Exoskeleton Technical Interchange Meeting
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Ongoing Related Standards Work

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National Institute of Standards and Technology
U.S. Department of Commerce

Outline

- Related Standards
  - Terminology
  - Safety
  - Performance
- Cross-Industry Measurements Applicable to Exoskeletons
  - Joint Rotation Axis Location
  - Industrial Mobile Manipulator
  - Response Robots
- Potential Exoskeleton Test Methods
  - Load Handling (load lift and carry)
  - Navigation (movement between locations)
  - Docking (load placement)
- Exoskeleton Test Dummy

Related Standards

Terminology

- ISO/TC 299/WG 1 Vocabulary and characteristics
  - ISO 8373:2012 Robots and robotic devices — Vocabulary
- ISO/TC 173/SC 2 Classification and terminology
  - ISO 9999:2016 Assistive products for persons with disability -Classification and terminology
- ASTM F3200-16 Standard Terminology for Automatic Guided Industrial Vehicles
- E2521-07a: Standard Terminology for Urban Search and Rescue Robotic Operations
- ISO/CD 19649 Robots and robotic devices ---Vocabulary for mobile robots (under development)

- ISO 8373 contains basic terms which relate to all robotic fields.
- At this time, there are no specific terms related to exoskeletons.
- Expected in the near future is that some terms will be developed during development of a performance or safety standard on exoskeletons.
- After these are finished, “we will look into the possibility of putting these new terms into ISO 8373 when we revise it.”

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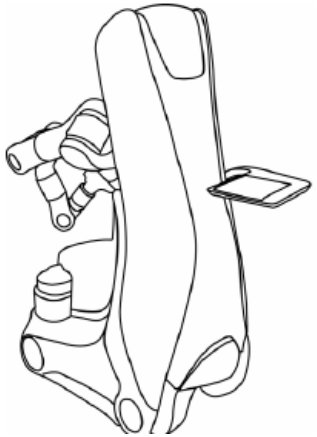
Related Standards

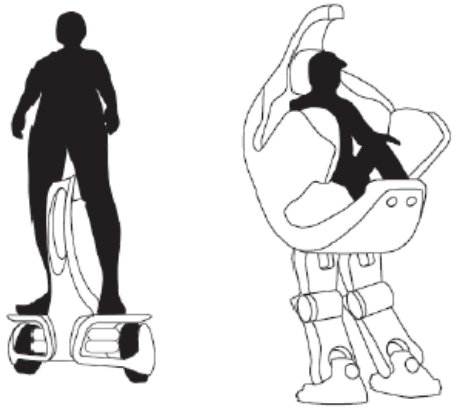
Safety

Personal Care

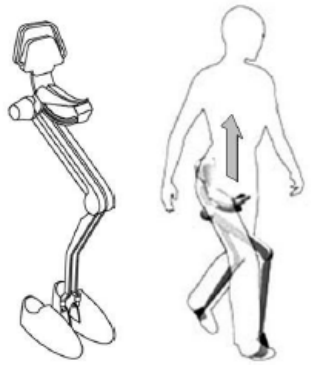
- ISO 13482:2014 Robots and robotic devices -Safety requirements for personal care robots (ISO/TC299/WG2)
- ISO/CD TR 23482-1 Robotics -Application of ISO 13482 -Part 1: Safety-related test methods (in-process)
- ISO/CD TR 23482-2 Robotics -Application of ISO 13482 -Part 2: Application guide (not started)
- JIS B 8446-2:2016 Safety Requirements For Personal Care Robots Part 2: Low Power Restraint-type Physical Assistant Robot



mobile servant robot



person carrier robot



physical assistance robot

Related Standards

Medical (e.g., …)

- IEC 60601-1:2005+AMD1:2012 CSV Edition 3.1 (2012-08-20); Medical electrical equipment—Part 1: general requirements for basic safety and essential performance
- IEC TR 60601-4-1; … employing degree of autonomy; in progress - available 2017
- JWG 5 Joint ISO/TC 299 IEC/SC 62A IEC/SC 62D WG: Medical robot safety

  With subgroups:
  - JWG 35: Surgical Robot Safety
  - JWG 36: Rehabilitation Robot Safety
- FDA publication on Medical Devices; Physical Medicine Devices; Classification of the powered exoskeleton (2015). https://federalregister.gov/a/2015-03692; 80 FR 9600; pp. 9600–9603

Assistive products for persons with disability ISO/TC 173/

- WG 1 Assistive products for walking
- WG 10 Assistive products for cognitive disabilities
- WG 11 Assistive products for tissue integrity
- WG 12 General requirement
- SC 1 Wheelchairs
- SC 2 Classification and terminology
- SC 7 Accessible design

Courtesy Eastin, Diabled-World.com

Related Standards

Other ISO/TC 299/

- SG 1 Study group on gaps and structure
- WG 4 Service robots
- WG 6 Modularity for service robots

Courtesy iRobot

Courtesy John Deere

Industrial Robots

- ISO TC299/WG3 ISO 10218-1:2011 Robots and robotic devices -Safety requirements for industrial robots -Part 1: Robots
- ISO TC299/WG3 ISO 10218-2:2011 Robots and robotic devices -Safety requirements for industrial robots -Part 2: Robot systems and integration
- ISO TC299/WG3 ISO/TS 15066:2016 Robots and robotic devices -Collaborative robots
- ANSI R15.06-2012 Industrial Robots and Robot Systems Safety Requirements
- ANSI R15.08-TBD Industrial Mobile Robot Safety (in-process)
- ISO TC299/WG3 Standard for End-of-Arm Tooling (in-process)

Courtesy Universal Robots

Automatic Industrial Vehicles

- ITSDF B56.5:2012 Safety Standard for Driverless Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles

Courtesy Swisslog

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Related Standards

Performance

Industrial Robots (ISO TC 299/WG3)

- ISO 9283 (ANSI/RIA R15.05) Manipulating industrial robots -Performance criteria and related test methods
- ISO/TR 13309:1995 Manipulating industrial robots -Informative guide on test equipment and metrology methods of operation for robot performance evaluation in accordance wit ISO 9283

Courtesy Fanuc

Autonomous Industrial Vehicles (all in ballot stages)

- ASTM F45.01 WK54576 Standard Practice for Environmental Effects
- ASTM F45.02 WK48955 Standard Test Method for Navigation: Defined Spaces for A-UGVs
  - Standard Test Method for Docking A-UGVs
- ASTM F45.03 WK54662 Standard Test Method for Grid-Video Test Method for A-UGVs
- ASTM F45.04 WK54431 Standard Practice for Communication and Integration Interruptions for A-UGVs

Courtesy Adept

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Related Standards

Performance

Rescue Robot

Mobility, Confined Area Terrains and Obstacles:

- ASTM E2801 Gaps
- ASTM E2802 Hurdles
- ASTM E2803 Inclined Planes
- ASTM E2804 Stair/Landings
- WK35213 Gravel
- WK35214 Sand
- ASTM E2826 Continuous Pitch/Roll Ramps
- ASTM E2827 Crossing Pitch/Roll Ramps
- ASTM E2828 Symmetric Stepfields

Human-Systems Interaction:

- ASTM E2829 Maneuvering, Sustained Speed
- ASTM E2830 Maneuvering Tasks, Towing Grasped/Hitched Sleds
- Maneuvering Tasks, Post/Hole Slaloms (in-process)
- ASTM E2853 Search Tasks, Random Mazes with Complex Terrain
- WK33260 Navigation Tasks: Hallway Labyrinths with Complex Terrain
- WK34434 Confined Space Voids with Complex Terrain

Sensors:

- WK42363 Image Acuity

Manipulation:

- WK27852 Door Opening and Traversal Tasks
- WK44323 Heavy Lifting: Surrounding Area



Courtesy US DoL, Mechanical Design 101, Kikuchi

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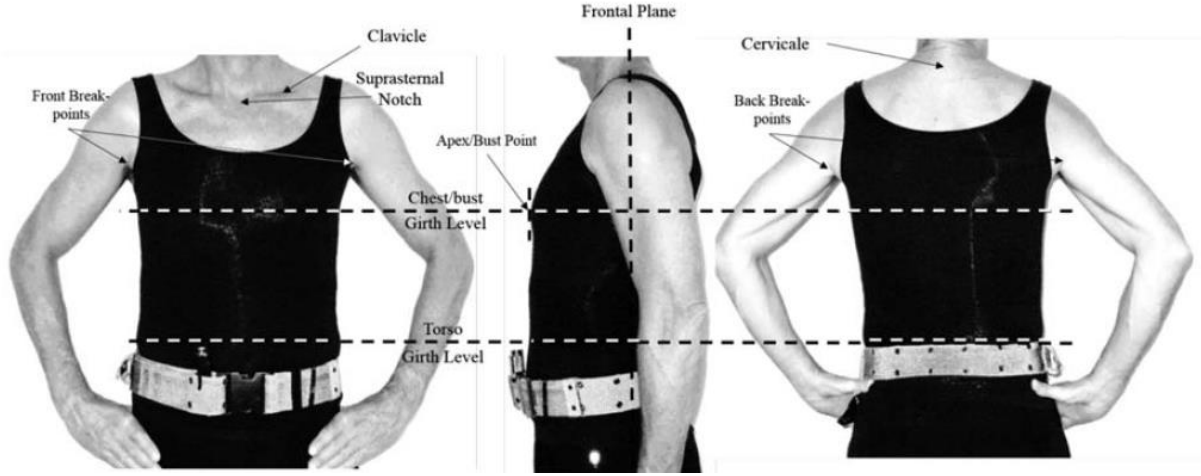
Related Standards

Other

- IEEE P1872:2015 Standard for Ontologies for Robotics and Automation
- IEEE P1872-1 Standard for Robot Task Representation (in-process)
- NIST SP 800-82, Revision 2, Guide to Industrial Control System (ICS) Security
- ASTM E2902-12 Standard Practice for Measurement of Body Armor Wearers
- ASTM E3003-15 Standard Practice for Body Armor Wearer Measurement and Fitting of Armor



Related Standards

ISO TC 199-12 – Safety of Machinery

- Working group starting to look at Human Machine Interactions
  - study mechanical safety data for physical contact between machinery and people
- To be a B type standard, i.e., very general standard that applies to all robots,
  - excludes military systems, medical systems, and toys

Other

- IEC ACART (Advisory Committee on Applications of Robot Technology) will be looking at safety and performance of robots and looking for gaps in the ISO standards.
- ISO-26262 provides guidelines for Hazard Analysis and Risk Assessment (HARA)*
  - (e.g., Active Balancing, Fall Detection, Collision Detection, and Automatic Motor Braking) technique used in established standards to measure the performance of safety-critical systems e.g., in the automotive industry

** Masood, Jawad, et al. "Active Safety Functions for Industrial Lower Body Exoskeletons: Concept and Assessment." Wearable Robotics: Challenges and Trends. Springer International Publishing, 2017. 299-303.*

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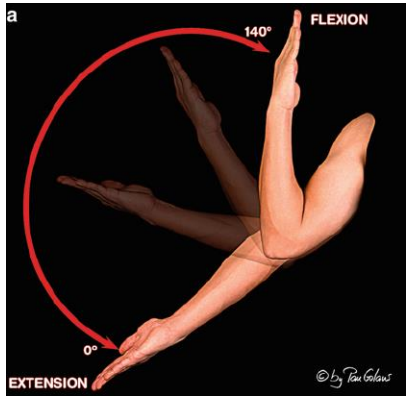
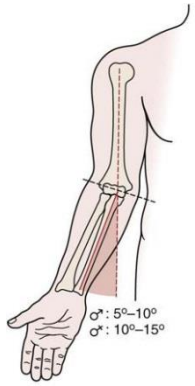
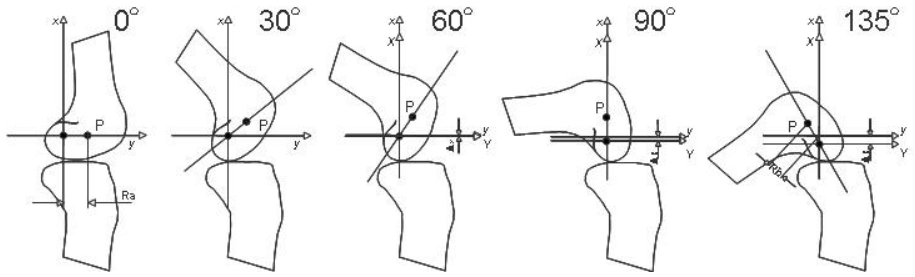
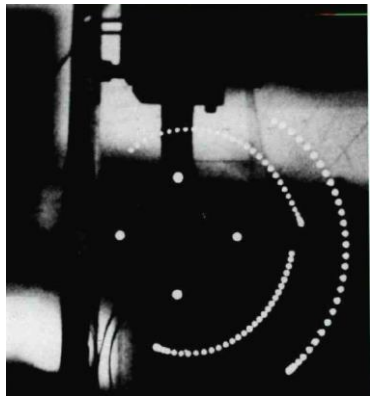
Cross-Industry Measurements Applicable to Exoskeletons

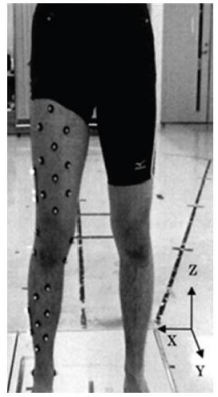
Joint Rotation Axis Location

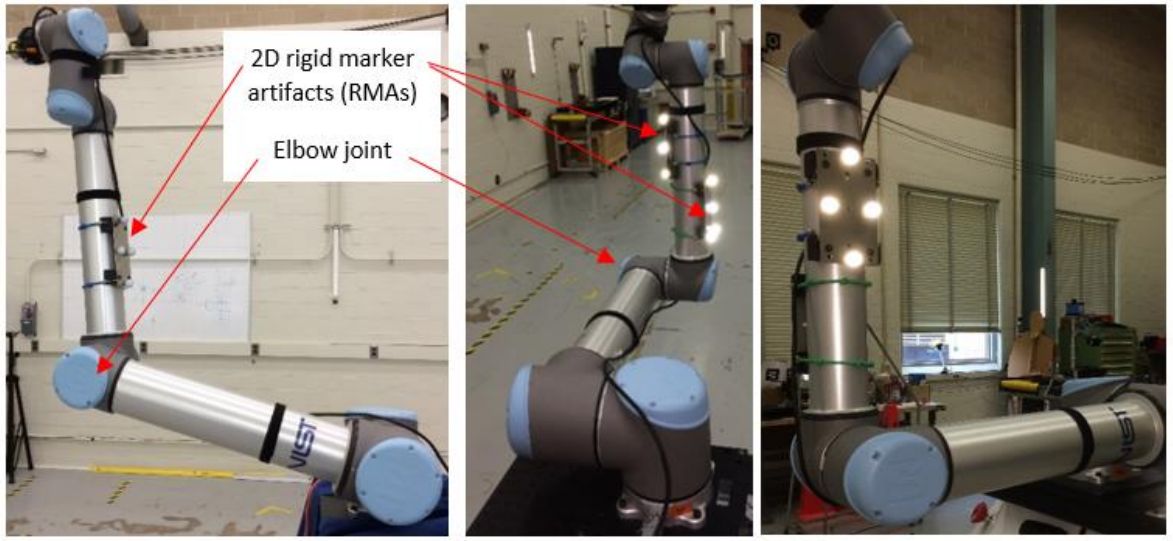








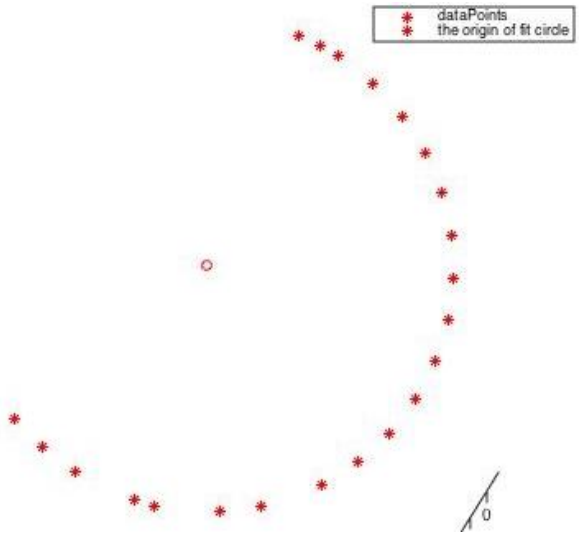


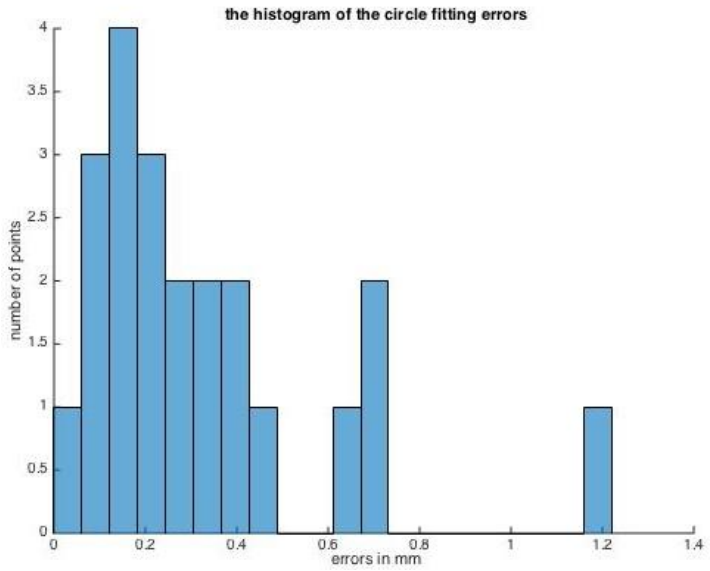


Cross-Industry Measurements Applicable to Exoskeletons

Joint Rotation Axis Location

- A circle was fit to the data set and a histogram of the circle fit error was calculated.
- Results showed a mean fitting error of 0.34 mm with an uncertainty of 0.27 mm, i.e., a relatively high confidence in the OTS measurement method.

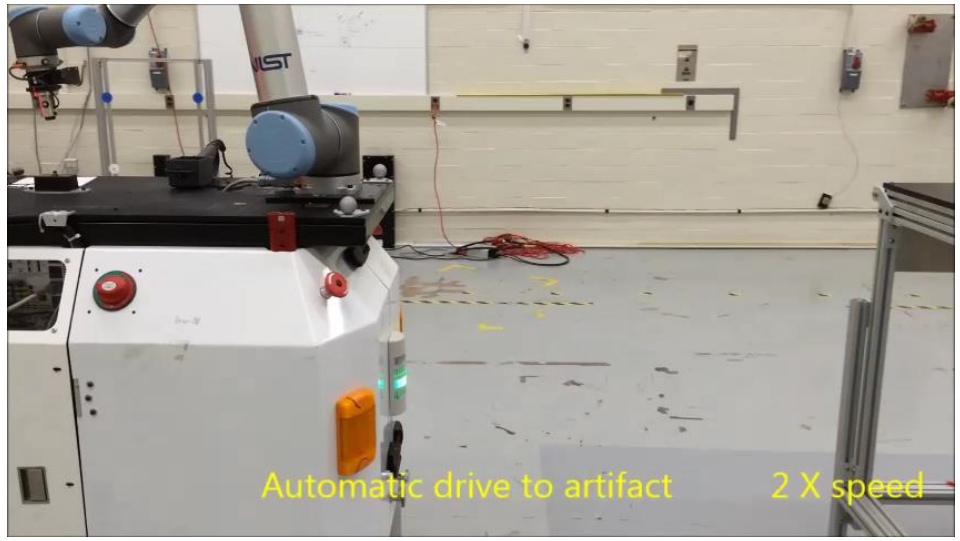


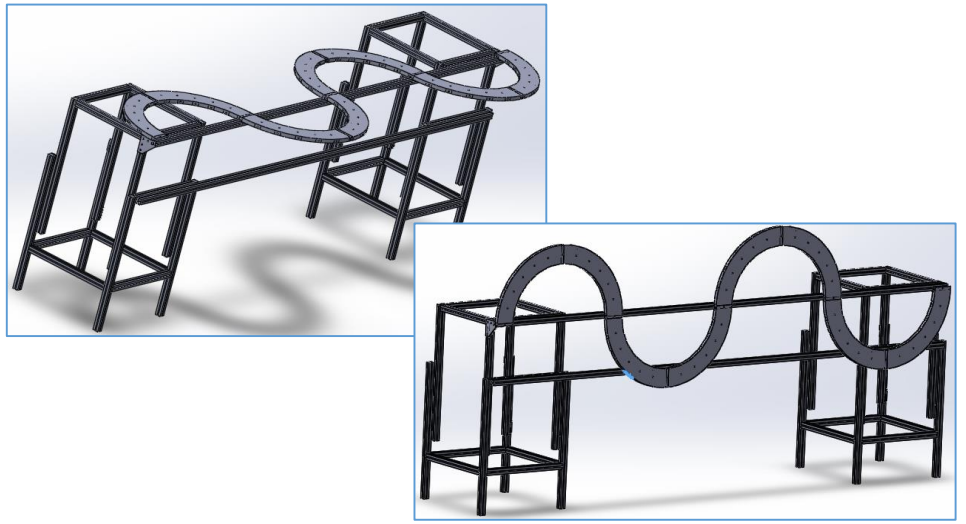


Cross-Industry Measurements Applicable to Exoskeletons

Industrial Mobile Manipulator

- Use of artifacts to measure mobile manipulator performance
- Simple, cost-effective, repeatable performance measurement methods are being tested towards potentially new performance standards for mobile manipulators
- Reconfigurable mobile manipulator apparatus
- Without making contact, the mobile manipulator can be measured to a known artifact when posed at an infinite number of vehicle orientations





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Cross-Industry Measurements Applicable to Exoskeletons

Response Robots

- Replicable test methods
- Simple to measure performance
- Incrementally more challenging conditions
  - measure how well a robot navigates inclined planes, steps, undulating floors or complex terrains, and around obstacles
- Each test generically simulates a particular capability which response robots must possess to be useful in critical situations

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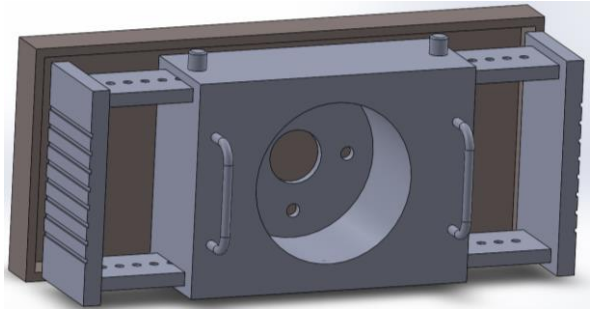
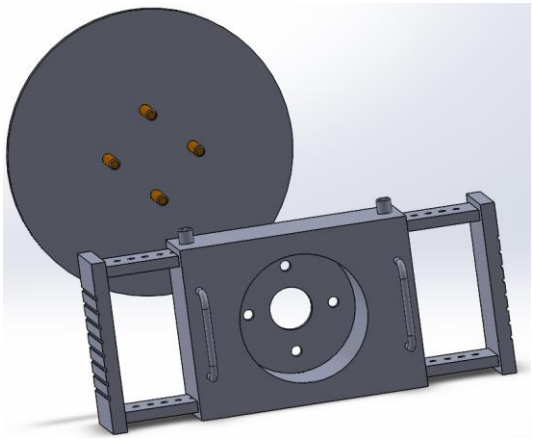
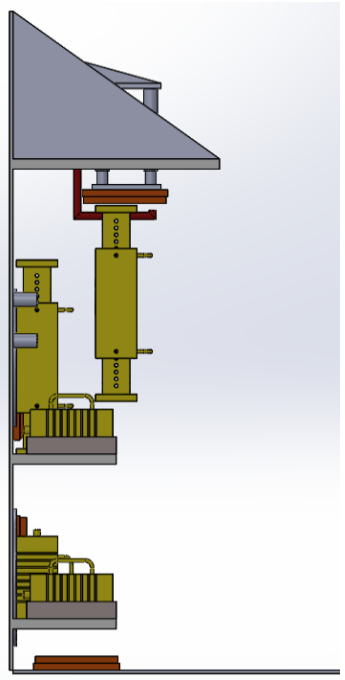
Potential Exoskeleton Test Methods

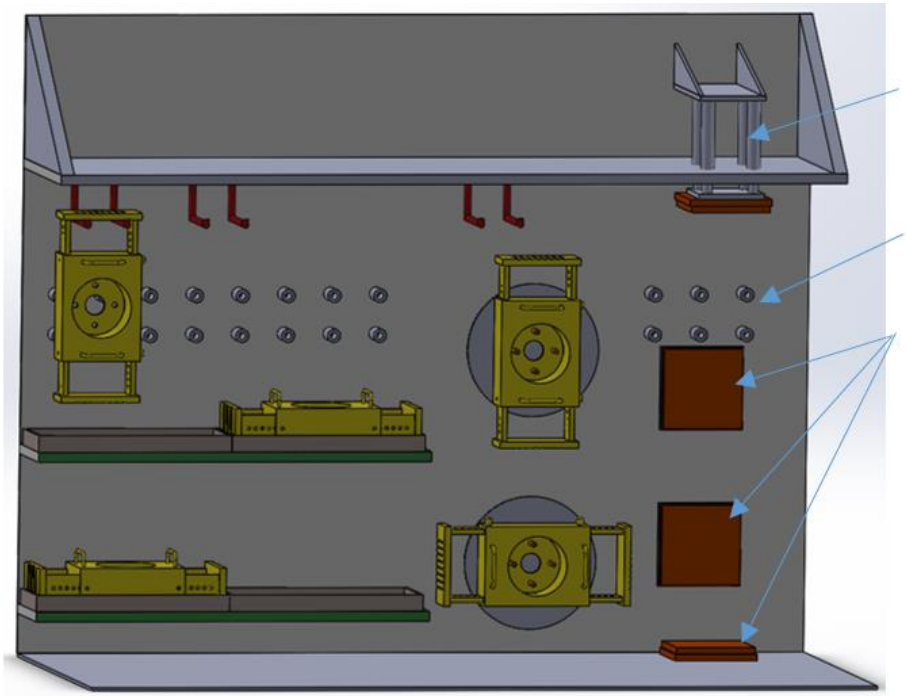
Load Handling

- Reconfigurable load artifact
  - Vary size, weight
  - Fit to a minimum tolerance tray
  - Fit to a bolt circle
- Load positioning (docking) wall of tests
  - Hooks
  - Bolt circles
  - Trays
  - Force plates
    - Hold tools against plates at various heights (ground, wall, ceiling)









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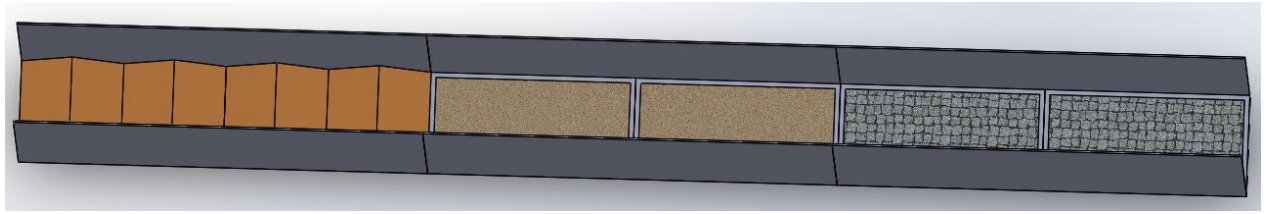
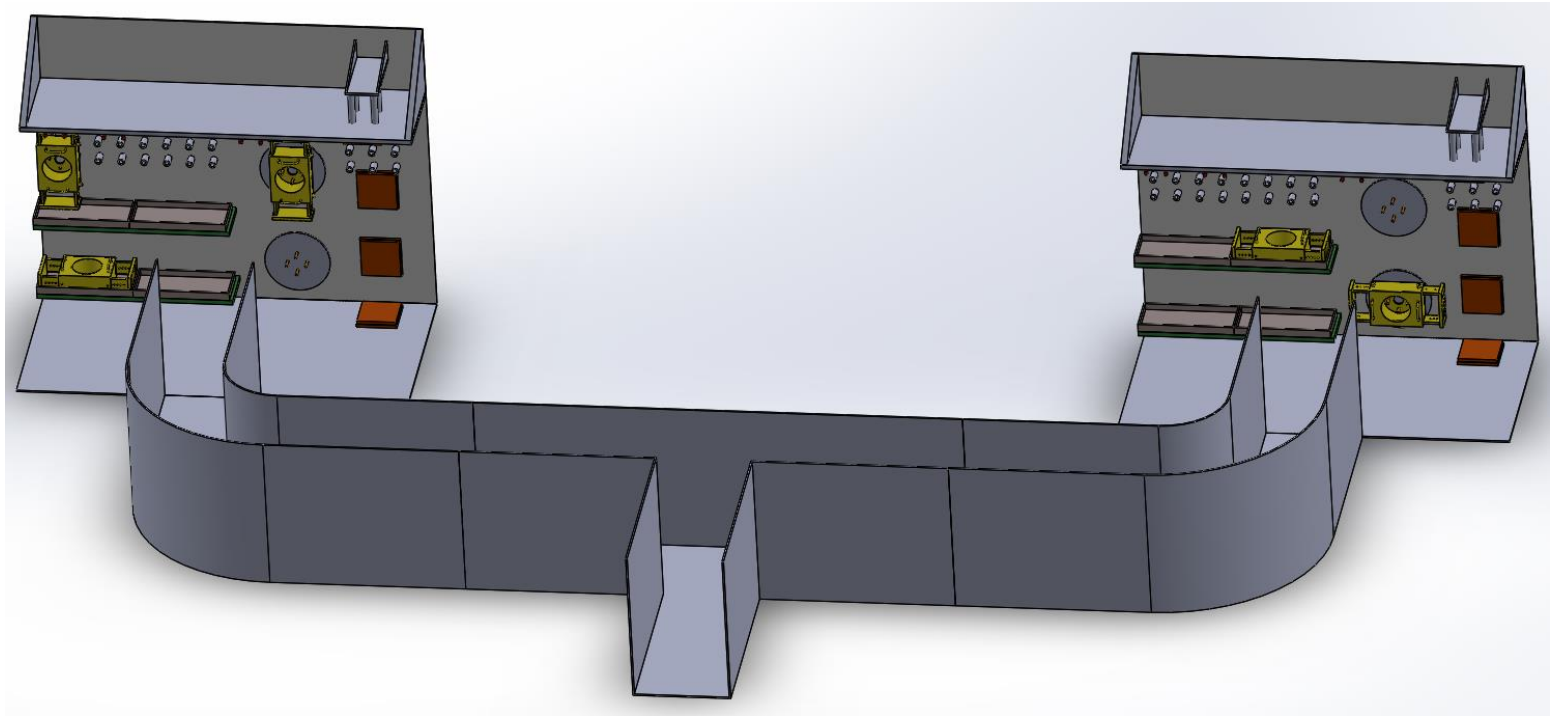
Potential Exoskeleton Test Methods

<u>Navigation</u>

- Varying terrains
  - Undulating
  - Soft (sand)
  - Cobblestone
  - Etc.
- Barriers from one Load Positioning Wall to another

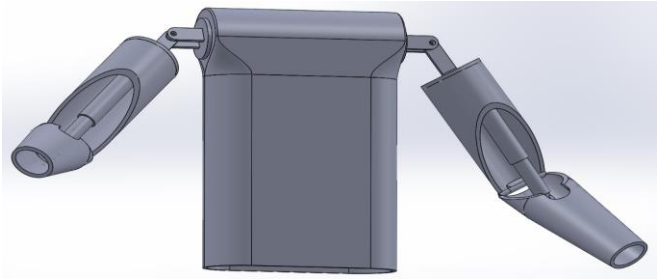




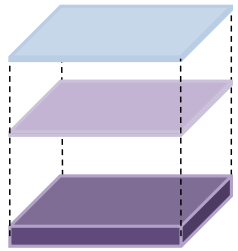
Exoskeleton Test Dummy

- Humanoid robots to be used as test dummies: “Evaluation of Assistive Devices Using Humanoid Robot with Mechanical Parameters Identification,” Proc. 14th IEEE-RAS Int’l Conf. on Humanoid Robots (Humanoids), pp.205-211, 2014.

- Goal: to mimic lumbar stresses, assistive forces, the rate that the assistance is applied, rated stress reduction rate, rated operating time, etc.
- Japan is working on a test dummy of “actuated pipes” and should soon have some information about it
- NIST is designing *a very early version* … modular, more human-like, test dummy with easily reproducible components to interchange, resize, etc. as desired for a variety of human shapes, sizes and internally actuated as much as possible
  - Use for mean time-between-failure of exoskeletons, skin effects, effects of off-axis joint rotation, long-term effects, and other areas where instead, fatigue or unsafe conditions may be evident for humans-in-the-loop
  - Body portions or full body, 3D printed components envisioned for low cost, replaceable components
  - Inclusion of twisting torso is also possible
  - Padding can mimic human flesh and change shape*
  - Sensors can be added to measure exoskeleton effects with signals output to exoskeleton components that use electrocardiography or electromyography for exoskeleton control



  - Sensors integrated can also measure chafing, device movement, torques and other forces, etc. to provide additional information
  - Passive measurement-exoskeleton strapped to a range of humans representing various sizes, shapes, fitness-levels, and both genders can measure actual human motion with data for replication in test dummies to mimic human motions when testing exoskeletons.
- Suggest piecemeal development – e.g., begin with ankle - knee, then ankle – knee - hip, … increasing complexity towards multi-limb with trunk test dummy



Wound dressing

Acrylic adhesive (t=0.005 mm)

Polyurethane gel (t=10 mm)

*Hardness of 0 as measured by an ASKER Durometer Type C

*ISO/CD/TR/23482

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Summary and Conclusions

- Lot's of standards basis across medical and industrial classes useful to exoskeletons
  - Useful for beginning terminology, performance and safety test methods
  - Potential to piggy-back onto one of the SDO's current efforts
  - We can already begin the process of developing our own task groups in the various classes and compiling normative data currently lacking in standards
- Cross-industry (industrial and rescue robots) tests can also serve as basis
  - Similar artifacts, test methods, terms, etc.
  - Combinations of test methods (e.g., navigation and docking) also useful for some testing
- Test dummy's may also prove useful for safe, repeatable MTBF, long term effects, and other testing that can provide real data across many exo's on a single human form

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