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Control of an Omnidirectional Walking Support Walker by Forearm Pressures

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***Abstract*—We have been developing an omnidirectional walker (ODW) for walking support. In walking support, it is necessary control the ODW following the user's direction and velocity intentions. In this paper, a novel interface is proposed to recognize the user's intentions according to the forearm pressures. The forearm pressures exerted to the ODW by the user with wrists and elbows are measured by 4 force sensors embedded in the ODW's armrest. 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. We conduct a path tracking experiment with the proposed method. The results show that the algorithm is applicable to control the ODW.**

I. Introduction

THERE are many people with walking disabilities due to either age or accidents. Therefore, the development of walking machines that can efficiently conduct walking rehabilitation and walking support is highly desirable. The authors along with colleagues have been developing an omnidirectional walker (ODW) [1], which allows a complex combination of motions, which includes not only forward and backward motions, but also right and left motions, oblique motions, and rotations.

Training programs for rehabilitation are stored in the walker and the user follows the ODW's movement to exercise during walking rehabilitation. Its effectiveness in walking rehabilitation was verified by clinical tests. However, during walking support with the ODW, it is necessary to know where the user intends to go and how the user intends to get there based on user manipulation, so that the ODW can support the user's movement according to his/her intentions. Actual intentions must, however, be identified from physical manipulation because a user's intention and physical manipulation are not always mutually consistent. To address this issue, a novel interface is proposed to recognize a user's direction and velocity intentions according to the forearm pressures exerted to the ODW by the user's wrists and elbows. The forearm pressures are measured by 4 sensors embedded in the ODW's armrest [2][3]. The relationship between forearm pressures and intentions was extracted as fuzzy rules and an algorithm was proposed for intention identification based on the distance type fuzzy reasoning method (DTFRM) [4].

This paper is organized as follows. Section II introduces the structure and modeling of the ODW. Section III describes the equipment of the force sensors and the experiment to measure the relationship between forearm pressure and direction intention. In Section IV, the relationship between forearm pressure and intentions is extracted as fuzzy rules and a directional intention identification algorithm is proposed based on the DTFRM. The algorithm's effectiveness is verified in a path tracking experiment. Section V concludes the paper and gives a plan for the future work.

II. Structure and Modeling of the Omni-directional Walker

The most important feature of the walker is the use of omniwheels. The structure of the ODW is shown in Fig. 1. An arrangement of four omniwheels at the bottom of the walker body enables the walker to move in any direction while maintaining its orientation.

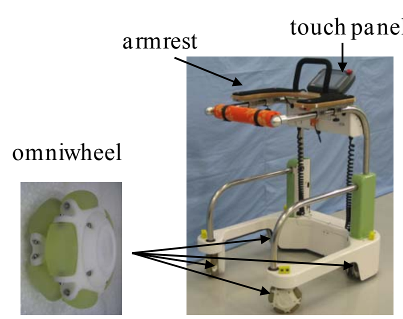

Fig. 1. Omni-directional walker and its omni wheels.

The physical parameters of the omni-directional walker are listed in Table 1. Two telescopic poles are designed to support both the upper part of the walker and the load from

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TABLE I
PHYSICAL PARAMETERS OF THE ODW

Parameter	Value	Unit
Height	900–1200	mm
Arm	600	mm
Mass	58	kg
Maximum load	80	kg
Maximum speed	0.25	m/s

the user. The walker height is adjustable from 900 to 1200 mm to accommodate the different heights of the users. The mass of the walker is 77 kg and the maximum speed is set to 0.25 m/s to ensure user safety. The coordinate settings and structural model are shown in Fig. 2.

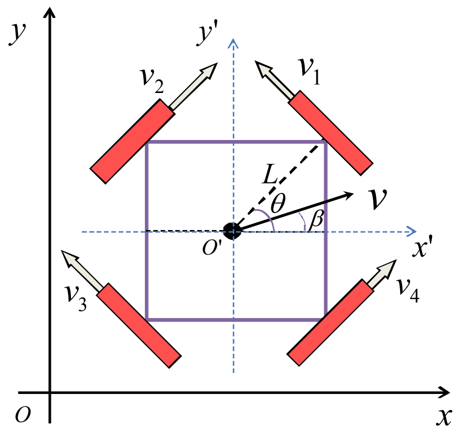


Fig. 2. Structural model of the omni-directional walker.

The parameters and coordinate system are as follows:

$\sum(x, y, O)$: Absolute coordinate system.

$\sum(x', y', O')$: Translation coordinate system of $\sum(x, y, O)$.

v: Velocity of the omnidirectional walker.

v_i: Velocity of an omnidirectional wheels (i=1,2,3,4).

L: Distance from the center of the walker to each omniwheel.

β: Angle between the x'-axis and the direction of v.

θ: Angle between the x'-axis and the position of the first omni-directional wheel.

Using the coordinate system in Fig. 2, the kinematic equations of the ODW are

$$\begin{cases} v_1 = -v_x \sin\theta + v_y \sin(\frac{\pi}{2} - \theta) + L\dot{\theta} \\ v_2 = v_x \cos\theta + v_y \cos(\frac{\pi}{2} - \theta) - L\dot{\theta} \\ v_3 = -v_x \sin\theta + v_y \sin(\frac{\pi}{2} - \theta) - L\dot{\theta} \\ v_4 = v_x \cos\theta + v_y \cos(\frac{\pi}{2} - \theta) + L\dot{\theta} \end{cases} \quad (1)$$

where $v_x = v\cos\beta$ and $v_y = v\sin\beta$ are the x and y components of the walker's velocity, respectively. The purpose of this study is to develop a method to identify the user intentions of v and β

III. FOREARM PRESSURE MEASUREMENT AND USER INTENTION IDENTIFICATION USING DTFRM

A. Sensor Equipment

Force sensors to measure the user's forearm pressure are embedded in the ODW armrest as shown in Fig.3, to identify direction intention based on the pressure information from the sensors. This novel interface can also be applied to other apparatuses such as wheelchairs. It has the following three advantages: 1) Safety during walking is ensured because the users need not intentionally manipulate devices to input directional instructions. 2) Cost is lower without using any biological measurement system compared with other direct interfaces that determine the human intentions through EEG or EMG [5].

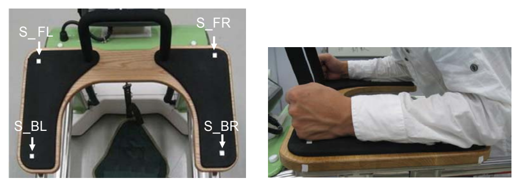


Fig. 3. Equipment of load sensors.

B. Velocity Intention Identification

The velocity intention is identified according to the resultant force the user exerts to the ODW. That is, the stronger the user pushes the walker, the faster he/she wants to walk. Resultant forearm pressure was calculated in the coordinate system shown in Fig. 4. Suppose the pressures measured by sensors S_FR, S_FL, S_BR and S_BL are w_fr, w_fl, w_br, and w_bl. They are considered force vectors with lengths of w_fr, w_fl, w_br, and w_bl and directions of 45°, 135°, 315° and 225°, on the vertices of a square.

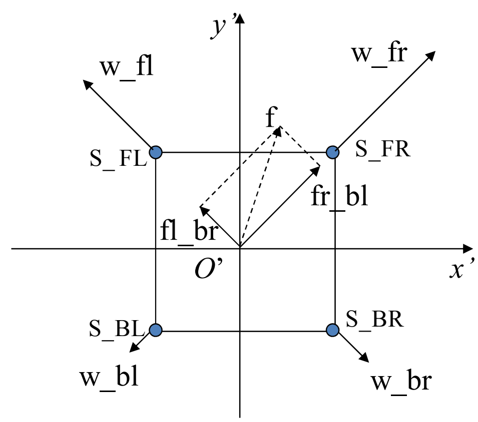


Fig. 4. Calculation of resultant output.

The resultant force vector of the four force vectors is f. f is calculated as follows.

$$f = \sqrt{fl\_br^2 + fr\_bl^2} \quad (2)$$

where fl_br= w_fl - w_br and fr_bl = w_fr - w_bl. The user's velocity intention is identified by equation (3)

$$v = \frac{f}{f_{\max}} v_{\max} \tag{3}$$

where $f_{\max}$ is the maximum resultant force of the user. Since $f_{\max}$ may be different from person to person because of their weight, height, muscle strength, and so on, $f_{\max}$ is calibrated every time before a user uses the ODW.

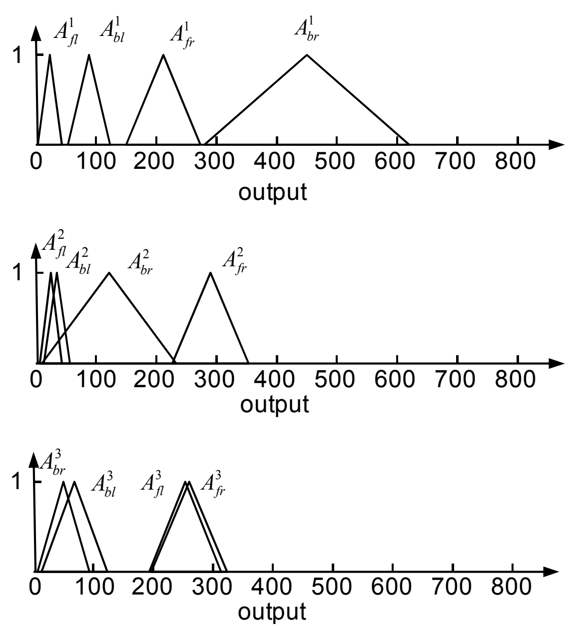
C. Direction Intention Identification

The relationship between direction intention and forearm pressures was investigated in a measurement experiment. Eight healthy male volunteers aged 20-25 yr participated in the experiment. Subjects were instructed to push the ODW with their forearms as if they wanted to go in the following 8 directions: 1) 0° - Right (R), 2) 45° - Forward right (FR), 3) 90° - Forward (F), 4) 135° - Forward left (FL), 5) 180° - Left (L), 6) 225° - Backward left(BL), 7) 270° - Backward (B), and (8) 315° - Backward right (BR).

Great relevance is found between forearm pressures and direction intention, which can be referenced to identify directional intention from forearm pressure. Based on the means and standard deviations (SD) of sensor output for the 8 subjects on each intended direction, the following 8 fuzzy rules were extracted.

$$\begin{aligned} Rule^i: if \quad & w\_fr = A_{fr}^i \quad w\_fl = A_{fl}^i, \\ & w\_br = A_{br}^i, \quad w\_bl = A_{bl}^i \qquad \Rightarrow \quad y = \beta^i \\ & i = 1,2,\cdots,8 \end{aligned} \tag{4}$$

where β^i is the *i*th directional intention. are listed in Table 1. *A* is a triangle-type fuzzy set defined by the means and SDs, with its vertices being (mean – SD, 0), (mean, 1) and (mean + SD, 0). The antecedents of rules 1-8 are shown in Fig. 5.



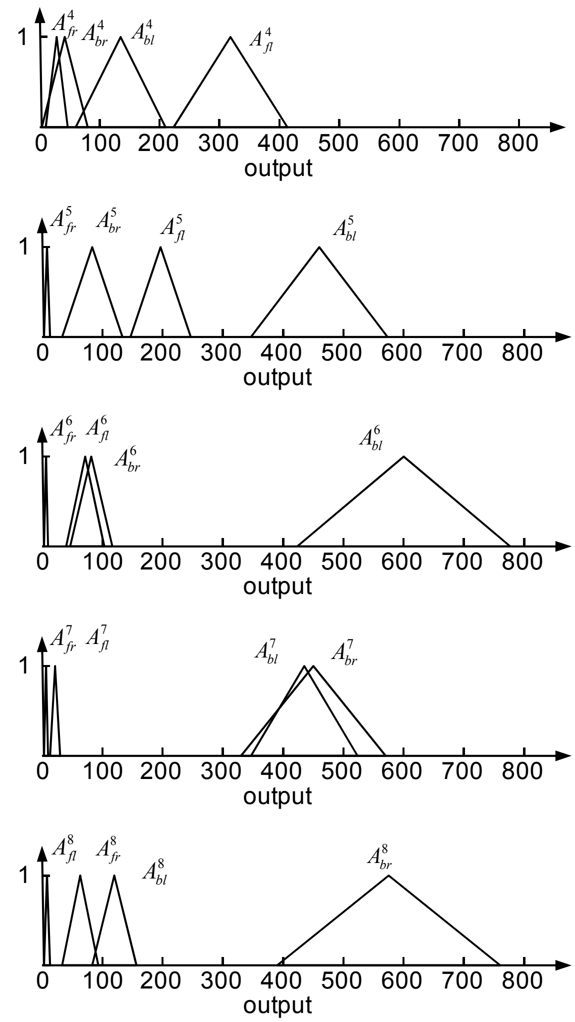


Fig. 5. Antecedents of fuzzy Rules. The unit of the sensor output is 0.025kgf, abridged for convenience.

The rule's consequents in Eq. (4) are represented by the following angles:

R: $\beta^1 = 360 \times l + 0$, RF: $\beta^2 = 360 \times l + 45$

F: $\beta^3 = 360 \times l + 90$, LF: $\beta^4 = 360 \times l + 135$

L: $\beta^5 = 360 \times l + 180$, BL: $\beta^6 = 360 \times l + 225$

B: $\beta^7 = 360 \times l + 270$, BR: $\beta^8 = 360 \times l + 315$

where l= -1, 0, 1.

The DTFRM is used to reason direction intention from forearm pressures. The directional intention identification based on the fuzzy rules can be described as follows.

Fact: $w\_fr = a\_fr, w\_fl = a\_fl, w\_br = a\_br, w\_bl = a\_bl$

Result: $y = \beta$

The fuzzy sets in the fact to be input are fuzzy singletons whose membership functions are 1 at the points of average outputs of the four sensors. Reasoning result, the intended direction, is also a fuzzy singleton.

IV. DIRECTION CONTROL EXPERIMENT

A path tracking experiment was carried out to verify the user intention identification method. In the experiment, a healthy male volunteers aged 32 yr was instructed to control the ODW to follow the path shown in Fig. 6 continuously.

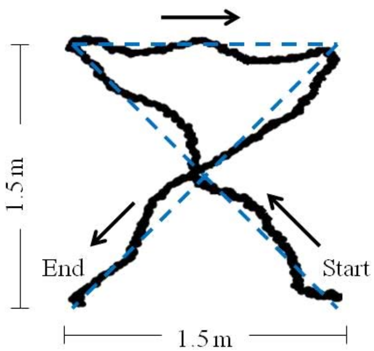


Fig. 6. Path tracking results. Dotted blue line is the reference path. Solid dark line is the track of the ODW.

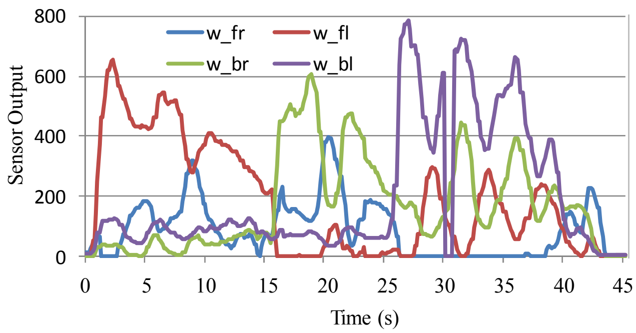


Fig. 7. Sensors' outputs.

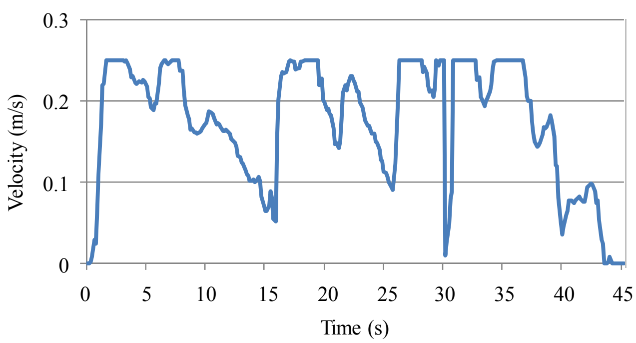


Fig. 8. Velocity of the ODW. Note that the maximum velocity of the ODW is 0.25 m/s.

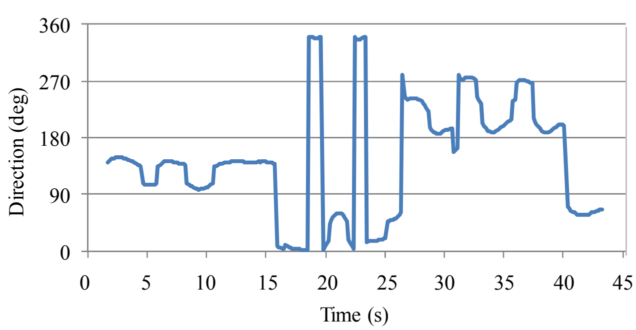


Fig. 9. Direction of the ODW.

Since the subject placed his arm against the armrest to partially support body weight throughout the experiments, the pressures for direction intention should be significantly larger than the baseline due to body support. In the experiment, the direction intention was calculated only when the average output of at least one sensor in one second was larger than 100. This condition ensures that increases in pressures are significant enough to be considered as direction intention.

Fig. 6 shows that the subject adjusted the direction of the walker as he walked. The subject revised the direction from time to time on the way until reaching the goal. Fig.7 shows sensor's outputs during the experiment. Fig.8 shows velocity of the ODW, which was calculated with equation (3). Fig.9. shows the reasoned direction intention. The blank period in the direction intention is caused by the data that do not meet the condition. Although the reasoning results vibrate sharply from 16s to 23s, their directions are similar (rightward).

There might be three main reasons for the errors in the path tracking experiment: 1) Human beings cannot control their forearm pressure accurately. 2) The fuzzy rules for direction intention are based on statistical experiment results. Individual differences are not considered. 3) During path tracking, error happens due to the center of gravity shift and the load changes caused by the user [6][7].

V. CONCLUSION

A novel interface to control the ODW in walking support is proposed to accurately identify the user's velocity and direction intentions based on forearm pressures. Future work will focus on improving its usability to make it comfortable for the people with walking disabilities.

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