TASK-LEVEL SIMULATION OF SUBJECT-SPECIFIC MOVEMENT USING OPENSIM

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Introduction & Objectives

How appropriate muscle pattern inputs are selected to achieve a specific movement task output is an open question and computer simulations are a vital tool for providing answers. It is well known that human movement involves closed-loop control coordinating inputs for desired outputs. Simulations can complement experiments to help uncover principles of coordinated and uncoordinated movements. Our objective was to merge approaches from biomechanics and robotics in a platform to advance the study of human movement control and outcome prediction.

Methods

We generated dynamic simulations by combining OpenSim's human movement simulation strengths with MATLAB's rapid design, control, and numerical strengths with a new interface (*Fig. bottom right*). Using biomechanics-based approaches [1], dynamic simulations with supporting contacts were generated, where input controls allow muscle forces acting on the model to be computed followed by joint moments resulting in joint accelerations and other state derivatives. Finally, state derivatives were numerically integrated to determine the model's simulated motion.

We combined the simulated motion with surrogate models of experimental motion capture data to begin forming the closed-loop control (*Fig. top right*). Surrogate response surfaces were developed to approximate subject-specific task-level motions. A separate quadratic surface was created for each desired subtask (e.g., swing foot position) as a function of a primary task (e.g., mass center position). Each surface required finding a set of polynomial coefficients via a linear least squares fit to the experimental data. Desired tasks were computed from the response surfaces as surrogates for subject-specific motion coordination. These surrogates allowed synthesis of a range of motions for a subject without experimental motion capture data (e.g., prediction of post-treatment outcome from pre-treatment motion).

We used differences between desired and simulated tasks to compute task errors (*Fig. top left*). These errors were inputs to proportional-integral-derivative (PID) controllers in the feedback loop for updating the simulated motion. Differences between experimental and simulated tasks were minimized by tuning PID controller gains to a specific subject. Desired task accelerations were delayed to represent time lags for neuromechanical processes. These delayed reference task accelerations included control policies for all desired task points.

We used the task accelerations to synthesize whole-body motions using robotics-based prioritized, multi-task approaches for a support-consistent formulation maintaining the foot-ground contact [1, 2] (*Fig. bottom left*). Each task force is comprised of the task acceleration multiplied with its task space inertia matrix, plus velocity and gravity compensation terms for each task. The joint torques are determined by multiplying task forces by their respective reduced Jacobians and priority-level-determined, dynamically-consistent null space matrices for each task. A composite torque was used to control all prioritized tasks simultaneously.

We used joint torques from the prioritized operational space motion control for a musculoskeletal dynamic simulation with supporting contacts (*Fig. bottom right*). Static optimization was used to solve the "distribution" problem from having more unknown muscle forces than joint torques. The sum of muscle activations squared was minimized subject to bounds and the constraint on net muscle moments, generated by multiplying muscles forces by their moment arms, must equal the total task joint torques. The muscle forces generated joint accelerations and other state derivatives that are numerically integrated to simulate the subject-specific, whole-body coordinated movement.

Results & Conclusion

We merged approaches from biomechanics and robotics for task-level simulation of subject-specific balance recovery. As an example application, we easy able to define multiple prioritized tasks to balance a musculoskeletal model on a single supporting limb in contact with the ground. The first priority task was to keep the whole-body mass center over the base of support foot. In addition, lower priority subtasks were the swing foot and torso positions relative to the whole-body mass center. The OpenSim/MATLAB combination provides a platform for using subject-specific models and motion coordination, feedback control loops, prioritized task-based motions with foot-ground contact, and predictive simulations of human movement.

References

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2. De Sapio, et al., *Multibody Syst Dyn* **16**:73-102, 2006.
3. Sentis, et al., *IEEE Trans Robotics*, **26**:483-501, 2010.