Simplification of the Hill Muscle Model Computation for Real-Time Walking Controllers with Large Time Steps

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Motivation & Proposed solution

Bio-inspired controllers are emerging as a promising way to implement dynamic walking. In this study, we implemented the one proposed by Geyer & Herr (2010), relying on reflex-controlled virtual Hill muscles. In this model, muscles’ state is determined by the length (lmtu) of their active, contractile element. However, its update rate is governed by a stiff and strongly non-linear state equation, thus requiring a small integration time step.

The contributions of this study are:

- the presentation of 3 methods to get the steady-state value of lmtu;
- the study of their accuracy and computational cost;
- the illustration that the lmtu dynamics can be neglected for fast muscles;
- a method to mix the steady-state approximation with the full muscle dynamic model for slow muscles.

Steady-state computation - Three methods to get lmtu without integration

Neglecting the muscle dynamics: lmtu is always at steady-state, i.e. lmtu = 0. Then, the problem is to solve f(lmtu, lce, A) = 0, i.e. to find lmtu = g(lce, A).

Look Up Table (LUT) interpolation

- generated off-line
- cost depends on the mesh refinement
- accuracy depends on the mesh refinement

Third-order polynomial (TOP) approximation

- generated off-line
- computationally efficient
- accuracy depends on the LUT to fit

Newton-Raphson scheme (NRS)

- no pre-process computation
- convergence to a stable equilibrium not guaranteed
- more than one iteration might be needed

Results

We compare the three steady-state lmtu profiles with a reference based on the muscle dynamics.

- LUT: refining the mesh increases the accuracy.
- TOP: accuracy deteriorated for some muscles at some phases of the gait.
- NRS: excellent fit with only one iteration, except when the gradient of f(-) is close to 0.

Slow dynamics muscles case

At some phases of the gait, the soleus muscle dynamics cannot be neglected, i.e. all steady-state approximations diverge from the actual lmtu value.

- Reference computed with a 0.5 ms time step, the others with a 10 ms one.
- Neither using the full dynamics model nor a steady-state approximation provided a correct fit.
- Combining these two signals led to a correct fit. Combination is done by saturating the lmtu determined by the full dynamics to the steady-state value.

Acknowledgment & Reference

This work is supported by FP7 under Grant 611832 (WALK-MAN), by UCLouvain (MRMC11/13) and by F.R.S.-FNRS (Ph.D. scholarship to N. Van der Noot).