

INTRODUCTION

Current Prosthesis Control

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

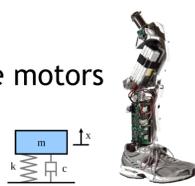
Semi-Active

- acts as a controlled damper
- cannot adapt to disturbances



Active

- equipped with torque motors
- impedance control



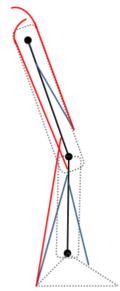
Virtual Muscle Control

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

Objectives

- 1 In simulation, create a virtual muscle model that produces torque given muscle activation
- 2 Obtain accurate results with minimum computation for real-time

METHODS



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

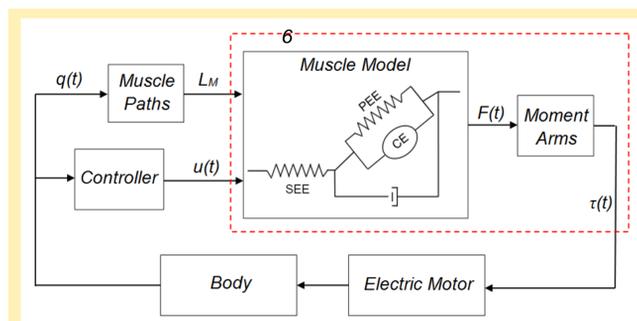


Fig 1. Block diagram of the muscle model, in which the red box indicates the scope of the current study

Contractile Element

Standard force-length and force-velocity relationships

Series/Parallel Elastic Elements

Modeled as nonlinear springs

Viscous Damping

Adds numerical stability

Mathematical Model

- Contraction dynamics

$$F_{SEE} = (aF_{max} \cdot f_{FL}(L_{ce}) \cdot f_{FV}(L'_{ce}) + F_{PEE}) \cos\phi + F_D$$

- Activation dynamics

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

- Implicit Formulation

$$f(x, \dot{x}, u) = 0 \quad x = [L_{CE,1} \dots L_{CE,6} \ a_1 \dots a_6]^T$$

- Fixed Time Step Rosenbrock Solver [3]

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

$$x_{n+1} = x_n + \Delta x$$

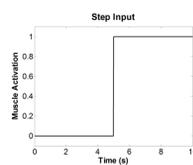
$$\dot{x}_{n+1} = \Delta x/h$$

- Implemented in MATLAB

Simulated Test Cases

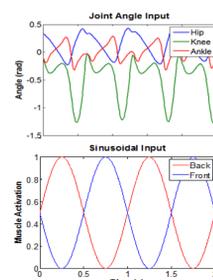
Model Evaluation

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



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



RESULTS

Model Evaluation

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

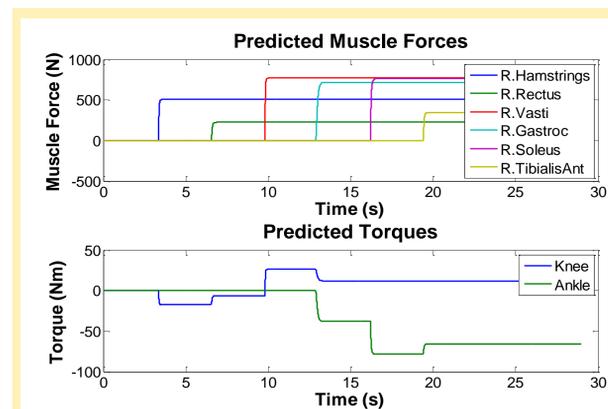


Fig 2. Predicted muscle forces (top) and torques (bottom) with constant joint angles $q(t)$ of zero and step control u .

- Muscle activation in the thigh and shank produce appropriate torque in the knee or ankle
- Torque directions 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 sizes larger than 16 ms

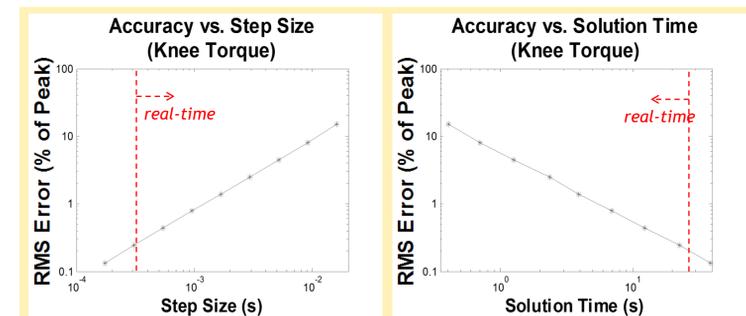


Fig 3. Accuracy is effected by the integrator step size (left) and computation speed (right). Error was quantified as a percentage of the maximum moments in the knee and ankle. Real-time is indicated by the dashed red line, which is faster than 30 seconds.

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

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