Preface

This book aims at gathering roboticists, control theorists, neuroscientists, and mathematicians, in order to promote a multidisciplinary research on movement analysis. It follows the workshop "Geometric and Numerical Foundations of Movements" held at LAAS-CNRS in Toulouse in November 2015.[1] Its objective is to lay the foundations for a mutual understanding that is essential for synergetic development in motion research. In particular, the book promotes applications to robotics—and control in general—of new optimization techniques based on recent results from real algebraic geometry.

Starting from a robotics perspective, the generation of goal oriented motion for robots obeys classically to a two-step paradigm. The first step is the planning, where the typical problem is to find a geometric path that allows the robot to reach the desired configuration starting from the current position while ensuring obstacle avoidance and enforcing the satisfaction of kinematic constraints. Motion planning lays its grounding on the decidability properties of this classic geometrical problem. Moreover, the traditional approaches that are used to find solutions rely on the global probabilistic certainty of the convergence of path construction stochastically sampled in the configuration space. The second step of motion generation is the control, where the robot has to perform the planned motion while ensuring the respect of dynamical constraints. Motion control seeks primarily for local controllability or at least the stability of the motion. The basic instances of these problems have long been tackled using local state-space control. However, the typical nonlinearity of the dynamics, together with the non-controllability of its linearization, leads more and more solutions to resort to model preview control. These methods allow to predict the outcome of a control strategy in a future horizon and to improve it accordingly, usually by using numerical optimizations which take

[1]The workshop took place in the framework of the Anthropomorphic Motion Factory launched by the European project ERC-ADG 340050 Actanthrope (2014–2018) devoted to exploring the computational foundations of anthropomorphic action. The workshop was also supported by the European project ERC-ADV 666981 Taming (2015–2019) and the French ANR project Entracte (2014–2017).

into account the safety constraints and efficiency intents. However, since few years, the improvement of computational capabilities and numerical algorithms allows more and more to deal with complex dynamical systems and for longer horizons. This allows these approaches to untighten the local nature of their applications and progressively start wider explorations of their reachable space. This evolution brings us to the question of the rising overlap between planning and control. Today, most planning problems would take too much time to be solved online with numerical approaches. Does that imply that the generation of motion will theoretically never be free of the necessity of a prior planning? Or on the contrary, is planning only a numerical issue?

All these questions are also addressed in Life Sciences. Indeed, movement is a fundamental characteristic of living systems. How roboticists may benefit from neurophysiologist know-how and vice versa? System modelling is one way to gather both communities.

While actions operate in a physical space, motions begin in a motor control space. For robots and living beings, the link between actions expressed in the physical space and motions originated in the motor space, turns to geometry in general and, in particular, to linear algebra. Geometric control theory and numerical analysis highlight two complementary perspectives on optimal human and humanoid motion. Among all possible motions performing a given action, optimization algorithms tend to choose the best motion according to a given performance criterion. Optimal motions then appear as plausible action signatures.

How to express actions in terms of motions? How to face the computational complexity of bridging the 3D physical space with the high-dimension control space? How to reveal movement synergies? How to account for the underactuation of the locomotion? What optimality criterion underlies a given action? All these questions open challenging issues to direct and inverse optimal control, with recent developments in polynomial optimization and real algebraic geometry.

The multidisciplinary perspective on movement analysis is reflected in the book by its table of content. After a specific chapter introducing the rational above, the chapters are gathered within four main parts addressing respectively mathematics (Part Geometry, Action and Movement), applied mathematics (Part Numerical Analysis and Optimization), life science (Part Foundations of Human Movement), and robotics (Part Robot Motion Generation).

Editing a book with a multidisciplinary perspective is not an easy task. We thank all the authors for their effort in making their own research field accessible to others and all the reviewers who helped us in reaching this objective.

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