# Speed Control of an Omnidirectional Walker by Forearm Pressures

## [Considering Features in Force Exertion with Forearms]

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## ABSTRACT

An omnidirectional walker (ODW) is being developed to support those who have walking difficulties with their indoor movement. In order to enable the user to control the ODW intuitively and safely, a novel human robot interface has been proposed in previous studies to recognize a user's control intentions, including direction, speed, and rotation, according to his/her forearm pressures. Since the features in the pressures exerted by the wrists and elbows are different due to human factors, such as handedness, height and body weight, it is necessary to recognize the control intentions with consideration of these features in order to improve the operability. The features of force exertion with forearms was therefore investigated in a measurement experiment, and was introduced into the calculation of the speed intention by changing the ratio of speed to force according to the direction. A control experiment demonstrated that the consideration of the features resulted in a smoother path and a less burden to the forearms.

## Categories and Subject Descriptors

H.1.2 [User/Machine Systems]: Human information processing; I.2.9 [Robotics]: Operator interfaces

## General Terms

Human Factors

## Keywords

omnidirectional walker, forearm pressure, control intention, human-robot interface

## 1. INTRODUCTION

The people with walking difficulties are increasing rapidly with the population aging, which makes the caring of these people a big burden on their families and the society. Technical supports to these people are actively researched in order that they can live an independent life[1, 2]. Since walking is most fundamental among all the abilities required in daily life, robots to improve the walking ability of the elderly have become a popular research topic in the field of robotics. Walking support robots can be divided into three main categories according to their mechanism to support walking: exoskeleton-type[4], cane-type[5], and walker-type [3]. Walker-type robots, with high handiness and stable structures to guarantee user safety, is considered more useful than exoskeleton-type or cane-type robots, especially for those with severe walking disabilities. The authors along with colleagues have been developing an omnidirectional walker (ODW) to provide indoor movement support [6, 7]. The ODW can perform a complex combination of motions, which includes not only forward and backward motions, but also right and left motions, oblique motions, and rotations, and thus it can support the natural walking of the human. Since human walking is a complex combination of motions, which includes not only forward and backward motions, but also right and left motions, oblique motions, and rotations, an ODW that realizes human-like movement can provide general support to a user.

The ODW needs to follow the control walking intentions of a user to provide support. It is, therefore, necessary for the ODW to recognize the user's control intention, and thus to support the user's movement. A human robot interface(HRI) that can recognize omnidirectional intentions, including any direction on any angle, clockwise and anticlockwise rotations, and speed, is desirable to control the omnidirectional movement of the ODW. To address this issue, a novel interface has been proposed to recognize a user's omnidirectional control intentions according to the forearm pressures exerted onto the ODW by the user's wrists and el-

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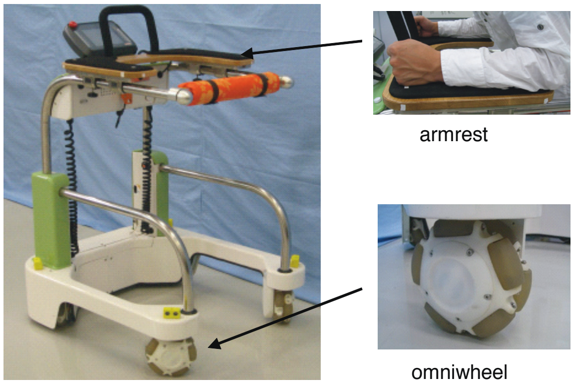


Figure 1: Omnidirectional walker

bows [8, 9, 10, 11]. Specifically, the speed intention was calculated in proportion to the resultant force of the pressures from the the user's wrists and elbows, hypothesizing that the stronger a user pushes the walker the faster he/she wants to walk. However, the ratio of speed to force in the calculation was the same regardless of the direction in which the user wanted to go, which neglected the features of force exertion of the wrists and the elbows. Since the features in the pressures exerted by the wrists and elbows may be different due to factors such as handedness, height and body weight, recognizing the speed intention with consideration of these features will make the HRI more usable. Hence, this study investigates the features of the force exertion with forearms in a measurement experiment, and introduces the features into the calculation of the speed intention by changing the ratio of speed to force according to the direction.

The remainder of this paper is organized as follows. Section II introduces the ODW and the user intention recognition with force sensors. Section III investigates the features of force exertion of the wrists and the elbows. Section IV proposes a method to calculate the speed intention of the user with consideration of the features statistically summarized in Section III. Section V conducts a control experiment in which the performance of the method with considering the features is compared with that of the previous method. Finally, Section VI concludes the paper and discusses the future work.

## 2. THE ODW AND USER INTENTION RECOGNITION

The structure of the ODW is shown in Fig. 1. The most important feature of the walker is the use of a special wheel, the powered omniwheel, shown in the bottom right of Fig. 1. The arrangement of the four omniwheels at the bottom of the walker body enables it to perform omnidirectional movement, the ability to move in any direction while maintaining its orientation. The walker height is adjustable from 900 to 1200 mm to accommodate the different heights of the users. The maximum speed is set to 0.25 m/s which is slow to ensure user safety. Four ultrasonic sensors to detect obstacles and touch sensors to detect the falling of the user are also equipped to improve safety.

The user's control intentions, including the direction in which and the speed at which to walk, need to be known by the ODW in order that the ODW can smoothly follow and support the user's walking. To address this issue, a novel interface has been proposed to recognize a user's control intentions according to the forearm pressures exerted on the ODW by the user's wrists and elbows [8]. A user usually puts his/her forearms onto the armrest of the ODW (top right of Fig. 1). When intending to go in a direction, the user will intuitively push the armrest. Hence, it is possible to recognize the user's control intention according to the force interaction between the user and the ODW. Four force sensors, S_FR, S_FL, S_BL and S_BR, to measure a user|s forearm pressure are embedded in the armrest of the ODW as shown in Fig. 2, to identify direction intention based on the pressure information from the sensors. The sensors were equipped on the four poles connecting the armrest to the body of the ODW. Since the armrest has a rigid bottom, all the loads that a user exerts on the armrest are finally transmitted to the poles and detected by the sensors. $w\_fr$, $w\_fl$, $w\_br$, and $w\_bl$ are the pressures detected by S_FR, S_FL, S_BL and S_BR, respectively.

This approach can recognize both directional and speed intentions. Since the force is detected by sensors embedded in the armrest, a user can intuitively push the ODW with his/her forearms, while paying less attention to manipulating devices, such as a joystick and a touch panel, in order to input instructions. Hence, safety is improved because users can keep supporting their body weight with their forearms while controlling the ODW. The cost using the force sensors is lower without the need for any biological measurement system compared with other direct interfaces that recognize human intentions through EEGs or EMGs[12, 13]. Compared with other studies using force interaction in the HRI such as [5], we use one-axis force sensors other than multi-axis force sensors. The control intention is recognized by the vertical pressures without considering the horizontal forces because it requires the involvement of the lower limbs to adjust the horizontal forces, which is difficult for a user with walking difficulties. Furthermore, one-axis force sensors are much cheaper and can withstand more forces than multi-axis force sensors.

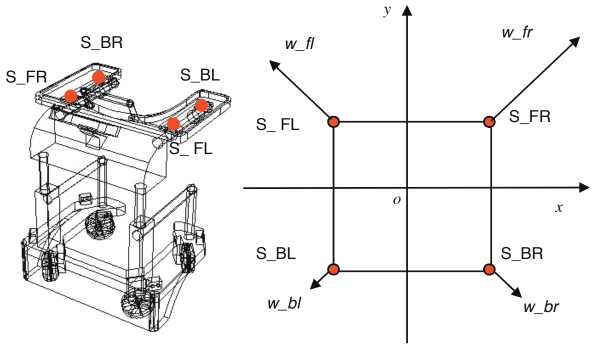


Figure 2: Sensor locations and parameters

In previous studies, the relationship between forearm pressure and user intentions was extracted as fuzzy rules and an algorithm was proposed for directional intention identification based on the distance-type fuzzy reasoning method[9, 14]; the speed intention was calculated in proportion to the resultant forearm pressure applied by the user[10]; and the rotational intention was recognized by adding two fuzzy rules related to clockwise and anticlockwise rotations[11].

## 3. MEASUREMENT OF THE FEATURES IN FORCE EXERTION WITH FOREARMS

The features in force exertion with forearms were investigated in a measurement experiment. Eight male subjects aged 20-25 years participated in the experiment. All of them were right-handed. They were instructed to push the ODW by using their forearms as if they wanted to go in the following four directions: 1) 45° - Front right (FR), 2) 135° - Front left (FL), 3) 225° - Back left (BL), and 4) 315° - Back right (BR). Instructions about the strength with which to push, that is to push strongly or slightly, were not given in order to study the natural features of force exertion.

The maximum pressures detected by the four sensors are shown in Fig. 3 to illustrate the features of the four direction. Fig. 3 only shows the pressures measured by the sensor corresponding to the four directions: $w\_fr$ for FR, $w\_fl$ for FL, $w\_bl$ for BL, and $w\_br$ for BR. The mean pressures of the 8 subjects are also provided. The experimental results suggest that although individual differences existed, the pressure information had great relevance to the specific sensors. On average, the pressures exerted by the elbows were greater than those by the wrists; and although not statistically significant, the pressures exerted by the left forearm were greater than those by the right forearm.

It is easier to push with the elbows than with the wrists since the body weight directly acts on the elbows, and thus the subjects on average exerted more pressure with the elbows than with the wrists. It is also implied that the subjects tended to exerted more forces with the non-dominant hand which are not as frequently used in daily life as the dominant hand.

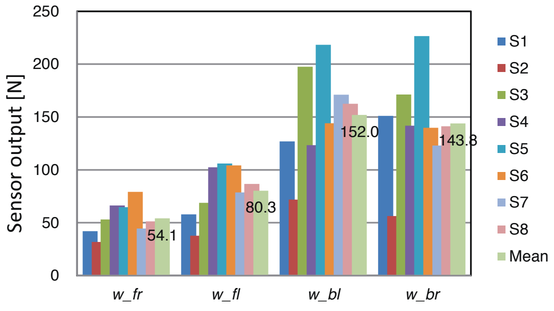


Figure 3: Forearm pressures

It is necessary to consider these features in the HRI to improve the user-friendliness. As to the directional intention recognition, these features have been implicitly included in the process of knowledge extraction which was based on the statistical features of the forearm pressures[9]. However, these features were neglected in the calculation of speed intention by an invariant ratio of speed to force[10]. This study involves these features into the calculation by a ratio that changes according to the directional intention.

## 4. SPEED INTENTION CALCULATION WITH CONSIDERATION OF THE FEATURES

The speed intention was identified according to the magnitude of the resultant force a user exerted on the ODW[10]. It is hypothesized that the stronger the user pushes the walker, the faster he/she wants to walk. The resultant forearm pressure was calculated in the coordinate system shown in the right of Fig. 2. Suppose that pressures $w\_fr$, $w\_fl$, $w\_br$, and $w\_bl$ are considered force vectors with directions 45°, 135°, 315°, and 225°, respectively, on the vertices of a square. The resultant force vector $f$ of the four force vectors is calculated as follows.

$$f = \sqrt{(w\_fl - w\_br)^2 + (w\_fr - w\_bl)^2} \qquad (1)$$

The user's velocity intention is calculated by Eq. 2,

$$v = \frac{f}{F} v_{max} \qquad (2)$$

where $F$ is the parameter to determine the ratio between $f$ and $v$. Since $F$ may be different from person to person because of the user weight, height, muscle strength, and so on, $F$ is calibrated before a user uses the ODW.

In the previous study, $F$ was set to be an invariable parameter no matter in which direction the user wanted to walk. As illustrated by the results of the experiment in Section 3, $F$ should be determined according to the direction. Intuitively, $F$ need to be smaller when the user walks forward than that when the user walks backward because it is more difficult to exert forces with the wrists that the elbows. In order to determine $F$ according to the direction, the features of $F$ in any direction is required. However, it is not applicable to measure all the forces in all the directions. An algorithm is therefore needed to approximate $F$ in a direction with the limited known features.

In the previous experiment, the features of the four directions 45°, 135°, 315°, and 225°, were investigated. The directional intentions of the four directions are usually expressed dominantly by the pressure measured by a single sensor due to the sensor locations. Thus, the features on the four directions are relatively easier to measure, and it is desirable to approximate $F$ according to the features on these four directions. In the current study, $F$ is defined as a piecewise function according to the intended direction as follows to consider the features in force exertion with forearms.

$$F = \begin{cases} \frac{f_{fr} f_{fl}}{\sqrt{f_{fr}^2 + (f_{fr}^2 - f_{fl}^2) cos^2(\alpha)}} & (\frac{\pi}{4} \leqslant \alpha < \frac{3\pi}{4}) \\ \frac{f_{fl} f_{bl}}{\sqrt{f_{fl}^2 + (f_{fl}^2 - f_{bl}^2) cos^2(\alpha)}} & (\frac{3\pi}{4} \leqslant \alpha < \frac{5\pi}{4}) \\ \frac{f_{bl} f_{br}}{\sqrt{f_{bl}^2 + (f_{bl}^2 - f_{br}^2) cos^2(\alpha)}} & (\frac{5\pi}{4} \leqslant \alpha < \frac{7\pi}{4}) \\ \frac{f_{br} f_{fr}}{\sqrt{f_{br}^2 + (f_{br}^2 - f_{fr}^2) cos^2(\alpha)}} & (-\frac{\pi}{4} \leqslant \alpha < \frac{\pi}{4}) \end{cases} \qquad (3)$$

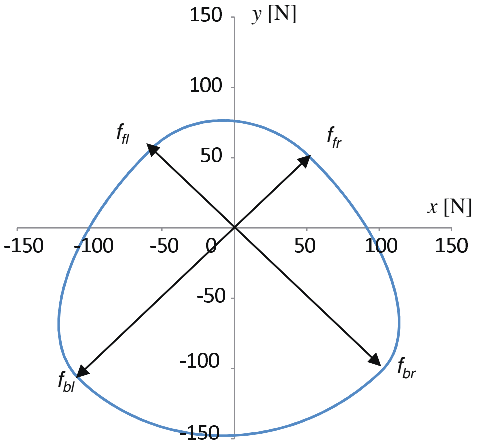


Figure 4: The example of $F$

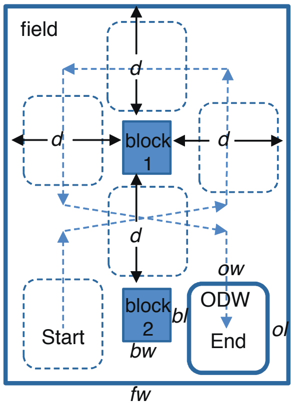
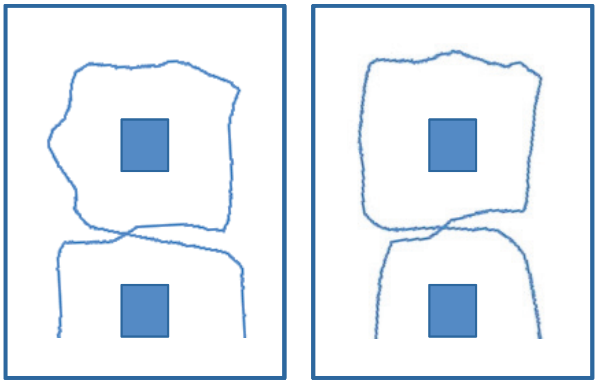


Figure 5: Experiment Settings

where $\alpha$ is the intended direction, which is recognized using the method proposed in [9]. $f_{fr}$, $f_{fl}$, $f_{bl}$, and $f_{br}$ are the maximum forces detected by S_FR, S_FL, S_BL and S_BR, respectively. $f_{fr}$, $f_{fl}$, $f_{bl}$, and $f_{br}$ are considered as the features on the four directions. Eq. 3 calculates $F$ on direction $\alpha$ based on the elliptic equation with $f_{fr}$, $f_{fl}$, $f_{bl}$, and $f_{br}$ being the major and minor axes. This definition is consistent with the intuitive trend of the maximum forces changing from one of the four directions to an adjacent direction. Fig. 4 shows the example of $f_{max}$ calculated by Eq. 3 with $f_{fr}$=54.1 N, $f_{fl}$=80.3 N, $f_{bl}$=152.0 N, and $f_{br}$=143.8 N, which are the mean maximum forces detected by S_FR, S_FL, S_BL and S_BR, in Fig. 3.

## 5. CONTROL EXPERIMENT

A control experiment was conducted to investigate the effect of considering the features with Eq. 3. The ODW was controlled in an indoor environment with two obstacles as shown in Fig. 5. A healthy subject aged 28 yr participated in the experiment. In the experiment, the subject was instructed to control the ODW with forearms to travel around the obstacles from the start point to the endpoint without rotation. Along the path from the start point, the ODW was controlled moving forward, rightward, forward, leftward, backward, rightward, and backward to the end point. The values of the parameters are as follows: $fl$=3.5 m, $fw$=2.7 m, $d$=1.1 m, $bl$=0.5 m, $bw$=0.45 m, $ol$=0.85 m, and $ow$=0.75 m. The subject controlled the ODW twice, one with the $F$ of Fig. 4 to determine the speed in a direction and the other with an invariant $F$ of 107.5, which is the average of $f_{fr}$, $f_{fl}$, $f_{bl}$, and $f_{br}$ in the previous experiment, as a comparison.



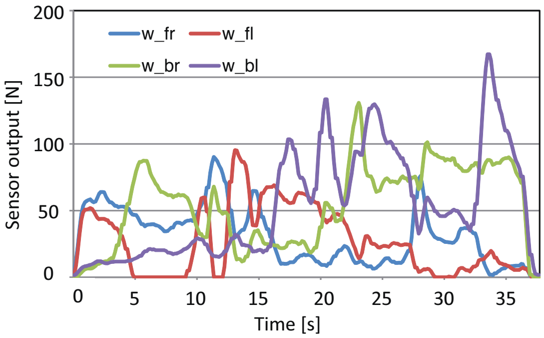
(a). Without using Eq. 3 (b). With using Eq. 3

Figure 6: Paths of the ODW

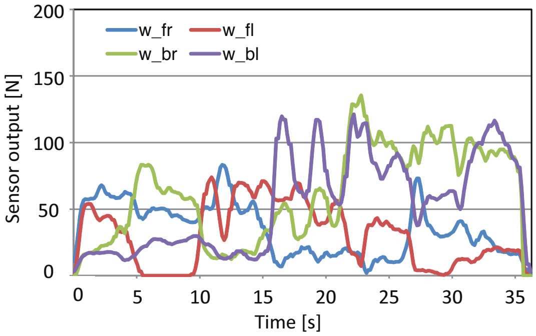
The paths of the ODW in the experiment were recorded with a camera, as shown in Fig 6. The path was smoother with using Eq. 3 (Fig 6(b)) than that without using Eq. 3 (Fig 6(a)). In both trials, the subject successfully controlled the ODW without colliding the obstacles from the start point to the end point. Considering the size of the ODW and the width of the passage, the experimental results suggest that the HRI proposed is applicable to control the ODW in a narrow environment.

The forearm pressures of the subject with and without using Eq. 3 are shown in Fig 7(a) and Fig 7(b), respectively. After considering the features in forearm pressures, the forces used to control the ODW became smaller on average, which the burden of the subject to adjust the speed was relieved. This indicated that the burden to control the ODW was relieved by introducing the features into the calculation. The speed intention calculated during the experiment are shown in Fig 8. The fluctuation in the speed without using Eq. 3 (Fig 6(a)) was much larger than that with using Eq. 3 (Fig 8(b)). Note that 0.25 m/s is the maximum speed of the ODW. It is suggested by comparing the results in Fig. 6-8 that the usability of the control method was significantly improved after introducing the features into the calculation of the speed intention.

Since the body weight mainly acts on the pressure of the elbows due to the body structure, it is easier to exert force with the elbows. Eq. 3 makes the force exertion with the wrists as easy as that with the elbows by adjusting the proportion according to the features in the force exertion with forearms. Although the control experiment was performed by a healthy subject, the performance can be achieved by calibrating the parameters $f_{fr}$, $f_{fl}$, $f_{bl}$, and $f_{br}$ in Eq. 3 when the method is applied to a specific user. More experiments including the experiments with the elderly are necessary in the future work to further validate the proposed method. The walking styles in the experiments will also be measured and discussed.



(a). Without using Eq. 3



(b). With using Eq. 3

Figure 7: Forearm pressures

## 6. CONCLUSIONS

A novel HRI has been proposed to recognize control intentions from forearm pressures to control the ODW which is developed to follow and support the indoor movement of the elderly and the disabled. This paper investigates the features of force exertion with forearms, and reflects the features in the calculation of speed intention by the definition of the ratio between speed and force. The results of a control experiment confirmed the improvement in the usability of the HRI contributed by considering the features. Future work will conduct more experiments to investigate the features of force exertion by different types of persons, such as the elderly and the disabled. The evaluation of the ODW with the control intention recognition method in some elderly care facilities will also be considered.

## 7. ACKNOWLEDGMENTS

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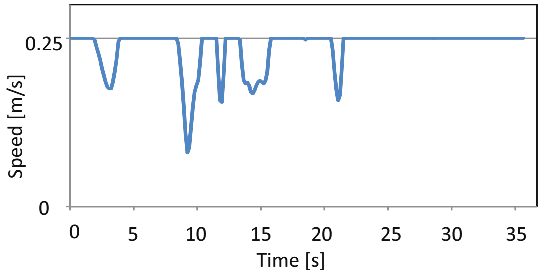
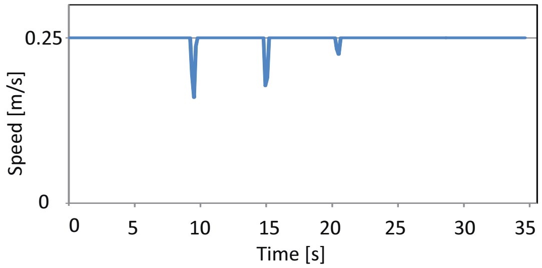


(a). Without using Eq. 3



(b). With using Eq. 3

Figure 8: Speed intention calculated

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