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„Path Control – A Strategy for Patient-Cooperative Training of Gait Timing“

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Path Control – A Strategy for Patient-Cooperative Training of Gait Timing

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INTRODUCTION

The rehabilitation robot Lokomat automates body weight supported treadmill training of patients with locomotor dysfunctions in the lower extremities such as spinal cord injury and hemiplegia after stroke [Colombo2000]. It comprises two actuated leg orthoses that are attached to the patient's legs. Each orthosis has one drive in the hip joint and one drive in the knee joint to induce flexion and extension movements of hip and knee. Present control strategies for the device are limited to replaying pre-recorded gait patterns using position or impedance control [Riener2005].

Motivated by a force-field controller applied in trials with spinal mice [Cai2006], we developed the new, patient-cooperative *path control* strategy for the Lokomat. The strategy allows patients to influence the timing of their own walking movements [Zitzewitz2006]. Thus, it introduces a new dimension of variance, which is intended to make robot-assisted treadmill training more effective.

To prepare the evaluation of the path control strategy in patients with incomplete spinal cord injury (iSCI), a suitable training task was designed. Subjects try to match the timing of an "ideal" gait pattern. This pattern is presented by graphical feedback: a "virtual mirror" that augments the patients' movements with the desired movements.

METHODS

PATH CONTROL

The path control algorithm is based on the impedance control architecture presented in [Riener2005]. However, the time-dependent walking *trajectories* are now converted to walking *paths* with free timing. This is comparable to fixing the patient's feet to rails, thus limiting the accessible domain of foot positions (which can be calculated as a function of hip and knee angle).

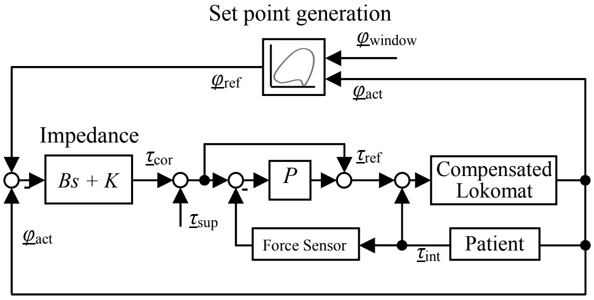

Fig. 1: Block diagram of path controller

Along these "virtual rails", which form a template for possible motions in space, the patients are free to move on their own. During stance phase, however, the patients' feet are propelled by the treadmill with constant speed. Therefore, free timing is effectively limited to swing phase movements.

Freedom of timing is implemented by augmenting the Lokomat impedance controller with a "set point generation" algorithm that derives the reference joint angles φ_{ref} from the actual angles φ_{act} (Fig. 1). The leg posture in the standard LOKOMAT gait pattern with the smallest Euclidean distance to the actual angles φ_{act} is chosen as controller reference φ_{ref}.

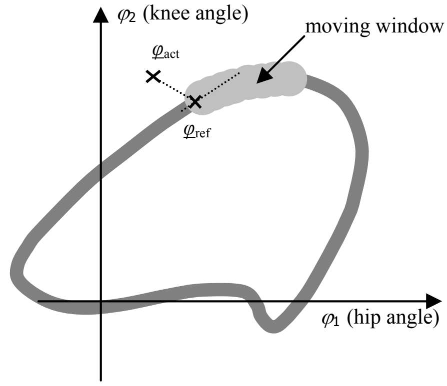

Fig. 2: Set point generation with moving window

In order to adapt the amount of freedom to the individual patients' capabilities, the region of free timing can be limited to a *moving window*. This window moves with a speed compatible to the velocity of the treadmill. It prevents large deviations from the desired timing while not interfering with smaller variations. In case of an active *moving window*, the "set point generation" algorithm limits the set of available control references to the possible postures contained in the moving window (Fig. 2).

Supplementary to the *corrective* actions ($\underline{\tau}_{cor}$) of the LOKOMAT, a *supportive* force field of adjustable magnitude can be added ($\underline{\tau}_{sup}$). Depending on the actual position of the patient's legs, forces tangential to the path are generated. The support is derived from the desired angular velocities of the default LOKOMAT movements at the current path location. Supportive forces make it possible to move along the path with reduced effort.

VIRTUAL MIRROR

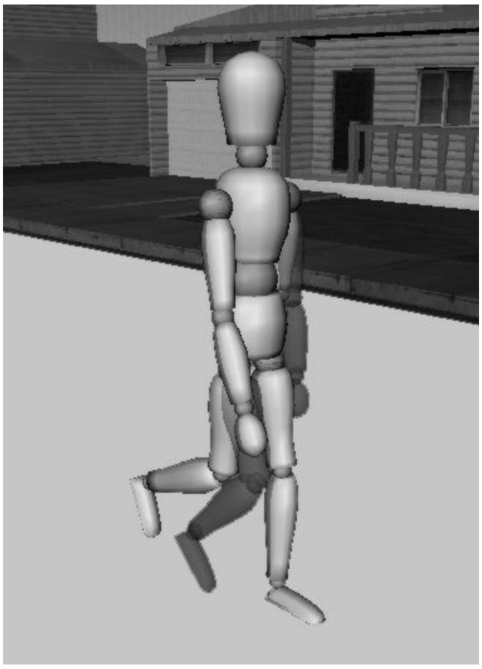

Fig. 3: Virtual mirror with "ghost avatar"

Visual information is used to intuitively display both task instructions and performance feedback to the patient. A virtual representation of the patient (avatar) is displayed via a 3x2 m projection screen. The patient avatar is overlaid by a semi-transparent "ghost avatar" that demonstrates the desired gait timing (Fig. 3).

As training task, the patients have to match the movements of their own avatar as good as possible with the movements of the ghost avatar.

RESULTS

The feasibility of the training task was evaluated with 7 healthy subjects and 1 iSCI patient. Fig. 4 shows the timing error distributions of 2 exemplary healthy

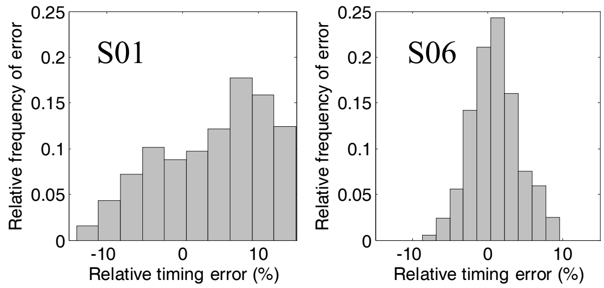

Fig. 4: Relative frequency of timing error

subjects walking in a moving window of +/- 15% of the gait cycle around the ideal timing (negative values: too fast, positive values: too slow).

DISCUSSION & OUTLOOK

First evaluation trials have shown the feasibility of the concept. The resulting timing error distributions allow for assessing the subjects performance: subject S01 shows e.g. poor performance, frequently in contact with the boundary of the moving window. Subject S06 shows good performance, indicated by a Gauss-like error distribution not touching the window boundaries.

Feedback of the test subjects revealed several minor issues that will be improved before a systematic clinical trial with iSCI patients starts. The trial will compare this new patient-cooperative approach with conventional position-controlled LOKOMAT training.

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