ROBOT ASSISTED STANDING-UP IN PERSONS WITH LOWER LIMB PROSTHESES

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Abstract-**Robot assisted standing-up manoeuver was tested in an intact person and a person after above-knee amputation. The subjects were asked to use as much leg activity as possible to lift their body while maintaining contact with the robot. The robot guided the subjects with three reference speeds. Kinematics and external forces acting on the body were recorded. The robot influence on the hip trajectory and the torques of the leg joints were studied. The subjects were able to track the robot movement. Thus, it is possible to use the robot to guide an impaired person along a desired trajectory during the standing-up process. In this way the impaired persons can be trained to accomplish an efficient sit-to-stand movement, while different trajectories of raising can be preprogrammed.**
Keywords - **Standing-up, assistive robot, above-knee amputation**

I. INTRODUCTION

The ability to stand up from a sitting position is essential for a person's independency. Successful raising is also the prerequisite for walking. However, the standing-up manoeuvre requires higher torque and larger ranges of motion in the joints of the lower limbs than walking. Standing-up is a frequent human activity. On average a healthy person stands up four times per hour [1]. Persons after the lower limb amputation are faced with the necessity to relearn standing-up in a different way than they were used to. Usually higher joint torques in the intact leg and improved balancing are required.

A robot was built to assist disabled persons during the sit-to-stand transfer. The robot is meant to be used as a training device, an assessment tool and to study the rising manoeuvre. When training with the robot assistive device, a disabled person can safely approach limits of his/her capabilities without risking to fall. Using the robot to measure rising is more comfortable than placing sensors such as infrared markers or goniometers on the patient's body. The assistive device can be programmed to interact with a person's voluntary activity in order to gain information about the standing-up process. The suitability to support paraplegic patients rising by the help of functional electrical stimulation was evaluated in [2]. A similar passive device supporting part of a paraplegic patient's body weight was used to study the FES control strategies during standing-up [3]. We believe that other categories of disabled persons, such as amputees and aging population can benefit from robot assisted training of standing-up.

The optimal trajectory of an amputee may differ from the optimal trajectory of an intact person. The present paper is a preliminary study mainly focused on the use of the robot as a device to guide a patient along a desired preprogrammed trajectory. Special attention was paid to interaction between the subject and the robot.

II. METHODOLOGY

The assistive robot resembles to half of a seesaw construction and has one active and one passive degree of freedom (Fig. 1). A rotating segment is driven by a hydraulic cylinder. A commercially available bicycle seat slides freely along the segment. The rotation and translation are measured by incremental encoders with resolutions of $0.072°$ and 0.137 mm, respectively. The pump powering the hydraulic system maintained a system pressure of 50 bar and provided a hydraulic current of up to 1 l/s. A current driven MOOG 76-100 servovalve (Moog Inc., New York, U.S.A.) controls the pressure difference of the hydraulic cylinder. The robot is supervised by a Pentium 150 MHz computer. The computer includes a custom made board with two LM628 motion controllers running at 620 Hz. The motion controllers generate trapezoidal reference trajectories, while employing PID control. The computer contains also an ISA bus I/O board capable of aquiring analog and digital signals.
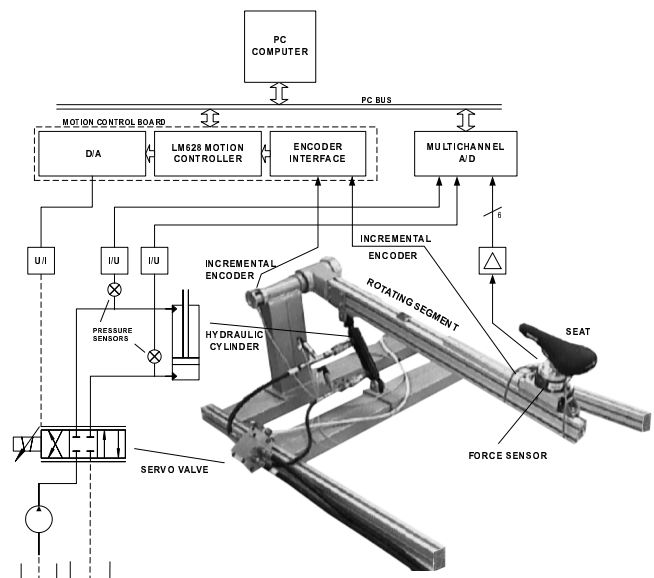

Fig. 1. The standing-up robot

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Abstract

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All external forces acting on the body as well as the body motion were recorded. The forces and torques under the feet were assessed using two AMTI force plates (AMTI, Inc., Newton, MA, U.S.A.). A JR3 six-axis robot wrist sensor (JR3, Inc., Woodland, CA, U.S.A.) mounted under the seat measured the force and torque vectors exerted on the seat. Trajectories of the infrared markers placed over the approximate centers of body joints were recorded with an Optotrak contactless optical system (Optotrak, Northern Digital Inc., Waterloo, Canada). A three-dimmensional inverse dynamic model based on the Newton-Euler formulation was used to calculate the joint torques and forces from the measured data [4]. The model consisted of 15 segments: feet, shanks, thighs, pelvis, trunk, head, upper arms, forearms and hands. The segmental anthropometric parameters were taken from [5].

One intact subject (UM, male, 83 kg, 174 cm, 24 years old) and one person after above-knee amputation of his left leg (AS, male, 85 kg, 179 cm, 44 years old, 23 years of prosthesis use) participated in the present study. The lower seat position was set to a height comparable to that of a normal chair. During standing the robot height allowed the subjects to stand with their body weight supported by the lower limbs while the seat still maintaining contact with the buttocks. The subjects kept their arms crossed during rising. Robot lifting was started by pushing a button which the subjects held in their hands. In the beginning each subject performed three rising manoeuvres without the help of the robot. Than robot assisted trials were performed with three different velocities: 0.09 rd/s, 0.18 rd/s and 0.36 rd/s. The highest speed was comparable to that of unsupported standing-up. The low and medium speed were arbitrarily chosen in order to gain information whether the interaction between the subject and the robot changes with respect to the robot speed. The subjects were asked to stand up, while maintaining contact with the seat and using as much leg activity as possible to lift their body. After a few practice risings, three trials were recorded for each speed of standing-up.

III. RESULTS

In subject UM the hip trajectories during standing up with the robot were similar to unsupported raising for all three speeds (Fig. 2). In the subject AS the ratio of vertical to horizontal speed was higher in the beginning of the manoeuvre during robot supported standing-up. The robot successfully caused the subject AS to change the trajectory he was used to perform. The robot assisted trajectories were more repetitive than in the subject UM.

In order to show the robot influence on the activity of the lower extremities, the ankle, knee and hip joint torques in the sagittal plane are presented in Fig. 3, Fig. 4 and Fig. 5, respectively.
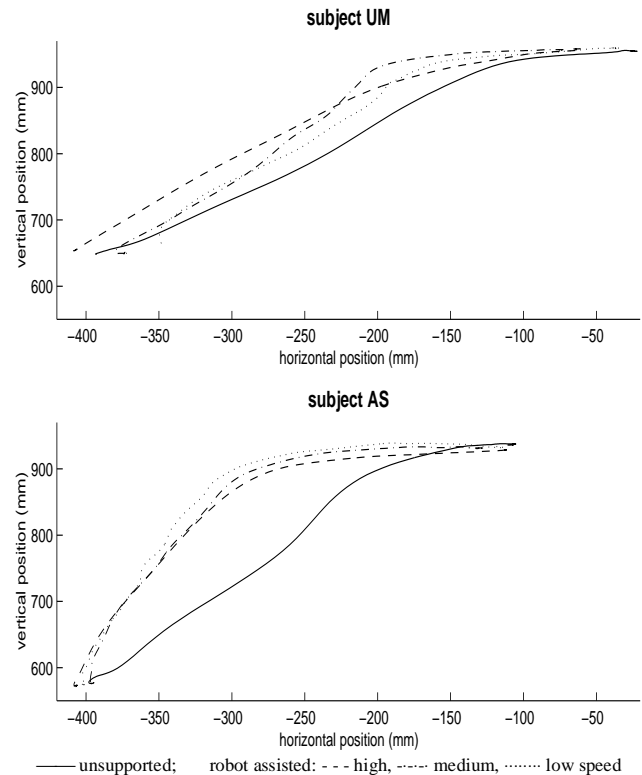

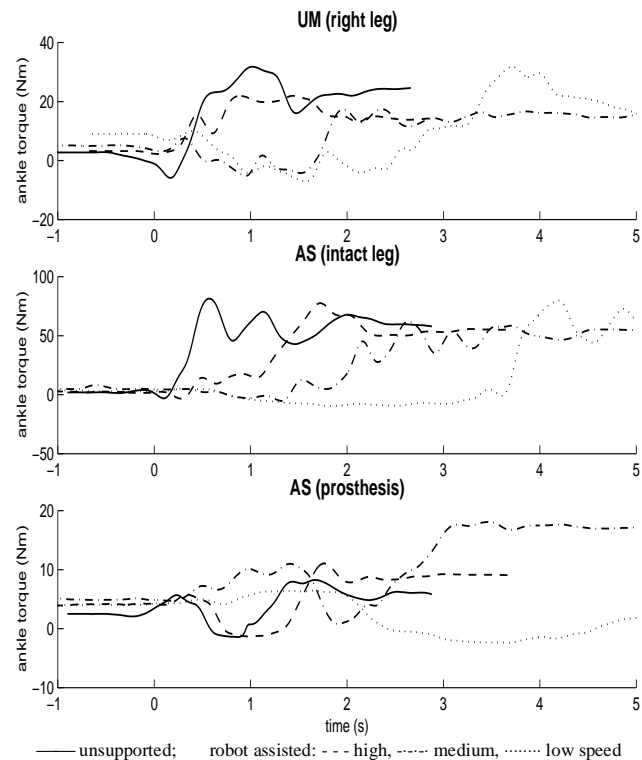Fig. 2. Hip trajectory in the sagittal plane
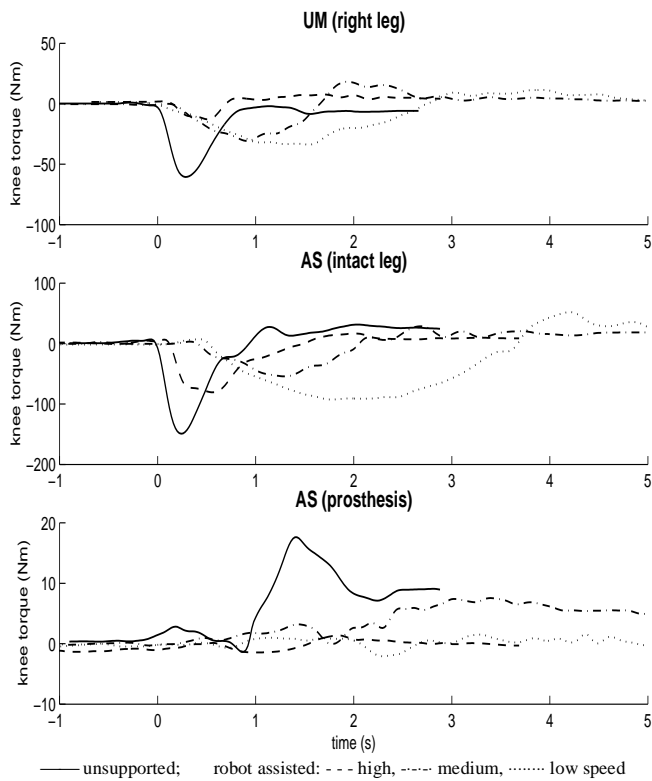

Fig. 3. Ankle torque in the sagittal plane.

Fig. 4. Knee torque in the sagittal plane.

Fig. 5. Hip torque in the sagittal plane.

During unsupported standing up the shapes of the torque time courses in subject UM were similar to the torques in the intact leg of the subject AS. However, the maximal values of the torques were significantly higher in the subject AS. In the impaired leg the torques in the passive ankle and knee joints as well as the active hip joint were lower and of different shape as compared to the intact leg.

In both subjects the time courses of the lower extremity joint torques retained some resemblance to unconstrained rising. However, the knee torque maximal values in subject UM and in the healthy leg of AS were considerably lower during robot assisted standing up. In Fig. 4 it can be observed that the prosthetic knee locks gradually during robot assisted rising, opposite to quick locking taking place during unsupported standing.

Both subjects adapted well to the robot induced motion. They had no troubles to maintain balance. No excessively high values, quick changes or uncontrolled oscillations of the leg joint torques occurred. The knee torques indicate that UM was lifted mainly by the robot without activating leg muscles during high speed rising. In the impaired leg's hip joint of AS similar oscillations were present during rising with and without the robot.
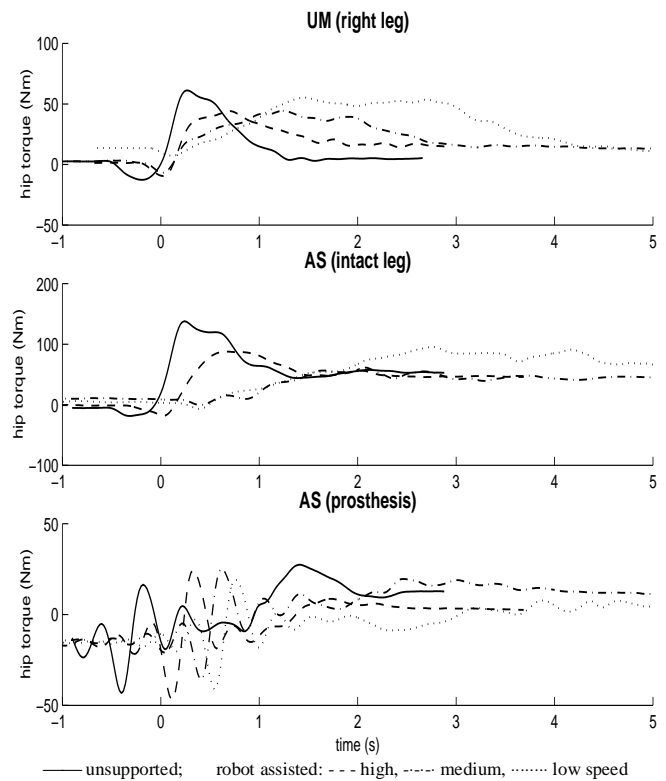
IV. CONCLUSION

Both subjects had no difficulties to track the robot induced movement. Considerably different trajectory was induced to the impaired subject when using the robotic aid, as compared to unsupported rising.

The robot partially supported the body thus modifying the torques in the leg joints. The body motion was similar regardless of the velocity of rising. In this way a person can be trained to follow a desired trajectory by gradually increasing the speed of rising.

One active and one passive degree of freedom are sufficient to achieve a movement which is similar to natural standing-up. In future investigations the seat translation is going to be driven by additional hydraulic cylinder to impose different hip trajectories. It was found that the trunk orientation can be imposed independently from the seat inclination. However, adding an active seat rotation might contribute to the subject's comfort.

A considerable number of investigations addressing the problem of optimal trajectory computation for open chain manipulators were done. The optimization approaches developed in robotics can be used to calculate efficient rising trajectories for prosthesis users. Martin [6] presented a strategy to calculate minimum effort motions. Another possibility is to find minimum time motion, while taking into account the limitations in lower extremity joint torques. A list of minimum time optimization methods can be found in [7].

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