Preface

During the last half century robotics has grown to become a mature technology with several and widespread applications. Due to the diversity in robotic applications, together with increasingly robust and sophisticated solutions, robotic technology has lead to both social and economic improvements that are apparent in our everyday life. In addition, several multi-billion industries are totally dependent on robotic solutions to keep production at competitive levels of price, quality, and efficiency.

The benefits on society that has arisen due to the increased use of robotic solutions are mainly found in manufacturing and assembly tasks on the factory floor using robotic manipulator arms. Examples include assembly of cars, pick-and-place tasks, packaging, spray paint and welding, assembly of electronic boards, and so on—all tasks that can be performed using a fixed-base manipulator arm bolted to the factory floor.

There is, however, a large potential in manufacturing also in locations outside the traditional factory floor. Distant locations and places that are hard or dangerous to reach for humans can also benefit from robotic solutions. In order to solve such tasks, the robots need to be both mobile—so that they can locomote themselves to the remote location—and they need to maintain their manipulation capabilities that have made robots so successful in factory manipulation tasks. In this book we will study this kind of robotic systems in great detail.

There are two main motivational factors that have encouraged the writing of this book. The first is that we believe the class of robotic systems that we will refer to as *vehicle-manipulator systems* deserves to be treated in detail as one topic. Even though the applications of these systems are many and diverse they can be described using the same framework, which makes this group of robots well suited to be treated in the form of a single book. Even though the applications of these systems are different in character, the modeling and control have several similarities. Particularly, the kinematic and dynamic coupling between the manipulator and the vehicle are present in all systems.

The second motivation for writing this book is the great impact that we believe these systems will have on the operation of remotely located fields or fields with difficult access that require some form of manipulation. In the same way that fixed-base robotic arms have revolutionized factory automation, it is our belief that mobile manipulators will change the way distant fields are operated in the future. The social and economic benefits of utilizing robotic technology in these fields will probably be as significant as the benefits that we have experienced from fixed-base manipulation over the last decades.

In addition to distant locations, vehicle-manipulator systems can also be used on or outside the factory floor in routine and time-consuming manipulation tasks. One example with great economic benefits is introducing agricultural robots in orchards and other fields, which will also relieve human workers from an ergonomically challenging working environment. Similarly, transportation and surveillance tasks can be performed more efficiently using robotic solutions in traditional factory production and manufacturing.

A final motivation for writing this book is to clarify some basic properties of vehicle-manipulator systems that have not been interpreted correctly in literature. When the dynamic equations are written in matrix form, we can identify several properties, especially of the inertia and Coriolis matrices, that greatly simplify the design of control laws. For example, the boundedness property of the inertia matrix is important both in simulation and in stability proofs of control laws. This property is always true for standard robotic arms, but not necessarily for vehicle-manipulator systems. The same is the case for the skew-symmetric property of the Coriolis matrix which is easily satisfied for single rigid bodies and standard robotic manipulators, but is not satisfied for the most commonly used representations of vehicle-manipulator dynamics. In this book we thus put great effort in clarifying for which representations these properties are in fact true. We also systematically derive the dynamic equations for which both these properties are satisfied.

After a brief introduction and a presentation of the most important concepts to be treated in the book in Chaps. 1 and 2, the first part of the book (Chaps. 3–5) treats the kinematics of rigid bodies, robotic manipulators, and vehicle-manipulator systems. We discuss several different representations of the state space and particularly representations that allow for robust formulations of the system kinematics and dynamics. Chapters 6–8 then discuss the dynamic equations of the same systems based on the formulations of the state space that we found in the previous chapters. Finally Chaps. 9–13 present a detailed treatment of different types of vehicle-manipulator systems aimed at different application areas such as underwater and space robots. In the introductory chapters on dynamics (Chaps. 6–8) only the rigid body properties of vehicle-manipulator systems are discussed. In the chapters that are dedicated to the different types of vehicle-manipulator systems we give a more specific presentation of these systems and include other considerations that apply only to that specific type of vehicle-manipulator system: for underwater systems we include buoyancy and gravitational forces as well as drag and added mass that come as a result of the mechanism being totally or partially submerged; for space manipulators we discuss how to choose the non-inertial reference frame and how to deal with a free-floating spacecraft in a free fall environment; for field robots non-holonomic constraints are discussed; and for a robotic manipulator mounted on a forced non-inertial base we show how the non-inertial motion of the base propagate to the manipulator dynamics.

There are several ways to read this book. The book can be used to give an introductory course in robotics by leaving out some of the final sections of each chapter, or as a more thorough treatment including several tools from differential geometry and Lie groups in order to obtain a more rigid formulation of the kinematics and dynamics.

Some sections that appear at the end of each chapter and large parts of Chap. 2 are not used in the subsequent chapters and can be left out. These sections discuss a more geometric approach to robot modeling using Lie groups and Lie algebras. The geometric formulations are important in order to derive a globally valid representation of the dynamics. The most common representations of vehicle-manipulator systems are not globally valid and we thus devote a large part of the book to show how to derive the dynamics without the presence of singularities. When working with vehicle-manipulator systems, this is a very important topic because the configuration space of the vehicle contains singularities when the standard vector representation is used to represent the position and velocity variables. There are many ways to solve this for a single rigid body, i.e., a vehicle with no manipulator attached, but for vehicle-manipulator systems the same approaches cannot be adopted directly. The geometric approach presented throughout the book can be used to derive the dynamics of single rigid bodies, robotic manipulators, and combinations of these without the presence of singularities.

The book can be read as an introductory course to robotics at bachelor level, or as a more advanced course including a geometric formulation on master/Ph.D. level:

Bachelor level

- For an overview of modeling of vehicle-manipulator systems and robotic systems in general, the reader can leave out the last sections of each chapter. The book can be used as an introductory course on robotics by including Chaps. 1–9 but leaving out the following sections:

  – Preliminaries: Sects. 2.5–2.10,
  – Kinematics: Sects. 3.3.6, 4.5.1, and 5.3.1,
  – Dynamics: Sects. 6.4.2–6.4.4, 7.6, and 8.3–8.3.3.

  The course will then start with the standard treatment of single rigid body modeling and modeling of robotic manipulators and multibody systems in general. The last part of the course on vehicle-manipulator systems will enhance the students understanding on state space representations, kinematic and dynamic coupling, and other aspects normally not found in standard textbooks on robotics.

Master/Ph.D. level

- For a more geometric treatment, the reader should include also the final sections of each chapter, starting with Chap. 2 (if not already familiar with differential geometry). In addition to the topics above, this will give an introduction to differential geometry and give a deeper understanding of how to derive well-defined and robust formulations of the kinematics and dynamics of general multibody mechanical systems.

Finally, the authors would like to express their gratitude to all those who have contributed to this book. First of all we would like to thank Professors Rolf Johansson, Olav Egeland, and Anton Shiriaev for their thorough feed-back on our early papers and the Ph.D. thesis of Pål Johan From. We would also like to show our gratitude to our colleagues at UC Berkeley, Vincent Duindam (now at Intuitive Surgical), Shankar Sastry, and Pieter Abbeel, who all have contributed by co-authoring several papers which first presented many of the results included in this book. They have also contributed with valuable discussions on several of the topics presented. We would also like thank Professor Stefano Stramigioli at University of Twente for discussions on the geometric approach used throughout this book. Finally we would also like to thank our students for proof-reading and valuable feedback.

Pål Johan From has received support from The Norwegian Nonfiction Writers And Translators Association (NFF).

Ås/Trondheim, Norway
December, 2012

Pål Johan From
Jan Tommy Gravdahl
Kristin Ytterstad Pettersen

http://www.springer.com/978-1-4471-5462-4

Vehicle-Manipulator Systems
Modeling for Simulation, Analysis, and Control
From, P.J.; Gravdahl, J.T.; Pettersen, K.Y.
2014, XXIV, 388 p. 52 illus., 33 illus. in color., Hardcover
ISBN: 978-1-4471-5462-4