Interaction Control of an Assistive Sit-to-Stand Trainer with Multi-Axial Pneumatic Soft-Actuators

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Introduction

This paper presents the final realization of a supportive robotic device for repetitive sit-to-stand (StS) training for stroke victims as well as for the elderly persons. The sit-to-stand process belongs to the activities of daily living (ADL) and is conducted several hundred times per day by the average healthy human. Regaining the ability to rise thus is an important aspect for the quality of life and self-dependence and has to be trained – after stroke as well as for the elderly.
The motivation is to develop supportive robots and devices to relieve physiotherapists, such that the robot takes over the physical demanding tasks, i.e. lifting a patient or moving the limbs, while the physiotherapist is able to focus on cognitive interaction and encouragement.

Methods

The sit-to-stand trainer consists of two leg orthoses (exoskeletons) which are attached to the lower extremities of a human. The exoskeletons are each equipped with actuators at ankle and knee for joint movements in the sagittal plane. An important property of robots required for safe and human-like interaction is compliant actuation combined with light-weight design. This requirement can be fulfilled by fluidic soft-actuators like pneumatic muscles due to inherent passive compliance and high power to weight ratio. The applied soft-actuators with rotary elastic chambers (REC) belong to the class of antagonistically arranged pneumatic muscles, allowing modular device assembly. The one-axis ankle joint actuator provides movements from 0° (extension) to 45° (flexion) while the actuator at the multi-axial knee joint is constructed as a series connection of two identical units to achieve a range of motion from 0° (extension) to 90° (flexion) with non-fixed axis of rotation. The inherent compliant pneumatic rotary soft-actuators provide safe and gentle interaction, but are challenging to control due to strong nonlinear behaviour and require appropriate control strategies (s. [1] for more details).

Results

The control concept especially aims at supportive repetitive StS training for stroke survivors suffering of hemiplegia with paralysis in one half of the body and is based on a master-slave position controller that transfers movements from the fit to the affected leg to stabilize the knee joint. Additional support for rising is generated automatically by means of a virtual position error or can be optionally adjusted manually by a hand-regulator. The development of alternative control concepts based on admittance control and force fields is in progress that should be applied for motor impaired persons with two affected legs or elderly.
The robot control unit is based on a modular PC-104 system placed in a compact housing. For intuitive operation a graphical user interface (GUI) was implemented in C++ with the Qt-framework. The GUI runs on a standard windows tablet-PC with touchscreen and consists of two menus related to basic settings and actual therapy respectively, where visual feedback and instructions are given. This offers a low-cost, versatile and “state of the art” replacement for the laboratory development environment.
The GUI has a setting menu and a therapy menu (see Fig. 1). The physiotherapist use the setting menu to adjust the basic torque support individual for stand up and sit down, saving the inclination angle for the support and select the affected side. The therapy menu is displayed during the therapy and contains the visual feedback for the patient. The feedback consist of two bars, the first bar shows the inclination angle and indicate the optimal angle with colored areas. The second bar shows the actual support torque.

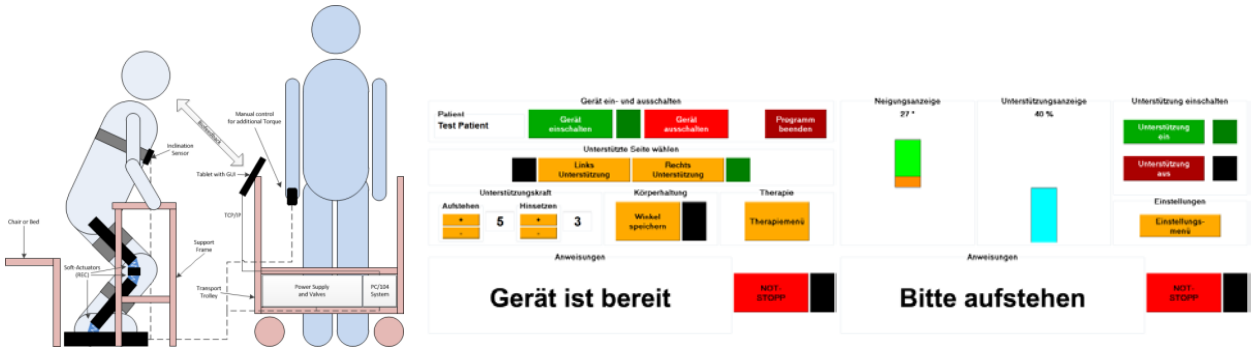

Fig. 1: Sit-to-Stand trainer: Conceptual design and Graphical User Interface with settings and therapy menu.

The controller program offers to create and reuse user names and stores motion profiles as well as operating parameters, i.e. actuator pressures and angles in data sets on the local hard drive. These data enables to evaluate the therapy progress subsequently.

Conclusion

After developing the control algorithm with a test-bed and trying it with healthy subjects, an enhanced prototype was designed. Besides improved mechanical adjusters for speeding-up the limb attachment, the controller now offers automatic support-torque generation with different levels of assistance for rising and sitting down. The prototype was tested by volunteers, who were still affected by residual symptoms after the stroke incident several years before, and approved positively. Currently the StS-trainer is tested for acute stroke therapy at the neurological clinic (stroke unit) at the Bürgerhospital of Klinikum Stuttgart, Germany (medical director Prof. Dr. Hansjörg Bäzner).

Fig. 2: Tests at the clinic for neurological treatment (stroke unit) at Klinikum Stuttgart, Bürgerhospital, Germany.

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References

[1] D. Baiden, O. Ivlev: Human-Robot-Interaction Control for Orthoses with Pneumatic Soft-Actuators – Concept and Initial Trails, 2013 IEEE International Conference on Rehabilitation Robotics (ICORR)

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