Book Reviews

Geometric Control of Mechanical Systems Francesco Bullo and Andrew D. Lewis (New York: Springer Science and Business Media, Inc., 2005). *Reviewed by Bill Goodwine*

I. Introduction

This book was written to serve as both a reference book for researchers as well as a text book for students and presents a comprehensive treatment of relatively recent results in analysis and control of mechanical systems. The term "mechanical systems" is used specifically in this text to refer to a class of Lagrangian systems (as opposed to, for example, Hamiltonian systems), which, while somewhat limited, is still sufficiently general to be of interest to the broader engineering community. Other than the obvious utility of the subject of controlling mechanical systems, the theme of the book is to utilize the natural mathematical overlap that exists in the fields of nonlinear control and mechanical systems. In particular, the book is based fundamentally upon the use of differential geometric methods in both nonlinear control and the analysis of mechanical systems where they are unified; namely, control of mechanical system. The use of differential geometric tools in the analysis of mechanical systems has a long history (for example, [1]) and a relatively more recent history in nonlinear control (for example, [2] and [3]), and this book provides a comprehensive presentation of the results of the natural mathematical commonalities between the two subject areas.

II. Outline of the Text

The book is explicitly divided into three parts: Part 1: Modeling of mechanical systems; Part 2: Analysis of mechanical control systems; and Part 3: A sampling of design methodologies.

In Part 1, Chapter 1 presents some introductory and motivational systems. Chapters 2 and 3 provide a very dense mathematical review of the necessary algebra and differential geometry required by the rest of the book. Chapter 4 presents the essential tools for the formulation of simple[1] mechanical control systems. Chapter 5 deals with symmetries and groups and the associated subjects of rigid body systems, connections and reduction theory.

In Part 2, Chapter 6 presents a review of standard stability results and their application to simple mechanical systems. Chapters 7 and 8 deal with controllability. In particular, these chapters present some results that are specific to simple mechanical systems and the variations and intricacies of the notion of controllability (and accessibility) for mechanical systems. Chapter 9 outlines standard results from perturbation analysis and the presents some initial applications to mechanical systems. Part 3 deals with the application of the material to the design problem. Chapters 9–12 deal with stabilization; in particular, stabilization using potential shaping, stabilization for fully actuated systems and stabilization using oscillatory controls, respectively. Chapter 12 also presents some results on tracking using oscillatory controls. Chapter 13 presents results on motion planning for underactuated mechanical systems.

Finally, the appendices present some mathematical details or complications that are best omitted from the body of the text for clarity of presentation. Appendix A deals with time dependent vector fields and Appendix B presents some proofs.

III. Conclusion

The book is extremely well written and organized and strikes a good balance between the competing goals of being self contained and being manageable in length. With regard to the former goal, the mathematical review material, especially Chapters 2 and 3, but also elsewhere in the book are very dense. For a reader generally familiar with the mathematical subject matter, this actually is a very nice feature in that a short, dense and concise presentation of the material makes a very good reference and review. However, with regard to students, potential instructors are cautioned to take the authors' description of the substantial mathematical prerequisites in the preface very seriously. While most students may be able to use the review material to fill in some missing gaps in their background, only the most exceptional student will be able to acquire a substantial portion of the necessary mathematical material from the background chapters without extended reference to outside material.

In contrast to the necessarily dense mathematical review chapters, however, the pace of the rest of the book, dealing with the mechanics and control issues, is appropriate for course work as well as reference material. It is especially worth noting that the book contains many suitable example problems that are presented *in sufficient detail* to serve two purposes. First, the usual role of example problems will help supplement the presentation of the material. Second, however, the differential geometric treatment of the material concisely expresses the essence of the problem at hand; however, the somewhat unusual problem of understanding the generalities of the theory but not the particularities seems to be a somewhat common problem in learning this type of material. The frequent and detailed examples are very helpful in this regard and are very welcome in that they are unfortunately somewhat unique in this type of literature.

In summary, the book is very well written and organized and is appropriate as both a text book for students with the appropriate mathematical preparation and very valuable for researchers in the fields of nonlinear control, mechanical systems, and particularly, the natural overlap between the two. Among its other obvious contributions to the literature it is the first comprehensive treatment of the subject matter in text book form and will nicely serve the role of further disseminating the useful results it contains to the engineering community.

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[1]The term "simple" has a specific mathematical meaning which the authors take care to point out is *not* synonymous with "easy."

References

[1] R. Abraham and J. E. Marsden, *Foundations of Mechanics*, 2nd ed. Reading, MA: Addison-Wesley, 1978.
[2] A. Isidori, *Nonlinear Control Systems*, 2nd ed. New York: Springer-Verlag, 1989.
[3] H. Nijmeijer and A. J. Van der Schaft, *Nonlinear Dynamical Control Systems*. New York: Springer-Verlag, 1990.