Assistive Control Concepts for Pneumatic Soft Robotic Rehabilitation Devices

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Dipl.-Ing. André Wilkening

Primary Supervisor:	Prof. Dr.-Ing. Axel Gräser
Secondary Supervisor:	Prof. Dr.-Ing. Kirsten Tracht
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Bremen, February 2016. André Wilkening

Abstract

Robot-assisted rehabilitation becomes increasingly important in neurorehabilitation since the late 90s, because treatment times of physiotherapists are limited and expensive. In orthopedic rehabilitation, for more than 30 years, continuous passive motion (CPM) machines are used to support therapists, but these simple and inexpensive devices are only guiding the patient's motion and ignoring their own effort.

However, the inherent stiffness of position controlled electromechanically driven devices limits the effect to relearn lost motor functions in neurological as well as to enhance muscle building in orthopedic rehabilitation. In order to improve robot-assisted neurorehabilitation, different patient-cooperative and assist-as-needed controllers have been developed, taken into account the patient's effort and abilities using force/torque sensors. Different studies indicate the effectiveness of interactive robot-assisted therapy in neurorehabilitation after stroke and spinal cord injury, but the developed rehabilitation robots with conventional electromechanical drives are mostly complex, expensive and often voluminous. Probably due to this, only a few of these devices are marketed and are used mostly in medical centers.

In general, soft-actuators with inherent compliance, like pneumatic muscles, are very suited to work in the direct environment of humans. Novel soft fluidic actuators based on rotary elastic chambers (REC-actuators) provide the basis for the development of compact, modular and cost-effective soft robotic rehabilitation devices (SRRDs) interacting with humans.

In this thesis, several assistive control concepts have been developed for SRRDs based on REC-actuators, that take into account the specific actuator characteristics as well as the patient's individual behavior, effort and abilities without using force/torque sensors. To identify unknown mass parameters of SRRDs as well as of human's extremities, that are required for concept realization, an approach to estimate mass parameters based on a minimal number of experimental measurements has been developed. Algorithms are first investigated in simulation and afterwards verified using several prototypes of assistive SRRDs with healthy subjects as well as exemplarily with patients in orthopedic rehabilitation.

The key result of this thesis is that using fluidic soft-actuators, the assistive control concepts can be realized without using force/torque sensors. Based on existing experimental data, it can be expected that assistive controlled cost-effective and compact SRRDs have the potential to improve the effectiveness of neurological and orthopedic rehabilitation.

Kurzfassung

Roboterunterstützte Rehabilitation ist seit Anfang der 90er Jahre in der neurologischen Rehabilitation immer wichtiger geworden, da die Behandlungszeiten von Physiotherapeuten begrenzt und kostspielig sind. In der orthopädischen Rehabilitation werden seit mehr als 30 Jahren „continuous passive motion“ (CPM) Bewegungsschienen eingesetzt, um Therapeuten zu unterstützen, wobei diese einfachen und kostengünstigen Geräte nur die Bewegung von Patienten führen und ihre eigene Kraft ignorieren.

Allerdings begrenzt die innewohnende Steifigkeit der positionsgeregelten elektromechanisch angetriebenen Geräte den Effekt motorische Fähigkeiten erneut zu erlernen sowie den Muskelaufbau zu begünstigen. Um die roboterunterstützte Therapie in der neurologischen Rehabilitation zu verbessern, wurden unterschiedliche „patient-cooperative“ und „assist-as-needed“ Regelungen unter der Verwendung von Kraft- und Drehmomentsensoren entwickelt. Unterschiedliche Studien weisen auf die Effektivität von interaktiver roboterunterstützter Therapie nach Schlaganfällen und Rückenmarksverletzungen hin, allerdings sind die entwickelten Rehabilitationsroboter oft komplex, kostspielig und voluminös. Wahrscheinlich deshalb sind nur wenige dieser Geräte vermarktet und finden ihren Einsatz hauptsächlich in Kliniken.

Generell sind Soft-Antriebe mit inhärenter Nachgiebigkeit, wie pneumatische Muskeln, sehr gut geeignet, um im direkten Umfeld von Menschen zu arbeiten. Neuartige fluidische Soft-Antriebe mit elastischen Rotationskammern (REC-Antriebe) bieten die Basis für die Entwicklung von kompakten und kosteneffektiven soften Rehabilitationsrobotergeräten (SRRDs).

In dieser Arbeit wurden unterschiedliche assistive Regelungskonzepte für SRRDs entwickelt, die die speziellen Antriebscharakteristiken sowie das individuelle Verhalten von Patienten ohne die Verwendung von Kraft- und Drehmomentsensoren berücksichtigen. Um die für die Konzeptrealisierung erforderlichen unbekannten Massenparameter der SRRDs und der menschlichen Extremitäten zu identifizieren, wurde eine Methode zur Schätzung von Massenparametern mit einer minimalen Anzahl von experimentellen Messungen entwickelt. Die Algorithmen wurden zuerst in der Simulation und anschließend mit unterschiedlichen SRRDs und unbeeinträchtigten Probanden sowie beispielhaft mit orthopädischen Patienten untersucht.

Das Hauptergebnis dieser Arbeit ist, dass durch die Verwendung von fluidischen Soft-Antrieben die assistiven Regelungskonzepte ohne den Einsatz von kostspieligen Kraft- und Drehmomentsensoren realisiert werden können. Basierend auf den vorhandenen experimentellen Daten kann erwartet werden, dass assistive SRRDs das Potential aufweisen, die Effektivität der neurologischen und orthopädischen Rehabilitation zu verbessern.

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