Monitoring Human Neuromusculoskeletal System Performance during Spacesuit Glove Use: A Pilot Study

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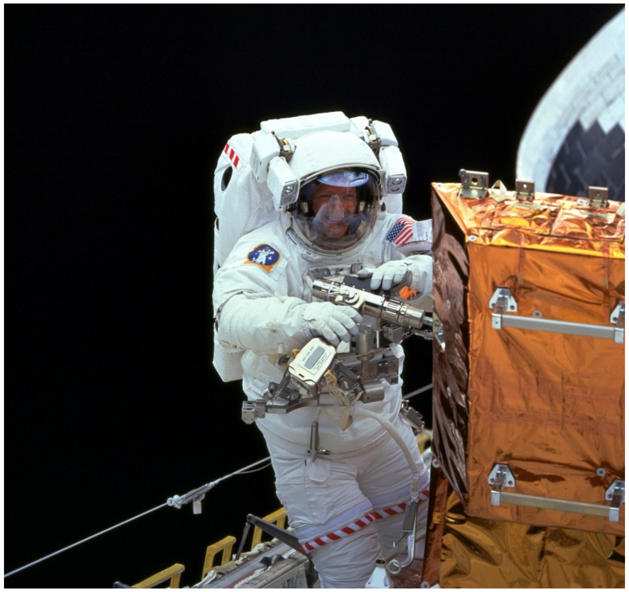
Motivation

Extravehicular Activity (EVA)



Source: nasa.gov

Source: spaceflight.nasa.gov

Motivation

Space program plagued by overuse/repetitive injuries in the hand and upper extremities[1]

Hand and forearm fatigue most common spacesuit glove-induced trauma during EVA flight[2]

Source: nasa.gov

Source: nasa.gov

Motivation

Fatigue:

Astronauts have repeatedly mentioned hand fatigue as the limiting factor in EVA productivity. After STS-61B, it was noted that after about four hours one crewmember experienced hand fatigue to the point that he felt he would have had extreme difficulty in a rescue situation where he was required to take care of the other EVA crewmember. During a ratchet operation on STS-6, an astronaut found it necessary to pause frequently to rest the hand and arm even though actual force required by the device was less than 25 lbf and the handle was designed to accommodate a full, natural cylindrical grasp.

Source: O'Hara et al., 1988.

Purpose of this Work

Aim

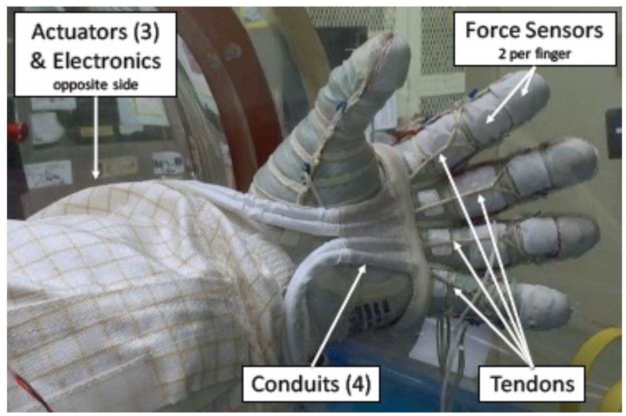
Utilize system-based monitoring to track fatigue-induced performance degradation during spacesuit glove use

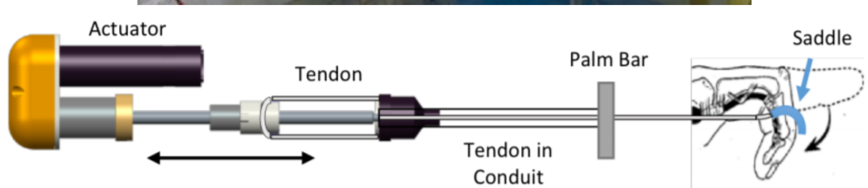
Impact

Help ensure astronaut safety and mission success through fitness-for-duty evaluation during EVA

Pilot Study

Spacesuit RoboGlove (SSRG)



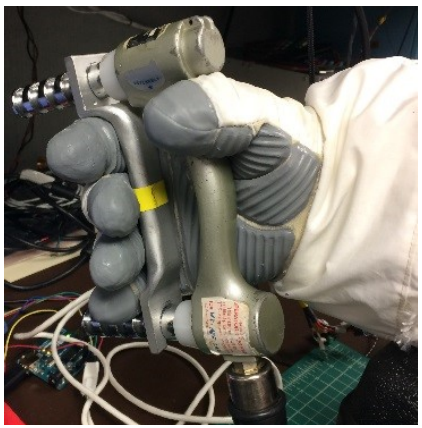


Source: Rogers et al., 2017

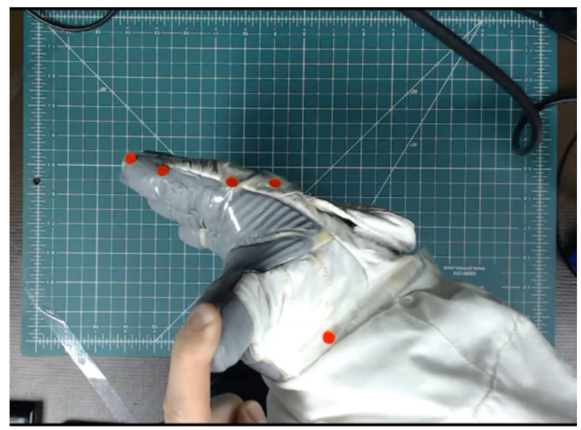
Pilot Study

Fatiguing Tasks

Isometric Grasping



Repetitive Movement

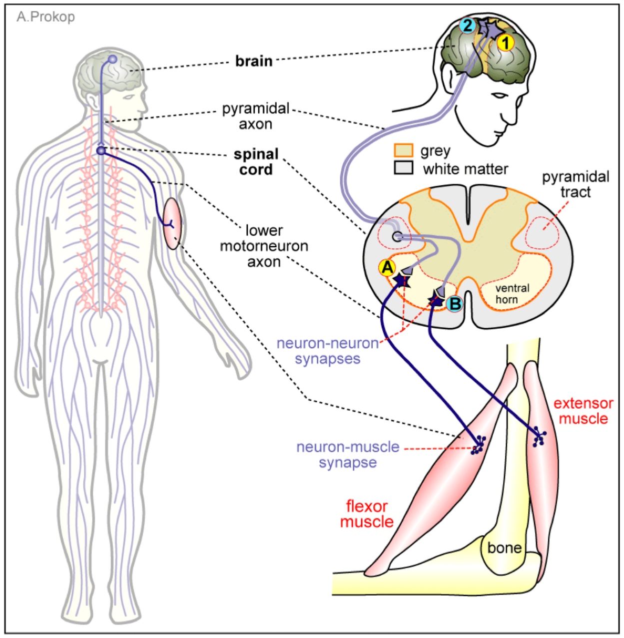


Background

What is fatigue?

Decline in the ability of a muscle to generate force

Background

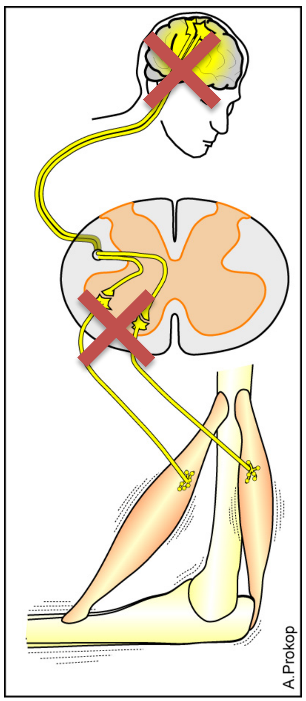


Neuromusculoskeletal (NMS) System

Source: https://droso4schools.wordpress.com/l3-neurons/

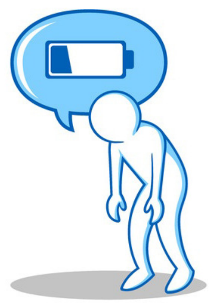
Background

How is fatigue assessed?



[1]

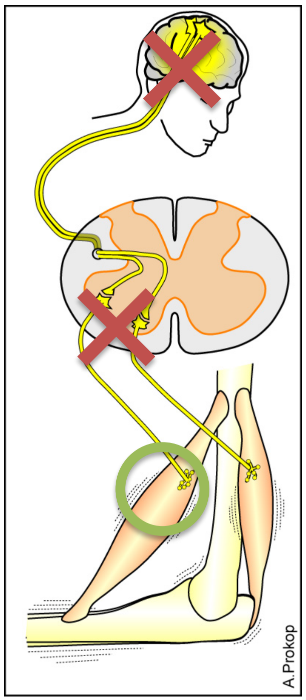
Psychological Perception


[2]

[1] https://droso4schools.wordpress.com/l3-neurons/
[2] healthguidance.org

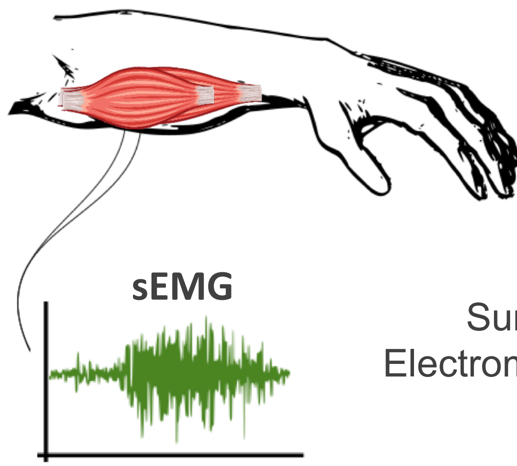
Background

How is fatigue assessed?



[1]

Physiological Response



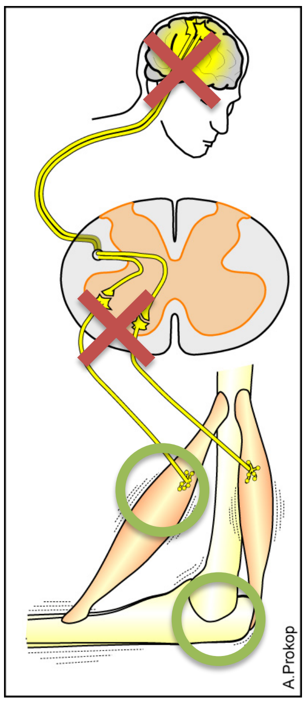
Surface Electromyography

NMS Peripheral Inputs

[1] https://droso4schools.wordpress.com/l3-neurons/

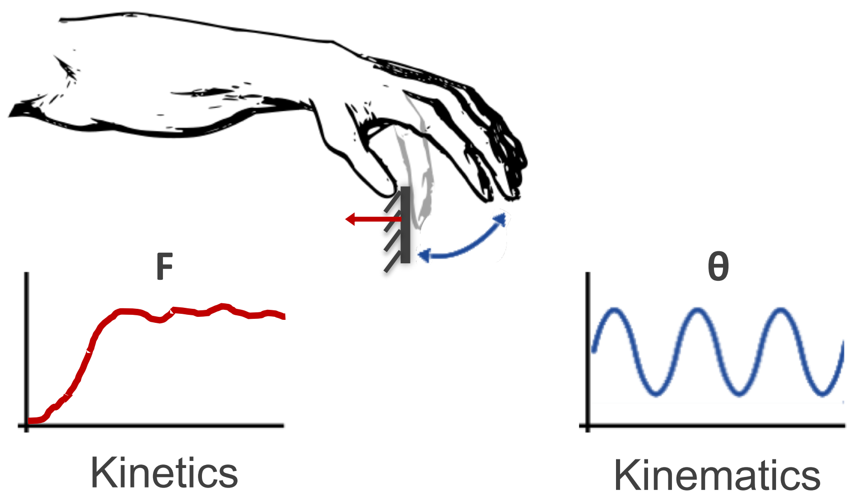
Background

How is fatigue assessed?



[1]

Performance Outcome Decay



NMS Peripheral Outputs

[1] https://droso4schools.wordpress.com/l3-neurons/

Background

Inherent need for more advanced approach to monitoring fatigue-induced performance degradation.

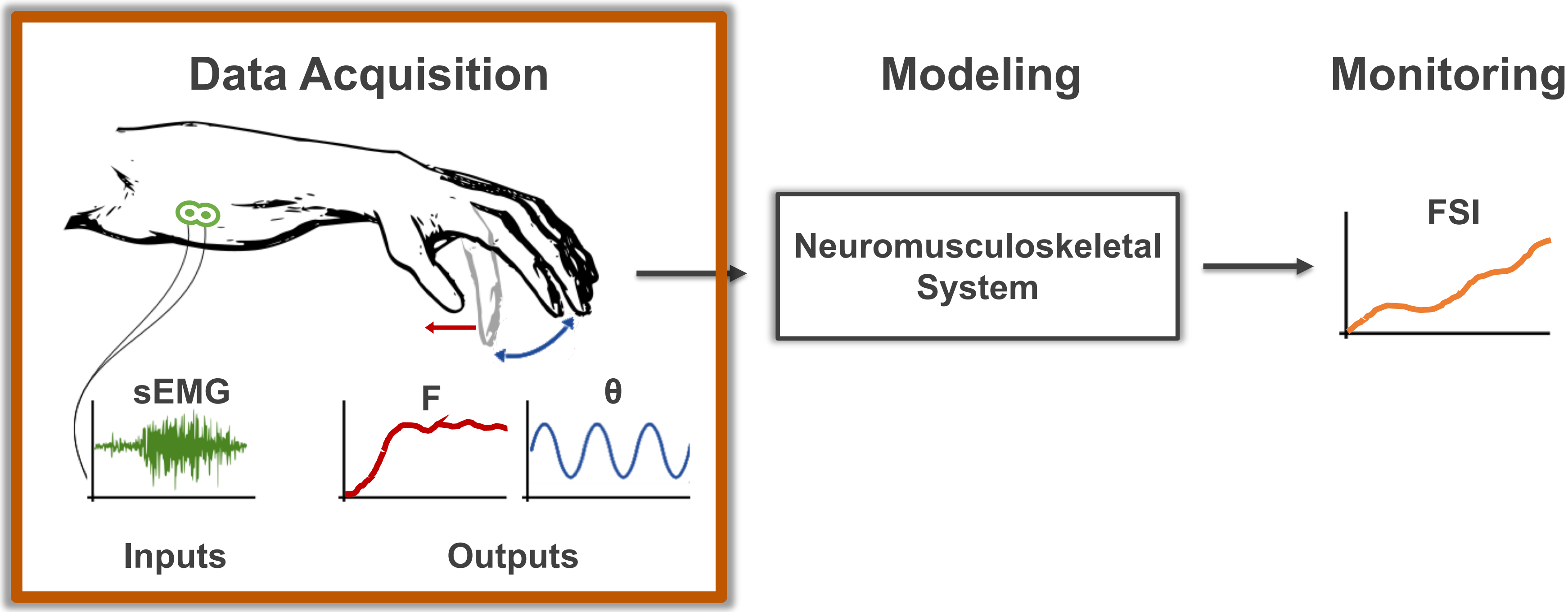
Proposed Solution

System-based Monitoring of Performance Degradation

Models and tracks the dynamic relationship between the physiological inputs and outputs of the NMS system.

Proposed Solution

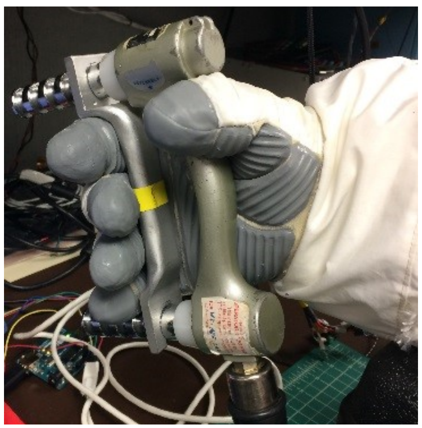
System-based Monitoring of Performance Degradation



Pilot Study

Fatiguing Tasks

Isometric Grasping



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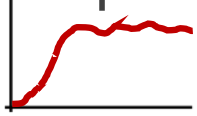
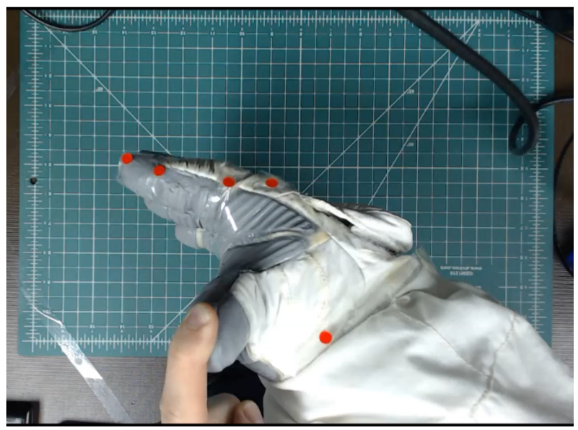


Repetitive Movement



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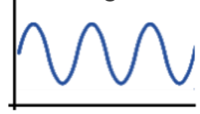
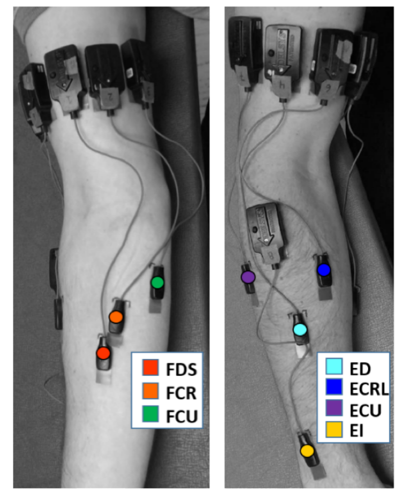
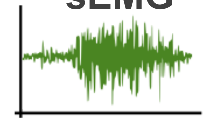


Muscles Utilized

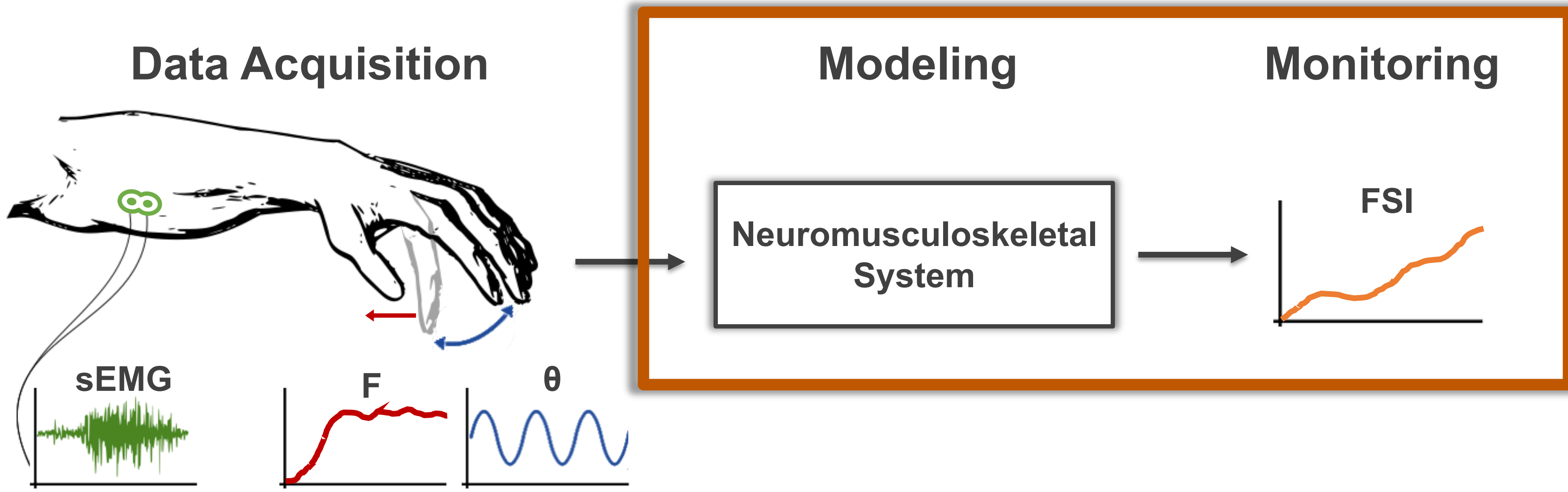


sEMG

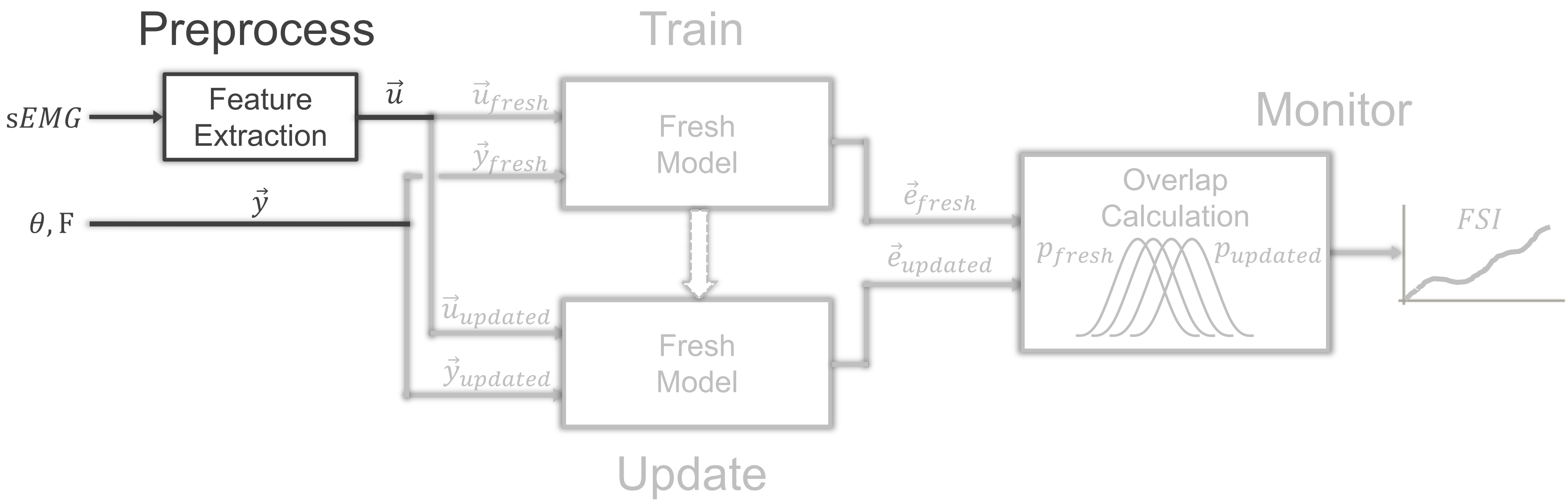


Proposed Solution

System-based Monitoring of Performance Degradation

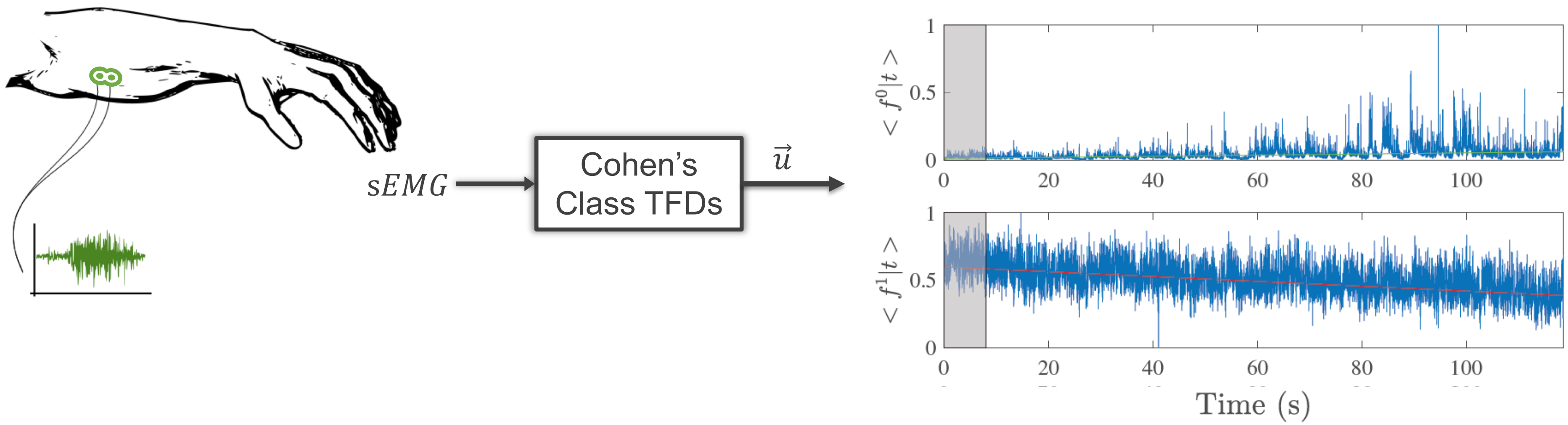


Neuromusculoskeletal Monitoring

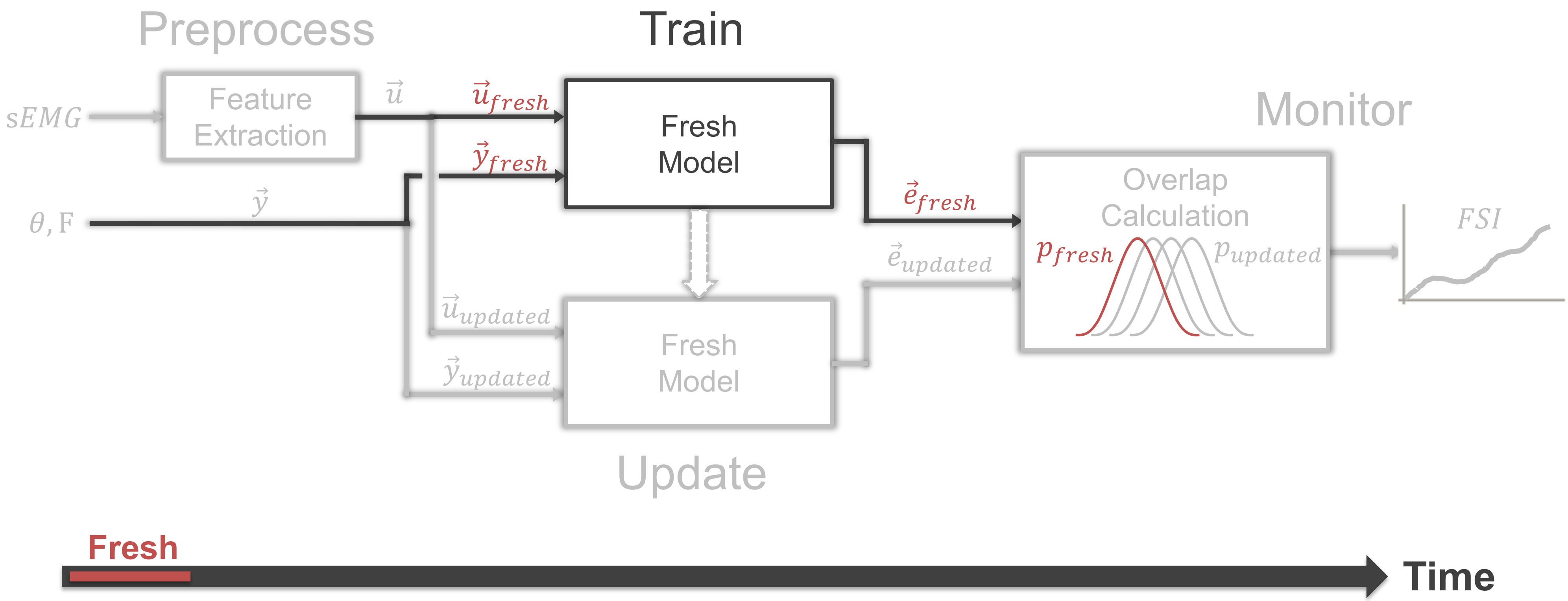


Neuromusculoskeletal Monitoring

Joint Time-Frequency Analysis

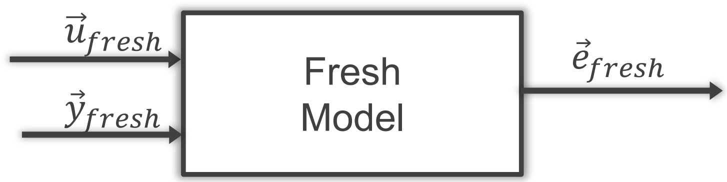


Neuromusculoskeletal Monitoring



Neuromusculoskeletal Monitoring

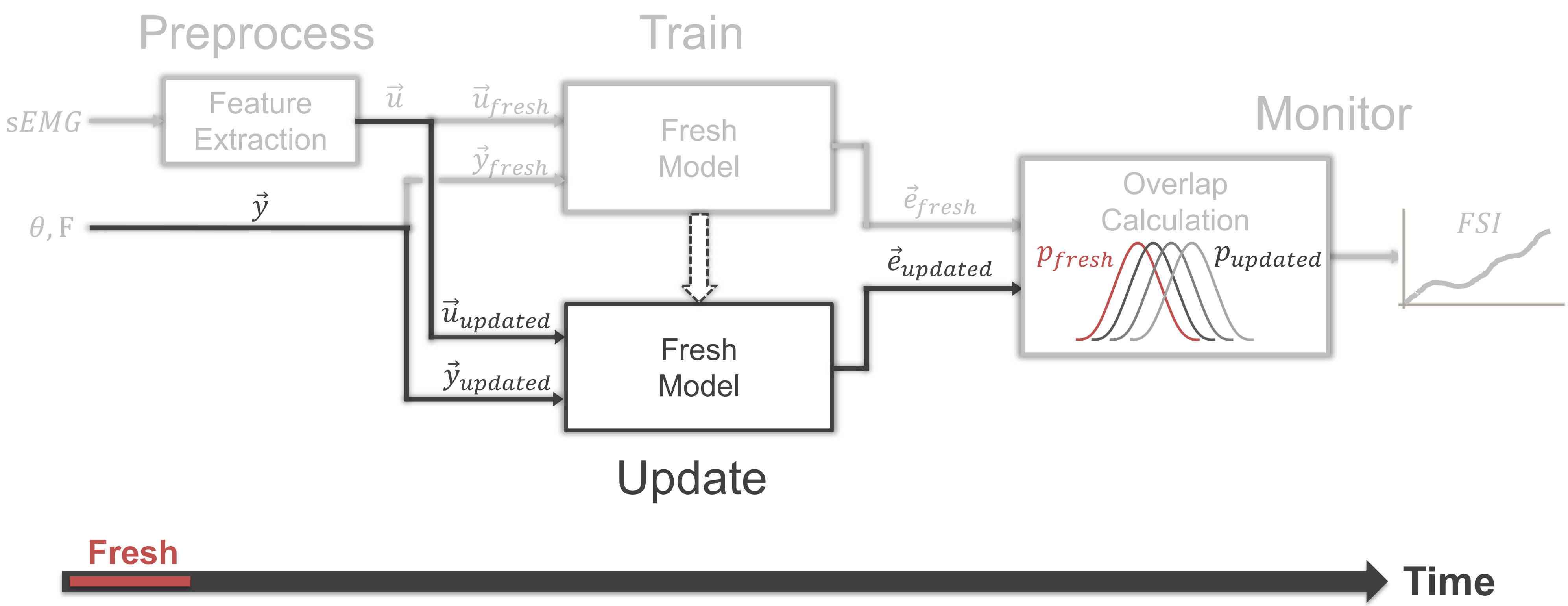
Autoregressive Moving Average Model with Exogenous Inputs (ARMAX)



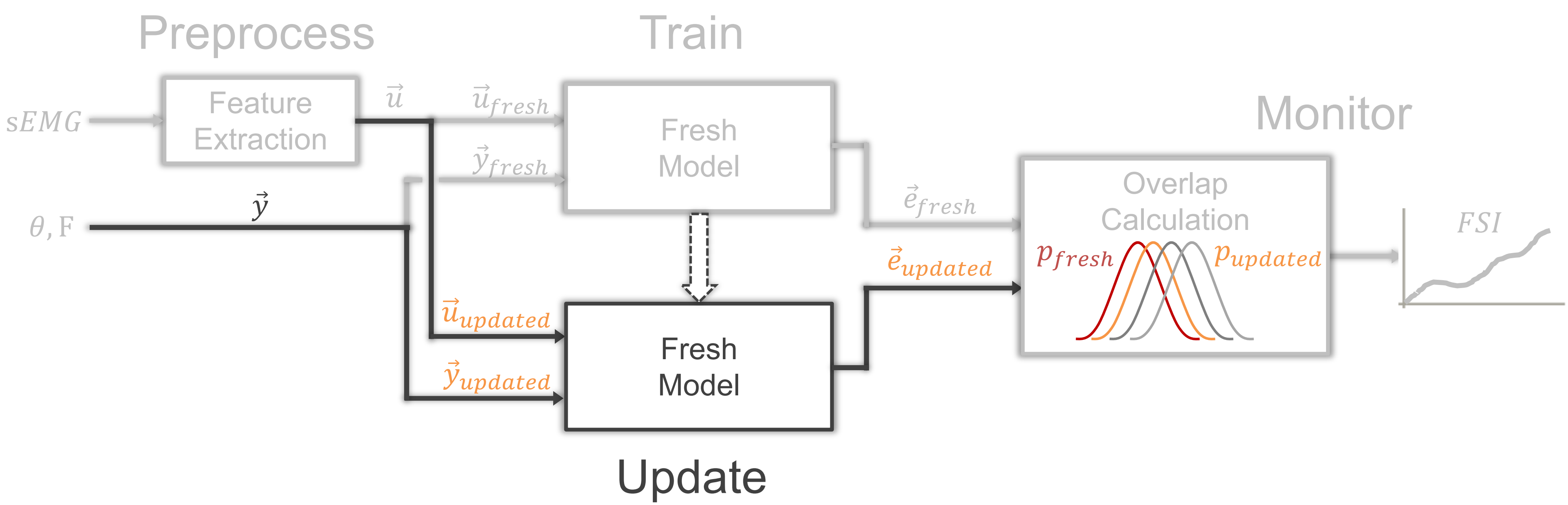
$$A(q)y(t) = B(q)u(t) + C(q)e(t)$$

$$A(q) = 1 + a_1 q^{-1} + \ldots + a_{n_a} q^{-n_a}$$
$$B(q) = b_1 + b_2 q^{-1} + \ldots + b_{n_b} q^{-n_b+1}$$
$$C(q) = 1 + c_1 q^{-1} + \ldots + c_{n_c} q^{-n_c}$$

Neuromusculoskeletal Monitoring



Neuromusculoskeletal Monitoring



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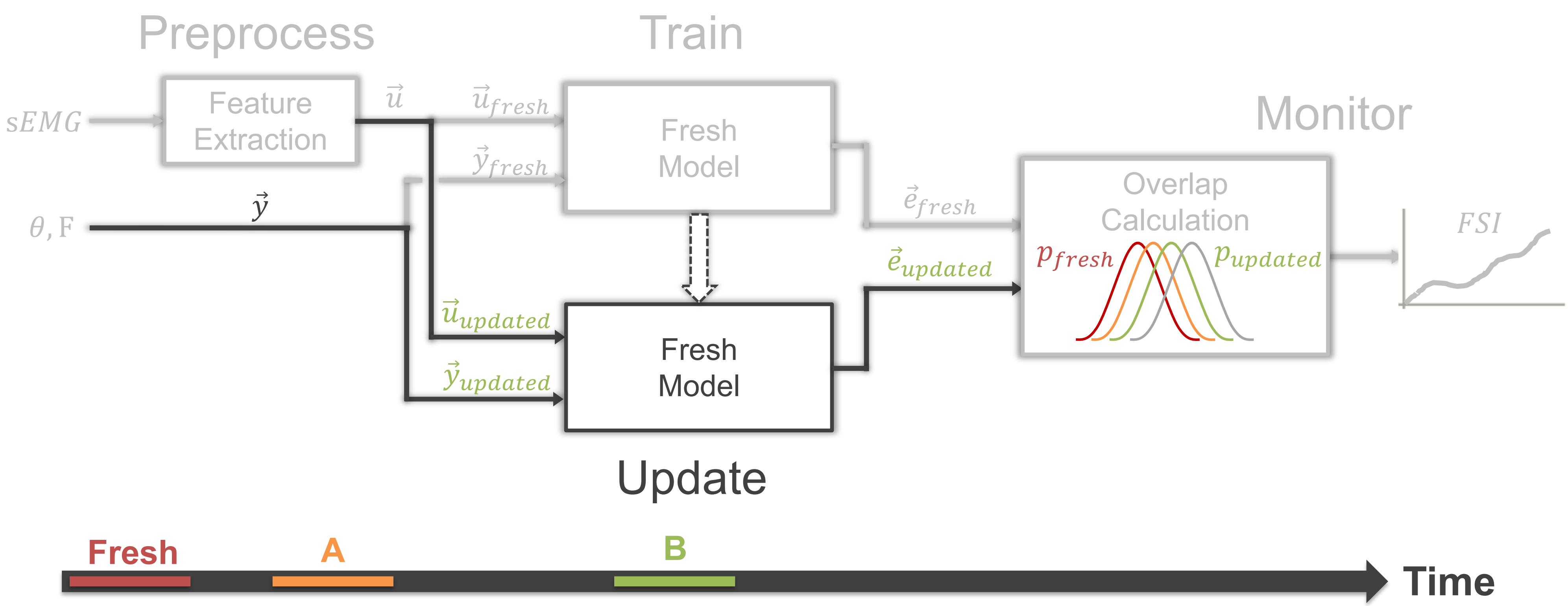

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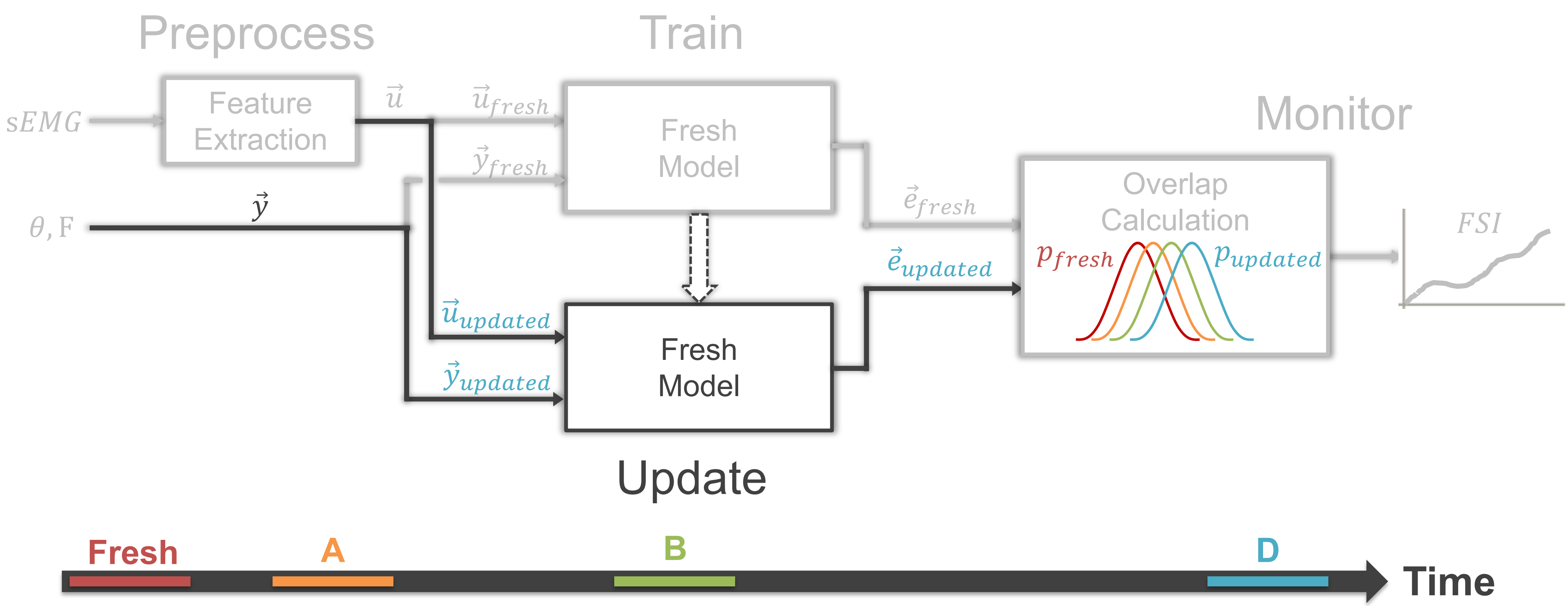
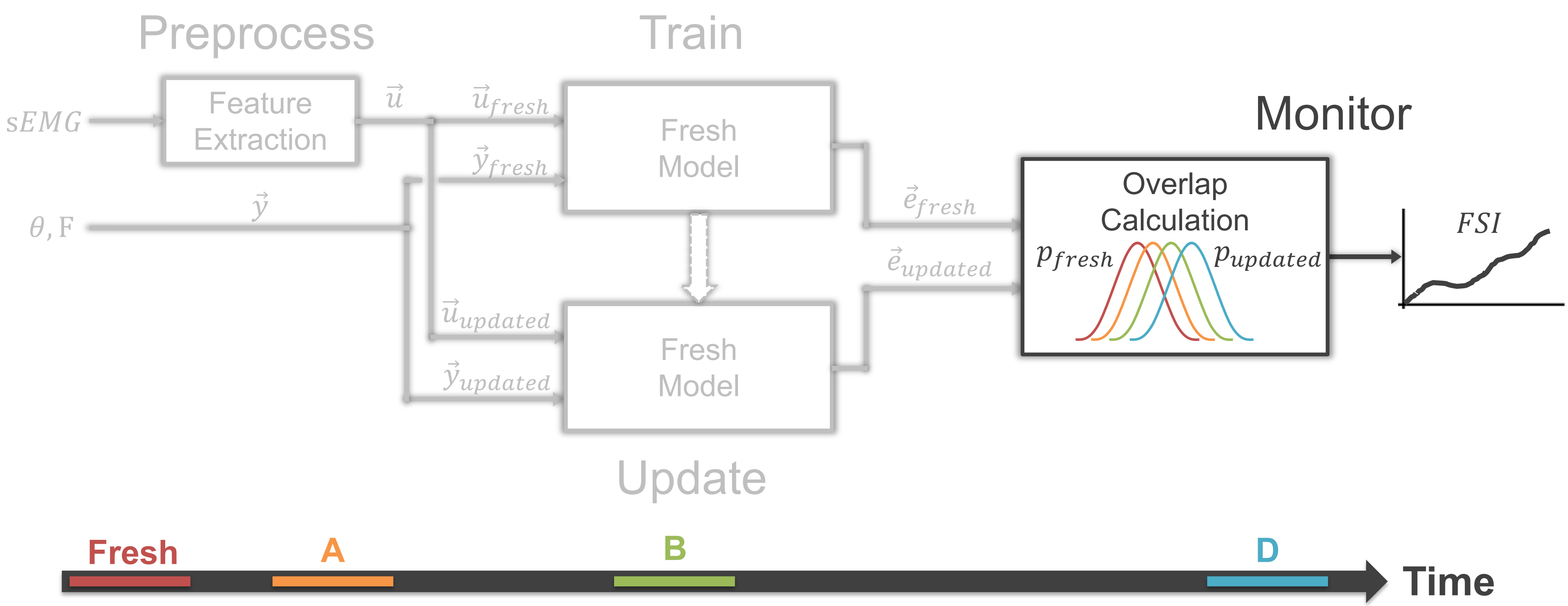


Neuromusculoskeletal Monitoring

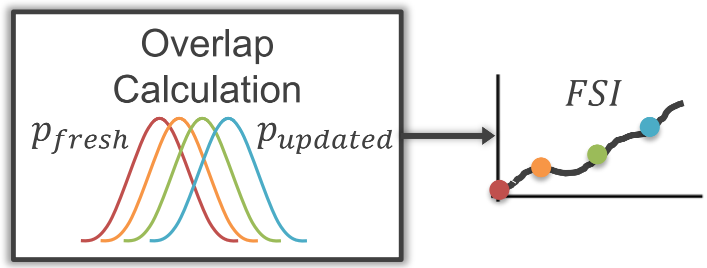


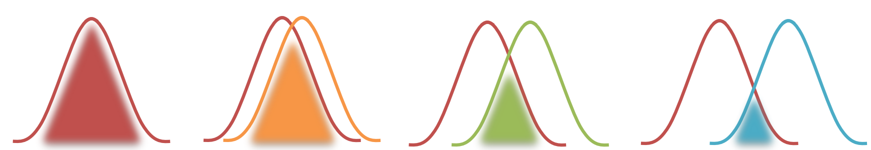
Neuromusculoskeletal Monitoring

Quantifying of Performance Degradation

Freshess Similarity Index

$$FSI = D_{KL}(p_1||p_2) = \sum_{i=1}^{N} ln(\frac{p_1}{p_2})$$





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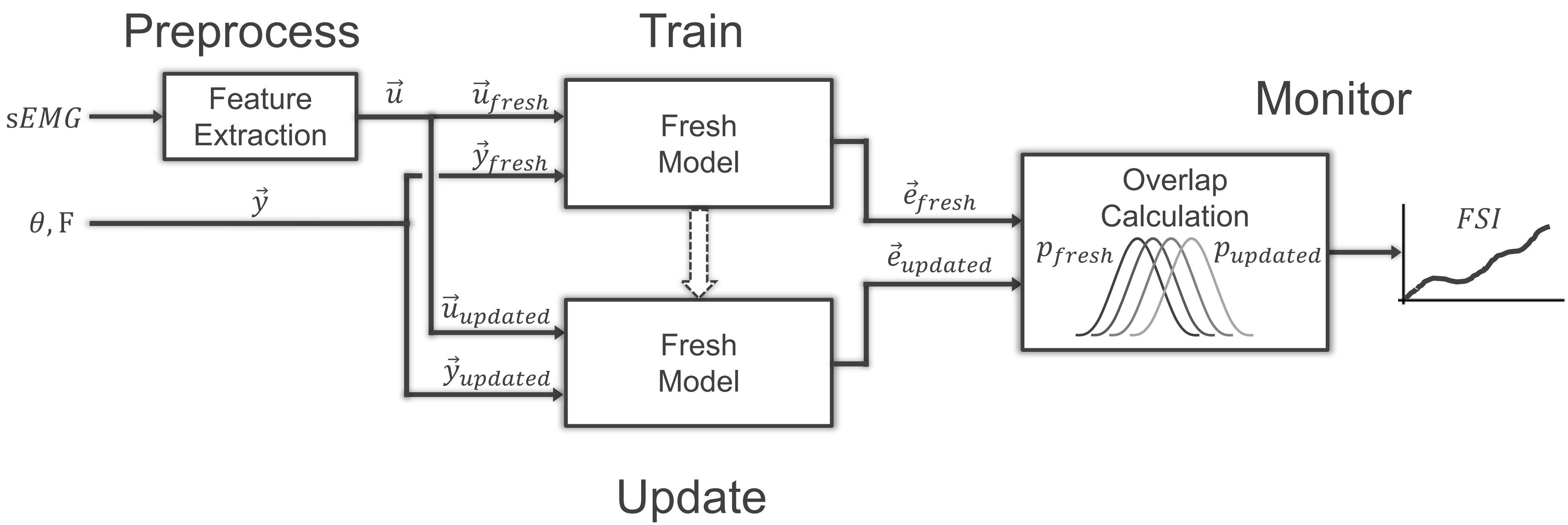
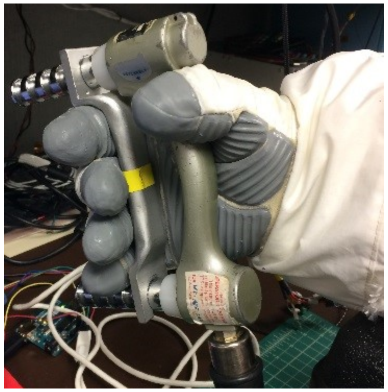


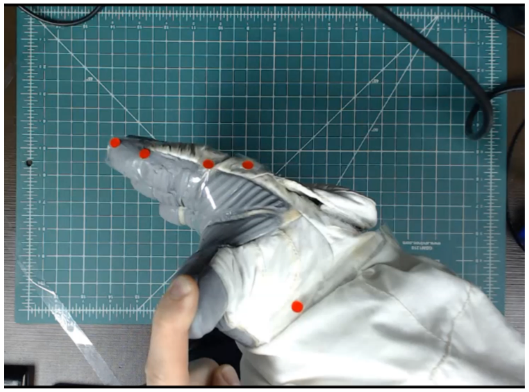
Pilot Study

Demonstrate efficacy of system-based monitoring in tracking fatigue-induced performance degradation during suited tasks.

Fatiguing Tasks



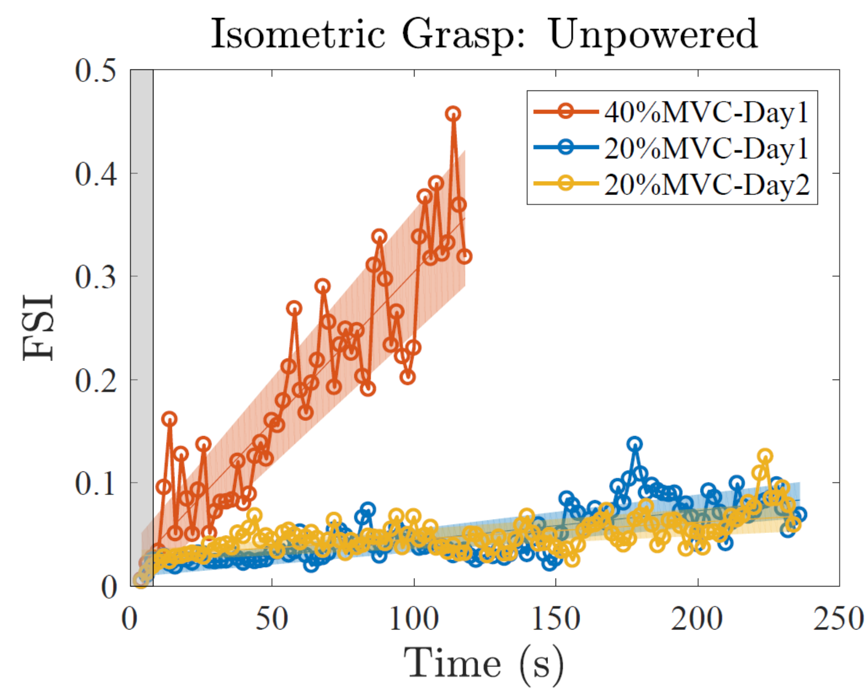
Isometric Grasping



Repetitive Movement

Results

Isometric Grasping Task



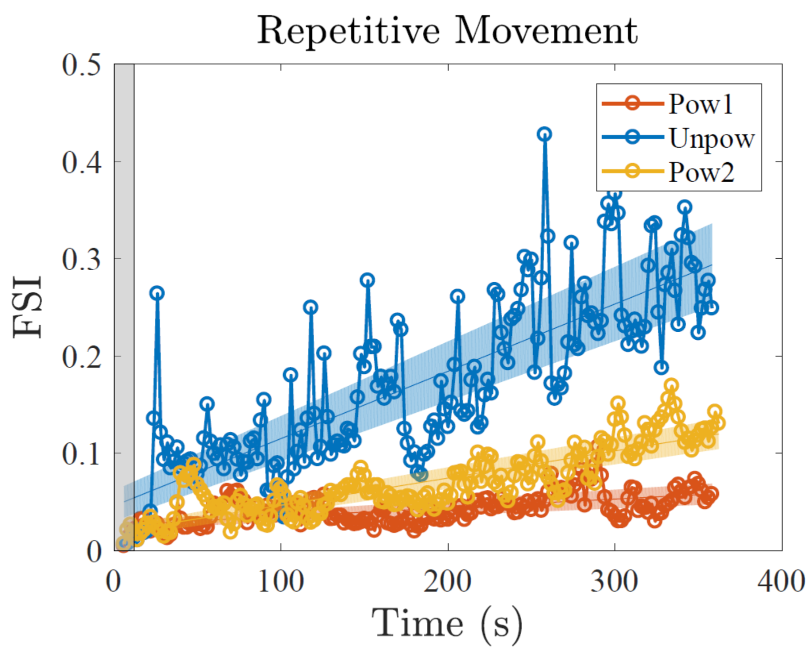
Results

Isometric Grasping Task

Test	Slope (Unpow)	Slope (Pow)
20% MVC day 1	2.8909×10^{-4}	4.1357×10^{-4}
40% MVC day 1	2.9011×10^{-3}	1.0983×10^{-3}
20% MVC day 2	1.6482×10^{-4}	1.6925×10^{-4}

Results

Repetitive Movement Task



Summary

Succinctly characterized rate of performance degradation during fatiguing EVA-type tasks.

Results were grounded via analysis of individual muscle fatigue using analogs of conventional methods.

Suitable for human-health monitoring during suited EVA activities.

Future Work

Modeling

Incorporation of electromechanical delay (EMD)

Recursive updating of model parameters

Root-cause diagnostics

Implementation

Large scale human subject study with pressurized SSRG

Validate using complex tasks

Suggested Applications

Tracking health status for injury prevention or fitness-for-duty evaluation

Designing exercise regimens for health enhancement

Source: bluewatertherapies.com

Source: stack.com

Source: reneu.robotics.utexas.edu

References

[1] Viegas, Steven F., et al. "Physical demands and injuries to the upper extremity associated with the space program," in The Journal of Hand Surgery, Vol. 29, No. 3, 359-366, 2004.

[2] Charvat, Chacqueline M., et al. "Spacesuit Glove-Induced Hand Trauma and Analysis of Potentially Related Risk Variables," in 45th International Conference on Environmental Systems, Bellevue, Washington, July 12-16, 2015.

[3] O'Hara, John M., et al. "Extravehicular Activities Limitations Study: Volume II," NASA Contractor Report AS-EVAL-FR-7801, Vol. 2 1988.

[4] Rogers, Jonathan, et al. "Development and Testing of Robotically Assisted Extravehicular Activity Gloves," in 47th International Conference on Environmental Systems, Charleston, South Carolina, July 16-20, 2017.

Acknowledgments

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Thank you!