Estimation of Body Part Acceleration While Walking Using Frequency Analysis

Estimate head acceleration from movement of upper trunk

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IARIA

Presenter

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Development of Gait Analysis System

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The topic of research interest

Gait analysis

Human dynamics

Healthcare system

Introduction (The usefulness of gait analysis)

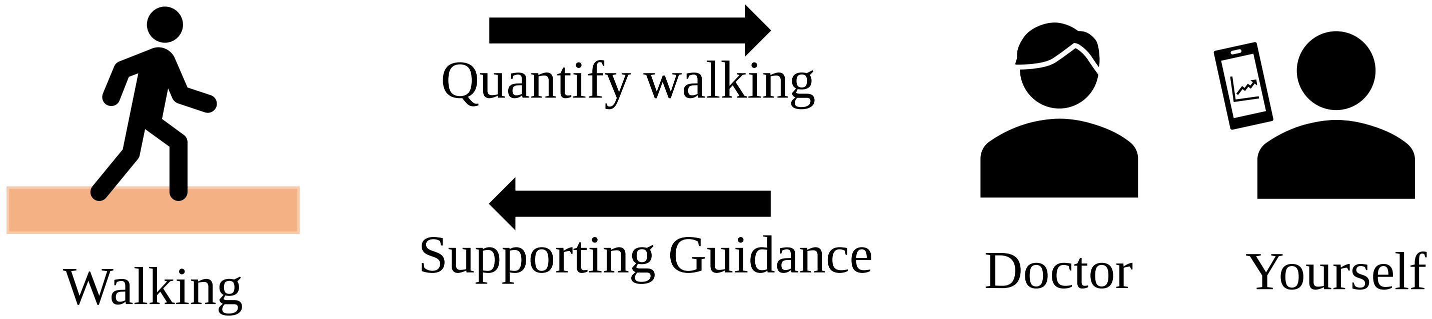
Gait analysis

- Speed
- Cycle
- Stride
- Center of gravity
- Floor reaction force
- Muscle activity. . etc.

These data are important information in the fields of

- Healthcare
- Clinical medicine
- Sports

<u>e.g.: Clinical medicine (Rehabilitation)</u>



- Quantifying your recovery status will help you stay motivated
- Not relying on rules of thumb

Introduction (Conventional method for measuring floor reaction force)

Obtaining floor reaction force

Fig.1 Force plate

Fig.2 Inertial sensor

Although the floor reaction force shown in Figure 1 can be measured accurately, it has some disadvantages such as high cost, disruptive gait, and limited measurement range.

Therefore, the research group proposed a simple method for estimating floor reaction forces using wearable inertial sensors.

Introduction (Method for estimating floor reaction forces in this research group)

Estimation of floor reaction force using wearable inertial sensor

The sum of the inertia forces of each part
is equal to the floor reaction force.

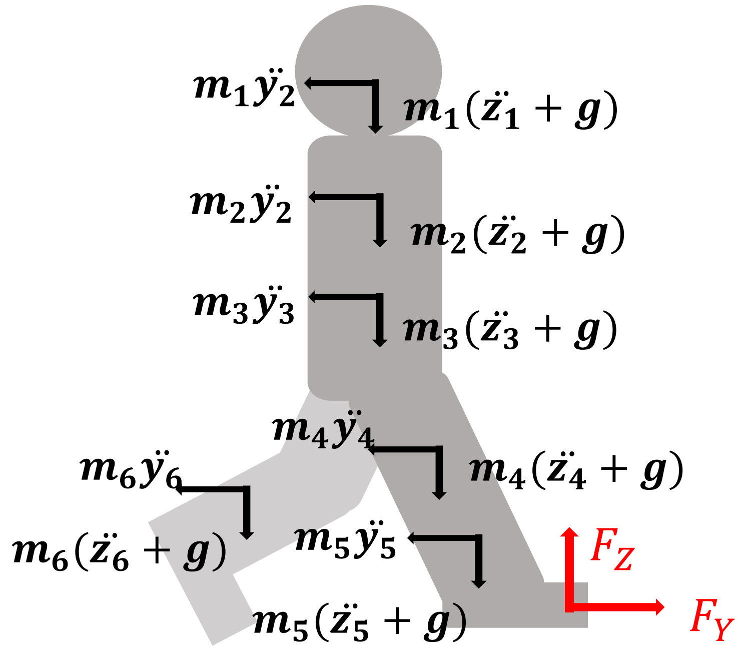


Fig.3 Relationship between inertia force and floor reaction force

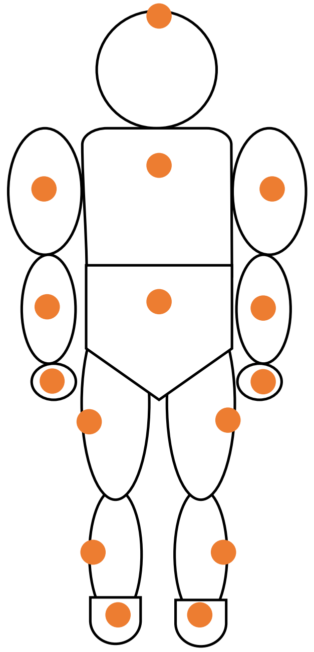


Fig.4 Sensor Attachment Position

- Attaching sensors to the center of mass positions at each part indicated by Ae et al [2].
- By attaching the sensor to 15 parts on the whole body, floor reaction force can be estimated accurately.

[2] M. Ae (1992). (in Japanese)

Introduction (Estimated accuracy of the conventional proposed method)

<u>Estimating the floor reaction force</u>

The number of sensors was reduced from 15 to 7 and 5 in order to simplify and reduce the burden on the user.

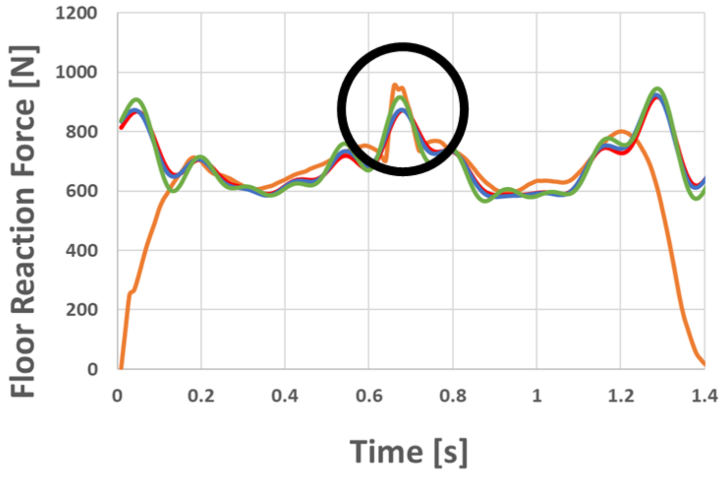


Fig.5 Vertical direction

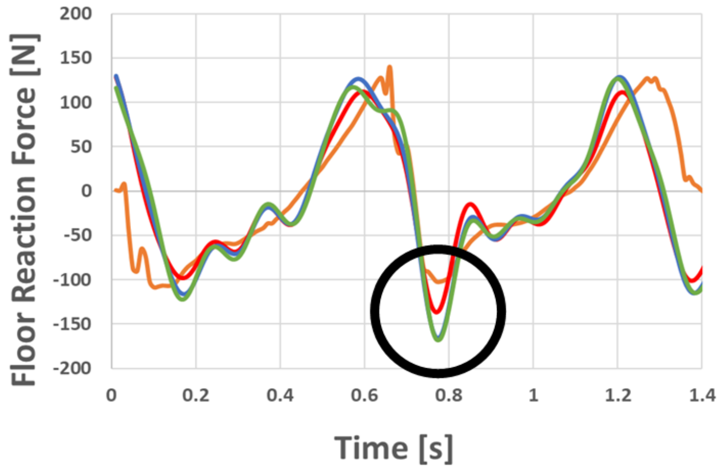
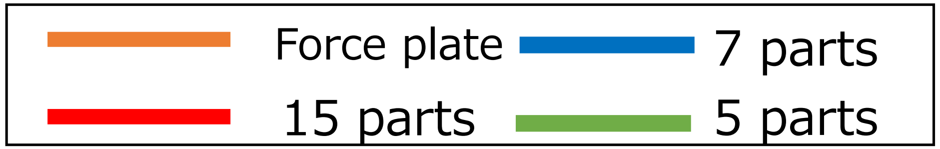
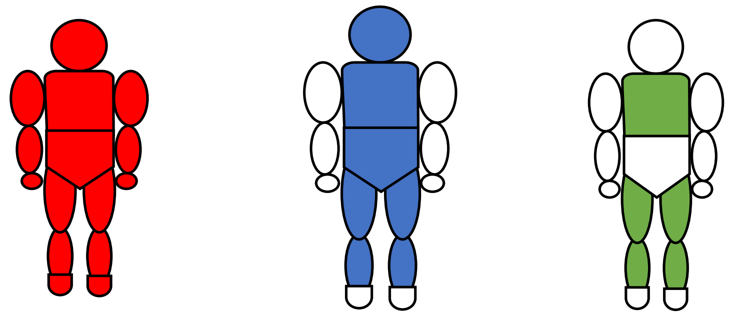


Fig.6 Walking direction





15 parts 7 parts 5 parts

Focusing on the black circles in Figures 5 and 6, the accuracy of estimating floor reaction force in the walking direction is reduced as the number of sensors was reduced.

Research Objectives

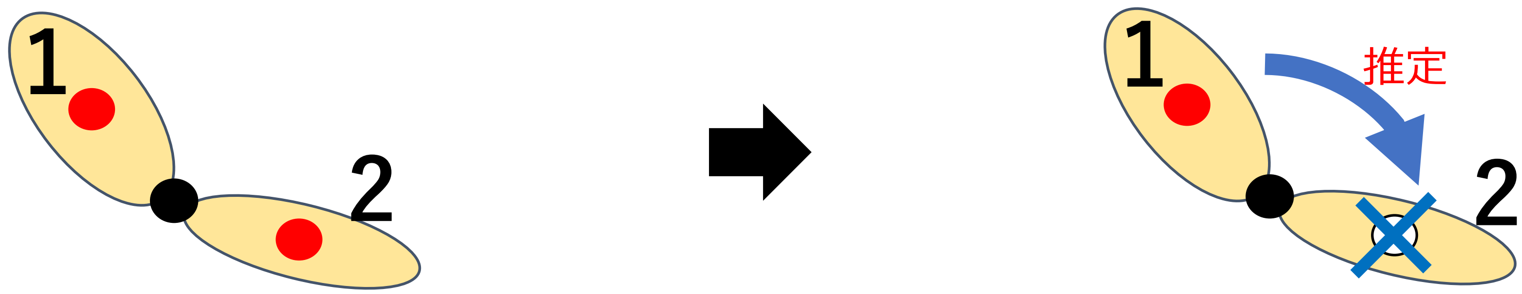
Accurate estimation of floor reaction force

Reduction in the number of sensors

Propose a new approach

Proposal Method

The acceleration of sensor 2 is estimated from sensor 1 as shown in the figure below. If it is possible to estimate the acceleration in other parts of the body, only one sensor can estimate the acceleration in each part of the body at the same time. To make this method possible, the relationship between the movements of the target part must be quantified.



Proposal Method

In the time domain, it is difficult to quantify the relationship of the movements between the two parts.

Previous Method

Time domain

Quantifying movement relationships △

Frequency analysis →

Proposal Method

Frequency domain

Quantifying movement relationships ○

In order to quantify the relationship between the movement, the acceleration at each part is converted to the frequency domain by frequency analysis.

Acceleration Estimation Process

1. Obtaining analysis Data
2. Frequency analysis
3. Motion mode function
4. Acceleration estimation

Experimental Methods

- Two healthy subjects (male: age 22 ± 0, height 1.75 ± 0.05 [m], weight 65 ± 5 [kg])
- Ten steps were measured from the beginning of the walk and the analysis area was the fifth and sixth steps
- The cadence sets to 100 BPM (0.6 seconds per walking cycle) with a metronome.
- 15 trials

- MC (manufactured by Motion Analysis Co., Ltd.)
  Force plate 3 units (manufactured by Tec Gihan Co., Ltd., TF-6090-C, TF-4060-D 2 units)

1. Obtaining Analysis Data (Time domain)

In this presentation, the acceleration of the head and upper trunk is used.

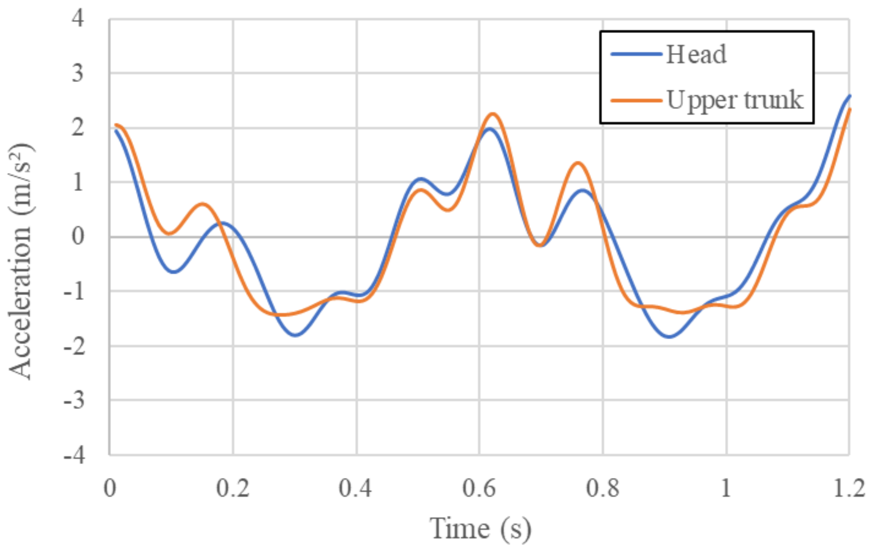


Fig.7 Vertical direction

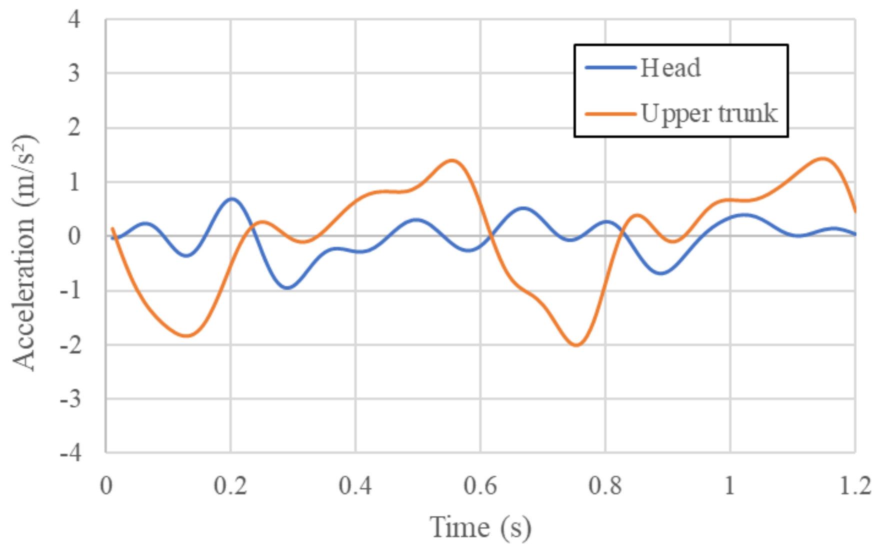


Fig.8 Walking direction

The relation between the movement of the head and the upper trunk in both the vertical and walking directions could not be quantified, and It is not possible to estimate the head acceleration from the upper trunk acceleration by correcting the constants.

2. Frequency analysis

- The acceleration data of the head and the upper trunk are decomposed into frequency components by a Fourier analysis.

- From the results, the important frequency values for estimating the acceleration of the unmeasured part of the head were identified.

- The magnitude and phase are shown as the mean and standard deviation calculated from 14 times of trial data.

2. Frequency analysis

- The Gait frequency component (1.667Hz) and its integer multiple components

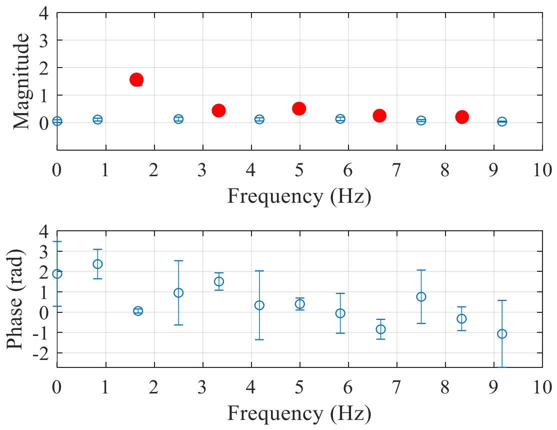


Fig.9 Result of frequency analysis of the head acceleration in the vertical direction

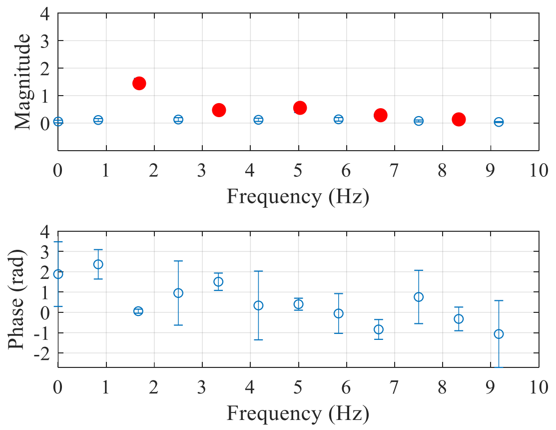


Fig.10 Result of frequency analysis of the upper trunk acceleration in the vertical direction

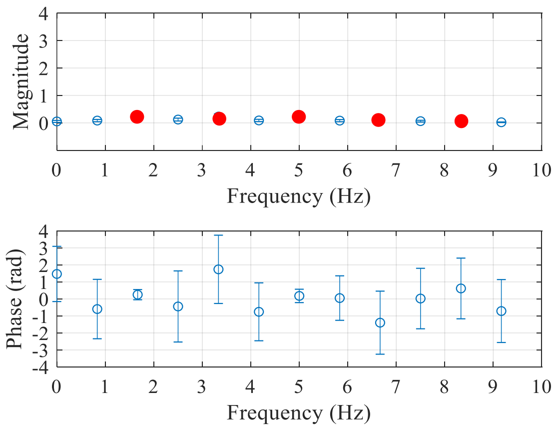


Fig.11 Result of frequency analysis of the head acceleration in the walking direction

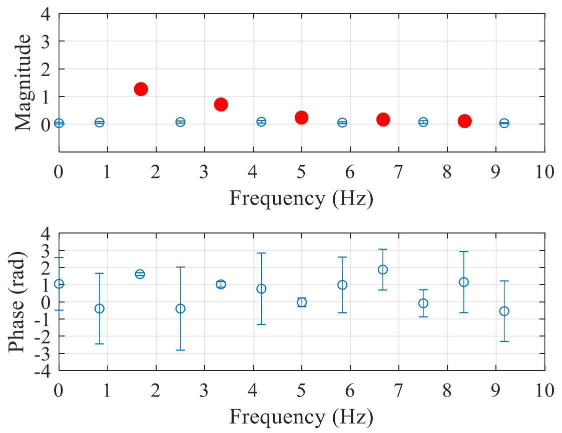


Fig.12 Result of frequency analysis of the upper trunk acceleration in the walking direction

2. Frequency analysis

- From Figure 9 to Figure 12, the gait frequency component (1.667Hz) and its integer multiple components have a magnitude in both the vertical direction and the walking direction.
- It was found that the magnitude of the gait frequency component was larger than any integer multiple component.

⬇

The head and the upper trunk movements were significantly influenced by the gait frequency component and its integer multiple component.
Among them, it was found that the gait frequency component is a characteristic of the movement.

3. Motion mode function

- The motion mode function shows the relationship between the movement of each part in the frequency domain.
- In this paper, the acceleration of the head is estimated from the upper trunk, so the upper trunk is used as a reference part.
- The motion mode function is derived by dividing the head by the upper trunk for each frequency component using the Fourier analysis results of the head and the upper trunk.
- Gains and phase differences of the results are shown as means and standard deviations obtained from 14 times of trial data.

3. Motion mode function

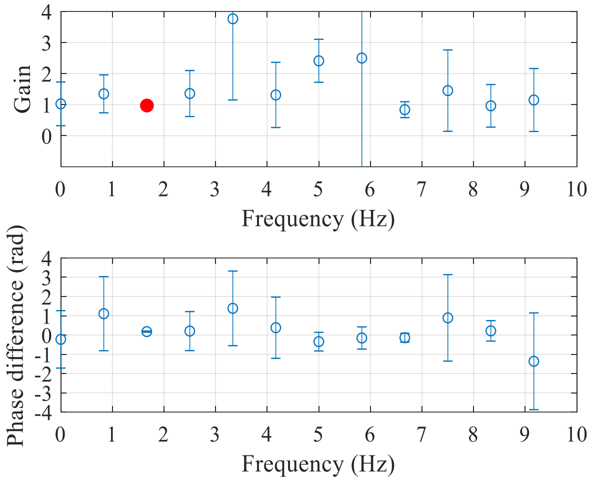


Fig.13 The average motion mode function in the vertical direction with the input as the upper trunk and the output as the head

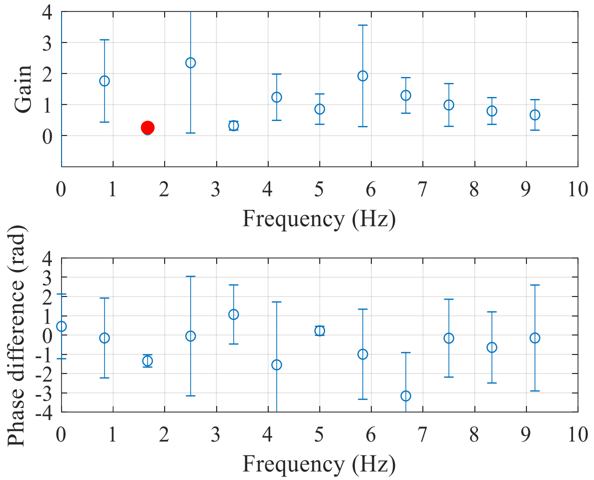


Fig.14 The average motion mode function in the walking direction with the input as the upper trunk and the output as the head

In the vertical direction, the most important gait frequency component has a gain of 1 and a phase difference of around 0, indicating that the head and the upper trunk move in a similar movement.

In the walking direction, the gain of the most important frequency component was around 0, indicating that the movement was smaller than that in the upper trunk.

4. Acceleration estimation

- The motion mode function obtained from the 14 times of trial data shown in Figure 13 and Figure 14, the head acceleration was estimated from the measured upper trunk acceleration for the remaining one trial data.

- The inverse Fourier transform is performed using a total of 5 points of the gait frequency component and its integer multiple components to convert them into a waveform in the time domain.

4. Acceleration estimation

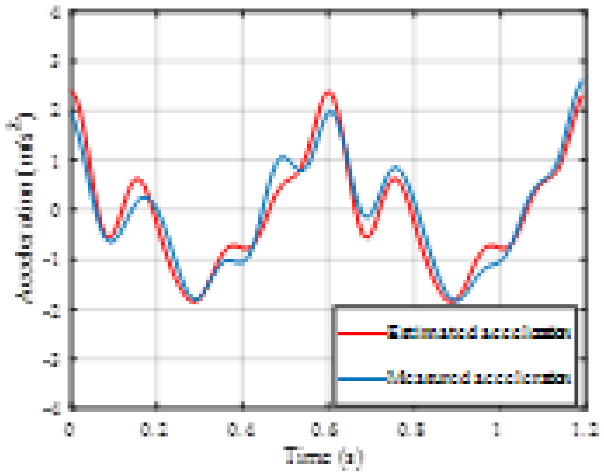


Fig.15 Comparison of head vertical acceleration estimated using the mean vertical motion mode function with measured values

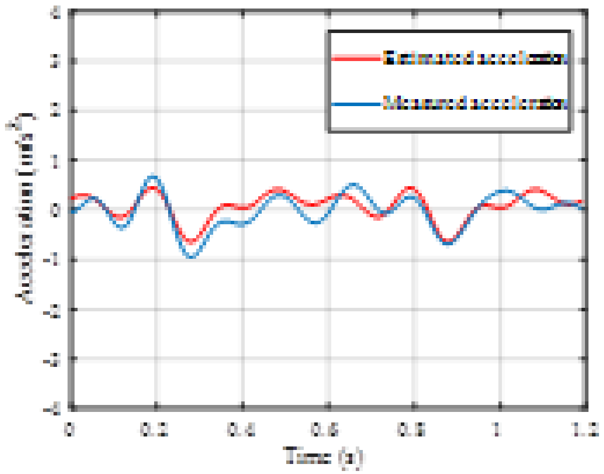


Fig.16 Comparison of head acceleration in the walking direction estimated using the mean vertical motion mode function with measured values

TABLE I. CORRELATION COEFFICIENT BETWEEN ESTIMATED ACCELERATION AND MEASURED ACCELERATION

	Vertical direction	**Walking direction**
Correlation Coefficient	0.961	0.822

- In the walking direction, the correlation coefficient is smaller than that in the vertical direction, but the correlation is stronger.

Conclusion

- In this paper, we have proposed a method to reduce the number of sensors to simplify the system and improve the accuracy of estimation.
- Frequency analysis was used to derive the motion mode function and to quantify the relationship between the movement of different parts of the body.
- As a result of Fourier analysis of the head acceleration and the upper trunk acceleration, it was found that the gait frequency and its integer multiple components have magnitude and are important for estimating the acceleration.
- Therefore, the inverse Fourier transform is performed using a total of 5 points of the gait frequency component and its integer multiple components to estimate the waveform of the head in the time domain.
- As a result, the correlation between the measured acceleration and the estimated acceleration at the head was high in both the vertical direction and the walking direction, and it was possible to accurately estimate.