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Emergence of Gait by an Active Walker

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***Abstract*—More than one million people have difficulty in walking at least only in Japan. Many kinds of walker have been developing so far for gait training though, they are used by grasping the front and/or the back part of them in order to hold trunk. It makes forward tilting or backward tilting of the upper half of the body and comes to difficult to keep right posture for walking. Moreover there are few examples of an active walker which is used if people have no muscular force for walking.**

In order to solve these issues, we have been developing the active walker by using the Hart Walker (HW) which consists of double upright knee ankle foot orthosis and 4-wheeled carriage with a stem located in the center of the carriage. Since waist part of the orthosis is attached to the top of the stem, there is no risk for falling, it is possible to keep the right posture, and both hands becomes completely be free. McKibben artificial muscles are attached to HW in order to control gait as an active walker. By walking experiment using child-size doll with the same kind of joints human has and weight, it is confirmed that human-like gait is realized by the active walker developed. Now the active walker is test working stage. Many subjects who have different kinds of disease are trying to use it and we have confirmed all of them can walk by using the active walker.

***Index Terms*— Active walker, Gait disorder, Hart walker, McKibben artificial muscle**

I. Introduction

At least more than one million people are gait disorder in Japan. Many kinds of walker have been developing so far for gait training and/also supporting walking motion though, they are used by grasping the front (Fig.1 (a)) or the back part of them in order to hold trunk. It makes forward tilting or backward tilting of the upper half body and comes to difficult to keep right posture for walking. To avoid falling and decrease the load, underwater gait training (Fig.1 (b)) and also hanging type treadmill (Fig.1 (c)) are applied. These are expensive and required a special facility. Moreover there are few examples of an active walker which is used if people have no muscular force for walking. Locomat [1] by ETH and robotics stepper by NASA and UCLA [2] are good and only examples for the active walker which consists of treadmill and manipulator attached to the body. They are very sophisticated though, they are very expensive and cannot use in daily life. Although wheel chair is normally used for people who is gait disorder, it makes disuse syndrome (amyotrophia, arthrogryposis and impediment of the circulatory system) and therefore to keep upright position and walking are very crucial indeed.

We have been developing the active walker by using the Hart Walker: HW (Fig.2) which consists of double upright knee ankle foot orthosis and 4-wheeled carriage with a stem located in the center of the carriage[3]. Since waist part of the orthosis is attached to the top of the stem, there is no risk for falling, it is possible to keep the right posture, and both hands becomes completely be free. By applying the McKibben artificial muscle to the Hart Walker as the active walker, people can walk by health-people-like gait even if he/she has no muscular force at all. Thus the active walker is simple, inexpensive and possible to use in daily life.


(a) Walker


(b) Underwater gait training


(c) Hanging type treadmill

Fig. 1 Walker and/or gait training system

In this paper, we introduce the structure and the system of the active walker in the first place. To realize health-people-like gait by the active walker, we analyze human gait and acquire the ideal gait pattern for the active walker. Feedback control method is applied to implement health-people-like gait and we find that our method is feasible and very flexible in weight and height change by the experiment used a doll which has the same kind of joints human has and weight. Currently clinical test has been undertaken and all kinds of patients applied the active walker have succeeded in walking.

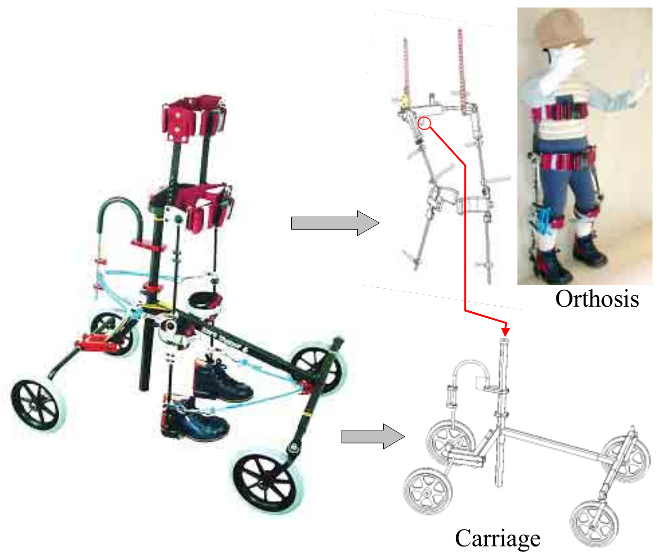

Fig. 2 Hart Walker

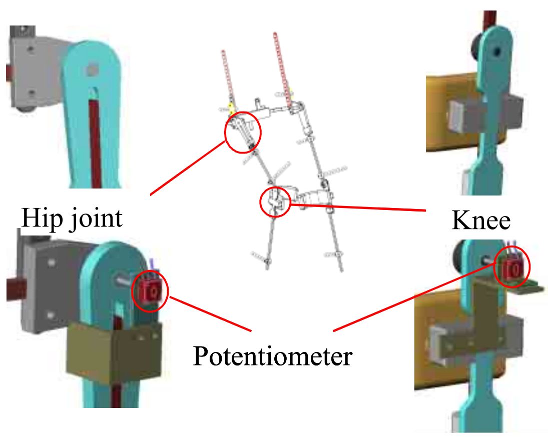

Fig. 3 Position of potentiometer

II. STRUCTURE OF THE ACTIVE WALKER

A. The Hart Walker

A hart walker shown in Fig.2 was developed in 1989 at England for mainly applying to infantile paralysis. 4100 children are using all over the world and more than 200 ones in Japan. It consists of knee-ankle-foot orthosis and carriage. The greatest asset of the hart walker is that user's hands become free and user can keep right posture. Load to the leg is controllable by modifying the position of connecting point between the stem and knee-ankle-foot orthosis. Moreover it is very easy to adjust the length of frames to the body.

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

B. McKibben Artificial Muscle

The McKibben-type actuator consists of an internal bladder surrounded by a braided mesh shell (with flexible yet non-extensible 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, tending to increase its volume. Due to the non-extensibility of the threads in the braided mesh shell, the actuator shortens according to its volume increase and/or produces a load if it is coupled to a mechanical load. About 35% contraction can be expected with no load, and more than 20% for a load of 20 kg.

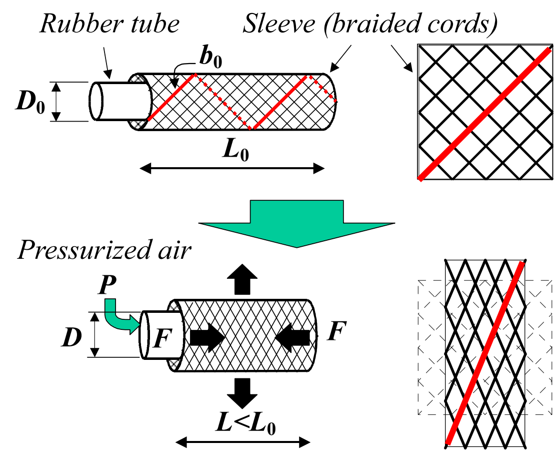

Fig. 4 Structure of McKibben artificial muscle

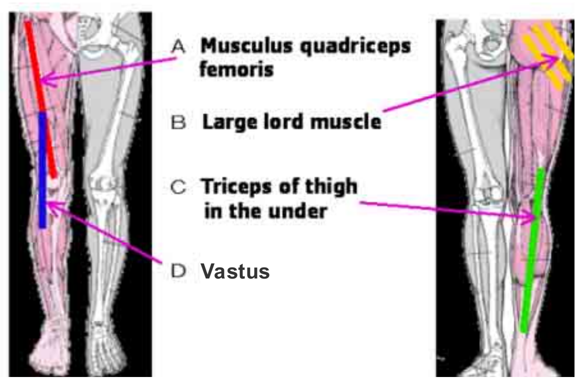

Fig. 5 Layout of human muscle

C. Actuator Layout

Referring to muscle of human used for walking shown in Fig.5, actuator layout for the active walker is decided as shown in Fig.6. Table I describes number of actuator and length. We have decided actuator layout by empirical method and/or trial and error method, and are not sure that it is optimum or not. It is arguable but as the first step of this research, since the hart walker is employed all over the world so far and just by using simple attachment frame, McKibben artificial muscles are possible to mount to the hart walker, we apply this layout.

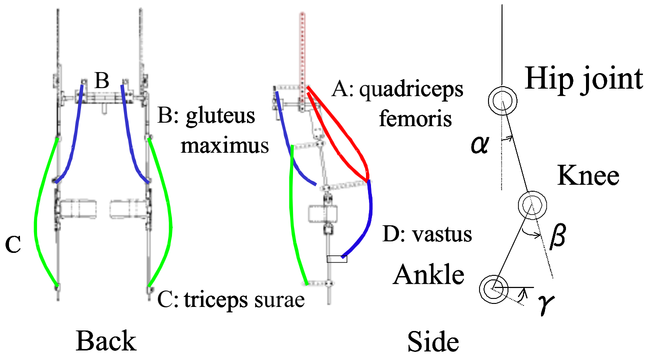

Fig. 6 Actuator layout

TABLE I. NUMBER AND LENGTH OF MCKIBBEN ARTIFICIAL MUSCLE

	A	B	C	D
number	2	1	1	1
Length(mm)	280	300	330	200

D. System Configuration

System configuration is shown in Fig.7. The active walker consists of PC, A/D, linear motor, its driver, compressor, potentiometers for measuring hip and knee joint angle, and electropneumatic regulator in order to control the output values of compressed air to the McKibben artificial muscles.

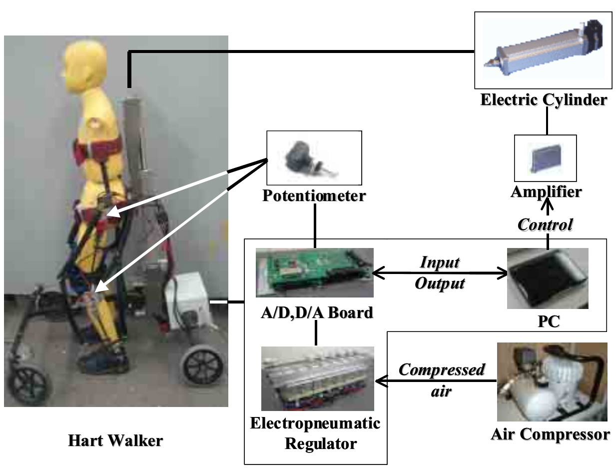

Fig. 7 System configuration

III. ANALYSIS OF HUMAN GAIT

In order to realize health-people-like gait by the active walker, in the first place, human gait must be investigated. 3D precise measurement instrument which has 0.1mm measurement error called “OPTOTRAK Certus” is used for measuring hip joint angle α, knee joint one β and ankle joint one γ. To analyze the effect of using orthosis (HW), 3 conditions are examined; i) normal gait, ii) with orthosis, and iii) with orthosis and carriage.

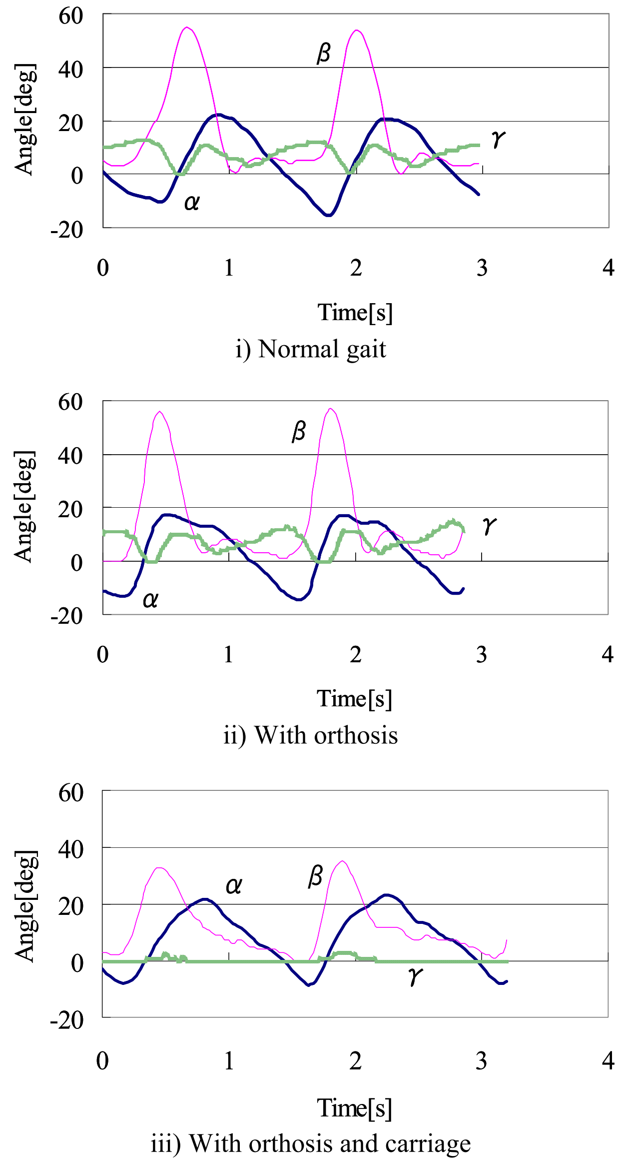

Fig. 8 Human gait measured

Fig.8 shows results from one subject. Fig.9 depicts maximum amplitude (angle) for i), ii) and iii) in terms of each 6 subject. Because of increase of the bodily restraint, we find that maximum amplitude become smaller in the order of i), ii), and iii).

Although it is subjective speaking, the phase difference shown in Fig.10 between maximum value of α and β is one of the most crucial factor for walking. Fig.11 shows phase differences for i), ii) and iii) in terms of each 6 subject. There is some differences between i), ii) and iii), and also each subject though, we can say that bodily restraint gives less effect on phase compare to amplitude. We decide to use 0.4 rad as phase differences which is the average value of all dates in Fig.11.

For safety, it is necessary to use carriage and therefore gait pattern of iii) is employed for the active walker. Since the value of γ is almost zero, we ignore γ in this paper.

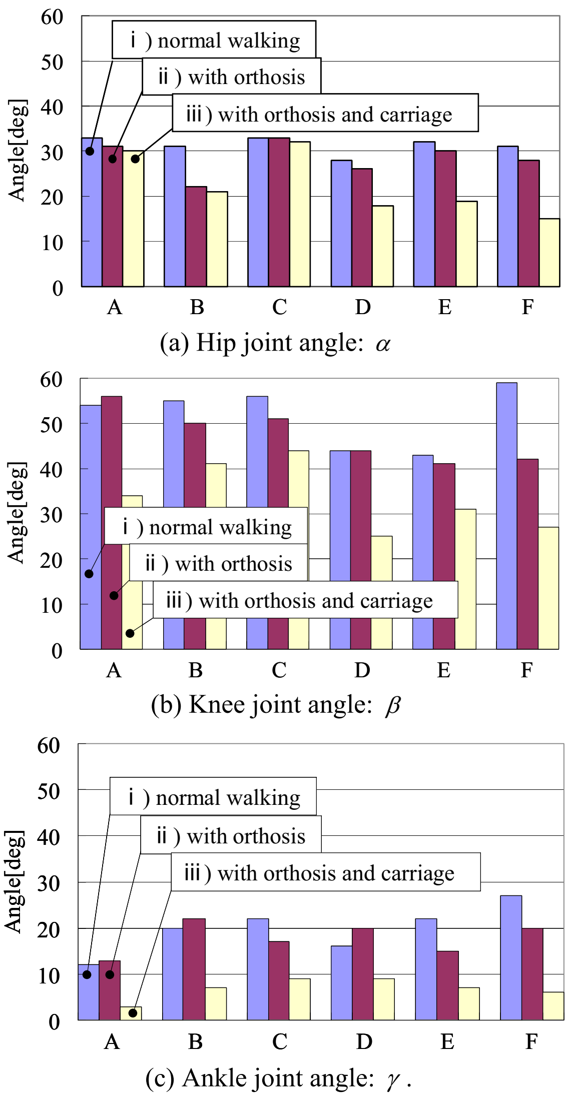

Fig. 9 Max. joint angle for 6 subjects (A to F)

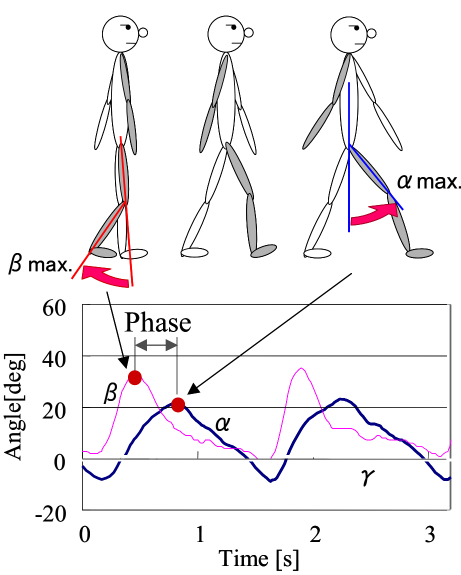

Fig. 10 Definition of phase

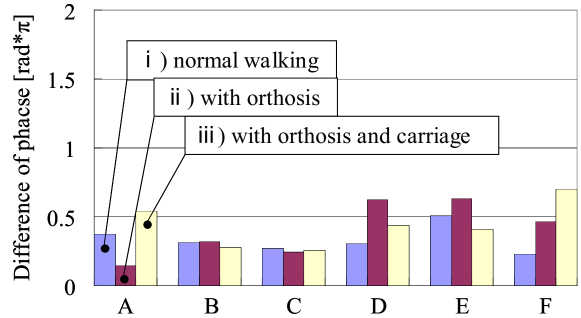

Fig. 11 Phase between α and β for 6 subjects

IV. Walking Experiment by the Active Walker

A. Target Gait Pattern

As the target gait pattern for the active walker, polynomial approximation was applied to curved fittings for α and β in Fig.8 iii). We had tried P control, PID control and so on though, we could not realize human-like gait at all. The reason might be the following. Human can control each angle with dexterity and moreover in this case, load changes dynamically especially when sole of the foot is on the floor or not. We then decide to focus on the amplitude and phase, and try to obtain gait pattern by trial and error method, i.e., to acquire values of compressed air for applying to each McKibben artificial muscle as patterns so that required amplitude and phase are realized. Fig.12 describes the gait pattern we achieved by the method mentioned above. Although curves are a bit different from Fig.8 iii), amplitude and phase differences are accomplished. Also it is difficult to explain from Fig.12 though, we find that walking of the doll is very natural in this case. Whereas gait is unstable in various situation, i.e., floor condition, weight change, and height change. Therefore, feedback control is applied as shown in next section.

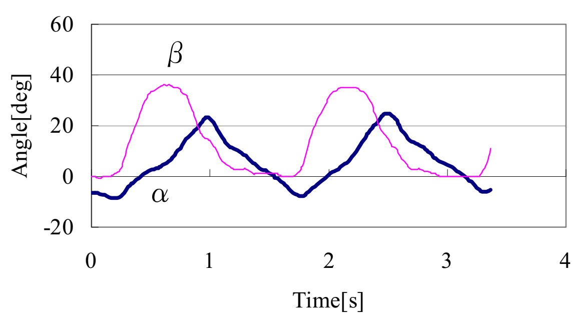

Fig. 12 Target gait pattern for the active walker

B. Gait Control

For controlling α, actuator A and B in Fig. 6 is utilized. For β, C and D. Control block diagram is shown in Fig.13. Variables in this figure describes as follows;

P_{FF} : target gait pattern (Fig.12)

θ^{cmd} : target joint angle

$\dot{\theta}^{cmd}$: target joint angular velocity

K_p : feedback gain: 0.02

K_v : feedback gain: 0.001

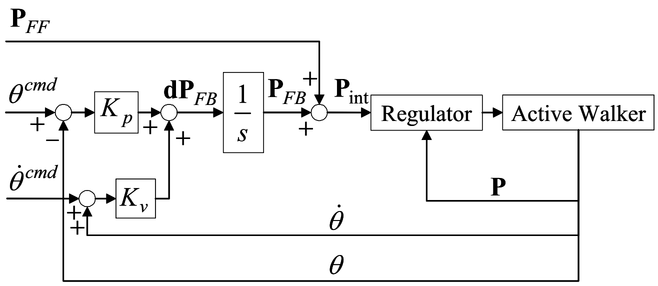

Fig. 13 Block diagram for feedback control

TABLE II. NUMBER AND LENGTH OF MCKIBBEN ARTIFICIAL MUSCLE

Height +10cm & -10cm	Weight +5kg & -5kg
140cm	38kg 33kg (ave. for 140cm) 28kg
130cm	28kg
120cm	28kg 23kg (ave. for 120cm) 18kg

C. Walking Experiment by using a Lifr-size Doll

Using a child-size doll (130cm height, 26kg weight) with the same kind of joints human has, walking experiment is undertaken. As mentioned before, HW has function to change the length easily. In case of 130cm height, we can change height in the range of +10cm to -10cm. Following by height change, weight should change in the range of +5kg to -5kg. Since we want to show how adaptive the active walker is in terms of height and weight change, we investigate experiments for several combinations with respect to height and weight as shown in Table II.

The most extreme combinations are 4 ones; +10cm and +5kg, -10cm and -5kg, +10cm and -5kg and -10cm and +5kg. Fig.14 shows the results of walking experiment for them. We find that amplitude and phase are realized in each case.

It is quite difficult to recognize from these figures thought, gait realized by the active walker was very natural. We apply the same experiment on the carpet which is the different floor condition and results are almost the same.

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

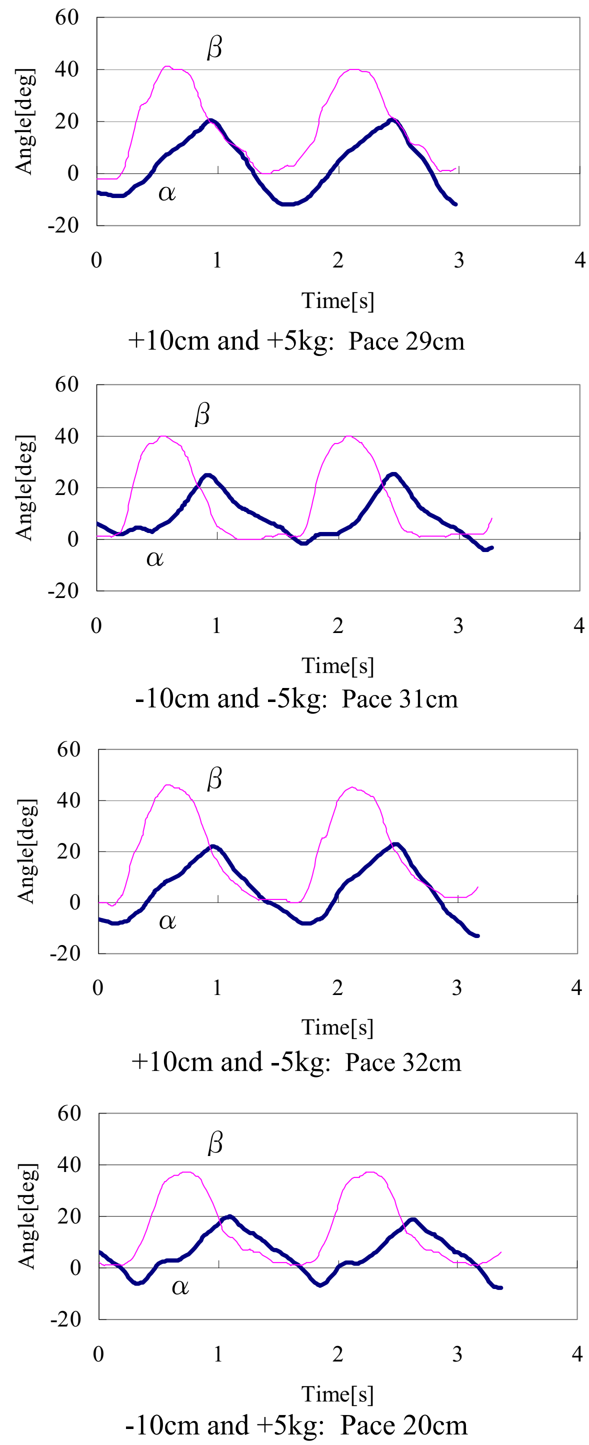

Fig. 14 Gait patterns obtained by the active walker

Fig.15 Brain paralysis: athetosis

Fig.16 Brain paralysis: quadriplegia

Fig.17 Central core disease

Fig.18 Spina bifida

Fig.19 Rett Syndrome

V. CLINICAL TEST

Because of the limitation of the paper length, we just introduce photos of clinical test. The active walker has been applied many kinds of diseases as shown in Figs. 15-21. We did not measure the change in α and β so far though, we confirm everyone can stand up and walk by using the active walker. Actually in real use, α and β are not so important. What is crucial is photos and movies during walking as an evidence.

Since there is no instrument by which people who is difficulty in walking can walk, the active walker comes to the front from PT and medical doctor. We are now planning to manufacture the commercial product.

Fig.20 Left-side paralysis

Fig.21 Cervical vertebrae injury

VI. CONCLUSION

Although in Japan, at least more than one million people has problem in gait, there are few developments of an active walker which is possible to use if people have no muscular force for walking. In this study, the active walker has been developing. The active walker consists of McKibben artificial muscle and the Hart Walker: HW which consists of double upright knee ankle foot orthosis and 4-wheeled carriage with a stem located in the center of the carriage.

We in the first place, analyze human gait in order to obtain ideal gait pattern for the active walker. Because of dynamical change in load for walking, it turns out that human gait pattern is not ideal for the active walker. We then focus on amplitude and phase of hip and knee angle, we produce the target gait pattern for the active walker. By using feedback control method, human-like gait is realized with size and weight adaptation.

The clinical investigation is undertaken now and We find that basically the active walker is applicable to any kind of disease. We hope the active walker would be used for many handicapped people in future.

REFERENCES

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