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Paper:

Development of an Active Walker and its Effect

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In Japan alone, more than one million people have walking difficulties. The many kinds of walker being developed thus far for gait training are used by grasping the front and/or back in order to balance the body. This requires tilting the upper half of the body forward or backward, making it difficult to keep the right posture for walking. There are moreover few examples of an active walker that is used if people have no muscular strength for walking. In order to deal with these issues, we have been developing an active walker using the Hart Walker which consists of a double upright knee-ankle-foot orthosis and a 4-wheeled carriage with a stem located in the center of the carriage. Since the waist of the orthosis is attached to the top of the stem, there is no risk of falling, it is possible to keep the right posture, and both hands become completely free. McKibben artificial muscles are attached to the Hart Walker in order to control the gait as an active walker. In walking experiments using a child-size doll with the same kinds of joints and weight that a human child has, we confirmed that a human-like gait is realized by the active walker we developed. Many patients who have different kinds of disease are using it and we have confirmed that all of them can walk by using the active walker. The active walker is now commercially available.

Keywords: active walker, gait disorder, hart walker, McKibben artificial muscle

1. Introduction

In Japan alone, more than one million people have gait disorders. Many kinds of walker being developed thus far for gait training and/or supporting walking motion however, are used by grasping the front (**Fig. 1(a)**) or back of the walker in order to balance the body. This requires tilting the upper half body forward or backward, making it difficult to keep the right posture for walking. To avoid falling and to decrease load, underwater gait training (**Fig. 1(b)**) and/or a hanging treadmill (**Fig. (c)**) are applied, but these are expensive and require a special facility. There are moreover few examples of an active walker that is used if people have no muscular strength for walking. The Locomat [1] made by ETH and the robotics stepper made by NASA and UCLA [2] are good and only examples of an active walker that consists of a treadmill and a manipulator attached to the body. Although they are very sophisticated, they are very expensive and cannot be used in daily life. Although wheel chairs are normally used for people who have gait disorders, it leads to disuse syndrome (amyotrophia, or progressive muscle waste), arthrogryposis (permanently contracted joints), and impediments of the circulatory system and keeping upright and walking are therefore very crucial indeed.

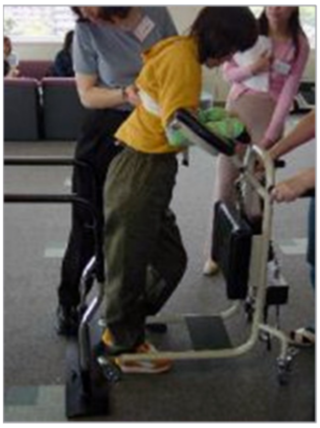
We have been developing an active walker using the Hart Walker (**Fig. 2**) which consists of a double upright knee-ankle-foot orthosis and a 4-wheeled carriage with a stem located in the center of the carriage [3]. Since the waist of the orthosis is attached to the top of the stem, there is no risk of falling, it is possible to keep the right posture and both hands become completely free. When the McKibben artificial muscle is applied to make the Hart Walker an active walker, people can walk like a healthy human gait even if they have no muscular strength at all. The active walker is simple, inexpensive and able to be used in daily life

In this paper, we first introduce the structure and the system of the active walker. To realize a healthy human gait using the active walker, we analyze the human gait and acquire the ideal gait pattern for the active walker. Sequential control is applied to implement a healthy human gait and we have found that our method is feasible and very flexible in weight and height change in experiments using a doll that has the same kinds of joints and weight that a human being has. A clinical test has also been undertaken and we have clarified that all kinds of patients have applied the active walker and have succeeded in walking.

2. Structure of the Active Walker

2.1. Hart Walker

The Hart Walker shown in **Fig. 2** was developed in 1989 in England for mainly applying in infantile paraly-



(a) Walker

(b) Underwater gait training

(c) Hanging type treadmill

Fig. 1. Walker and/or gait training system.

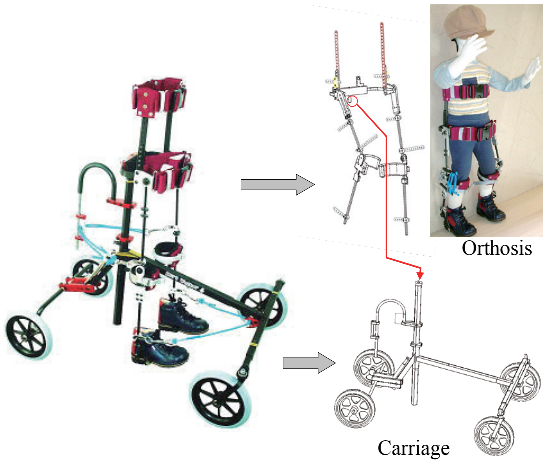


Fig. 2. Hart walker.

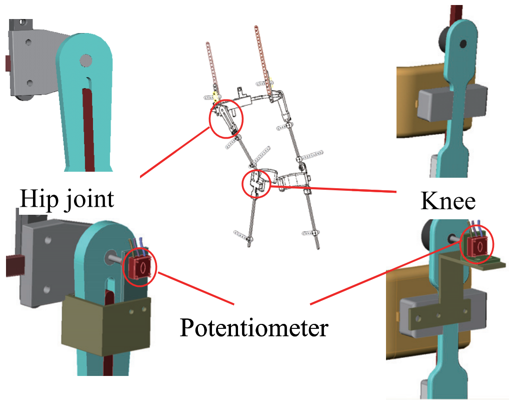


Fig. 3. Position of potentiometer.

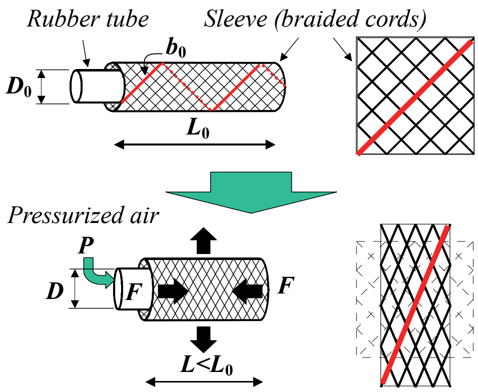


Fig. 4. Structure of McKibben artificial muscle.

sis. Over 5000 children are using it all over the world and more than 250 ones use it in Japan. It consists of a knee-ankle-foot orthosis and a carriage. The greatest advantage of the Hart Walker is that the user's hands become free and the user can keep the right posture without any risk of falling. The load on the leg is controllable by modifying the height of connection point between the stem and knee-ankle-foot orthosis. It is very easy moreover to adjust the length of frames to the body.

In order to measure angles for hip and knee joints, we utilize the potentiometers described in **Fig. 3**.

2.2. McKibben Artificial Muscle

The McKibben artificial muscle consists of an internal bladder surrounded by a braided mesh shell with flexible yet nonextensible threads that is attached at either end to fittings. As shown in **Fig. 4**, when the internal bladder is pressurized, the highly pressurized air pushes against its inner surface and against the external shell, increasing its volume. Due to the nonextensibility of the threads in the braided mesh shell, the actuator is shortened according to its volume increase and/or produces a load if it is coupled to a mechanical load. Contractive force depends basically

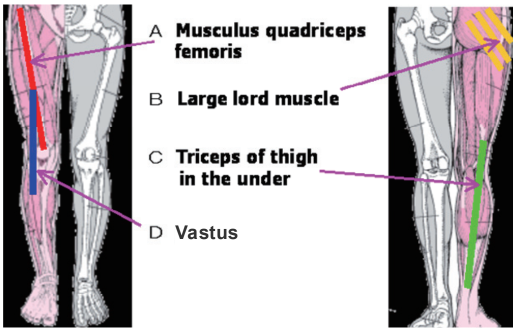


Fig. 5. Layout of human muscle.

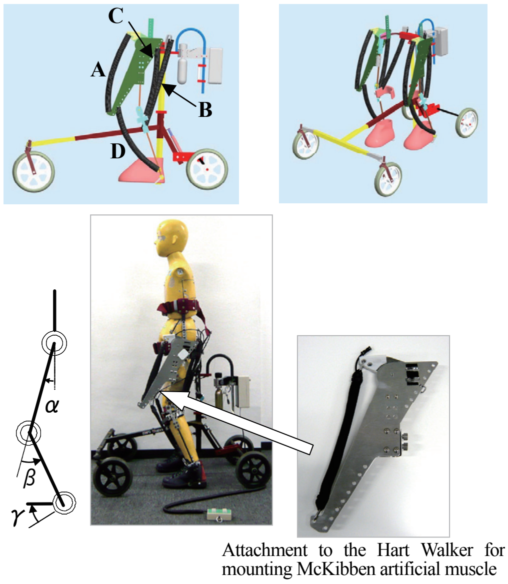


Fig. 6. Actuator layout for the active walker.

Table 1. Number and length of McKibben artificial muscle.

	A	B	C	D
Number	1	1	1	1
Length (mm)	300	330	300	200

on the diameter, and in the case of the 15 mm diameter that we are using, about 35% contraction can be expected with no load and more than 20% for a load of 20 kg.

2.3. Actuator Layout

Referring to the muscles used for walking shown in **Fig. 5**, the actuator layout for the active walker is decided as shown in **Fig. 6**. **Table 1** describes the number and length of actuators for one leg. We have decided the actuator layout by an empirical method and/or by trial and error, and are not sure whether it is optimum or not. It is arguable, but as the first step in this research, we apply this layout since the Hart Walker is employed all over the world so far and McKibben artificial muscles are possible to mount on the Hart Walker by using a simple attachment frame, as described in **Fig. 6**.

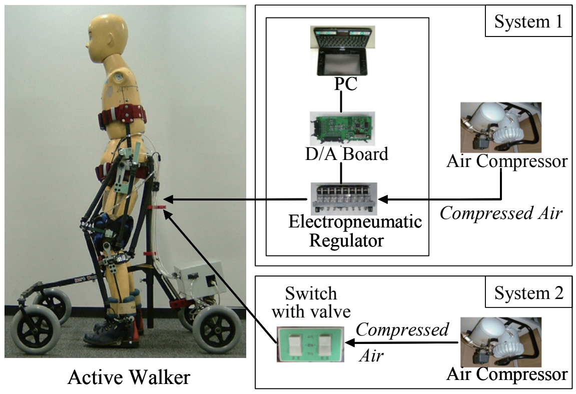


Fig. 7. System configuration.

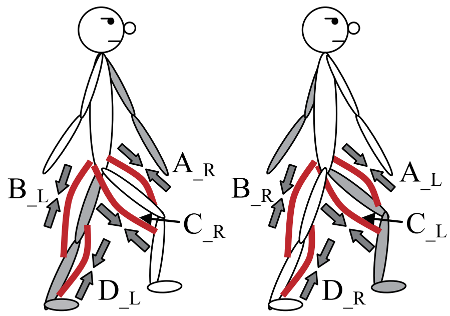


Fig. 8. Two motion patterns for realize walking.

2.4. System Configuration

The system configuration is shown in **Fig. 7**. There are two control systems.

System 1 consists of a PC, A/D, compressor, and electropneumatic regulator in order to control the output values of compressed air applied to McKibben artificial muscles. It is possible to implement the human-like natural walk, mentioned later, by using system 1, although it costs about US$5,000.

In considering system 2, when we think of the commercial product for real use, the system must be cheap and simple. We find that if we realize two motion patterns, as shown in **Fig. 8** where _L depicts the left leg and _R the right leg, it is able to produce a natural walking motion. By using a switch, we implement these two motion patterns as system 2 in **Fig. 7**. Inputting and releasing compressed air is controlled to realize two motion patterns by pushing two bottoms.

In this paper, we discuss the active walker using system 1 in order to achieve a healthy human walk.

3. Analysis of Human Gait

In order to realize a health human gait by using the active walker, the human gait must first be investigated. Optotrak Certus, a 3D precise measurement instrument, has 0.1 mm measurement error and is used for measuring hip joint angle α, knee joint one β, and ankle joint one γ as shown in **Fig. 9**. To analyze the effect of using the ortho-

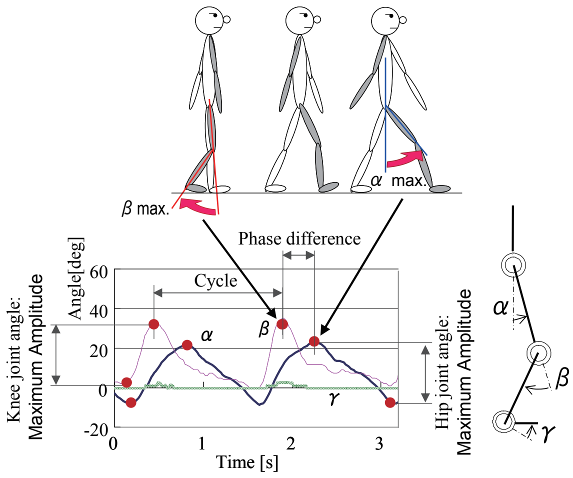


Fig. 9. Definition of parameters for gait.

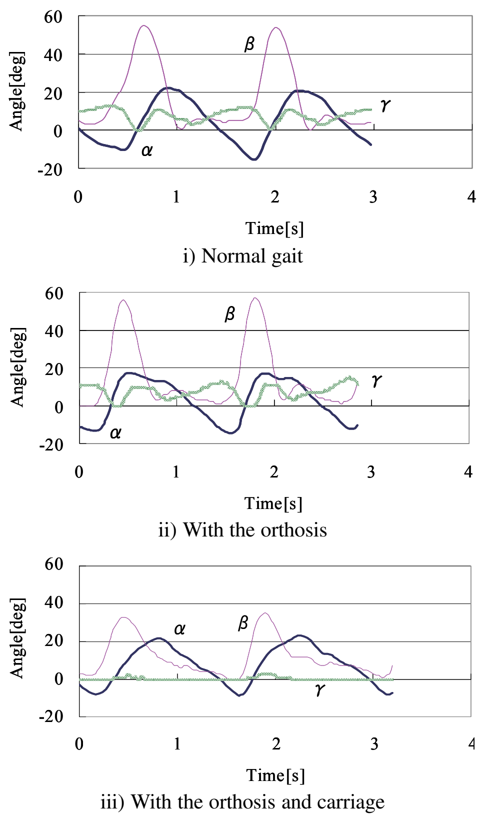


Fig. 10. Human gait measured.

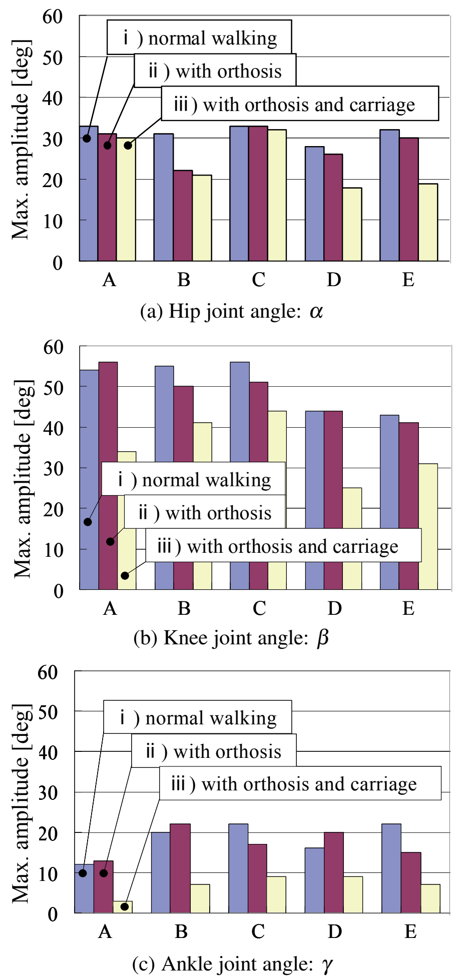


Fig. 11. Maximum amplitude for 5 subjects.

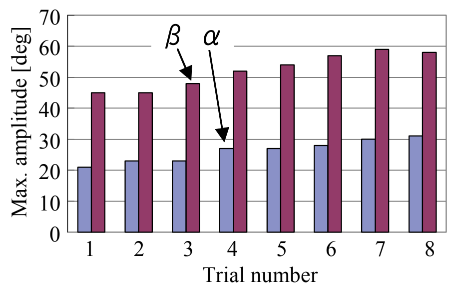


Fig. 12. Proportionality relation between α and β.

sis (Hart Walker), 3 conditions are examined: i) normal gait, ii) with the orthosis, and iii) with the orthosis and a carriage. Note that when the carriage is used, the gait becomes difficult when the user cannot control the motion of the ankle joint because the heel and/or toe disturbs walking. The movable angle of γ is structurally restricted within 5°.

Five subjects (A to E) are asked to take a few steps for 8 times in order to measure angles of α, β, and γ. **Fig. 10** shows the results for two steps of one subject in terms of i), ii), and iii). **Fig. 11** depicts the maximum amplitude (see **Fig. 9**) of α, β, and γ for i), ii), and iii) with respect to the 5 subjects. Because of an increase in bodily constraint, we find that the maximum amplitude becomes smaller in the order of i), ii), and iii). For safety reasons, it is necessary to use a carriage and the gait pattern of iii) is therefore employed for the active walker. Condition iii) will be discussed hereafter in this paper. Note that since the value of γ is almost zero, we focus on the control of α and β in this study.

From **Fig. 11**, we find that there is an individual difference among subjects, and we cannot decide which value we should use. Whereas let's check angles of α and β for each step. **Fig. 12** shows them obtained from one subject. Values express the average of each 8 trials. For easy understanding, the order is changed in an ascending se-

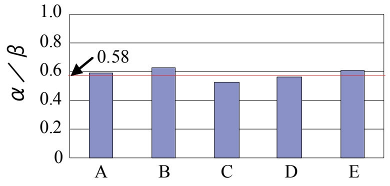
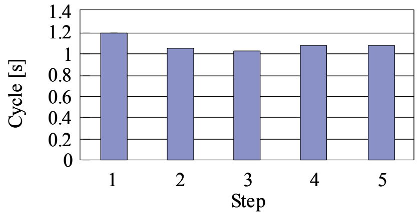
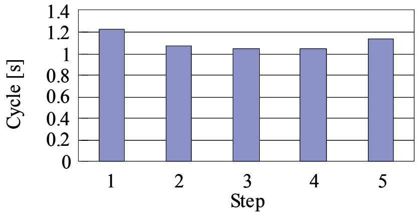


Fig. 13. Average of α/β for each subject.



(a) Subject A



(b) Subject B

Fig. 14. Cycle for 5 steps of subjects A and B.

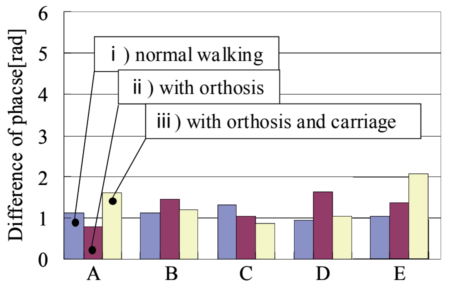


Fig. 15. Phase between α and β for 5 subjects.

quence. A proportionality relation is observed between α and β, i.e., if α is bigger, β is also bigger. The average of α/β for each subject is calculated as shown in **Fig. 13**. We can say that α/β has almost the same value and the average is 0.58.

The cycle that shows the time for one step is a factor crucial to the gait. **Fig. 14** describes a cycle of 5 steps obtained from subjects A and B. There are some differences observed between subjects, although these are small, and the average of all subjects and all steps is 1.1 second. We think that it is a valid value to use as the cycle.

Although this is subjectively speaking, the phase difference shown in **Fig. 9** that depicts term between the maximum values of α and β is also one of the factors crucial to gait. **Fig. 15** presents phase differences for i), ii), and iii) in terms of the 5 subjects. When focusing on iii), we must say there is no tendency at all, i.e., it is distributed from 0.8 to 2. We therefore use the range of 0.8–2 as a rough standard for the phase difference.

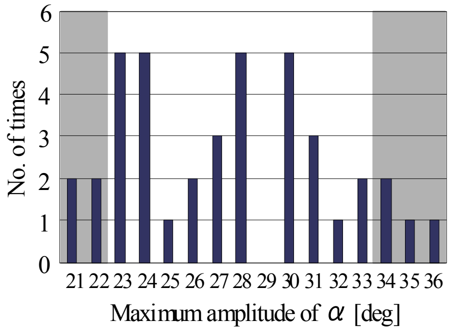


Fig. 16. Histogram of α for 5 subjects.

Table 2. Gait pattern and target values for the active walker.

Pattern	Max. amp. of [deg]	Max. amp. of [deg]	Phase dif. [rad]	Cycle [s]
I	23	40	0.8–2	1.1
II	27	47		
III	33	57		

4. Walking Experiment Using the Active Walker

4.1. Target Gait Pattern

According to human gait analysis, we find the following:

(a) α/β: 0.58,

(b) phase differences: 0.8–2,

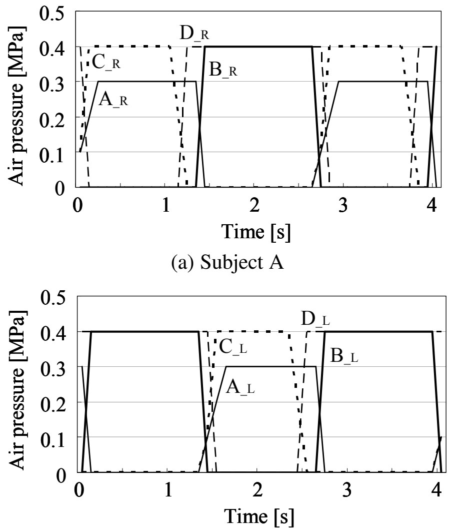
(c) cycle: 1.1 seconds.

In order to realize a human-like gait, these factors must be implemented in the active walker. Let's here check α and β. **Fig. 16** describes the histogram in terms of the maximum amplitude of α. There are 40 data items in total with respect to 8 trials for the 5 subjects. As mentioned above, there is no tendency at al regarding values. In this study, we neglect the upper and lower 10% and then select maximum, minimum and average values, i.e., 23, 33 and 27 to utilize as the target gait. Because α/β equals 0.58, β should be 40, 57 and 47 respectively. The 3 target gait patterns are thus selected as presented in **Table 2**.

4.2. Gait Control

Because of the difficulty in using actual patients for the active walker from the beginning, we use a child-size doll 130 cm tall and weighing 26 kg which is average for a 130 kg height. A universal joint is applied for each hip, knee and ankle.

A polynomial approximation was first applied as the target gait pattern for the active walker to the curved fittings for α and β in **Fig. 10 iii)**. We then tried P control and PID control by using the doll although we could not realize the same curve at all. The reason may be because a human being can control each angle with dexterity and load to the legs changes dynamically especially depending on when the sole of the foot is on the floor or not. We



(a) Subject A

(b) Subject B

Fig. 17. Input air pressure values for individual McKibben artificial muscles for gait pattern III.

Table 3. Height and weight combination.

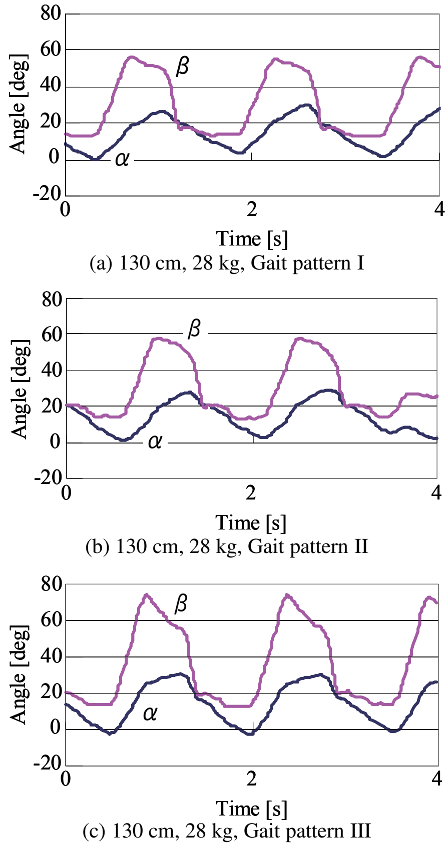
Height (+10 cm & −10 cm)	Weight (+5 kg & −5 kg)	Pattern
140 cm	38 kg 33 kg (ave. for 140 cm) 28 kg	(1) (2) (3)
130 cm	28 kg	(4)
120 cm	28 kg 23 kg (ave. for 120 cm) 18 kg	(5) (6) (7)

then decided to focus on realizing the factors shown in **Table 2**. Trial and error were applied to decide sequential values of compressed air to be applied to each McKibben artificial muscle so that patterns I, II and III are realized. **Fig. 17** depicts an example of input values for each McKibben artificial muscle in order to realize pattern III. We thus utilize sequential control.

4.3. Walking Experiment Using a Life-Size Doll

As mentioned before, the Hart Walker has a function to change length easily. In the case of a 130 cm height, height can be changed in the range of +10 cm to −10 cm. Since we wanted to show how adaptive the active walker is in terms of height and weight change, we investigated experiments using several combinations of height and weight on a hard wooden floor as shown in **Table 3**.

Figure 18 shows angle changes for gait patterns I, II and III in case of a 130 cm height and 28 kg weight. **Fig. 19** and **Table 4** describe the average values of maximum amplitude for α and β and phase differences in terms of the 3 gait patterns depicted in **Table 2** and different height-weight combinations shown in **Table 3**. **Table 2** also describes target values for 3 gait patterns and from **Fig. 19** and **Table 4**, maximum amplitude are realized for α and β within 5.6% error, and phase differences are achieved in the range of target values. We thus



(a) 130 cm, 28 kg, Gait pattern I

(b) 130 cm, 28 kg, Gait pattern II

(c) 130 cm, 28 kg, Gait pattern III

Fig. 18. Gait patterns obtained by the active walker.

find that target values are almost realized despite different height-weight combinations and gait patterns. It is quite difficult to recognize from these results though, that the gait realized by the active walker was very natural. We applied the same experiments to carpet which is a different floor condition and results were almost the same. We presume that this is because the McKibben artificial muscle has enough torque to realize maximum amplitude for α and β, the phase difference and the cycle regardless of different floor conditions.

We concluded that the active walker we have developed can realize a human-like gait with size and weight adaptation.

5. Clinical Test

Since there is no instrument so far by which people who have walking difficulties can walk without using the upper body, applying the active walker to patients was a very challenging trial. Each patient has different symptoms, i.e., different stiffness of joints and muscles, and it was difficult to realize α and β. We then focused on whether a patient can walk or not safely by using the active walker that we first developed.

Experiments were undertaken on a hard wooden floor or vinyl sheeting. Note that the active walker can be used by patients who do not have any pain when stand up, except in cases of orthostatic hypotension.

The active walker has been applied to subjects with

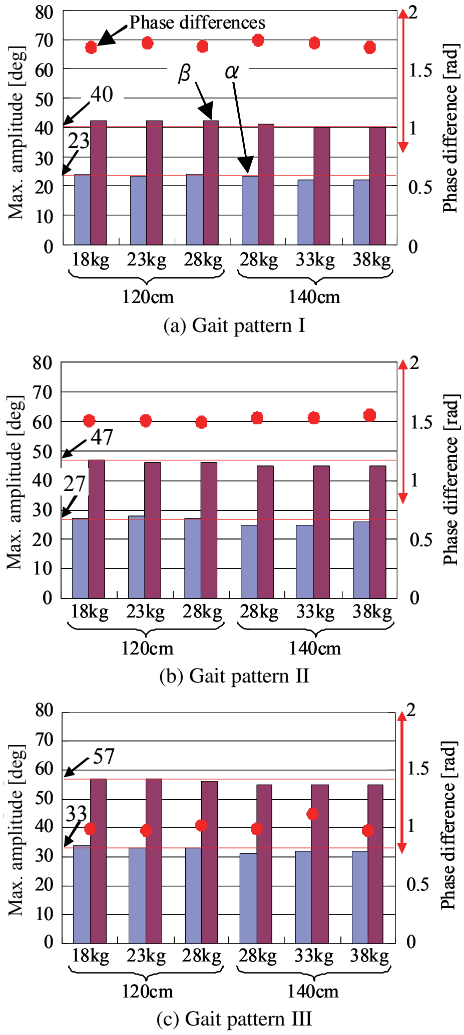


Fig. 19. Maximum amplitude and phase differences.

12 kinds of symptom – spine damage, cervical vertebrae damage, acroparalysis due to apoplectic ictus, quadriplegia due to traumatic brain injury, cerebral athetosis, spina bifida, Rett syndrome, muscular dystrophy, central core disease, Alzheimer disease, walking difficulties due to brain disorders, and functional disorders of the extremities due to congenital schizencephaly (brain grey-matter malformation) – and 28 patients who could not walk by themselves. Their parents and physical therapist observed the walking experiment. **Figs. 20–25** display examples. We confirmed that all could stand up and walk using the active walker. Note that we often observed that parents cried because their kid walked. Also patients often watched their legs during walking with the active walker, since landscape changed but they could not feel that their legs were moving.

We thus found that the active walker is very effective for gait training and actually anyone can walk by using it. The active walker is now commercially available,[1] although the system applied is system 2 in **Fig. 7** for the reason of economical efficiency and handiness. Because the active walker is a new type of instrument, it will take some time for it to be accepted widely. We believe however, that the active walker will be used together with the wheel chair in the near future in order to avoid disuse syndrome which has become a big social problem.

1. http://www.hart-walker.co.jp/products/phs.html

Table 4. Gait pattern for the active walker.

Pattern		Max.amp. of α [deg] (error [%])	Max.amp. of β [deg] (error [%])	Phase dif.[rad]	Cycle[s]
I	Target	23.0	40.0	0.8 - 2	1.1
	(1)	23.5(2.2)	41.5(3.8)	1.73	1.1
	(2)	22.9(0.4)	41.5(3.8)	1.74	1.1
	(3)	23.4(1.7)	41.4(3.5)	1.73	1.1
	(4)	23.0(0.0)	41.0(2.5)	1.75	1.1
	(5)	23.0(0.0)	40.5(1.3)	1.75	1.1
	(6)	22.5(2.2)	40.0(0.0)	1.74	1.1
	(7)	22.6(1.7)	40.0(0.0)	1.73	1.1
II	Target	27.0	47.0	0.8 - 2	1.1
	(1)	27.0(0.0)	47.0(0.0)	1.52	1.1
	(2)	27.5(1.9)	46.5(1.1)	1.52	1.1
	(3)	27.0(0.0)	46.5(1.1)	1.50	1.1
	(4)	27.0(0.0)	46.0(2.1)	1.50	1.1
	(5)	25.5(5.6)	45.5(3.2)	1.55	1.1
	(6)	25.5(5.6)	45.5(3.2)	1.55	1.1
	(7)	26.5(1.9)	45.0(4.3)	1.60	1.1
III	Target	33.0	57.0	0.8 - 2	1.1
	(1)	33.5(1.5)	57.0(0.0)	1.00	1.1
	(2)	33.0(0.0)	57.0(0.0)	0.98	1.1
	(3)	33.0(0.0)	56.5(0.9)	1.05	1.1
	(4)	33.0(0.0)	56.5(0.9)	1.00	1.1
	(5)	31.5(4.5)	55.5(2.6)	1.00	1.1
	(6)	32.0(3.0)	55.5(2.6)	1.18	1.1
	(7)	32.0(3.0)	55.5(2.6)	0.97	1.1

Fig. 20. Brain paralysis: athetosis.

6. Conclusion

In Japan alone, at least one million people have gait problem, but there have been few cases of the development of an active walker that is possible to use even if people have no muscular strength for walking. The active walker developed in this study consists of a McKibben artificial muscle and the Hart Walker, which consists of a

Fig. 21. Brain paralysis: quadriplegia.

Fig. 22. Central core disease.

Fig. 23. Spina bifida.

Fig. 24. Rett syndrome.

Fig. 25. Muscular dystrophy.

double upright knee-ankle-foot orthosis and a 4-wheeled carriage with a stem located in the center of the carriage. Note that the Hart Walker is used only for children less than 150 cm tall and that the active walker is also for children.

We begin by analyzing the human gait in order to obtain an ideal gait pattern for the active walker. The maximum amplitude of the hip and knee joints, the phase differences between them, and the gait cycle are investigated to realize the active walker. Because it is difficult to use actual patients from the beginning in walker development, we utilize a doll that is 130 cm tall and weighs 26 kg. Sequential control is applied and we confirm that a human-like gait is realized by a doll with size and weight adaptation.

A clinical investigation has been undertaken and we find that the active walker is basically applicable to a person with any of the cases we have discussed in this paper. We can say that the active walker we have developed is the only walker thus far to realize safe, good posture walking without using the upper body even if the user has no muscle strength for standing and controlling both the lower and upper body.

The active walker is now commercially available. We believe that the active walker will be used together with wheel chairs in the near future in order to avoid disuse syndrome, which has become a big social problem.

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Main Works:
- human-robot interaction
- human interface
- human physical support system
- welfare robots
- image processing

Membership in Academic Societies:
- IEEE Robotics and Automation Society (RAS)
- The Japan Society of Mechanical Engineers (JSME)
- The Robotics Society of Japan (RSJ)
- Human Interface Society (HIS)

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1986- Associated Professor, Kurume College of Technology
1999- Professor, Kurume College of Technology
2003- Representative Director, Hart Walker Japan Co., Ltd.

Main Works:
- surface modification by ion beam bombardment
- human physical support system

Membership in Academic Societies:
- The Japan Society for Welfare Engineering (JSWE)
- The Japanese Society of Prosthetics and Orthotics (JSPO)