Underactuated Mechanical Systems

Analysis and Control of Underactuated Mechanical Systems

A. Choukchou-Braham, B. Cherki, M. Djemai, and K. Busawon, Springer, New York, 2014, 138 pages.

Analysis and Control of Underactuated Mechanical Systems is a timely book. Currently, there are several major research projects in robotics aimed at creating better solutions to the problem of locomotion. One of the major challenges is the underactuated nature of locomotion systems. Another challenge is the broad and often seemingly unsystematic nature of not only the problem but also the literature. The authors attempt to deal with these issues.

The book consists of five chapters and four appendixes. Each chapter ends with many excellent references. The first chapter is an introduction and historical literature review. There have been few attempts like this to assemble the literature and present a systematic framework for the control of underactuated mechanical systems (UMSs). Although this chapter does not cover all of the vast number of techniques that are available, it does provide many references for those not described. The focus is mainly on unified frameworks that include nonlinear deterministic approaches.

The second chapter covers generalities and the state of the art on the control of UMSs. It discusses in depth the concept of what it means to be underactuated (essentially a system possessing more degrees of freedom to be controlled than there are control inputs), and what the potential sources of underactuation can be.

Typically UMSs not only render many well-known results and properties for analysis and control invalid but also exhibit undesirable properties such as nonminimum phase behavior. The authors do a good job of pointing out known characteristics that are helpful, such as the fact that UMSs do not satisfy a known necessary condition for the existence of smooth time-invariant feedback stabilization.

After discussing how challenging and interesting these types of systems can be, the authors present an overview of several methods of control, such as energy based (swing the system up into a linear region then switch to a linear controller), passivity based (swing into a desirable orbit then switch), output-feedback, feedforward, small gains synthesis, and sliding mode control.

The authors state that since UMSs are so varied in type, and are typically addressed on a case-by-case basis, this book attempts to present a means by which to look for common patterns and determine what appropriate control method should be applied rather than outlining every possible controller. The classification of the problem is a key step, and this chapter introduces the two main classifications: the control flow diagram (CFD) methods of Seto and John Baillieul and the analytical methods of Reza Olfati-Saber.

Before the classifications can be presented in detail, UMSs must be described carefully. The third chapter presents UMSs from the Lagrangian formalism. The authors state that two major advantages of the Euler–Lagrange formulation are 1) the resulting equations are invariant and 2) they allow one to compute the evolution of mechanical systems as a result of applied forces. The equations are first derived for fully actuated mechanical systems, then for UMSs, and finally a comparison with nonholonomic systems is drawn. The chapter then describes the various forms of partial linearization that are applicable to UMSs and finishes with common cases (the inverted cart-pendulum, acrobot, and several others).

The fourth chapter details the two main methods for classifying the UMSs and explores the possibility of a link between them. The key steps of each method are laid out, and several examples are provided, further aiding in cementing the reader's understanding. For example, the CFD method classifies every UMS into a combination of a tree structure, chain structure, or isolated vertex. The authors provide a balance of mathematical development with clear explanation so that the reader is not overloaded. Ultimately, the two classification systems are determined to be independent but parallel tools.

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In the fifth and final chapter, the authors describe control approaches to address all of the classifications within the CFD method. Historically, backstepping was the proposed design method originally applied to the tree structures only. The authors extend and develop control approaches for the remaining structures in this chapter. Both examples and results from various applications are described, once again clarifying the concepts.

If the reader does not posess a background in nonlinear stability and control when he or she opens this book, the appendices are a good starting point for fully appreciating the contents of the book. They describe theory, analysis approaches, appropriate geometry, and some warnings about destabilization.

Analysis and Control of Underactuated Mechanical Systems is a rare work in that it attempts to take a literature full of disparate cases and techniques and collate it into a coherent formal methodology without limiting the final approach to a single control strategy. If roboticists are going to solve the problem of dynamic locomotion, it is likely that they will have to employ the type of formal but flexible methodology presented in this book.

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