TOWARD THE FUTURE OF MANNED SPACE EXPLORATION

A NOVEL WEARABLE INTERFACE FOR OPTIMAL HUMAN-ROBOT COLLABORATION

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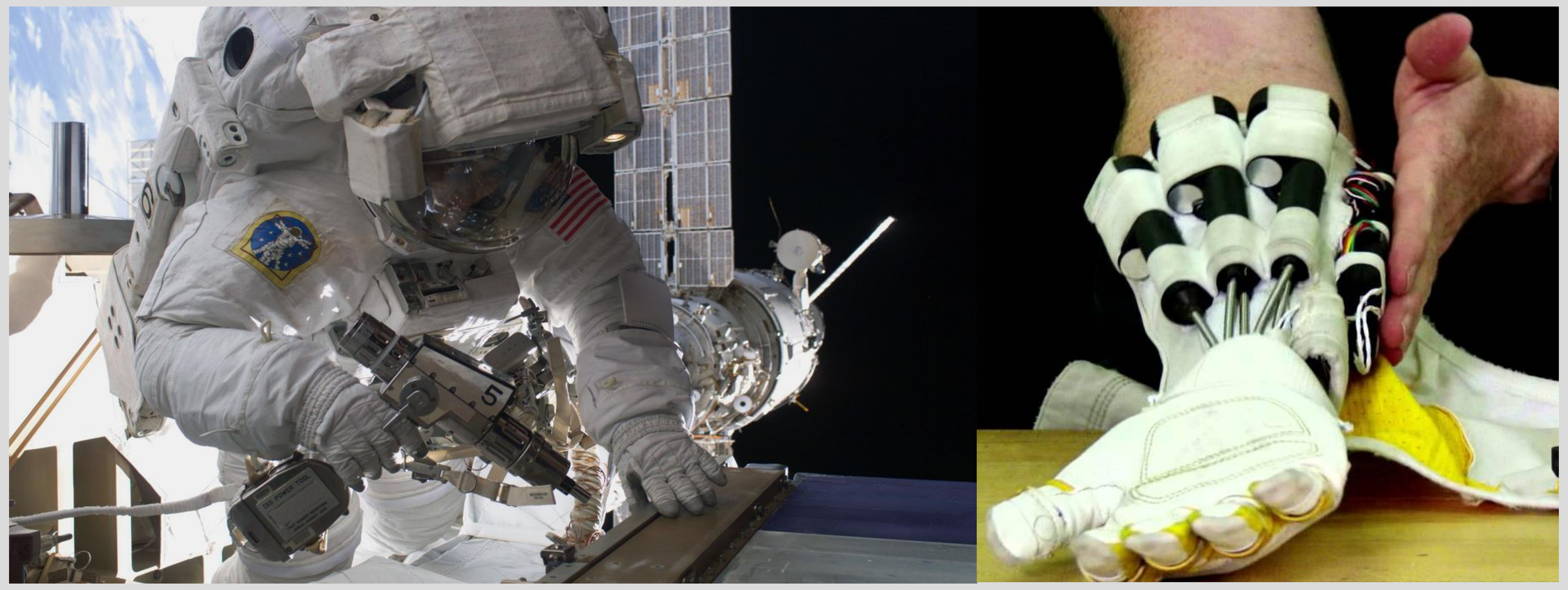
BACKGROUND

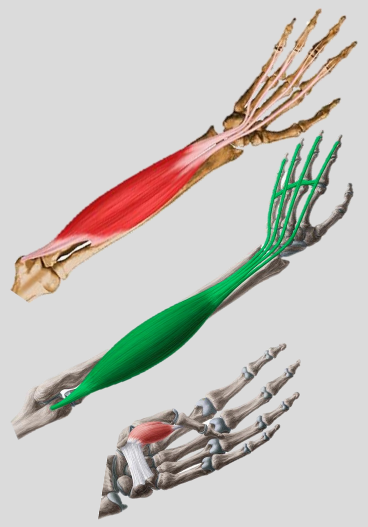
- **Human-Robot interaction (HRI) can help astronauts** during dangerous or taxing EVAs by providing assistive forces and torques to reduce neuromuscular load
- **Sub-optimal interaction** between humans and robots produces antagonistic forces and torques, diminishing control stability and degrading performance



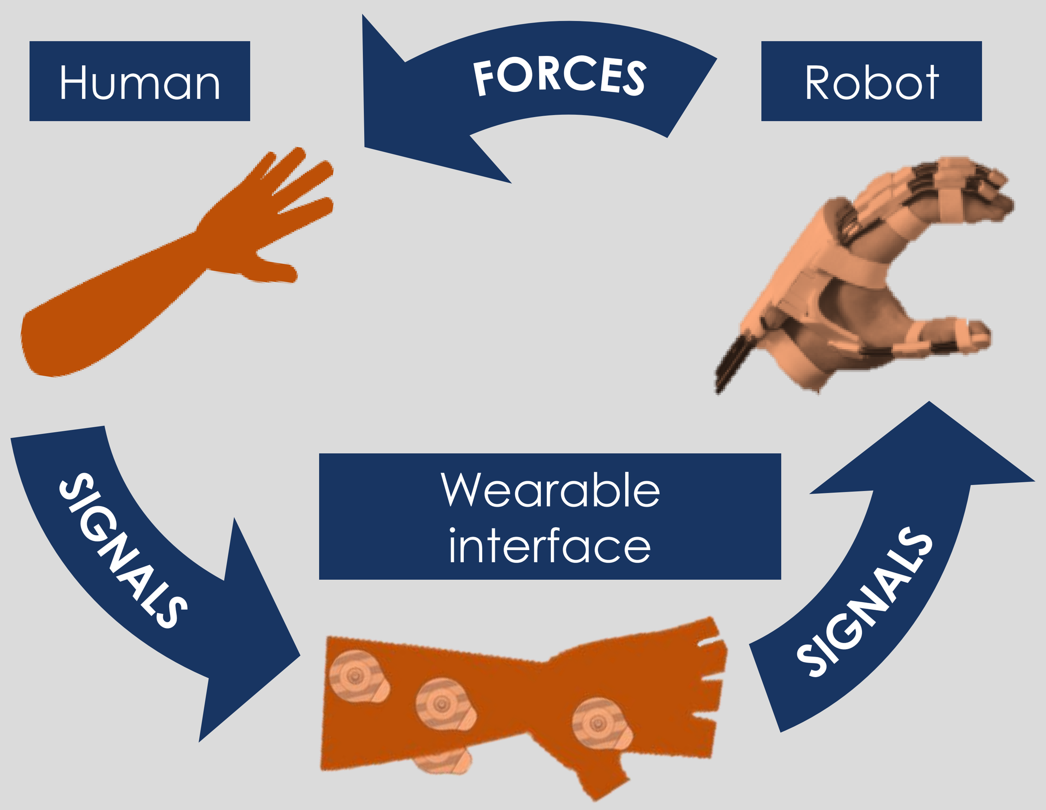
(left: Astronaut Sunita Williams using a high torque hand-held tool, right: A robotic hand device for assistance during space walks)

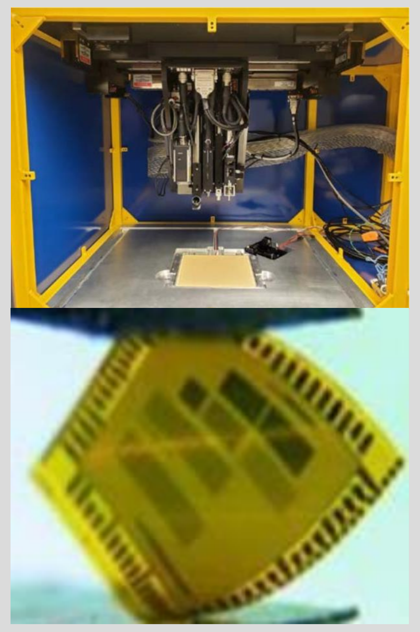
METHODS

3D printed flexible electrodes embedded in a fabric sleeve will be used to estimate fatigue and movement intent for more optimal human-robot collaboration



target muscles: Flexor digitorum superficialis (top), extensor digitorum (middle), flexor pollicis brevis (bottom)





3D printed Flexible sensor electronics

IMPLEMENTATION

Modeling fatigue: For non-isometric tasks, sEMG time-frequency spectral characteristics correlate to fatigue

Estimating intent: Decomposition of sEMG signal gives muscles contributions ($W_{[i,j]}$) to intended movements, ($H_{[i,j]}$).

Intent Prediction Process

$$H_{[i,j]}^{n+1} = H_{[i,j]}^{n} \frac{((W^n)^T V)_{[i,j]}}{((W^n)^T W^n H^n)_{[i,j]}}$$

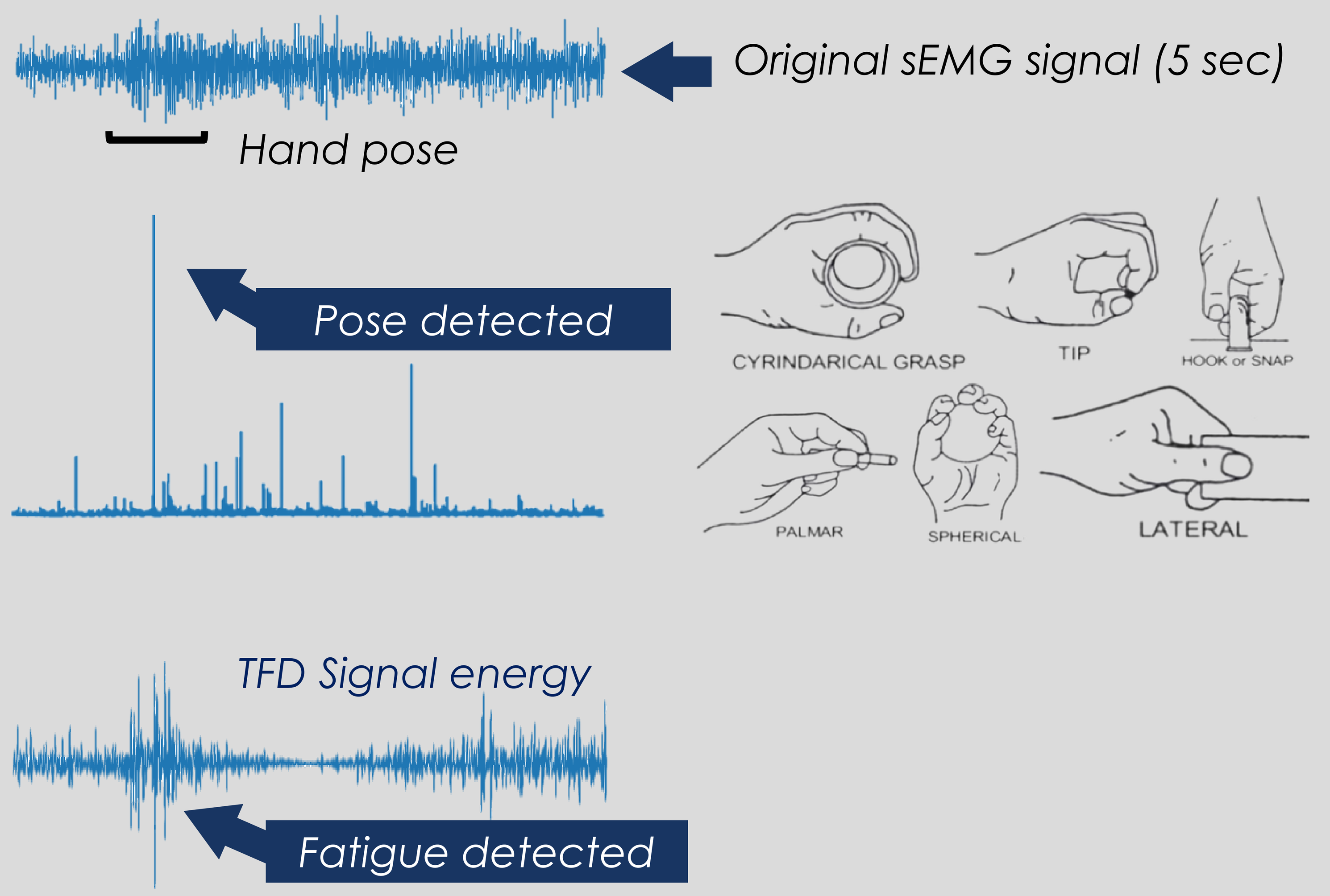
$$W_{[i,j]}^{n+1} = W_{[i,j]}^{n} \frac{(V(H^{n+1})^T)_{[i,j]}}{(W^n H^{n+1} (H^{n+1})^T)_{[i,j]}}$$

Fatigue Estimation Process

$$C(t,f) = \frac{1}{4\pi^2}\int_{-\infty}^{\infty} f\left(u+\frac{\tau}{2}\right) f^*\left(u-\frac{\tau}{2}\right) e^{-2\pi i\tau f}\, d\tau$$

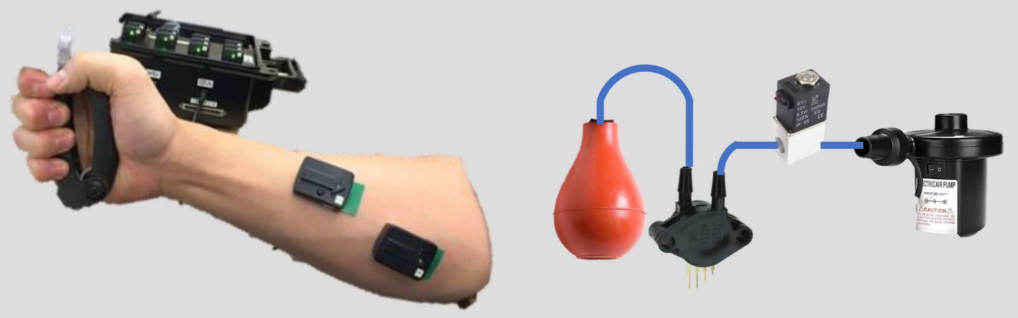
$$< f^0 t >= \int_{-\infty}^{\infty} C(t,\omega)\, d\omega = |a_i(t)|^2$$

$$< f^1 t >= \int_{-\infty}^{\infty} \frac{C(t,\omega)}{<f^0 t>}\, \omega\, d\omega = f_{in}(t)$$



Experimental Validation Protocol

Stage 1. Validation



Stage 2. Comprehensive human subjects trial

Stage 3. Trial with spacesuit glove

CONCLUSIONS

Preliminary results suggest that the interface is able to *model both neuromuscular fatigue and movement intent accurately*, advancing the state of the art in HRI

This work meets practical needs in space-suit mounted robotics and human robot interaction more broadly, as no other work has presented such an approach. Future work will include a comprehensive system usability study

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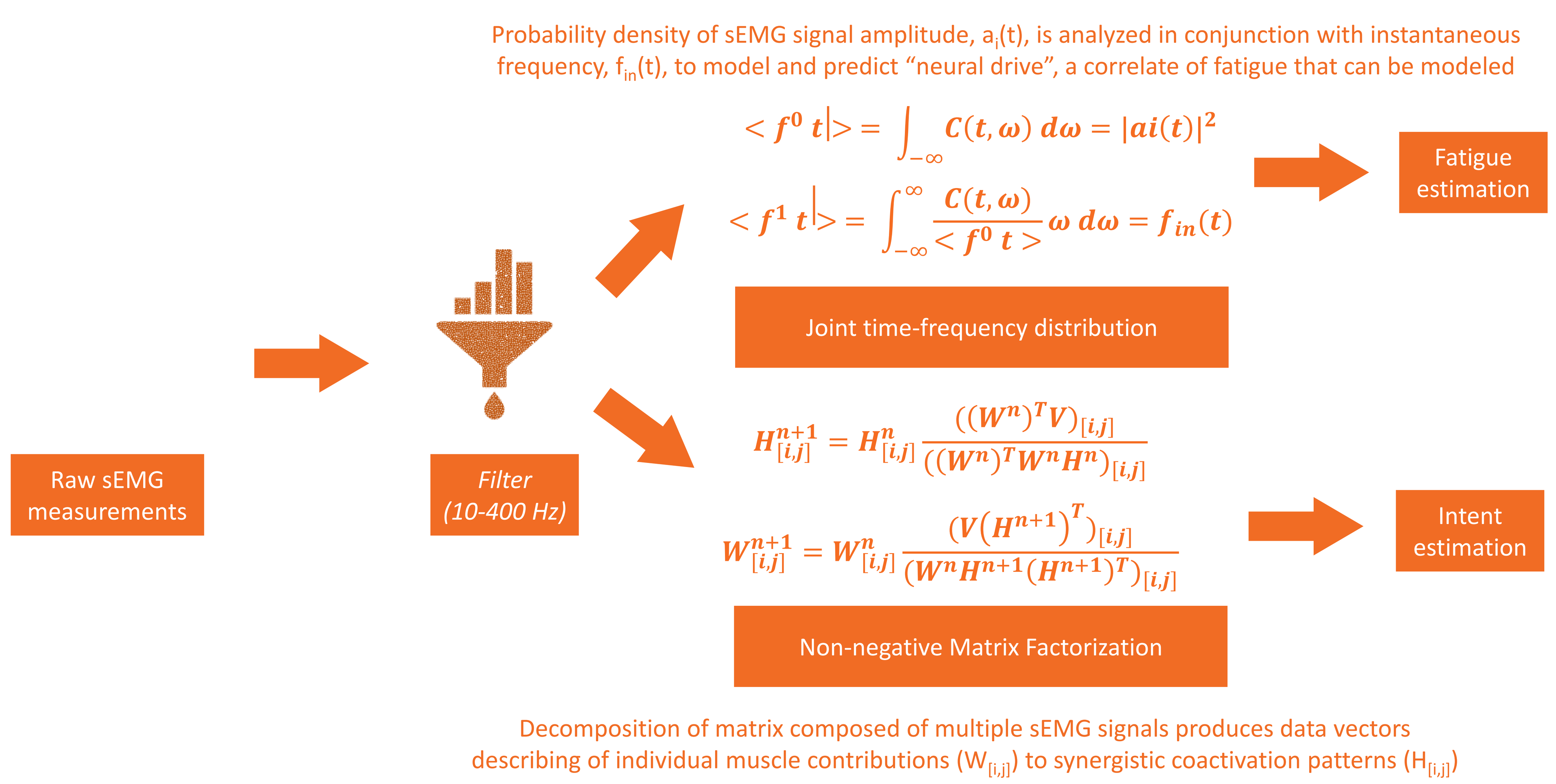
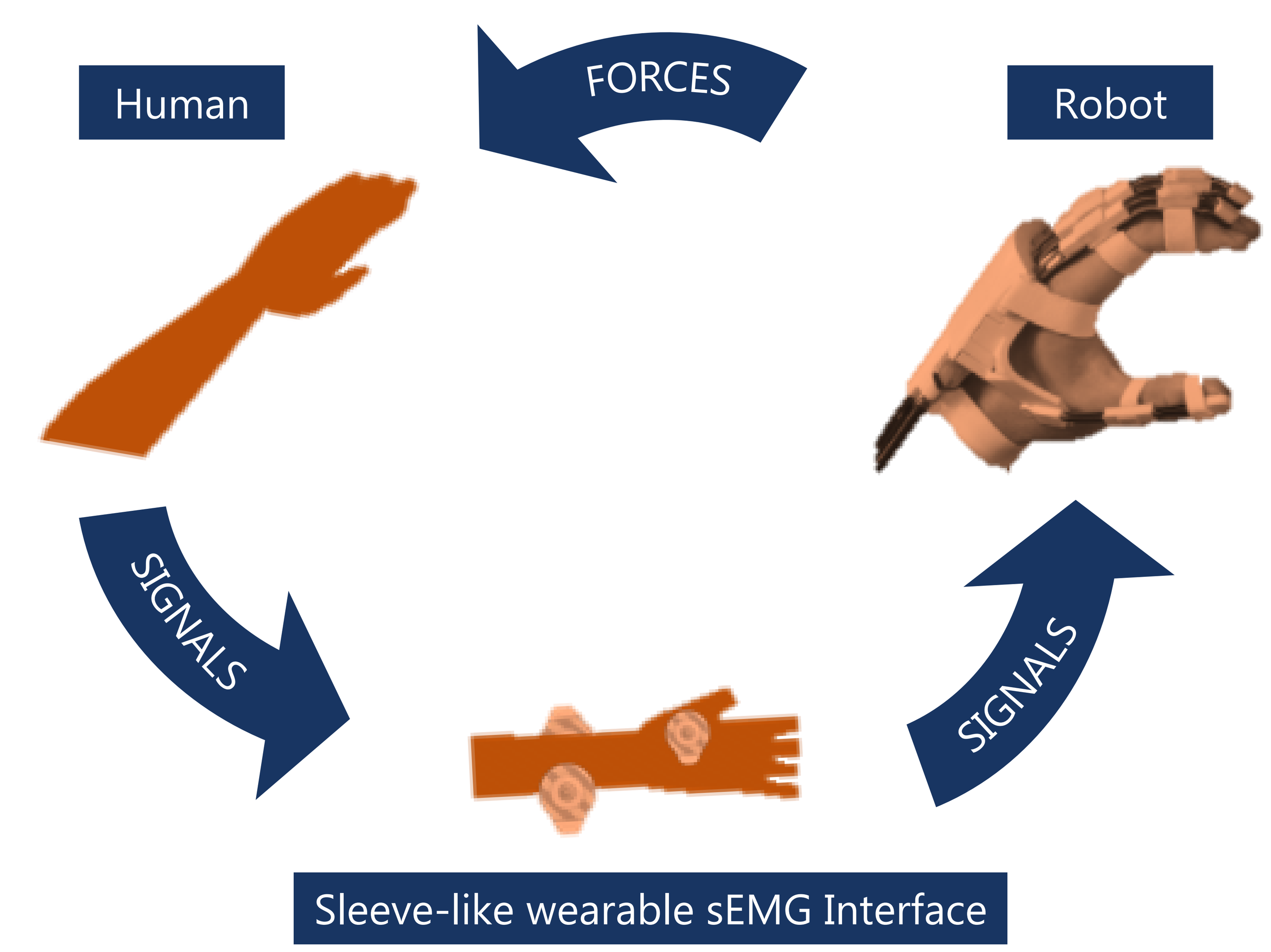
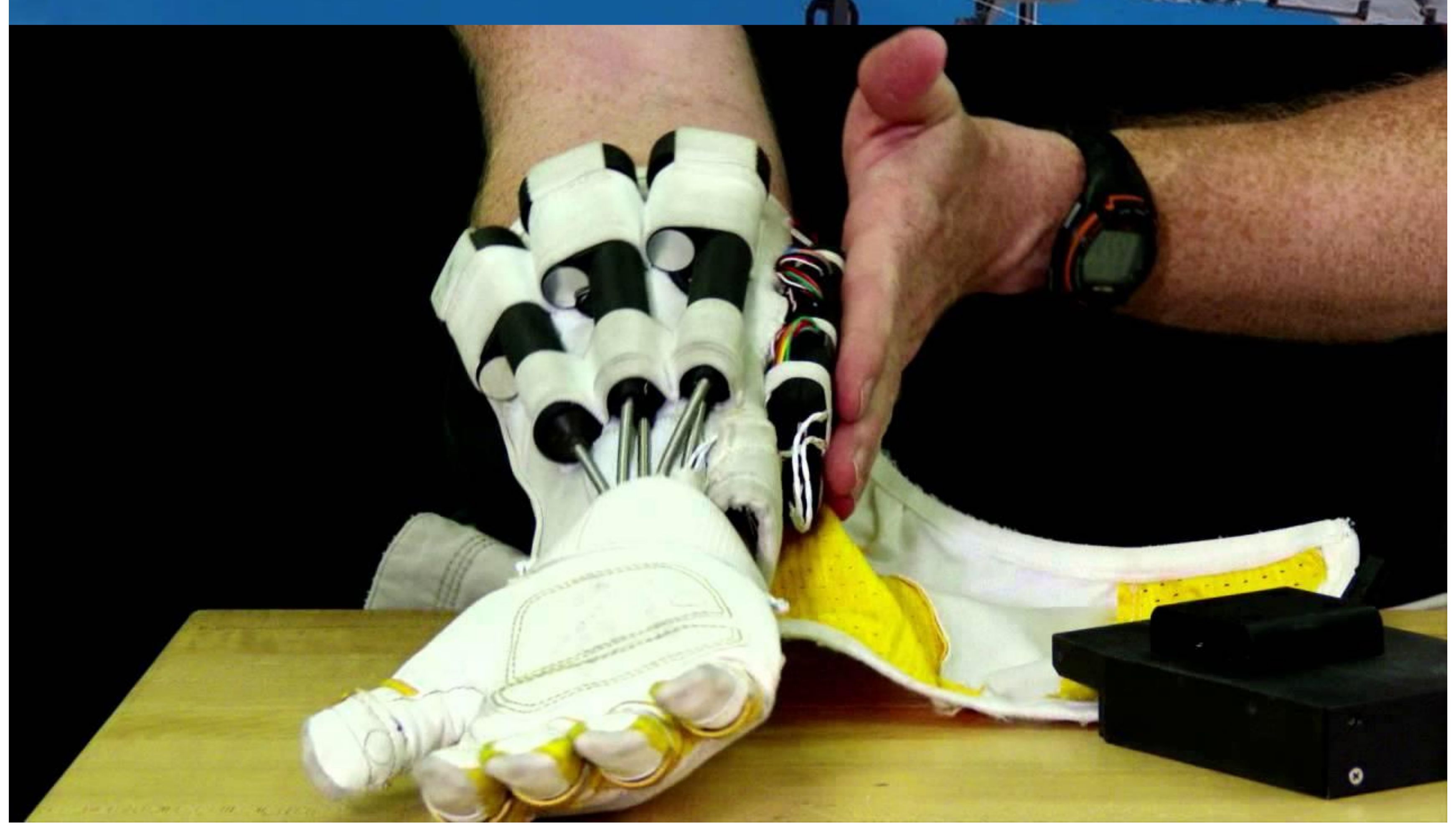
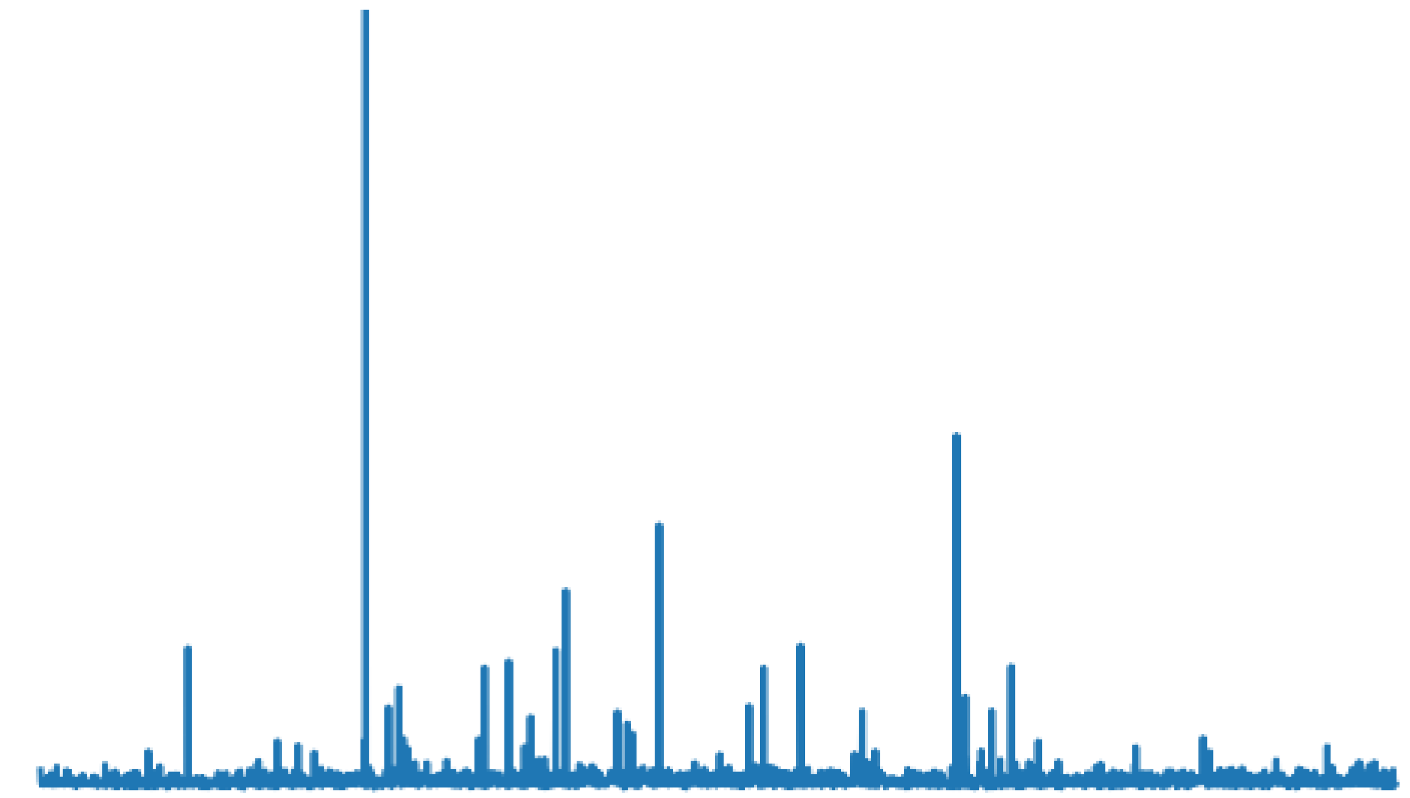
Human-robot interaction plays a key role in healthcare, automation, and military infrastructure, and will continue to enhance human performance in these and other areas.

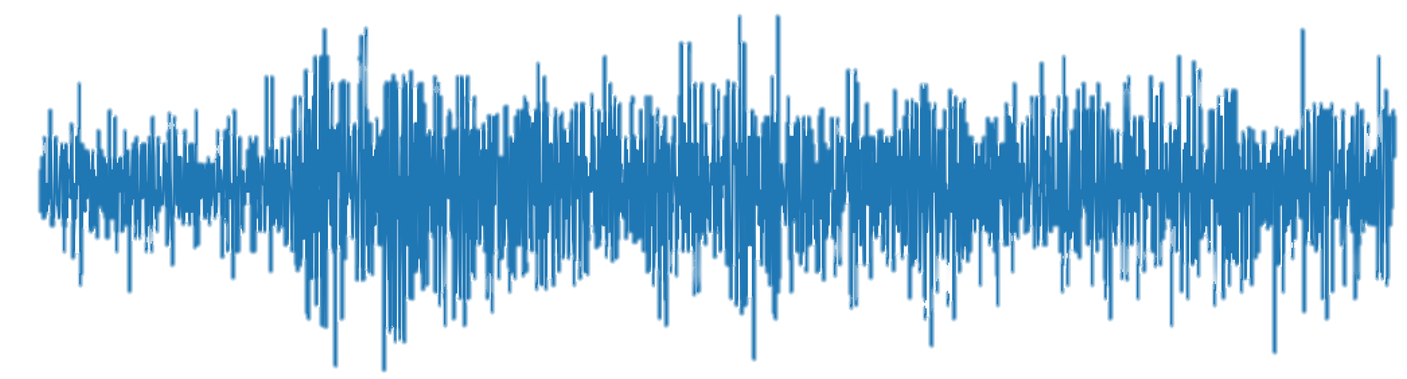
No standard interface has yet been developed to evaluate and predict muscle fatigue and movement intent.

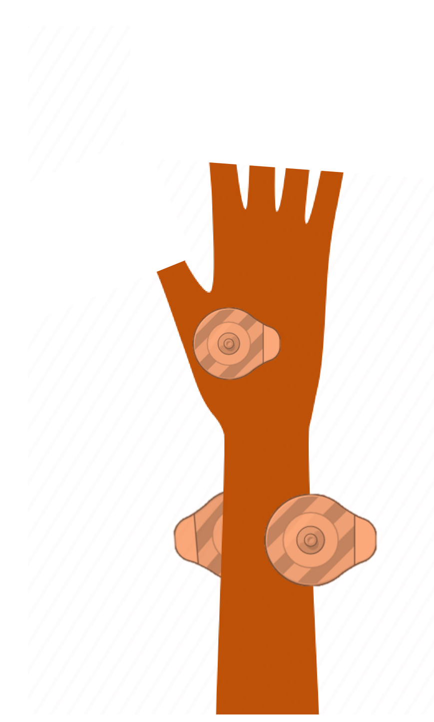


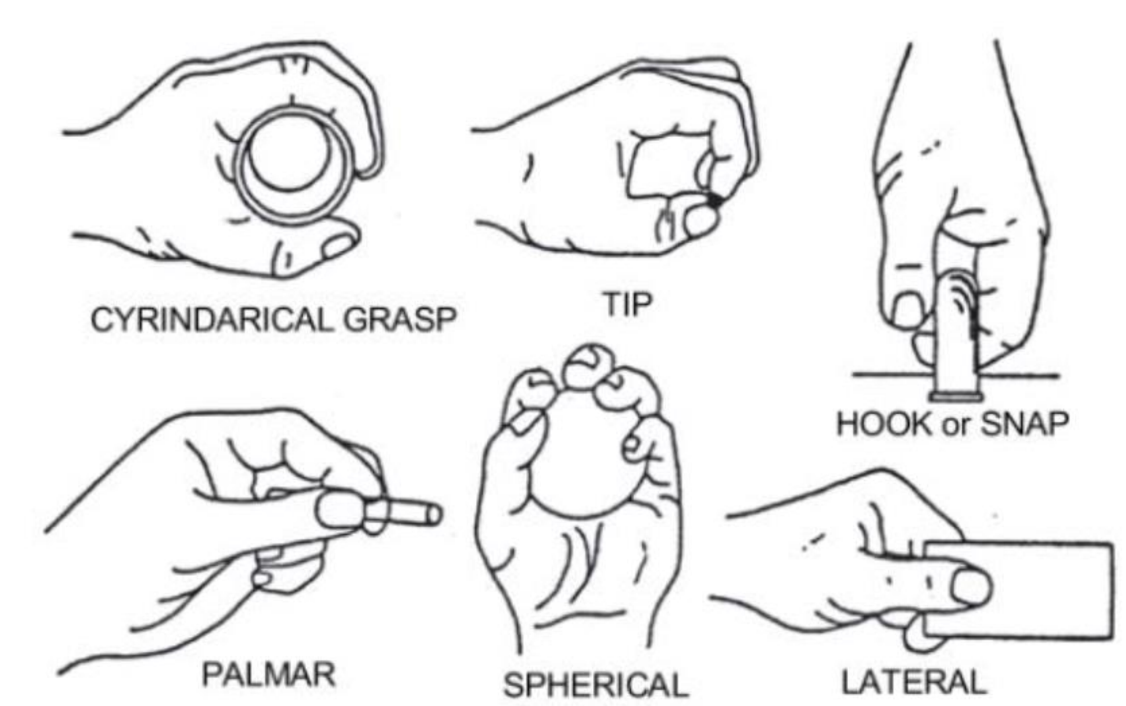











CYRINDARICAL GRASP
TIP
HOOK or SNAP
PALMAR
SPHERICAL
LATERAL


CAUTION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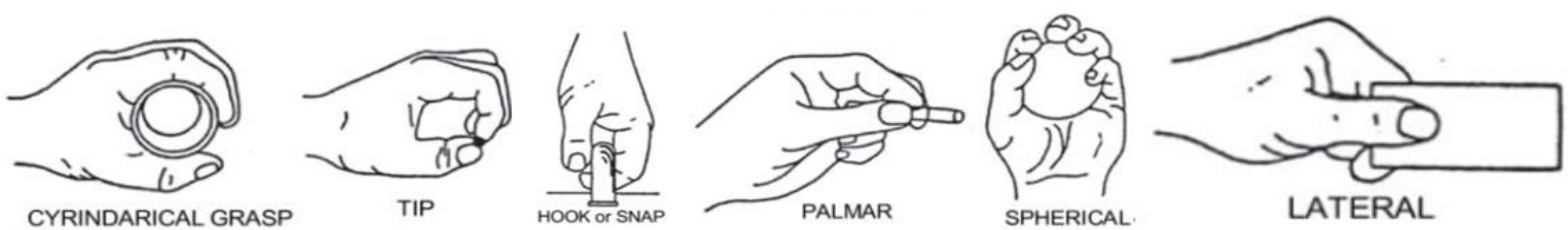
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Toward the Future of Manned Space Exploration:
A Novel Wearable Interface for Optimal Human-Robot Collaboration

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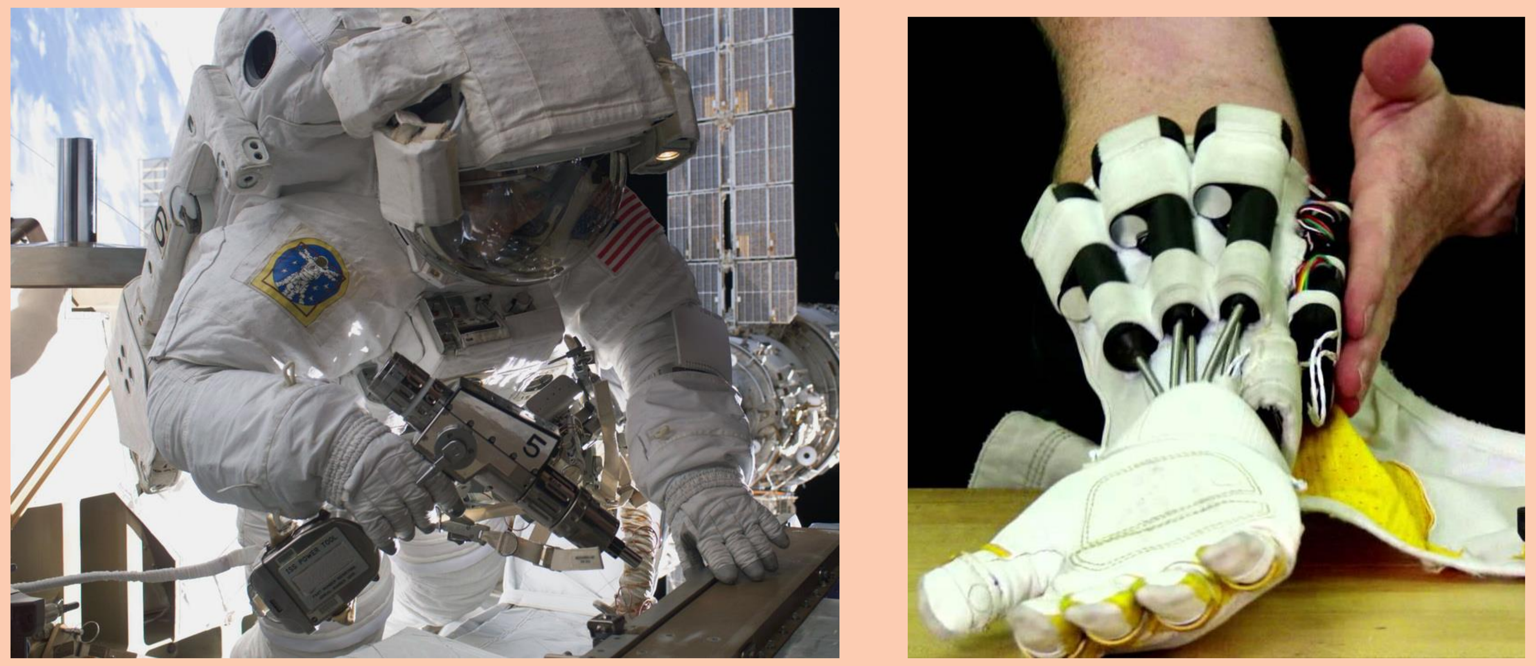
BACKGROUND

Robots can assist astronaut during dangerous or taxing EVAs by providing assistive forces and torques to reduce neuromuscular load.

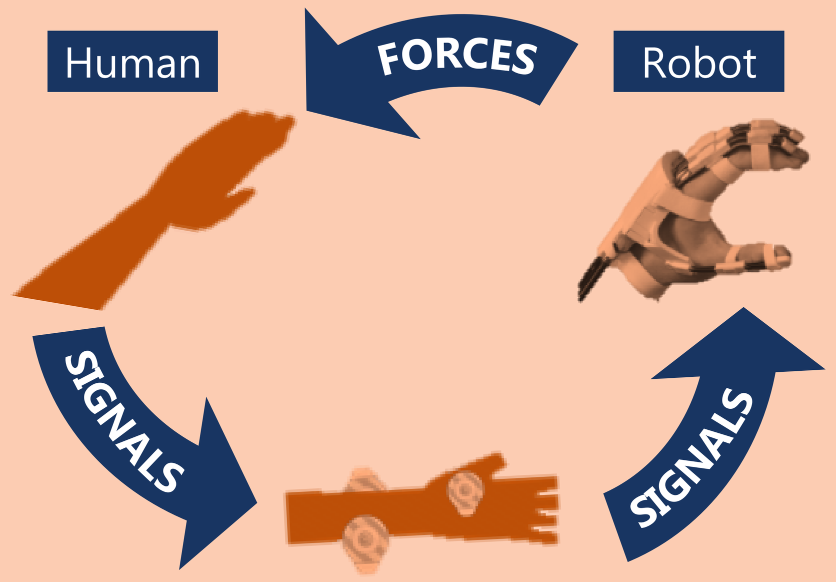
Sub-optimal interaction between humans and robots due to produces antagonistic forces and torques, diminishing control stability and degrading performance



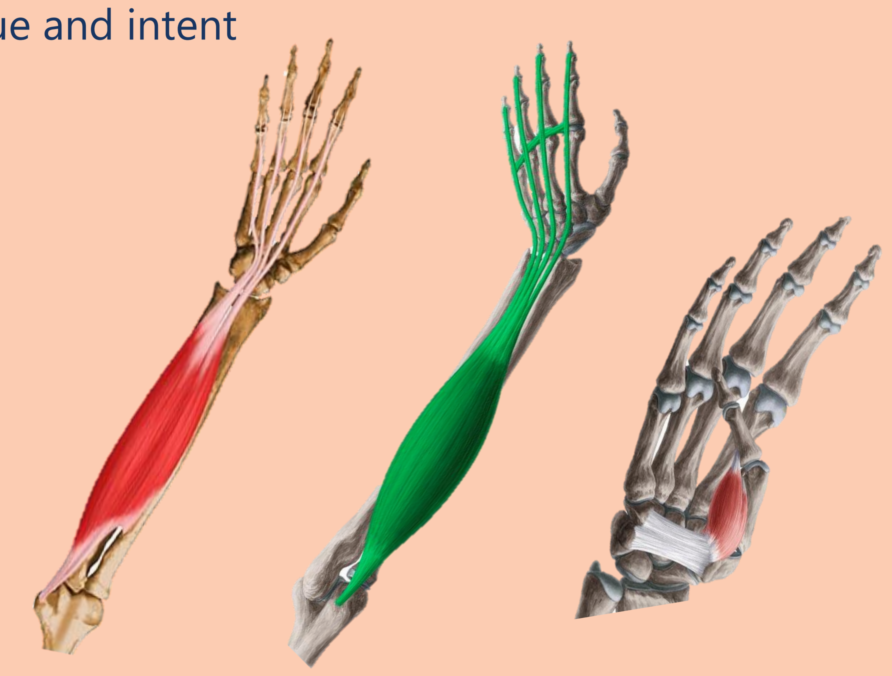
(left: Astronaut Sunita Williams using a high torque hand-held tool, right: A robotic hand device for assistance during space walks)

METHODS

A wearable interface embedded with surface electrodes allow for analysis of neuromuscular characteristics including fatigue and intent



Sleeve-like wearable interface



Flexor digitorum superficialis (left), extensor digitorum (middle), flexor pollicis brevis (right)

IMPLEMENTATION

Processing of the muscle signals includes joint analysis of the probability density of sEMG signal amplitude, $a_i(t)$, and instantaneous frequency, $f_{in}(t)$ to model and predict fatigue. Decomposition of sEMG signal matrices will quantify contributions of muscles ($W_{[i,j]}$) to intended movements models ($H_{[i,j]}$).

Non-negative Matrix Factorization

$$H_{[i,j]}^{n+1} = H_{[i,j]}^{n} \frac{((W^n)^T V)_{[i,j]}}{((W^n)^T W^n H^n)_{[i,j]}}$$

$$W_{[i,j]}^{n+1} = W_{[i,j]}^{n} \frac{(V(H^{n+1})^T)_{[i,j]}}{(W^n H^{n+1} (H^{n+1})^T)_{[i,j]}}$$

→ **Intent estimation**

Joint time-frequency distribution

$$< f^0 | t > = \int_{-\infty}^{\infty} C(t,\omega)\, d\omega = |ai(t)|^2$$

$$< f^1 | t > = \int_{-\infty}^{\infty} \frac{C(t,\omega)}{< f^0 | t >} \omega\, d\omega = f_{in}(t)$$

→ **Fatigue estimation**

CONCLUSIONS

This work presents a novel human-robot interface which analyzes user fatigue and movement intent using surface electromyography.

reduces garment, It generates and communicates control parameters to wearable robots to minimize their response latency and minimize user fatigue. No other work has presented such an approach, and this work meets a need not only in the literature, but also a felt need in areas such as tele-health and rehabilitation, to Space-suit mounted robotic assistance. Future work includes a comprehensive system usability and efficacy study in a human-subjects context.

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