Estimation of Floor Reaction Force During Walking Using Physical Inertial Force by Wireless Motion Sensor

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Abstract. Floor reaction force is widely used to evaluate walking. Generally, floor reaction force is measured by a floor reaction meter. However, floor reaction meter is not suitable for clinical practice due to the limitation in walk condition, measurement range and device size. This study suggests a simple method to estimate floor reaction force by processing dynamic acceleration information to be provided from small wireless motion sensors. In the experiment, optical motion capture and the floor reaction meter were used. The result shows that the sum of the inertial force of the whole body and gravity equal floor reaction force obtained through an experiment using optical motion capture. We consider that physical inertial force of the whole body could be estimated from the dynamic acceleration of the lower trunk and right/left thighs. A similar result obtained with the motion sensor. An estimation of floor reaction force by measuring the inertial force is effective, and much simpler walk analysis could be possible with using appropriate signal handling of wireless motion sensor information. This method can be applied to biofeedback.

Keywords: Floor reaction force · Physical inertial force · Gait analysis · Wireless motion sensor · Signal handling

1 Introduction

People walking every day. Reaction force by gait analysis is widely used in walk analysis in medical care and field sports [1]. Representative walk analysis is a combined system of floor reaction meter and optical motion capture. However, this system is not suitable for clinical practice due to the limitation in walk condition, measurement range and device size. Simpler system without floor reaction mater and optical motion capture is needed for a simple walk analysis. This study group suggests new analytical method to estimate of floor reaction force without the floor reaction meter [2]. This method uses only three motion sensors. This estimated system supposes that inertial force of the whole body equals floor reaction force. In the experiment, optical motion capture and the floor reaction meter were used. Estimate floor reaction force by processing dynamic acceleration information to be provided from small wireless motion sensors.

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2 Methods

Figure 1 shows a split plot design of physical. That estimates an inertial force from that mass and dynamic acceleration. Multiply physical mass coefficient by whole physical mass and the product is each physical mass. Table 1 shows physical mass coefficient. This coefficient used the Estimation of Inertia Properties of the Body Segments in Japanese Athletes [3].

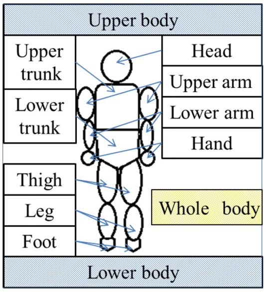

Fig. 1. Physical constitution.

Table 1. Physical information.

Body part	Mass ratio	Vertical direction acceleration	Movement direction acceleration
Head	0.069	$A_{hez}1$	$A_{hey}1$
Upper arm	0.027	$A_{uaz}2$	$A_{uay}2$
Lower arm	0.016	$A_{laz}3$	$A_{lay}3$
Hand	0.006	$A_{haz}4$	$A_{hay}4$
Upper trunk	0.302	$A_{utz}5$	$A_{uty}5$
Lower trunk	0.187	$A_{ltz}6$	$A_{lty}6$
Thigh	0.11	$A_{thz}7$	$A_{thy}7$
Leg	0.051	$A_{lez}8$	$A_{ley}8$
Foot	0.011	$A_{foz}9$	$A_{foy}9$

Dynamic acceleration a_z and a_y (Table 1) twice differentiates the vertical and movemant direction positional information. The dynamic acceleration of left/right part the sum of the right and left dynamic acceleration. A measurement interval equal h and a position (speed) of the time in the next expression i(i = 0–n) equal fi. (1) is a start point, (2) is differential calculus type of other time, (3) is endpoint.

$$f_0' = (-3f_0 + 4f_1 - f_2)/(2h) \tag{1}$$

$$f_i' = (-f_{i-1} + f_{i+1})/(2h) \tag{2}$$

$$f_n' = (f_{n-2} - 4f_{n-1} + 3f_n)/(2h) \tag{3}$$

Measurement dynamic acceleration included a high-frequency not to be included the normal walk. So make Butter worth digital filter in a Matlab, and to perform low-path handling of interception frequency 9 Hz for smooth [4].

Floor reaction force of the whole body F_w, Upper body F_u, and lower body F_l estimated all physical mass, dynamic acceleration of fifteen parts and acceleration of gravity. A coefficient including the gravity that the total of the consider body parts.

$$\begin{aligned} F_{uz} = M(&0.069a_{hez} + 0.027a_{uaz} + 0.016a_{laz} + 0.006a_{haz} \\ &+ 0.302a_{utz} + 0.187a_{ltz}) + 0.656Mg \end{aligned} \tag{4}$$

$$F_{lz} = M(0.11a_{thz} + 0.051a_{lez} + 0.011a_{foz}) + 0.344Mg \tag{5}$$

$$F_{wz} = F_{uz} + F_{lz} \tag{6}$$

Suppose that the upper body part ignores the dynamic acceleration of the arms as symmetric movement, the dynamic acceleration of a head and the body can represent dynamic acceleration of the lower trunk that is a center of gravity position from whole body, the dynamic acceleration of a lower body can represent dynamic acceleration of the right/left things that is lower part of the body centroid. Estimated floor reaction force of the representative upper body F_{repu}, the representative lower body F_{repl}, the representative whole body F_{repw}.

$$F_{repuz} = 0.558Ma_{ltz} + 0.656Mg \tag{7}$$

$$F_{replz} = 0.162Ma_{thz} + 0.344Mg \tag{8}$$

$$F_{repwz} = F_{repuz} + F_{replz} \tag{9}$$

As for The estimated floor reaction of vertical direction, (4)–(9) by replace vertical direction and movement direction (Table 1), expression for the acceleration of gravity.

Figure 2 shows two floor reaction meters (Tec Gihan Co.,Ltd. TF-4060) and ten motion captors (Motion Analysis Co.Ltd.) which uses walk experiment. Figure 3 shows the reflexive marker sticking position. The research participants measured three times of each three male physically unimpaired people in twenties at sampling frequency 100 Hz. Instruct them one leg instructed floor reaction maters adding up like Fig. 2 and to do a normal walk. The positional information that obtained from motion captors converts a plumb, a line into acceleration used expression (1)–(3). Let substitute smoothing acceleration and mass for (4)–(9) and let estimated floor reaction force. Compare the estimated floor reaction force from whole body, estimated floor reaction force and floor reaction force from reaction maters. Furthermore, experimented three motion sensors.

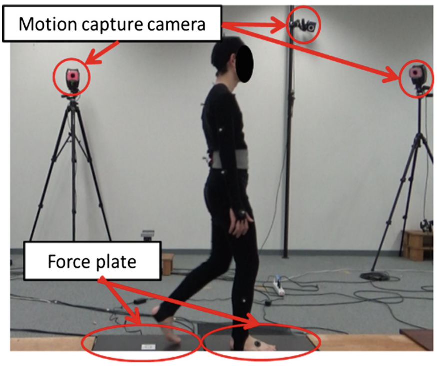

Fig. 2. Motion analysis system.

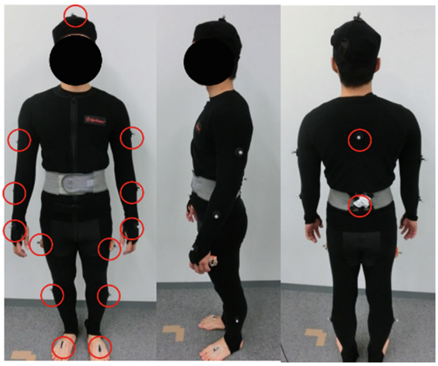

Fig. 3. Marker position.

3 Results

Figures 4 and 5 shows estimate floor reaction force by upper body F_u and the estimate floor reaction force by represent upper body F_{repu}. The result shows that the F_u displays similar amplitude cycle to the F_{repu}.

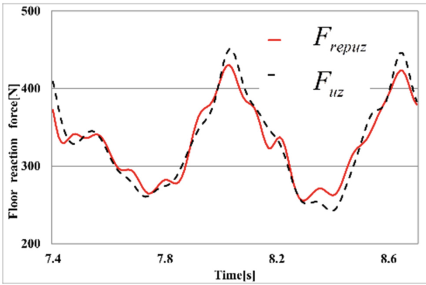

Fig. 4. Floor reaction force of vertical direction by the upper body.

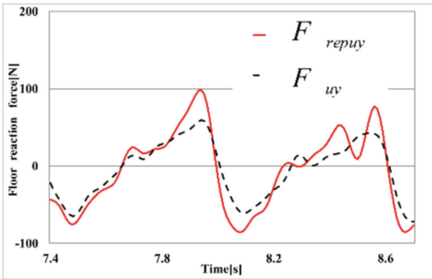

Fig. 5. Floor reaction force of movement direction by the upper body.

Figures 6 and 7 shows estimate floor reaction force by lower body F_l and the estimate floor reaction force by represent lower body F_{repl}. The result shows that the F_l displays similar amplitude cycle to the F_{repl}.

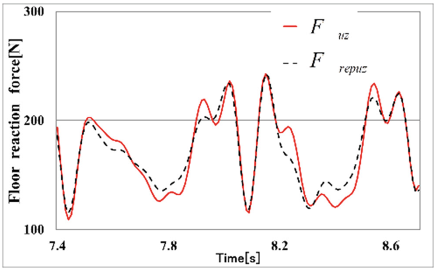

Fig. 6. Floor reaction force of vertical direction by the lower body.

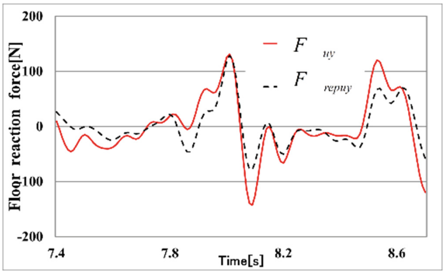

Fig. 7. Floor reaction force of movement direction by the lower body.

Figures 8 and 9 shows estimate floor reaction force by whole body F_w, the estimate floor reaction force by represent whole body F_{repw} and floor reaction by floor reaction maters. The result shows that the F_w displays similar amplitude cycle to the F_{repw}.

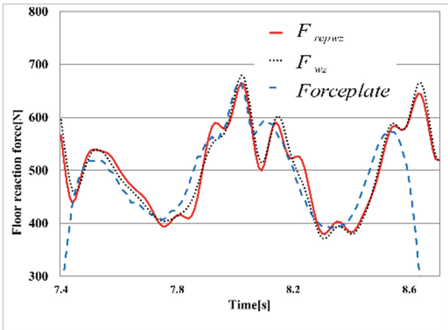

Fig. 8. Floor reaction force of vertical direction by the whole body.

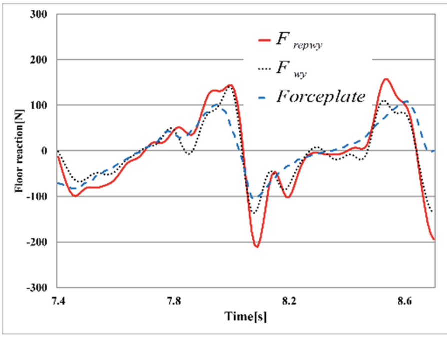

Fig. 9. Floor reaction force of movement direction by the whole body.

Next is the same experiment result using motion sensors. Figures 10 and 11 shows the estimate floor reaction force by represent whole body F_{repl} and three motion sensors. The result shows that the motion sensors displays similar amplitude cycle to the motion captures.

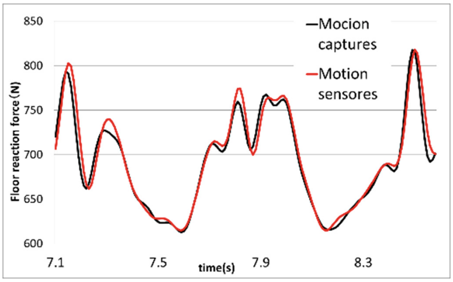

Fig. 10. Floor reaction force of vertical direction by the whole body.

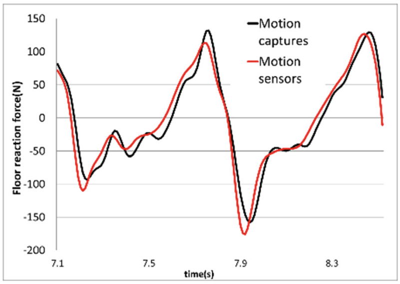

Fig. 11. Floor reaction force of movement direction by the whole body.

4 Discussion

The result shows that the sum of the inertial force of the whole body and gravity equal floor reaction force obtained through an experiment using optical motion capture. We consider that physical inertial force of the whole body could be estimated from the dynamic acceleration of the lower trunk and right/left thighs. The same result was obtained by wireless motion sensor. This study suggests that an estimation of floor reaction force by measuring the inertial force is effective, and much simpler walk analysis could be possible with using appropriate signal handling of wireless motion sensor information.

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