U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

Exoskeletons for Soldier Augmentation: Current Research Perspectives

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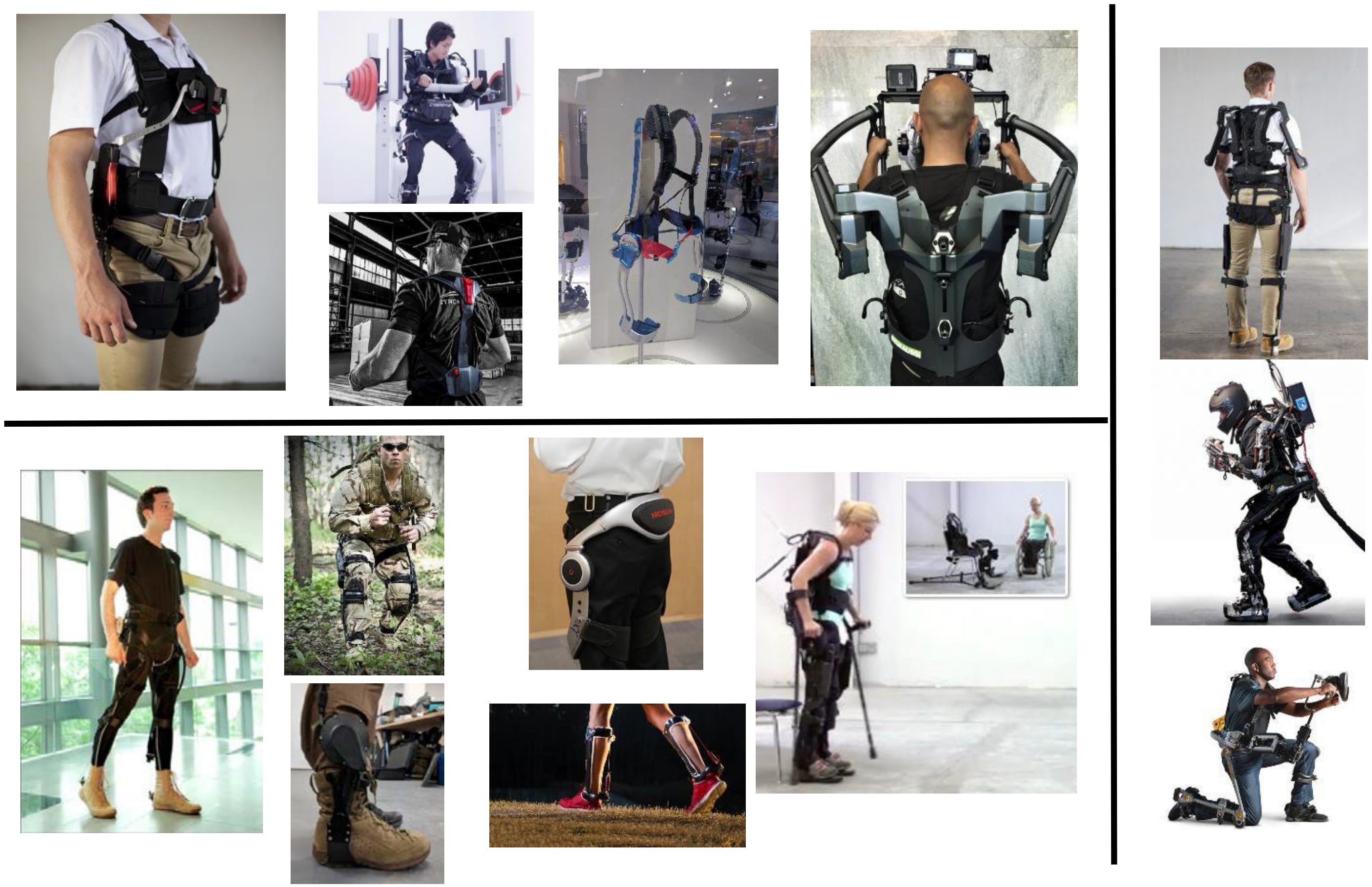
TECHNOLOGY PROLIFERATION

UNCLASSIFIED



WHAT IS AN EXOSKELETON?

Definition:

- Exoskeleton: Rigid human wearable device that augments, enables, or enhances motion or physical activity. In the context of augmentation, an exoskeleton is commonly powered or unpowered. Powered systems are commonly active or semi-active systems and include actuators and power supply. Unpowered systems are commonly passive or semi-passive systems.
- Exosuit: Non-rigid human wearable device that augments, enables, or enhances motion or physical activity.
- Augmentation System: Equipment designed to enhance performance; exoskeleton, wearable robot, wearable augmentation, and augmentation system are commonly used interchangeably.

Crowell, H.P., Kanagaki, G.B., et al., 2018. *NSRDEC/ARL Joint Report: Methodologies for Evaluating the Effects of Physical Augmentation Technologies on Soldier Performance.* Technical Report ARL-TR-8444. Aberdeen Proving Ground, MD: US Army Research Laboratory

INTERNATIONAL EXOSKELETON ACTIVITIES

- ASTM International Committee F48 Exoskeletons and Exosuits
  - Sept 2017: Addresses safety, quality, performance, ergonomics, and terminology for systems and components during the full life cycle of the product
  - Covers military, industrial, emergency response, medical, and consumer applications
  - October 2018 Meeting OCT 3-4, 2018 ASTM International HQ, W. Conshohocken, PA
- TTCP HUM JP1 Activity Plan "Human-centred design of wearable assistive technologies for dismounted combatants"
  - June 2017: Develop standardized testing and analysis methodologies for the evaluation of assistive devices; determine the biomechanical, physiological, and psychophysical benefits of these wearable assistive devices; inform industry's development of wearable assistive devices through human-centered design; and provide evidence-based design guidance identifying tasks and body location(s) where augmentation would provide the greatest benefit.
- NATO Integration of Exoskeleton in the Battlefield Workshop
  - Nov 2017: Understand exoskeleton technology and potential for application for Explosive Ordinance Disposal (EOD)

PURPOSE AND INTENT

1. Summarize the current state of exoskeletons for DoD applications
2. Identify the critical research areas to advance technologies for close combat overmatch

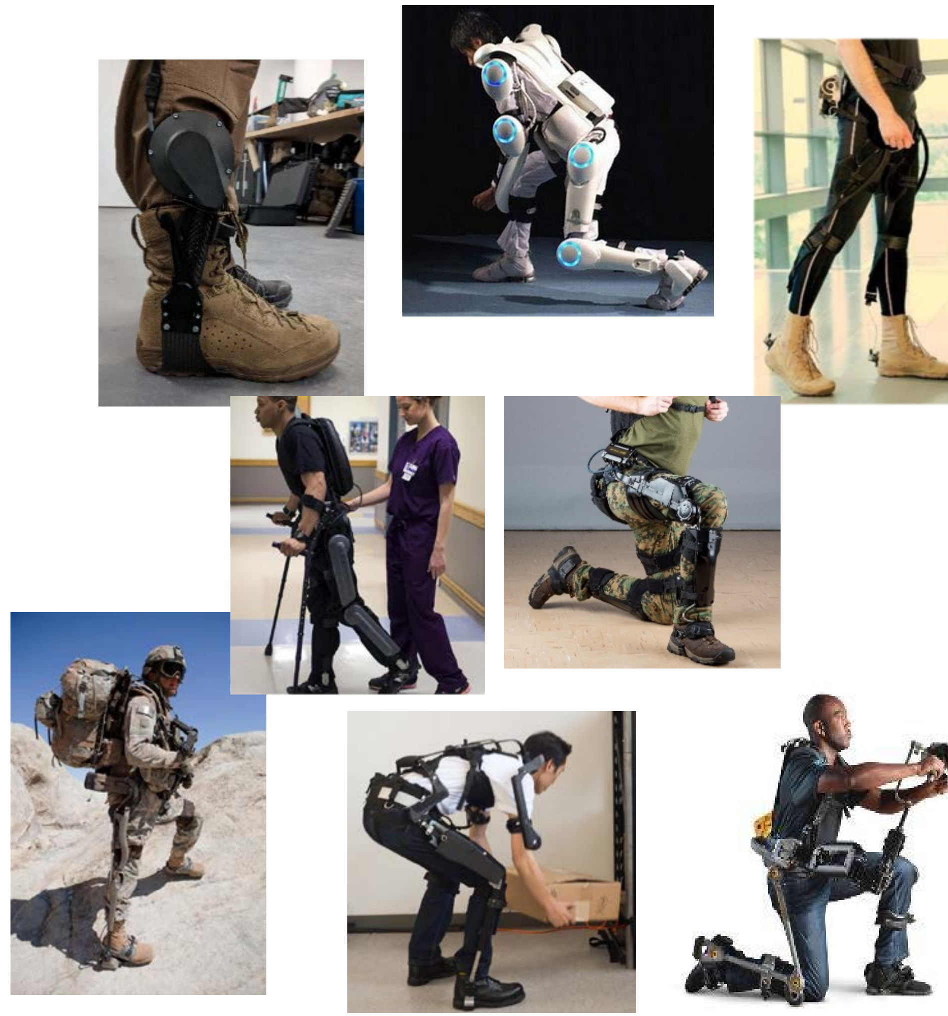
DOD/OUSD(R&E) EXO TECHNICAL INTERCHANGE

- **Date:** 25-26 APR 2018 @ NSRDEC
- **Sponsor/Why:** OUSD(R&E), Supports SECDEF Mattis' Close Combat Lethality Task Force & Army's Soldier Lethality CFT
- **Hosts:** Mr. Dale Ormond (OUSD(R&E)),
- BG Vincent Malone (CDR NSSC, DepCDR RDECOM), Mr. Doug Tamilio (Dir, NSRDEC)
- **Participants:** ~95 across DoD, Industry, Academia
- **Panels:**
  - DoD User Capability Panel
  - DoD R&D Investments Panel
  - Exoskeleton Developer Panel
  - Exo State of the Science Panel

EXOSKELETONS

What do people think of when they hear the term "exoskeleton"?

What do current exoskeleton systems actually look like?



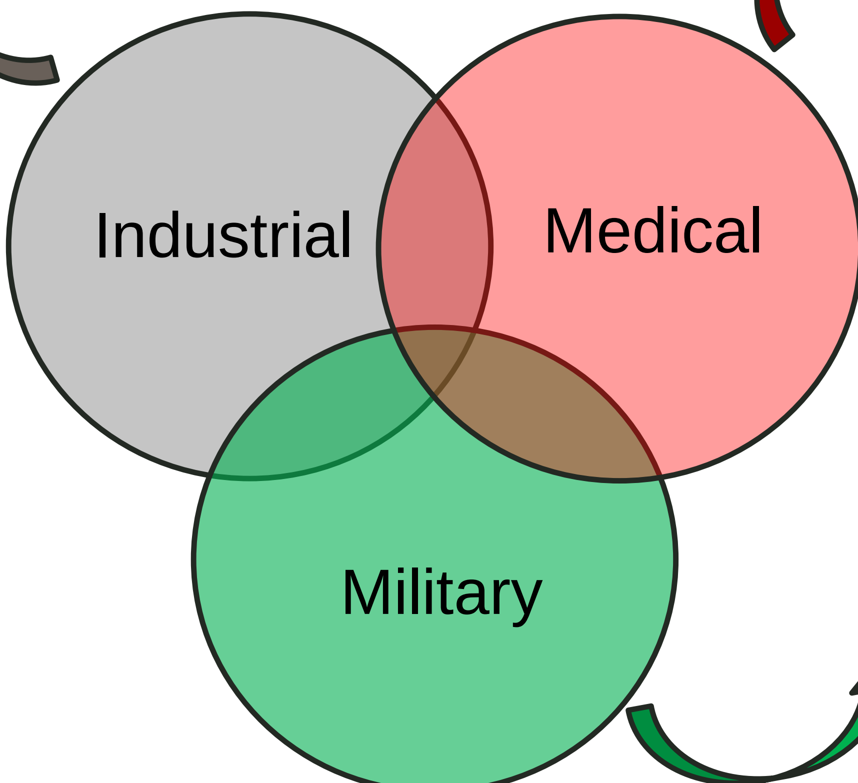
WHAT ARE THE CURRENT APPLICATIONS?

Injury Reduction & Increased Workplace Safety

- task specific and lower mobility
- tool handling support systems
- postural support systems
- manual material handling

Quality of Life (QOL) Improvements to Reduce the Secondary Effects of Spinal Cord Injury (SCI) and Stroke

- mobility and exercise
- bone loss
- bladder issues
- lean tissue loss



Increased Soldier Performance & Injury Reduction

- Movement & Maneuver
  - endurance, strength, speed
  - high mobility
  - load carriage
- Sustainment
  - task specific and lower mobility
  - tool handling support systems
  - postural support systems
  - manual material handling

MEDICAL APPLICATIONS

Purpose: Can Exoskeletons safely & effectively provide: upright walking mobility, increased physical activity & energy expenditure, better self-esteem, QOL, and overall health by mitigating some of the secondary medical consequences of SCI?

Results:

- Seated forward and lateral stability was improved.
- Energy expenditure was moderately increased from sitting and standing during Exo Assisted Walking.
- Most participants lost fat mass.
- Participants self-reported significant improvements in bowel and bladder function, better sleep and reduced pain.
- HDL-c levels were improved
- Not all individuals are eligible users of these systems
- Individual response to training varies.

ReWalk 2010
(ReWalk Robotics, Inc., Israel)

Ekso 2011
(Ekso Bionics,Berkeley, CA)

Indego 2013
(Parker Hannifin Corp., Cleveland, OH)

Spungen, A.M., “Exoskeletal-Assisted Walking for Persons with Spinal Cord Injury,” DoD Exoskeleton Technical Interchange (ETI) April 25-26 2018; NSRDEC; Natick, MA

MEDICAL GAPS

https://peteredwards2012.wordpress.com/ekso-bionics-elegs/

Gaps:

- Who are best candidates and for which devices?
- How much training is needed to become proficient?
- What is the best bone criteria to avoid risk of a fragility fracture?
- Can these devices be used safely and effectively in acute inpatient rehabilitation?
- What is the dosing level to get positive changes for any of the various health- or medical-related outcomes?
- What tests should be used to define proficiency?
- Can standards for testing skills and level of assistance be developed?
- Can devices be used safely independently?
- Can walking speeds be safely increased to be more in line with normal walking velocity (fastest velocities range from 0.15 – 0.72 m/s; average adult is 1.39 m/s).

Spungen, A.M., "Exoskeletal-Assisted Walking for Persons with Spinal Cord Injury," DoD Exoskeleton Technical Interchange (ETI) April 25-26 2018; NSRDEC; Natick, MA

INDUSTRIAL APPLICATIONS

Purpose: Can exoskeletons be used in the workplace to provide postural, tool handling, and manual material handling support while also reducing ergonomic risk factors?

Results: Limited assessments of industrial exos are being conducted at Boeing, Ford, BMW, and Lockheed Martin, therefore results are site and system dependent. In general:

- Appear to provide assistance for the specific tasks they are designed to assist
- Subjective feedback is varied & changes over time in the device
- Some systems show reductions in muscle activity and utilization, as well as in lumbar shear and compressive forces
- Fit accommodation for varying body dimensions still needs improvement

Gaps: How do you measure value and ROI on an exoskeleton?

- Prospective, long term, and life cycle data are still needed, especially with regard to injury prevention
- Relative contributions to productivity, quality control, payback time, and injury savings still need to be quantified.

Lockheed Martin FORTIS™ exoskeleton

Ekso Bionics

3M StrongArm

Kyte, K.A.K., "Industrial Exoskeletons: Experiences from Boeing Towards Industry Adoption", DoD ExoskeletonTechnical Interchange (ETI) April 25-26 2018; NSRDEC; Natick, MA

MILITARY APPLICATIONS

Purpose: Can exoskeletons be used in operational and combat settings to increase Soldier performance, reduce injury, and provide close combat overmatch?

Results: Over the last decade, multiple systems designed to augment load carriage have been assessed by NSRDEC and ARL-HRED. Additionally, a subset of high TRL Movement & Maneuver and Sustainment systems are being acquired to assess their potential to enhance the Soldier.

- Movement & Maneuver Systems have recently demonstrated a reduction in energy expenditure for load carriage walking tasks in controlled settings (6-20% reduction, depending on the system and condition tested).
- Users differ in their response to the applied augmentation
- Fit of the system affects comfort, user acceptability, and performance.
- Operational environments present the most difficult scenarios for system controls development
- Assessment of prototype exo systems for both Movement & Maneuver and Sustainment tasks are underway

DEPHY – BIONIC BOOT

Description: Boot-integrated exoskeleton providing lightweight, dynamic, and powered mobility.

Potential Operational Benefits:

- Go faster and farther by increasing endurance and walking speed
- Reduce time for movement to objective
- Maintain peak performance longer
- Allowing Soldiers to stay in the fight, increasing lethality
- Extend battlefield space / Warfighter reach
- Reduce physical exertion, thereby reducing injury risk
- Provide full range of joint motion and allow for running, crawling, and jumping

Current Contract Goals:

- TRL 4 → TRL 5+
- Metabolic Reduction: 25%
- Walking Speed Increase: 15%
- Durability: 450 miles
- Power Consumption: 50W / leg
- Don and Doff: 30 seconds
- Environmental protection: Dust and rain proof
- Speed and terrain adaptive controllers

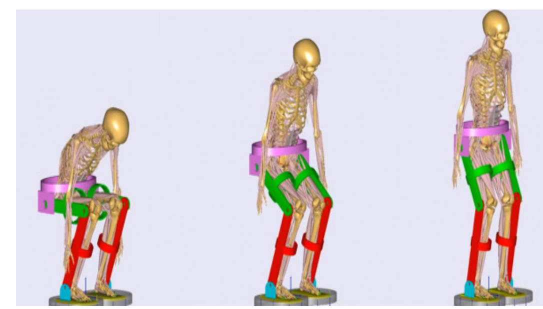
Schedule:

- FY16-18: Iterative device development & evaluations
- FY19: Delivery of prototypes and evaluation
- FY19: Final Report
- FY19: Limited user field evaluation (Tentative)

MILITARY GAPS:

RESEARCH AREAS IDENTIFIED TO ADVANCE SYSTEMS FOR CLOSE COMBAT OPERATIONS

- Define/Measure Operational Success – ARL-HRED
  - Demonstration and validation of the relationship between laboratory measures and operational performance outcomes
- Task Characterization & Human Performance Variability – ARL-HRED
  - Robust data sets characterizing warfighter performance on basic and close combat tasks to inform augmentation system requirements
- Modeling & Simulation
  - M&S tools to aid with the design and development of wearable exoskeletons (i.e., sophisticated human model and exoskeleton model in same environment with accurate characterization of the complex human-machine interaction)
- Medical Implications of Exo Use—USARIEM/MRMC
  - Examine device dependent impacts on potential acute and long-term injury
  - Characterize injuries and injury rates over time, from USARIEM's Total Army Injury and Health Outcomes Database (TAIHOD) resource and targeted field studies
  - Understand the prescribed use and extent of augmentation to maintain strength/capability/performance, while reducing likelihood of injury or injury recurrence

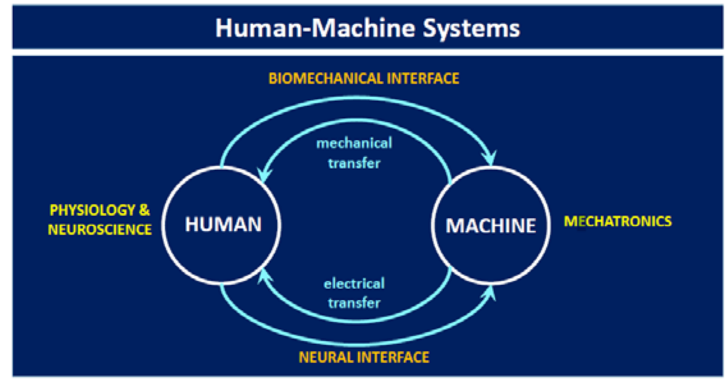


Marinov B., Modeling **a Human in an Exoskeleton: AnyBody Simulation,** Exoskeleton Report May 22, 2015

MILITARY GAPS:

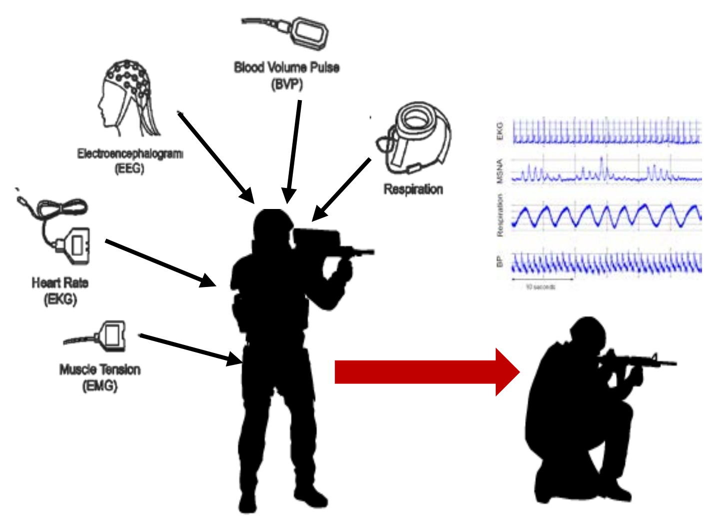
RESEARCH AREAS IDENTIFIED TO ADVANCE SYSTEMS FOR CLOSE COMBAT OPERATIONS

- Smart Adaptive Controls to Promote Fluency and Embodiment -- NSRDEC
  - Use bio-signals (e.g., imbedded EEG and EMG sensors) to detect user intention, transitional states (e.g., walk to run), and other non-steady-state movements (e.g., moving over terrain and tactical movements involving slow, deliberate postures) and to sense/adapt to individual users and user states to optimize performance (e.g., sense fatigue and provide greater augmentation).



Daniel Ferris, PhD., Robert W. Adenbaum Professor of Engineering Innovation

- Adaptation & Training -- NSRDEC
  - Understand differences between users with regard to using augmentation technologies in order to tailor use and training for optimal user-system performance. For example, some individuals are quick learners and trust the systems and others require more training time and potentially a different type of exposure to the system to facilitate acclimatization.

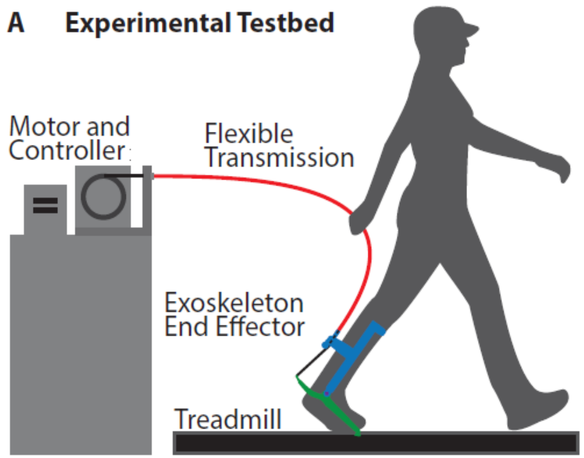


MILITARY GAPS:

RESEARCH AREAS IDENTIFIED TO ADVANCE SYSTEMS FOR CLOSE COMBAT OPERATIONS

- Increased Experimental Throughput and Human–in-the-Loop Testing for Advanced Development -- NSRDEC
  - Exoskeleton system performance is influenced by many hard to quantify variables; therefore, robust Human-in-the-Loop testing is necessary for successful development.
  - Employ emulators to increase the throughput of experimental tests to identify the appropriate joints to actuate, the magnitude of actuation, and the timing of the actuation needed for a given task to optimize human performance.

Human-in-the Loop Optimization



http://biomechatronics.cit.cmu.edu/publications/Witte_2015_ICRA.pdf

CONCLUSIONS

- Sustainment exoskeletons are more mature in their development and the military has the potential to leverage the industrial systems for near-term military use
- Movement & Mobility exoskeletons are quickly advancing and show promise for dismounted operations, to include movement to an objective and close combat operations
- Targeted resourcing and support to research areas highlighted are required to advance the state of the art and realize combat overmatch via physical augmentation systems. Research areas needed are:
  1. Advancing the design of exoskeleton controls
  2. Enhancing the communication between the human and the system
  3. Increasing the understanding of training and adaptation on user-system performance