A REAL-TIME VIRTUAL MUSCLE CONTROLLER FOR POWERED PROSTHESES

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INTRODUCTION

Powered prostheses are theoretically capable of replicating able-bodied movements. These devices are typically actuated by single-joint electric motors with time-varying linear impedance control [1]. Though better than passive prostheses, able-bodied gait is usually not achieved. We hypothesize that a more muscle-like actuation system can improve performance and simplify the feedback control. It has been shown through simulation that these properties contribute substantially to the stability of walking [2].

Real-time simulation of muscle dynamics is challenging because the differential equations that describe muscle dynamics are nonlinear and contain near-singularities. Fixed step solvers can become unstable and variable step solvers will be slow due to small time steps. An alternative implicit formulation has the potential to achieve accurate results with minimal computation time [3]. Here we consider the possibility of actuating a powered prosthetic system with torques generated by a real-time simulation of muscle dynamics.

METHODS

A planar leg model with six muscles was used, three of which were monoarticular groups (Vasti, Soleus, Tibialis Anterior) and three were biarticular (Rectus Femoris, Hamstrings, Gastrocnemius). The inputs to the system were musculotendon length (L_m) derived from joint angles (q) at the hip, knee, and ankle and the control signals (u) for the six muscles, as shown in Figure 1. The force $F(t)$ generated by each muscle was multiplied by moment arms to obtain its contribution to the knee and ankle torques $\tau(t)$.

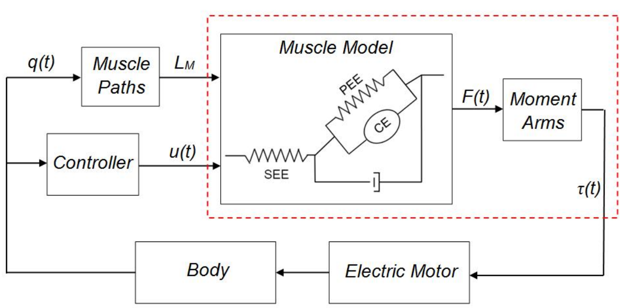

Figure 1: Block diagram describing the inputs and outputs of the model, in which the red box indicates the scope of this study

Muscles were represented by a Hill-type model with a contractile element (CE), series/parallel elastic elements (SEE/PEE), and a small amount of viscous damping in parallel to the contractile element. The CE has standard force-velocity and force-length properties, while PEE and SEE are modeled as nonlinear elastic. Muscle contraction dynamics was formulated as a first-order implicit differential equation (IDE). An additional first-order IDE represented the activation dynamics.

Tests were performed using joint angle time histories $q(t)$ for 30 seconds of normal walking and 1 Hz sinusoidal test signals for the muscle excitations $u(t)$. Simulations were performed in Matlab with a first order Rosenbrock solver [3] using fixed time steps ranging from 0.08 to 16.0 ms. Joint torques $\tau(t)$ generated by the model were compared to the result from the smallest time step in order to determine numerical error in the simulations as a percentage of the maximum moments. Computation times were measured in all tests.

RESULTS AND DISCUSSION

Muscle forces and joint torques responded appropriately to sinusoidal muscle activations. Table 1 shows how the accuracy and speed of the simulation depended on the integrator step size. Even at 0.18 ms, the simulation was faster than real-time and the simulation errors were well below 1%. Substantially larger time steps still resulted in acceptable accuracy, though became unstable for time steps larger than 10 ms.

Table 1: Integrator step size and its effect on accuracy and computation speed. Error was quantified as a percentage of the maximum moments in the knee and ankle.

Simulation Step Size (ms)	% RMS error Knee moment	% RMS error Ankle moment	Solution Time (s)
0.10	0.14	0.07	40.80
0.18	0.25	0.13	23.10
1.60	1.44	0.71	2.50
16.00	15.48	6.75	0.26

CONCLUSIONS

We have shown that joint torques can be obtained in a real-time simulation of muscle dynamics. Computation time and numerical accuracy are within the requirements for real-time application, and the simplified, implicit formulation ensures it can operate in embedded systems that use low-level programming languages.

REFERENCES

1. Sup F, et al. Design and Control of a Powered Transfemoral Prosthesis. *International Journal of Robotics Research*, 27(2), 263-273, 2008.
2. Gerritsen KG, et al. Intrinsic muscle properties facilitate locomotor control - a computer simulation study. *Motor Control* 2(3): 206-220, 1998.
3. van den Bogert AJ, et al. Implicit methods for efficient musculoskeletal simulation and optimal control. *Procedia IUTAM*, 297-316, 2011.