DoD Research and Engineering

2016 Ground Robotics Capabilities Conference
National Defense Industrial Association

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March 3, 2016

Defense R&E Strategy

1. **Mitigate current and anticipated threat capabilities**
   - Cyber
   - Electronic Warfare
   - Counter Space
   - Counter-WMD
   - Missile Defense

2. **Affordably enable new or extended capabilities in existing military systems**
   - Systems Engineering
   - Modeling and Simulation
   - Capability Prototyping
   - Developmental Test & Evaluation
   - Interoperability
   - Power & Energy

3. **Create technology surprise through science and engineering**
   - Autonomy
   - Data Analytics
   - Human Systems
   - Hypersonics
   - Quantum Systems
   - Basic Sciences

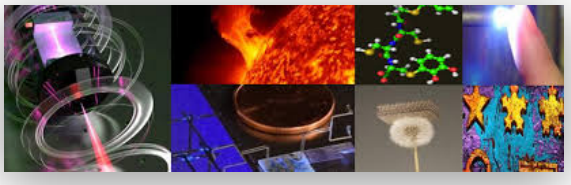
Researchers and Engineers doing game-changing work

Technology Needs

- Cyber / Electronic Warfare
- Engineering / M & S
- Capability Prototyping
- Protection & Sustainment
- Advanced Machine Intelligence
- Anti-Access/Area Denial (A2/AD)

Preserving Technological Superiority

- **US and Allies have been able to count on a decisive technological advantage for more than 40 years**
  - Advantage built on technologies developed by and for the US military
    - Precision weapons, long-range intelligence, surveillance and reconnaissance (ISR), stealth



- **What has changed:**
  - Increasingly global access to resources, technology and talent
  - Competitors investing in capabilities directly designed to counter US technical advantage: tactics, techniques, technologies, procedures
  - Responding to such an environment requires agility and a commitment to invest to keep pace with technical opportunity
  - Drives a focus on cost and cycle time

DoD Innovation

- **In response to this long-term challenge, DoD seeks competitive advantage through innovation…**
  - ***Leveraging all sources of innovation opportunity***:
    - Academia, Commercial, Defense Industry, Organic (DoD Labs), Global Sourcing (Allies and Partners)
  - ***Time to market matters*** – Accelerate the Technology Adoption Cycle
    - Out-innovate competitors with access to the same commercial technology base
  - ***Speed transition from Laboratory to Fleet***
    - Prototyping, Demonstrations, Operational Experiments
  - ***Innovation enables Strategy***

Technology Influences Strategy

- An offset is some means of ***asymmetrically compensating*** for a disadvantage, particularly in a military competition.

- Rather than match an opponent in an unfavorable competition, ***changing the competition*** to more favorable footing enables the application of strengths to a problem that is otherwise either unwinnable or winnable only at unacceptable cost.

- An offset strategy consequently seeks to deliberately change an unattractive competition to one more advantageous for the implementer. In this way, an offset strategy is a type of ***competitive strategy that seeks to maintain advantage over potential adversaries over long periods of time*** while preserving peace where possible.

"…he [Secretary Carter] asked us to seek game changing technologies and make more discreet technological bets that exploit our advantages as well as adversary weaknesses. "

– Bob, Work, Deputy Secretary of Defense, Budget Rollout Brief, 9 Feb 2016

Previous Offset Strategies

- **"First Offset Strategy"**
  - Emphasis on ***nuclear deterrence to avoid the large increase in defense expenditures*** necessary to conventionally deter Warsaw Pact forces during the 1950s.
- **"Second Offset Strategy"**
  - Following the Vietnam War, U.S. tolerance for defense expenditures plummeted while Warsaw Pact forces outnumbered NATO forces by three to one in Europe.
  - DoD sought ***technology to "offset" the numerical advantages*** held by U.S. adversaries.
    - Emphasized: ***Intelligence, Surveillance, and Reconnaissance (ISR) platforms; Precision-Guided Weapons; Stealth***; and the expansion of space's role in military communications and navigation.
    - Guided by a long-range research and development plan that enabled U.S. and allied forces to ***hold adversary forces at risk long before they could bring superior numbers to bear***.
  - ***Shaped, in many ways, the U.S. military of today.*** Key resulting systems include:
    - Airborne Warning and Control System (AWACS) found on the E-2s and E-3s
    - F-117 stealth fighter and its successors
    - Modern precision-guided munitions
    - Global Positioning System (GPS)
    - Significant enhancements in reconnaissance, communications, and battle management

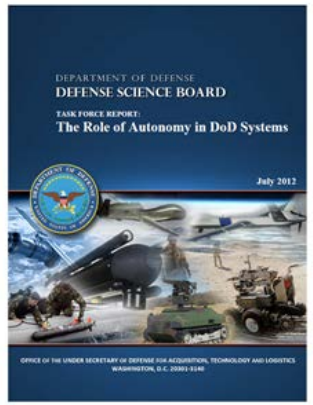
These Offset Strategy's technologies continue to enable U.S. global precision strike today

Toward a Third Offset Strategy

- **Autonomous Learning Systems**
  - Delegating decisions to machines in applications that require faster-than-human reaction times
    - Cyber Defense, Electronic Warfare, Missile Defense
- **Human-Machine Collaborative Decision Making**
  - Exploiting the advantages of both humans and machines for better and faster human decisions
    - "Human strategic guidance combined with the tactical acuity of a computer"
- **Assisted Human Operations**
  - Helping humans perform better in combat
- **Advanced Manned-Unmanned System Operations**
  - Employing innovative cooperative operations between manned and unmanned platforms
    - "Smart swarm" operations and tactics
- **Network-enable, autonomous weapons hardened to operate in a future Cyber/EW Environment**
  - Allowing for cooperative weapon concepts in communications-denied environments

Thinking About Autonomy

- **What does military autonomy mean?**
  - Autonomy as a capability…
  - Collaboration between the technology and the operator / warfighter
    - Natural use interfaces, trusted human-system collaboration
    - Perception and situational awareness to operate in complex environments
  - Within specified design limits on actions and decision
    - Explicit allocation of cognitive functions
    - Varying by mission, phase, and echelon
    - Operating within explicitly defined tradespace
  - Trust: Systems, Software, Platforms, Operators
    - Bringing together military operators, academia, not-for-profit labs, and industry



Unmanned Systems Require these Capabilities

- **Focused Situational Awareness**
  - Semantic labeling of objects & behaviors
  - Relationships
- **Adaptive Tactical Reasoning**
  - Learning
  - Mission & Task Knowledge
- **Efficient Proactive Interaction with Humans**
  - Shared mental model
- **Safe Secure and Adaptive Movement**
  - Adaptive behavior
  - Cognizance of mission & environment
- **Interaction with the Physical World**
  - Move and manipulate

Autonomy and Robotics

- **DoD Investments in Autonomy**
  - Focus on developing autonomous systems that allow for ***performing complex military missions in dynamic environments*** – with the right balance of warfighter involvement

- **New applications**
  - Harsh, hazardous, and unknown environments
  - Rapid response and 24/7 awareness; timely, persistent and enduring
  - Advanced medical applications; critical response and end-to-end critical care
  - ***Enabling new operational concepts***

Autonomy COI

Purpose

Advancement of autonomous systems, and identification of potential investments. to advance or initiate critical enabling technology development

What's driving Autonomy S&T?

- **Manpower efficiencies**
  - Reduce human footprint
  - Reduce personnel cost
- **Rapid response, 24/7 aware**
  - Timely, persistent, enduring
- **Harsh environments**
  - Day/night, hot/cold
  - Weather/rubble
- **New mission requirements**
  - Increasing competence
  - New capabilities
- **Advanced medical applications**
  - Critical response
  - End-to-end critical care
- **Logistical support**
  - Reduce logistics burden

Autonomy Focus Areas

Machine Perception, Reasoning and Intelligence (MPRI)

- World model
- Learning & reasoning

Human/Autonomous System Interaction & Collaboration (HASIC)

- Common understanding of perceptions and decisions
- Human-machine interaction & trust

Scalable Teaming of Autonomous Systems (STAS)

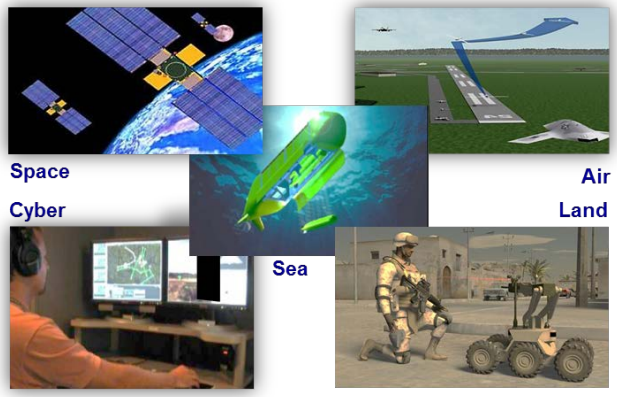
- Decentralized perception, planning, & execution
- Self-organization, adaptation, and collaboration

Test, Evaluation, Validation, and Verification (T&E/V&V)

- Test & Evaluation of learning systems
- Verification & Validation of highly complex software

Autonomy COI
Enduring Gaps

- ***Open, cognitive architectures*** that facilitate interaction between intelligent systems and human
- Planning and reasoning for ***dynamic, uncertain operational and physical environments***
- Concepts for ***decentralized perception, planning, collaboration*** among large groups of heterogeneous, autonomous agents
- Robust ***supervised and unsupervised learning***
- ***Natural, intuitive communications*** between humans and intelligent agents/systems

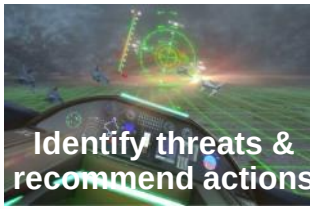


- Creation of ***"common ground" and communicating intent*** (abstract reasoning)
- Means for ***assessing the safety and performance*** of systems that learn and alter behavior over time

Technology for Increasingly Intelligent Systems

Human-Machine Teams

Machine-Assisted Operations



Logistical Operations

Operating Safely & Efficiently

Near-Term	Mid-Term	Far-Term
Present - 2020	2020-2030	2030+

Teaming of Men and "Intelligent Machines" to Expand Capabilities

Autonomy S&T

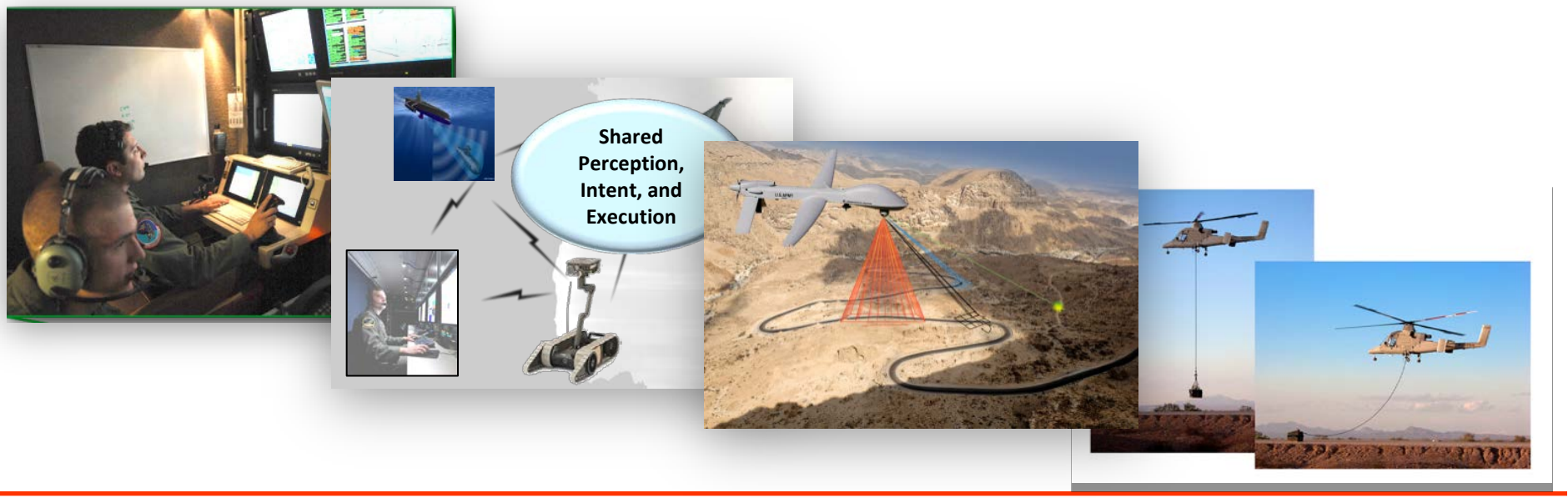
- **Autonomy at rest**
  - High Speed Decision Making
  - Human / Machine Collaboration
  - Operating with large data

- **Autonomy in motion**
  - Mobile systems on battlefield
  - Human / Robot Teaming
  - Air / Land / Sea (Cross-domain)
  - Operations in denied-communications / -GPS environments

Autonomy that allows Warfighters to focus on their primary mission, not on operating their tools

Autonomy S&T Challenges

- Human / Autonomous System Interaction and Collaboration
- Scalable Teaming of Autonomous Systems
- Machine Perception, Reasoning and Intelligence
- Test, Evaluation, Validation and Verification

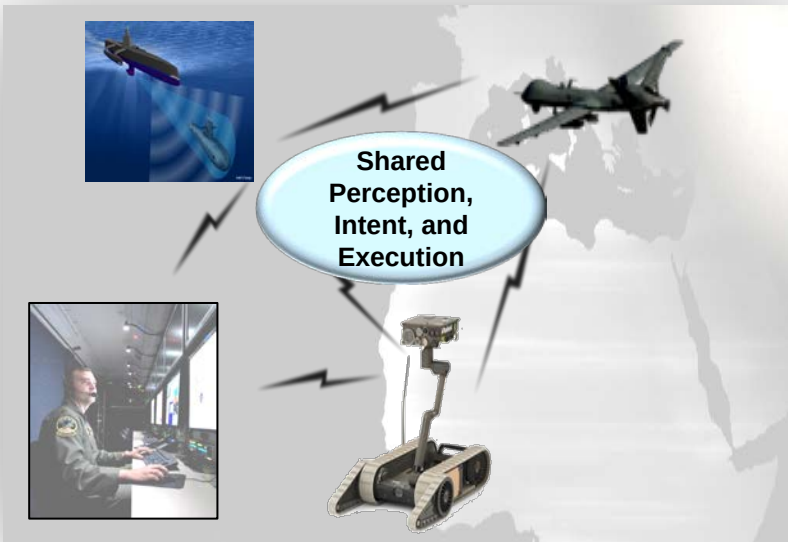


Human / Autonomous System Interaction and Collaboration

- **Central Technical Challenge: Shared Perception and Understanding**
  - Robust Cognitive & Neurological Models
  - Integration of Artificial Intelligence & Human Cognitive Models
  - Trust in Automation /Transparency
  - Control Station Human Factors Engineering
  - Advanced Feedback interfaces to Maximize Machine
  - Machine Perception

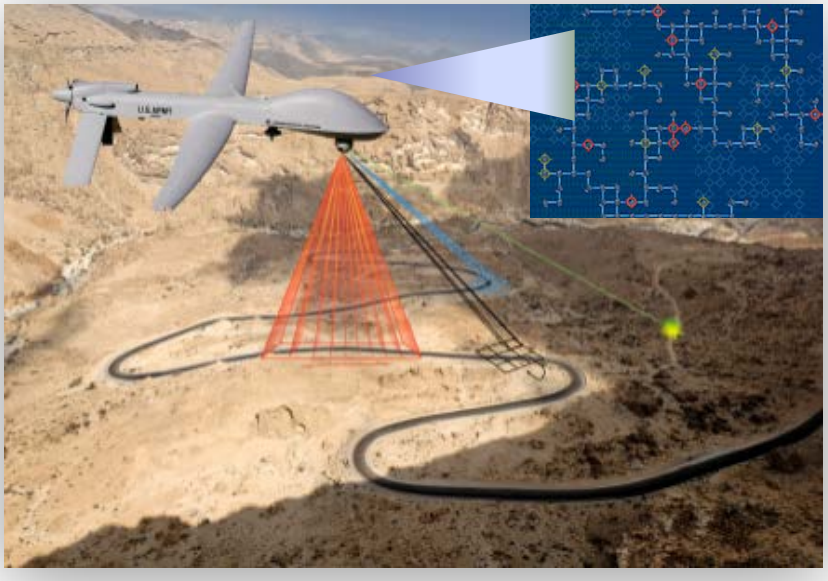
Scalable Teaming of Autonomous Systems

- **Central Technical Challenge: Shared Mission Intent and Execution**
  - Secure Communication Between Multi-Agents
  - Shared Problem Solving & Reasoning
  - Shared Perception
  - System Health Management
  - Shared Mission Planning/Execution
  - Agent Attrition Management



Machine Perception, Reasoning and Intelligence

- **Central Tech Challenge: Integrated Contextual Decision Making**
  - Data-Driven Analytics
  - Sensor/Data Decision Models
  - Advanced Algorithms to Enable Operations
  - Contingency-based Control Strategies
  - Advanced Decision Making Algorithms
  - Adaptive Guidance and Control
  - Synchronized Space Mgmt & Mission Control



Test, Evaluation, Validation and Verification

- **Central Tech Challenge: From algorithms up to scalable teams of multiple systems, safe and secure ops**
  - **Simulated and Live Test Beds for:**
    - Human-Agent Teaming
    - Controlled, Coordinated Actions by Multiple Agents
    - Operation in Complex, Contested Environments

Formal design for certification must be accomplished in early requirements development to maximize the operational gains of advanced autonomy

DARPA Robotics Challenge Winners (June 6, 2015)

First Place

Team KAIST
Daejeon, South Korea
Robot: DRC Hubo

Second Place

Team IHMC Robotics
Pensacola, Florida
Robot: Running Man (ATLAS)

Third Place

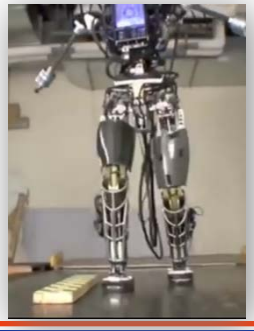
Team Tartan Rescue
(CMU / NREC, Largely now Uber)
Pittsburgh, Pennsylvania
Robot: CHIMP

DRC High Level Achievements

- The ***DARPA Robotics Challenge (DRC)*** improved the ability of human-supervised robots to operate in significantly degraded physical and radio free environments.

- **Prior to the DRC, performance of ground robotics required either:**
  1. Highly structured environments where geometry was precisely understood, or
  2. Highly reliable communications to support real-time situational awareness and "joystick" type control

- **The DRC demonstrated:**
  1. ***Predictive operator interfaces*** that gave supervisors situational awareness and control, even under highly degraded communications
  2. ***Task-level robot autonomy*** (like "open the door") that works even when precise geometry is not known and communications is down
  3. Compliant ***robots that are both more capable of adapting*** to unknown geometries and also safer for humans to be around
  4. A real-time simulation capability that allows ***development of complex human-supervised robotic systems*** in a realistic unstructured environment



An Enterprise-Wide Focus on Innovation

- **Grow and sustain our S&T capability…**
  - Force of the Future
  - Defense Innovation Unit-Experimental
  - Speed to Market
  - Prototyping, demonstrations, and experimentation
  - Science, Technology, Engineering and Math (STEM)
  - Better Buying Power: Innovation, Technical Excellence, Speed to Market
  - Modular, Open Systems Architecture

Force of the Future

- **Recruit and retain a workforce** ready to address the technical and operational demands ahead

- A Department ***open to ideas*** and the ***flow of talent*** in and out of DoD
  - Talent must not be taken for granted
  - Address generational, technological, and labor market changes
  - Increase permeability of the DoD workforce: Sabbaticals, internships, transitions
  - Continue to attract the talent needed to demonstrate high standards of performance, leadership, ethics, honor and trust

DoD Science, Technology, Engineering and Mathematics (STEM) Efforts

Mission: *Attract, inspire, and develop exceptional STEM talent across the education continuum and advance the current DoD Science and Engineering workforce to meet future defense technological challenges*

- ***Communicate*: Growing opportunities to work cutting edge, leap-ahead technologies**
- ***Inspire*: Young scientists and engineers to consider careers with the Department**
- ***Cultivate*: Culture of Innovation to sustain our competitive edge**
- ***Promote*: Diversity and agility of thought**
- ***Enhance*: Continued professional development and growth**

DoD Innovation Strategies

- **Shifting culture → Leaning forward into a complex security environment**
  - Technologies, operational and organizational constructs, people
- **Growing organically → Looking externally**
  - DoD Laboratories, academia, defense industry, DIUx, global sourcing (allies and partners)

- **Avoid technology surprise → Seeking asymmetric advantage**
  - Third Offset Strategy; Robotics, Big Data, Visualization, Microelectronics, Hypersonics, Directed Energy, …?
- **Leveraging new sources of technology → Servicing and expanding core competencies**
  - Prototyping, demonstrations, and experimentation; Modular, Open Systems Architecture; Manufacturing Innovation Centers

DoD R&E Enterprise:
Pursuing Sustained Technical Advantage







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