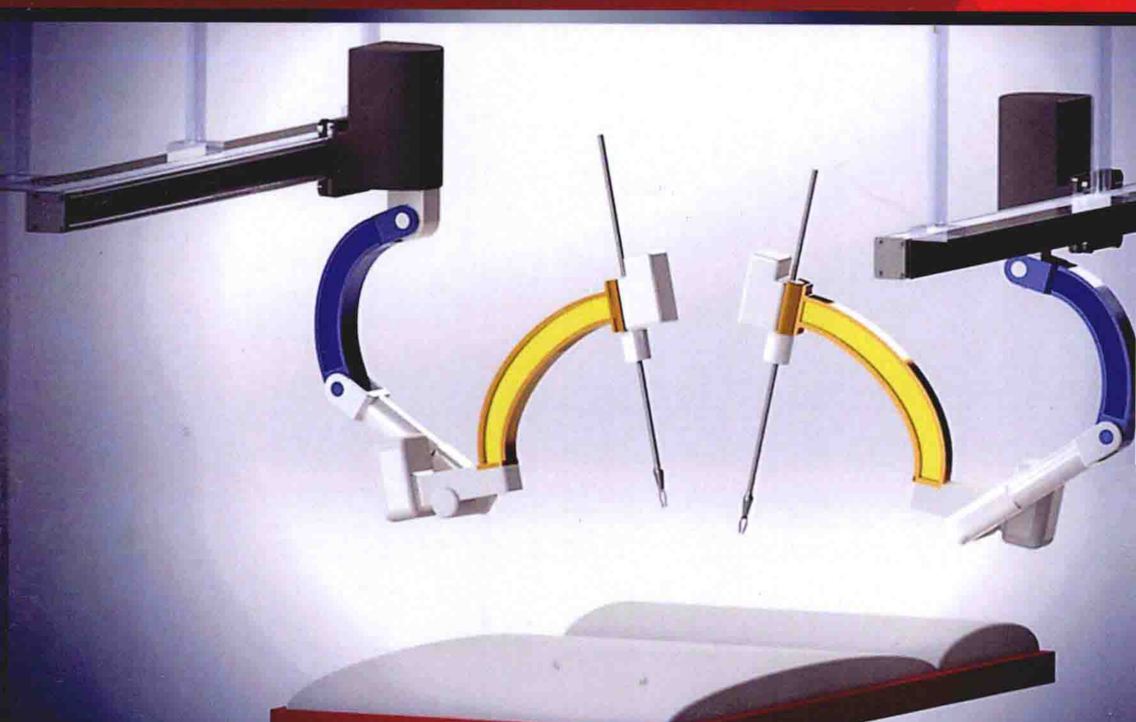
Robotic Surgery

Smart Materials, Robotic Structures, and Artificial Muscles

Mohsen Shahinpoor
Siavash Gheshmi



Robotic Surgery

Smart Materials, Robotic Structures, and Artificial Muscles

Mohsen Shahinpoor
Siavash Gheshmi

Pan Stanford Publishing

Published by

Pan Stanford Publishing Pte. Ltd.
Penthouse Level, Suntec Tower 3
8 Temasek Boulevard
Singapore 038988

Email: editorial@panstanford.com
Web: www.panstanford.com

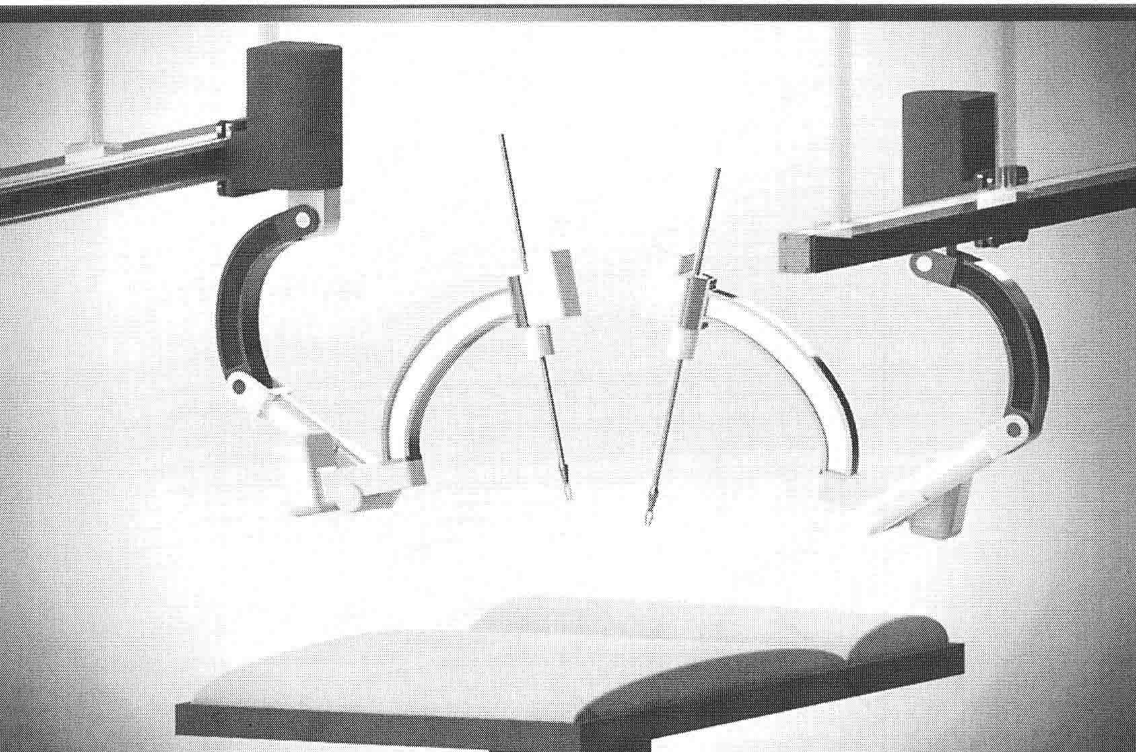
British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Robotic Surgery: Smart Materials, Robotic Structures, and Artificial Muscles

ISBN 978-981-4316-23-1 (Hardcover)
ISBN 978-981-4463-51-5 (eBook)

Printed in the USA

Robotic Surgery



To the memory of my parents,
Zarrin Taj and Aliasghar

—Mohsen Shahinpoor

To my parents,
Farahnaaz and Akbar

—Siavash Gheshmi

Preface

Robotic surgery is one of the fields where medicine and technology come together to enhance the quality of life. There are many books on robotic surgery that are specifically written for surgeons to describe how to use a robotic system to perform a surgical intervention. The focus of these books is purely medicine. There was a lack of a technical book that covers both the engineering design aspect of robotic surgical systems and how surgeons can benefit from them, which was our motivation to write the first textbook on robotic surgery that covers both medical and engineering aspects of this emerging field of remote surgical operations, and also offer homework problems to further enhance the underlying educational endeavors. *Robotic Surgery with Smart Materials, Robotic Structures and Artificial Muscles* is respectfully presented to the researchers and students of various disciplines of engineering and medicine to further expand their understanding of the field. This book also answers the need for a comprehensive review of medical robotics and their applications. The material presented in this text book is the result of collaborations of engineers and surgeons.

This book is the first textbook in robotic surgery that discusses the integration of smart multi-functional soft and biomimetic materials with robotic end effectors to provide haptic and tactile feedback to surgeons. It is also the first textbook in robotic surgery that comes with a solutions manual which makes it useful as a supplement to faculty members teaching many different programs and courses such as robotics, medical devices, surgical interventions and many more.

This book can be adapted by professors to teach the subject, used by graduate students and researchers to enable them to further employ their creativity and knowledge and by undergraduates to simply get an excellent grasp of this exciting field. It is also useful to those interested in the field for self-study. The background required to this book is college-level mathematics, matrix analysis, geometry and medical/surgical terminologies.

We acknowledge the collaboration and help of a number of surgeons who have contributed towards completing this book. In particular Dr. David Soltanpour, MD, Ophthalmologist and Microsurgeon at New York Eye and Ear Infirmary, Dr. Alireza Ghaffarieh, Ocular Pathology Fellowship, Department of Ophthalmology and Visual Science at University of Wisconsin, Madison as well as Michelle Toder, MD, Bariatric Robotic Surgeon at Eastern Maine Medical Center.

Mohsen Shahinpoor
Siavash Gheshmi

Foreword

Robotic surgery has already created a paradigm shift in medical surgical procedures and will continue to expand to all surgical and microsurgical procedures. There is no doubt that in doing so robotic surgical systems, such as the da Vinci surgical system, will become much more intelligent and sophisticated with the integration, implementation, and synergy of new intelligent material systems that will make surgical tools and equipment more functional and more intelligent in biomimetic sensing and actuation and kinesthetic interaction with organs during robotic surgery.

The current robotic surgical systems evolved from laparoscopic surgical procedures and made it possible for surgeons to perform surgery away from the patient, with much more concentration and ease. However, what was lost in this transition by the surgeons was the feeling sensation of tissues and organs and the kinesthetic force feedback during surgery. It is interesting to note that even during laparoscopic surgery surgeons can still feel and sense the tissues and organs they are handling and operating on with laparoscopic/endoscopic tools and feel the kinesthetic forces at work. However, kinesthetic force feedback was replaced with visual feedback during robotic surgery. It is to be noted that some of this kinesthetic force feedback was lost in the transition from open to laparoscopic surgery due to trocar friction and varying lever arms, anyway. However, using smart materials such as ionic polymer metal composites (IPMCs) and appropriate calibration and tuning, one may be able to recover the kinesthetic force feedback during surgery. IPMCs are great for such robotic force feedback applications because they work perfectly well in the wet human body environment and generate a millivolt-level sensing signal for kinesthetic force feedback. We believe that considering IPMCs for haptic and kinesthetic force feedback is novel. This topic is covered in Chapter 5.

Chapter 1 introduces surgical robots and their general or specific configurations for various types of surgery. Chapter 2 presents direct kinematics, inverse kinematics, and workspace considerations for surgical robots. Chapter 3 covers a thorough discussion and description of ophthalmic surgical robots and systems for performing microrobotic surgery. Chapter 4 presents a number of novel designs on deployable laparoscopic robotic surgical systems with 3D flexibility and orientational capabilities during robotic surgery. Chapter 5 discusses applications of intelligent materials and artificial muscles in robotic surgery in connection with haptic, tactile, and kinesthetic force feedback to surgeons during robotic surgery. Chapter 6 presents a summary of the coverage, as well as conclusions and future prospects for robotic surgery. The book ends with a large number of references, an appendix of MATLAB codes used, an authors' index, and a detailed subject index.

Contents

Chapter 1

Introduction to Surgical Robots' General Configurations

1.1 History of Robotics

Malone (1978) mentions that Aristotle was the first to discuss the concept of automation as a means to avoid the need for servants. The first versions of robots mostly consisted of clocks, such as the clepsydra (the water clock that measures time through a graduated flow of liquid passing through a small opening [Bedini, 1962]), pioneered by Ctesibius of Alexandria (c. 270 BC) (Rosheim, 1994), subsequently followed by self-moving machines or automatons. The use of automatons was also related to clocks, such as the case of 1497, where two bell-striking giants decorated the clock tower in Piazza San Marco, Venice. Later in history, cuckoo clocks emerged and gained popularity, especially in Germany. Leonardo da Vinci did considerable and notable work on robotics, mostly found in his renowned book *Codex Atlanticus*. Da Vinci planned to build an *anthrobot*, though a proper source of energy or the necessary high-precision part manufacturing to build such a robot did not exist in contemporary technology (Pires, 2000). The invention of the textile machine in 1801 by Joseph Jacquard was one of the catalysts and symbols of the Industrial Revolution, which took place in 1750–1850. The first industrial robot was designed by Seward Babbitt in 1892. This was a motorized crane with a gripper for the removal of

Robotic Surgery: Smart Materials, Robotic Structures, and Artificial Muscles
Mohsen Shahinpoor and Siavash Gheshmi

ISBN 978-981-4316-23-1 (Hardcover), 978-981-4463-51-5 (eBook)
www.panstanford.com

ingots from a furnace. Tesla (1898) gave his precious contribution in robotics through his patented remotely controlled device, the first of its kind, among many other inventions that are products of his work.

The word "robot" seems to have first become popular when the Czech playwright Karel Capek's play, entitled "Rossum's Universal Robots" (RUR), was first performed in Paris, France, in the 1920s. In that play, small, artificial, and anthropomorphic creatures strictly obeyed their master's orders. In Czech and Russian these creatures were called *robotnic*, from *robota*, which are the Czech and Russian words for "drudgery" and "hard work." "Robotics" as a term, on the other hand, was introduced later, in 1942, by Isaac Asimov in the story "Runaround," in which the author also submitted the laws of robotics (Asimov, 2012). These laws can be summarized as follows:

(a) Law 1: A robot may not harm a human being or, through inaction, allow a human being to come to harm.
(b) Law 2: Robots must obey orders given by humans, except those that would conflict with the higher-order laws.
(c) Law 3: Robots must protect their own existences as long as such protection does not conflict with the higher-order laws.

Asimov's laws have found real-world applications, particularly in modern surgical robots. According to Shahinpoor's (2011) book entitled *Intelligent Robotic Systems: Modeling & Simulation*, a robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for a variety of tasks. This definition covers a broad spectrum of robot manipulators, and within this definition, there are different classes of robots. These classes include the following:

1. *Automated or flexible manufacturing.* These "industrial" robots are employed in a wide range of manufacturing processes, including parts assembly and inspection, materials handling, welding, and materials painting.
2. *Remote exploration.* This class of robotic manipulators is designed to survive in environments that humans cannot tolerate. These robots can be used to explore the unknown, from the edge of our solar system to the depths of the earth's oceans.