Robotic Exoskeleton For Rehabilitation Of The Upper Limb

Gait disorder is a commonly lasting side-effect for stroke and spinal cord injury survivors. Conventional gait rehabilitation trainings provided by therapists are largely dependent on their experience. Such trainings are often challenging for the therapists due to their physically intensive nature. Hence, consistent optimal results cannot always be achieved. Robotic technologies were thus introduced to automate the gait rehabilitation trainings, in order to emancipate therapists from physically intensive work as well as making rehabilitation training more accessible to patients. Research have shown that task specific repetitive training and patients' active participation can lead to more effective gait rehabilitation. However, conventional trajectory tracking controlled robotic gait rehabilitation could change the dynamics of the walking task, reduce inputs from patients' motor systems, lower their physical effort and thus result less effective outcomes. Therefore, it is important to ensure that the robotic gait rehabilitation training is more analogous to actual human walking and maximize the training subject's active participation. The goal of this thesis is the development of a new robotic GAit Rehabilitation EXoskeleton (GAREX) that is compliant with the current neurorehabilitation theories in order to achieve optimised robotic gait rehabilitation. Such goal is tackled systematically in terms of both robotic design and control algorithm research. GAREX was designed to provide safe, task specific gait rehabilitation to stroke patients. Pneumatic muscles (PM) actuators were used to drive GAREX, due to their high power/force to weight ratio and
intrinsic compliance. Specially, the intrinsic compliance can create a wide range of dynamic environment for control strategy development. However, the negative correlation between PM's force output and contracting length means a trade-off between torque and range of motion specifications of the actuation system. The design of GAREX comprehensively addressed torque and joint range of motion requirements imposed by task-specific gait rehabilitation training. Control strategies are the key to implement the training theories into robotic operations. In order to encourage patients' active participation, the robot should be controlled to supply just enough guidance/assistance a patient needs to complete treadmill based gait training. To implement assist-as-needed (AAN) concept, the robot should also be able to assess the extent of active participation and change the assistance provided accordingly. The intrinsic compliance of GAREX's PM actuation system could be utilized to change the level of guidance. A new multi-input-multi-output (MIMO) sliding model (SM) controller was developed to adjust assistance while guiding training subjects to walk in predefined gait trajectories. Technical experimental validation indicated that controller was able to track reference gait trajectories and the desired joint space average antagonistic PM pressures. A study with 12 healthy subjects revealed strong statistical evidence that the proposed MIMO SM controller is able to vary the compliance of the exoskeleton To online assess the training patient's active participation, a fuzzy logic compliance adaptation (FLCA) controller is proposed. The FLCA algorithm utilizes the robotic kinematics and human-exoskeleton interaction torque of the knee joint, to estimate the extent of the patient's active participation. Based on the estimation, the desired compliance level can be automatically adjusted with higher compliance for more active participation and vice versa. Nevertheless, the FLCA algorithm does not require models of the
exoskeleton and biomechanics of the training subject, which means less preparation work and easier implementation. Performance of the FLCA control system was validated with three healthy subjects who simulated different extents of participation. The FLCA control system could successfully adapt the joint actuation compliance accordingly in all the scenarios. This dissertation presents the development of an upper-body exoskeleton and its control framework for robotic rehabilitation of the arm and shoulder after a neurological disorder such as a stroke. The first step is designing an exoskeleton hardware that supports natural mobility of the human upper body with a wide range of motion for enabling most rehabilitation exercises. The exoskeleton is equipped with torque-controllable actuation units for implementing various robotic rehabilitation protocols based on force and impedance behaviors. The control framework is designed to exhibit a highly backdrivable behavior with a gravity compensation for the robot's weight and optional gravity support for user's arm weight to promote voluntary movements of patients with motor impairments. The control framework also serves as a `substrate' of other robotic control behaviors for rehabilitation exercises by superimposing desired force or impedance profiles. A stability analysis is performed to examine the coupled stability between the robot and human. After designing the hardware and control, several experiments are carried out to test the mobility and dynamic behavior of the robot. Lastly, a human subject study evaluates the effectiveness of the robot's shoulder mechanism and control algorithm in assisting the coordination around the shoulder. The results show that the robot induces desirable coordination in the presence of abnormalities at the shoulder. Soft Robotics in Rehabilitation explores the specific branch of robotics dealing with developing
robots from compliant and flexible materials. Unlike robots built from rigid materials, soft robots
behave the way in which living organs move and adapt to their surroundings and allow for
increased flexibility and adaptability for the user. This book is a comprehensive reference
discussing the application of soft robotics for rehabilitation of upper and lower extremities
separated by various limbs. The book examines various techniques applied in soft robotics,
including the development of soft actuators, rigid actuators with soft behavior, intrinsically soft
actuators, and soft sensors. This book is perfect for graduate students, researchers, and
professional engineers in robotics, control, mechanical, and electrical engineering who are
interested in soft robotics, artificial intelligence, rehabilitation therapy, and medical and
rehabilitation device design and manufacturing. Outlines the application of soft robotic
techniques to design platforms that provide rehabilitation therapy for disabled persons to help
improve their motor functions Discusses the application of soft robotics for rehabilitation of
upper and lower extremities separated by various limbs Offers readers the ability to find soft
robotics devices, methods, and results for any limb, and then compare the results with other
options provided in the book
The new technological advances opened widely the application field of robots. Robots are
moving from the classical application scenario with structured industrial environments and
tedious repetitive tasks to new application environments that require more interaction with the
humans. It is in this context that the concept of Wearable Robots (WRs) has emerged. One of
the most exciting and challenging aspects in the design of biomechatronics wearable robots is
that the human takes a place in the design, this fact imposes several restrictions and
requirements in the design of this sort of devices. The key distinctive aspect in wearable robots
is their intrinsic dual cognitive and physical interaction with humans. The key role of a robot in a physical human–robot interaction (pHRI) is the generation of supplementary forces to empower and overcome human physical limits. The crucial role of a cognitive human–robot interaction (cHRI) is to make the human aware of the possibilities of the robot while allowing them to maintain control of the robot at all times. This book gives a general overview of the robotics exoskeletons and introduces the reader to this robotic field. Moreover, it describes the development of an upper limb exoskeleton for tremor suppression in order to illustrate the influence of a specific application in the designs decisions.

This book contains the proceedings of the 1st Latin American Congress on Automation and Robotics held at Panama City, Panama in February 2017. It gathers research work from researchers, scientists, and engineers from academia and private industry, and presents current and exciting research applications and future challenges in Latin American. The scope of this book covers a wide range of themes associated with advances in automation and robotics research encountered in engineering and scientific research and practice. These topics are related to control algorithms, systems automation, perception, mobile robotics, computer vision, educational robotics, robotics modeling and simulation, and robotics and mechanism design. LACAR 2017 has been sponsored by SENACYT (Secretaria Nacional de Ciencia, Tecnologia e Inovacion of Panama).

Rapid prototyping is used to design and develop medical devices and instrumentation. This book details research in rapid prototyping of bio-materials for medical applications. It provides a wide variety of examples of medical applications using rapid prototyping, including tissue engineering, dental applications, and bone replacement. Coverage also discusses the
emergence of computer aided design in the development of prosthetic devices. This book presents the synthesis of a Hand Exoskeleton (HE) for the rehabilitation of post-stroke patients. Through the analysis of the state-of-the-art, a topological classification was proposed. Based on the proposed classification principles, the rehabilitation HEs were systematically analyzed and classified accordingly, that is effective to both perceive the demand for proposing application-specific solutions and provide some useful guidelines for the design of a new HE. Further, a novel rehabilitation HE was designed to support patients in cylindrical shape grasping tasks with the aim of recovering the basic functions of manipulation. Numerous multi-objective optimizations followed by building a final prototype. The experimental results of the preliminary tests are promising and demonstrate the potential for clinical applications of the proposed device in robot-assisted training of the human hand for grasping functions. 

Wearable Robotics: Systems and Applications provides a comprehensive overview of the entire field of wearable robotics, including active orthotics (exoskeleton) and active prosthetics for the upper and lower limb and full body. In its two major sections, wearable robotics systems are described from both engineering perspectives and their application in medicine and industry. Systems and applications at various levels of the development cycle are presented,
including those that are still under active research and development, systems that are under preliminary or full clinical trials, and those in commercialized products. This book is a great resource for anyone working in this field, including researchers, industry professionals and those who want to use it as a teaching mechanism. Provides a comprehensive overview of the entire field, with both engineering and medical perspectives Helps readers quickly and efficiently design and develop wearable robotics for healthcare applications

The potential of robotic systems to aid in the rehabilitation of populations with cerebral palsy is a burgeoning area of research. It is able to provide more repeatable and enjoyable physiotherapy regimes, in addition to lessening the burden on physiotherapists, shifting their work to a supervisory role. In this research, a control architecture for a wearable elbow exoskeleton device is presented. The exoskeleton contains a novel actuation joint, presented as the Bio-Sensor & Joint (BJS) and this is used to apply torques to the elbow joint. A torque controller based on sliding mode control (SMC) was derived from a model of the system and compared to a feedback-linearised proportional derivative (PD) controller for pure trajectory tracking. It was found that the SMC controller was more robust to disturbances and modelling uncertainties. The SMC controller was then tested for efficacy in applying torques to the elbows of human
participants, while they conducted Activities of Daily Living (ADLs), where it was found that constant torques could be applied regardless of the presence of variable human motion. Tests were also conducted by integrating the SMC torque controller into an impedance-based control scheme and it was shown to reduce trajectory tracking error for both healthy participants and a participant diagnosed with cerebral palsy. Finally, a high-level gravity augmentation controller was developed that uses Denavit-Hartenberg parameters to estimate the component of gravity perpendicular to the forearm. With this information, the SMC torque controller can be commanded to exert a torque on the elbow that varies in response to orientation relative to the gravity vector, thus simulating the lifting of a weight. Experiments were conducted where participants were asked to lift a combination of physical and simulated weights, with surface-electromyography (sEMG) signals recorded as a measure of exertion. While the controller was able to accurately vary the torque on the elbow as the orientation relative to the gravity vector changed, it was not possible to draw statistically significant conclusions regarding the effect of the augmented gravity conditions on the participants’ physical exertion.

The concepts represented in this textbook are explored for the first time in assistive and rehabilitation robotics, which is the combination of physical,
cognitive, and social human-robot interaction to empower gait rehabilitation and assist human mobility. The aim is to consolidate the methodologies, modules, and technologies implemented in lower-limb exoskeletons, smart walkers, and social robots when human gait assistance and rehabilitation are the primary targets. This book presents the combination of emergent technologies in healthcare applications and robotics science, such as soft robotics, force control, novel sensing methods, brain-computer interfaces, serious games, automatic learning, and motion planning. From the clinical perspective, case studies are presented for testing and evaluating how those robots interact with humans, analyzing acceptance, perception, biomechanics factors, and physiological mechanisms of recovery during the robotic assistance or therapy. Interfacing Humans and Robots for Gait Assistance and Rehabilitation will enable undergraduate and graduate students of biomedical engineering, rehabilitation engineering, robotics, and health sciences to understand the clinical needs, technology, and science of human-robot interaction behind robotic devices for rehabilitation, and the evidence and implications related to the implementation of those devices in actual therapy and daily life applications.

Wearable robotic exoskeletons (WRE) represent a promising rehabilitation intervention for locomotor rehabilitation training that aligns with activity-based
neuroplasticity principles in terms of optimal sensory input, massed repetition, and proper kinematics. Thus far, most studies that investigated the effects of WRE have used WRE that provide full robotic assistance and fixed trajectory guidance to the lower extremity (L/E) to generate close-to-normal walking kinematics, usually at very slow speeds. Based on clinicians' feedback, current commercially-available WRE have additional control options to be able to integrate these devices into the recovery process of individuals who have maintained some ability to walk after an injury to the central nervous system. In this context, WRE now offer additional degrees of movements for the L/E to move freely and different strategies to assist or resist movement, particularly during the gait cycle's swing phase. However, the extent that these additional WRE control options affect L/E neuromuscular control during walking, typically characterized using muscle synergies (MSs), remains unknown. This thesis measures and compares MSs characteristics (i.e., number, temporal activation profile, and muscles contributing to a specific synergy [weightings]) during typical overground walking, with and without a WRE, in six different control modes, in able-bodied individuals (Articles #1 and #2) and individuals with incomplete spinal cord injury (iSCI; Article #3). Surface EMG of key L/E muscles were recorded while walking and used to extract MSs using a non-negative matrix
factorization algorithm. Cosine similarity and correlation coefficients characterized, grouped, and indicated similarities between MS characteristics. Results demonstrated that: 1) the number of MSs and MS temporal activation profiles in able-bodied individuals walking without WRE are modified by walking speed and that, as speed increased, specific MSs were fused or merged compared to MSs at slow speeds; 2) In able-bodied individuals walking with WRE, few WRE control modes maintained the typical MSs characteristics that were found during overground walking without WRE. Moreover, freeing the L/E swing trajectory imposed by the WRE best reproduced those MSs characteristics during overground walking without the WRE; and 3) After an iSCI, alterations to the number and the composition of MSs were observed during walking without WRE. However, of all WRE control modes that were investigated, only HASSIST (i.e., freeing WRE control over L/E swing trajectory while assisting the user's self-selected trajectory) reproduced the number and composition of MSs found in abled-bodied individuals during overground walking without WRE. Altogether, the results of this thesis demonstrated that different walking-related biomechanical demands (i.e., walking speed) and most of the WRE control modes can alter some MSs, and their characteristics, in able-bodied individuals. This research also confirmed that impaired muscle coordination, assessed via MSs, can adapt
when walking with a WRE set with specific control options (e.g., HASSIST). These MS adaptations mimicked typical MS characteristics extracted during overground walking. The evidence generated by this thesis will support the decision-making process when selecting specific L/E control options during WRE walking, allowing rehabilitation professionals to refine WRE locomotor training protocols.

The coupling of several areas of the medical field with recent advances in robotic systems has seen a paradigm shift in our approach to selected sectors of medical care, especially over the last decade. Rehabilitation medicine is one such area. The development of advanced robotic systems has ushered with it an exponential number of trials and experiments aimed at optimising restoration of quality of life to those who are physically debilitated. Despite these developments, there remains a paucity in the presentation of these advances in the form of a comprehensive tool. This book was written to present the most recent advances in rehabilitation robotics known to date from the perspective of some of the leading experts in the field and presents an interesting array of developments put into 33 comprehensive chapters. The chapters are presented in a way that the reader will get a seamless impression of the current concepts of optimal modes of both experimental and applicable roles of robotic devices.
Rehabilitation of the hands is critical for restoring independence in activities of daily living for individuals with upper extremity disabilities. Conventional therapies for hand rehabilitation have not shown significant improvement in hand function. Robotic exoskeletons have been developed to assist in therapy and there is initial evidence that such devices with force-control based strategies can help in effective rehabilitation of human limbs. However, to the best of our knowledge, none of the existing hand exoskeletons allow for accurate force or torque control. In this dissertation, we design and prototype a novel hand exoskeleton that has the following unique features: (i) Bowden-cable-based series elastic actuation allowing for bidirectional torque control of each joint individually, (ii) an underlying kinematic mechanism that is optimized to achieve large range of motion and (iii) a thumb module that allows for independent actuation of the four thumb joints. To control the developed hand exoskeleton for efficacious rehabilitation after a neuromuscular impairment such as stroke, we present two types of subject-specific assist-as-needed controllers. Learned force-field control is a novel control technique in which a neural-network-based model of the required torques given the joint angles for a specific subject is learned and then used to build a force-field to assist the joint motion of the subject to follow a trajectory designed in the joint-angle space. Adaptive assist-as-needed control, on the other hand,
estimates the coupled digit-exoskeleton system torque requirement of a subject using radial basis function (RBF) and on-the-y adapts the RBF magnitudes to provide a feed-forward assistance for improved trajectory tracking. Experiments with healthy human subjects showed that each controller has its own trade-offs and is suitable for a specific type of impairment. Finally, to promote and optimize motor (re)-learning, we present a framework for robot-assisted motor (re)-learning that provides subject-specific training by allowing for simultaneous adaptation of task, assistance and feedback based on the performance of the subject on the task. To train the subjects for dexterous manipulation, we present a torque-based task that requires subjects to dynamically regulate their joint torques. A pilot study carried out with healthy human subjects using the developed hand exoskeleton suggests that training under simultaneous adaptation of task, assistance and feedback can module challenge and affect their motor learning. There are 6.8 million people in the United States that have mobility disorders and must rely on the use of assistive devices to aid in locomotion \cite{kaye2000mobility}. The human body was designed for a particular bipedal locomotion pattern, and deviations from that method of locomotion can result in secondary injuries. Many of the current solutions for mobility disorders are
primitive, such as crutches or canes if possible and wheelchairs when not. In recent years, more intelligent, robotic systems have been developed to aid this population that needs assistance walking. Among these new robotic solutions are robotic exoskeletons. Robotic exoskeletons have become a more popular rehabilitation tool in recent years, particularly for those with spinal cord injury. There are currently three robotic exoskeletons with US Food and Drug Administration approval for clinical use. One barrier to wider adoption is the cost of these devices. To reduce cost, a more minimal design was developed at the Human Engineering and Robotics Laboratory at the University of California with only two actuators at the hips and a semi-passive locking mechanism at the knee. While this design can help reduce the weight and cost, it introduces additional complexity to the gait development due to the lack of actuation. The gait development strategies discussed in this paper are inspired by clinical gait data collected from healthy subjects. After all, the ultimate goal of an exoskeleton system as a rehabilitation device is to rehabilitate the pilot to the point that the patient's gait is restored to a natural walking pattern and the device is no longer necessary. Using clinical gait data and biomechanical studies, several models are developed for the design considered. A kinematic model was developed to better understand the angular constraints during both single stance and double
stance. A dynamic model was also developed that models the behaviour of the system for different phases of the gait. Finally all these models were linked together in a finite state machine to form a hybrid automaton. The finite state machine specifies the switching conditions for each state. One method for gait development is to design gaits that are tunable such that the gait practitioner can tune the gait to the pilot's comfort and rehabilitation needs. In this endeavour, a kinematic model is used to define the constraints of the double stance phase. The gaits are then generated using a quartic polynomial spline using the node parameters from the kinematic analysis. This method empowers the gait practitioner by using tuning parameters that they understand from gait rehabilitation literature. Another method for gait development is to use optimal gaits based on a hybrid automaton model of the system. The automaton implements three states or phases of the gait cycle including their associated dynamic models. Using this model, the gaits can be optimized for the torques necessary for these gaits under minimal input assumptions from the pilot in each of the phases. This optimization allows for a more detailed understanding of the system dynamics and an optimal gait given constraints of both the system and the gait cycle. Furthermore, the optimization method can be utilized as a gait generator that is tailored to each individual pilot, effectively reducing the workload.
of the gait practitioner. Neuro-robotics is one of the most multidisciplinary fields of the last decades, fusing information and knowledge from neuroscience, engineering and computer science. This book focuses on the results from the strategic alliance between Neuroscience and Robotics that help the scientific community to better understand the brain as well as design robotic devices and algorithms for interfacing humans and robots. The first part of the book introduces the idea of neuro-robotics, by presenting state-of-the-art bio-inspired devices. The second part of the book focuses on human-machine interfaces for performance augmentation, which can seen as augmentation of abilities of healthy subjects or assistance in case of the mobility impaired. The third part of the book focuses on the inverse problem, i.e. how we can use robotic devices that physically interact with the human body, in order (a) to understand human motor control and (b) to provide therapy to neurologically impaired people or people with disabilities. This book contains the papers of the 7th International Workshop on Medical and Service Robots (MESROB) that was planned to be held in Basel, Switzerland, in July 2020. Since the conference could not be held due to the worldwide Corona pandemic, the proceedings are published in this book and presentation of the accepted papers will be postponed to next year’s conference (MESROB 2021).
The main topics of the workshop include: design of medical devices, kinematics and dynamics for medical robotics, exoskeletons and prostheses, anthropomorphic hands, therapeutic robots and rehabilitation, cognitive robots, humanoid and service robots, assistive robots and elderly assistance, surgical robots, human-robot interfaces, haptic devices, medical treatments, medical lasers, and surgical planning and navigation. The contributions, which were selected by means of a rigorous international peer-review process, highlight numerous exciting ideas that will spur novel research directions and foster multidisciplinary collaboration among different specialists, demonstrating that medical and service robotics will drive the technological and societal change in the coming decades.

Stroke is one of the leading cause of physical disability in New Zealand and many suffer paralysis to their limbs. Unfortunately, fewer than 50% of survivors regaining their independence after 6 months particularly due to the inability to walk properly. One of the reason for the slow recovery of the gait function is that the current rehabilitation technique used is labour intensive and time consuming for the therapists and difficult to perform it effectively. In order to improve the gait rehabilitation process, robot assisted gait rehabilitation has gained much interest over the past years. There have been many prototypes and commercial products
for the robot assisted rehabilitation, but many had limitations. One of which is being bulky and had uncomfortable attachment for the patients. Improper attachment not only create uncomfortable feeling and pain for the patient but also causes human-robot axis misalignment which could lead to an injury with long term use. Another limitation is the lack of mechanical compliance which is the key to improve the safety of the operation and comfort for the patient. In order to address the limitations identified, a new robot orthosis, Human-inspired Robotic Exoskeleton (HuREx) was developed. HuREx consists of a compact exoskeleton parts custom fit for each individual patient manufactured using a rapid prototyping technique. Pneumatic Muscle Actuators (PMA) were used as they exhibit natural compliance and configured antagonistically. The design of the orthosis and the actuation mechanism made the system highly nonlinear. Therefore, an advanced model-based feedforward (FF) controller was designed and implemented to achieve the speed and accuracy of the response required. Many experiments were carried out to observe the performance and verify the proof of concept. The contributions of this research are the development of new robotic exoskeleton device designed to be light weight, comfortable and safe to use for gait rehabilitation for stroke patients, which were lacking in the existing devices. Another contribution is the establishment of new manufacturing technique that
allow custom exoskeleton component for each individual patient. Finally the development of advanced model-based FF controller that achieves fast and accurate tracking performance.

Wearable exoskeletons are electro-mechanical systems designed to assist, augment, or enhance motion and mobility in a variety of human motion applications and scenarios. The applications, ranging from providing power supplementation to assist the wearers to situations where human motion is resisted for exercising applications, cover a wide range of domains such as medical devices for patient rehabilitation training recovering from trauma, movement aids for disabled persons, personal care robots for providing daily living assistance, and reduction of physical burden in industrial and military applications. The development of effective and affordable wearable exoskeletons poses several design, control and modelling challenges to researchers and manufacturers. Novel technologies are therefore being developed in adaptive motion controllers, human-robot interaction control, biological sensors and actuators, materials and structures, etc. In this book, the editors and authors report recent advances and technology breakthroughs in exoskeleton developments. It will be of interest to engineers and researchers in academia and industry as well as manufacturing companies interested in developing new
markets in wearable exoskeleton robotics.

This book describes the development of portable, wearable, and highly customizable hand exoskeletons to aid patients suffering from hand disabilities. It presents an original approach for the design of human hand motion assistance devices that relies on (i) an optimization-based kinematic scaling procedure, which guarantees a significant adaptability to the user’s hands motion, and (ii) a topology optimization-based design methodology, which allowed the design of a lightweight, comfortable device with a high level of performance. The book covers the whole process of hand exoskeleton development, from establishing a new design strategy, to the construction and testing of hand exoskeleton prototypes, using additive manufacturing techniques. As such, it offers timely information to both researchers and engineers developing human motion assistance systems, especially wearable ones.

Present Your Research to the World! The World Congress 2009 on Medical Physics and Biomedical Engineering – the triennial scientific meeting of the IUPESM - is the world’s leading forum for presenting the results of current scientific work in health-related physics and technologies to an international audience. With more than 2,800 presentations it will be the biggest conference in the fields of Medical Physics and Biomedical Engineering in 2009! Medical physics, biomedical engineering and bioengineering have been driving forces of innovation and progress in medicine and healthcare over the past two decades. As new key technologies arise with significant potential to open new options in diagnostics and therapeutics, it is a multidisciplinary task to evaluate their benefit for medicine and healthcare.
with respect to the quality of performance and therapeutic output. Covering key aspects such as information and communication technologies, micro- and nanosystems, optics and biotechnology, the congress will serve as an inter- and multidisciplinary platform that brings together people from basic research, R&D, industry and medical application to discuss these issues. As a major event for science, medicine and technology the congress provides a comprehensive overview and in–depth, first-hand information on new developments, advanced technologies and current and future applications. With this Final Program we would like to give you an overview of the dimension of the congress and invite you to join us in Munich! Olaf Dössel Congress President Wolfgang C.

Robotic rehabilitation and assessment of the human upper-limb following stroke is currently limited in part by the inability of robots to replicate natural motion. In particular, motion of the shoulder girdle is usually neglected, despite the fact that the shoulder girdle is necessary to stabilize and orient the upper-limb during activities of daily living. Without direct control of the shoulder girdle, it is not possible to monitor or prevent a patient from making compensatory movements, which inhibits functional recovery, nor is there a means to properly regain strength and coordination. The more the robot is able to realistically mimic upper-limb motion, the more able the robot will be to assist with true functional movement training, which gives the patient the best chance of motor recovery. To address this issue, a new adjustable robotic exoskeleton called MEDARM is proposed for rehabilitation and assessment of the shoulder complex. MEDARM provides independent control of six degrees of freedom of the upper-limb: two at the sternoclavicular joint, three at the glenohumeral joint and one at the elbow. A key design feature of the new robot is an innovative curved track mechanism actuated by a cable-
drive transmission system. To facilitate a performance evaluation of this new mechanism, a planar version of MEDARM was designed. A full prototype of this planar robot was constructed and several fundamental metrics, including friction, inertia, and compliance, were used to test its mechanical performance. Additionally, the functionality of the robot was examined using preliminary data recorded during a standard reaching task, and by implementing some basic rehabilitation algorithms. This thesis describes the design of MEDARM and its planar counterpart in detail and the performance evaluation of the prototype is presented.

This book contains the selected papers of the Sixth International Workshop on Medical and Service Robots (MESROB 2018), held in Cassino, Italy, in 2018. The main topics of the workshop include: design of medical devices, kinematics and dynamics for medical robotics, exoskeletons and prostheses, anthropomorphic hands, therapeutic robots and rehabilitation, cognitive robots, humanoid and service robots, assistive robots and elderly assistance, surgical robots, human-robot interfaces, haptic devices, and medical treatments.

This book constitutes the refereed proceedings of the 13th Conference on Towards Autonomous Robotic Systems, TAROS 2012 and the 15th Robot World Congress, FIRA 2012, held as joint conference in Bristol, UK, in August 2012. The 36 revised full papers presented together with 25 extended abstracts were carefully reviewed and selected from 89 submissions. The papers cover various topics in the field of autonomous robotics.

The mobility of the lower extremities may be affected by neurological conditions such as stroke or spinal cord injury. When, motor function, gait coordination and muscle strength are impaired. Rehabilitation can improve the autonomy of legs movement in order to carry out everyday tasks such as walking or stand up, also known as a Sit-To-stand. Sit-To-Stand is a task that
requires considerable effort for those who have suffered a stroke or other type of injury. To perform the Sit-To-stand movement there are variables such as force, velocities, position angles, among others that can be modeled with the use of robotic exoskeletons. This project develops a Sit-To-Stand control strategy implemented in a robotic exoskeleton. This is based on previous work on the development of control strategies for the rehabilitation of the Sit-To-Stand. Where Sit-To-Stand transition phases combined with position and admittance control strategies are used. The objectives of this project are to find optimal values of the angles of the joints involved in the transition of the phases and to propose an improvement in the control strategy to assist people with lower extremities movements.

Rehabilitation Robotics gives an introduction and overview of all areas of rehabilitation robotics, perfect for anyone new to the field. It also summarizes available robot technologies and their application to different pathologies for skilled researchers and clinicians. The editors have been involved in the development and application of robotic devices for neurorehabilitation for more than 15 years. This experience using several commercial devices for robotic rehabilitation has enabled them to develop the know-how and expertise necessary to guide those seeking comprehensive understanding of this topic. Each chapter is written by an expert in the respective field, pulling in perspectives from both engineers and clinicians to present a multi-disciplinary view. The book targets the implementation of efficient robot strategies to facilitate the re-acquisition of motor skills. This technology incorporates the outcomes of behavioral studies on motor learning and its neural correlates into the design, implementation and validation of robot agents that behave as ‘optimal’ trainers, efficiently exploiting the structure and plasticity of the human sensorimotor systems. In this context,
human-robot interaction plays a paramount role, at both the physical and cognitive level, toward achieving a symbiotic interaction where the human body and the robot can benefit from each other’s dynamics. Provides a comprehensive review of recent developments in the area of rehabilitation robotics Includes information on both therapeutic and assistive robots Focuses on the state-of-the-art and representative advancements in the design, control, analysis, implementation and validation of rehabilitation robotic systems

Every year there are about 800,000 new stroke patients in the US, and many of them suffer from upper limb neuromuscular disabilities including but not limited to: weakness, spasticity and abnormal synergy. Patients usually have the potential to rehabilitate (to some extent) based on neuroplasticity, and physical therapy intervention helps accelerate the recovery. However, many patients could not afford the expensive physical therapy after the onset of stroke, and miss the opportunity to get recovered. Robot-assisted rehabilitation thus might be the solution, with the following unparalleled advantages: (1) 24/7 capability of human arm gravity compensation; (2) multi-joint movement coordination/correction, which could not be easily done by human physical therapists; (3) dual-arm training, either coupled in joint space or task space; (4) quantitative platform for giving instructions, providing assistance, exerting resistance, and collecting real-time data in kinematics, dynamics and biomechanics; (5) potential training protocol personalization; etc. However, in the rehabilitation robotics field, there are still many open problems. I am especially interested in: (1) compliant control, in high-dimensional multi-joint coordination condition; (2) assist-as-needed (AAN) control, in quantitative model-based approach and model-free approach; (3) dual-arm training, in both symmetric and asymmetric modes; (4) system integration, e.g., virtual reality (VR) serious
games and graphical user interfaces (GUIs) design and development. Our dual-arm/hand robotic exoskeleton system, EXO-UL8, is in its 4th generation, with seven (7) arm degrees-of-freedom (DOFs) and one (1) DOF hand gripper enabling hand opening and closing on each side. While developing features on this research platform, I contributed to the robotics research field in the following aspects: (1) I designed and developed a series of eighteen (18) serious VR games and GUIs that could be used for interactive post-stroke rehabilitation training. The VR environment, together with the exoskeleton robot, provides patients and physical therapists a quantitative rehabilitation training platform with capability in real-time human performance data collection and analysis. (2) To provide better compliant control, my colleagues and I proposed and implemented two new admittance controllers, based on the work done by previous research group alumni. Both the hyper parameter-based and Kalman Filter-based admittance controllers have satisfactory heuristic performance, and the latter is more promising in future adaptation. Unlike many other upper-limb exoskeletons, our current system utilizes force and torque (F/T) sensors and position encoders only, no surface electromyography (sEMG) signals are used. It brings convenience to practical use, as well as technical challenges. (3) To provide better AAN control, which is still not well understood in the academia, I worked out a redundant version of modified dynamic manipulability ellipsoid (DME) model to propose an Arm Postural Stability Index (APSI) to quantify the difficulty heterogeneity of the 3D Cartesian workspace. The theoretical framework could be used to teach the exoskeleton where and when to provide assistance, and to guide the virtual reality where to add new minimal challenges to stroke patients. To the best of my knowledge, it is also for the first time that human arm redundancy resolution was investigated when arm gravity is
considered. (4) For the first time, my colleagues and I have done a pilot study on asymmetric dual-arm training using the exoskeleton system on one (1) post-stroke patient. The exoskeleton on the healthy side could trigger assistance for that on the affected side, and validates that the current mechanism/control is eligible for asymmetric dual-arm training. (5) Other works of mine include: activities of daily living (ADLs) data visualization for VR game difficulty design; human arm synergy modeling; dual-arm manipulation taxonomy classification (on-going work).

This book addresses cutting-edge topics in robotics and related technologies for rehabilitation, covering basic concepts and providing the reader with the information they need to solve various practical problems. Intended as a reference guide to the application of robotics in rehabilitation, it covers e.g. musculoskeletal modelling, gait analysis, biomechanics, robotics modelling and simulation, sensors, wearable devices, and the Internet of Medical Things.

Current physical rehabilitation services for stroke utilize a manual hands-on approach with little to no application of modern technology. As a result, physiotherapy treatment is lacking in availability, is highly subjective and can only employ very basic exercises. Increasing efforts are being made in the research and development of rehabilitation robots to address these issues. This research explores the use of an exoskeleton robot for physical rehabilitation of the human upper limb. Analysis of past exoskeleton designs have revealed major limitations in these exoskeletons' shoulder mechanism which limit the range of motion and the movements that can be performed on the shoulder. To overcome the shortcomings of past mechanism designs, a novel 4R mechanism is proposed. However, there are a range of kinematic designs of the 4R mechanism that can meet the performance requirements of a shoulder exoskeleton.
To address this, a set of performance criteria are formulated and the NSGA II optimization algorithm is applied to identify an optimal design. The resulting 4R mechanism is capable of reaching the entire shoulder workspace with high performance and without mechanical interference. Performance comparisons with other shoulder mechanism designs confirm the optimized 4R mechanism has superior performance. The optimized 4R mechanism is then used to develop a 5 DOF active exoskeleton system for the shoulder and elbow joints. To maneuver the exoskeleton, an algorithm is developed to generate smooth point-to-point trajectories that are similar to the trajectories in normal human motion. This algorithm is further expanded into a trajectory planner which combines a sequence of point-to-point movements into a single smooth trajectory. To control the exoskeleton, two types of interactive control strategies are developed. Admittance control allows the user’s limb to move the exoskeleton by applying forces at the designated interfaces, during which the exoskeleton can assist or resist user movement. Impedance control involves actuation of the exoskeleton to move the user's limb through a specified trajectory with an artificial compliance. Experimental results on a healthy human subject demonstrate the diverse capabilities of the exoskeleton. The tools developed in this research open up new possibilities in the field of physical rehabilitation.

The volume set LNAI 11740 until LNAI 11745 constitutes the proceedings of the 12th International Conference on Intelligent Robotics and Applications, ICIRA 2019, held in Shenyang, China, in August 2019. The total of 378 full and 25 short papers presented in these proceedings was carefully reviewed and selected from 522 submissions. The papers are organized in topical sections as follows: Part I: collective and social robots; human biomechanics and human-centered robotics; robotics for cell manipulation and
characterization; field robots; compliant mechanisms; robotic grasping and manipulation with incomplete information and strong disturbance; human-centered robotics; development of high-performance joint drive for robots; modular robots and other mechatronic systems; compliant manipulation learning and control for lightweight robot. Part II: power-assisted system and control; bio-inspired wall climbing robot; underwater acoustic and optical signal processing for environmental cognition; piezoelectric actuators and micro-nano manipulations; robot vision and scene understanding; visual and motional learning in robotics; signal processing and underwater bionic robots; soft locomotion robot; teleoperation robot; autonomous control of unmanned aircraft systems. Part III: marine bio-inspired robotics and soft robotics: materials, mechanisms, modelling, and control; robot intelligence technologies and system integration; continuum mechanisms and robots; unmanned underwater vehicles; intelligent robots for environment detection or fine manipulation; parallel robotics; human-robot collaboration; swarm intelligence and multi-robot cooperation; adaptive and learning control system; wearable and assistive devices and robots for healthcare; nonlinear systems and control. Part IV: swarm intelligence unmanned system; computational intelligence inspired robot navigation and SLAM; fuzzy modelling for automation, control, and robotics; development of ultra-thin-film, flexible sensors, and tactile sensation; robotic technology for deep space exploration; wearable sensing based limb motor function rehabilitation; pattern recognition and machine learning; navigation/localization. Part V: robot legged locomotion; advanced measurement and machine vision system; man-machine interactions; fault detection, testing and diagnosis; estimation and identification; mobile robots and intelligent autonomous systems; robotic vision, recognition and reconstruction; robot mechanism and design. Part VI: robot motion analysis
and planning; robot design, development and control; medical robot; robot intelligence, learning and linguistics; motion control; computer integrated manufacturing; robot cooperation; virtual and augmented reality; education in mechatronics engineering; robotic drilling and sampling technology; automotive systems; mechatronics in energy systems; human-robot interaction.

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