Preface

Recent advances in sensing, communication and computation technologies have enabled a group of agents, such as robots, to communicate or sense their relative information and to perform tasks in a collaborative fashion. The past few years witnessed rapidly-growing research in cooperative control technology. Applications range from space interferometry sensing to environmental monitoring, to distributed computing, and distributed target surveillance and tracking. However, the analytical techniques used in cooperative control algorithms have been disparate, and a unified theory has been wanting.

In this book, we present a passivity-based framework that allows a systematic design of scalable and decentralized cooperative control laws. This framework makes explicit the passivity properties used implicitly in existing results and simplifies the design and analysis of a complex network of agents by exploiting the network structure and inherent passivity properties of agent dynamics. As we demonstrate in the book, this passivity-based framework can be easily tailored to handle classes of cooperative control problems. Each of these problems has important applications in practice. For example, formation control and coordinated path following allow vehicles to maintain a tight relative configuration, thereby achieving effective group sensing or drag force reduction. Attitude coordination ensures that multiple spacecraft keep a precise relative attitude, which is important in space interferometry missions. Cooperative load transport enables robots to move an object around meanwhile exerting desired internal forces on the object.

To demonstrate the design flexibility offered by the passivity-based framework, we feature various adaptive redesigns. Adaptivity is important in multi-agent systems, as it implies that the agents can adjust their control according to changing conditions. A particularly useful scenario is when a group leader has the group mission plan while the remaining agents have only partial information of the plan. As the leader autonomously modifies the mission plan, it is essential that the rest of the group be able to adapt. We develop adaptive designs with which the agents recover the leader's mission plan. Another scenario that requires adaptivity is when uncertainty exists in agents' controls, such as wind and viscous damping. In this case, the agents should adapt their control laws to simultaneously accommodate this uncertainty and achieve the required task. We illustrate this scenario with adaptive designs for agreement of multiple Euler-Lagrange systems.

The intention of this book is to summarize in a coherent manner the authors' recent research in passivity-based cooperative control of multi-agent systems. Related passivity approaches are applicable to other interconnected systems, such as data communication networks, biomolecular systems, building heating, ventilation, and air conditioning (HVAC) systems, and power networks, though these applications are outside the scope of this book. The organization of this book is as follows:

Chapter 1 introduces cooperative control and presents the necessary background in graph theory and passivity.

Chapter 2 presents the passivity-based approach to cooperative control and applies it to the agreement problem. We illustrate a position-based formation control problem that can be transformed into the agreement problem. We also study a distance-based formation control under the same passivity-based framework and compare it with the position-based formation control.

Chapters 3 and 4 consider the situation where only one agent possesses the group reference velocity information and develop adaptive designs that recover such information for the other agents. Chapter 3 adopts an internal model approach while Chapter 4 parameterizes the reference velocity with time-varying basis functions. These two adaptive schemes illustrate the design flexibility offered by the passivity-based approach.

Chapter 5 investigates attitude agreement of multiple rigid bodies. We adapt the results in Chapters 2 and 4 to a similar passivity-based framework that addresses the agreement of agents in $SO(3)$.

Chapter 6 studies agreement problem of multiple Euler-Lagrange systems. In particular, we consider the case where uncertainty exists in agents' dynamics. We present two adaptive designs that ensure the agreement in the presence of uncertainty.

Chapter 7 presents a synchronized path following problem, where the agents achieve tracking of a desired formation by synchronizing path parameters. The synchronization of the path parameters is solved by the passivity-based agreement designs in Chapter 2.

Chapter 8 studies cooperatively transporting a common load by multiple robots. We formulate this problem in a similar fashion to the position-based formation control in Chapter 2 and validate it with experiments.

Chapter 9 provides an investigation of robustness properties for a second order linear cooperative control system.

The Appendix includes technical proofs and tools utilized in this book.

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