

Directional Control of an Omnidirectional Walker for Walking Support with Forearm Pressures

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Abstract— Walking is a fundamental human ability necessary for everyday life. We have developed an omnidirectional walker (ODW) for walking support to those who have walking disabilities. It is necessary for the ODW to know which direction the user is intending to go during walking support. A novel interface is proposed for the ODW to recognize directional intention according to the user's forearm pressures which are measured by force sensors embedded in the armrest. The relationship between forearm pressures and directional intention was extracted as fuzzy rules and an algorithm is proposed for directional intention identification based on distance type fuzzy reasoning method. In this paper, we conduct walking support experiments with the proposed method. The results show that the algorithm is applicable to directional control in walking support.

Keywords- walking support; omnidirectional walker; directional intention identification; distance type fuzzy reasoning method

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. In previous studies, the authors along with colleagues have developed an omnidirectional walker (ODW) [1][2]. This walker allows omnidirectional movement. In walking rehabilitation, training programs are stored in the walker so that rehabilitation can be carried out without the presence of physical therapists. Its effectiveness in walking rehabilitation was verified by clinical tests [3][4].

In walking support, it is necessary for the ODW to know the direction the user intends to go based on user manipulation. Actual directional intent must, however, be identified from physical manipulation because a user's directional intent and physical manipulation are not always mutually consistent. In this paper, a novel interface is proposed to recognize a user's directional intention according to the forearm pressures exerted to the ODW by the user with wrists and elbows. The forearm

pressures are measured by 4 sensors embedded in the ODW's armrest [5][6]. The relationship between forearm pressure and directional intention was extracted as fuzzy rules and an algorithm was proposed for directional intention identification based on distance type fuzzy reasoning method (DTFRM) [7][8]. The effectiveness of the algorithm was verified by experiment results. However, in the previous experiments the ODW was fixed on the ground. The intended directions were identified only when the ODW was stationary. If the ODW moves while the subject pushes it, forearm pressures should differ due to body sway and change of the supporting foot. This is not convenient in real walking support. Therefore, in this paper, we examine the effectiveness of the proposed method in walking support experiments when the ODW moves. The results show that users can control the ODW with the proposed method by adjusting direction as they walk.

II. STRUCTURE AND MODEL OF THE OMNIDIRECTIONAL WALKER

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

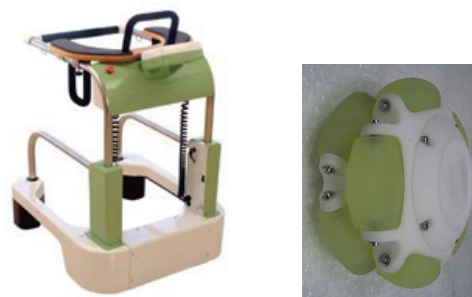


Figure 1. ODW and one of its omni wheels.

TABLE I. PHYSICAL PARAMETERS OF THE WALKER

Parameter	Value	Unit
Height	900–1200	mm
Arm	600	mm
Mass	58	kg
Maximum load	77	kg
Maximum speed	0.25	m/s

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

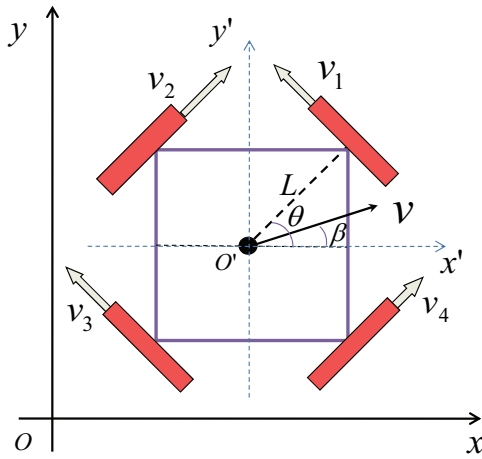


Figure 2. Structural model of the omnidirectional walker.

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

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

v : Speed of the ODW.

v_i : Speed of an omniwheels ($i=1,2,3,4$).

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 omniwheel.

Using the coordinate system shown 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.

III. DIRECTIONAL CONTROL BY FOREARM PRESSURES USING DISTANCE TYPE FUZZY REASONING METHOD[7][8]

Force sensors to measure the user's forearm pressure are embedded in the ODW armrest as shown in Fig.3, to identify directional 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 [9].

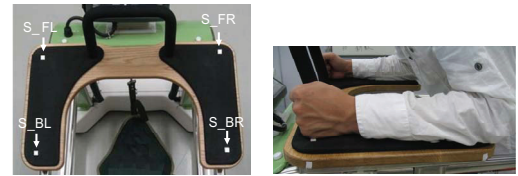


Figure 3. Equipment of load sensors.

The relationship between directional 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). There is great relevance between forearm pressures and directional intention, which can be referenced to identify directional intention from forearm pressure. Means and standard deviations (SD) of sensor output for the 8 subjects on each intended direction are listed in Table 1 (The unit is 0.025kgf, abridged for convenience below).

TABLE II. SENSORS' OUTPUT STATISTICS

	w_fr		w_fl		w_br		w_bl	
	mean	SD	mean	SD	mean	SD	Mean	SD
R	216.5	58.1	17.1	15.3	454.1	165.5	81.9	45.7
FR	290.3	66.1	23.9	18.2	121.7	110.6	34.8	20.4
F	255.7	57.8	249.5	55.0	51.1	44.5	69.4	44.4
FL	17.6	13.9	321.3	93.65	41.5	41.2	128.3	83.2
L	4.7	4.65	199.9	55.4	81.0	49.9	465.1	117.0
BL	3.4	3.2	74.1	30.7	82.6	32.9	607.9	174.8
B	3.0	2.7	16.9	9.7	454.9	117.7	440.5	83.8
BR	66.9	30.8	3.2	2.7	575.4	179.4	109.8	36.9

w_fr, w_fl, w_br, and w_bl are outputs of sensors S_FR, S_FL, S_BR and S_BL.

Directional intention can be reasoned from forearm pressures using the fuzzy rules about relevance between forearm pressures and directional intentions extracted in Section 3. Based on these results, the following fuzzy rules were extracted as fuzzy rules, used as knowledge in fuzzy reasoning.

$$\begin{aligned} \text{Rule}^i : \text{if } w_fr = A_{fr}^i \quad w_fl = A_{fl}^i, \\ w_br = A_{br}^i, \quad w_bl = A_{bl}^i \quad \Rightarrow \quad y = \beta^i \\ i = 1, 2, \dots, 8 \end{aligned}$$

where i is numbers 1) - 8) in Table 1 and β^i i th directional intention. A is a triangle-type fuzzy set defined by the data in Table 1, with its vertices being (mean - SD, 0), (mean, 1) and (mean + SD, 0). 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.

$$\text{Fact: } w_fr = a_fr, w_fl = a_fl, w_br = a_br, w_bl = a_bl$$

$$\text{Result: } y = \beta$$

The DTFRM is used to reason directional intention from forearm pressure. An angle can be specified by innumerable degrees. However, the conclusion of DTFRM is affected by the specific degrees due to its asymptotic characteristic. If, for example, the distances between input fact and Rule^1 , Rule^8 are much smaller than those between facts and the other rules, the reasoning conclusion, or intended direction, should be between R and BR due to the asymptotic characteristic. When calculating the conclusion, if R is specified as 0° and BR is specified -45° , then conclusion $\beta \in (0, -45)$, between R and BR. However, if R is specified as 0° and BR is specified 315° , then conclusion $\beta \in (0, 315)$, not between R and BR, because direction R and BR are adjacent to each other while 0° and 315° are far distant. Therefore, when calculating the reasoning result, the degrees for specifying directions are determined as follows. The consequent degree of the fuzzy rule whose antecedent has the smallest distance among all the rules is determined as $\alpha \in [0, 360)$. The degrees for specifying the other directions are determined as $\gamma \in (\alpha - 180, \alpha + 180]$. If, for example, when Rule^7 has the smallest distance, $\beta^1 \sim \beta^8$ are determined as $360^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, 225^\circ, 270^\circ, 315^\circ$. When Rule^1 has the smallest distance, $\beta^1 \sim \beta^8$ are determined as, $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, -135^\circ, -90^\circ, -45^\circ$.

IV. DIRECTION CONTROL EXPERIMENT

A path tracking experiment was carried out to verify the directional intention identification method. In the experiment, a healthy male volunteers aged 31 yr was instructed to push the ODW using his forearms to follow a $1.5\text{m} \times 1.5\text{m}$ square on the ground. Since the subject placed his arm against the armrest to partially support body weight throughout the experiments, even when not intending to go any direction. Therefore, the pressures for direction identification should be stable and significantly larger than the baseline due to body support. In

the experiment, the directional intention was calculated when one second of data meet the two following conditions: 1) During this second, outputs of at least one sensor were all larger than 100. 2) During this second, SDs of outputs of all the sensors were less than 20. The first condition ensures that increases in pressures are significant. The second condition ensures that the pressures are stable.

The experiment results were shown in Fig.4, Fig.5 and Fig.6. Fig.4 shows the path tracking results of 6 attempts. Fig.5 shows the sensor's outputs during the 6th attempt. Fig 6 shows the reasoning results of the 6th attempt. In the experiment, the subject adjusted the direction of the walker as he walked. He revised the direction from time to time on the way until reaching the goal. It is indicated by the results that the proposed algorithm is applicable in walking support.

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 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 [10-12].

V. CONCLUSIONS

This study examined the effectiveness of the proposed directional intention identification method. The path tracking experiment indicated the applicability of the method in walking support.

In addition to the straight movements in the experiment, rotation movements, clockwise and anticlockwise rotation, are also very important during walking. Rotation movements are not considered in the current study because rotational intentions cannot be denoted by angles, which are different from the straight directional intentions. Rotational intentions can also be expressed by the forearm pressures. For example, we can define that pushing S_FR and S_BL means to rotate clockwise and S_FL and S_BR means to rotate anticlockwise. Future work will deal with this problem by adding knowledge of rotational intentions to the knowledge base.

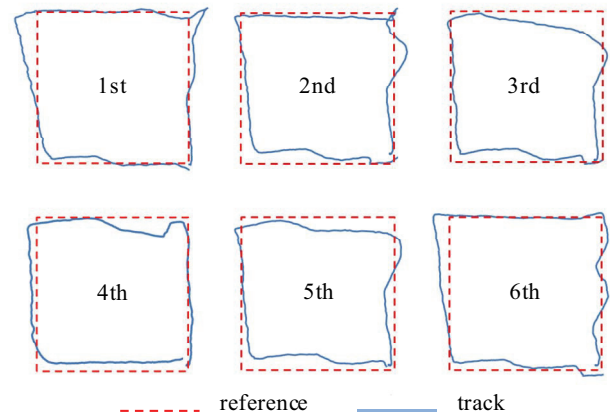


Figure 4. Path tracking results

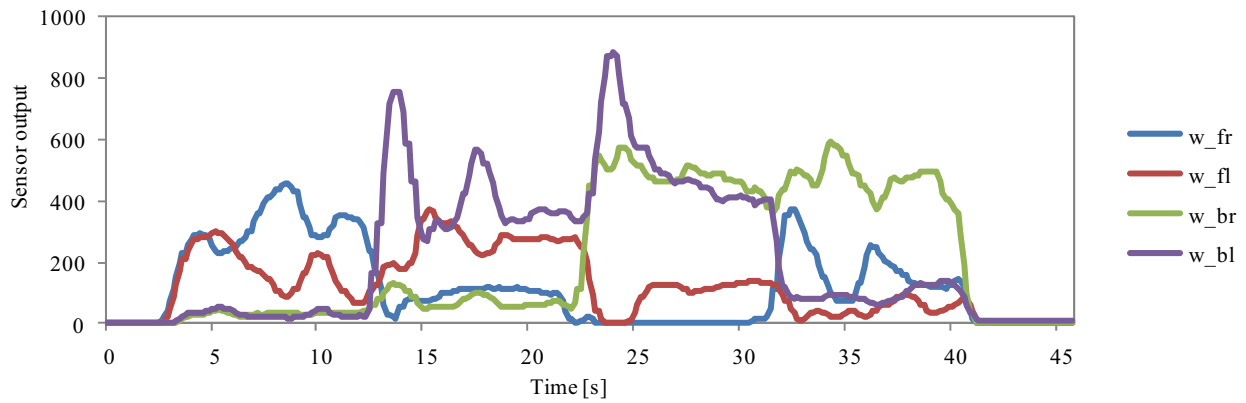


Figure 5. Sensors' outputs of the 6th attempt

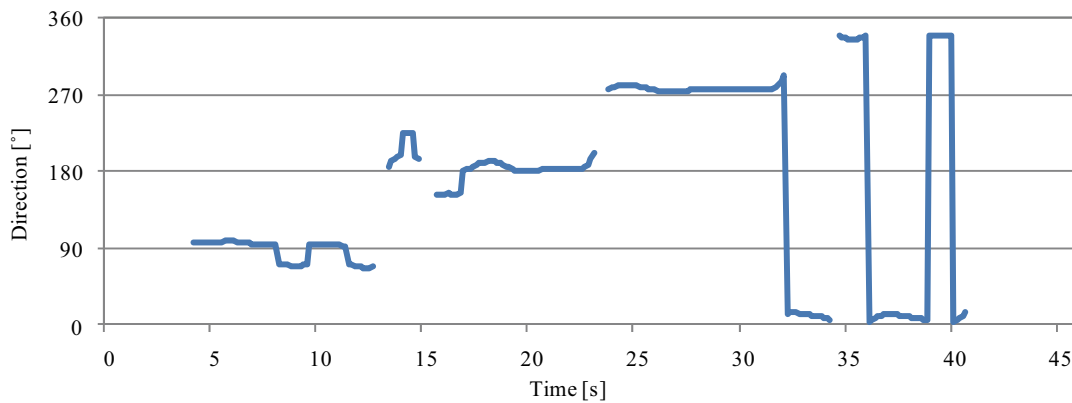


Figure 6. Reasoning results of the 6th attempt. The blank period is caused by the data that do not meet the 2 conditions. Although the reasoning results vibrate shaply from 34s to 42s, their directions are similair.

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