Are virtual muscles are reflex controllers capable of describing variations within the human gait cycle?

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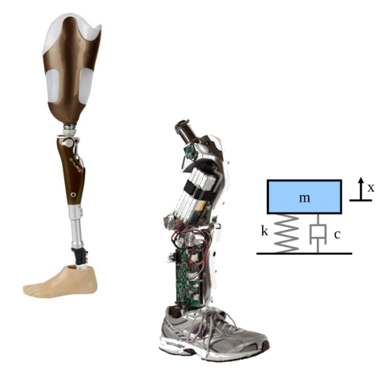
Introduction

- Various strategies for controlling modern prosthetic devices have been proposed, though able-bodied locomotion is usually ***not*** achieved
- Virtual muscles and autonomous reflex control produces realistic human locomotion in simulations and hardware [1]
- Reflex models are not usually tuned or validated using human walking data obtained through experiments



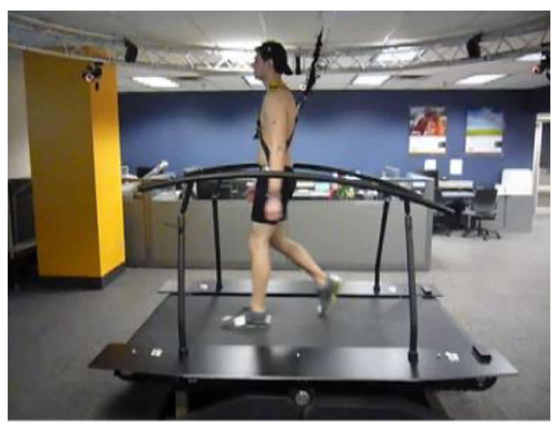
Objectives:

1 *Use optimization to tune the parameters of the Virtual Muscle Reflex (VMR) system to produce realistic joint torques using human experimental data*

2 *Evaluate the performance of reflex models in describing the variations within and between gait cycles under the effect of mechanical perturbations*

Methods

Ten subjects walked on an instrumented treadmill (0.8, 1.2, and 1.6 m/s) while being longitudinally perturbed by Gaussian white noise [2]. Joint angles and joint torques were obtained through traditional inverse dynamics [3].



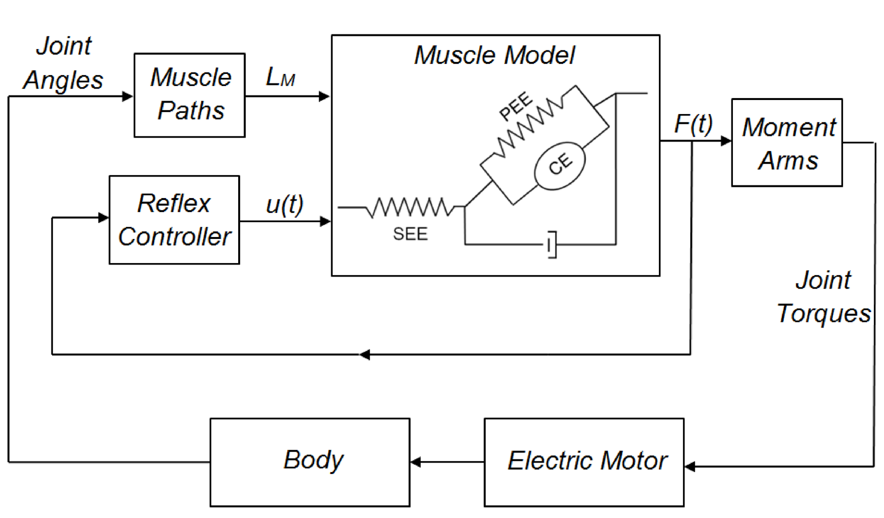
Mathematical Muscle Model:

- *Three Hill-type muscles:* *Gastrocnemius, Soleus, and Tibialis Anterior*
- *Activation dynamics*

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

- *Contraction dynamics*

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



- *Implicit Formulation solved by fixed-step Rosenbrock solver [4] in MATLAB*
- *Torque (τ) is obtained by multiplying muscle force by the moment arm*

Reflex Control:

Muscle control signals (u) were generated by the reflex controller of Geyer et al. [1].

- *Stance Phase*

$$u_{SOL} = S_{0,SOL} + G_{SOL}F_{SOL}(t - t_{SOL})$$

$$u_{TA} = S_{0,TA} + G_{TA}\left[\left(l_{CE,TA}(t_d) - l_{OFF,TA}\right)\right]G_{SOLTA}F_{SOL}(t - t_{TA})$$

$$u_{GAS} = S_{0,GAS} + G_{GAS}F_{GAS}(t - t_{GAS})$$

- *Swing Phase*

$$u_{GAS} = S_{0,GAS} + G_{GAS}F_{GAS}(t - t_{GAS})$$

$$u_{TA} = S_{0,TA} + G_{TA}\left[\left(l_{CE,TA}(t - t_{TA}) - l_{OFF,TA}\right)\right]$$

$$u_{GAS} = S_{0,GAS}$$

Particle Swarm Optimization [5]:

- *Optimize 8 control parameters, series/parallel element slack-lengths, and muscle reflex delays*
- *Minimize the multi-objective cost function:*

$$C = W_1\left(\sqrt{\frac{1}{N}\sum\left(\tau_{VMR} - \tau_{exp}\right)^2}\right) + W_2\left(\sqrt{\frac{1}{N}\sum a^2}\right)$$

Results

Results from one test subject (male, age = 21, mass = 64 kg) are shown here, where the control parameters were optimized using 5 gait cycles and the 1.2 m/s walking speed.

The model reproduces the joint torque observed in the experiment (**Fig. 1**):

- *Produces variations in peak moment between gait cycles, correlating to the torque exhibited by the subject*
- *Matches the amplitude and timing of ankle push-off*
- *Mimics the shape of the experimental torque during the swing phase*

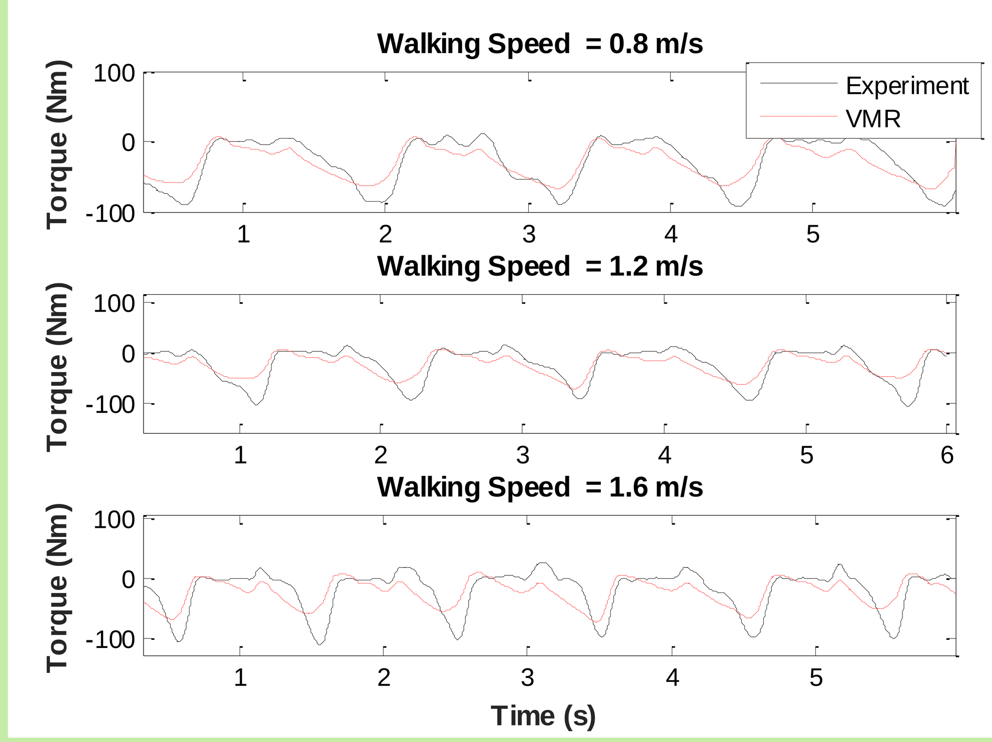


Fig 1: Experimental joint torque (black) and VMR joint torque using optimized reflex control parameters (red). Negative torque corresponds to plantarflexion.

The model produces realistic muscles forces (**Fig. 2**) that agree with those reported in literature:

- *Gastrocnemius and Soleus produce the large peak required for ankle push-off*
- *Soleus is activated before the Gastrocnemius*
- *Tibialis Anterior is minimally activated*

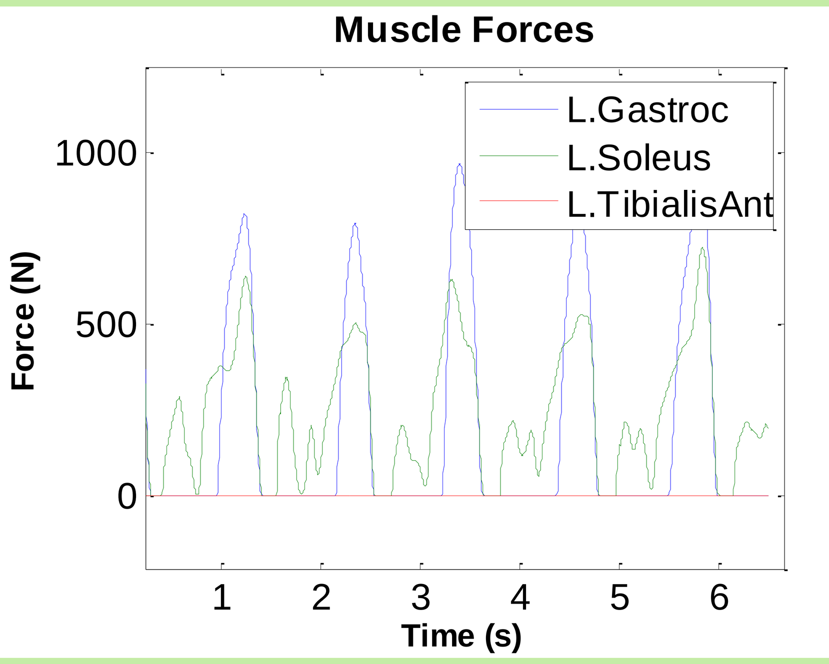


Fig 1: Estimated muscle forces of the Gastroc. (blue), Soleus (green), and Tibialis Anterior (red), at 1.2 m/s walking speed

Conclusion

Completed Objectives:

- ✔ The VMR produces realistic joint torques produced by test subjects
- ✔ Initial findings suggest that the controller is also capable of replicating human response to perturbations and may describe important aspects of the human control system

Future Work:

- Compare results across multiple subjects
- Allow longer computation time for optimizations (greater accuracy)
- Expand model to include the knee and hip
- Implement and test in hardware (INDEGO exoskeleton)

References

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