


Dexterous Robotic Manipulators and Exoskeletons for Glovebox Use in Nuclear Waste Sites

Presented by
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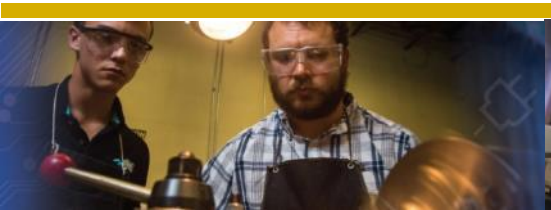
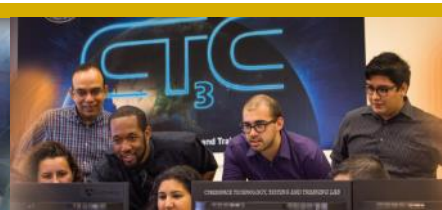


Team

Dr. Leonel Lagos, Dr. Ou Bai, Dr. Erik Engeberg, Dr. Aparna Aravelli, Dr. Rick Demmer

Students: Christopher Nataros, Maria Ovalle, Rodrigo Ramon, Sai Srinivas Divvela, Iker Gonzales, Craig Ades, Mostapha Al-Saidi, Christopher Garcia, Tong Yi

Introduction

Workers at various DOE national laboratories and other sites conducting glovebox and hot cell operations, perform repeated, dull and time consuming tasks which lead to hand, back and body fatigue, sometimes leading to injuries.

Application of robotics and sensors is a great avenue to minimize fatigue and reduce injuries to the workforce

Project Objectives

Objective 1

Investigation of potential for dexterous robotic manipulators to be used with the glovebox (on the outside reaching in) to reduce human fatigue

Objective 2

Investigation of muscle fatigue caused during prolonged glovebox manipulations

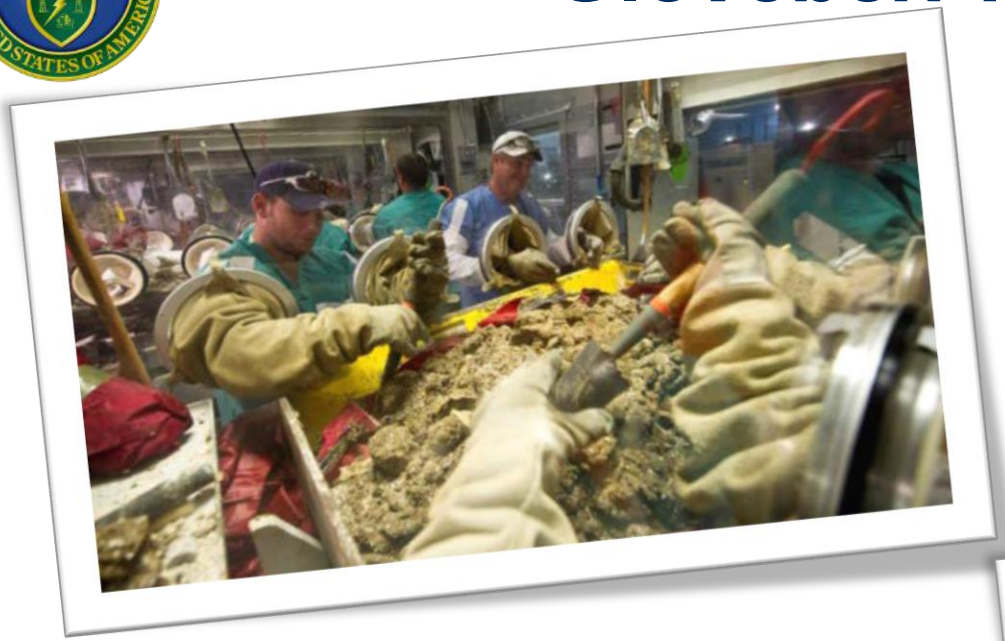
and

To develop a wearable robotic exoskeleton device for the glovebox operators

Project Benefits

- Removing hands-on interaction of humans with hazardous situations and materials.
- Less space is needed within the box and virtually no modifications to the facility are necessary.
- Delicate, repetitive tasks may become semi-autonomous
- Increase in worker health, safety and productivity due to reduced strain from working with arms extended in a box and having to take frequent breaks because of hand fatigue (which leads to musculoskeletal injuries).
- Better ability to modify, reconfigure and repair robotic arm because it is not directly exposed to the contamination. In other applications, an expensive robotic arm could be “lost” due to simple malfunctions because it is inside a high contamination area.

Glovebox Tasks



- Waste sorting/segregation
- Polishing samples
- Weighing samples
- Mixing chemicals

- Disassembly of items
- Packaging cleanup
- Applying fixatives
- “smear” surveys - determine contamination levels

Robotics in Gloveboxes

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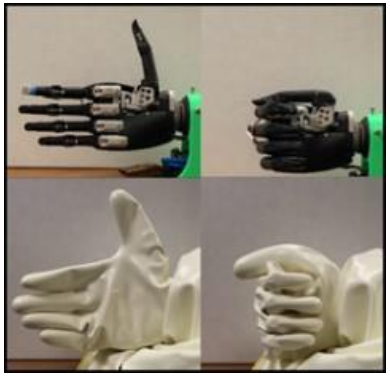
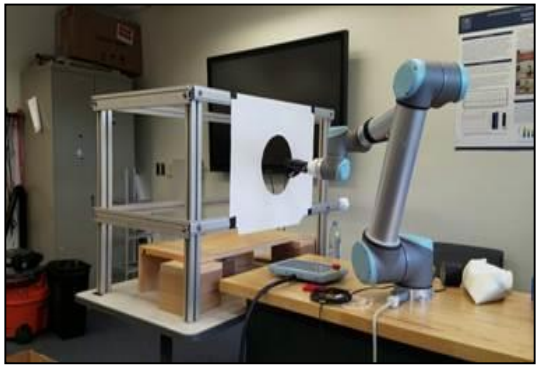
Robotic Arm and Hand Combination in glove boxes and hot cells





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Hand: i-limb

Arm: UR5

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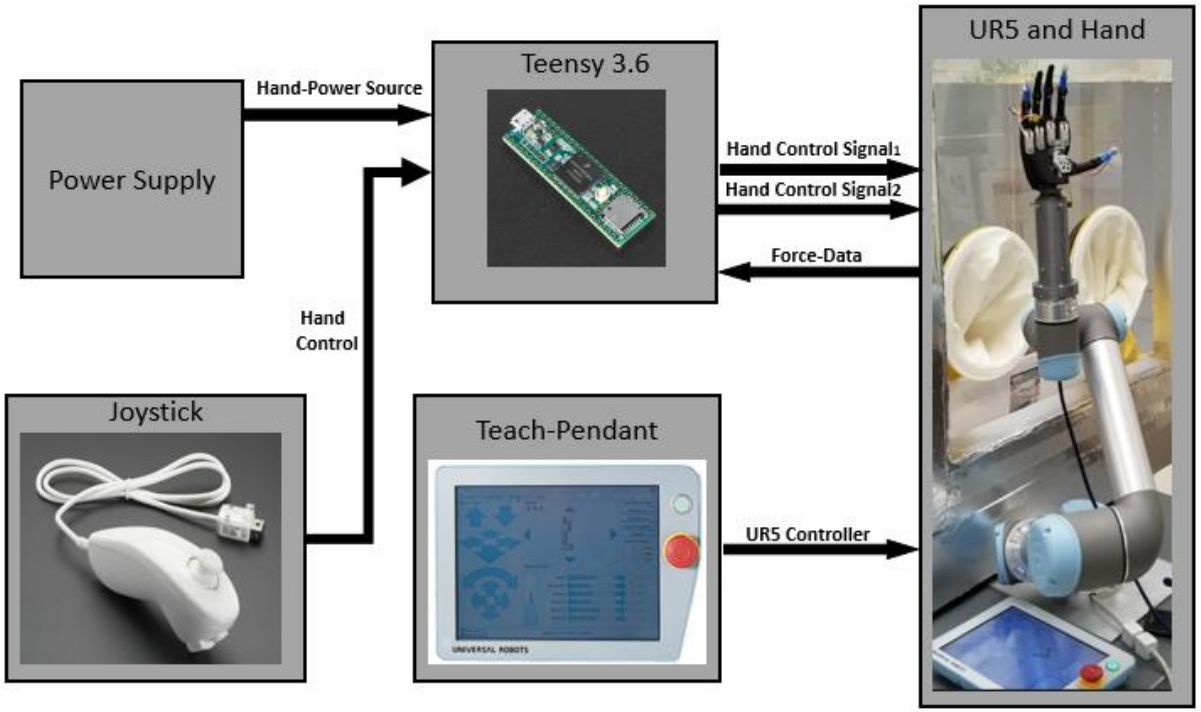
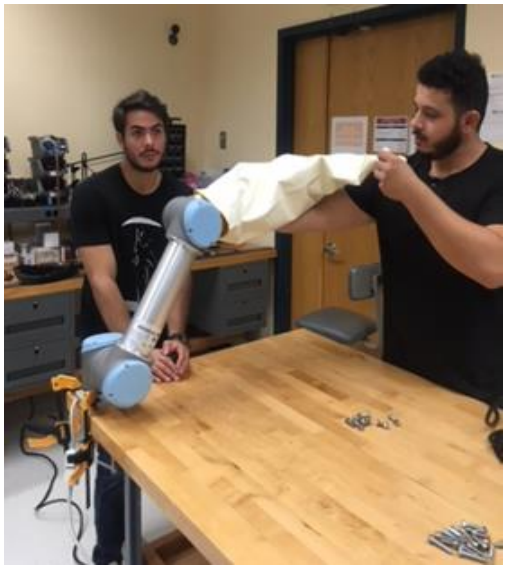
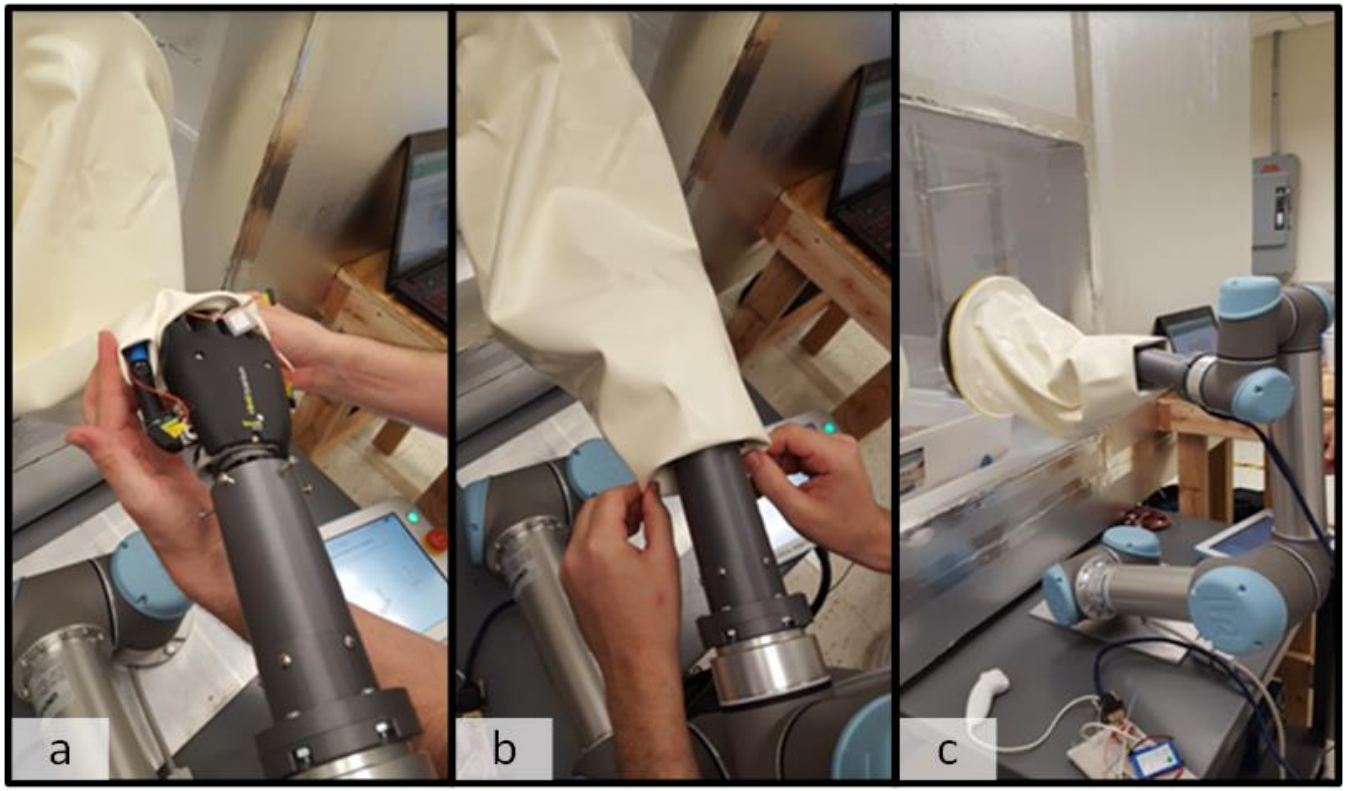
Robotic System Control



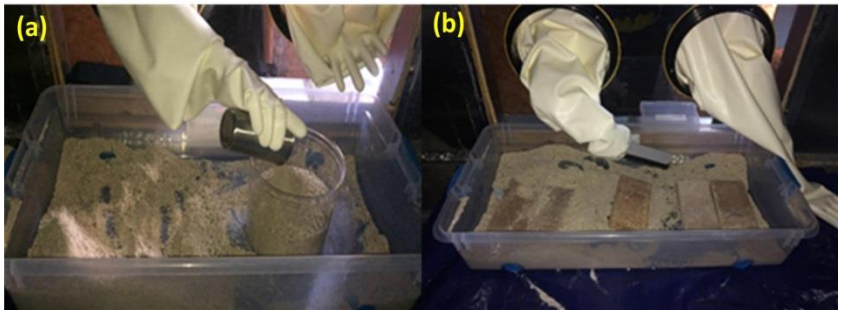


Procedure to Insert Robotic Hand Into the Glovebox



Simulated Glovebox Operations

- Sand task
  - Scooping sand from a reservoir and pouring into bins (to replicate waste handling tasks)
- Brick task
  - Brushing bricks using a brush (to replicate cleaning and brushing tasks)



Robot sweeping bricks task

Robot scooping sand task

Human and Robotic Test comparison


HumanSandTask.mp4


RobotSandtask.mp4


HumamBrickTask.mp4


RobotBrickTask (1).mp4

Fingertip Force Sensor

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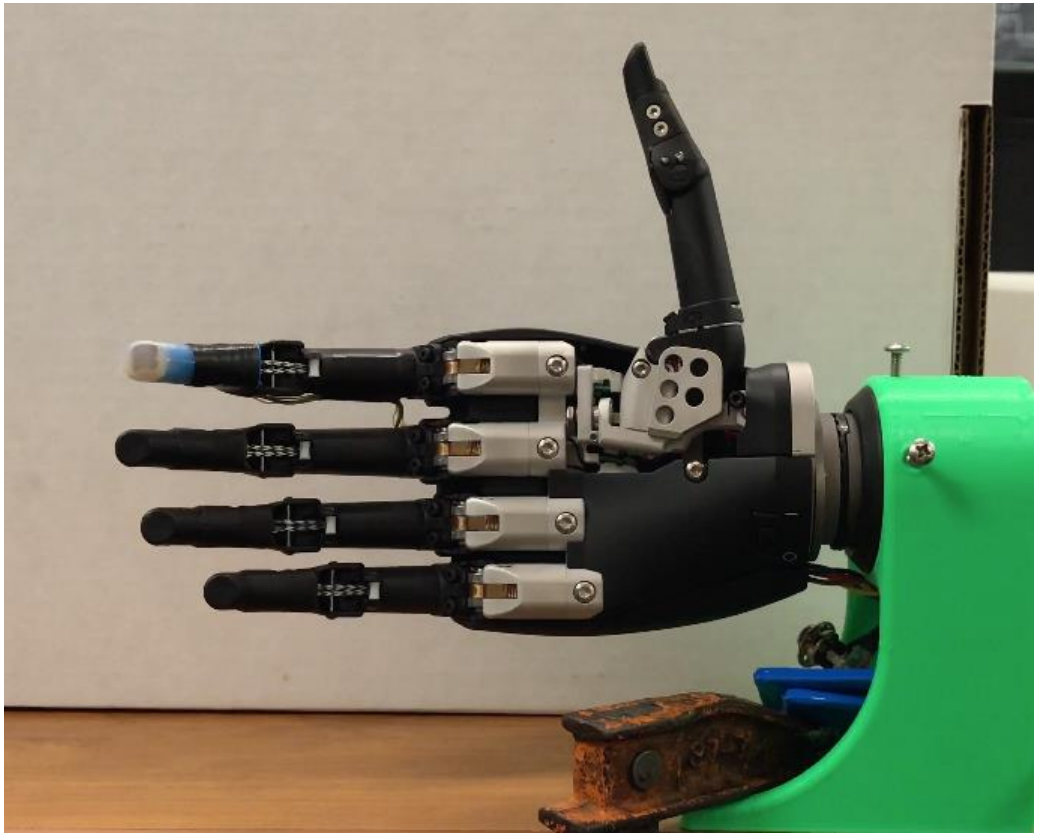
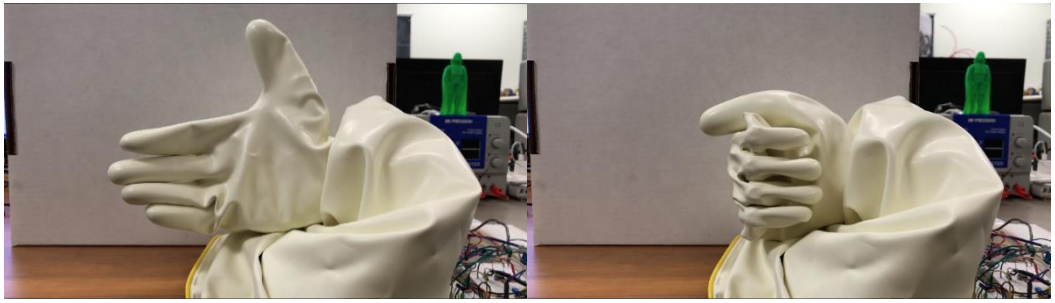
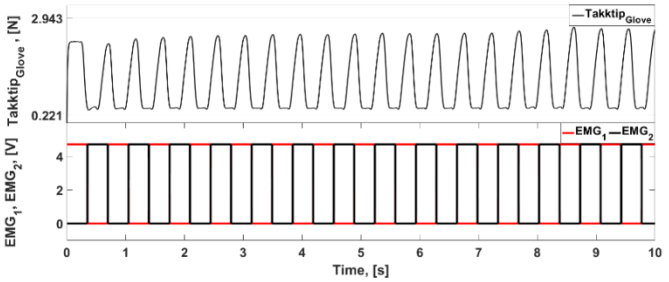
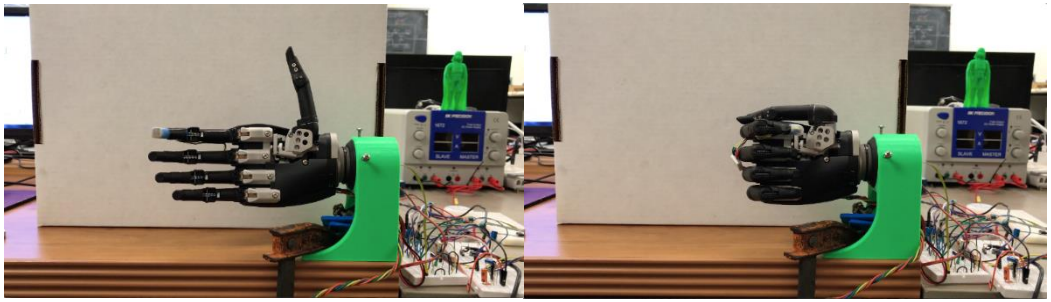
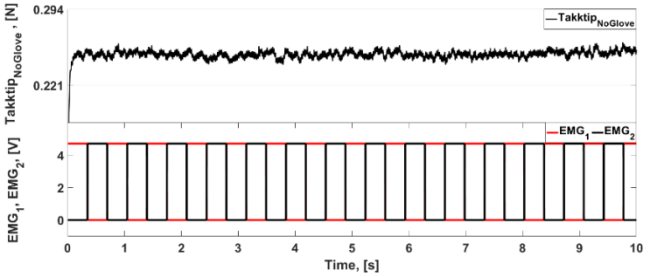


Open/Close

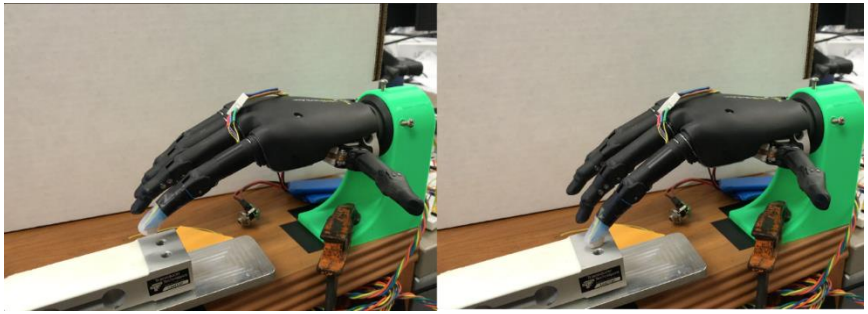


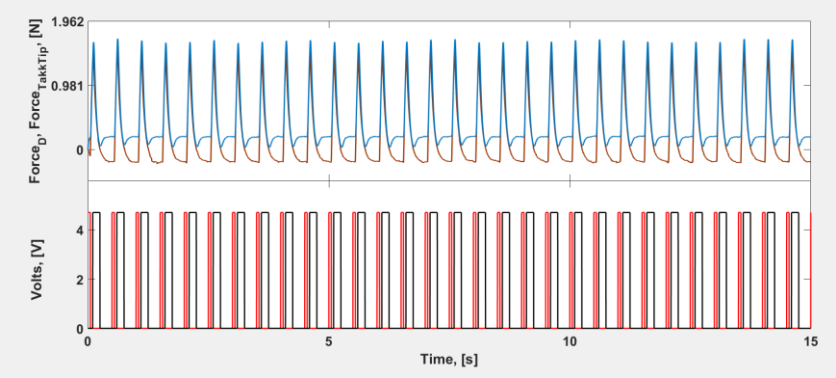

Takktip_Glove
2.943
0.221
Takktip_Glove, [N]
EMG_1, EMG_2, [V]
EMG_1
EMG_2
Time, [s]

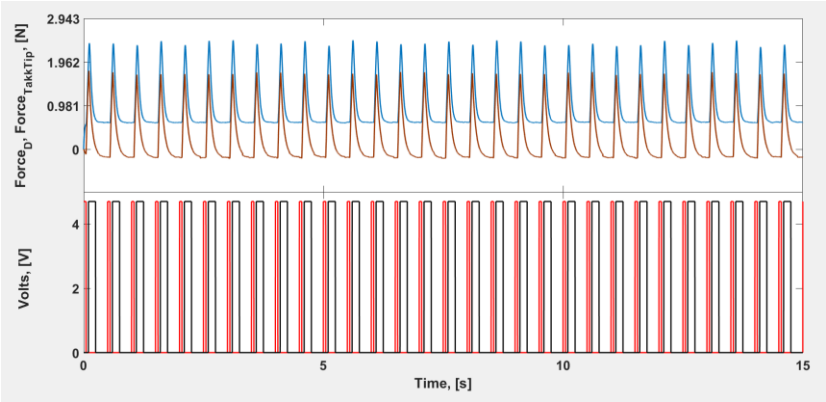



Takktip_NoGlove
0.294
0.221
Takktip_NoGlove, [N]
EMG_1, EMG_2, [V]
EMG_1
EMG_2
Time, [s]

Intermittent Tapping







Fatigue Quantification (Sensors)

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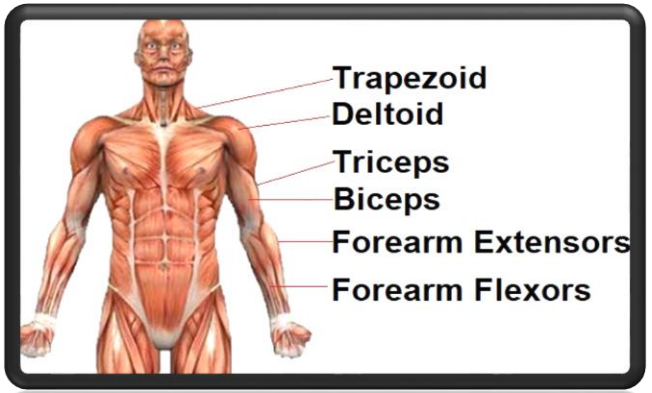
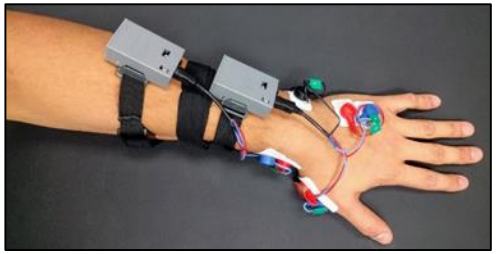
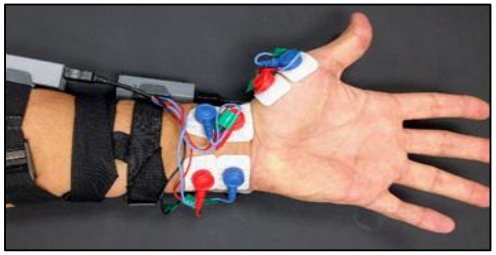
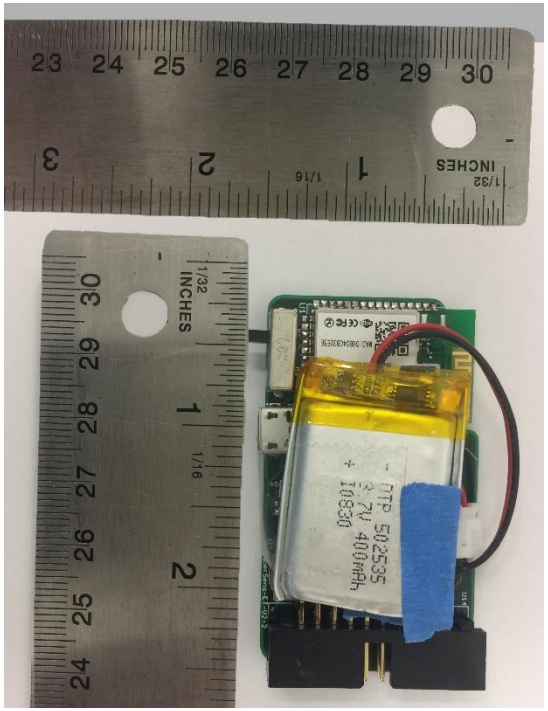
- Electromyography (EMG) sensors
  - Measure muscle response or detect electrical activity in response to a nerve's stimulation to the muscle.
- Single chip Micro controller unit (MCU)
- Wi-Fi certified
- Easy to use on any part of the human body
- Glovebox compatible
- Non-invasive



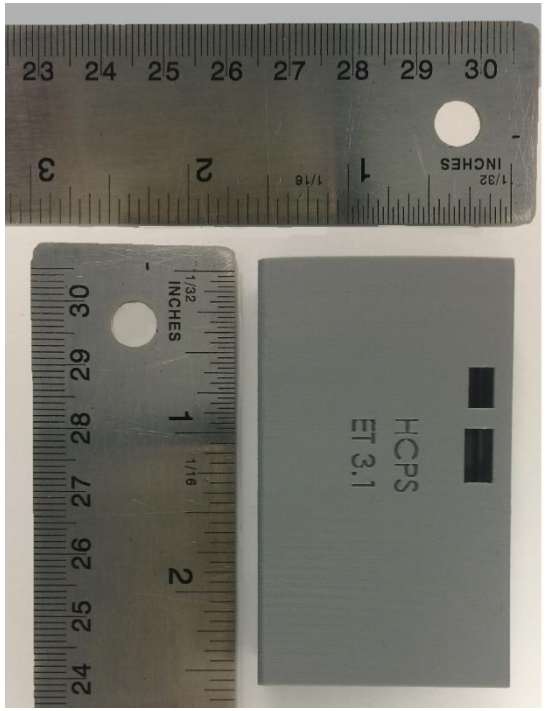




EMG Recording Devices



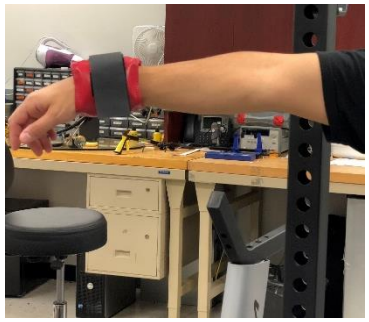
EMG PCB Device

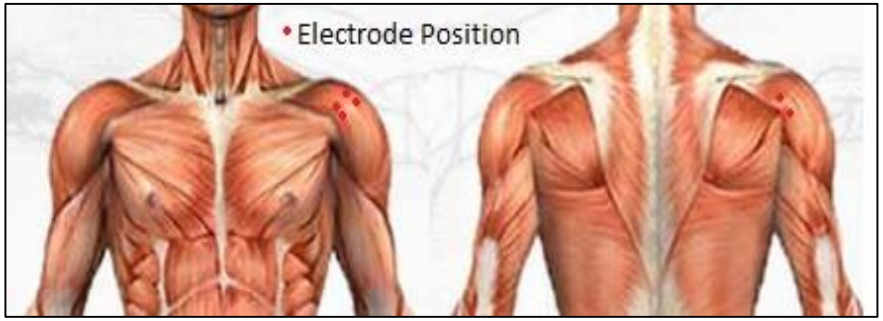


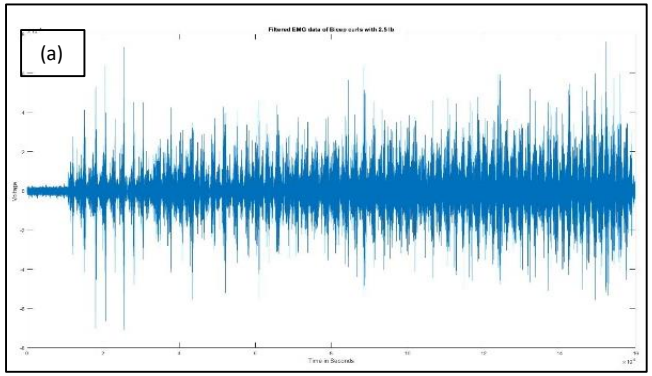
EMG recording device outer cover

EMG recording Electrodes.

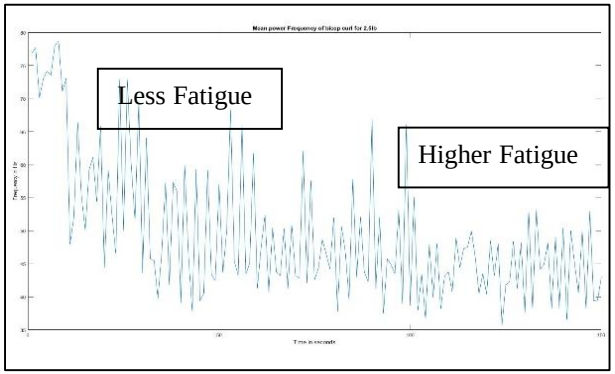
Muscle Fatigue Testing







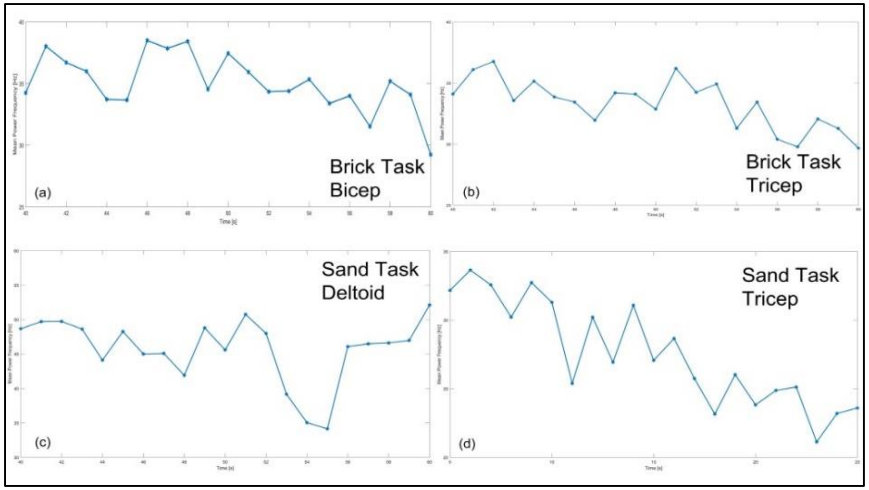
Bicep EMG (Voltage Vs time graph)



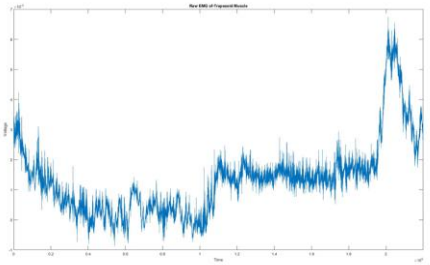
Frequency (Mean) Vs time graph

Method and Results

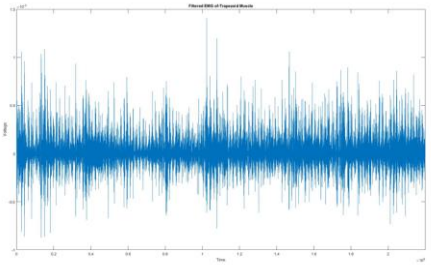
- 8 human subjects tested for fatigue in glove box operations.
- Subjects performed 15 minutes of the sand task and 15 minutes of the brick brushing task with 30 minutes of resting in between tasks.
- Data collection and processing
  - 8 channels with a sampling rate of 500 Hz
  - Butterworth 8th order 20 Hz high pass filter
  - Mean frequency of every 8 seconds is calculated and plotted
- Decreasing trend in mean frequency was observed in all muscle groups which shows fatigue during tasks.



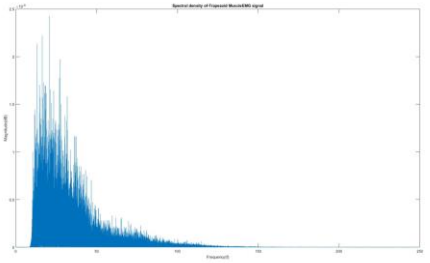
Results



Raw EMG of Trapezoid Muscle



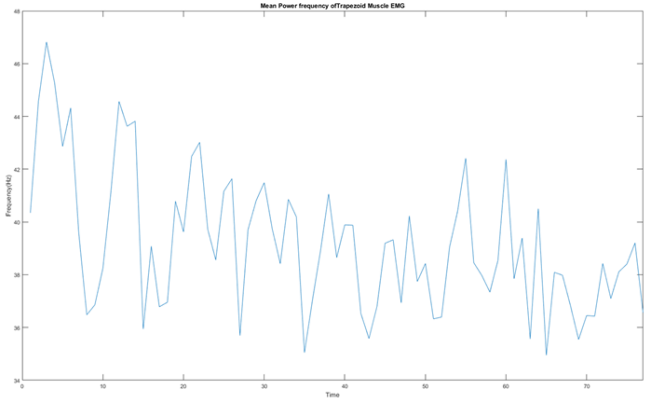
Filtered EMG of Trapezoid Muscle



Spectral density of Trapezoid Muscle

Muscle Group	Over all Mean frequency of EMG before fatigue(Hz)	Over all Mean frequency of EMG after fatigue(Hz)
Trapezoid Muscle	45	36
Deltoid Posterior Muscle	42	36
Deltoid Anterior Muscle	25	18
Deltoid middle Muscle	53	43
Triceps Muscle	32	20
Biceps Muscle	40	30
Forearm extensors Muscle	53	45
Forearm flexors Muscle	45	30

Sand Task Mean Frequency

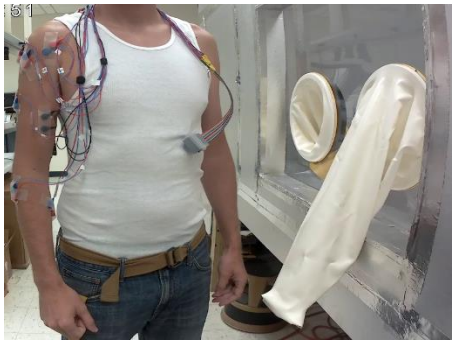


Mean Power Frequency for Trapezius Muscle – Sand Task

Sand Scooping Task

i)Glove box inside view

ii)Subject with sensors



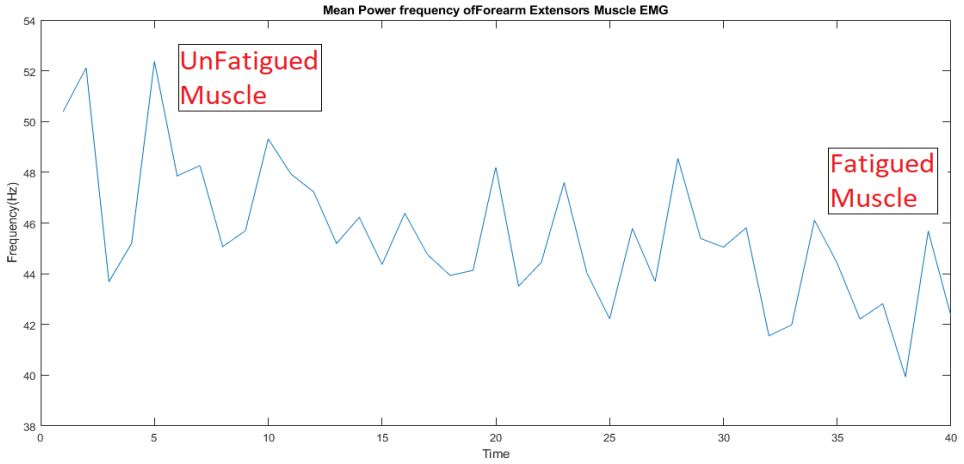
iii)Subject during task

Sand Scooping Task		
Subject	FatigueStartTime (In seconds)	Muscles Fatigued
1	384	Forearm Flexors
2	240	Trapezoid
2	288	Tricep
2	320	Bicep
2	280	Forearm Flexors
3	480	Forearm Extensors
4	640	Tricep
5	304	Deltoid Posterior
5	288	Deltoid Middle
5	288	Forearm Extensors
6	880	Deltoid Middle

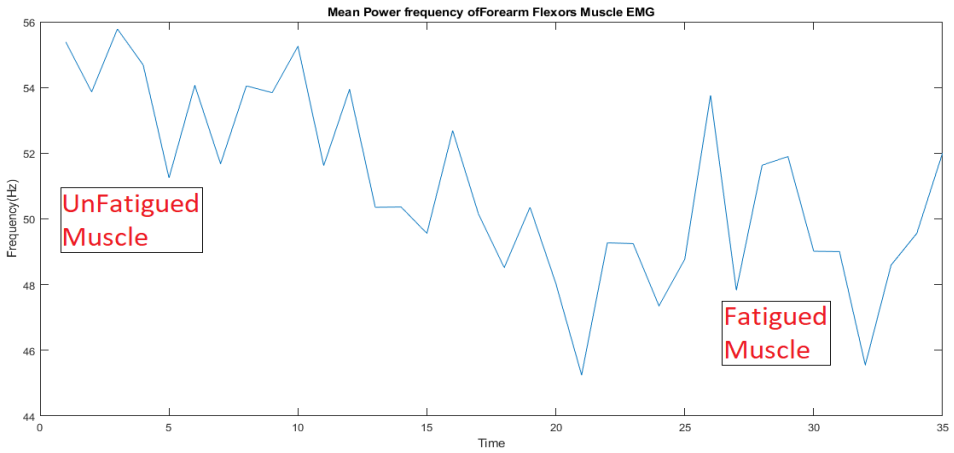
iv)Inside view while subject performing task

Sand Scooping Task

Subject 5: Forearm Extensor muscle mean frequency plot.



Subject 5: Forearm Flexor muscle mean frequency plot.



Brick Cleaning Task

Glove box inside view

Subject with sensors

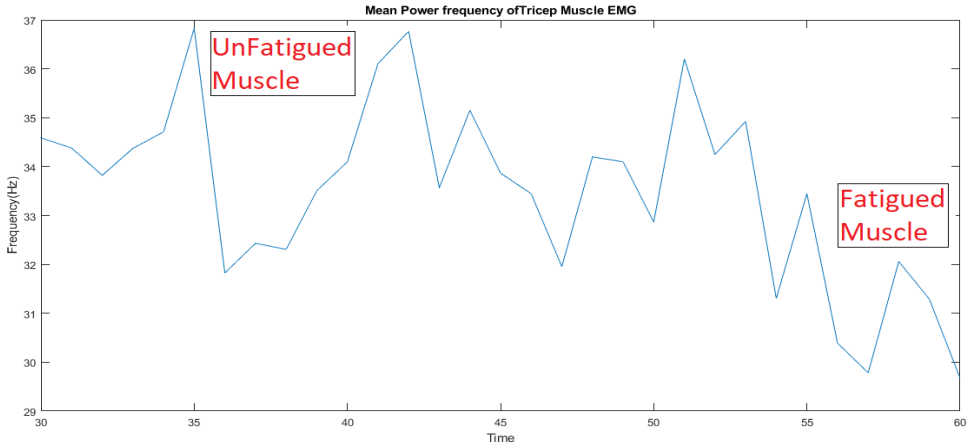
Subject during task

Inside view while subject performing task

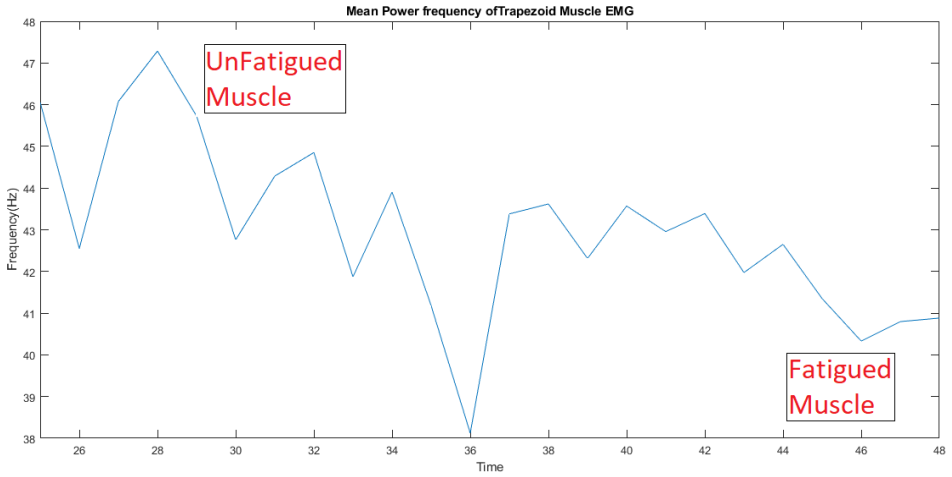
Brick Cleaning Task		
Subject	FatigueStartTime(In seconds)	Muscles Fatigued
1	464	Tricep
1	440	Bicep
2	No Noticable fatigue	NA
3	360	Trapezoid
4	No Noticable fatigue	NA
5	No Noticable fatigue	NA
6	No Noticable fatigue	NA

Brick Cleaning Task

Subject 1: Triceps muscle mean frequency plot.



Subject 3: Triceps muscle mean frequency plot.



Robotic and Human Testing

- Test Method
  - Sand task 15 minutes of human scooping followed by 15 minutes of robotic scooping
  - Same with the brick task
- Test Metrics
  - amount of sand collected (weight)
  - number of spills
  - number of slips

Productivity Measurement

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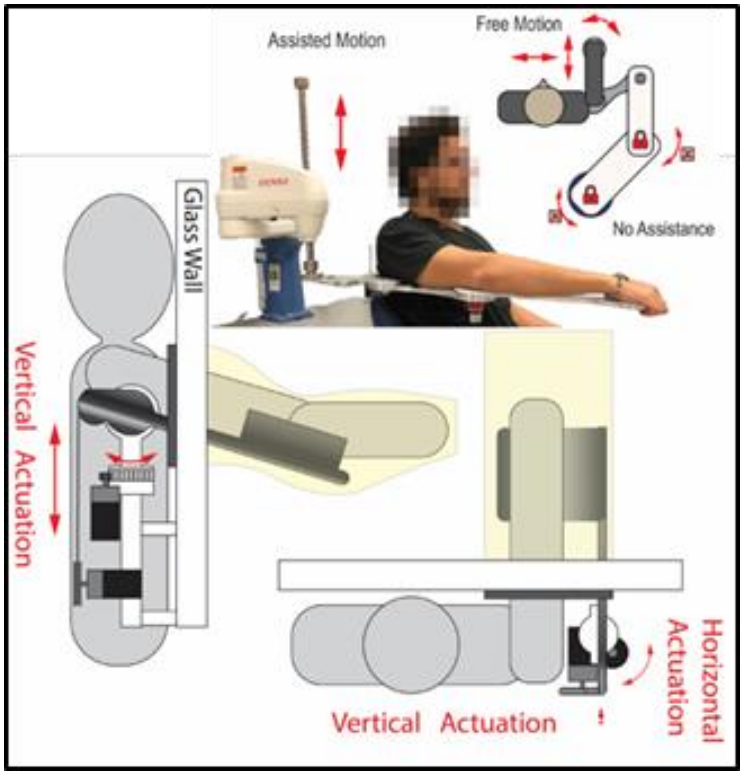
Sand Scooping	Sand Collected (Human Subject) (lb.)	Spilled Sand (lb.)	Sand Collected (Robot) (lb.)	Spilled Sand (lb.)
Subject 1	840.6	1.1	184.5	0
Subject 2	466.1	0	196.9	0
Subject 3	362.4	0	208.1	0.44
Subject 4	328.9	0.3	166.4	0
Subject 5	166.0	0	172.6	0
Subject 6	296.5	0	181.4	0
Subject 7	338.6	0.4	190.3	0

Brick Task	Human Subject (Number of brush strokes)	Robot (Number of brush strokes)
Subject 1	1160	860
Subject 2	1300	860
Subject 3	1100	860
Subject 4	1020	860
Subject 5	1150	860
Subject 6	1220	860
Subject 7	980	860

Muscle Groups	Mean Frequency(Hz) (Beginning)	Mean Frequency(Hz) (End)
1	39.3	37.1
2	33.7	21.2
3	21.0	20.5
4	40.6	39.9
5	20.4	17.1
6	22. 2	19.0
7	23.0	17.7
8	34.4	20.6
9	40.1	35.3
10	19.6	17.7
Average	29.4	24.6
Standard Deviation	8.5	8.6

Design of Exo-skeleton for Gloveboxes

Investigate the feasibility of using hand exo-skeleton for fatigue reduction in glove box operators



Exoskeleton Research in HCPS/ARC Laboratories

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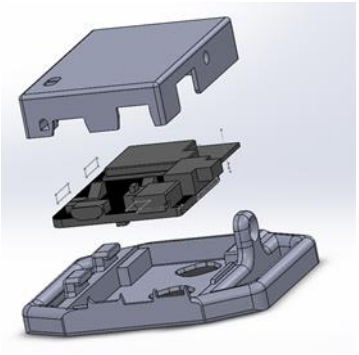
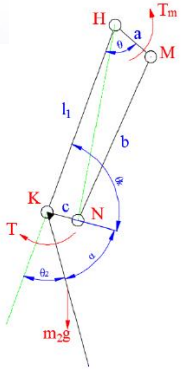
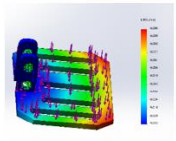
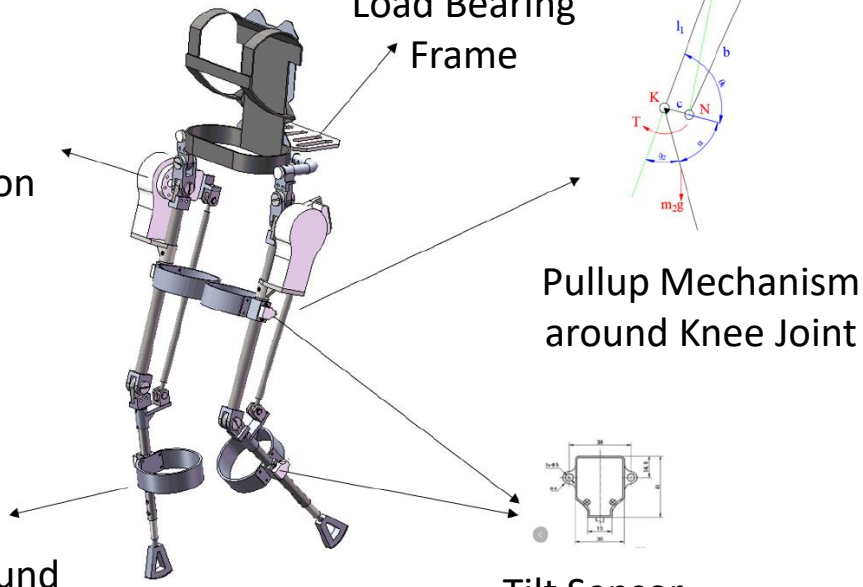




Exoskeleton Motor



Load Bearing Frame



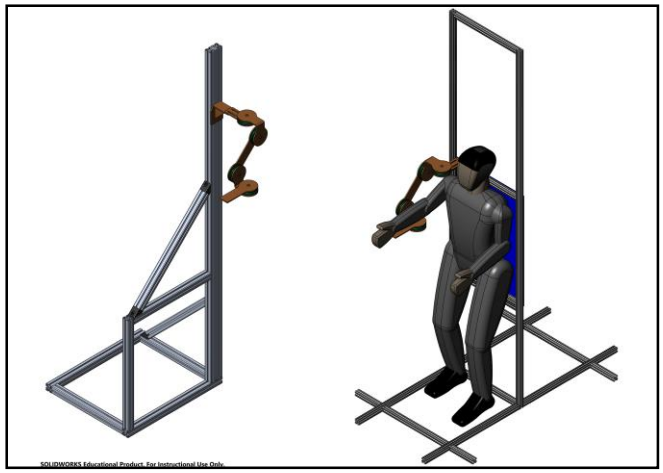
Pullup Mechanism around Knee Joint

Reconfigurable Ground Touching Leg

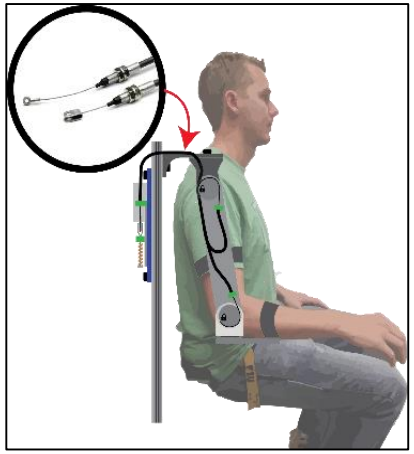
Tilt Sensor

Load Bearing Exoskeleton

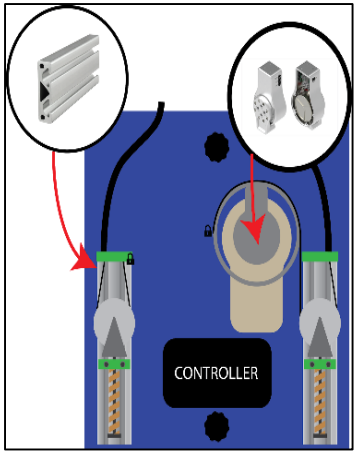
Exoskeleton Design Concepts



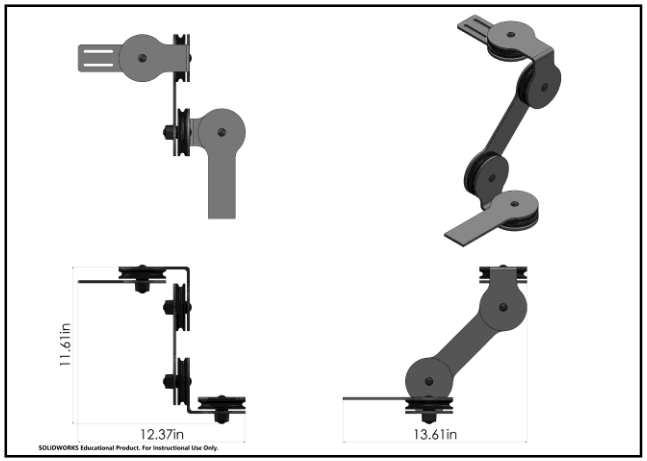
Standing Position

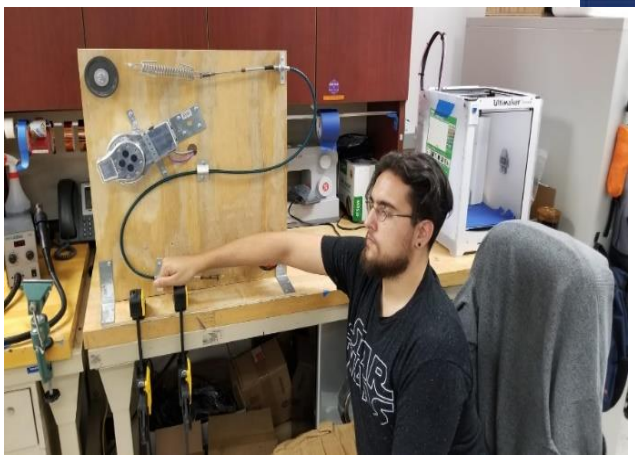


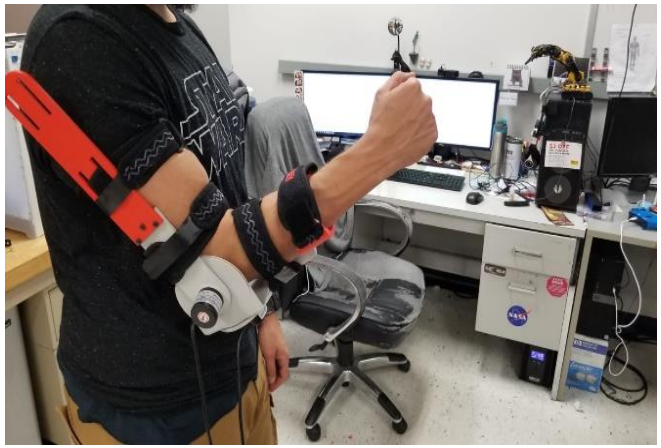
Sitting Position



CAD Models and Experiments







Accomplishments

- Present research investigated muscle fatigue in glovebox operators conducting various tasks and the feasibility of the use of robotics for routine tasks.
- Designed and prototyped electromyogram (EMG) sensors for wearable, wireless sensing of muscle fatigue during glovebox operation and developed computer algorithms for EMG signal processing and feature extraction for a sensitive and reliable muscle fatigue assessment in 10 muscle groups on the hand, arm and shoulder.
- The custom-made EMG device can be used to determine the risk of muscle injury during prolonged glove-box operations.
- Fabricated customized robotic fingertips to integrate force sensing abilities on a robotic hand and investigated its movements placed in a glove.
- Conducted human and robotic arm/hand testing at FIU's glovebox mock up for the designed tasks, compared human subject tests with the robotic hand and arm testing and identified challenges for future research.
- Trained the future STEM workforce. A total of 8 FIU and FAU STEM minority students and 1 post-doctoral fellow were involved in Year 1 research activities and submitted 3 conference papers.

Conclusion and Future Work

- The autonomous robot could help assist glove-box operations to a certain extent but the flexibility as well as the productivity using autonomous robot is currently very limited. A lot of effort is needed to program a certain task.
- Combination of robot and humans in the form of exo-skeleton is being investigated and seems promising.
- Future study of smart robotic operation that can self-teach/learn glove-box operation using artificial intelligence is needed.

Thank you.
Questions?