Basic Study for a New Analysis Method for Biological Signals to Evaluate in Human Walking

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***Abstract*—Recently, in developed countries, especially in Japan, the population of elderly people has grown. The care load for elderly people has been steadily growing. Most important for such care is to provide support for elderly people in walking. There are many reports on analyses of Human Walking, but there are few commercially available products that are able to provide support for Human Walking. The utilization rate of such support is 8.7% in Japan. Therefore, it is bionic, and the development of expensive walk apparatus for such applications is necessary. The purpose of this study is to propose a new analysis method for biological signals to evaluate in human walking. Concretely, in this experiment, a new measurement system was developed for human walk movement analysis with an embedded system including a microcomputer chip and a motion tracking device. Using this measurement system, electrical muscular potential and the acceleration of toe or instep of foot. In our results, this measurement system was found to clearly discriminate the difference in walking movements when wearing a pair of sandal or not. We think that these data are useful to design guidelines for a new accessibility system for human walking.**

Keywords-Human walking; Surface myoelectric potential; Walk assisting apparatus; Analysis method; Biological signal.

I. INTRODUCTION

Recently, in developed countries, especially in Japan, the population of elderly people has grown. There is a high risk of falling among elderly people, with about a 28 to 35% chance of falls in those over 65 years old [1]. In severe cases, it may be a serious problem because their physical strength may be lowered due to bed rest and being bedridden may result. Especially preservation therapy is performed in 90% of such cases as a cure for degenerative joint disease and arthrogryposis. It is a serious problem in that chances of healing and recovery to a self-reliant life are less than 50% [2]. Methods for increasing functional base of support (FBOS), such as a cane for walk assistance and stabilization are effective for posture maintenance, but their rate of dissemination is poor [3]. As a result, rehabilitation stations are being expanded more frequently, and there seems to be a demand for lower limb orthotic conservative therapy. However, according to the research on age care payment costs, it was 8.7% in 2017 and, considering the present conditions of the diffusion rate of a walk aid being covered by nursing care insurance, cannot be said to be spreading [4]. Accordingly, our laboratory, aimed for the development of a walk aid which has a high bionic application level. In addition, we developed a new measurement system and, for walk movement analysis, introduced it and performed a surface electromyography (EMG) of the group of muscles being used in conjunction with the walk movement and simultaneous measurement of the acceleration of the foot part. Thus, the experiment extracts a quantitative index for the development of the walk aid and could in this way perform an analysis of the physical load and evaluation of the lower limb orthotic in a walking motion. Therefore, we

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tested footwear in which the load of the foot bottom was differentiated to be examined and reported [5].

The structure of this paper is Section 5. In Section 1, we describe the background, necessity and purpose of this research. In Section 2, we introduce a simple measurement system and experiment method. In Section 3, we explain using a figure how little foot subduction is taken. In Section 4, we will examine the results. Section 5 describes the usefulness of this experiment and future tasks.

II. EXPERIMENTAL METHOD

In this study, we tried to measure transformation of the arch of foot. The transformation of minute joint was ignored in the current measurement device such as force plate and the Three-dimensional motion capture system. Therefore, there are few examples that the transformation of the joints is considered in the development of welfare device. In order to measure the very small deviation of the foot during walking, we developed measuring system by using accelerometer and measured the walking movement.

1. Subjects

The subjects were five healthy men who had no history of orthopedic disease or neurological disease. Age, heights, weights, the average and standard deviation of age, height and weight was 23.8±0.9, 168.8±3.6cm, 66.5±9.9kg respectively.

2. Informed consent

We carried out this experiment with sufficient informed consent of the subjects after the approval of the Tokyo Univ. of Science, Suwa Ethical Review Board.

3. Measurement system

The use apparatus used Raspberry Pi 3 and MPU6050. The MPU6050 is a device that measures acceleration.
Specifications of the MPU-6050:

- Digital-output triple-axis accelerometer with a programmable full scale range of ±2g, ±4g, ±8g and ±16g (Table 1).
- The MPU-6050 then communicates with a system processor as a slave through an I2C serial interface.
- Chip built-in 16 bit AD converter, and 16 bits data output.
- A sampling rate that is programmable from 4 to 1,000Hz.
- Two I2C addresses.

The measurement system connected two MPU6050 to Raspberry Pi 3 and communicated using I2C. The program used python and executed things with Raspberry Pi 3. The range of measurement confirmed that ±16g was not necessary in a preliminary experiment. Therefore, the range of measurement was set to ±8g and had better precision. The sampling rate was measured at 1,000Hz. The data obtained from the sensor was corrected to the physical value by the following formula.

Acceleration = 16 bit value of sensor / LSB sensitivity [6].

The measurement data were saved to a PC through wireless communication of RaspberryPi3.

4. Method

A. Arrangement of accelerometer on the instep

Acceleration measurement of the instep was made by placing an accelerometer on the navicular bone to accord with Acceleration measurement of the arch. The x axis, the y axis and the z axis are of adduction direction, advancing direction, and the height direction to plus respectively.

B. Measurement of accelerometer on the instep

An accelerometer is put under the navicular bone to accord with the Acceleration measurement of the instep. The x axis, the y axis and the z axis are each of adduction direction, advancing direction, and the height direction to plus respectively.

C. Measurement by accelerometer on the instep

Acceleration at the time when hallux was stepping was measured. The accelerometer was adjusted to be placed

Table 1. The accelerometers sensitivity per LBS

Full Scale Range	LSB Sensitivity
±2g	16384 LSB/g
±4g	8192 LSB/g
±8g	4096 LSB/g
±16g	2048 LSB/g

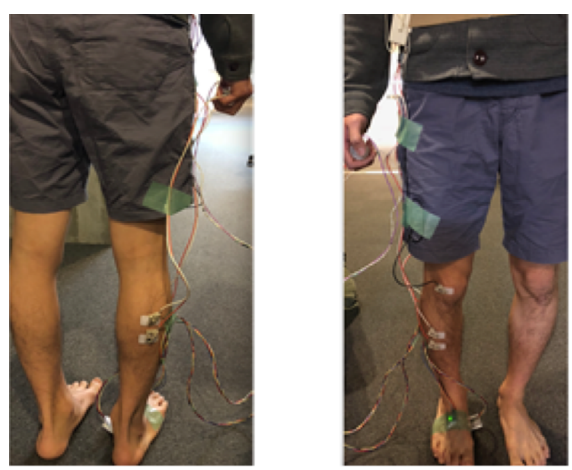

Figure 1. Surface EMG adhesion position

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under the rough surface of the first metatarsal bone. The x axis, the y axis and the z axis are of adduction direction, advancing direction, the height direction to plus respectively.

D. Placement of surface electromyogram

The surface electromyogram (EMG) measured a muscular group (Tibialis anterior muscle, Gastrocnemius muscle) concerning the walk movement (Figure 1). In the experiment, a sufficient amount of fat and keratin was removed, and electrodes (Advance; LecTrode) were affixed.

E. The experiment method

The subjects attached two accelerometer and surface EMG meters to the lower limbs, and walked straight for approximately 10m indoors. During that time, we measured each eight times walking bare foot and wearing sandals.

A) The subject stands by in the standing position, starts measurement, and then starts to walk on the measurement person's signal.
B) The subject walks about 10 m.
C) The subject stops walking on the signal of the experimenter and waits in the standing position.
D) The subject keeps standing till there is a sign that the experiment has ended.

In addition, subjects were asked to press the switch at the time of heel contact and used as an indication of the start of the walk cycle. The accelerometer was connected with a microcomputer and saved acceleration data to the personal computer with a wireless connection.

EMG derived data with a multi telemeter (Nihon Kohden Tomioka Corp; Multi-telemeter), performed A / D conversion (ADinstrulmental; PowerLab), and saved EMG data to the personal computer (SONY; PCG-5M5N). The trigger input used an LED circuit of 5V output to synchronize with other data. While walking, the trigger was given to the examinee and was pressed when the toes left the ground and the heel made contact [7]. Furthermore, rectification, Root Mean Square analysis and examination was performed on the EMG data.

F. Analysis method

We thought of my legs as a simple model (Figure 2). From the motion picture at walking time, the angle from the center of gravity to the foot which was measured in advance from the front / side of the subject was mathematically examined. Compare the extension and deformation of the foot with the accelerometer and the extension / deformation at the resting standing position. Regarding the walking motion from terminal stance to loading, the position change due to acceleration was obtained by the following equation by integration. X is the variable distance, a is the acceleration obtained from the accelerometer, and g is the gravitational acceleration.

$$x = \sum_{i=0}^{t} \{\mathrm{T(i)} - \mathrm{T(i-1)}\}^2 \times a \times g \qquad (1)$$

III. EXPERIMETAL RESULTS

A. *Measurment*

As for experimental results, the acceleration of instep, arch and hallux was measured and a correspondence between the Tibialis anterior muscle and Gastrocnemius muscle could be confirmed.

Figure 3 shows the waveform of one subject accelerometer as a representative example. It represents one cycle from heel contact to heel contact. The vertical axis is the gravitational acceleration applied in each direction, the horizontal axis is time, x, y, z are the direction orthogonal to the traveling direction, the traveling direction and the height direction.

- Figure 3-a shows the results when placing acceleration on the instep and arch of the foot while walking with bare feet.
- Figure 3-b shows the results when placing acceleration on the instep and arch of the foot while walking with sandals.
- Figure 3-c shows the results when placing acceleration on the instep and the first toe while walking with bare feet.
- Figure 3-d shows the results when placing acceleration on the instep and the first toe while walking with sandals.

Figure 3 also shows the movement distance by one subject from the loading to the terminal stance as a representative example.

B. *Analysis method*

From the equation (1), we compare the changes in the long axis direction and the short axis direction of the foot with the micro displacement distance between the stationary state and the dynamic state. At that time, the area and norm were examined using the micro displacement distance.

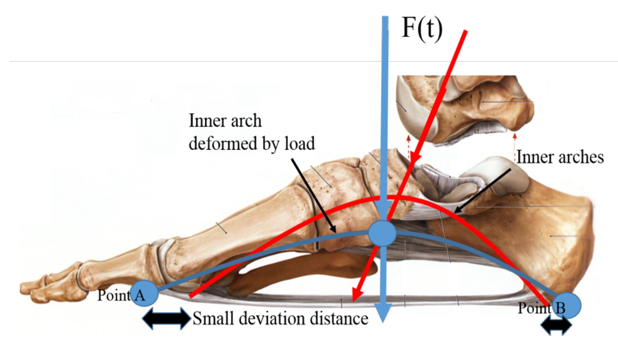

Figure 2. Simple skeleton model: Load response to feet as viewed from the side

This seems to be related to foot changes due to accelerometer load. In addition to not extending the elongation of the foot in one direction, it tends to elongate in the long axis direction due to individual differences and it tends to stretch in the minor axis direction, so compare the major axis direction, minor axis direction, area and norm.

IV. Discussion

A. Measurement

In this research, we focused on the deformation of the arch during walking by using an accelerometer at walking in a force plate and a three - dimensional motion analyzer, and measured a minute displacement of the biological motion difficult to measure. We simulate a human body model that

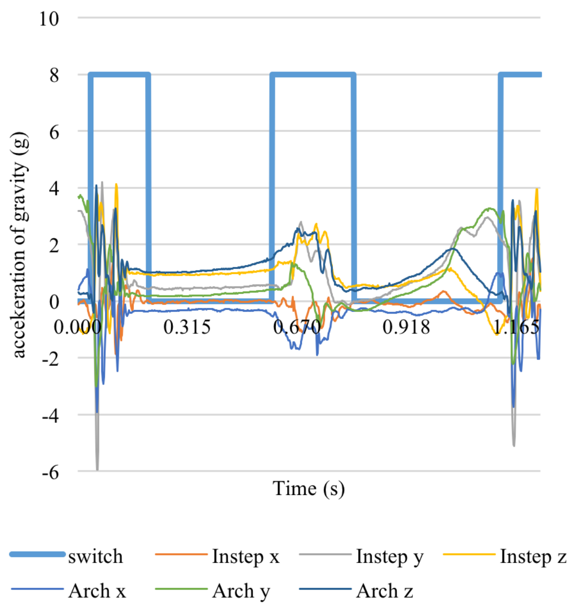

Figure 3-a. Walking with barefoot

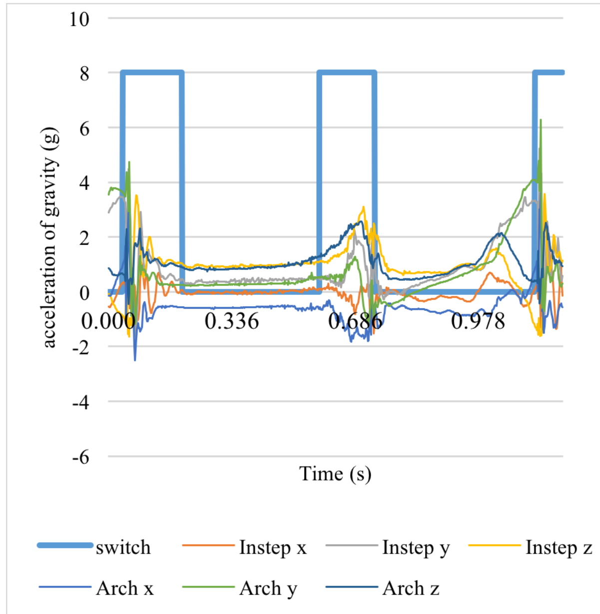

Figure 3-b. Walking with sandals

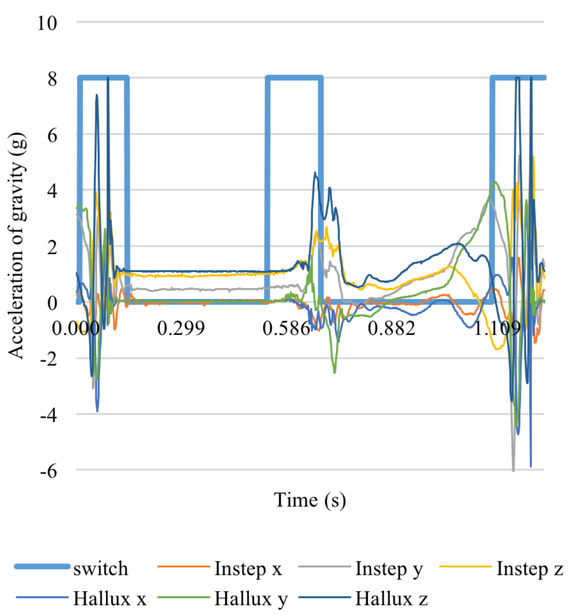

Figure 3-c. Walking with barefoot

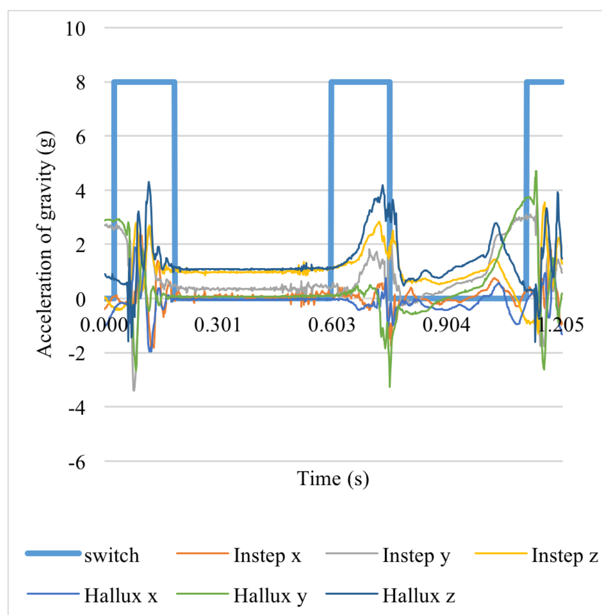

Figure 3-d. Walking with sandals

approximates a rigid body using a force plate and a three-dimensional motion analysis device used for the current gait analysis, and in many cases do not consider joints of the forefoot part. Therefore, at this time, there are no useful goods and welfare equipment. Thus, in order to measure minute displacement of walking feet, walking analysis was carried out using an accelerometer, and advanced bioengineering application was developed. We will explain experimental considerations on acceleration data, addition average, standard deviation, simple skeleton model, measurement deviation distance. Especially, consider area and norm. Regarding the arch change in the direction of travel and transverse direction by walking, norm and inner product value are obtained, and as a result of comparing the load change, the norm of the foot has a higher proportional relationship, the arch variable has the norm, I Found a possibility to be an indicator of the load evaluation on the foot.

This experiment yields the results that the hallux becomes the main axis from the moving distance of the instep, plantar arch, and hallux of the foot, and the possibility of center of gravity movement is considered.

According to Kanabe et al., "The hallux has supportive action at the position in front of the center of gravity". We think that the hallux also supports the center of gravity while walking. We consider that it is important not only to support the vertical direction but also to support the hallux, which is thought to have the support function of the center of gravity with respect to the horizontal force. The amount of change of the foot bottom is different from a bare foot in conjunction with having an insole or not.

Table 2. Comparison with area

subjects	*Total load (mm^2)*	*Barefoot change due to acceleration (mm^2)*	*Acceleration of sandals and change during use (mm^2)*
A	32.0	1.85	1.23
B	130.0	$3.4*10^{-4}$	0.09
C	16.0	$1.8*10^{-4}$	0.04
D	20.0	0.81	0.17
E	18.0	0.13	1.38
F	18.0	18.44	1.16

Table 3. Comparison with norm

subjects	*Total load (mm)*	*Barefoot change due to acceleration (mm)*	*Acceleration of sandals and change during use (mm)*
A	90.0	2.77	7.25
B	25.0	0.43	0.73
C	17.0	0.03	0.16
D	19.0	1.93	0.93
E	18.0	0.76	2.72
F	13.0	3.69	2.63

In conclusion, this study proposed a new gait analysis method to measure microtremors of muscles and bones. In order to develop the insole which enables easy posture maintenance, we measured the parameters used as the index of the insole. The deformation of the arch that is difficult to measure with the method frequently used for biometric measurement was able to be grasped as the area and norm from the deviation distance. From this result, shock absorption of walking can be seen, and it is possible to quantitatively measure the change of the arch considering the bow of the foot which is greatly involved in the walking function. However, it is still inadequate to develop insole, which is the object of this research, and it is necessary to further improve the system, experiment and inspection, but it is necessary to further improve system, experiment and inspection by a simple and simple method suggesting the possibility.

V. Conclusion and Future work

In this experiment, the subduction of the foot during walking was measured using an accelerometer. I think that it is the first step of a system which can analyze walking anywhere, rather than using expensive equipment such as force plates or 3-dimensional motion analysis equipment. It can be used in limited space and is relatively inexpensive. Moreover, it is possible to observe the subduction of the foot and to estimate the subduction with the footwear. This study is relatively simple and can capture minute fluctuations of the foot. At the present stage, attention was focused on the vertical component at the time of grounding, aiming for new obstacles to the assistive devices by confirming minute fluctuations of the feet, but also comparing and examining the free legs and the horizontal component and further concrete Try to become an indicator. For that purpose, we

will do further data analysis, discussion and proceed with development of sole for practical use.

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