8. Workshop Automatisierungstechnische Verfahren für die Medizin vom 20.-21. März 2009 in Berlin

„Path Control – A Strategy for Patient-Cooperative Arm Rehabilitation“

Marco Guidali, Alexander Duschau-Wicke, Melanie Büchel, Andreas Brunschweiler, Robert Riener
Sensory-Motor Systems Lab, Institute of Robotics and Intelligent Systems (IRIS), ETH Zurich, Switzerland
E-Mail: marco.guidali@mavt.ethz.ch

Robert Riener
Spinal Cord Injury Center, University Hospital Balgrist, Zurich, Switzerland

Tobias Nef
Center for Applied Biomechanics and Rehabilitation Research, National Rehabilitation Hospital, Washington, USA

Alexander Duschau-Wicke
Hocoma AG, Volketswil, Switzerland

Band: Fortschritt-Bericht VDI Reihe 17 Nr. 274 „Automatisierungstechnische Verfahren für die Medizin, 8. Workshop, Tagungsband“
Editors: Thomas Schauer, Henning Schmidt, Marc Kraft
ISBN: 978-3-18-327417-8
Pages: 5-6

Path Control – A Strategy for Patient-Cooperative Arm Rehabilitation

Marco Guidali[1], Alexander Duschau-Wicke[1,4,] Melanie Büchel[1], Andreas Brunschweiler[1], Tobias Nef[3], Robert Riener[1,2]

[1]Sensory-Motor Systems Lab, Institute of Robotics and Intelligent Systems (IRIS), ETH Zurich, Switzerland
[2]Spinal Cord Injury Center, Balgrist University Hospital, Zurich, Switzerland
[3]Center for Applied Biomechanics and Rehabilitation Research, National Rehabilitation Hospital, Washington, USA
[4]Hocoma AG, Volketswil, Switzerland

Contact: marco.guidali@mavt.ethz.ch

Introduction

Task-orientated repetitive movement can improve movement performance in patients with neurological lesions. The application of robots such as ARMin can serve to assist, enhance and evaluate rehabilitations of movements.

Audiovisual displays in combination with the robots are often used to provide task-orientated training and motivate the patient. Besides simple games for the training of single joint movements, more functional movements should be trained to have a better transfer to daily life [1]

With the latest version of ARMin we are able to train activities of daily living (ADL) tasks. ARMin III has seven actuated degrees of freedom (DOF); including a one DOF hand module. To support the movements of the patient during ADL training a dynamic trajectory planner and a suitable control strategy are required.

Motivated by the *path control algorithm* [2], which was developed for robot-aided gait training, we present a patient-cooperative *path control* strategy for ARMin. The strategy allows patients to move freely within the borders of a virtual tunnel around the spatial path of a desired trajectory. Additionally, an adjustable force field along the path can help the patient to reach the target. The reference trajectory to build the tunnel is based on the minimum angular jerk method [3].

To evaluate the control strategy, a healthy subject had to perform several ADL task with ARMin.

Methods

Trajectory Planner

One approach to generate trajectories that are suitable for reaching movements during ADL tasks is the minimum angular jerk method [3]. This method requires the target position in joint space to build the trajectory. Given a certain hand position in task space the position of the elbow is not clearly determined. Therefore, the orientation of the hand is used as an additional constraint to reduce this redundancy problem to only one solution. The hand orientation can be described as a function of upper and lower arm rotation [4] and is determined by the task, e.g., the goal is to grasp a glass, then the hand orientation is vertical. Instead of a target position we define for each task a target pose (p_{target}) consisting of the target position in task space and the hand orientation. This allows the trajectory planner to calculate the target joint angles for each possible task within the workspace of the robot.

Path Control

The path control algorithm for ARMin is based on the algorithm presented in [2]. The idea is to build a virtual tunnel between start and end position in space. The calculated reference trajectory is used as the center of this tunnel. A radius defines the diameter of the tunnel. The walls of the tunnel are implemented with a soft impedance controller that pushes the hand back to the tunnel. To calculate the direction of this force, the smallest Euclidean distance between the current end-effector position and the reference trajectory is used.

Inside the tunnel patients can move freely and choose their own timing to reach the target. To allow free movements of the arm, gravity and friction of the robot should be well compensated. With position sensors and a model of ARMin we are able to compensate the weight of the robot and the dynamic friction (τ_{comp}).

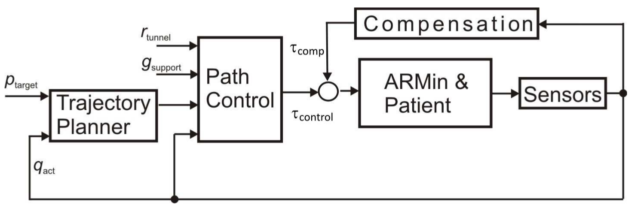

Fig. 1: Block diagram of path controller

To support the patients while they move inside the tunnel, a force field can be added. The direction of the force field is tangential to the reference trajectory.

To adapt the amount of freedom and the support to the individual patients' capabilities, the radius of the tunnel (r_{tunnel}) and the magnitude of the force field ($g_{support}$) can be changed (Fig. 1).

ADL

To test the path controller the system was combined with a virtual environment. A bathroom scenario, where the subject can perform several ADL tasks, was chosen (Fig. 2). The whole task consist of six reaching movements: picking up the toothbrush from the shelf and laying it down in the other hand, fetching the toothpaste and bringing it to the toothbrush, laying the toothpaste back on the shelf and reaching for the water tap. The virtual arm is synchronized with the joint angles of ARMin.

Fig. 2: Bathroom scenario

The virtual environment controls the task sequence. Once a task is achieved, the next task is started by sending the next target position in task space and the next desired hand orientation to the controller.

Results

The virtual tunnel expands from the starting hand position to the target position (Fig. 3). The solid point in the middle of the hand is used as end-effector position.

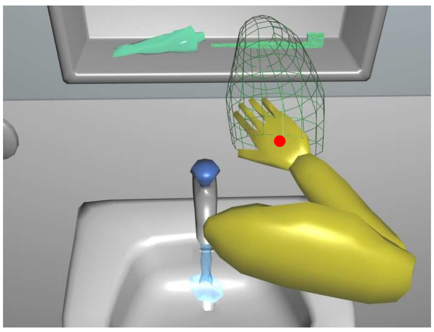

Fig. 3 Visualization of the virtual tunnel

Preliminary tests showed that for a soft tunnel wall an impedance of $K = 250$ N/m is appropriate. The radius r_{tunnel} was set to 10 cm. During the movement's position, velocity and applied support force were recorded. The difference between an active and a passive subject performing the same ADL task is shown in Fig 4. The force field magnitude $g_{support}$ was adjusted between 0 N for active and 10 N for completely passive movements.

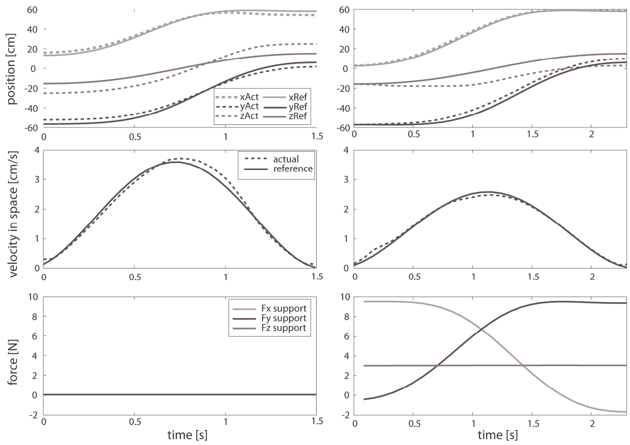

Fig. 4: Position, velocity in space and supporting force gradients of an active (left) and a passive subject (right)

Discussion & Outlook

The first evaluation showed that the basic concept is feasible. The subject was able to complete the ADL tasks and stated that the force field inside the tunnel helped to reach the target with less effort.

Because the subject's arm weight is not compensated passive movements were always performed at the bottom of the virtual tunnel and the amount of support has to be increased until the task can be achieved without any effort. Therefore an adaptive support estimation algorithm has to be developed to automate the training.

Furthermore the system will be tested with patients to show that a clinical application is possible.

Conclusion

The test with a healthy subject showed that even if acting completely passive the desired ADL task could be accomplished. With the adjustable force field the path control algorithm is a meaningful strategy to support patients during ADL training.

References

[1] B. French, L.H. Thomas, MJ Leathley, CJ Sutton, J. McAdam, A. Forster, P. Langhorne, CIM Price, A. Walker, CL Watkins: "Repetitive task training for improving functional ability after stroke (Review)", The Cochrane Collaboration, 2008

[2] A. Duschau-Wicke, J. v. Zitzewitz, M. Wellner, A. König, L. Lüneberger, R. Riener : „Path Control – A Strategy for Patient-Cooperative Training of Gait Timing, *Automed Workshop, 2007*

[3] M. Kawato, Y. Maeda, Y. Uno, R. Suzuki: "Trajectory Formation of Arm Movement by Cascade Neural Network Model Based on Minimum Torque-Change Criterion", *Biol-Cybern.*, 62, 275-288, 1990

[4] J.J. Marotta, W.P. Medendorp, J.D. Crawford: "Kinematic Rules for Upper and Lower Arm Contributions to Grasp Orientation", *Journal Neurophysiology, 90, S.3816-3827, 2003*