Controlling Biomechanical Models To Move Like Humans Do

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Purpose:

Reconstructing human motion dynamics with simulated biomechanical models is important for understanding motor control strategies, predicting surgical outcomes and optimizing rehabilitation regimes. Here, we demonstrate a robotic-control based technique that can efficiently reconstruct human motions recorded with optical markers, and can also synthesize novel human motions.

Material and Methods:

We reconstruct human motions by controlling virtual markers placed on a biomechanical model to track optical markers placed on a human subject [1]. Mathematically, the control algorithm treats the biomechanical model as a tree of connected rigid bodies and moves it by actuating the generalized coordinates with forces. To move one marker, the controller computes and applies:

$$F_{gen} = J_{marker}^T * F_{marker},$$

$$F_{marker} = \Lambda * F^* + \mu + p,$$

where F_{gen} are generalized forces applied to the biomechanical model, J_{marker} is the Jacobian that relates joint velocities to marker velocities, Λ is the operational space inertia matrix, F^* is the marker trajectory-tracking force computed with a PID controller, μ is the centrifugal and coriolis force vector, and p is the gravity force vector.

The markers, however, are not independent, and their motions conflict when the biomechanical model and marker sensing are imperfect. We resolve such marker conflicts by placing marker controllers in priority levels, with markers on constrained limbs in the null-space of markers on more mobile limbs. To move all the markers simultaneously, the controller computes and applies:

$$F_{gen} = \sum_{i=1}^{levels} N_{i-1} * \sum_{j=1}^{markers} J_j^T * F_j,$$

where N_i is the inertia-scaled null space of a set of markers in a level i, and N_0 is the identity matrix. To synthesize motions, we add new operational space controllers at suitable priority levels [2].

Results:

Our motion reconstruction technique reproduced a subject's full body dynamics in real time with millimeter marker-position accuracy along the motion trajectory [1]. Adding more operational space tasks helped synthesize new motions based on the original recorded human motion [3].

Conclusions:

Control-based human motion reconstruction techniques are accurate, efficiently resolve model and sensing errors using null space decompositions, and can be readily extended to modify existing motions as well as synthesize new ones. Using control-based motion reconstruction is thus very attractive, specially for biomechanics users who wish to synthesize and observe how subject motions change with added constraint tasks.

[1] Demircan. E., Besier, T., Menon, S. and Khatib, O., *Human motion reconstruction and synthesis of human skills*, ARK (2010)

[2] Sentis, L. and Khatib, O., *Synthesis of Whole-Body Behaviors Through Hierarchical Control of Behavioral Primitives*, IJHR (2005)

[3] Human motor control demos: http://cs.stanford.edu/groups/manips/research/neuromuscular-control