A Platform for Dynamic Simulation and Control of Human Movement

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Introduction: Musculoskeletal conditions cost the U.S. economy over $849 billion per year and place great demands on healthcare systems worldwide [1]. Rehabilitation and treatment of these conditions could greatly benefit from computational tools that offer a better understanding of human movement and predictive capabilities for optimal treatment planning. MATLAB is a powerful software package for rapid design, control, and simulation of dynamic systems, but it has limited resources for simulating neuromusculoskeletal systems. On the contrary, OpenSim [2] is a free software system for modeling, simulating, and analyzing these systems, but it lacks the robust design and control tools of MATLAB. In this paper, we combined the model-based design and powerful numerical methods strengths of MATLAB with the simulation and human movement dynamics strengths of OpenSim by developing a new interface between the two software packages.

Materials and Methods: The MATLAB and OpenSim interface was developed using a three step process. First, we developed a MATLAB S-function as a Simulink block that works with any OpenSim model regardless of the number of input controls (e.g., muscle excitations or joint torques) or output states (e.g., kinematics). Second, we created a generic open-loop Simulink model that loads and executes the OpenSim-based S-function (Fig. 1). To demonstrate the open-loop characteristics of this model, we used a 3D musculoskeletal model with 23 degrees of freedom and 92 muscle-tendon actuators. The motion resulting from a simulation of walking using our interface was directly compared with that of a separate forward dynamic simulation using OpenSim alone. Third, we developed a closed-loop Simulink model by adding a muscle stretch-reflex controller [3] to maintain balance in spite of support-surface translations. Muscle fiber lengths and velocities were used to create an error signal for the controller and the controller's gains were tuned using Simulink to maintain balance. Support-surface translations were 6 cm in the anterior and posterior directions, with a peak velocity of 23 cm/s [4].

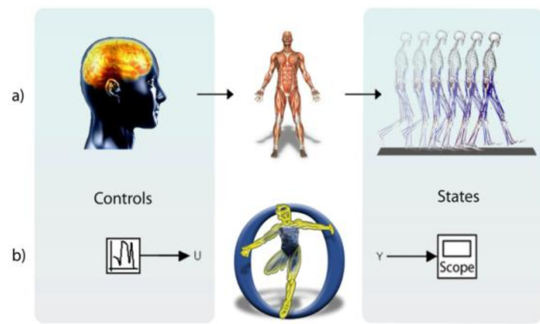

Figure 1. Open-loop (a) physiological system and (b) generic Simulink model.

Results and Discussion:
The new interface between MATLAB and OpenSim allowed rapid model-based design and numerical simulation of human movement using both open-loop (Fig. 1) and closed-loop (Fig. 2) control systems. Root mean squared differences remained small for the ankle (0.1º), knee (0.6º), and hip (0.9º) angles from separate simulations of walking using our interface and OpenSim alone. These results indicated an OpenSim model and its controls behave similarly in MATLAB and OpenSim. The implementation of a stretch-reflex controller was successful in balancing the model; however, more intelligent controllers may be developed to extend this work. The closed-loop control system adds the unique ability of real-time changes to controls for OpenSim models, which has otherwise been unavailable to OpenSim users to this point and is necessary for feedback control systems to study movement disorders such as cerebral palsy.

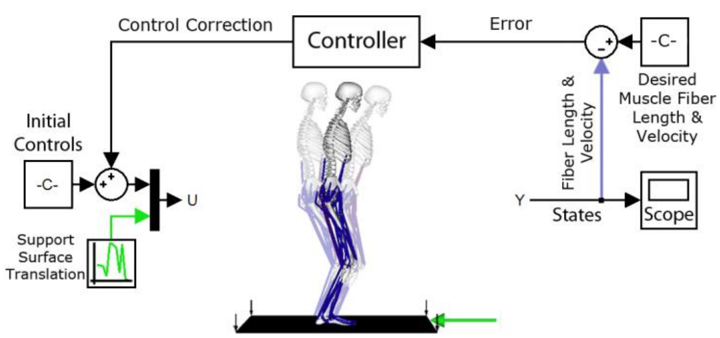

Figure 2. Closed-loop Simulink model of balance recovery using a muscle stretch-reflex controller.

Conclusions: The new S-function interface combines robust design, powerful math, and control system strengths of MATLAB with the numerical simulation and human movement dynamics strengths of OpenSim. This integrated platform shows promise for a better understanding of movement control and the potential to improve treatment planning.

Acknowledgements: Supported by a subaward from NIH Roadmap for Medical Research U54 GM072970.

References:
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4. Woollacott M, et al. *Dev Med Child Neurol* **47**: 455-461. 2005.