Design and control of a knee exoskeleton powered by pleated pneumatic artificial muscles for robot-assisted gait rehabilitation

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Powered exoskeletons for humans have long triggered the imagination. Merely two decades ago a role was envisaged for these devices in the assistance and rehabilitation of the impaired, and the number of powered exoskeletons for the upper and lower limbs has steadily grown ever since. Gait rehabilitation exoskeletons in particular were introduced to assist in the intensive and repetitive gait training of persons with gait impairment due to spinal cord injury, stroke and other neurological disorders. In this way physiotherapists could be relieved from the strenuous effort involved in gait assistance and patients could benefit from intensive and quantifiable assistive training.

Rehabilitation robots are now entering rehabilitation practice, and recent advances in rehabilitation technology and science are seeking to improve the effectiveness of robot-assisted training. “Assistance-as-needed”, a concept that has gained much attention in recent years, aims at making the robotic assistance adaptable, task specific and tailored to the needs of the individual patient. In this human-centered approach physical human-robot interaction plays a key role, and from an engineering viewpoint it requires wearable exoskeleton designs, high performance actuators and dedicated control strategies.

In this dissertation several design and control concepts related to the use of pleated pneumatic artificial muscles to power a gait rehabilitation exoskeleton are investigated in view of safe and adaptable human-robot interaction. The high force-to-weight ratio and the built-in adaptable compliance of this specific actuator suit the demand for high assistive torques and compliant robotic behaviour. A dedicated assistive controller is needed that benefits from these features, while ensuring safety and adaptability of interaction. KNEXO, a powered knee exoskeleton, has been developed and the proposed concepts were evaluated in robot-assisted walking experiments with unimpaired subjects, a stroke patient and a multiple sclerosis patient.