Robotic Exoskeleton For Rehabilitation Of The Upper Limb

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

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).

The book reports on advanced topics in the areas of wearable robotics research and practice. It focuses on new technologies, including neural interfaces, soft wearable robots, sensors and actuators technologies, and discusses important regulatory challenges, as well as clinical and ethical issues. Based on the 4th International Symposium on Wearable Robotics, WeRob2018, held October 16-20, 2018, in Pisa, Italy, the book addresses a large audience of academics and professionals working in government, industry, and medical centers, and end-users alike. It provides them with specialized information and with a source of inspiration for new ideas and collaborations. It discusses exemplary case studies highlighting practical challenges related to the implementation of wearable robots in a number of fields. One of the focus is on clinical applications, which was encouraged by the colocation of WeRob2018 with the International Conference on Neurorehabilitation, INCR2018. Additional topics include space applications and assistive technologies in the industry. The book merges together the engineering, medical, ethical and political perspectives, thus offering a multidisciplinary, timely snapshot of the field of wearable technologies.

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.

A Topological Classification, Synthesis, Design and Manufacture of a Novel Hand Exoskeleton

Interfacing Humans and Robots for Gait Assistance and Rehabilitation

Interfacing Humans and Machines for Rehabilitation and Assistive Devices

Technology and Application

Converging Clinical and Engineering Research on Neurorehabilitation IV

Mechatronic Systems in Engineering

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.

Dr Jan Veneman is employed by Hocoma AG. All other Topic Editors declare no competing interests with regards to the Research Topic subject.

Current ROM (range of motion) rehabilitation is done by a therapist helping each patient individually, which can be done more effectively and efficiently by robotic devices. The goal of this work is to design and develop a robotic finger exoskeleton system as a CPM device for finger ROM rehabilitation. The research introduces a novel mechanism for finger exoskeleton design. The main concepts of the proposed design are having no interference and no translational forces on phalanges. The finger exoskeleton consists of 3 identical joint mechanisms which, for each, adopt a six-bar RCM as an equivalent revolute joint incorporating with 2 prismatic joints to form a close-loop mechanism with one anatomical joint. Cable and hose, known as Bowden cable transmission, is adopted to reduce burden from weight of driving modules. The prototype is driven by 3 motors moving flexion/extension of each joint individually, i.e. an MCP (metacarpophalangeal) joint, a PIP (proximal interphalangeal) joint and a DIP (distal interphalangeal) joint. The mechanism concept is preliminarily evaluated by simulation with the real anatomical joint trajectory. The simulation result shows that the mechanism can accommodate 2 adjacent phalanges at all configurations. The requirement based evaluation and the subjective test show that the device can move a subject's finger with quite natural and unimpeded motion along the predefined path. The device is successfully tested with 14 healthy subjects.

This book contains a comprehensive overview of all current uses of robots in rehabilitation. The underlying principles in each application are provided. This is followed by a critical review of the technology available, of the utilization protocols, and of user studies, outcomes, and clinical evidence, if existing. Ethical and social implications of robot use are also discussed. The reader will have an in depth view of rehabilitation robots, from principles to practice.

Robust Torque Control And Gravity Augmentation For A Wearable Robotic Exoskeleton Used In Rehabilitation Of Cerebral Palsy

Biomechatronic Exoskeletons

Proceedings of the 15th IFToMM World Congress on Mechanism and Machine Science

Advances in Theory and Practice

Tuning and Evaluation of a Control Strategy of an Exoskeleton for Sit-to-stand Motion

Development of Human-inspired Robotic Exoskeleton (HuREx) Designed for Lower-limb Gait Rehabilitation for Stroke Patients

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.

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-ToStand. 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.

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.

Advances in the material sciences, 3D printing technology, functional electrical stimulation, smart devices and apps, FES technology, sensors and microprocessor technologies, and more have lately transformed the field of orthotics, making the prescription of these devices more complex than ever before. Atlas of Orthoses and Assistive Devices, 5th Edition, brings you completely up to date with these changes, helping physiatrists, orthopaedic surgeons, prosthetists, orthotists, and other rehabilitative specialists work together to select the appropriate orthotic device for optimal results in every patient.

Rehabilitation Robotic Hand Exoskeletons

An Intelligent Pneumatic Muscle Actuated Exoskeleton for Robotic Gait Rehabilitation

Proceedings of the 2nd International Symposium on Wearable Robotics, WeRob2016, October 18-21, 2016, Segovia, Spain

Rehabilitation Robotics

DESIGN AND DEVELOPMENT OF A ROBOTIC FINGER EXOSKELETON FOR REHABILITATION

Proceedings of the 4th International Symposium on Wearable Robotics, WeRob2018, October 16-20, 2018, Pisa, Italy

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.

Exoskeletons in Rehabilitation RoboticsTremor SuppressionSpringer Science & Business Media

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

This book gathers the proceedings of the 15th IFToMM World Congress, which was held in Krakow, Poland, from June 30 to July 4, 2019. Having been organized every four years since 1965, the Congress represents the world's largest scientific event on mechanism and machine science (MMS). The contributions cover an extremely diverse range of topics, including biomechanical engineering, computational kinematics, design methodologies, dynamics of machinery, multibody dynamics, gearing and transmissions, history of MMS, linkage and mechanical controls, robotics and mechatronics, micro-mechanisms, reliability of machines and mechanisms, rotor dynamics, standardization of terminology, sustainable energy systems, transportation machinery, tribology and vibration. Selected by means of a rigorous international peer-review process, they highlight numerous exciting advances and ideas that will spur novel research directions and foster new multidisciplinary collaborations.

Proceedings of CLAIB-CNIB 2019, October 2-5, 2019, Cancún, México

Wearable Robotics

Proceedings of the 5th International Conference on Neurorehabilitation (ICNR2020), October 13–16, 2020

Robotic Assistive Technologies

Wearable Robotics: Challenges and Trends

A wearable robot is a mechatronic system that is designed around the shape and function of the human body, with segments and joints corresponding to those of the person it is externally coupled with. Teleoperation and power amplification were the first applications, but after recent technological advances the range of application fields has widened. Increasing recognition from the scientific community means that this technology is now employed in telemanipulation, man-amplification, neuromotor control research and rehabilitation, and to assist with impaired human motor control. Logical in structure and original in its global orientation, this volume gives a full overview of wearable robotics, providing the reader with a complete understanding of the key applications and technologies suitable for its development. The main topics are demonstrated through two detailed case studies; one on a lower limb active orthosis for a human leg, and one on a wearable robot that suppresses upper limb tremor. These examples highlight the difficulties and potentialities in this area of technology, illustrating how design decisions should be made based on these. As well as discussing the cognitive interaction between human and robot, this comprehensive text also covers: the mechanics of the wearable robot and it's biomechanical interaction with the user, including state-of-the-art technologies that enable sensory and motor interaction between human (biological) and wearable artificial (mechatronic) systems; the basis for bioinspiration and biomimetism, general rules for the development of biologically-inspired designs, and how these could serve recursively as biological models to explain biological systems; the study on the development of networks for wearable robotics. Wearable Robotics: Biomechatronic Exoskeletons will appeal to lecturers, senior undergraduate students, postgraduates and other researchers of medical, electrical and bio engineering who are interested in the area of assistive robotics. Active system developers in this sector of the engineering industry will also find it an informative and welcome resource.

The book reports on advanced topics in the areas of wearable robotics research and practice. It focuses on new technologies, including neural interfaces, soft wearable robots, sensors and actuators technologies, and discusses important regulatory challenges, as well as clinical and ethical issues. Based on the 2nd International Symposium on Wearable Robotics, WeRob2016, held October 18-21, 2016, in Segovia, Spain, the book addresses a large audience of academics and professionals working in government, industry, and medical centers, and end-users alike. It provides them with specialized information and with a source of inspiration for new ideas and collaborations. It discusses exemplary case studies highlighting practical challenges related to the implementation of wearable robots in a number of fields. One of the focus is on clinical applications, which was encouraged by the colocation of WeRob2016 with the International Conference on Neurorehabilitation, INCR2016. Additional topics include space applications and assistive technologies in the industry. The book merges together the engineering, medical, ethical and political perspectives, thus offering a multidisciplinary, timely snapshot of the field of wearable technologies.

Optical Fiber Sensors for the Next Generation of Rehabilitation Robotics presents development concepts and applications of optical fiber sensors made of compliant materials in rehabilitation robotics. The book provides methods for the instrumentation of novel compliant devices. It presents the development, characterization and application of optical fiber sensors in robotics, ranging from conventional robots with rigid structures to novel wearable systems with soft structures, including smart textiles and intelligent structures for healthcare. Readers can look to this book for help in designing robotic structures for different applications, including problem-solving tactics in soft robotics. This book will be a great resource for mechanical, electrical and electronics engineers and photonics and optical sensing engineers. Addresses optical fiber sensing solutions in wearable systems and soft robotics Presents developments—from foundational, to novel and future applications—of optical fiber sensors in the next generation of robotic devices Provides methods for the instrumentation of novel compliant devices

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 ap- plicable roles of robotic devices.

Design, Control and Applications

Systems and Applications

From Brain Machine Interfaces to Rehabilitation Robotics

Textbook of Neural Repair and Rehabilitation

Dual Reconfigurable Exoskeleton Hand System with Opposable Thumbs

Neuro-Robotics

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.
A preliminary study with 3 healthy subjects and 1 stroke survivor was conducted to provide information about linear acceleration, joint angle, and walking speeds during different ambulation tasks (e.g. over-ground walking, stair ascent and stair descent). Afterwards, a pilot study with 10 stoke subjects (5 male, 5 female, aged 58.1℗ł9.9 years old) was conducted. Each subject enrolled in this study received 20 sessions of 1-hour robotic gait training over a period of 4 weeks. All subjects wore the exoskeleton robot knee and were required to complete the following tasks: 2 sets of 10 minutes of continuous over-ground walking, 10 minutes of stair walking on a therapeutic staircase, and 2 sets of 20 times sit-to-stand movement. Gait recovery was assessed prior and post intervention by the following clinical outcome measures: Functional Ambulation Category (FAC), 6-minute walk test (6MWT) and 10-meter walk test (10MWT), Berg Balance Scale (BBS), Modified Ashworth Scale (MAS), and Fugl-Meyer Assessment for the lower extremity (FMA-LE). The results showed that patients participated in this study gained significant improvement in walking independency FAC (p9Þ0.025), reduced spasticity MAS (p9Þ0.037), and increased walking distance 6MWT (p9Þ0.005). Performance parameters during the training compared the mean walking distance, gait speed and number of climbed stairs in 10 minutes at baseline and last session. The results showed a statistically significant improvement in gait speed (p9Þ0.001), walking distance (p9Þ0.001) and number of walked stairs (p9Þ0.001) in 10 minutes. Subjects were able to maintain or further improve their lower limb functions in the 6-month follow-up, demonstrated by FAC (p9Þ0.034), MAS (p9Þ0.012), FMA-LE (p9Þ0.028), and 6MWT (p9Þ0.013). These results suggest the potential efficacy and feasibility of using the exoskeleton knee robot system in a clinical setting for lower limb rehabilitation post-stroke. However, a larger clinical trial is needed to verify the findings. In the future, we would like to explore the possibility of using the exoskeleton robot knee as a complement to task-specific training, rather than a stand-alone lower limb rehabilitation approach.
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).
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.
Human-Centric Robotics
Paraplegia
Advances in Mechanism and Machine Science
Design and Control of Robotic Systems for Upper Extremity Rehabilitation Following Stroke
Exoskeleton Robots for Rehabilitation and Healthcare Devices
Wearable Robots
This book provides state-of-the-art scientific and engineering research findings and developments in the area of service robotics and associated support technologies around the theme of human-centric robotics. The book contains peer reviewed articles presented at the CLAWAR 2017 conference. The book contains a strong stream of papers on robotic locomotion strategies and wearable robotics for assistance and rehabilitation. There is also a strong collection of papers on non-destructive inspection, underwater and UAV robotics to meet the growing emerging needs in various sectors of the society. Robot designs based on biological inspirations are also strongly featured.
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.
Volume 1 of the Textbook of Neural Repair and Rehabilitation covers the basic sciences relevant to recovery of function following injury to the nervous system.
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.
Principles and Practice
A Hand Exoskeleton with Series Elastic Actuation for Rehabilitation
Development of an Upper-body Robotic Rehabilitation Platform that Furthers Motor Recovery After Neuromuscular Injuries
Proceedings of the 1st Latin American Congress on Automation and Robotics, Panama City, Panama 2017
Novel Robotic Mechanisms for Upper-limb Rehabilitation and Assessment

Interactive Exoskeleton Robotic Knee System for Lower Limb Rehabilitation

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 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.

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.

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.

Advances in Automation and Robotics Research in Latin America

Optical Fiber Sensors for the Next Generation of Rehabilitation Robotics

Proceedings of the 20th International Conference on Clawar 2017

Tremor Suppression

Control and Dynamic Manipulability of a Dual-Arm/Hand Robotic Exoskeleton System (EXO-UL8) for Rehabilitation Training in Virtual Reality

Soft Robotics in Rehabilitation

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.

Between a global pandemic, aging population, and labor shortages, there is an ongoing spike in the demand for healthcare that cannot be satisfied with traditional methods and the human workforce. Robotic technology offers a solution to this dilemma; applying robotics to healthcare is an active area of research that has begun to be widely commercialized. Whilethere are many potential avenues for robots to improve health and well-being, my research has focused on two areas in particular: the development of robotic hand exoskeletons for rehabilitation and the enhancement of robotic surgery via automation and sensor development. Exoskeletons have been shown to be effective for use in physical rehabilitation of numerous conditions including spinal cord injury and stroke. However, at present, the huge majority of exoskeleton systems are constructed for only the arm (from shoulder to wrist), back, lower limbs, or hands. Few systems have been developed that combine both full arm and hand systems, and those that do generally have limited actuation of the hand. This is partly because the mechanical complexity of the hand requires rigid hand exoskeletons to be complex and bulky if they are able to control many of the important degrees of freedom. This bulk and complexity makes the hand systems challenging to successfully integrate onto the distal end of an arm exoskeleton. However, there is significant demand for combined arm and hand rehabilitation exoskeletons because many activities of daily living, that physical therapy focuses on retraining, require reaching and grasping together. The overarching goals of this research are to develop a novel hand exoskeleton, experimentally evaluate its capabilities in preparation for application to stroke rehabilitation, and integrate it on the existing EXO-UL8 and concurrently developed BLUE SABINO upper limb exoskeleton systems. Chapter 1 provides an introduction on hand exoskeleton systems, with a focus on those designed for rehabilitation. My work on hand exoskeletons started by inheriting a hand exoskeleton mechanical design from Brando Dimapasoc, a graduating Master's Degree student, that was developed as part of NSF Award #1532239. The system was intended to be attached to the EXO-UL8 and BLUE SABINO arm exoskeletons, had six active and six passive degrees of freedom, had three reconfigurable linkages to control the thumb and two groupings of fingers, used a bowden cable transmission system to enable remote placement of actuators, and was optimized to fit 90% of the general population. However, the design had only been tested as a 3D-printed prototype in a modified and simplified form. Further, the necessary electronic hardware (other than motor and sensor selection) and control software had not been started. Thus, the first stage of my research was to bring this first-generation hand exoskeleton to a functional state. This involved the mechanical assembly, the electrical design and assembly, and the software and control development of the system. Through testing, it was determined that a significant number of improvements must be made to the system in order for it to be suitable for use. Details of this work are contained in Chapter 2. With the lessons learned from development and testing of the first-generation hand exoskeleton, the next stage of my research involved the nearly complete redesign of the system in order to create the second-generation hand exoskeleton named the "Opposable-Thumb Hand Exoskeleton for Rehabilitation" or "OTHER Hand". As the name implies, the system is designed to control opposition/reposition of the thumb in addition to the flexion/extension of each digit. This is a notable feature, not only because of the importance of opposition/reposition in many grasping tasks, but also because only a handful of exoskeletons in the literature control this motion. The OTHER Hand shares a number of features with the first generation system, though the execution of each is different. It attaches to both the EXO-UL8 and BLUE SABINO arm exoskeletons, is actuated using a Bowden Cable transmission such that the motor pack can be located remotely, has three reconfigurable linkages to control the thumb and two groupings of fingers in order to enable nearly all grasps, and is optimized to fit 90% of the population. The system has six active and eight passive degrees of freedom per hand. Chapter 3 documents the design of the OTHER Hand. Due to the numerous novel design choices made for the OTHER Hand, combined with the mechanical complexity of the hand in general, and thumb in particular, it is not feasible to know with certainty the types of grasps that can be actuated in the exoskeleton for the wide range of hand shapes and sizes. As such, it is necessary to validate the design of the OTHER Hand through testing with a group of subjects. This was accomplished through adaptation of the Anthropomorphic Hand Assessment Protocol for use with an exoskeleton to test the ability of thirteen subjects to grasp and manipulate 25 objects of the Yale-Carnegie Mellon-Berkeley Object Set using eight prehensile grasps and two non-prehensile hand postures. Additionally, the OTHER Hand was mounted on the EXO-UL8, and both systems were manually controlled to verify compatibility, workspace, and ability to bi-manually grasp a sample object. Chapter 4 presents the testing protocol and results. While exoskeletons for rehabilitation is an increasingly popular research area, robotic surgical platforms already have widespread commercial use and profound effects on clinical outcomes. Classically, these systems are controlled directly by a surgeon at a console in the same or adjacent room. They can augment the senses and movement precision of the surgeon during open or laparoscopic surgery in order to enhance the surgeon's skills. However, surgeons commonly work exceptionally long hours in an environment where a single mistake can be fatal. Additionally, certain surgical subtasks are time-consuming, repetitive, and common to many different operations. Automating these subtasks has the potential to reduce the burden on surgeons while standardizing outcomes. Automation of one such subtask, soft tissue manipulation, is described in Chapter 5. Cataract surgery ranks among the most common operating room procedures worldwide. The aim of the surgery is to replace the clouded biological lens with a clear synthetic lens. Despite the prevalence, this operation is currently performed manually by a surgeon, and generally is fast, standardized, and safe. However, the human body is notably non-optimal for performing cataract surgery due to the transparency and fragility of the tissues of the eye. In order to remove the lens, it is standard to break it apart with phacoemulsification, use an irrigation/aspiration handpiece to aspirate the lens material, and then polish any remaining lens material from the capsular bag. Unfortunately, the back of this bag, the posterior capsule, is transparent, mere microns thin, and easily ruptured from contact, ultrasound energy, or pressure. Rupturing the posterior capsule causes the vitreous of the inner eye to spill out, resulting in critical failure of the surgery. Additional information about the location of the tool tip within the eye could be used to reduce the risk of such a failure. To this end, a proof-of-concept modification of a tool to add bioelectrical impedance sensing and tissue classification was developed and tested on porcine eyes. This research is summarized in Chapter 6

This book can serve as a reference resource for those very same design and control engineers who help connect their everyday experience in design with the control field of mechatronics. This book also consists of basic and main mechatronic system's laboratory applications for use in research and development departments in academia, government, and industry, and it can be *used as a reference source in university libraries. It can also be used as a resource for scholars interested in understanding and explaining the engineering design and control process and for engineering students studying within the traditional structure of most engineering departments and colleges. It is evident that there is an expansion of mechatronics laboratories and classes in the university environment worldwide.*

The book reports on advanced topics in the areas of neurorehabilitation research and practice. It focuses on new methods for interfacing the human nervous system with electronic and mechatronic systems to restore or compensate impaired neural functions. Importantly, the book merges different perspectives, such as the clinical, neurophysiological, and bioengineering ones, to promote, feed and encourage collaborations between clinicians, neuroscientists and engineers. Based on the 2020 International Conference on Neurorehabilitation (ICNR 2020) held online on October 13-16, 2020, this book covers various aspects of neurorehabilitation research and practice, including new insights into biomechanics, brain physiology, neuroplasticity, and brain damages and diseases, as well as innovative methods and technologies for studying and/or recovering brain function, from data mining to interface technologies and neuroprosthetics. In this way, it offers a concise, yet comprehensive reference guide to neurosurgeons, rehabilitation physicians, neurologists, and bioengineers. Moreover, by highlighting current challenges in understanding brain diseases as well as in the available technologies and their implementation, the book is also expected to foster new collaborations between the different groups, thus stimulating new ideas and research directions.

VIII Latin American Conference on Biomedical Engineering and XLII National Conference on Biomedical Engineering

Exoskeletons in Rehabilitation Robotics

Design, Control and Applications of

Atlas of Orthoses and Assistive Devices E-Book

Design, Control and Experimentation

Wearable Exoskeleton Systems

This book gathers the joint proceedings of the VIII Latin American Conference on Biomedical Engineering (CLAIB 2019) and the XLII National Conference on Biomedical Engineering (CNIB 2019). It reports on the latest findings and technological outcomes in the biomedical engineering field. Topics include: biomedical signal and image processing; biosensors, bioinstrumentation and micro-nanotechnologies; biomaterials and tissue engineering. Advances in biomechanics, biorobotics, neurorehabilitation, medical physics and clinical engineering are also discussed. A special emphasis is given to practice-oriented research and to the implementation of new technologies in clinical settings. The book provides academics and professionals with extensive knowledge on and a timely snapshot of cutting-edge research and developments in the field of biomedical engineering.

In the last decade, diverse research areas have developed novel approaches to overcome dysfunctions after a spinal cord injury (SCI). Even though motor restoration attracts the most clinical attention, sensory, autonomic, and mental health are also aspects fundamental to improving the quality of life of SCI patients. Over four sections of therapeutic, rehabilitation, and technological approaches, this book examines preclinical and clinical studies using mesenchymal stem cells and pharmacological or electrical stimulation strategies. Chapters also address the impact of paraplegia and associated loss of autonomic functions, including bowel and sexual dysfunction, as well as the convergence of new technologies aimed at providing postural support and enhancing mobility.

New Trends in Medical and Service Robotics