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Gait Analysis based Speed Control of Walking Assistive Robot*

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***Abstract*— The lack of caregivers in an aged society with low birth rate has become a serious social problem. The independent living ability of elderly people are expected, and walking ability is necessary to live an independent life. We are developing a walking assistive robot that can be adapted to the user's walking condition. This study uses proximity sensors, which were attached to the front of the walking support robot, to measure the walking of a user gait analysis and control of the robot according to the gait. Gait analysis was performed based on the relative distance of the user's leg to the inner front of the robot. Various experiments were conducted to study the difference between normal walking and waling with pseudo-disability, and to compare different control strategies based on gait analysis. The results showed that the measurement method is feasible to measure walking while using a walking assistive robot, and that speed control considering the characteristics of walking is a more suitable control method than linear speed change. These results will be useful for the development of automatic rehabilitation robots according to an individual's walking condition.**

I. Introduction

Recently, the elderly people aged 65 or over account for 27.3% of the total population of Japan, which is the highest level among the aging rate of developed countries. While the number of the elderly people is increasing, the lack of manpower of care workers makes it a more serious social problem. The elderly people are expected to live an independent life, both for relieving the burden to the society and for their own quality of life. Among, walking ability is especially necessary for our daily life. Degradation of walking ability due to aging leads to narrowing of the range of life and physical aging. Therefore, routine walking assistive is desired to support rehabilitation and daily life. A walking support machine is used as an instrument to assist walking of elderly people. As a previous research on walking assistive robot, there are staff type that can used in narrow places [1] and wheel barrow type [2]. These walking assist robot operate by using force sensor. The walking assist robot used this study can support upper body [3]. But operability of this robot is too bad because it operates stick equipped on the table. That is why, the purpose of this study is develop a system to measure the movement of the foot and control walking assistive robot.

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II. Walking Assistive Robot and Gait Measurement

A. *Walking assistive robot*

Fig.1 shows the walking assistive robot used in this study. It is possible to support walking in all directions by the omni-directional movement realized with the mechanical wheels. It is possible to drive the walking assistive robot with the control box in front right of the table. In addition, PC control is possible by switching the control box to enable serial communication between PC and the robot.

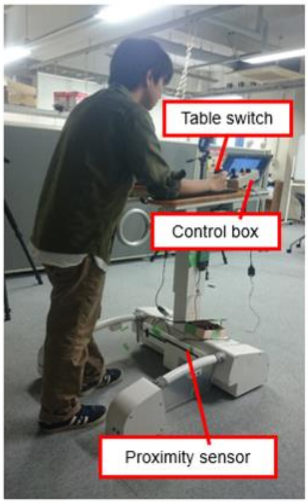

Fig. 1: Walking assistive robot

B. *Proximity sensor*

There are many researches on walking analysis. Three-dimensional motion analysis using infrared cameras [4] and floor reaction force gauge [5] can analyze accurate walking motion, but the device is large, and it can be used only within a limited range. There is also a method of measuring by wearing an acceleration sensor [6], but it inhibits the movement of the user. There is a method using a RGB camera [7] or LRF [8] [9] as a measuring method that can be installed in a small size. However, it takes time to measure the RGB camera. LRF is a type of infrared sensor. In this study, we used a proximity sensor which is a type of infrared sensor[10]. Proximity sensors were adopted to measure a user's walking while using the walking assistive robot. The proximity sensor used in this study is made by NSK Ltd. (Fig.2). 2 types of proximity sensors were used reflection type and ToF (time of flying) type. Their difference in performance is shown in Table 1. Reflection type measures the amount of reflected light of the irradiated infrared ray. ToF type measures the arrival time of reflected light of irradiated infrared rays. They are located on a flexible printed circuit board so that they can be fixed to objects with different shapes. The proximity sensors were attached to the front of the walking assistive robot to measure the relative distance between the user's leg and the robot.

(a) Reflection type

(b) ToF type

Fig. 2: Proximity Sensors

Table 1. Parameters of the proximity sensors

	Proximity sensor	
	Reflection type	***ToF type***
Sampling cycle[ms]	5	150
Measurement range[mm]	500	1200

C. *Gait measurement system*

Fig.3 shows the gait measurement system. The proximity sensor measures the distance and sends data to a microcomputer (SH74552, Renesas, Japan). The microcomputer converts CAN communication data to Serial communication data and sends them on a PC (Personal Computer). The application on the PC has two functions, recording the distance data and controlling the walking assistive robot.

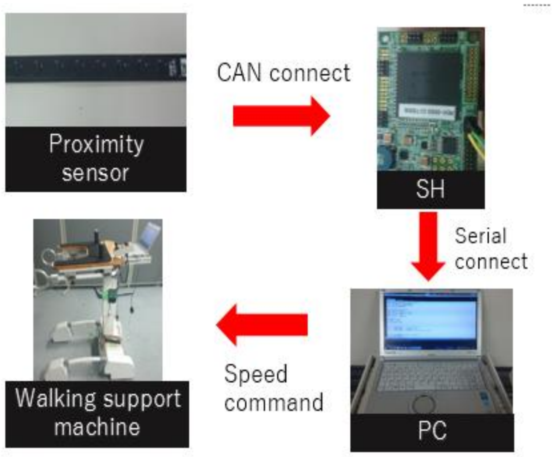

Fig. 3: Gait measurement system.

III. System Design

This section describes the control system of the walking assistive robot. Fig.4 shows how to control walking assistive robot. In the current study, only the forward movement of the robot were controlled based on the distance measured by the proximity sensors. First, the proximity sensors measure the distance between user's legs and the robot. Then, the speed of the robot was controlled according to the distance. We proposed two strategies to calculate the speed from the distance, as shown in Eq.1 and Eq.2. Gains A and B have 3 common conditions.

- The closer the distance, the faster the walking assistive robot moves.
- Measurement range is set to be 60 cm in order to avoid unnecessary movement.
- The limit of walking assistive robot's speed is 0.42m/s

This study is targeted at elderly people who are difficult to walk themselves indoor. The reason why the limit of walking assistive robot's speed is 0.42 m/s is that indoor walking speed required is at least 0.4 m/s. Gain A was a linear conversion from distance to speed. Gain B incorporated additional conditions to reflect the walking speed changes in a walking cycle separated by the intersection of the two legs. To decide the parameters of Gain B, we did a preliminary experiment. We recorded walking moving using proximity sensor when a subject walked 5m following the walking assistive robot and search the distance of crossing foot position. This experiment was carried out 3 times. As a result, the average position of leg intersection was 32.2 cm. The relation between the distance and the speed is shown in Fig.5.

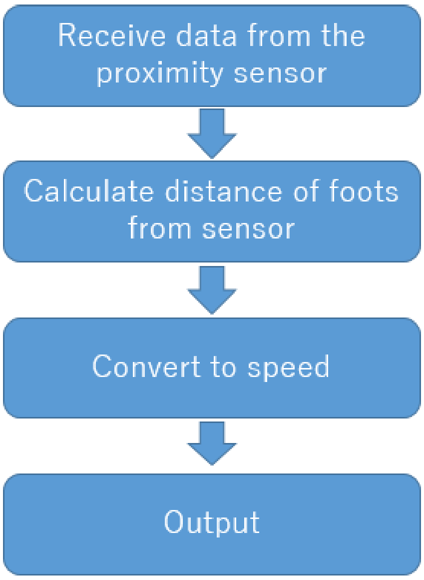

Fig. 4: Control by foot position

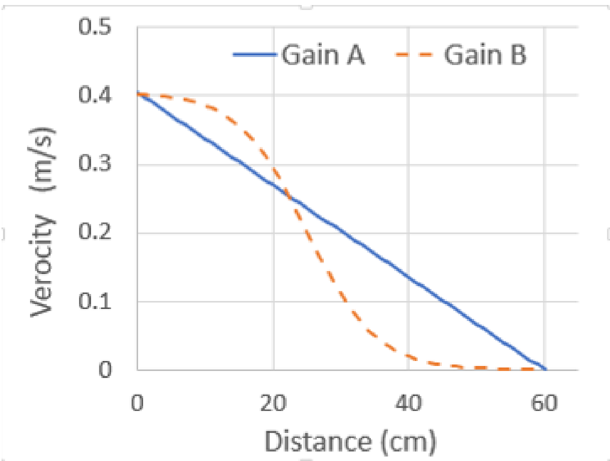

Fig. 5: Distance-based velocity control

Gain A

$$y = k\left(1 - \frac{x}{60}\right). \tag{1}$$

Gain B

$$y = k\left(\frac{-1}{1 + e^{-0.2x+5}} + 1\right). \tag{2}$$

IV. Experiments

We conducted two types of experiment to test the two types of proximity sensor.

A. *Verification of configuration system*

The following experiment was conducted to verify the usefulness of the data obtained by the reflection type of proximity sensor when using the walking assistive robot. The subjects walked 10 m following the robot 5 times. The speed of the robot was 0.27 m/s. The subjects were two 20's healthy male. Two walking conditions were included, normal gait and restraint gait.

The restraint condition fixed the left knee joint and hip joint to simulate the walking of the elderly.

Fig.6 shows data of the left and right feet obtained from the proximity sensors. The vertical axis shows the distance from the proximity sensor, and the horizontal axis shows time. In this experiment, we attached 3 proximity sensors to walking assistive robot. 3 proximity sensors were divided into the left and right data groups at the center, and the mean value of each was calculated. To make comparison easier, data on the start of walking and near the completion of walking were excluded. The right foot of subject 1 was nearer to the robot in restraint gait that in normal gait. This is considered to support the body weight since the left leg was restraint. The left foot of subject 2 was far away. It is considered that the left leg was late from the robot. In this experiment, the robot moved at a constant speed. Only the left leg is slower, it is possible that user can't follow the robot. That is necessary that speed control of robot for user's gate.

As a result, it can observe the difference between two walking condition.

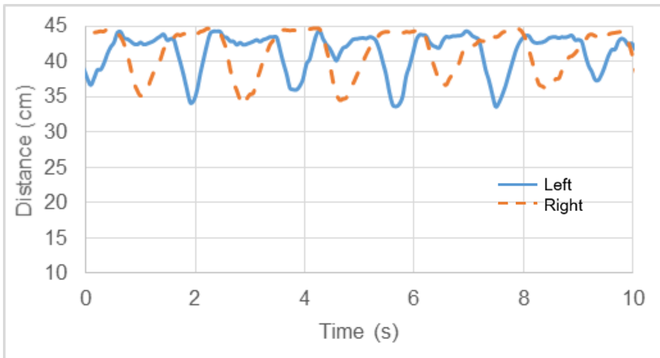

Fig.6-1 (a) Subject 1 Normal gait

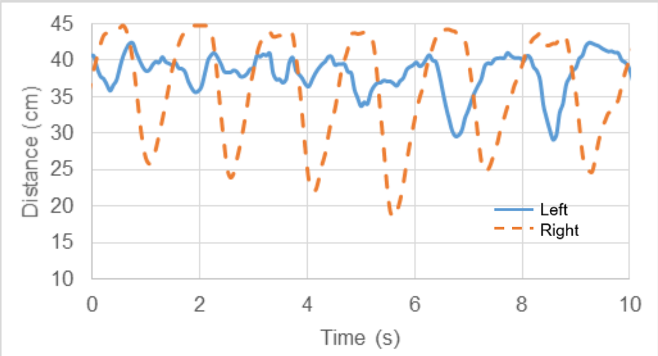

Fig.6-1 (b) Subject 1 Restraint gait

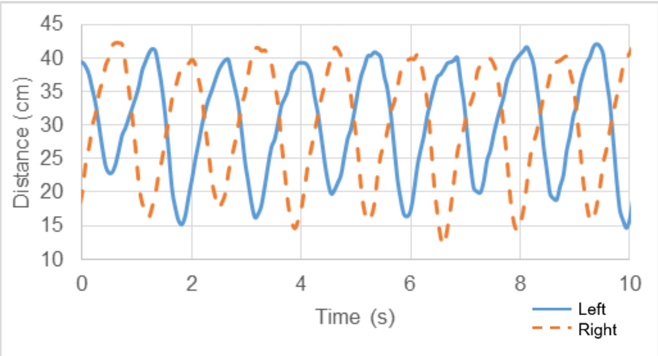

Fig.6-2 (a) Subject 2 Normal gait

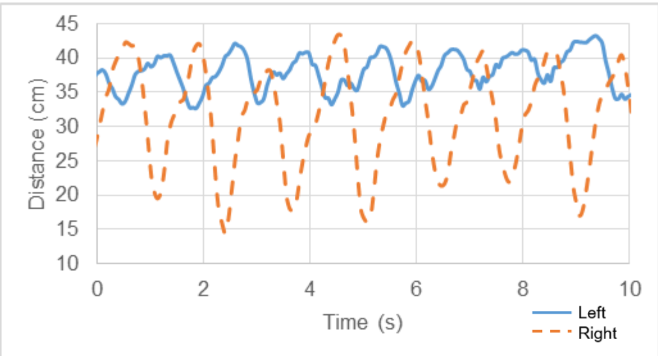

Fig.6-2 (b) Subject 2 Restraint gait

B. Speed control according to leg movement

This experiment compared the two strategies of speed control according to the distance. The subject walked 10 m for each gain type 3 times. A questionnaire was asked about which strategy the subject prefer to and the reason for the choice after the experiment. The subjects were 5 healthy subjects in their 20's labelled A, B, C, D and E.

The questionnaire results were that the subjects of A, B, D, E chose gain B and the subject C chose gain A. The reasons for choosing gain B were as follows.

· This gain generated a suitable speed. (Subject A, B, E)

· The speed of gain B was more smooth than gain A (Subject D)

On the other hand, the reason for choosing gain A was that

· The center of gravity when using Gain A was more stable than that when using gain B.

Fig.7 shows the walking time. This chart indicated that the average speed of usSping gain B was faster than gain A for subjects A, B, E. It is consider to make it possible for the walking assistive robot to perform smooth speed control without disturbing the walking of the subject. That might be the reason that gain B was suitable for them to follow the walking assistive robot.

Fig.8 shows the standard variation of stride length for each subject. This chart shows how much the stride fluctuated. Assuming that the stride was almost constant during normal walking, subject D felt gain B was smooth because gain B led to smaller stride variation than gain A. On the contrary, gain A of subject C had smaller stride variation than gain B. That is why, subject C felt that gain A led to more stable center of gravity than gain B.

As a result, it was suggested that gain B was suitable for speed control of the walking assistive robot.

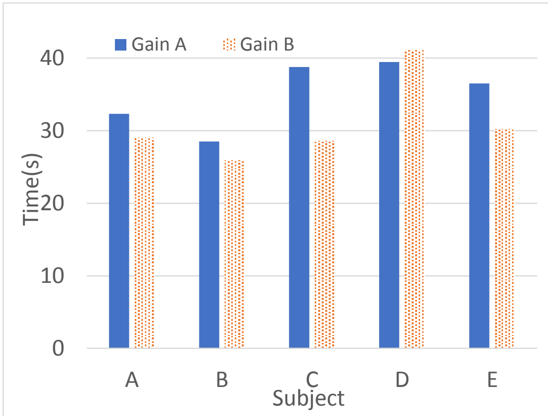

Fig. 7: Walking time

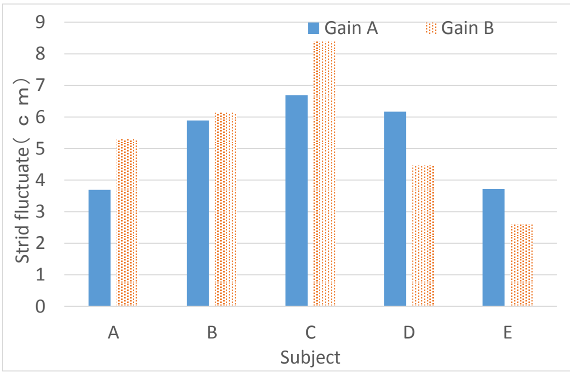

Fig. 8: standard variation of stride length

V. CONCLUSION

This study aimed at gait measurement whole using a walking assistive robot for the elderly people who are difficult to walk by themselves and develop a system to measure the movement of the foot and control walking assistive robot. We developed a gait measurement system by attaching the proximity sensors to the inner front of the robot. In verification of configuration system, it can observe the difference between two walking condition. Then, compared the two strategies of speed control, it is suggested that more suitable gain for speed control of the walking assistive robot.

In future study, we will further verify the walking parameters in consideration of difference in walking ability and usefulness of gait analysis by acceleration sensors. In addition, the goal of this study is to develop walking assistive robot that elderly people can do safe rehabilitation themselves.

REFERENCES

[1] K.Wakita, J.Huang, P.Di, K.Sekiyama and T.Fukuda "Human-Walking-Intention-Based Motion Control of an Omnidirectional-Type Cane Robot," IEEE/ASME Transactions on Mechatronics,Vol18,285-296 , February 2013

[2] Y.H.Hsieh ,Y.C.Hung, K.Y.Young, C.H.Ko and S.K.Agrawal "Motion Guidance for a Passive Robot Walking Helper via User's Applied and Forces," TRANSACTIONS ON HUMAN-MACHINE SYSTEMS, VOL. 46, NO. 6,pp.869-881,September 2016

[3] Y.Wang and S.Wang "Motion Control of a Walking Support Robot Considering Pressure and Thrust from Users," Joint 7th International Conference on Soft Computing and Intelligent Systems and 15th. International Symposium on Advanced Intelligent Systems, pp. 392-397, December 2014

[4] T.Nobuo and N.Masanori "Efficacy of Rehabilitation in Parkinson's Disease Patients using the Unified Parkinson's Disease Rating Scale (UPDRS) and Three-dimensional Motion Analysis" The Japanese Journal of Rehabilitation Medicine,VOL47, pp.791-800,November, 2010

[5] Y.Hayashi, N.Tsujiuchi, T.Koizumi, Y.Matsuda, Y.Tsuchiya and Y.Inoue "Unrestrained Human Gait Motion Analysis of Healthy Subjects and Trans-Femoral Amputee Using Mobile Force Plate," The Japan Society of Mechanical Engineers VOL 42 No5,pp.567-576.September 2013

[6] T.Kobayashi, Y.Miyake, Y.Wada, M.Matsubara "Kinematic Analysis System of Walking by Acceleration Sensor:An Estimation of Walk-Mate in Post-operation Rehabilitation of Hip-joint Disease," The Society of Instrument and Control Engineers Vol.42,No5,pp.567-576 March 2009

[7] H.Zhang and C,Ye "RGB-D camera based walking pattern recognition by supportvector machines for a smart rollator," International Journal of Intelligent Robotics and Applications pp.32-42, January 2017

[8] M.Ozawa, A.Yorozu, T.Matsumura and M.Takahashi "Gait Measurement System Using Laser Range Finder," The Japan Society of Mechanical Engineers VOL 79 pp.325-335,May 2012

[9] Y.Akimoto, E.S.shimokawara, Y.Fujimoto and T.Yamaguchi "A Model-Based Syste Development of a Walking SupportWheelchair Robot, " International Conference on Control, Automation and Systems, pp.613-618, October 2014

[10] Y.Suzuki "Design Method of Proximity sensors for Robots," The Robotics society of japan VoL 35 PP.656-659 December 2017