehicle cooling system design and computational fluid dynamics analysis of a notional ground combat vehicle cooling system.**

The operating environment, mobility requirements, and survivability requirements imposed on military ground vehicles present a significant challenge in cooling system design. Military ground vehicles are required to operate at high tractive effort mobility conditions in hot, dusty environments while providing sufficient ballistic protection. The mobility requirements result in designs with high horsepower engines and correspondingly large cooling loads. Providing sufficient cooling at high ambient temperatures requires large air mass flow rates. Ballistic grilles, designed to meet survivability requirements, increase resistance to air flow. Because of these factors, the cooling systems on military ground vehicles can consume a large percentage of engine power and vehicle volume. Often, the mobility performance of military ground vehicles is limited by the ability of the vehicle thermal management system to provide sufficient cooling. The requirements for increased electrical power generation, vehicle electrification, and fuel efficiency in the next generation of combat vehicles significantly increases the challenges and complexity of cooling system design. This study provides some insights into the challenges in military ground vehicle cooling system design. Additionally, the methods, results, and design insights gained from a Computational Fluid Dynamics (CFD) study of the cooling system for a notional ground combat vehicle are presented. Because of the large flow rate of cooling air and large pressure rise, the fan power required for cooling can be greater than 20% of the available engine power. This power, sometimes referred to as a parasitic load, reduces the power available to move the vehicle or perform other functions and increases fuel consumption. Thus, optimizing the cooling system to reduce fan power consumption is important. Computational Fluid Dynamics (CFD), is an important tool to aid the cooling system design engineer. A summary of such an analysis for the cooling system on a notional ground combat vehicle is described below. For the vehicle and operating condition considered in the study, the transmission and engine heat rejection is 59% of the rated engine power. Power electronics cooling is about 3% of the engine power, and the climate control system heat rejection is about 4% of the engine

power. The CFD model of the cooling system included multiple liquid to air heat exchangers: 2 condensers, electronics cooler, fuel cooler, engine oil cooler, transmission oil cooler, and a radiator (engine coolant to air cooler). All heat exchangers were represented using a porous media (pressure drop versus air velocity) approach. The inlet ballistic grilles were also modeled using porous media. The actual geometry of the exit ballistic grilles was modeled due to the complexity of the design and mixing of exhaust in the exit area. The effects of induction air flow, scavenge air flow (required for induction air filtration), and engine exhaust were included in the analysis. The results for this design at the specified operating condition show that ideal fan power (not including aerodynamic or motor losses) required to provide cooling is 8% of the maximum rated engine power. Assuming typical aerodynamic and drive losses, the power required at the engine is 11% of maximum rated power. Breaking down the system in terms of power required to move the air through various regions shows that 46% of the fan power is consumed in moving the air from the fan exits, through the exit grilles, and expanding to the ambient pressure. Approximately 31% of the fan power is consumed by moving the air through the cooling pack. The results show that, for this system, design effort would be best spent on the fan exit side of the air flow paths. Ideally the majority of the power should be spent moving the air through the cooling pack, since the main function is to provide cooling.

**Siopsis, G. • Lawrie, B.J.  
• Pooser, R.C.**

#### Quantum-secured communications over an optical network.

Photon-based qubits have a huge potential to scale for quantum processing for applications in sensing and secure communications. They are also the best candidate for interfacing with a quantum-secured communication network as there are no alternatives to optical-frequency photons for reliable long-range carriers of quantum information, and no optical-microwave interconversion would be necessary if all the quantum processing and communications were in the optical domain. Despite this huge scaling potential, photonic qubits have not been as popular in the larger research community as trapped ion and superconducting qubit technologies, since non-linear quantum interactions are hard to realize in the photonic domain. Recent work and new insights suggest that photonic quantum processing may be not only well within reach -- using continuous-variable-entangled clusters of 100s of thousands of modes that have been experimentally demonstrated, along with the necessary 'de-Gaussification' step facilitated by photon number subtraction induced by photon-number-resolving detection -- but also can outperform and out-scale competing qubit technologies with a sustained effort over the next few years. A photon-based quantum-capable processor would be valuable for building non-classical receivers for optical communications and sensing, which could far outperform conventional systems -- a subject matter that was studied in great detail by some of our collaborators in DARPA's InPho program. We have expertise in continuous-variable quantum optics. We have proposed an implementation of the non-Gaussian cubic phase gate [K. Marshall, R. Pooser, G. Siopsis, and C. Weedbrook, Phys. Rev. A 91, 032321 (2015)],

and developed continuous-variable quantum algorithms for various applications (quantum field theory [K. Marshall, R. Pooser, G. Siopsis, and C. Weedbrook, Phys. Rev. A 92, 063825 (2015); K. Yeter-Aydeniz and G. Siopsis, Phys. Rev. D 97, 036004 (2018)], machine learning [H.-K. Lau, R. Pooser, G. Siopsis, and C. Weedbrook, Phys. Rev. Lett. 118, 080501 (2017); S. Das, G. Siopsis, and C. Weedbrook, Phys. Rev. A 97, 022315 (2018); G. Siopsis, arXiv:1804.01558 (2018)], etc.). We have recently investigated fundamental limits of covert quantum communications [K. Bradler, T. Kalajdziewski, G. Siopsis, and C. Weedbrook, arXiv:1607.05916 [quant-ph] (2016); K. Bradler, G. Siopsis, and A. Wozniakowski, arXiv:1704.07281 [quant-ph] (2017)]. We have also been working on measurement-device-independent quantum key distribution (MDI QKD) in free space [B. Qi, H.-K. Lo, C. C.-W. Lim, G. Siopsis, E. A. Chitambar, R. Pooser, P. G. Evans, and W. Grice, 2015 IEEE International Conference on Space Optical Systems and Applications (ICSOS), New Orleans, LA, 1 (2015)], and quantum position verification [B. Qi and G. Siopsis, Phys. Rev. A. 91, 042337 (2015); C. C. W. Lim, F. Xu, G. Siopsis, E. A. Chitambar, P. G. Evans, and B. Qi, Phys. Rev. A 94, 032315 (2016); S. Das and G. Siopsis, arXiv:1711.03392 [quant-ph] (2017)] in the quantum information sciences program of the Office of Naval Research. We envision designing an all-optical quantum secure cloud network with continuous-variable (CV) fault-tolerant quantum processors interspersed at nodes, connected via a network of CV all-photonic quantum repeaters. This network will enable long-distance entanglement generation at high rates, quantum secured communications and various other multi-party privacy preserving protocols with unconditional security. In addition, it will provide other quantum-enabled security features -- such as provably covert and anti-spoof communications, and intrusion detection -- whose security relies on the laws of physics as opposed to our perceived hardness of certain mathematical problems. The ultimate goal is that this quantum network will facilitate long-distance entanglement generation, which will enable provably covert access for distributed blind quantum computing (i.e., users submitting private quantum computing jobs on the cloud) and various quantum-secure multi-party distribution communication and computing protocols. The goal of the proposed program is to investigate, identify, and demonstrate key primitive components of the above network, in a close-knit theoretical-experimental effort. The long-term program objective will have strong involvement from theoretical and experimental standpoints. This is a massively challenging problem, and requires a strong collaboration with other research teams in physics, optics, materials, and engineering with relevant expertise. Part of the goal is to develop such collaborations.

#### **Soto, N.**

Soldier-borne power generation in tier 1 environments.

**Spero, E. • Beals, N.E. • Gerdes, J.W.  
• Humann, J.D.**

On-demand small unmanned aircraft systems. The US Army seeks modernization by turning ideas into actions through continuous user feedback and prototyping, thereby preventing further erosion of the comparative US Military advantage. This strategy relies on incorporating

requirements from Warfighters, who are being asked to make decisions at lower levels in a joint operations area that is rapidly evolving and increasingly complex. Small unmanned aircraft systems (UAS) can facilitate this level of decentralized decision-making by assisting in operations that rapidly develop situational understanding. However, traditional Military Group 1 UAS (e.g., Raven, Puma, Wasp) are incompatible with this vision as one-size-fits-all designs built on aging technology that are slow to acquire and expensive to operate and maintain. The incompatibility between UAS solutions currently available to the Warfighter and the increasing pace of operational demand can be addressed through a merging of small UAS and advanced manufacturing to rapidly generate a purpose-built small UAS for a specific mission. The proliferation of forward-deployed advanced manufacturing enables a new acquisition strategy that relies on manufacturing at the point of need and prototyping of Warfighter ideas. Previous, comparable research efforts have innovatively applied 3-D printing to reduce manufacturing time and cost for small UAS performing a predetermined flight profile. These projects designed small UAS which can be copied many times via 3-D printing manufacturing techniques. Our approach is unique, in that it integrates research in engineering design processes, manufacturing capability, materials, and available components together with requirements for vehicle performance and effectiveness in order to drive the design of a mission-tailored asset through an interactive decision support system. In this way, we harness the strengths of 3-D printing in the design process to drive toward UAS designs that meet missions which are not known a priori. Innovatively combining these technologies into an organic, integrated design and manufacturing process bypasses long and expensive acquisition cycles, and avoids part obsolescence through a modifiable and updatable library of components. With this approach we demonstrate in a relevant environment the design, print, and assembly of representative UAS within 24 hours. Interactions with Soldiers and Marines that use Group 1 UAS routinely in infantry operations revealed a mismatch between existing vehicle capabilities and emerging mission needs. This feedback has directly informed the integrated design and manufacturing research as well as specific feature updates of a scalable small UAS research platform, including reduced overall part count, snap-in arms, standardized interfaces, and visual assembly aids. We present current status as well as future research directions in multi-agent modeling and simulation, human-systems integration, power and energy, materials and manufacturing, and interactive exploration of the small UAS capability space.

#### **Spoenlein, S.**

Network/C3I Army modernization priority. Network/C3I is the Army's #4 modernization priority area. Network/C3I provides the "Eyes, Ears, and Voice" to enable the Army's fundamentals of Move, Shoot, and Communicate to support of all the Modernization Priorities. Significant adjustments to the S&T strategy have been made over the past 12 months as a result given focus on near peer threat. This talk will review the updated Network/C3I S&T vision and investment strategy as tied to the CFTs.

## Stead, M. • Zhou, W.

**Photonic broadband spectral analysis of a single, sub-microsecond RF pulse in W-band.**  
The purpose of this work is to demonstrate an RF-photonic analog auto-correlation system capable of performing broadband spectral analysis of a single, sub-microsecond, RF signal sample over most or all of the W-band (75-110 GHz) with finer than 50 MHz resolution. Modernizing the army's networked hardware, software and infrastructure for C4ISR and maintaining electromagnetic spectrum dominance is high priority for the army. Recently, there has been a proliferation of RF microwave technology for high frequency, ultra-wideband frequency hopping, and short pulse applications. We developed this new technology which, combined with our previous works, has the potential to provide the soldier with complete information of what RF-frequencies are being used for communications and radar in future contested environment up to 100 GHz with fast frequency hopping which may be employed by future adversary systems. The system relies on our patented unique technology of using a photonic recirculation loop to perform analog time-domain autocorrelation of an optical pulse, modulated by an RF input signal and performing a Fourier transformation on the auto-correlated products to obtain the frequency spectrum. The advantage of this method is that, it can catch an ultrashort RF pulse, shift it to the optical domain for live correlation, thereby providing an "instant picture" of the RF signal pulse in the frequency domain. Due to the technical challenge of directly converting 100GHz modulated light to a W-band RF signal, we developed an optical down-conversion scheme to shift the RF range. The detected RF signal of interest in the W-band is used to modulate a sub-microsecond optical (1550 nm) pulse, creating a pair of optical sidebands. In addition, a 60 GHz reference signal is used to modulate the same optical carrier, again producing optical sidebands, but of a known wavelength. The reference and signal pulses are combined into one pulse, and the optical carrier is removed with a narrow band filter, leaving only the signal and reference sidebands. That pulse is fed into a pulse-replicating fiber optic loop, with a small percentage of the light being tapped out with each loop transit and with loop losses being replaced through optical amplification. The optical sidebands experience slightly different travel times due to dispersion in the fiber, creating progressively larger time differentials between the sidebands in the replicated pulses. When the optical sidebands are mixed in a photodetector, they reproduce 2 copies of the original RF signal, down-converted by 60 GHz, with progressively larger phase differentials in each replicated RF pulse pair. When the RF replica pairs are mixed in a square law detector, they produce a low frequency signal with an amplitude dependent upon the phase differential which is linearly related to the number of times the optical signal transited the loop before being tapped out. This is an auto-correlation, which can be Fourier transformed to extract the spectrum of the RF signal of interest. In prior work, we demonstrated single pulse spectral analysis up to 65 GHz with 50 MHz resolution. In this work we extend that range to at least 90 GHz (and potentially 100 GHz) while maintaining 50 MHz resolution. The total time for pulse replication and a Fourier transform produced by an FPGA would be as low as 10s of milliseconds. This allows for a rapid update of spectral information and a comparison of new

spectra to old so that a user may determine what is background and what is a signal of interest. The broad band, resolution and rapid updating capability make the system practical for rapid identification of new signals of interest for other systems. It could be used to target a super-heterodyne system on a relevant signal to obtain even higher resolution information, to track a frequency hopping communication, or to identify multiple frequencies used in spread spectrum communications. Current systems which rely on large, bulky mixing architectures to cover broad ranges could be replaced by a single relatively small and inexpensive system.

## Surdu, J.R.

### Embedding simulation into mission command systems.

Multi-domain battle requires Mission Command staff processes that analyze all domains to find the opportunities in time and space to generate overmatch, present multiple dilemmas to the enemy, and enable joint force freedom of movement and action. Multi-domain battle requires multi-domain situational understanding. Future adversaries will employ sophisticated operations, to include Army Airspace and cross-domain Air Defense capabilities on physical, electromagnetic, cyber, and human terrain of their choosing. Adversaries will challenge the air, space, cyberspace, and electromagnetic spectrum supremacy the U.S. enjoyed in recent decades. Conversations with Mission Command Center of Excellence personnel and recent statements by the Chief of Staff, Army, indicate that years of directed COAs have eroded staff officer skills relating to the Military Decision-Making Process. In particular the process of developing several courses of action and wargaming them to determine the best one to develop into the mission plan is seldom executed. We address this problem by: Integrating simulation into mission command systems to speed COA analysis and comparison; Using simulation provides rigor to the process over the manual action-reaction-counteraction method; This will speed decision making while enabling the staff to consider several COAs, and The simulation we have used in our proof of principle solution is inherently multi-domain so that the commander can explore different options for creating dilemmas for our adversaries. The idea of using simulation to facilitate mission command is not new (1). The DARPA Deep Green program had at its heart the use of integrated simulation to enable the twin concepts of anticipatory planning and adaptive execution (2). Previous efforts have not provided a full integration of simulation into mission command systems. Instead gateways and translators, such as the Mission Command Adapter Web Service (MCA-WS) have enabled simulations to generate messages that stimulate mission command systems and enable mission command systems to pass specified commands to the simulation entities, such as call for fire messages. This has allowed the training audience to train using their go-to-war mission command systems, but they still require a large amount of overhead to operate the simulations. Through these efforts, the simulation community has learned a great deal about how mission command systems work, but they have fallen short of full integration within a mission command system. Full integration means that the simulation is a fully-embedded component that requires little or no additional downloads, installations,

operators, or training. It is a seamless part of the mission command system. In fact, when fully integrated, which simulation system is used should be completely transparent to the user. Full integration also means the absence (or perceived absence) of intermediate representations, scenario files, or other artifacts. The simulation system should draw its data (e.g., order of battle and plans) from the mission command system's data store. Results of the simulation should likewise be reposed in the mission command system's data store. In late 2016 Cole Engineering Services, Inc. (CESI) recognized the value of SitaWare as a platform for an embedded simulation capability. This was a year before the Army signed a contract with Systematic for an Army-wide site license for SitaWare Headquarters and Frontline products to form the foundation for the Common Operating Environment (COE) version 3 (COEv3) Mission Command Information System (MCIS) and Mounted Mission Command (MMC) systems currently under development by Product Manager Mission Command (PdM MC). CESI used a combination of seed money from the OneSAF program, internal research and development funding, and limited engineering support (less than 25 hours) from Systematic to integrate OneSAF and the Marine Air Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS) into the SitaWare Headquarters product. We have recently demonstrated this capability at I/ITSEC 2017 and to MG Mingus, Director Mission Command Center of Excellence, and LTC Daiyaan, PdM MC, and the response has been universally enthusiastic. The initial proof-of-principle integration was completed in less than 90 days between December 2016 and February 2017. Since then, CESI has used IRAD funding to enhance the capability.

## Szedlmayer, M. • Clerkin, P.J. • Kim, K.S. • Kruger, K.M. • Kweon, C.M.

### Adverse effects of altitude and fuel properties on UAV propulsion.

Some diesel engines used in midsize and larger unmanned aerial vehicles are adapted from the automotive industry and not specifically engineered for flight applications. This has led to reliability issues in the field. The major factors leading to decreased reliability stem from the altitudes that the engines are operated at, and the fuel supplied to the engines. At high altitude, the density and temperature of the air is drastically reduced, which leads to delays in ignition of the fuel inside the engine's cylinders. Additionally, the low air density forces the turbochargers on the engines to run at much higher speeds than they would in automotive applications, increasing their risk of failure if the effect of altitude is not considered during turbocharger selection. Combined with these issues is the variability in fuel properties of the standard military JP-8 and F-24 fuels. Unlike the diesel fuel for which these engines were designed, the properties of jet fuel can vary widely, even when the fuel batch meets Army certification requirements. Particular issues result from low cetane number, a measure of ignition quality. Low ignition quality fuel is shown to have an additive effect with the cold and low pressure conditions of high altitude, resulting in severely delayed ignition. Fuel lubricity and thermal stability may also be problematic for some components such as high pressure fuel injection pumps and/or proper fuel delivery in general. The purpose of this research is to quantify how these adverse conditions impact engine operation, and

develop means to offset losses in performance. Experiments were designed to measure performance and combustion characteristics for a direct-injection turbocharged multi-cylinder diesel engine. The engine was operated at a number of altitudes from sea level to 25,000 feet (7620 m), with outside air temperatures as low as -40 °F (-40°C). The engine was fueled with five different specialty fuel blends which match the certification requirements of F-24 jet fuel. Each fuel has a specified cetane number, of 35 or 40, and aromatic content of 4, 14, or 24%. Findings are presented in terms of the maximum in-cylinder pressure rise rate (MPRR), and the coefficient of variation of the indicated mean effective pressure (IMEP COV). High MPRR values, which were found for low cetane, high altitude conditions, indicate that combustion is occurring too rapidly in the cylinders, resembling detonation, and can potentially damage the cylinders and cause the engine to seize. High IMEP COV, found for low engine power settings, indicates that combustion is occurring erratically, and not producing a consistent power level. Such conditions can lead to "flame-out," where the combustion ceases, and the engine produces no power. The recommended approach to solve such issues is to recalibrate the engine's fueling parameters using a systematic approach that accounts for fuel properties variation. Alternatively, the engine's ability to detect the properties of the onboard fuel can be improved so that it the engine can take corrective action. Such technology has significant value for practical application, as it can greatly improve the reliability of UAV systems already in the field, as well as future systems which may need to operate on an even wider array of fuels. Through advances in the reliability of UAV systems, we can expect to empower the success of all soldiers in their Army mission. This study was performed using the Small Engine Altitude Research Facility, which is part of the new Center for Unmanned Propulsion (CUP) at the US Army Research Laboratory. It is the first comprehensive work on the combined effects of altitude and fuel properties on diesel engines, and represents a highly original contribution to the engine research and development field. The effort detailed here represents a broad collaboration across the Army, from the Army Research Laboratory, the Aviation and Missile Research, Development, and Engineering Center, and the Unmanned Aerial Systems Projection Management Office.

### Tang, X.

#### The development of an energy recycling system consisting of a thermal-electric generator and a thin film luminescent solar concentrator.

Technological advancements in the applications and usage of renewable energy resources are one of the best options available for the reduction of carbon emissions while maintaining the usage of energy. It is known that most of the naturally-existing energy resources, such as solar and thermal energy, are unused. Using these energy sources can increase energy security and dependence as well as energy mobility. However, narrow range of applications and high monetary costs were known to be barriers which prevent the effective usage of these unmined energy resources. The purpose of this project, a novel development of an energy recycling system, was to undermine these barriers, recycle unused energy, and make solar and thermal energy resources more accessible to military and civilian everyday appliances. This system contained two

parts. Utilizing the properties of total internal reflections (TIR), part 1 of this system was created using cost-efficient synthesized, size-controlled, and ultraviolet (UV) wavelength corresponding acrylic glass sheet with UV solar cells placed around its edges. A spectrophotometer was then used to test its ability to capture and transform UV radiation (280 nm <  $\lambda$  < 365 nm) into usable electricity while maintaining transparency to the rest of the visible spectrum. Using the Peltier effect, part 2 of this system was able to transform temperature difference across both sides of its semiconductors into electricity. Using a cell phone, a sample chosen from everyday electronic appliances, the presence of this system caused a significant increase ( $p < 0.05$ ) in runtime compared to controls without this system. In conclusion, this system was able to break the known barriers and effectively mine unused thermal and solar energy resources with the advantages of wide variety of applications\*, visual transparency, low cost, and low requirements for land area. Applications of the system includes: any glass surfaces in contact with sunlight (windows, mobile electronic devices, smart glasses, etc.); any surfaces with temperature differences (mobile electronic devices, handheld lighting devices, vehicle engines, etc.).

### Tatoian, J.

#### A compact modular high-power microwave system for air missile defense, immobilization of vehicles, boats, and ground surface and buried explosive hazards neutralization.

During 2002-2010, Eureka has been developing and testing many spark-gap-based HPMS, where microwave energy was used to disable and/or damage the electronic control module (ECM) that controls vital engine functions in boats and vehicles. The original four HPM systems built and tested by Eureka utilized spark-gap switches in the flat-plate and coaxial Blumlein architecture; the work was sponsored by MARCORSYSCOM, OSD, NIJ, and JNLWD. While these systems clearly demonstrated that vehicle engines can be stopped by a single 30-50ns long, peak power microwave pulse at field levels in 10-60 kV/m range (and even less for boat engines), they also have many serious drawbacks, which present serious impediments for building operationally and commercially viable systems. Most drawbacks are associated with the operation of spark-gap switches, problematic nature of which include: (1) the necessity to use oil or pressurization chambers to hold off large voltages, (2) unreliability, (3) non-repeatable performance, (4) difficulties in achieving multi-frequency operation (tuning), and (5) large jitter in multi-switch environments. Moreover, microwave sources that utilize spark-gap switches tend to be bulky and heavy and, generally speaking, not well suited for applications where compact lightweight systems are desirable. In recent years, Eureka's effort is focused on the development of tunable and compact HPMSs-electromagnetic guns-utilizing precisely controlled Gallium Arsenide (GaAs) PCSSs, which will significantly enhance the state-of-the-art of existing microwave sources by reducing the size and weight of high power systems by an order of magnitude. The approach utilizes a novel Integrated Blumlein Antenna (IBA) microwave source architecture. The technology presently limiting the implementation of the IBA systems is the availability of compact,

high-power, fast semiconductor switching. PCSSs have a great potential to overcome the limitations associated with spark-gap switches currently used in pulse-power microwave sources, specifically the requirement for very high voltages and very fast charging circuits necessary to obtain switch closure in low inductance and small transition times. In such an IBA array system, the microwave source is integrated into the antenna structure and the radiated power at the output face of the aperture or antenna is limited only by the breakdown strength of the environment around the antenna. The integration of the high-power pulse source in the antenna is made possible by utilization of PCSSs, that handle high voltage and close with sub-ns resistive transition, sub-nanoheny (nH) inductance and picosecond (ps) resolution. Moreover, the system utilizes switch-trigger laser integration within the same chip; likely candidates include vertical cavity surface emitting lasers (VCSELs). The building block of IBA array is an individual PCSS-based Blumlein module capable of handling more than 30kV hold-off voltage and yielding fast (<350ps) closure times. The ultimate target system is tunable in the 200-1350MHz range, and the modular design provides the flexibility of employing as many modules as needed to achieve the desired field strength at the required range. As an illustrative example, a 1m×1m×0.1m full-scale IBA array at L-band will generate electric fields in excess of 150kV/m at 100m range, Integration of photoconductive switches makes the modules significantly more robust and further reduce weight and size of the system. The current Eureka's effort culminates in field testing and demonstration of an M×N Integrated Blumlein Antenna (IBA) array aperture at power levels limited only by the breakdown of the antenna environment. Finally, the modularity of the architecture permits integrating the apertures as large as needed to achieve a desired range The IBA array system can be used in vehicle-portable and human-portable or as a stationary ground-based microwave delivery systems. Specific benefits of the game-changing PCSS use in the IBA architecture are: 1) reduction of size and weight, 2) increase in PRF and pulsewidth and thus increase in average power 3) improvement in system's radiated waveform (increasing parameter Q), 4) increase in effective operational range, and 5) increase in peak power radiated. Successful completion of the PCSS-based IBA array system currently under the development at Eureka's microwave lab will lead to design and fabrication of very efficient, tunable, and compact HPMS, which will significantly exceed the performance of existing state of the art. Specifically, the effort will lead to reduction of weight and size and increase in operational range, thus making IBA-based HPMSs efficient and practical. Tapping into this technology will further improve the capabilities of the directed energy technologies for a variety of DoD and Law-enforcement applications including air and missile defense, nonlethal area denial for ground and airborne targets, vehicle/boat immobilization, and IED neutralization.

### Ter-Gabrielyan, N.

#### Crystalline waveguide lasers for directed energy applications.

ARL has long been supporting the research and development of scalable laser technologies for Directed Energy (DE) applications for use in Air and Missile Defense (AMD). The ultimate goal of the effort is to identify a technology which will

mitigate thermal and non-linear effects in High Power/ High Energy lasers in order to achieve higher output per single DE aperture to reduce the SWaP of future High Energy Laser Platforms. Traditional, fiber lasers based on "glass core/ glass cladding" structures are approaching power limits for single mode operation imposed by surface damage threshold, thermal- and non-linear effects in the fiber core as well as numerous other factors. One way to increase their power scalability is to use Large-Mode-Diameter fibers (and Photonic Crystal fibers) which was recently successfully implemented to yield more than 2 kW of diffraction-limited, single mode output. However, further power scaling to tens of kilowatts of power relies on various beam combining techniques, coherent or incoherent, which require single-mode, narrow-bandwidth output of every laser channel. As a result, reducing the number of combined channels remains a priority for managing system complexity. Since Rare Earth (RE)-doped crystalline materials have significant advantage over glass in mechanical, thermal and spectroscopic properties, crystalline fibers and waveguides (WGs) hold very high power scaling potential. Higher thermal conductivity and stronger laser transition allow to achieve even higher output powers per single aperture. The advantages of fully crystalline fibers become even stronger in the longer wavelength range around 1.6 micrometers – an important atmospheric transmission "window" – where Erbium-doped materials operate in the low quantum defect, 3-level, resonantly pumping laser schemes. Erbium is known to demonstrate strong, energy transfer up-conversion which significantly restrict its doping concentration on the one hand and serves as additional heat source on the other. Thus, weakness of the absorption and luminescent transition cannot be compensated by increased Erbium content, as can be done in Ytterbium-doped media. This drawback limits the output power of the traditional bulk crystalline laser media which should be kept short to maintain spatial overlap between the low-brightness pump emission and high brightness laser cavity mode. Both fully crystalline, double-clad fibers and planar waveguides (PWGs) provide adequate pump confinement over the significantly longer optical paths and, in addition, the rectangular geometry of the PWG accommodates direct pumping with laser diode stacks, optimizing pump utilization. The latter directly affects overall laser performance since InGaAs/InP pump diodes (for resonant pumping of Erbium around 15xx nm wavelength) are not as efficient as InGaAs/GaAs diodes (9xx nm) for pumping Yb lasers. With Er:YAG as a waveguide core, one can manipulate the Numerical Aperture (NA) of the core/cladding structure by having cladding made of YAG, doped with other RE ions to adjust its index of refraction. We demonstrated a fully crystalline, double clad Yb(1%):YAG/Er(1%):YAG/Yb(1%):YAG planar waveguide laser with the core NA of 0.013 and clad NA of 0.46 for pumping with a diode bar stack. This was the first demonstration of the Er-doped laser WG. The laser yielded an output of 75 W at 1645 nm with a slope efficiency of 64% with respect to the absorbed pump power at 1532 nm. The development of fully crystalline waveguides is significant for achieving High Energy lasing in Q-switch regimes that the existing glass fiber laser technology was not able to deliver. We also demonstrated the first fully crystalline double clad Yb:YAG/YAG fiber laser with the slope efficiency of 75%. The Yb:YAG core was grown using Laser Heated Pedestal Growth

method, while the cladding was manufactured with Liquid Phase Epitaxy growth. Currently, we identify this technology as the most promising and cost effective way to advance crystalline waveguide lasers for DE applications for AMD. However, other, relatively novel methods, like femtosecond laser inscription or polycrystalline laser development with gradient doping should be considered as well.

### Thompson, A.

#### Deep learning application for radio frequency data.

This talk seeks to give an overview about deep learning applied to general RF data and will be structured in three parts: 1. RF Environment Overview: Challenges and Advantages: Provides background into the nature of radio frequency data: how it's collected and manipulated including general pros and cons of the space. Wireless transmissions occur at various power levels and are susceptible to interference, multi-path, jamming, and spoofing, among others. On the other hand, there's generally an infinite amount of available training data and labeling can be assisted with classical signal processing detection techniques. 2. Motivation and Use Cases along with supporting examples: We will discuss the applications of deep learning to solving common threats, particularly in the defense community. With success on signal classification, one can design threat detection systems targeting specific signal-types in addition to nefarious actions like GPS jamming or spoofing. For existing RF applications featuring classical signal processing detection algorithms with a high false alarm rate, we can stress that even if deep learning can't provide adequate classification results, it can limit the overall amount of relevant data needed for further processing. 3. Deep Learning Techniques with RF Data: Digital RF is usually made up of complex (I/Q) data that is sampled at a given rate and filtered and tuned to a specific frequency. Deep learning has been applied to this raw form by Tim O'Shea and Nathan West of Virginia Tech in their attempt to classify digital modulation schemes. This approach differs from that done by KickPavel Intelligent Processing Applications in their signal processing deep learning lab taught by NVIDIA's Deep Learning Institute where RF data is converted to the spectral domain (a time vs frequency image) and classified using standard CNN models. Further, Synthetic Aperture Radar (SAR) imagery is typically presented as a two-channel magnitude and phase image. A presentation of classification results using standard CNN networks (AlexNet, VGG, etc) will be presented using these three different input forms. Extending beyond classification, researchers can use object detection and semantic segmentation deep learning techniques to identify specific time and frequency locations of signals of interest. Knowing a transmission's position in the time/frequency domain can assist in tuning, geolocation, noise mitigation, and feature extraction – to name a few. Major take-aways: 1. Deep learning on RF can enable threat detection resulting in safer communities; 2. For legacy applications with traditional signal processing, deep learning can be used to, at a minimum, reduce the false alarm rate; 3. There are many areas of active research including input data domain format, customized models exploiting RF characteristics, and burst location via object detection and semantic segmentation techniques.

### Tobias, A.V. • Schwalm III, N.D. • Sund, C.J.

#### Genetic tools and synthetic biology "parts" for *Clostridium acetobutylicum*, a microbe of military interest.

The military environment requires specialized durability and functionality of equipment. The Biotechnology Branch has begun to explore and evaluate the ability of synthetic biology to contribute to the unique materials and mobile energy needs of the future soldier. The most commonly studied chassis organisms in synthetic biology are unable to survive outside the laboratory, let alone in extreme environments. The anaerobic soil bacterium *Clostridium acetobutylicum* forms highly stable, temperature-resistant spores and rapidly converts a wide variety of naturally-occurring carbohydrates to commodity/specialty chemicals. These attributes have inspired our interest in engineering this microbe into a worthwhile chassis organism for military applications. With increased ability to control the behavior and metabolism of *C. acetobutylicum* through synthetic biology techniques, we could utilize the bacterium to produce other small molecules (e.g. monomers, fuels) of military interest, as well as create "living materials" incorporating its cells. One embodiment of the latter would be films or fibers embedded with catalytic *Clostridium* spores displaying enzymes of our choosing on their surfaces for filtration or detoxification applications. Manipulation of *C. acetobutylicum* has been hindered by the difficulty of introducing DNA and a dearth of synthetic biology "parts" that function in the organism. We describe our efforts as part of the Synthetic Biology Applied Research for the Advancement of Science & Technology Priorities (ARAP) to genetically manipulate *C. acetobutylicum* and endow it with novel sense-and-respond functionalities via development of a tailored synthetic biology toolkit. We have implemented a system for more efficient introduction of DNA to *C. acetobutylicum*, allowing for the deletion of undesired sequences and insertion of synthetic pathways into the chromosome. We have tested multiple synthetic control mechanisms responsive to small molecules or light to activate expression of particular proteins (and thus, chemical production in future strains) only when triggered. Additionally, we have increased the number of functional reporters (fluorescent proteins or easily-assayed enzymes) in *C. acetobutylicum* to enable visual confirmation of the "on" or "off" state of genetic programs. Our presentation will detail the specific technical approaches we have undertaken and the results we have achieved toward the development of genetic and synthetic biology tools for *C. acetobutylicum* for the greater goal of increasing soldier lethality by providing expeditionary sources of energy and tailor-made living materials.

### Tomac, M. • Salavani, R.

#### Photovoltaic/Thermal (PV/T) energy addition to expeditionary buildings.

Purpose - The DoD has a goal of reducing field consumption of fossil fuels in order to improve energy efficiency and operational resiliency. One cost-effective solution is to provide field assets that can operate independent of the power grid by harnessing renewable energy. Photovoltaic (PV) energy, for example, has been investigated as an option for integration with existing expeditionary



structures to increase resiliency and produce energy at the demand point, yet deployment of assets that incorporate renewable energy options has not been widely adopted in the field. Few fully commercialized PV technologies are suited to meet operational use in military environments, the majority of high efficiency commercialized panels are monocrystalline PV, and only ~11% to 19.5% efficient. When solar radiation strikes the surface of the panel, most is absorbed as heat, some reflected, and some absorbed and output as electric power in the cells. After the module temperature is raised, the heat is either radiated back into the environment or ejected to the surroundings predominately by convective heat transfer. Fluid, such as air or water, can be used to capture the excess heat escaping the backside of the panel, which would increase the amount of energy that could potentially be gained from the panel area. This is known as a photovoltaic/thermal (PV/T) panel; the heat removal from the panel, results in an increase in the amount of energy captured. In fact, studies have shown that PV/T-a (air) can be up to 55% efficient and PV/T-w (water) up to 75% efficient at extracting solar energy as heat. The technology presented provides potential for retrofit of expeditionary buildings exclusively with PV/T that allows operation "off-grid". Design/ Methodology/Approach - The capabilities, operating characteristics, and overall power gain of the PV/T configuration was examined during studies at AFCEC test site, Tyndall Air Force Base, FL and results will be presented. The system's performance was examined under varying operating scenarios to assess electrical and thermal performance. An AFCEC team constructed steel buildings (known as K-Spans) as test structures for evaluation of the PV/T hybrid technology. Overall energy efficiency was determined with respect to electrical capacity, electrical storage, and operating utility. For proof of concept, two operating scenarios were investigated; 1) PV and PV/T were demonstrated as a retrofit to a containerized latrine, 2) PV and PV/T panels were attached to semi-permanent K-Span structures, constructed from curved metal sheets with raised standing seams. Varying flowrates were used to investigate the trade-off between heated water and higher electrical efficiency. Similarly, control algorithms were used to control the flow and output water temperatures compared to a non-controlled baseline unit. Findings - A standard military portable (containerized) latrine unit was retrofitted with PV/T hybrid panels that generate hot water and electricity. Potable water is the only required input. The installed electrical production capacity totaled 2.475 kW with an associated battery bank (44 kWh). The PV/T added 6.0 kW of additional potential thermal energy depending upon variation in the panel flow rates and PV/T configuration. Similarly, addition of PV/T to a K-Span, or similar structure, offers a unique opportunity to harness energy by retrofitting an established structure. The resulting array can continuously produce over 1.0 kW electrical power for >7 hrs. with a power output that is scalable. The array can be attached to a semicircular building, although the flat panels resulted in a decrease in efficiency (as low as 78%) due to the non-optimal angle of incidence at this latitude. Adding a tilt or use in more equatorial latitudes would likely provide greater efficiency. Overall, PV/T tripled the amount of energy captured compared to PV alone. These results show that PV/T should be used in place of traditional PV and that it is possible to produce

warm water to be used as preheat or sink/shower ready potable hot water. Practical Applications - The DoD has a goal of reducing consumption of fossil fuels. One cost-effective solution is to retrofit expeditionary structures with the ability to harness renewable energy. The addition of PV/T panels provides both electrical energy and thermal energy. PV/T arrays are commercially available (traditionally used for parallel production of solar electrical power and water heating in residential recreational pools). Original Value - The current study represents the first demonstrated integration of PV and PV/T on expeditionary structures. Additionally, this represents the first study of PV and/or PV/T array on a semi-circular building. The panels capable of generating electricity and producing hot water for immediate usage in the field. The results of the experiments show that an addition of a thermal absorber to a PV module can increase the energy collected by the module up to 80% whereas PV alone has roughly 14.5% efficiency.

### **Touryan, J. • Gordon, S.M.**

#### **Novel approach for the assessment of cognitive state in complex environments.**

Understanding and improving Soldier performance is a critical element of a number the US Army's modernization priorities. Developing quantitative models of human state and the tools needed to measure such states in complex environments will enable significant advances in this arena. Armed with a better understanding of the human, the next generation of Soldier-systems will be able to mutually adapt to the Soldier while the Soldier, in parallel, adapts to both the system and current task demands. However, robustly measuring human state without disrupting ongoing task performance has proven to be a significant challenge. Researchers and engineers have employed a variety of techniques to infer state, often through the measurement of overt behavior or physiological responses driven by autonomic nervous system function. In contrast, utilization of the central nervous system (CNS) to infer state has largely been constrained to the laboratory. The purpose of our work is twofold: 1) develop methods for assessing and interpreting CNS activity in complex environments and 2) identify application areas in which current knowledge of CNS activity can have the greatest impact on future Soldier technologies. For our work, we begin by acquiring scalp EEG (Electroencephalography), which enables direct measurement of CNS activity. However, scalp EEG has a low signal-to-noise ratio and is highly susceptible to individual differences, making interpretation difficult. To help overcome these issues, we developed novel deep learning architectures, based on convolutional networks that efficiently exploit information from EEG. Armed with these deep learning tools, and a wealth of prior empirical data, we trained a single deep model to assess a specific aspect of CNS function: visual information processing. Our prior empirical data included numerous controlled laboratory studies spanning hundreds of subjects and hundreds-of-thousands of trials. Once trained, we analyzed our model to determine that it both 1) encapsulates the variety of distinct neural responses observed in controlled laboratory studies and 2) is extensible to the types of dynamic, complex environments used to train the modern Soldier. While we are in the initial stages of this work, we have applied our model to two military-relevant tasks. Our

first task involves shared situational awareness for improved human-human and human-agent teaming. In this task, we use the model to detect the discrete neural responses that occur when humans visually perceive an object of interest, or stimulus relevant to the current task. Importantly, we link our model with eye movement activity to enable application in a naturalistic viewing environment. By simultaneously combining the outputs from multiple individuals, we build a common representation of the environment that can be shared across teams or with autonomous agents. Our second task involves real-time estimates of human state. Here, we apply our model to a cohort of 13 Soldiers performing a simulated reconnaissance mission on a ride-motion platform. In this simulated mission, Soldiers were driven from a Forward Operating Base (FOB) to a city, through the city to various checkpoints, and then back to the FOB. At each phase of the mission, stimulus frequency varied as did the amount of background tasking. Thus, the Soldiers had to continuously balance the demands of concurrent background tasks with the demands of the primary reconnaissance task. We demonstrate that the model outputs are sensitive to these changes in the mission environment. We also show that our model uncovers individualized adaptations in visual information processing that relate to the manner in which each Soldier accomplishes the primary task.

### **Troyer, L.**

#### **Biophysics-based measuring and modeling of social dynamics.**

PURPOSE: The objective of this research program is to (1) develop new objective measures of collective action to overcome existing biases in conventional measures (self-report, observation); (2) generate and validate new predictive models that capture the dynamic nature of large-scale collective action to correct conventional approaches that treat social action as a simple aggregate of individual behaviors. THEME: This research program addresses Empowering a Soldier's Success by providing Warfighters with new tools to identify threat in the operating environment and enhance capacity of mission leaders to predict key influence groups, risk points, and emerging instabilities. It enables long-chain analysis of complex interdependencies among social collectives at global scales recognizing that today's security environment is a global one featuring both kinetic and non-kinetic factors. The focus of the research program is in two areas: (1) Soldier Lethality (Human Systems Integration, Neuroscience, Human Performance Optimization and Enhancement); (2) Future Technologies (Disruptive Technologies). DESIGN, METHODOLOGY, APPROACH: This research program comprises a portfolio of projects. These projects have demonstrated that biometric technologies (e.g., thermography, pupillometry, fMRI, EEG, vocal acoustics, epigenetic processes), when tracked over time in collectives as interdependent dynamics among actors, generate predictable patterns of changing social dynamics, such as shifts from collective peaceful protest to large scale destabilizing violent action, diffusion of influence across a population; emergence of radical adversarial groups, development of social cohesiveness. Moreover at macro scales, integration of technologies such as computer visioning, geospatial tracking, financial market analysis provide data to enable new models of large-scale population dynamics,

including in- and out-migration and mobilization leading to sociopolitical instability. These new sensing/measurement technologies are coupled with computational models derived from physics, epidemiology, and Bayesian mathematics to generate new predictive capacities that more directly capture the complexity of social dynamics as they unfold over time and space. **FINDINGS:** The research, which relies on archival open-source data and experimental methods, is already demonstrating that social influence can be tracked non-intrusively by identifying dominance in low frequencies of the voice spectrum, which is not detectable by humans. It has also provided evidence that emergence of collective action plans in a group are correlated with convergence in brain wave activity. One of the projects has also shown that emotion diffusion in a group (e.g., anger) can be tracked through facial thermography. Additionally, this collection of biophysics based measuring and modeling projects has shown that civilian mobilization to unseat a political power can be detected through integration of utility and geospatial data. Another project shows that propensities for hyper-aggression (e.g., violence) are traceable to epigenetic processes in which the presence of particular genetic alleles creates susceptibility for hyper aggression towards others when an individual experiences injustices, demonstrating the importance of social context in determining the behavioral effects of genetics. **PRACTICAL APPLICATIONS:** This research will provide Soldiers and decision-leaders with new tools and models to better detect allies and adversaries in volatile and turbulent environments. For instance, it will lead to development of technologies to rapidly assess emergence of hostility (e.g., through combinations of computer visioning and facial thermography); capacity to assess mobilization of large collectives (e.g., through integration of geospatial tracking, social media analytics, and models of crowd dynamics inspired by physics); identification of influence networks at both local and global levels (e.g., through improved modeling capabilities drawing on models of crowd dynamics inspired by physics-based herding, swarming, flocking and models of diffusion and transmission inspired by epidemiological models of disease spread). The sensing (i.e., measuring) and modeling advances will be coupled with visualization tools to rapidly enable detection of threat and risk in evolving environments. **ORIGINAL VALUE:** This new research program is changing how social processes are scientifically studied. Importantly, it is enabling new theoretical advances in the social sciences that better reflect the complexity of how social dynamics unfold over time and space at different levels of granularity. Furthermore, it is enabling testing and validation of longstanding theoretical principles that identify fundamental mechanisms of social behavior. The research is also demonstrating the advantages of multidisciplinary approaches to addressing fundamental social science problems.

**Tseng, V.F.G. • Bedair, S.S. • Lazarus, N.**

Wireless power transfer using acoustic energy focusing.

Recently, ARL has been investing in the research and development of wireless power transfer (WPT), which can be used to power on-soldier equipment (to enhance soldier lethality by eliminating cognitive burden of recharging

portable devices), power UAVs/UGVs (tactical unit energy independence), power/communicate with embedded sensors (vehicle structural health monitoring), and provide power for on-board munition fuze applications, all of which we are actively pursuing. In particular, our work has focused on developing acoustic WPT for through-air and through-metal applications. We have experimentally verified that acoustic WPT can achieve higher power transfer efficiencies than conventional inductive WPT when the transmit-to-receive distance is above several times the diameter of the coils/transducers. This is because ultrasonic waves propagate with much shorter wavelengths compared to electromagnetic waves and can be focused much easier, leading to relatively higher efficiencies at larger distances. This also allows smaller transducers and lower operating frequencies to be used. For our work on through-air acoustic WPT, we demonstrated—for the first time—the feasibility of using an acoustic phased array transmitter to achieve power beaming. With a 37 element phased-array transmitter constructed out of 40 kHz resonant ultrasonic transducers, acoustic focusing was used to increase the efficiency by nearly 40 times within the near field region (0.2 W received with 5% efficiency at 5 times the transducer diameter distance), with minimal detectable external signature since the acoustic power is focused to a single focal point. Experimental results were shown to closely match modeling results, predicting that the efficiency can be further doubled by increasing the array element density. Electronic beam steering could also be used to steer the focal point to the receiver location, achieving orientation independent power transfer. We also investigated the design of a 7 element receiver array to further increase the efficiency (by 4.25 times) and provide higher charging voltage to assist high-voltage, rapid charging of capacitors (suitable for fuze electronic safe arming). A unique advantage of acoustic waves is that it can propagate through metal without being impeded, while electromagnetic waves (used in all other forms of WPT technologies) are blocked by metal barriers due to Faraday shielding. Therefore, it is possible to achieve through-metal power (and data) transfer with acoustic waves. We also demonstrated for the first time the acoustic power transfer to and data communication with a wireless sensor node entirely embedded within solid metal for structural health monitoring. The sensor node consists of a receiver transducer, representative sensor, and battery as well as electronics for power and data back transmission, all contained within a single compact package (0.73 in<sup>3</sup>). The entire sensor node was embedded within a casted fusible alloy cube to demonstrate its functionality. The measured power transfer and sensor data response all corresponded well with modeling results, achieving a peak power transfer efficiency of 33% at 440 kHz. Currently, we are expanding on this through-metal acoustic WPT technology and applying it to munition fuze initiation applications by transferring power to charge fuzes through plate waves propagating within the munition metal casing.

**Villanueva, E. • Pagan-Trinidad, I. • Pittman, D.W. • Whalin, R.W.**

A framework for successful educational outreach while enhancing diversity.

In 1986, personnel from ERDC (then Waterways Experiment Station), the nation's largest federal civil engineering laboratory, made the first annual

recruitment trip to UPRM. The goal was to increase the number of Hispanic engineers and scientists in the workforce. The ERDC deemed the initial trip a success: three job offers were made and two were accepted. The 1991 recruiting trip featured a courtesy visit to the UPRM Civil Engineering and Surveying Department Chair. The ERDC Director inquired if there were any areas (other than recruiting) in which the ERDC could assist the department. The Chair mentioned a professional practice elective course he wanted students to capitalize on, particularly graduate students seeking summer jobs. Many who found jobs dropped out of graduate school. The ERDC Director made an on-the-spot commitment to accommodate as many as 10 students. This conversation initiated an experiential learning research internship program that thrives to this day. Eight years later, in 1999, the partnership was formalized with the signing of an Education and Research Partnership Agreement authorized by Public Law, which includes many initiatives. The breadth of work performed by the ERDC-UPRM interns are at the highest level. Interns must write proposals, reports, and give at least two oral technical presentations. They also write an essay on values cultivated while at the ERDC. Their work is evaluated by ERDC mentors and UPRM faculty. The UPRM-ERDC partnership was initiated by federal policy to strive for a workforce with demographics reflective of the national population and the population of engineers and scientists. Laws, policy, executive orders, and regulations encouraged recruitment strategies for all government organizations to improve the disparity that exists for underrepresented groups in any government organization. For three decades, both institutions have maintained an educational and research relationship for the purpose of: (1) promoting the professional, educational, and research development of world-class engineers and scientists in Puerto Rico, and; (2) providing world-class engineers and scientists of Hispanic background access to ERDC. The students are required to comply with the demands of a professional career experience and academics, and ERDC supports the academics requirements while meeting its mission goals. The UPRM Program Manager, coordinates and helps expand interest throughout the UPRM campus. The ERDC Program Manager, assists with many components of the partnership and also serves as the technical evaluator for the summer program. Several executive Coordinators for ERDC have offer key sustained leadership commitment to the success of this partnership. The funds to support the internships are disbursed by the government through mission research programs. Research funding has also been received by UPRM periodically for faculty research or continued graduate research by students. To date, the partnership between both institutions has resulted, (directly or indirectly) in: the elimination of a gross underrepresentation of Hispanic engineers and scientists at the ERDC (less than 0.5%) bringing it to 5% and rising and over 575 experiential summer internships. As a result, participants are better prepared for professional practice because of their intense engineering experiences. Their experiences include laboratory and field work, mathematical modeling, engineering mechanics evaluation, environmental processes, experiment designs, state-of-the-art technology, and computer software and programming skills. Additionally, ERDC has recruited 72 permanent hires (with 65% retention over 30 years); many UPRM professors bring

their research expertise to the ERDC (in 2018 one professor was on sabbatical at ERDC). ERDC researchers have served on graduate committees of 15 master's degree recipients; 4+ have received UPRM temporary assignments and some serve on the UPRM Department Advisory Committee. Other USACE Districts have also leveraged the ERDC-UPRM relationship by recruiting engineers and scientists, thereby enabling UPRM to make positive contributions to the Corps community and enhancing UPRM's reputation as a "gold mine" of talent. The partnership, which initially included only the UPRM Civil Engineering and Surveying Department, has now grown to include 18 engineering and science departments. The ERDC-UPRM framework paves the way for other federal laboratories and/or corporations interested in establishing an enduring partnership with a Minority Serving Institution. Building a sustained mutual laboratory and university partnership between geographically distant organizations with different cultures is hard work that requires sustained commitment to gradually build trust through actions. As proven by the above results, the mutual partnership between the laboratory and the university is now a part of the culture of both institutions.

**Vlahopoulos, N. • Kulkarni, K.B. • Thyagarajan, R. • Zhang, G.**

**Elements of set based design for effective decision making in Army vehicle applications.** The modernization priorities of the Army expect the appropriate balance between firepower, protection, mobility, and power generation capabilities for the next generation of combat vehicles (NGCV). The same objective is stated in the US Army TARDEC's 30-year strategy focusing on protected mobility and in providing mission-appropriate balance of survivability and mobility technologies. This paper presents how concepts from Set Based Design (SBD) enable these objectives while balancing survivability and mobility during the design process of a Ground Combat Vehicle (GCV). A specialized optimization algorithm based on elements of the SBD process is discussed. Results from applying the new algorithm in the design of a notional GCV are presented. The value of SBD in driving the design process, defining design requirements, and understanding how different vehicle configurations achieve the desired performance is demonstrated. These capabilities are very important for DoD organizations when exploring the design space and defining requirements either for new vehicles like NGCV or for upgrading fielded programs. The SBD methodology was developed for gradually reducing the design space while understanding the implications that diverse mission requirements have on the potential solutions. Compared to the commonly used single point design approach, the SBD avoids honing too early into a single solution while the operational requirements are still evolving. By retaining a larger number of solutions within the design space, it is possible to make design decisions that will provide higher flexibility for meeting the constantly changing geopolitical threats. Further, the SBD approach is most suitable for DoD in defining performance requirements for procurement instead of a pursuing a single point design. During the space reduction process the interactions among multiple and competing performance expectations and requirements (i.e. survivability, mobility, fuel economy, etc.) are considered. Including a high level of diversity in the retained

design space is important in order to allow prime contractors to propose a diverse set of solutions. The SBD algorithm which is presented in this paper identifies the "sweet spots" of the design space that balance successfully survivability and mobility expectations, while operating in diverse battlespaces. These areas of the design space are investigated further and ranges for performance expectations are identified. Technical details for the two main differentiators (definition of the design variables and the bi-level decision making algorithm) of the SBD method are presented. Unlike single point optimization methods, the SBD utilizes ranges for determining the desirable sections of the design space. Therefore, design variables that facilitate the definition of the desirable design space are established. Further, in the SBD algorithm flexibility is permitted in meeting the constraints, as long as a significant enough improvement is realized in the performance. The levels of flexibility introduced in each constraint become part of the design variables. The SBD algorithm operates in a bi-level structure that considers, for example, the requirements from multiple battlespaces and identifies the regions of the design space that include all vehicle configurations with high probability of completing successfully missions under multiple engagement scenarios. The mathematical formulation of the bi-level algorithm is presented in this paper. A notional vehicle is used in this paper for demonstrating the new type of information that is generated by the SBD algorithm. The performance of the vehicle in two different battlefields (urban and open terrain) is considered. The new SBD algorithm identifies a reduced region of good performance that contains a large number of alternative vehicle configurations. The results are investigated further in order to understand how different vehicle configurations use mobility and survivability for achieving good performance, and for determining how diverse the alternative configurations are. The research presented in this paper establishes a systematic, mathematical structure for making decisions based on principles of SBD. The new capability provides a SBD framework that will benefit programs such as NGCV and will generate GCV that will enable the warfighters to accomplish their missions successfully and safely. A new bi-level algorithm based on elements of SBD is presented. It is a useful decision-making tool for balancing mobility and survivability attributes of a GCV in order to successfully operate in different battlefields. The originality of this paper stems from the mathematical formulation of the new SBD algorithm and its application in the analysis of a notional GCV.

**Volek, J. • Kraemer, W. • LaFountain, R. • Miller, V. • Phinney, S.D.**

**Strategies for ketosis and keto-adaptation to optimize human performance and resilience.** Purpose: Long-standing conventional wisdom mandates that humans consume a high-carbohydrate diet to perform optimally. Over time for many athletes and soldiers this approach is associated with less than desirable health and performance outcomes (obesity, inflammation, deteriorating metabolic health, slow recovery). Ketogenic diets result in sustained increases in ketones to physiological beneficial levels. In addition to serving as fuel for the brain, recent evidence indicates that the primary circulating ketone beta-hydroxybutyrate (BHB) is a potent

cellular signaling molecule that positively affects gene expression, inflammation, protection from oxidative stress, insulin resistance, and longevity. Sustained ketosis over weeks results in a keto-adapted phenotype characterized by broad-spectrum health benefits (e.g., decreased adiposity, reversal of metabolic syndrome and type 2 diabetes, neuroprotection, etc.). Keto-adaptation has enabled endurance athletes to set course/national records and a growing number of military personnel are using ketosis to improve physical and cognitive performance, and manage obesity, metabolic health, oxygen toxicity symptoms, and post-traumatic stress disorder. Ketosis may also be achieved by using exogenous ketones. We believe that methods to induce ketosis represent a paradigm-shifting technology that has the potential to deliver superior extended warfighter performance and an enhanced ability to cope with stress. Methodology/Approach: We have studied how different approaches to inducing ketosis impact performance and metabolic adaptations in athletes and military personnel including, 1) a cross-sectional study exploring Fat-Adapted Substrate Use in Trained Elite Runners ('FASTER'), 2) a 12-wk diet and training intervention in military personnel, Tactical Athletes in Nutritional Ketosis ('TANK'), and 3) performance outcomes in response to acute ingestion of a ketone-salt/caffeine supplement versus a control condition ('Ketone Supplement'). Findings: The 'FASTER' Study revealed that compared to a matched group of high-carbohydrate controls, keto-adapted athletes (n=10) showed two-fold higher rates of fat oxidation at rest and during exercise, similar levels of pre- and post-exercise muscle glycogen, higher insulin sensitivity, increased muscle membrane fluidity, and altered gene expression and metabolomic profiles reflective of a high-capacity to oxidize lipid. The 'TANK' Study revealed that a group of primarily Army ROTC cadets/officers (n=15) who underwent a resistance training program adapted to an ad libitum ketogenic diet as evidenced by daily blood ketones consistently >1 mM. Compared to a matched high-carbohydrate diet control group, the keto-adapted group lost greater body mass (-7.7 vs 0.1 kg), fat mass by dual-energy x-ray absorptiometry (-5.9 vs -0.6 kg), and visceral fat by magnetic resonance imaging (-44 vs 8%). Despite the significant loss of body mass, the keto-adapted group gained strength and power and were able to complete military specific tasks. Analyses of protein content and oxidative capabilities of mitochondria isolated from skeletal muscle biopsy samples were consistent with enhanced tolerance to the training, potentially through greater induction of mitohormesis in keto-adapted individuals. The 'Ketone Supplement' Study revealed that a ketone-salt/caffeine supplement containing 7.2 g BHB and 100 mg caffeine ingested 15 min prior to a staged cycle ergometer time to exhaustion test increased performance (8.3%) and decreased perceived exertion in a group of non-keto-adapted individuals (n=12). We replicated this experiment in a separate group of keto-adapted individuals (n=12) and observed similar and significant improvements in performance (9.8%) These results indicate that acute ingestion of a relatively small amount of BHB-salts plus caffeine is well tolerated, induces a rapid but transient nutritional ketosis, and improves high-intensity exercise performance in both non-keto-adapted and keto-adapted moderately-trained individuals. Practical Application: In addition to well-established clinical applications of keto-adaptation (i.e., anti-obesity

and reversal of the insulin resistant phenotype), the above studies exploring various methods of inducing ketosis paint a promising picture of ketosis and keto-adaptation for optimizing human performance and resilience. Original Value: Ongoing studies are needed to shed additional light on the most effective methods of inducing ketosis for optimizing human performance and health. Military-appropriate food/meals and various ketone technologies could easily be developed to facilitate practical implementation in select units. Also, due to the high energy density of dietary lipid, an ultra-light-weight ration could be developed to dramatically reduce pack weight while delivering superior field performance, representing a quantum leap in combat ration technology.

## **Wang, J.**

### **Toward the Army's science and technology career: successful first steps from the Army's science and engineering apprenticeship program for high school students.**

This case study gives an anecdotal account of my participation in, as a high school junior, the Army's Science and Engineering Apprenticeship Program (SEAP) that led to unexpected but fruitful research experience. There are two purposes this case study illustrates. First, an average high school student can greatly benefit from the out-of-classroom stimulus provided by the apprentice's mentor scientist and the research environment that are not available through standard high school curricula and settings. Second, it proposes a mechanism to extend the mentor-apprentice relationship beyond the duration of the summer program that can potentially benefit the Army mentor's mission and deepen the student's involvement with Army science and technology. The out-of-classroom apprenticeship started with my Army mentor introducing me to the Army Research Laboratory's missions and how it is positioned among Bohr's, Edison's, and Pasteur's quadrants. Very methodologically, my mentor taught me the basic concepts of digital signal processing, and I was tasked to convert some components of a toolkit designed for analyzing shock-and-vibration data using the Python programming language. Though I had a slow start in the first few weeks, I managed to make a significant contribution to the toolkit when the apprenticeship concluded. During the apprenticeship and afterwards, I have studied digital signal processing further and completed a science project in music signal processing aimed to determine the effect of harmonic and inharmonic spectral contents on musical timbres generated by acoustic instruments and synthesizers. The rest, as the phrase goes, is history. After successfully competing at the regional and state levels, I have become a finalist at Intel's International Science and Engineering Fair (Intel ISEF) and a finalist at the National Junior Science and Humanities Symposia (JSHS) sponsored by the Army, Navy, and Air Force. Looking back at this incredible journey, I am grateful for my Army mentor's investment in me as well as the opportunities the Army Educational Outreach Program's (AEOP) SEAP provided me. My participation in SEAP is truly a catalyst to many unexpected but pleasant surprises. After participating in multi-day science competitions such as the Virginia JSHS, I witnessed firsthand that the great majority of contenders are students from many regional Governor's Schools

where resources and environments appear to be more conducive to performing scientific inquiries. Retrospectively, though I was lucky to have apprenticed at the Army lab which enabled me to compete at the same level with students from Governor's schools, the eight-week apprenticeship was ephemeral compared with that of ten-month long Governor's schools. Therefore, in this case study, I propose to enhance the SEAP in a way to allow apprentices, if interested and permissible by the mentor, to continue performing relevant work under the guidance of the mentor. This continued apprenticeship after the eight-week summer program can potentially be very beneficial to the Army mentor, since most apprentices tend to reach their peak productivity after being mentored for approximately six weeks. The science project that I conducted after the apprenticeship is a case in point – I believe I would have made much more progress with less road traveled, and, as a volunteer apprentice beyond the eight-week program, it would have simultaneously benefited the Army's warfighters. From my observations, many of my peers successfully conduct and showcase their research, mostly in the bio-chemistry and medical fields, in which both the mentor and mentee are mutually benefited. It will be great to see more military-related research by high school students – covering topics outlined in this symposium – in events such as the National JSHS. As a two-time apprentice with the Army Research Lab, I am confident that the Army STEM outreach programs can make even greater positive impacts to both Army scientists and apprentices. Without violating security protocols or regulations, I firmly believe that the Army SEAP can be enhanced toward involving apprentices for longer terms to further develop their talents while building up an army of future Army scientists.

## **Weyhrauch, W.S.**

### **A mindset for strategic thinking: assessments for Army leader development.**

This research was conducted to accomplish three major objectives: synthesize literature on the core competencies of strategic thinking, identify the characteristics of a strategic thinking mindset, and assess the characteristics with two different methods. Identifying the necessary skills and characteristics of strategic thinkers and then developing assessments for them are critical steps in helping the Army identify and manage talent for career-long development. Junior leaders who can, and are encouraged to, practice and apply a strategic thinking mindset to complex problems at a tactical level will more easily transition into the demands of leadership at the operational- and strategic-level positions. Cognitive assessments are a critical part of optimizing and enhancing Army leaders' human performance. By building assessments, the Army can more effectively manage its talent and individual Army leaders can use assessments to improve their self-awareness and guide their self-development efforts. Talent management and self-development processes should be informed by carefully developed and innovative cognitive assessments. Many organizational and military scholars have conceptualized the components of strategic thinking. This first phase of this research was a synthesis of these models and generation of an informed list of the core strategic thinking competencies. Furthermore, this synthesis was used to identify the characteristics of a mindset that supports these competencies. Certain

fundamentals, such as broad knowledge in the area and advanced intellectual ability, are fairly self-evident requirements for complex cognition. A third fundamental need is the right mindset. The three prominent characteristics of this mindset for strategic thinking are flexibility, humility, and inclusiveness. The second major phase of this research was developing two different types of assessment of this mindset, each with a distinct source of inference. First, a situational judgment test (SJT) was developed, which presents respondents with a series of ambiguous problem scenarios accompanied by a range of response options. The respondent's mindset is inferred from the nature and consistency of their choices among these options. Army leaders participated in three stages of test development (N = 424) prior to validity testing (n = 177). Secondly, a more standard personality-type scale employing self-report was developed (n = 236). In this format, respondents rate their level of agreement with a variety of statements describing how they approach dealing with ambiguous problems. The findings of the research indicate some issues of psychometric measurement, specifically low internal-consistency reliability, but, despite this constraint, general support for the construct validity of the assessments. The strategic thinking competency model and mindset assessments can be of practical use to the Army in several ways. First, they can be used to introduce developing leaders to strategic thinking, the ideas of intellectual flexibility, humility, and inclusiveness, and how nurturing this kind of mindset will facilitate their development into the senior leaders needed by the Army. Secondly, the specific scenarios in the SJT can be used to prompt discussions about how these characteristics can be applied in a tactical problem environment. These discussions could take place in institutional settings, such as Army PME courses, or in operational settings, during performance counseling, one-on-one mentorship, or commander's staff leader professional development sessions. Third, the Army could develop these assessments for use in talent management and curriculum evaluation functions, as a metric showing individual differences between individuals and patterns of change within individuals over time. This research is of a broader scientific value in several ways. The conceptual synthesis portion provides an analysis of the ways in which competency models from military and other organizational scholars differ and overlap. Further, the identification of the three mindset characteristics contributes to theory on the career-long development of strategic thinkers and ways to identify and manage talent. Third, the pairing of the two assessments provides an excellent opportunity for exploration of the difference between self-perceptions of tendencies (through self-report) and a more direct assessment of tendencies (through situational judgment). Both methods rely on different sources of information about the individual's actual mindset tendencies and suffer from different weaknesses of measurement. By utilizing multiple approaches, both researchers and end-users can benefit from the relative strengths of each.

**Wind, A. • Adis, C. • Canali, K.  
• Wisecarver, M.**

### Development of a game-based assessment of systems thinking ability: initial model and construct validation.

In the future operational environment, Army personnel will increasingly work with or within multiple systems. Systems are complex dynamic sets of interconnected elements organized in a coherent way that achieve a function or purpose. Soldiers encounter complex sociocultural systems on deployments. Officers need to lead and manage organizational systems. Operators must concurrently defend Army cyber networks while maintaining the capacity to dominate in the digital realm. Examples could continue as the battlefield of the future will be comprised of interconnected, nested, and changing systems of various types. Given the growing pervasiveness of systems across Army jobs and requirements, being able to identify personnel who have an aptitude for systems thinking, independent of domain, would be a useful selection and classification tool for attaining human performance optimization and enhancement. In this project, systems thinking ability (STA) is defined as a constellation of closely related abilities that enable individuals to identify the elements of a system, understand system relationships, evaluate and revise system models, and apply an integrated understanding of the system to a problem. Additionally, a number of cognitive attributes, the literature suggests, are also conceptually relevant to STA. Eight key cognitive attributes conceptually relevant to STA were identified from the literature: Hierarchical Working Memory Capacity (HWMC), Spatial Ability (SA), Cognitive Flexibility (CF), Pattern Recognition (PR), Cognitive Complexity (CC), Creativity, Curiosity, and Openness to Information. Such a complex conceptualization of STA is not uncommon. It is unsurprising then, that traditional approaches to assessment have been unable to faithfully measure all intricacies of STA without focusing on a narrow domain of performance. New technologies, however, are opening up new avenues to assessment of such capabilities. Through game-based assessment, the STA assessment will allow measurement of systems thinking abilities and related cognitive attributes. This research develops and examines initial construct validity evidence for 5 sub-tests of the cognitive attributes (HWMC, SA, CF, PR, and CC) related to STA. Assessment approaches were developed for each of five cognitive attributes. HWMC was operationalized using a multi-level complex memory span task in which participants were asked to recall sequences of item locations at different levels of an organizational hierarchy. Four dimensions of Spatial Ability were measured using tasks that included shape searching, slicing 3-D shapes, interpreting fluid levels in a container, and taking various perspectives using photographs. The operationalization of Pattern Recognition required participants to identify anomalies in a factory-like setting. Cognitive Complexity used a dynamic object sorting task, and Cognitive Flexibility uses a scenario-based hypothesis formation task as well as a reaction time test for switching from a macro to a micro perspective. For all of the measures, with the exception of HWMC, multiple dimensions were captured: two each for Cognitive Flexibility and Pattern Recognition; three for Cognitive Complexity; and four for Spatial Ability. Data for the validation were collected using a sample of workers from Amazon Mechanical Turk. The

number of participants (aged 18-50) ranged from 119 for SA to 137 for PR. Participants could choose to take only one of the tests or multiple tests if they wanted, up to all five of the tests. Results generally provided support for the construct validity of these measures, although the level of support varied. Construct validity evidence was the strongest for HWMC, Extrinsic-dynamic SA, Micro/Macro Task Switching CF, and Abstract Grouping CC, and was the weakest for Extrinsic-static SA and scenario-based hypothesis formation task CF. Convergent and discriminant relationships were generally significant and in the expected direction, though of moderate magnitude. Only one dimension of SA failed to show convergence with related constructs. Findings from this research provide initial psychometric and validity evidence for five cognitive assessment tools related to STA. Several of the assessment tools may have applications beyond STA to other military occupational specialties. For example, spatial ability is relevant to numerous MOS. The next step for further development of the STA test will create the game-based assessment of STA that combines the five existing assessments within a unified game environment and expands STA to include three additional attributes: creativity, openness to information, and curiosity as well as the processes utilized in systems thinking. The final measure would be a significant advancement measurement and potentially powerful tool for the Army.

**Wolff, J.R. • Gair, J. • Hall, A.**

### 3D-printed interface strengthening via post-print annealing.

Additive manufacturing has traditionally been used for product design by big companies as a prototyping tool in an early stage of the development cycle. Recently, it has been used as a method to produce complex parts or to quickly manufacture replacement parts at a point of need. Currently, at forward operating bases (FOB), the warfighter is employing additive manufacturing technology to save costs and reduce the military logistics burden. Such components have the potential to allow soldiers to manufacture mission-critical components at the point of need, at the time of need, rather than waiting for hours or even days for supplies to reach them. This becomes even more critical when soldiers operate in highly-contested environments or deep in adversary territory. The promise of such capabilities is limited by the types of materials which may be printed as well as properties inherent to the print process. More specifically, mechanical characteristics at the raster-raster interface is far weaker than bulk polymer properties, and thus dominates failure and component longevity. One method to circumvent this obstacle is to anneal the sample after the print. By raising the component temperature just above the glass transition temperature, not only may discrete boundaries between rasters be erased, but residual stresses which accumulate during the print process may be eliminated. To investigate the viability of an annealing post-print-process as a method for enhancing mechanical performance in 3D-printed materials, short-beam shear fatigue tests with and without an annealing step have been performed. In an effort to expand the mechanical range of 3D-printable components beyond common 3D printed thermoplastic polymers such as poly lactic acid (PLA) and acrylonitrile butadiene styrene (ABS), a new class of poly(urethane-urea) (PUU) materials

have also been tested. To determine the effect of the annealing step on fatigue, each material (excluding the control samples, which were not annealed), was heated for 5 minutes at 0, 5, 10, and 20°C above its glass transition temperature. These experiments have produced fatigue profiles with various degrees of annealing post-treatment for ABS, PLA, PC, and two versions of PUU. Additionally, the data suggests the utility of using such a method in fielded 3D-printed military components.

**Wolfson, M.Y. • Boyle, P.M. • Dunn, J.G.**

### Bioinformatic and deep-learning insight into engineered DNA at synthetic biology foundries.

Synthetic biology is a growing industry that is poised to disrupt traditional modes of manufacturing. By designing sequences of DNA in silico and then “printing” those sequences using DNA synthesis technology, synthetic biologists can engineer organisms for myriad new capabilities, from in-situ resource utilization to novel materials. The advances in high-throughput DNA synthesis and genetic engineering that underpin these foundries have enabled synthetic biologists worldwide to design organisms with unprecedented speed, ease, and scale: at Ginkgo Bioworks alone, our automated organism engineering foundries use over 250 million base pairs of synthetic DNA per year. The exponential growth in engineering capability surfaces core questions: What are the operative parameters for sequence design? How can we identify designs that pose risk or are prone to failure? Can we detect the presence of engineered DNA? Fortunately, the growth in sequence data concomitant with this growth in engineering scale presents a significant opportunity to address such questions with machine learning. In this presentation, we summarize organism design and engineering at Ginkgo Bioworks and describe how Ginkgo has leveraged bioinformatic and deep learning approaches to address the above questions. We begin by describing the high-throughput synthetic biology foundries at Ginkgo and their use in developing engineered organism solutions. After the overview, we outline the challenge of finding relevant candidate sequences for design projects, and describe the theory behind Paralign, a tool used at Ginkgo to assist with candidate sequence search. We then describe the related biosecurity challenge of DNA synthesis regulation and show how the techniques of Paralign are adapted to a classifier that can expand the scope of potential threats identified. We then describe the related problem of synthesizability—predicting the success or failure of a given DNA design from its sequence before its synthesis is attempted. We discuss previous efforts Ginkgo has made in this area and how the understanding of synthesizability is related to the inverse problem—detecting the presence of engineered DNA in a sample, which is another contemporary biosecurity challenge. We outline a framework under development at Ginkgo Bioworks for addressing this engineering detection problem with techniques in deep learning. Finally, we close with notes on how such computational synthetic biology solutions can be integrated with existing biosecurity resources to produce a compound solution greater than the sum of its parts.

**Wright, W.G. • Cheever, K. • Langford, D. • Mansell, J. • Tierney, R.**

### Vestibular ocular-motor assessment in young adult contact sport athletes.

Purpose: Vestibular ocular-motor clinical testing is emerging as important assessment to help identify a concussion and target therapy post injury. One of the more commonly used tests in this domain is the vestibular ocular-motor screen (VOMS). The VOMS relies on self-reported symptoms provoked following by clinician instructed eye (e.g., saccades) and head movements (e.g., VOR). Due to its increasing use clinically, it is important to continue to gain an understanding of normal values and factors (e.g., sex, concussion history) that may affect VOMS scores. This is particularly important in the physically active young adult population due to the high concussion incidence in this age cohort. Theme: Repetitive sub-concussive head trauma can occur in many types of standard military training. These low-level impacts can occur during paratrooper training, armored vehicle and tank training in rugged terrain. Additionally, blast exposure events involve forces due to the shock wave from an explosion, with the secondary and tertiary forces being blunt force events. There are a multitude of jobs in the military that involve blast exposure events, which require the service member to be near an explosive weapon or device, e.g. breachers, anti-tank missile crew, special operators, machine gunner, riflemen, infantry. Assessing the effects of repeated sub-concussive and concussive head trauma from blunt-force trauma in civilian athletes may provide insight relevant to military personnel training or battlefield conditions. Methods: A total of 158 participants (male,  $n = 119$ ; female,  $n = 39$ ) between the ages of 18 to 24 from university club sport teams (i.e., rugby and ice hockey) completed the VOMS during concussion baseline testing. Independent variables were sex (male vs. female) and history of concussion (yes vs. no). The dependent variables were total VOMS symptom provocation and Near Point of Convergence (NPC) scores. Symptom provocation ratings for headache, dizziness, nausea, and foggiess were recorded using a 10-point Likert scale following each VOMS test domain (i.e., smooth pursuits, saccades, VOR, NPC, and visual motion sensitivity). NPC measurements were recorded with a convergence ruler as described previously. Inter-tester reliability for the measures was established previously (ICCs ranged from .91 to .99). Descriptive statistics and independent-samples t-tests were used to analyze the data using IBM SPSS version 24 ( $p < .05$ ). Temple University Institutional Review Board and HRPO approved the protocol. Results: The mean VOMS score for the entire cohort was  $0.40 + 1.25$  symptoms. Approximately 13% (20/158) of baseline scores were above the previously reported clinical cut-off score for more than one VOMS domain. Over 35% of NPC scores were greater than the previously reported clinical cut point of  $> 5$ cm. No differences were identified in total VOMS score due to sex or concussion history. There was a statistically significant difference ( $p = .04$ ) in NPC scores between males ( $4.93 + 2.8$  cm) and females ( $3.89 + 2.36$  cm), only. Conclusion & Clinical Relevance: Overall, VOMS symptoms reported by this cohort were low. Based on previously established cut-points these young adult contact sport athletes exhibited a low percentage of VOMS symptom provocation score false positives. This is important as symptom provocation scores of greater than

2 in any test domain could be indicative of a concussion. Over a third of participants recorded NPC scores higher than the clinical cut point which was not associated with history of concussion. Additionally, male contact sport athletes also exhibited higher baseline NPC scores than their female counterparts. Although the results warrant further study, it calls into question the clinical usefulness of the previously established NPC cut point.

**Yang, C. • Ding, Y. • Pesaran, A. • Shi, Y. • Smith, K.**

### Li-ion battery pack lifetime prediction based on 3D electrochemical/thermal model.

Li-ion batteries have been considered for commercial vehicle electrification due to their high energy and power density. They may also potentially provide a solution to meet the power and energy need for next generation combat vehicles (NGCV). Li-ion battery lifetime is controlled by multitude of degradation mechanisms, some driven by cycle aging and some driven by calendar aging. Aging mechanisms interact with one or another, contributing together to the overall aging. To optimize design and unitization of a battery over its lifetime requires characterization of its performance degradation under difference storage and cycling conditions, which is time consuming and expensive. Battery life model has been demonstrated to be an effective tool to identify and quantify battery fade mechanisms with limited number of characterization experiments and able to predict battery performance at off-characterization conditions. Testing statistics are crucial to life model accuracy, providing inputs to the life model including depth of discharge, temperature variation, average C-rate, capacity throughput, etc. Due to the limits of battery testing, information such as temperature can be only measured in a practical way. For example, battery temperature is measured external to the battery during operation. Because the potential large temperature gradients between battery cell internal and external, the measured parameters are insufficient sometimes to represent battery temperature. Particularly, large format batteries have more significant non-uniform temperature and potential fields leading to differential cycling and thus aging of certain cells within the pack. Without accurate inputs, the life model could fail to capture non-uniform cell degradation in a large battery system. A life modeling approach is developed at NREL for lifetime assessment of a 1.5kW lithium ion battery for ground vehicles. The approach is based on interactively coupling of a 3D electrochemical-thermal model and reduced-order physical-based aging model with a period of cycle numbers. By integrating a 3D electrochemical-thermal model and reduced-order degradation physics-based life model, the proposed approach is aimed to enhance life model accuracy for battery aging diagnosis and life extrapolation. A 3D electrochemical-thermal model gives temperature and potential throughout the battery unit for arbitrary drive cycles and thermal environments. Working like reference performance tests during aging experiments, 3D electrochemical-thermal simulation is performed per a period of life cycles. Its results are statistically analyzed with the physics-based life model to obtain new input values for the electrochemical-thermal model at the next state of life. The 3D electrochemical-thermal model is electrically and thermally calibrated versus

electrical characterization testing (i.e. capacity and hybrid pulse power characterization) and calorimetry measurement respectively. Accelerated aging experiments were performed at 38, 50 and 60 degree Celsius. Part of this experimental data is used for life model parameter extraction. Prediction capability of the model is validated with rest of the aging experimental data. It demonstrates the approach enables prediction of performance changes of individual cells without extra measurements.

**Zhou, G. • Church, C. • Shaaban, A.H.**

### Active Cooling Thermally Induced Vapor-Polymerization Effect (ACTIVE).