Contribution of Proprioceptive Feedback to Ankle Extensor Activity in Freely Walking Cats

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Summary

Our objective is to gain insight into the relative importance of feed forward (FF) control and different proprioceptive feedback (FB) pathways to ongoing ankle extensor activity during walking in the conscious cat. We assume that the FF signal can be characterized by a simple trapezoidal function, and that muscle modulation during level walking is due to feedback. Apart from testing this assumption, we want to verify the following main hypothesis: the same central command (FF signal) and the same proprioceptive gains used during level walking can automatically compensate for changes in the walking slope. Therefore, we formulate and solve two least-squares parameter estimation problems based on a simple muscle activity model to determine the relative contribution of the feedback signals and the feed forward signal. The results of the optimization problems allow us to verify our hypothesis.

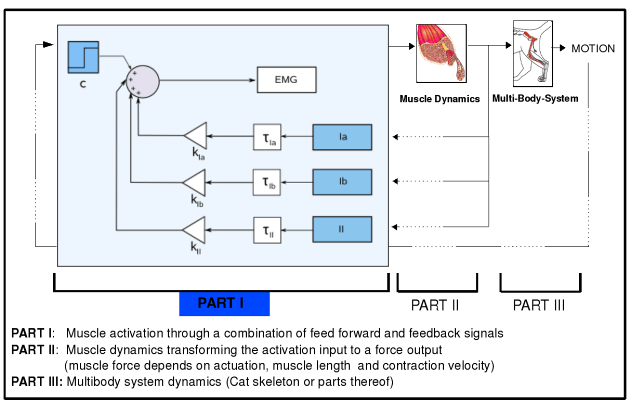

Figure 1: Illustration of three parts in motion generation.

Introduction

The goal in this project is to improve the understanding of neuromechanical and muscular processes in a walking cat. An input signal from the Central Nervous System (CNS) is transformed into a motion of the cat involving complex muscle dynamics and multibody dynamics as well as processes related to proprioceptive feedback (Figure [1]). We are interested in the first part of this model. We want to determine the relative contribution of feed forward control and different proprioceptive feedback pathways to ongoing ankle extensor activity during walking on different slopes in a freely walking cat.

Methods

Experiments: Two animals were trained to walk on a pegway at five different slopes: +25°,+10°,0°,-10°,-25° (Figure [2]). The medial gastrocnemius has been isolated and the magnitude of its activity at different muscle

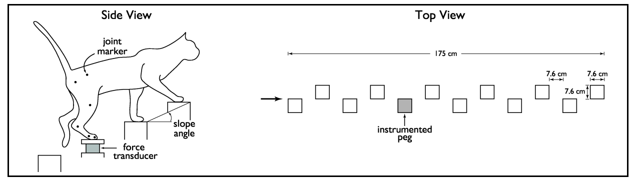

Figure 2: Illustration of the experiment procedures.

lengths, velocities and forces has been measured. Mathematical models of proprioceptive dynamics predicted the feedback signals Ia, Ib and II [1].

Modeling and Optimization: We model muscle activity M as the sum of a the feed forward signal $c(t)$ (CNS signal), and three feedback signals $Ia(t)$, $Ib(t)$ and $II(t)$:

$$M(t)=k_{Ia}\,Ia(t-\tau_{Ia})+k_{Ib}\,Ib(t-\tau_{Ib})+k_{II}\,II(t-\tau_{II})+c(t),$$

where the gain factors k_{Ia}, k_{Ib}, k_{II}, the delays $\tau_{Ia}, \tau_{Ib}, \tau_{II}$, and the control function $c(t)$ are unknown. Based on this model, we formulate and solve two least-squares parameter estimation problems with a control function by applying a generalized Gauß-Newton method [2]. Both problems determine the unknowns in the muscle activity model by minimizing the distance between measurements and the model answer in a least-squares sense , but the first type of problem considers only level walking, whereas the second type of problem takes all slopes into account.

Results and Discussion

We solved two types of least-squares parameter estimation problems and determined the control function $c(t)$ and the relative contribution of Ia, Ib and II to muscle activity taking each slope separately into account, and for all slopes at once. The results verify that muscle activity can be described by our model and is almost completely explained by the CNS signal $c(t)$ and the feedback signal Ib (Figure 3). Furthermore, our results indicate that changes is slope do not significantly change the gain factors and the feed forward signal $c(t)$, changes in slope are almost completely compensated by the feedback signals.

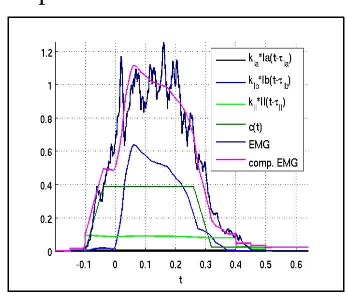

Figure 3: Model fit for slope 0°.

References

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