Mobile Platform Pelvic Robot  
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Abstract

After neurological damage muscle activation control can be severely impaired which may impose considerable constraints to human locomotion mechanisms and force the patients to adjust their gait accordingly. Rehabilitation robots seem to successfully complement conventional therapist gait assisted rehabilitation they however typically focus on movement of the extremities and rarely handle also the movement of the pelvis or the trunk. We propose a mobile platform pelvic robot that preserves 6 DOF movement of the pelvis and at the same time is capable to deliver adjustable force field or perturbation impulses to subject pelvis during over ground walking. Preliminary testing has shown that stable haptic interaction can be achieved and that the level of performance variability if perturbation impulses are delivered in different directions is low and is comparable to performance variability of normal walking without perturbations.

1 Introduction

Energy efficient gait demands synchronous movement of human body in all three planes of movement: cyclical leg movement and forward propulsion in sagittal plane, weight transfer and foot clearance in frontal plane, turning in transversal plane and dynamic balance control in all planes of movement combined. However after neurological damage muscle activation control can be severely impaired which may impose considerable constraints to human locomotion mechanisms [1]. In attempt to adapt to these constraints patients are often forced to change their gait pattern accordingly. Consequently they face significant challenges during turning, maintaining static and dynamic balance stability, forward propulsion and weight transfer. To some extent their function can be improved if the brain is properly stimulated to form new neuron pathways and synapses [2,3]. It has been shown that task oriented gait rehabilitation with physiotherapists manually guiding a patient to properly complete many repetitions of a particular movement early after neurological injury often may give notable improvements. Such a rehabilitation program continually puts to the test the neuro-control of the patient but on the other hand requires a substantial amount of focus and effort on the part of the therapists as well. While providing corrective actions, the therapist must also ensure fall safe training conditions by providing manual support to the pelvis and trunk when necessary. Recently several technical solutions have been developed that attempt to substitute and alleviate the work of a therapist. Rehabilitation robots concentrate on delivering repeatable movement and providing objective assessment about patient performance [4,5,6]. While they typically focus on movement of the extremities they rarely handle also the movement of the pelvis or the trunk. Instead they tend to keep them both safely constrained to enhance gait stability and safety but also to circumvent associated design and control challenges. Failing to integrate appropriate pelvis and torso movement in gait rehabilitation of such devices severely limits the extent to which gait function can be successfully restored as pelvis as well as trunk are profoundly involved in elementary gait mechanisms such as dynamic balance control and appropriate weight transfer. Furthermore currently no device exists, that would enable fall-safe dynamic balance support and training during over ground gait training, where the pelvis would be appropriately supported while coordinated motion of the entire body could be trained.

We therefore propose a mobile platform pelvic robot that preserves 6 DOF movement of the pelvis and at the same time is capable to deliver adjustable force field to subject pelvis during over ground walking. Performance of the proposed device in terms of repeatability and variability of movement was evaluated in a series of tests of perturbed walking where force/moment impulses were delivered to pelvis of a neurologically intact subject in forward/backward, left/right and clockwise/counter clockwise direction.

2 Methods

2.1 Mobile platform pelvic robot

Mobile platform pelvic robot (Figure 1) consists of a motorized mobile platform (1) that is capable to deliver forward/backward movement and the angular movement around vertical axis of the device, universal joints (2) on mobile platform that further connect via two vertical rods (3) to the pelvic element (4) by means of conventional spherical joints (5), linear actuators (6) that deliver actuation for two degrees of freedom of each vertical rod and force sensors (7) to measure interaction forces between the subject's pelvis and the pelvic element. When actuated motion of both vertical rods is delivered to pelvic element,
subject’s pelvis is subjected to three simultaneously actuated degrees of freedom: forward/backward inclination in sagittal plane, left/right inclination in frontal plane and rotation of the pelvis around vertical axis in the transversal plane in clockwise/counter clockwise direction. Connections of the vertical rods with the pelvic element via spherical joints add three additional passive degrees of freedom: tilt of the subject’s pelvis forward/backward in sagittal plane, tilt of the subject’s pelvis downward/upward in frontal plane and vertical movement of the pelvis. Three actuated degrees of freedom are controlled through admittance-based scheme which enables rendering of desired mechanical impedance.

2.2 Study design

The proposed mobile platform pelvic robot has been evaluated in an exploratory manner in terms of repeatability and variability of movement in a single neurologically intact individual (height 182 cm, weight 76 kg) during perturbed straight line walking at moderate speed of 0.55 m/s. Four experimental conditions were assumed according to the type of perturbation: i) no perturbation ii) perturbation in forward/backward direction, iii) perturbation in left/right direction and iv) perturbation in clockwise/counter clockwise direction. Under each experimental condition perturbation direction was randomly selected between two possible directions (e.g. left or right) and was repeated until at least six repetitions were acquired for each perturbation direction. Foot insole with embedded switch was used for detecting left foot strikes and for providing a trigger signal for initiating perturbation. Perturbation always commenced 400 ms after the left foot strike, thus imposing disturbance approximately during the middle of single stance of the left leg and lasted for 250 ms. In order to provide enough time for proper response to perturbation consecutive perturbations were kept at least four seconds apart. Based on prior testing the amplitudes of linear perturbations were set to 70 N whereas the amplitudes of angular perturbations were set to 10 Nm. Throughout the evaluation the device was operating in transparent mode except during perturbation period when the desired amplitude of perturbation was added to the measured interaction forces between the subject and the pelvic element to generate the desired perturbation. The main objective of evaluation was to examine characteristic graphs of pelvis movement and interactive forces/moments between the subject and the pelvic element in relation to selected perturbations.

3 Results

Figures 2, 3 and 4 present pelvis movement and interactive forces/moments between the subject and the pelvic element during perturbations in forward/backward, left/right and in clockwise/counter clockwise directions, respectively. Results of pelvis displacement show dominant displacement responses in the
direction of the perturbation and almost negligible displacement in the remaining degrees of freedom in all experimental conditions. Likewise, analysis of the interaction forces between the subject’s pelvis and the pelvic element shows high interaction forces in the direction opposite to the direction of perturbation during perturbation period which gradually decline in response to subject’s effort to regain stability and only minor interaction forces in the remaining degrees of freedom. Interaction forces additionally show stable haptic interaction. Variability of the displacement responses as well as interaction forces is small and shows high repeatability in the performance of the device in all experimental conditions.

4 Conclusion

Evaluation of the performance of the proposed device in a series of tests that encompassed perturbed walking has shown that stable haptic interaction can be achieved and that the level of performance variability in all experimental conditions is low and comparable to normal walking. This leads us to believe that
the developed device is capable of providing adequate testing conditions for studying balance mechanisms during perturbed over ground walking in neurologically intact as well as impaired individuals.

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Figure 4. Kinematics and kinetics during clockwise/counter clockwise perturbation.