Preface

Robots were used for rehabilitation purposes since the 1960s. Application of robots in rehabilitation was initially more focused on replacing lost functions in individuals with physical disabilities through the use of devices such as robotic orthoses, workstations, feeding devices and robotic wheelchairs. Over the last two decades, there has been an increasing amount of research into the use of robots in physical therapy. The goal of rehabilitation is to recuperate a patient from impairment or disability and improve mobility, functional ability and quality of life. This impairment can be the result of a stroke, a injury or a neurological disease.

Since robots are well suited for repetitive tasks and can be designed to have adequate force capabilities, their use in the execution of these exercises will be able to reduce the physical workload of therapists and can potentially allow the therapists to simultaneously oversee the treatment of multiple patients in a supervisory role. By using robotic devices, diagnosis and prognosis can be made more objectively with the help of quantitative data, and comparisons between different cases can also be made more easily. Several successful rehabilitation robots have undergone clinical trials and are currently being used in hospitals and clinics for neuromotor rehabilitation. However, the research and development of advanced robotics for medical rehabilitation are still at an early stage, and further research and development in this area are becoming more and more urgent.

This book systematically reviews the recent research and development of the innovative technologies for advanced robotics in medical rehabilitation. Through systematic overview of the existing systems and recent approaches of rehabilitation robots, interaction control and rehabilitation, the problems that emerged from recent approaches have been identified. To overcome these problems and to develop a series of novel advanced rehabilitation robotics, research and development of medical robotics for human impaired limbs have been carried out. These include the introduction of physiological masticatory model development, the modelling of human shoulder and elbow mechanisms, an exoskeleton development for upper limb rehabilitation, kinematic and computational model of human ankle, development of ankle rehabilitation robot and its adaptive control strategies. These research topics and findings constitute the main contents of this book.

The aim of this book is to provide a snapshot of our recent research outcomes and implementation studies in the field of advanced rehabilitation robotics. As the title suggests, Chap. 1 gives an overview of medical rehabilitation robotics. It briefly introduces the history and background of the medical robotics and this is followed by the discussion on the current issues involved in existing robotics and the motivation of our work presented in this book.

Chapter 2 presents the historical background of advanced robotics for medical rehabilitation. This chapter has highlighted the main motivations and objectives of this book through an overview of rehabilitation robots, interaction control and rehabilitation. The different types of rehabilitation devices developed in literatures were considered, with particular focus on their mechanical design, actuation methods and control schemes. Subsequently, studies relating to human limb kinematics and computational modelling of the ankle were also examined.

Targeting masticatory system modelling, Chap. 3 introduces the associated numerous complexities, and a new physiological model with two DOFs was developed for it. An in-depth study was performed on the mandibular muscles to properly characterise all accessible mandibular muscle EMG signals from which to base the physiological model. Based on the findings of the EMG signal study, the physiological model of the masticatory system was reconfigured and the concept of a hybrid model was introduced. The effectiveness of hybrid model was proven through experiments from multiple subjects and was analysed offline.

To further address the robotic system for upper limb, Chap. 4 proposes a kinematically redundant 4R spherical wrist model for shoulder and elbow joints, with its kinematics modelled by DH notation to solve the forward and inverse kinematic problems. This chapter also presents an EMG-driven physiological model of the elbow joint that was developed in the sagittal plane. In this chapter, the physiological model of the developed elbow joint model was coupled with linear envelope processing and experimentally validated with data from multiple subjects.

The design of an active upper limb exoskeleton prototype is presented in Chap. 5. A redundant 4R spherical wrist mechanism is proposed for a shoulder exoskeleton to solve the singularity and workspace limitations. The 4R mechanism has been optimised using multi-objective optimisation algorithm to achieve the entire human shoulder workspace while operating far away from singular configurations and without interfering with the user. Numerous important design factors were considered in this chapter in realising the final exoskeleton design to ensure that it can operate effectively alongside a human user's upper limb.

Chapter 6 further develops the motion and interactive control methods for upper limb exoskeleton. This chapter presents the minimum jerk trajectory planner, which is developed to generate smooth trajectories for the 5-DOF upper limb exoskeleton. This chapter also presents force-based control strategies that allow the exoskeleton to interact with and respond to the unpredictable behaviour of the user's limb. The concept of admittance and impedance in the interaction between two physical systems is discussed and applied to the exoskeleton system.

To model the human ankle joint, motion of the ankle–foot structure is discussed in Chap. 7. This chapter presents a computational ankle model developed to facilitate controller development of the ankle rehabilitation robot and provides a description of the ankle mechanical characteristics through considerations of forces applied along anatomical elements around the ankle joint, which include ligaments and muscle–tendon units. The dynamics of the ankle–foot structure and its surrounding ligaments and muscle–tendon units were formulated into a state space model to facilitate simulation of the robot. Finally, based on observations from preliminary testing, a modified recursive least squares algorithm was proposed and tested on experimental data.

Chapter 8 begins with an overview of the design requirements of an ankle rehabilitation robot. A suitable kinematic structure of the robot is then designed. Workspace, singularity and force analyses of mechanisms having this structure are then presented. This is followed by a description of the robot hardware and interface. Operation of the developed rehabilitation robot relies on implementation of a suitable interaction controller, and a force-based impedance control approach had been taken in this research. This chapter details the development of the multi-input multi-output (MIMO) actuator force controller devised in this work.

Chapter 9 further details the dynamic model of the parallel mechanism for ankle rehabilitation and presents variable impedance control approaches to achieve adaptive interaction control. In this chapter, the basic impedance control law is extended to yield a more advanced interaction control scheme for passive range of motion and active-assistive exercises. This chapter also explores the use of an assistance adaptation scheme to achieve the implementation of a control module to facilitate active user participation in the rehabilitation exercises.

Chapter 10 seeks to summarise the main outcomes and conclusions of this research, as well as highlight the contributions made in this book. This chapter also provides a discussion of future directions that can be explored to extend or advance the work presented in this book. The future trends in various aspects including the design, modelling and control of the advanced robotics for medical rehabilitation are discussed. This may be used to guide coming research, or act as a reference for institutions to design and develop new medical robotic systems.

This book also contains an Appendix that summarises some of the design and development of rehabilitation robotics. It provides the source code of the robotic simulation and control. These are excellent examples for users or developers.

I would like to take this opportunity to express my deep appreciation to those who have contributed to this book. The authors are also grateful to Wei Meng, Yun Ho Tsoi, James Pau and Ho Shing Lo for their assistance in compiling the book. It is our sincere hope that readers will find this book useful to their study and research.

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