Extended Abstracts

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Unifying framework for decision-making dynamics: optimal control and infinite horizon perspectives

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Resum *(CAT)*

L'objectiu principal d'aquest projecte és desenvolupar un marc teòric unificat de la propriocepció, el control motor i la presa de decisions. Primerament, es presenta una introducció al càlcul variacional i la teoria del control òptim per establir una base teòrica sòlida. A continuació, es proposa un sistema dinàmic lineal com a aproximació al sistema físic estudiat i es desenvolupa un model seqüencial per predir trajectòries. Davant la dificultat de trobar una solució analítica exacta, s'utilitza el filtre de Kalman per estimar els perfils de posició i velocitat.

Keywords: *motor control, decision-making, proprioception, optimal feedback control (OFC).*

Abstract

Movement is the only way to express our thoughts and moods, which in its full expression determines our overall behaviour. A vast amount of research has been devoted to study how the brain generates and controls movement over the last century. Furthermore, the study of the principles underlying how the brain generates movement are of significant relevance both from a scientific but also clinical perspective, as most disorders are often quantified in terms of the motor deficits they imply, e.g., Parkinson's disease, ictus or simple ageing.

Recent studies have described the generation and control of movements in terms of the benefits and costs associated with potential movements [7], thus establishing a fundamental relationship between movement generation and decision-making theory. The combination of movement related choices and more cognitive decisions determines our responses and the behaviour with which we interact with the environment. This can be studied and modelled mathematically through *optimal decision making* and *motor control theory* [8]. However, these theories fall short to consider the contribution and role of the inner perception of our body, namely the bodily perception or *proprioception*, which plays a crucial role when planning and executing movements. In particular, proprioception provides internal corroboration that a movement is ongoing, it is hence a distributed phenomenon implicated in processes of *top-down prediction* and *bottom-up correction*.

Despite its obvious practical and clinical importance, proprioception remains one of the least studied senses, often overshadowed by its more familiar counterparts. Consequently, the central purpose of this project is to present a *unified theory* that, unlike simpler models of motor control, encompasses the *explicit incorporation of neural signatures of proprioception* into a *comprehensive model*. The proposed model may be able to describe the *interactions between proprioception and its influence on motor control*.

For this purpose, on the first chapter, an introduction to the state of the art theories and recent work on the principles of optimal feedback control (OFC) and movement related choices is presented, as stated by experts of the field, [6, 8], to fully contextualize the problem.

On the second chapter, robust theoretical formulation on optimal control framework is presented in order to provide a solid mathematical background as a means to understand the dynamical system studied as an Infinite horizon optimal control problem, [2, 3, 5].

The experimental approach followed on this project is based on planar reaching movements, as described on previous studies [4]. On Chapter 3, an introduction to time series theory is presented to understand the data analysis conducted over the experimental distributions gathered, since they are given by time series to apply the optimal feedback control approach as described by the Kalman filter, [1]. On Chapter 4, a more detailed insight to the experimental configuration is stated, concerning the explicit development of the dynamical system studied, as proposed by [6, 7]. Following the theoretical framework built in the previous chapters, the sequential computational approach implemented is stated on Chapter 5.

Finally, the results obtained from implementing the OFC model are stated in Chapter 6, as well as an exhaustive comparison and analysis between the experimental and simulated distributions.

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References

[1] P. J. Brockwell, R. A. Davis, *Introduction to Time Series and Forecasting*, Second edition, With 1 CD-ROM (Windows), Springer Texts Statist., Springer-Verlag, New York, 2002.

[2] D. A. Carlson, A. B. Haurie, A. Leizarowitz, *Infinite Horizon Optimal Control. Deterministic and Stochastic Systems*, Second revised and enlarged edition of the 1987 original, Springer-Verlag, Berlin, 1991.

[3] F. Clarke, *Functional Analysis, Calculus of Variations and Optimal Control*, Grad. Texts in Math. **264**, Springer, London, 2013.

[4] I. Cos, N. Bélanger, P. Cisek, The influence of predicted arm biomechanics on decision making, *J. Neurophysiol.* **105(6)** (2011), 3022–3033.

[5] W. H. Fleming, R. W. Rishel, *Deterministic and Stochastic Optimal Control*, Applications of Mathematics **1**, Springer-Verlag, Berlin-New York, 1975.

[6] L. Rigoux, Compromis entre efforts et récompenses: un modèle unifié de la décision et de la motricité, PhD thesis, Paris 6, 2011.

[7] L. Rigoux, E. Guigon, A model of reward- and effort-based optimal decision making and motor control, *PLoS Comput. Biol.* **8(10)** (2012), e1002716, 13 pp.

[8] S. H. Scott, Optimal strategies for movement: success with variability, *Nature Neuroscience* **5** (2002), 1110–1111.