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Development of a walking assist machine using crutches (Composition and basic experiments) †

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Abstract

This paper proposes a walking assist machine for people with walking difficulties. It has crutches operated by the user and a wearable mechanism generates motion of the leg and foot relative to the upper body. First, a healthy person's swing-through walking using axillary crutches was measured and kinematically analyzed. Based on the results, a composition of a walking assist machine using crutches (WAMC) was proposed. An Experimental apparatus of WAMC was designed and built. It realized walking with desired constant step length. And it was clarified that error of the step length decreases its walking stability. Then we investigated the relationship between walking stability and parameters of walking motion by dynamic simulations. The desired parameters were determined through the simulations Sensors and switches which convey user's intentions to WAMC were also designed and attached to the WAMC.

Keywords: Assisting device; Crutch; Life support; Mechanism; Motion; Walking assist

1. Introduction

Many paraplegics use wheel chairs for locomotion. Though the energy efficiency and stability of a wheel chair are good enough, it requires a large space and its useful range is limited due to its difficulty in handling steps. Since social environments have been designed with walking in mind, walking support devices which utilize users' lower limbs or use biped locomotion strategies are expected to help make users' lives more independent. Levels of ability and disability of paraplegics should be taken into consideration when walking support devices are developed. The goal of our work is to develop a walking support machine with actuators for persons who cannot move their lower limbs voluntarily but can move their upper body, including their arms.

We took self mobility, economy, safety, and health enhancement into consideration in the conceptual design of the walking support machine. Then, we determined the following conditions for the machine.

(1) It should be wearable for space efficiency and should be light weight.
(2) It should utilize user's remaining function and ability, such as upper limbs.
(3) It should operate in accordance with user's intention.
(4) It must not exert excessive load on user's joints.
(5) It should not require excessive force/power by user's upper body during walking.
(6) It should use few actuators and be energy efficient.
(7) It may contribute to rehabilitation of lower limbs.

Studies on walking assist machines with actuators have been done. A walking assist machine supporting whole legs by the soles of the user's feet has been developed [1]. It is intended to assist the walking of elderly handicapped persons who have less leg strength.

We developed a walking assist machine using crutches (WAMC). A wearable device with actuators generates motion in the lower limbs to create a swing-through crutch gait while the user operates axillary crutches with both arms. To make a practical WAMC, the mechanism, energy source, control system, and operating system should be determined by taking into account several walking patterns in daily life, such as straight walking and turning motions, safety measures for external disturbances, etc. In the present paper, a basic composition for the WAMC is proposed and built based on observation of the swing-through crutch gait of a healthy person. WAMC realized walking of desired constant step length. And it was clarified that an error of the step length decreases its

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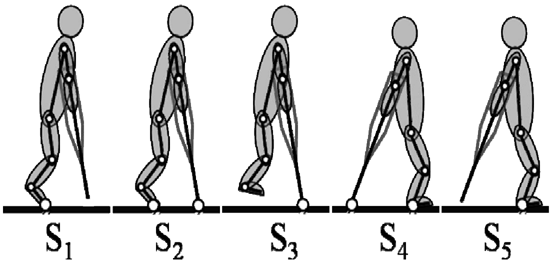


Fig. 1. Walking phase S_1,~S_5.

walking stability. Then, we investigated the relationship between walking stability and parameters of its walking motion by dynamic simulations. Sensors and switches which convey user's intentions to WAMC were also designed and attached to WAMC.

2. Analysis of crutch locomotion

To clarify the motion which should be generated by WAMC, we measured swing-through crutch locomotion by a healthy person. From the results, we divided crutch locomotion into five walking phases shown in Fig. 1. The functions of the lower limbs during crutch locomotion are summarized as follows.

(1) Ankle joint extends during S_2 so that the body moves forward.
(2) Hip, knee, and ankle joints contract in the first half of S_3 for sufficient clearance between the foot and the ground.
(3) Knee joint extends from the latter half of S_3 to the former half of S_4 to prepare contact of the foot with the ground.

3. Composition of WAMC

Based on the results obtained in the previous section, the hardware composition of WAMC was proposed as shown in Fig. 2. WAMC is mainly composed of two telescopic links with a linear actuator and a foot plate. In order to support the user's body and weight, a waist harness was used. Motion of the lower limbs is replaced linear actuator. WAMC has sensors to detect a user's intentions (start and stop walking, walking direction, step length and emergency) and disturbance. The control system of the WAMC was proposed as shown in Fig. 3, and the reference trajectory of the linear actuator was designed as shown in Fig.4. t_i means end time of the phase S_i. The actuator extends with constant acceleration $\ddot{l}_2$ during phase S_2, shrinks with constant velocity $\dot{l}_3$ during the former half of phase S_3 and extends with constant velocity $\dot{l}_3$ during the latter half of phase S_3.and S_4.

4. Experiments

Fig. 5 shows the experimental apparatus of the WAMC that we designed and built. It does not have any sensor and switch.

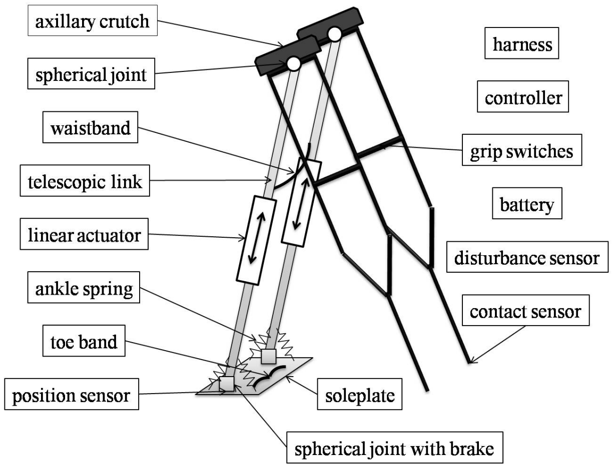


Fig. 2. Hardware composition of WAMC.

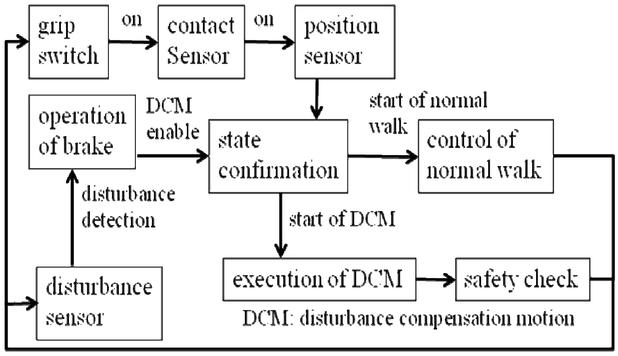


Fig. 3. Control system of WAMC.

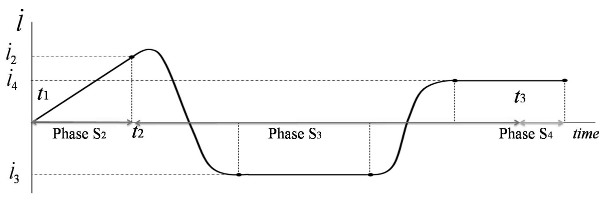


Fig. 4. Reference trajectory of the linear actuator.

The linear actuator is composed of a DC servo motor, a reduction gear, and a rack-pinion. Control of the actuators was done by a wired computer. We asked the subject, who was a 23-year-old healthy male, to walk with a constant step length, indicated on the floor, and to use his own lower limb strength as little as possible to model paraplegics. As shown in Fig. 6, a swing-through crutch walking of desired constant step length by using the experimental apparatus was successfully realized. And it was clarified that error of the step length decreases its walking stability.

5. Stability analysis of WAMC

To design a reference trajectory of the linear actuator for stable walking, we investigated the relationship between walking stability and parameters of the walking motion by dynamic simulations. We modeled a human and WAMC as a

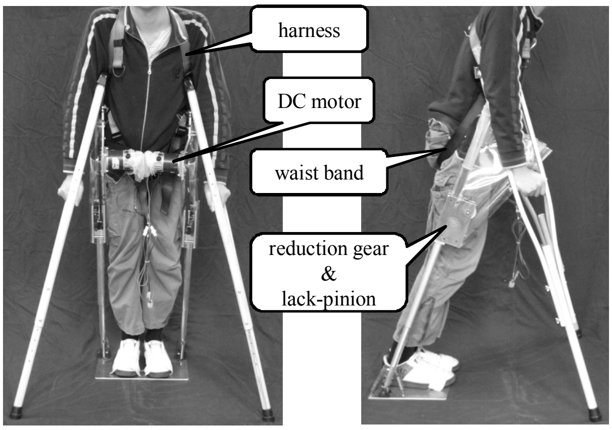


Fig. 5. Experimental WAMC apparatus.

Fig. 6. Photos of experiments.

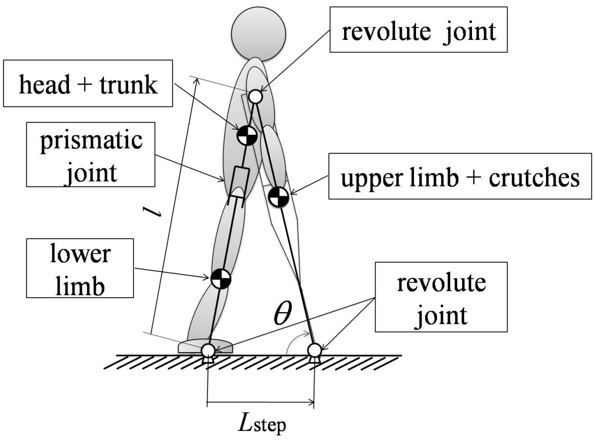


Fig. 7. Analysis model of walking using crutches.

planar three-link serial mechanism during the single support phase, and as a four-link closed-loop mechanism during the double support phase as shown in Fig. 7. We considered acceleration $\ddot{l}_2$, velocity $\dot{l}_3$, step length L_{step}, displacement of the linear actuator at t_1 and the angle θ_2 between ground and crutch at t_2 as the walking motion parameters.

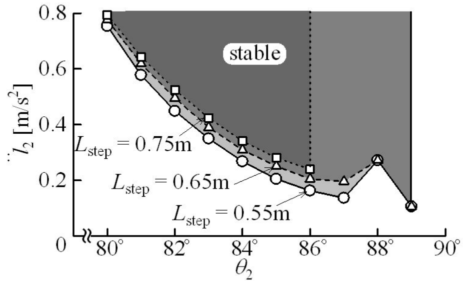


Fig. 8. Stable walking area.

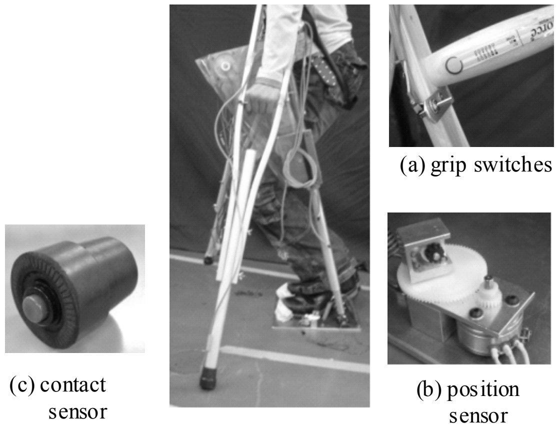


Fig. 9. Sensors.

From the results of the simulations, it was clarified that $\ddot{l}_2$, θ_2, and L_{step} are dominant for walking stability. Fig. 8 shows bounds of $\ddot{l}_2$ and θ_2 to realize stable walking, and the upper region of the figure is stable.

6. Sensors to detect user's intention

Sensors to detect user's intentions such as start and stop waking, walking direction, step length, and emergency stop, were designed and attached to the WAMC as shown in Fig. 8. User's intention to start and stop walking is deduced by two grip switches (Fig. 9(a)). One is a toggle switch which is not only a main power switch but also an emergency stop switch. The other is a pressure sensor which detects the intention to start walking for each walking cycle. It also detects an emergency when the user grips strongly or lets go of the grip of the crutch. Walking direction and step length are detected by position sensors (Fig. 9(b)). A contact sensor (Fig. 9(c)) detects the contact of the crutch tip with the ground by the user's operation of the crutch.

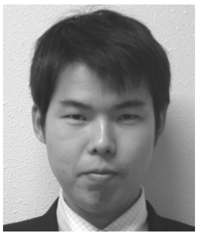
7. Conclusions

In the present paper, we proposed a walking assist machine using crutches (WAMC) as a device to assist paraplegics walking. Basic composition of its hard-ware and control system was presented. And experiments and dynamic simulations were executed to investigate its walking stability. Our conclusions are summarized as follows.

(1) Functions of the lower limbs in the swing-through crutch gait were clarified based on kinematic analysis of the crutch gait performed by a healthy person.
(2) Composition of the WAMC in which a linear actuator moves the lower limb was proposed. We also determined its motion for normal straight walking based on dynamic simulations.
(3) Experimental apparatus of WAMC was designed and built. It realized walking of constant step length. And it was clarified that error of the step length decreases its walking stability.
(4) It was clarified that the acceleration $\ddot{l}_2$, the angle θ_2, and the step length L_{step} are dominant about walking stability of WAMC from the simulations.
(5) To detect a user's intentions, grip switch, position sensor, and contact sensor are designed and attached to the WAMC.

References

[1] E. Tanaka, T. Ikehara, T. Omata, T. Owada, K. Nagamura, K. Ikejo, K. Sakamoto, and Y. Inoue, "Development of a Walking Assist Machine Sup-porting Whole Legs from Their Soles," *Transactions of JSME, Series C.*, 72 (724) (2007) 3871-3877.



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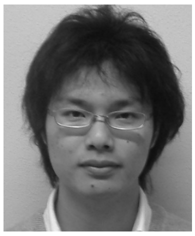

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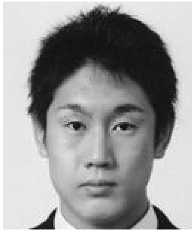

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