A fast motor control framework for predictive simulation of musculoskeletal systems

Reza Sharif Razavian, Borna Ghannadi, Valerie Norman-Gerum, John McPhee
University of Waterloo, Waterloo, Canada.

INTRODUCTION

The human musculoskeletal system is very challenging to control. How the nervous system controls the movements is still unknown. This research presents a *computational framework for the fast and near-optimal feedback control of musculoskeletal systems*. This framework is beneficial in predictive musculoskeletal simulations, and motor control theories evaluation.

METHODS

Our motor control framework relies on the muscle synergy [1] and uncontrolled manifold [2] theories. The core feature of our model is the "task-space" control; i.e., only the task-related variables are considered, disregarding the joint-space complexities. Thus, the muscles' action in the joint-space and the conversion from joint-space to task-space are not needed. This approach also bypasses the possible kinematic redundancies in the musculoskeletal system, enabling the motor control model to handle such systems without significant mathematical complexity.

To complete a task, muscles should produce the required task-space accelerations. In our formulation, we consider a muscle's action in the task-space as one of its basis vectors; these basis vectors can be used to decompose a desired task-space acceleration vector (see Fig. 1A). This decomposition is similar to the muscle-force-sharing problem, and may not have a unique solution (number of muscles > task-space dimensions). Muscle synergies (co-activation of a number of muscles) simplify the computations further by reducing the number of the basis vectors. If the synergies are identified optimally beforehand (e.g. using non-negative matrix factorization on optimal muscle activation data), the task-space vector decomposition will result in synergy coefficients that generate the desired task-space acceleration (Fig. 1B). This process is fast and gives near-optimal muscle activities.

The schematic of the proposed framework is shown in Fig. 1C. The high-level task-space controller compares the task-space variables with the target and outputs a reference task-space acceleration to complete the task. Then, the low-level acceleration-to-activation mapping translates this acceleration into muscle activities, which are fed to the musculoskeletal system.

RESULTS

We have applied this motor control framework to control the movements in a variety of musculoskeletal settings, including a 3D reaching with a 4-degree-of-freedom upper extremity model, a 2D sit-to-stand, and a 2D cycling motion. Fig. 1D shows example results for predictive motion control of the 15-muscle arm model (framework is compared against an optimal controller).

DISCUSSION

The developed motor control framework is a viable tool for predictive musculoskeletal simulations. It can generate near-optimal muscle activities in a fully predictive manner and significantly faster than optimization methods.

REFERENCES

[1] Bizzi, et. al. (2008). Combining modules for movement. Brain Research Reviews, 57(1), 125–33.
[2] Scholz & Schöner (1999). The uncontrolled manifold concept: identifying control variables for a functional task. Experimental Brain Research. 126(3), 289–306.

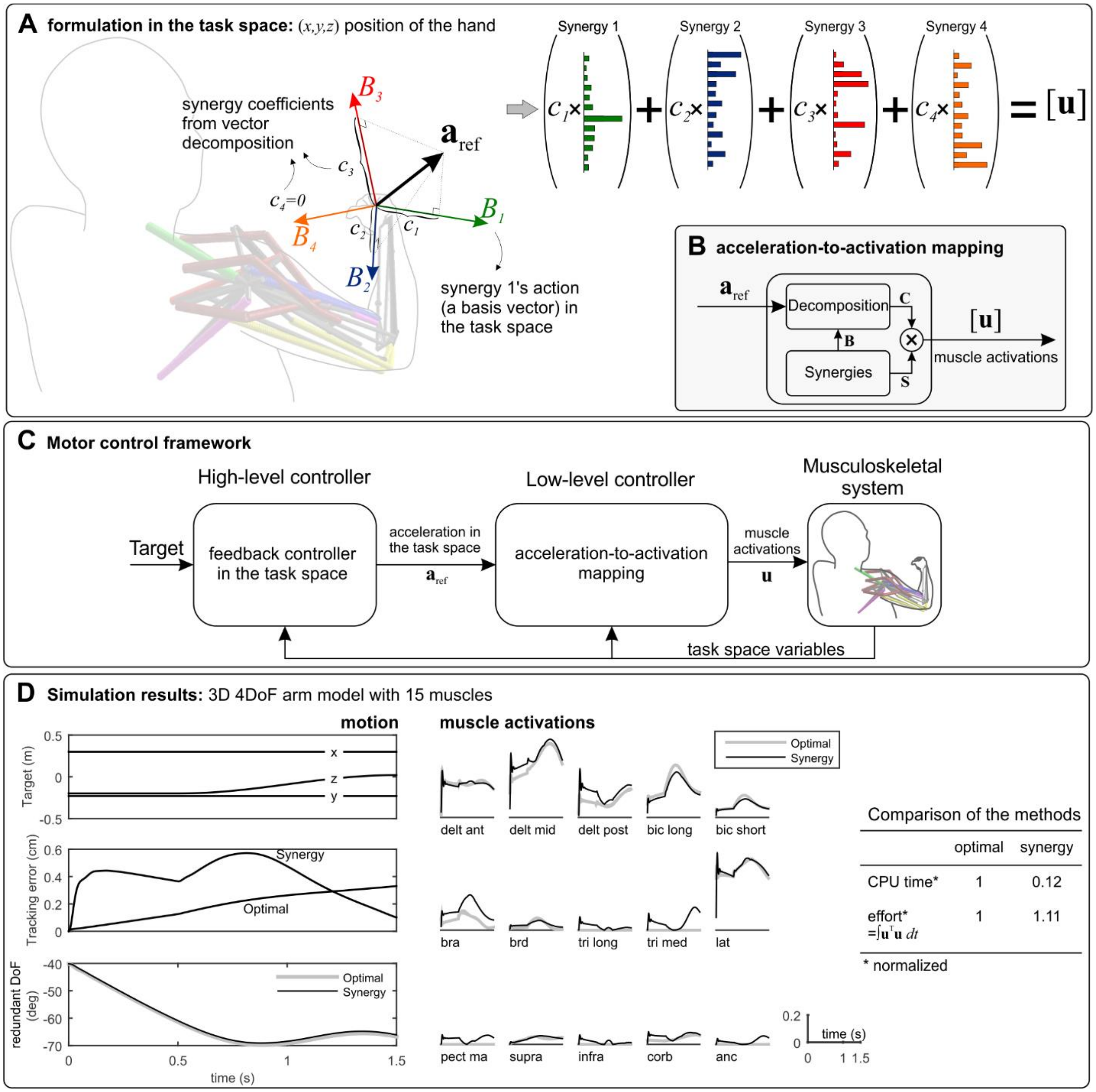

Figure 1. (A) Task-space formulation. (B) Acceleration-to-activation mapping. (C) Motor control framework. (D) Simulation results