Anticipatory adaptation of proprioceptive reflex-gains to external perturbations in simulated locomotion

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Summary

The ability of animals to react and adapt efficiently to varying environments and perturbations is important for robust locomotion. Reflexes compensate quickly for uncertainties in the environment, allowing for compensation of the unexpected. Reflexes have been studied extensively in computer simulation. Anticipatory preparation, however, has been studied less but allows to adjust the control strategy preemptively, e.g., to handle larger variations in terrain height. This study investigates anticipatory adaptation of a subset of muscle reflex gains to varying slopes. This is a first step towards investigating robust adaptation strategies in animal locomotion.

Introduction

Proprioceptive reflexes based on muscle length and force can generate versatile behavior in computer simulations of human locomotion [1,2]. For this, many parameters are re-optimized to achieve the different behaviours. On the contrary, changing only the soleus reflex gain in anticipation of step-down perturbations can enhance robustness [3] and leads to experimentally observed adaptations of center-of-mass kinematics [4]. In this study, we investigate a simple controller adapting reflex gains to varying terrains slopes. Our goal is to achieve versatile terrain adaptations by simplifying the optimization problem, focusing on a subset of muscle gains to maintain balance rather than adjusting the full control parameter space.

Methods

We use a versatile reflex-based controller [2] to generate steady-state walking on level ground. The simulation for each muscle is calculated from monosynaptic and antagonistic length L_{CE} and force feedback F_{CE} pathways from muscles crossing the same joint. A new anticipatory layer of control (Fig. 1) modulates the reflex gain k by a factor R in dependence of the slope angle (α) (or step-down height (h))

$$u_{SOL}(t) = c + \sum_{i \in R_{SOL}} [R_i^L(\alpha) k_i^L L_i(t) + R_i^F(\alpha)\, k_i^F F_i(t)] \, .$$

First, we optimize the parameters *c, k* for walking on flat terrain achieving stable locomotion. Then, we re-optimize for different conditions to find $R(\alpha)$ or $R(h)$ while all other parameters are fixed. Finally, we derive a control model to adjust the reflex controller to slopes and step-down perturbations in an anticipatory manner, i.e., based on future information about slope and height. The model was implemented and tested using a neuromusculoskeletal model actuated by 18 Hill-type muscles implemented in the HyFyDy simulation engine [5].

Results and Discussion

We adapted the controller to slope and step-down perturbations by optimizing a full set and a subset of muscle activations. The number of optimization parameters was reduced from 71 to 4 by selecting the key parameters: R_{SOL} - tibialis anterior and soleus force and length feedback pathway gains. The anticipatory strategy with both reduced and full control complexity generated stable walking. These findings suggest that the adaptation of a subset of reflex parameters is an efficient strategy to enable robustness across different terrain variations.

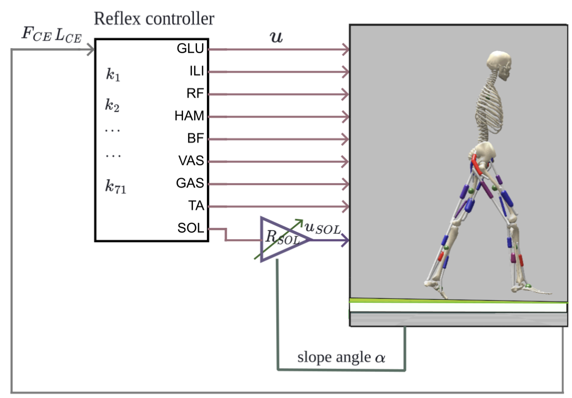

Figure 1: Reflex-based walking control with anticipatory adaptation: monosynaptic and antagonistic feedback with tuned soleus gains for stability on the environment with slope

Conclusions

Our findings confirm previous studies about the importance of the soleus muscle during step-down perturbations [2]. The concept is the basis to explore the functional roles of other individual reflexes for their contribution to specific aspects of versatile gaits. Integrating muscle-inspired activation dynamics and reflex mechanisms into systems could provide a promising approach to achieving more robust and adaptive locomotion.

References

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