A REAL-TIME VIRTUAL MUSCLE SYSTEM FOR PROSTHESIS CONTROL

Sandra K. Hnat, Antonie J. van den Bogert
Parker Hannifin Human Motion and Control Lab (hmc.csuohio.edu)
Department of Mechanical Engineering, Cleveland State University

INTRODUCTION

Current Prosthesis Control:

Various control strategies have been proposed for controlling prostheses [1], though able-bodied gait is not usually achieved.

Semi-Active

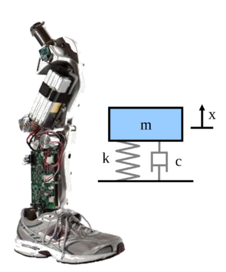
-acts as a controlled damper

-cannot adapt to disturbances

Active

-equipped with torque motors

-impedance control



Virtual Muscle Control:

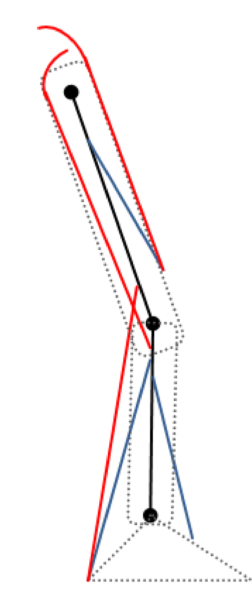
A muscle-like actuation system may simplify feedback control and improve performance. Muscle properties contribute substantially to stability during walking when compared to torque-driven control [2].

Objectives:

1. *Create a virtual muscle model that produces torque given muscle activation*
2. *Obtain accurate results with minimum computation for real-time application*

METHODS

A planar leg model with three monoarticular muscle groups (Vasti, Soleus, Tibialis Anterior) and three biarticular groups (Rectus Femoris, Hamstrings, Gastrocnemius) was used. System inputs were neural excitation signals (u) for the six muscles and musculotendon length (L_m) derived from joint angles $q(t)$ of the hip, knee, and ankle (**Fig. 1**). Torque $\tau(t)$ was be obtained by multiplying the force $F(t)$ generated by each muscle with the moment arms.



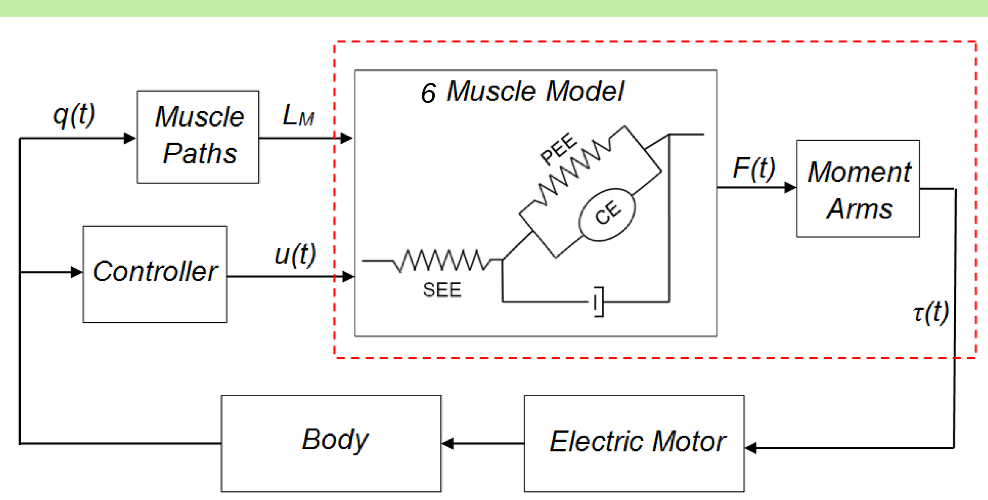


Fig 1. Block diagram of the muscle model, in which the red box indicates the scope of this current study

Hill Muscle-Model:

- *Contractile Element (CE)*

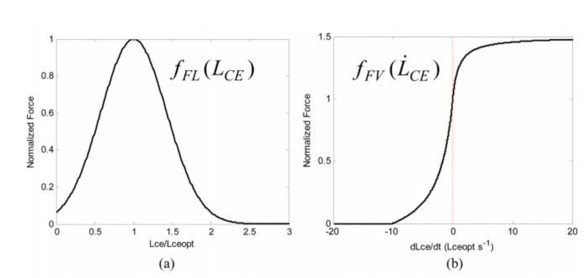
  Standard force-length and force-velocity relationships

- *Series/Parallel Elastic Elements(SEE/PEE)*

  Modeled as nonlinear springs

- *Viscous Damping*

  Adds numerical stability



Mathematical Model:

- *Contraction dynamics*

$$F_{SEE} = \left(aF_{max} \cdot f_{FL}(L_{ce}) \cdot f_{FV}(\dot{L_{ce}}) + F_{PEE}\right)\cos\phi + F_D$$

- *Activation dynamics*

$$\dot{a} = (u-a)\left(\frac{u}{T_{act}} - \frac{1-u}{T_{deact}}\right)$$

- *Implicit Formulation*

$$f(x,\dot{x},u) = 0 \qquad x = \left[L_{CE,1} \ldots L_{CE,6}\ a_1 \ldots a_6\right]^T$$

- *Fixed Time Step Rosenbrock Solver [3]*

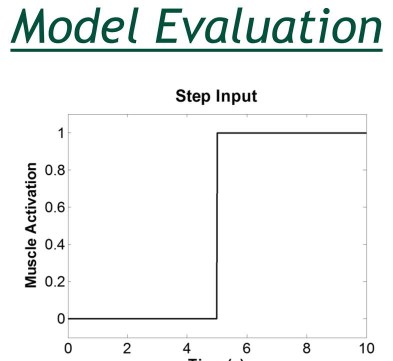
$$\Delta x = \left(\frac{\partial f}{\partial x} + \frac{1}{h}\frac{\partial f}{\partial \dot{x}}\right)^{-1}\left(\frac{\partial f}{\partial \dot{x}}\dot{x}_n - f(x_n,\dot{x}_n,u_n)\right) - \frac{\partial f}{\partial u}\cdot(u_{n+1}-u_n)$$

$$x_{n+1} = x_n + \Delta x$$
$$\dot{x}_{n+1} = \Delta x / h$$

- *Implemented in MATLAB*

Simulated Test Cases:

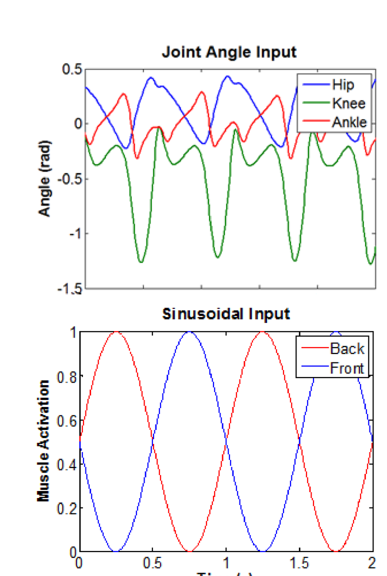
Model Evaluation



- Joint angles held constant at zero
- Step input control signals (u)
- Muscles activated at different times to see effects

Speed and Accuracy

- Joint angles from 30 seconds of walking data
- Sinusoid control signals (u)
- Muscles in front and back of leg are out-of-phase (maximum possible torque)



RESULTS

Model Evaluation:

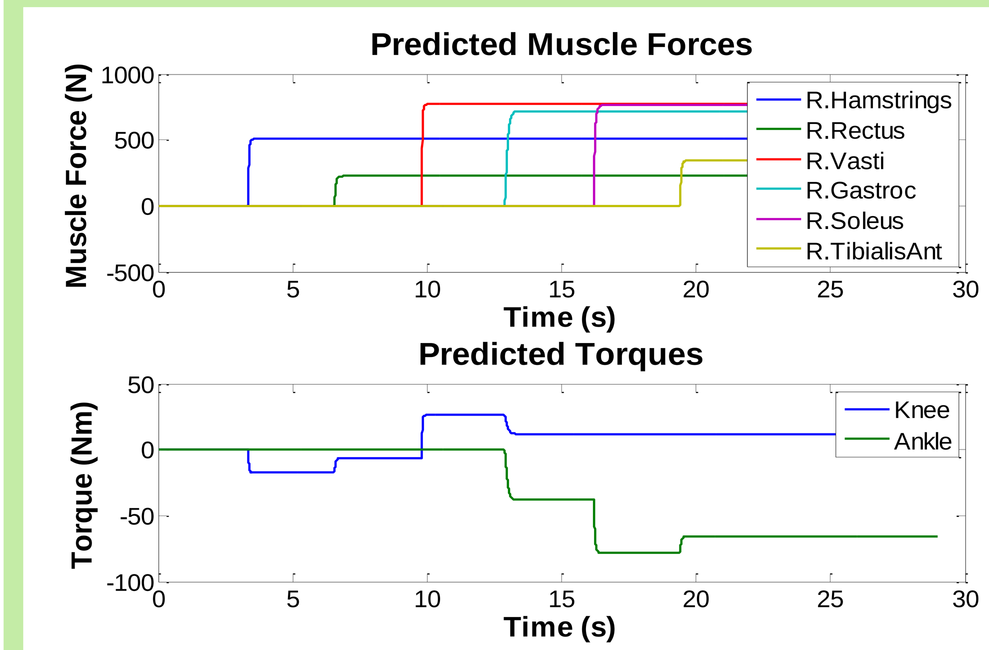


Fig 2. Predicted muscle forces (top) and torques (bottom) with constant joint angles q(t) of zero and step control u

The muscle forces and joint torques obtained through the model behave as expected to the prescribed muscle excitations (**Fig. 2**):

- *Muscle activation in the thigh and shank produce appropriate torque in the knee or ankle*
- *Torque directions are influenced by muscle activations in the front or back of the leg*
- *Gastrocnemius (biarticular) generates torque in both the ankle and knee*

Speed and Accuracy:

Fixed time steps between 0.8 and 16 ms were used. The accuracy is effected by the integrator step size and the computation time **(Fig 3)**.

- *Real-time is achieved with step sizes as small as 0.18 ms with simulation errors less than 1%*
- *Simulation becomes unstable for step size > 16 ms*

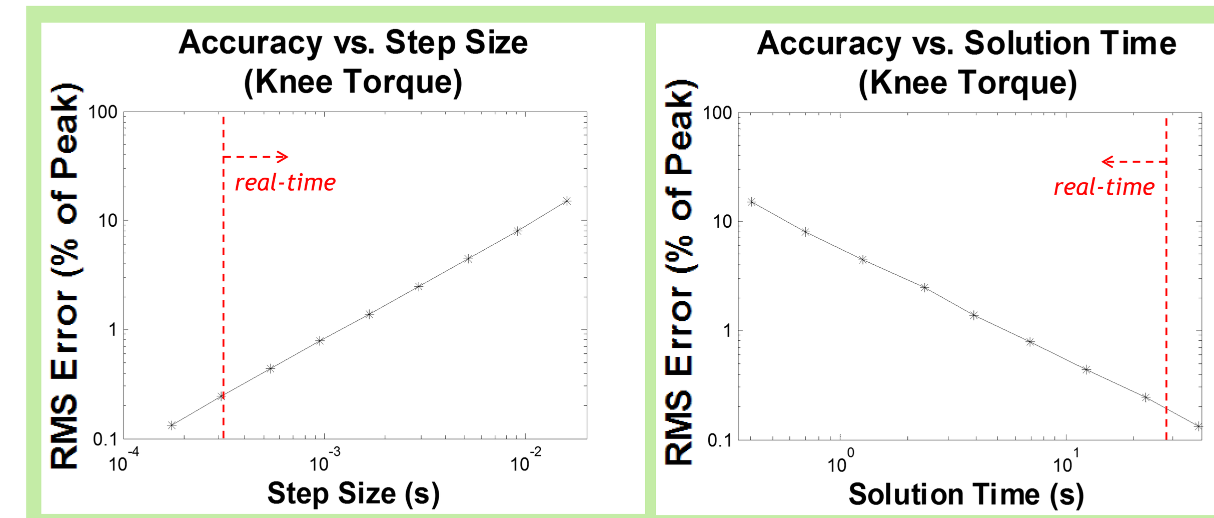


Fig 3. The accuracy is effected by the integrator step size (left) and computation speed (right). Error was quantified as a percentage of the maximum moments in the knee and ankle. Real-time is indicated by the dashed red line, which is faster than 30 seconds.

CONCLUSION

Completed Objectives:

✓ Created a virtual muscle model that outputs torque given muscle activation in real-time

✓ Obtained accurate results with minimal computation time

Future Work:

- Movement simulations to investigate stability of virtual muscle control
- Derive muscle excitation signals (u) from human walking
- Implement and test in actual hardware

REFERENCES

1. F. Sup et al, *International Journal of Robotics Research*, 2008
2. K. G. Gerritsen et al., *Motor Control*, 1998
3. A.J. van den Bogert et. Al, *Procedia IUTAM*, 2011

Acknowledgements: Supported by the National Science Foundation under Grant No. 1344954 and the Parker Hannifin Graduate Research Fellowship Program