

NOVEL ROBOTIC SYSTEM FOR IMPROVED MOTOR CONTROL IN MICROGRAVITY. P. A. Johnson^{1,2}, J. C. Johnson^{1,2}, and A. A. Mardon^{1,2}. ¹University of Alberta, Edmonton AB, Canada, (jcj2@ualberta.ca)
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Introduction: Microgravity conditions in orbit and on celestial bodies with lower gravitational field, such as the Moon, can be physiologically compromising. Of these, motor and fine-dexterity tasks involving the extremities, particularly in locomotion, grasp and release, are influenced becoming delayed and placing greater force demands. Our group has recently developed an advanced model incorporating a sensorimotor platform that integrates sensing accelerometers with additional enhancements for use in prosthetic systems and performed simulations to test its efficacy [1]. We now propose an innovative incorporation into spacesuits and demonstrate a proof-of-concept for its implementation in orbit or extraterrestrial environments under microgravity conditions.

Tri-axial Design: The mechanism of this model relies on the use of a tri-axial system, whereby sensors and controllers are utilized to detect and correct for key motor control elements consisting of 1) segment orientation, 2) motion compensation, and 3) inertial platform (Fig. 1) [2,3]. Segment orientation is a compensatory mechanism for the accelerometer that takes into consideration the gravitational forces and tri-dimensional, spatial alignments in order to accommodate the motor demand accordingly. Alternatively, motion compensation adapts for the positioning using the surrounding prosthetic limb segment kinematics. Furthermore, the inertial platform controller uses holistic, mathematical analysis of prosthesis in interaction with an object of interest.

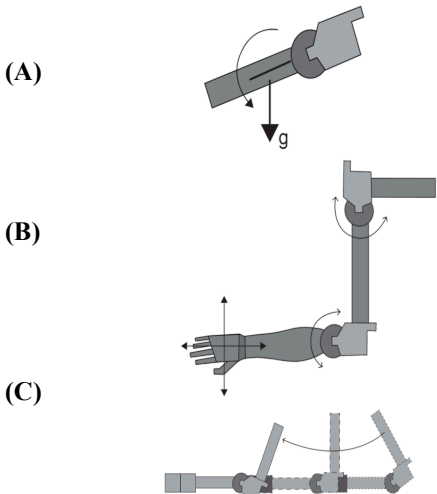


Figure 1. (A) segment orientation (B) motion compensation and (C) inertial platform. Adapted from Kyberd & Poulton [2].

Spacesuit Design Features: In order to upgrade existing spacesuit designs and add robotic elements using this design, it is necessary to create a high sensitivity accelerometer that reduces noise:

Accelerometer Design Features. The optimal design standards for material properties in sensor construction included the following variables.

Table 1. Design parameter optimization to enhance signal detection quality.

Parameter	Description
Q-factor	Low Q-factors results in damping, which achieves a lower sensitivity within a system. As such, a system with higher Q-factors is favoured in an optimization.
Inertial Mass	Higher inertial masses are preferred to increase system sensitivity. However, masses must be optimized to ensure the structural stability of the system.
Spring Constant	Materials with higher spring constants (e.g., piezo-ceramics), which also tend to have associated modulus parameters, favour higher sensitivity systems.
Rigidity	Within a system, the sensor’s damping coefficient, which is based on the material’s resistance to the drag force at a given velocity, should be low to ensure a higher Q-factor.
Cantilever Dimensions	Length, thickness, and width of the cantilever affect vibrational frequency capacities of the sensor. Higher design sensitivity features an inverse relationship between length and thickness producing higher deflection and Q-factor values. Width also influences the spring constant of the system.
Deflection	Higher deflection is an indicator for a higher cantilever design sensitivity and associated with lower signal noise events
Young’s Modulus	A material’s resistance to applied mechanical stresses and strain capacity are key variables in deflection and Q-factor measurements in the system. Typically, a higher strain capacity and lower stresses are achieved in an ideal system.

Proof-of-Concept: We have previously described design specifications for 1-G conditions; however, these specifications must still be optimized for micro-

gravity conditions depending on the location of intended use.

The novel accelerometer design utilizing our model was tested using MATLAB simulations and compared to existing gold standards for its sensitivity. Simulation Modelling was based on crank-slider mechanism optimization, which uses predictive and output data to calculate position, crank velocity, and acceleration over time [4].

We utilized available tracked prosthetic movement data with six DOFs and generated acceleration over time plots to compare the signal-to-noise ratio and drift between conventional accelerometers and our novel design. Fig. 2 displays the dynamics data capturing translational movement along an X-axis, translation along a Y-axis, translation along a Z-axis, rotation around a roll axis, rotation around a pitch axis, and rotation around a yaw axis. This data includes movement requiring segment orientation, motion compensation and an inertial platform.

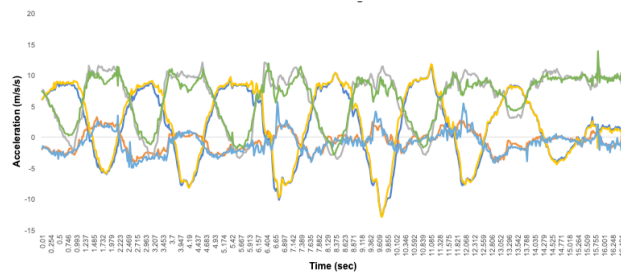


Figure 2. Raw dynamics data displaying range of motion acceleration profile utilizing the novel accelerometer design prototype.

In Fig. 3, results of the simulations for a calibrated conventional accelerometer model and our novel prototype design model are shown. It displays the difference in signal quality during segment orientation, motion compensation, and inertial platform. As a result, these algorithms can then be used to generate command outputs in a prosthetic system. Of the two, our prototype was determined to reduce signal-noise effects observed in conventional accelerometers. Our modeling and prototype therefore demonstrates it is not only possible to mechanically dampen a system, but also that we can reduce noise and increase signal sensitivity by upgrading accelerometer design specifications.

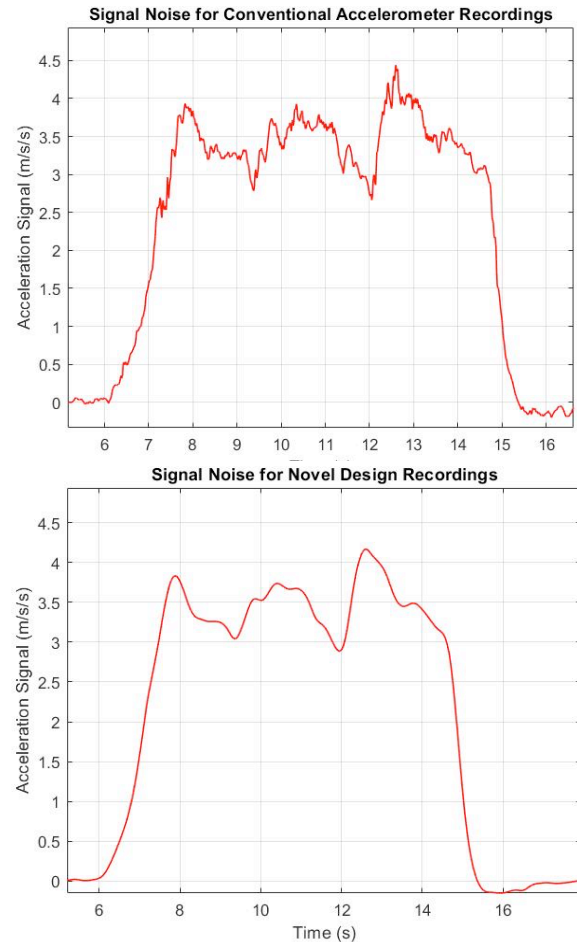


Figure 3. Signal-noise reduction in novel design prototype.

Limitations: While promising, this model has certain limitations: (i) it is a proof-of-concept and only been tested via simulation and must be further evaluated in varying microgravity conditions, (ii) our simulation focuses on two main accelerometer subtypes in modelling signal, (iii) considerations must still be made for mass and design of an incorporated and functional spacesuit system, and (iv) model needs to be enhanced for six or more degrees of freedom for maximal motor control.

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References: [1] Johnson P. A. et al. (2020) *medRxiv*, doi:10.1101/2020.07.17.20151605. [2] Kyberd P. J. and Poulton A. (2017) *IEEE Trans Neural Syst Rehabil Eng*, 25, 1884-1891. [3] Yang J. et al. (2017) *10th CISP-BMEI*, 1-6. [4] Halicioglu R. et al. (2014) *J Phys Conf Ser*, 490, Paper #12053.