Patient-Cooperative Rehabilitation Robotics in Zurich

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Abstract— **This paper gives a short overview of new patient-cooperative robotic approaches applied to the rehabilitation of gait and upper-extremity functions in patients with movement disorders. So-called patient-cooperative controllers take into account the patient's intention and efforts rather than imposing any predefined movement. Audiovisual displays in combination with the robotic device can be used to present a virtual environment and let the patient perform different gait tasks and activities of daily living. Furthermore, the sensors implemented in the robots allow to measure and assess the patient performance and, thus, evaluate the therapy status. It is hypothesized that such patient-cooperative robotic approaches can improve patient motivation and the quality of the therapy compared to conventional approaches.**

Keywords— **Rehabilitation Robotics, Gait Therapy, Treadmill Training, Arm Therapy, Patient-Cooperative**

I. Robot-aided rehabilitation

Task-oriented repetitive movements can improve muscular strength and movement coordination in patients with impairments due to neurological or orthopaedic problems. A typical repetitive movement is the human gait. Treadmill training has been shown to improve gait and lower limb motor function in patients with locomotor disorders. Similarly, repetitive arm therapy is used for patients with paralysed upper extremities after stroke or SCI. Several studies prove that arm therapy has positive effects on the rehabilitation progress of stroke patients. It was observed that more and longer training sessions per week and longer total training periods have a positive effect on the motor function. The finding that the rehabilitation progress depends on the training *intensity* motivates the application of robot-aided therapy [1-5].

In contrast to manually assisted movement training, with automated, i.e. robot-assisted, gait and arm training the duration and number of training sessions can be increased, while reducing the efforts spent by the therapists per patient. Furthermore, the robot provides quantitative measures, thus, allowing the observation and evaluation of the rehabilitation process [1]. An example for a typical arm therapy robot is presented in Fig. 1.

II. Patient-responsive control

So-called "patient-responsive" strategies will recognize the patient's movement intention and motor abilities in terms of muscular efforts and adapt the robotic assistance to the patient's contribution. The best control strategy will do the same as a qualified human therapist – it will assist the patient's movement only as much as needed. This will allow the patient to actively learn the spatiotemporal patterns of muscle activation associated with normal gait and arm/hand function.

The term "patient-responsive" comprises the meanings of *compliant*, because the robot behaves soft and gentle and reacts to the patient's muscular effort, *adaptive*, because the robot adapts to the patient's motor abilities, and *supportive*, because the robot helps the patient and does not impose a predefined movement. It is assumed that patient-responsive strategies will maximize the therapeutic outcome.

Among many different patient-responsive controllers developed so far [2] one of the most promising is a "path-controller", where not the robot, but the patient is controlling the timing of the movements. The patient can move freely along a path corresponding to a physiological walking pattern, and is corrected by a surrounding force field when he/she deviates from the path. An additional

Fig. 1 The Zurich arm rehabilitation robot ARMin [3-5]

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Fig. 2 Lokomat equipped with a multimodal display comprised by a stereo projection system, a doubly surround sound system, a wind-generating fan, and the Lokomat providing haptic feedback. Virtual objects can be projected motivating the patient to lift the leg.

supportive force can assist the patient's efforts as much as needed. The strategy can be adapted to the individual patient's capabilities.

III. Biofeedback and virtual reality

Optimal training effects during gait therapy depend on appropriate feedback about performance. For the patient, the quality of movement and extent of activity are significant measures of performance that are not easily assessed subjectively, particularly when there are also deficits in sensation, proprioception, and cognition.

The robotic devices ARMin and Lokomat are instrumented with potentiometers and force transducers, and thus, are capable of providing online feedback about joint movement and joint moment production, respectively. The feedback values enable easy presentation by graphical, acoustical, or tactile displays to the patient motivating him/her to improve his/her gait pattern during the therapy.

Special Virtual Reality (VR) techniques are being established allowing the patients to perform specific gait or reach-and-grasp tasks. For example with the Lokomat virtual obstacles can be displayed that must be crossed by the patient (Fig. 2). An acoustic display generates the step sound and other environmental sound sources. Hitting the obstacle can be seen, heard and felt by a 3D screen, surround sound system and a force displayed by the Lokomat, respectively. A fan produces a wind that increases its intensity with increasing gait speed. Similarly, with the ARMin system any virtual scenario can be generated by multi-modal (visual, acoustic, and haptic) displays allowing the patient to solve any virtual activity of daily living (ADL). These VR tasks can increase the motivation of the patients to participate.

IV. Robot-aided patient assessment

Compared to manual treadmill therapy, there is a loss of physical interaction between therapist and patient with robotic gait retraining. Thus, it is difficult for the therapist to assess the patient's contribution and to provide necessary feedback and instructions. The values recorded by the robot sensors can provide feedback not only to the patient but also to the therapist allowing him to evaluate the patient's effort and assess the therapeutic progress.

Important measures to be assessed are primary and secondary impairments originating from brain or spinal cord injuries including muscle weakness/strength, muscle tone/spasticity, active and passive joint range of motion etc. These measures provide important outcome indicators for the therapist in assessing functional improvement with any therapy. Performing each of these tests during every rehabilitation session would be time-consuming. However, implementation of tests that can measure these parameters could be achieved by appropriate instrumentation of robotic devices. The enhancement of the robotic trainers would be a viable approach because no additional acquisitions are required. For example, force transducers offer a means to evaluate muscle strength and voluntary force. Potentiometers offer a convenient method to extract joint range of motion information. Last but not least, imposing joint movements at different speeds and concomitant measurements from force transducers offer a possibility to evaluate passive joint stiffness as well as active and passive muscle properties.

V. Conclusion

The aim of patient-responsive control strategies is to consider voluntary efforts and exploit remaining natural control capabilities of the central nervous system after damage of brain or spinal cord. The force information is used to adapt the robotic assistance to the patient's motor abilities enabling the patient to contribute as much as possible to the movement. At the same time, force and movement recordings can be displayed to the patient for biofeedback purposes and serve the therapist to evaluate the long term results of the movement therapy.

The effects of the responsive strategies on the patient can be compared to the behavior of a qualified human therapist, who moves the patient's limbs with some amount of compliance.

It is expected that the above-mentioned patient-cooperative strategies will stimulate active participation by the patient and maximize the therapeutic outcome in terms of reduced therapy duration and an improved gait quality.

The high potential for future robot-aided treadmill training lies in the combination of robot-assisted training with robot-assisted assessment. Thus, only one device is required to do both training and assessment. No additional efforts of donning and doffing are necessary, because the patient can use the training device also for the assessment before, during or after the therapy. Furthermore, the instrumented robotic actuation makes training as well as assessment not only repeatable, but also recordable. This is an important prerequisite for intra- and inter-subject comparisons required to assist the therapist in the evaluation of the rehabilitation process. In summary, patient-cooperative rehabilitation robotics has a high potential to make future gait and arm therapy easier, more comfortable, and more efficient. However, broad clinical testing is still required to prove these assumptions.

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