Doctoral Thesis

Robot assisted arm rehabilitation
cooperative control strategies for activities of daily living

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Publication Date: 2012

Permanent Link: https://doi.org/10.3929/ethz-a-007333148

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Robot Assisted Arm Rehabilitation: Cooperative Control Strategies for Activities of Daily Living

A dissertation submitted to

ETH ZURICH

for the degree of

Doctor of Sciences

presented by

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2012
Abstract

Patients after stroke receive arm therapy to restore motor function of their impaired limb. Plasticity of the non-affected brain areas allows to relearn lost motor functions. According to current knowledge, the training should be of long duration, intensive, task-orientated, repetitive and challenge the patient to actively participate. Robot-assisted arm rehabilitation has become a common tool to address those key elements. Similar to the therapist in conventional physiotherapy, robotic devices can support a movement when the patient is not able to do it by himself. Additionally, the robot can measure biomechanical limb functions and assess performance and progress of the therapy. Several studies have shown that robot-assisted training of motivating games has positive effects on therapy outcome, but that the transfer of learned skills to daily life activities is rather limited. Another challenge for rehabilitation robots is to allow active participation of the patient and provide only the required amount of assistance. Most control strategies do not take the individual needs of a patient into account and tend to force the patient to follow predefined movements. This strongly limits the capabilities of the patient to actively participate in the training.

The focus of this dissertation is to develop a human-centered control architecture that maximizes active participation of the patients and enables the training of activities of daily living (ADL) with the robot.

Such a rehabilitation system can be broken down into three main components: robot, tasks and control. The robot interacts with the patient and can support the joints required to execute functional tasks. These have to be selected carefully and presented in a motivating way. Key component of the therapy system is the patient-cooperative controller that not only assists the patients according to the principles of motor learning and motor rehabilitation, but also learns from the patients, detects their movement intention and provides appropriate feedback.

ARMin is an arm rehabilitation robot developed at ETH Zurich. The device was improved and extended to seven active degrees of freedom including opening and closing of the hand. Instrumented handles allow to measure the interaction of the hand with the robot. Kinematics and dynamics of the robot have been calculated. A safety concept to
enable a safe operation of the device has been implemented. The evaluation focused on
the developed hand module, the inverse dynamic model and the safety concept. Forces
in the hand can be measured with a high resolution and accuracy. The inverse dynamic
model the robot accurately relates measured kinematics to required torques and can be
used for online compensation of ARMin. Safe operation of the prototype allows to apply
the device in clinical practice.

Activities of daily living have been selected with the assistance of therapists and
patients and were implemented in a virtual environment. Virtual tasks were designed
to motivate the patient and facilitate motor rehabilitation with repetitive tasks. A
state-of-the-art game engine was chosen to create realistic behavior of virtual objects.
State machines control the flow of action and send information about the task to the
control system. Haptic rendering was added to increase the level of realism of the virtual
world. Evaluation of the virtual task showed that they fulfill the requirements of motor
rehabilitation. It was possible to render virtual objects in a realistic way and improve
the sensation of the virtual world.

Control is the last component of a rehabilitation system, which can also be seen as
intelligence of the robot. To meet the requirements derived from neuroscience a con-
trol strategy should include algorithms to detect the movement intention and methods
to asses, evaluate and display performance. A patient-cooperative controller, the path
controller, provides assistance during the training of ADL tasks, but allows spatial and
temporal freedom. Extended with a learning algorithm and movement intention detec-
tion, the controller could reduce the amount of support required by maximally involving
the patient. The clinical feasibility could be shown with several stroke patients.

The assessment of patient performance is the last part addressed. Assessments can
be used to optimally setup the controller or task for the patient. A method to estimate
the patient’s contribution to a robot-assisted movement was developed to encourage but
also control the active participation. The method provides accurate and comprehensive
values, which is important for the patient but also for the therapist to track the progress
of the patient.

The complete rehabilitation system can be used to train activities of daily living
with ARMin. Patients were very motivated to train and could actively participate and
perform ADLs. Assessment of the patient either before training or during training
helped to optimally setup control parameters and might be very important to motivate
the patient. For future developments, a closer link between robotic assessments and
training is desirable and could help to optimize the therapy for the individual patient.
Zusammenfassung


Der Fokus dieser Dissertation ist es eine Regelungsarchitektur zu entwerfen, bei der der Mensch im Mittelpunkt steht. Aktive Teilnahme des Patienten soll gefördert und das Training von alltagsnahen Aktivitäten ermöglicht werden.


