

Control Concept for a Mobile Robot Assisted Gait Rehabilitation System

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Siniša Slavnić

Abstract

Robotized gait rehabilitation systems (RGRS) are complex electromechanical-systems that are used to restore or improve gait pattern of patients through the number of rehabilitation iterations. The RGRS can be of different level of complexity, depending on the target group of patients. The complexity relates to: numbers of degrees of freedom (passive or actuated) that are allowed by the system, number of sensors and actuators, complexity of the mechanical structure, complexity of control algorithms and level of automation of the system. Systems with commercialization potential are usually simpler in design so that they are of moderate complexity. These systems are usually aimed for specific groups of patients. Moderate complexity of the system positively influences safety aspects of the system, reduces costs of development, acquisition and maintenance and improves system usability (no need for technically skilled personnel). The rehabilitation systems that could potentially cover larger groups of patients and that are nearly fully automatized tend to be very complex. Such systems are still under research and development and commercialization of such systems is a long-term goal.

The aim of this Thesis is to develop and implement methods to model, identify and control complex mobile gait rehabilitation robotic systems that are in direct physical contact with humans. The work presented was done in the frameworks of two projects, the RoboWalker and the CORBYS project in which a feasibility concept and a concept and a physical system are developed, respectively. Some of the introduced methods are novel. However, those which are not novel, as they were already reported in literature, were used in a novel application within this Thesis work. A cycle of research and development of a complex robotic system, in this case a novel mobile gait rehabilitation system is presented. Therefore, an approach in modelling of robotic system and human robot-interaction, an approach in modelling, identification and control of a novel push-pull cable actuated mobile rehabilitation system and an approach in robot software architecture decomposition and definition are described and results are presented.

The Thesis demonstrates how a complex robotic system can be effectively modelled using modern CAD based modelling tools and how such models can be integrated and used in novel robot control software architecture. Not only the CAD based modelling methods that were developed are presented, but also the dynamic models of the robot were programmatically implemented in order to design model-based controllers for the considered robotic system. The developed models were successfully evaluated on the gait rehabilitation robotic system CORBYS. Besides modelling aspects, the Thesis deals with identification and control of an

exoskeleton based gait rehabilitation system actuated by a novel push-pull control cable actuation system. After characterization of the actuation system, the control algorithms for the rehabilitation system were designed, implemented and evaluated while using the system with healthy subjects. The software architecture that was defined has been successfully used for control of the CORBYS robotic system.

The results presented in the Thesis show that the modelling stage during research and development of a new technical system can significantly contribute to evaluation of design concepts, to early definition and development of communication interfaces, to development of control algorithms, to generation of simulation data, and to evaluation of different algorithms (e.g. transfer functions). Also, results on control of the gait-rehabilitation system and development of a software control architecture using the state-of-the-art software frameworks and tools demonstrated how a complex system can be effectively deployed.

Kurzfassung

Robotergestützte Gangrehabilitationssysteme (RGRS) sind meist sehr komplexe, elektromechanische Systeme, die für die Wiederherstellung oder Verbesserung des Gangbildes bei Patienten mit Gangstörungen verwendet werden. Die Komplexität des RGRS ist abhängig von den vorhandenen, positiven oder aktiven, Freiheitsgraden des Systems. Hinzu kommt noch die Abhängigkeit von der Anzahl der verwendeten Sensoren und Aktoren, dem Automatisierungsgrad des Systems sowie der Komplexität der verwendeten Regelungs- und Mechanik-Strukturen. Die Systeme, die für die Vermarktung hergestellt werden, sind in der Regel von einfachem mechanischem sowie elektrischem Aufbau und gelten deshalb als Systeme mittlerer Komplexität. Solche Systeme sind normalerweise auf eine bestimmte Patientengruppe ausgerichtet. Die moderate Komplexität wirkt sich positiv auf die Sicherheitsaspekte des Systems aus und reduziert die Kosten für die Entwicklung und Wartung. Die Verwendbarkeit verbessert sich auch, da die Benutzung autodidaktisch ist. Die RGRS hingegen, die für (mehrere) Patientengruppen mit unterschiedlichen Gangstörungen geeignet wären, könnten hochautomatisiert werden, sind aber sehr komplex hinsichtlich der Entwicklung und potentiellen Anwendungen. Solche Systeme sind derzeit allerdings noch in der Forschungs- und Entwicklungsphase. Somit ist für die Einführung und Vermarktung solcher Systeme ein längerfristiger Zeitraum geplant.

Das Ziel der Dissertation ist die Entwicklung und Umsetzung von Methoden zur Modellierung, Identifizierung und Steuerung von komplexen, mobilen Gangrehabilitations-Robotersystemen, die im direkten physischen Kontakt mit Menschen stehen. Die Dissertationsarbeit ist im Rahmen von zwei Projekten durchgeführt worden. Während des ersten Projektes, dem sogenannten RoboWalker-Projekt, ist eine Machbarkeitsstudie durchgeführt worden. Im zweiten CORBYS-Projekt wurde anschließend zusätzlich ein physikalisches System entwickelt. Die vorliegende Dissertation führt einige neue Methoden zur Modellierung und Regelung von Robotersystemen ein. Einige davon, die auch in der Literatur beschrieben sind, wurden in der Anwendung umgesetzt/implementiert. Ein Forschungs- und Entwicklungsprozess eines komplexen Robotersystems wird vorgestellt, einschließlich der Ansätze zur Modellierung von Robotersystemen und der Mensch-Roboter-Interaktion. Im Weiteren werden die Modellierung, Identifikation und Steuerung eines von einem neuartigen Druck-Zugkabel angetriebenen, mobilen Rehabilitationssystems sowie die Strukturierung und Definition der Roboter-Softwarearchitektur behandelt.

Diese Dissertation zeigt auch, wie ein komplexes Robotersystem mit Hilfe moderner, CAD-basierter Modellierungstools effektiv entwickelt werden kann und

wie solche Modelle in einer neuartigen Roboter-Softwarearchitektur integriert werden können. Die Methoden für CAD-basierte Modellierung und Erstellung von dynamischen Robotermodellen, die für modellbasierte Regelung geeignet sind, werden vorgestellt. Die entwickelten Modelle sind erfolgreich auf das Gangrehabilitations-Robotersystem CORBYS angewendet worden. Neben den Modellierungsaspekten befasst sich die Dissertation auch mit der Identifizierung und Regelung eines Exoskeletts, dass durch ein neuartiges Druck-Zugkabel-Antriebssystem bewegt wird. Nach der Identifizierung des Antriebssystems wurden die Regelalgorithmen für das Rehabilitationssystem entwickelt und umgesetzt. Anschließend wurde das System in Form von Versuchen an gesunden Testpersonen erprobt und bewertet. Die Softwarearchitektur, die definiert worden ist, wurde erfolgreich für die Steuerung des CORBYS-Robotersystems implementiert.

Die in der Dissertation dargestellten Ergebnisse zeigen, dass die Modellierungsphase während der Forschung und Entwicklung eines neuen technischen Systems schon frühzeitig sowohl zur Auswertung der Designkonzepte als auch zur Definition und Entwicklung von Kommunikationsschnittstellen eingesetzt werden kann. Weiterhin wird durch die Modellierungsphase erreicht, dass sich die Entwicklung von Steueralgorithmen für die Erzeugung von Simulationsdaten und die Bewertung verschiedener Algorithmen beispielsweise hinsichtlich deren Übertragungsfunktionen vereinfachen können. Die Auswertung der Ergebnisse der Regelung des Gangrehabilitations-Systems zeigen auf, wie solch ein komplexes System effektiv eingesetzt werden kann. Dabei wurde eine Software-Steuerungsarchitektur mit „State-of-the-Art“-Softwareframeworks und -Tools eingesetzt.

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