A Novel Robotic Walker for Over-Ground Gait Rehabilitation

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Abstract Recovery from impaired gait of stroke patients is in increasing need. Conventional robotic gait rehabilitation systems based on treadmill restrict pelvic horizontal motion and lack of presenting natural gait patterns with actual foot contact on the ground. To overcome these limitations, we proposed a novel robotic walker for gait rehabilitation. It consists of an active omni-directional mobile platform and a body weight support (BWS) unit to assist gait motions. The control algorithm automatically executes force assistance during gait. 3 healthy young subjects were recruited to evaluate force assistance of robotic walker. Recorded assistive forces of the walker to pelvis showed beneficial influence.

1 Introduction

Many individuals are suffering from gait impairments caused by stroke, cerebral palsy or traumatic brain injury. There are generally not many methods available for lower limb rehabilitation due to the added complications, such as balance and stability while standing/walking.

Rehabilitation robotics has potentials in reducing labor intensity for caregivers, and presenting ultimately better functional outcome than conventional therapies. To restore ambulatory functions of lower limbs, most current robotic systems for gait training are developed on treadmill-based walking platforms with over-head harness body weight support (BWS) system. The well-known examples include LOPES [1], Gait Trainer GT I [2], Lokomat [3] and WalkTrainer [4]. However,

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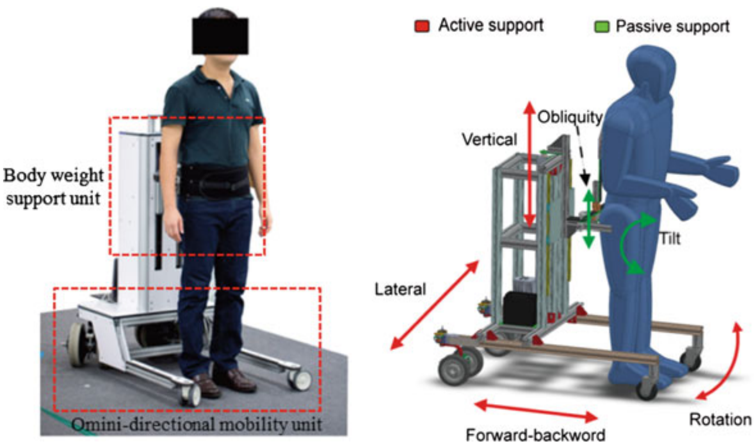
most of them and other current robots impose restrictions in translational and rotational movements of pelvis. These movements are essential for optimization of energy consumption and natural walking patterns during gait [5]. Constraining patients to a fixed platform results in unnatural gait patterns and less satisfactory functional outcomes. Therefore, fixation of pelvic movements should be avoided for effective restoration of a more aesthetic locomotion after robotic gait training. Compared with over-ground walking, walking on a treadmill indicates significantly greater cadence, smaller stride length, stride time and reductions in joint angles, moments, powers and pelvic rotation excursion [6]. Thus, for enhancing gait performance and presenting natural gait patterns with actual foot contact, rehabilitation devices with over-ground walking are more recommendable.

A more effective robotic system with sufficient assistance for pelvic motions is critical to overcome limitations in current devices and to bring benefits to a broad spectrum of patients. In this paper, we introduced the design and experimental results of a novel robotic walker (shown in Fig. 1a) with pelvic motion assistance and over-ground walking.

2 Construction of the Robotic Walker

2.1 Mechanical Construction

As shown in Fig. 1a, the robot consists of an omni-directional mobile platform integrated with an active body weight support unit and wearable modular body motion sensors. It has 4 active and 2 passive DOFs to perform pelvis movements, shown as in Fig. 1b. The omni-directional mobile platform supports pelvic motions



(a) Over-ground walking and BWS (b) DoFs of pelvic assistance

Fig. 1 Robotic walker

in Anterior-Posterior (AP, V_y), Medio-Lateral (ML, V_x), and rotational (RT, ω) movements. These three DoFs of pelvic motions are implemented by two sets of ASOC (active split offset castor) units, consisting of two coaxial conventional wheels with All-in-One Hub Motors.

The pelvic brace consists of a harness and pads to passively support both pelvic tilt and obliquity. By applying the pelvic support brace, unloading certain percentage of the body weight is achieved to support patients with weak muscles to practice gait training more in this design. The BWS unit was connected to a Force/Torque sensor with a closed loop force controller. The forces and torques measured in real-time are used for precise control of the walker during gait.

2.2 Control Algorithm

Control algorithm of the robotic walker has two levels. The lower level is an admittance based interaction control, using a mass damper model that equates a dynamic system to achieve the velocity control. The higher level is an adaptive shared control on adjustment of control allocation between users and the walker, in order to enhance self-motivated ambulatory ability. The control algorithm may adopt human-in-charge mode and robot-in-charge mode for rehabilitation exercises.

In the human-in charge mode, the robot provides passive motion only to follow the user's movement. In the robot-in-charge mode, an assistive controller is used to assist the user rather than replace the user in performing his/her training task. The assistive controller has a force trajectory generator that generates a nominal force trajectory based on the pelvic force demand during gait cycle. This force trajectory is determined by the measurement of the interaction force between the walker and human subject with F/T sensor, which showed a distinctive "W" shape during each gait cycle. Depending on relative control allocation, the control system conducts human-in-charge, shared or robot-in-charge modes. The control scheme is as shown in Fig. 2.

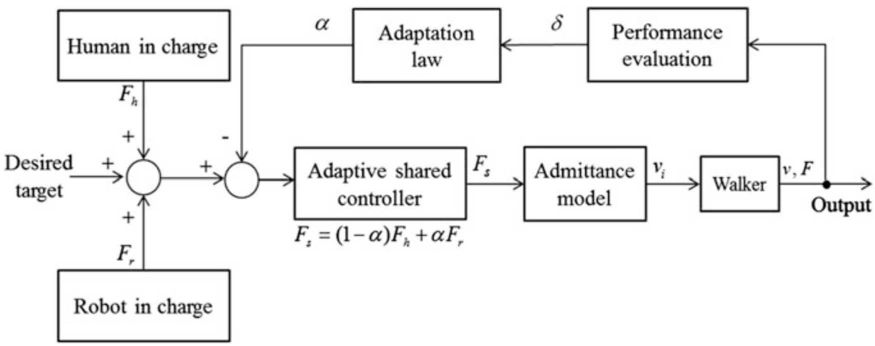


Fig. 2 Control scheme of adaptive shared control

3 Experiments and Results

For evaluating effectiveness of force assistance for the robotic walker, preliminary experiments were conducted on healthy subjects. Their gait phases and assisted forces from the walker during gait will be investigated and analyzed. A suit of 7 wearable Inertial Measurement Unit (IMU) sensors were integrated into the robotic system to monitor and measure human kinematics of both legs for gait phase estimation. They were attached to the back of left and right feet, front of calf, front of thigh and front of waist. Gait phases could be estimated by a gait phase estimation algorithm built in the control system of the walker.

3 healthy young subjects participated in the experiments. Subjects were only recruited if they had no prior clinical gait abnormalities or musculoskeletal and neurological disorders. Informed consent following an approved IRB protocol was obtained from them before the experiments began. Experimental condition is that the subjects received force assistive of their 10 % body weights from the walker during gait. 6 trials as a session were conducted for each subject. Before experiments, subjects were taught to take several trials to be familiar with the walker and experimental protocol. Subjects were required to perform the gait as naturally as possible.

Figure 3 shows a part of regulation records of assistive forces measured from the F/T sensor on the walker during gait cycles. The assistive rotational, lateral and anterior-posterior forces are periodically generated while the adaptive control is applied. The control algorithm functioned while users' walking speeds were in the

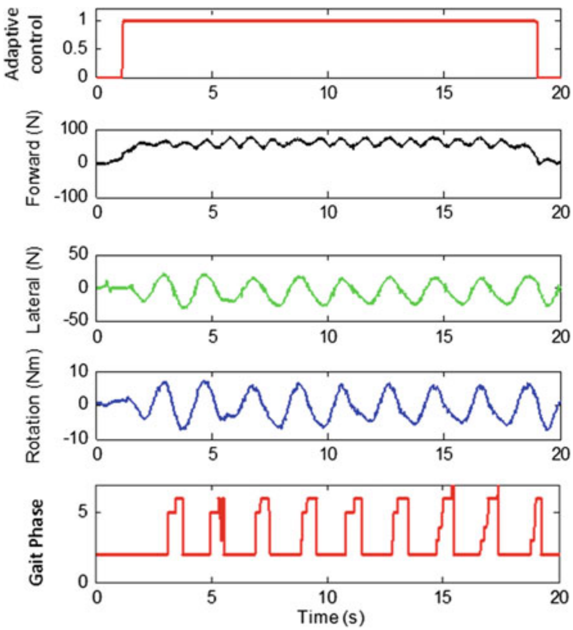


Fig. 3 Regulation of assistive forces of the walker during gait cycles

range of 0.2 and 0.5 m/s, otherwise the walker would just be passively follow users' movements, i.e. in human-in-charge mode. Meanwhile, the users lost feeling of continuous control while walking speed changed as assistive movements of the walker applied a certain reaction time for adjustment of walking speeds. This loss of independence for users is undesirable.

4 Conclusion

The proposed robotic walker with over-ground walking and full pelvic motion assistance effectively supported users without being constrained in a single forward plane of movements. The proposed adaptive shared control algorithms effectively regulates the control authority between the robot and the user. As part of the on-going work, more experimental results will be obtained to further improve the control of the system and clinical trials with stroke patients will be conducted to validate the effectiveness of the system.

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