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Khac Duc Do • Jie Pan

Control of Ships and Underwater Vehicles

Design for Underactuated and Nonlinear Marine Systems

Springer

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The first author dedicates this book to his parents, Do Thi Duyen and Do Khac Yen, and his little daughter, Do Thu Trang.

The second author dedicates this book to his parents, Liyou Pan and Hungxiu Diao.

Series Editors' Foreword

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. New technology, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies..., new challenges. Much of this development work resides in industrial reports, feasibility study papers, and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

When advances are made in industrial control technology, for example, sensors, actuators, controllers, communications, and computing power, there are at least three possible consequences for system control. The control engineering may decide to use the new hardware to make an existing control system perform better. Another possibility is that the new hardware advances make a proposed but previously impractical control method feasible. Alternatively, it may be necessary to devise a completely new control technique in order to exploit the new hardware. However, in many cases, it is often economically impossible to advance an aspect of the system's control hardware until there is a major upgrade of the system and the industrial control engineer has to grapple with the limitations of the system as it exists. (This is where control engineering science becomes an art!) Underactuated marine vessels are a case in point. In most configurations, a vessel's main actuators are propellers and rudders, yet a marine vessel has six degrees of freedom in its motion, and the marine control engineer simply has to work with the control surfaces and sensors available. One area that may advance control performance is the use of better control designs, and recently control engineers have become more interested in what nonlinear control might have to offer.

Researchers Khac Duc Do and Jie Pan have published a sequence of journal and conference papers on new control algorithms for underactuated systems. Most of this work has used models of marine systems (surface ships and underwater vehicles), but some of the work has been with other mechanical system models (wheeled mobile robots, vertical take-off and landing (VTOL) aircraft). Now they have taken the opportunity to capture this research and development work in a monograph en-

titled *Control of Ships and Underwater Vehicles: Design for Underactuated and Nonlinear Marine Systems* for the *Advances in Industrial Control* series. This will enable industrial control engineers and control researchers to read and study a systematic presentation of their ideas and work. The book opens with chapters that introduce the appropriate nonlinear control theory and marine vessel models used in the research, proceeds to controller derivation and development, and finally details simulation results for a series of nonlinear control schemes devised for marine vessel control problems like point-to-point navigation and path-following. Also presented are some field results of a laboratory-scale vessel on a local river. In one chapter other applications fields are considered and the nonlinear control results for a simple wheeled robots and a simple VTOL aircraft model are given. Each of the applications chapters contains illustrative simulation studies and control results.

The monograph will interest control researchers, graduate students, and industrial control engineers alike, particularly those involved in marine and wheeled robotic motion control problems. The Series Editors, being based in Glasgow, Scotland, have always had an interest in marine control problems and have endeavoured to ensure that the *Advances in Industrial Control* series has useful volumes from this field of control application. Past volumes have included: *Ship Motion Control* by Tristan Perez (ISBN 978-1-85233-959-3, 2005), *Compressor Surge and Rotating Stall* by Jan Tommy Gravdahl and Olav Egeland (ISBN 978-1-85233-067-5, 1998), and *Robust Control of Diesel Ship Propulsion* by Nikolaos Xiros (ISBN 978-1-85233-543-4, 2002), and we are pleased to welcome this new volume, *Control of Ships and Underwater Vehicles* into the series.

Industrial Control Center
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M.J. Grimble
M.A. Johnson

Preface

Control of ocean vessels including ships and underwater vehicles is an active field due to its theoretical challenges and important applications such as passenger and goods transportation, environmental surveying, undersea cable inspection, offshore oil installations, and many others. Most ocean vessels are underactuated meaning that they have more degrees of freedom to be controlled than the number of independent control inputs. Ships do not usually have an independent sway actuator while for underwater vehicles there are often no independent sway and heave actuators. As a result, motion control of underactuated ocean vessels opened a new territory in applied nonlinear control, and attracted special attention from both marine technology and control engineering communities.

If classical motion control systems designed for fully or overactuated vessels are directly used on underactuated vessels, the resulting performance of controlled systems is very poor or control objectives cannot be achieved. For example, the traditional approach, in which a combination of a conventional autopilot and a line-of-sight algorithm is used to steer an underactuated ship from one point to another on a straight line, does not impose on minimizing the lateral distance. Consequently, the shortest traveling distance is not achieved. Another example is that underactuated ocean vessels cannot be stabilized by any time-invariant continuous state feedback controllers although they are open loop controllable. This fact resulted from a direct application of the Brockett necessary condition to feedback stabilization of underactuated ocean vessels.

Inspired by progress in the field, we present this monograph on control of underactuated ocean vessels including ships and underwater vehicles to senior and postgraduate students, researchers and practitioners of marine technology, control engineering, mechanical engineering, electrical engineering, and mechatronics. This is the first book in the literature that offers various solutions to advanced feedback control topics of practical importance including stabilization, trajectory-tracking, path-tracking, and path-following for underactuated ocean vessels. In the control development and stability analysis of the controlled systems, practical motivations as well as nontrivial techniques are carefully detailed. The techniques presented in

the book can be readily applied to other underactuated mechanical systems such as aircraft, spacecraft, mobile robots, and robot arms.

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