Assessment of Walking Condition Using Pressure Sensors in the Floor Mat

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***Abstract*— Monitoring equipment and systems for older people and those with health problems are usually based on measuring vital signs and monitoring behavior and have the problems of invasion of privacy and difficulty with operation. We have developed a floor mat-type walking measurement device with a pressure sensor to determine natural walking conditions in daily life. The equipment consisted of a grid of eight pressure sensors, each perpendicular and parallel to the direction of walking. Although walking speed was calculated using the least-Squares Method, we did not show its relevance to walking assessments. In this study, to confirm the usefulness of walking assessments with this equipment, we simulated visual and motion limitations due to weight loading on the trunk and upper and lower limbs and compared the results with the Timed Up and Go test used in rehabilitation assessments. In addition to the conventional least-Squares analysis using programming, we directly calculated walking speed by manually judging footprints and suggested key points in the calculation of walking speed. We analyzed data from the Timed Up and Go test, various movement restrictions using a floor mat-type sensor device, and normal walking with no movement restrictions. Four requirements were found to determine the calculation of walking speed, suggesting the usefulness of this device.**

Keywords-Walking Assessment; Floor mats; Pressure Sensors; Activities of Daily Living; Timed Up and Go test.

I. INTRODUCTION

The world is currently aging, with Japan having the highest rate of aging among countries. Early assessment of poor health conditions of people with health issues, including older people and people with disabilities, is useful to provide health care support. Equipment use has become an important part of providing support. Many monitoring support equipment and systems for older people and others with health problems have been developed and marketed in recent years [1]-[5]. These systems use not only video but also sensors, such as sheets, magnets, tags, ultrasound, infrared, etc., to judge problems from vital sign measurements to actions. Judgments are often based on vital sign measurements to assess health conditions and motion monitoring using video and infrared equipment. However, these have issues such as invasion of privacy and difficulty in using the device.

We have been studying monitoring systems for those with health issues and have developed monitoring equipment using a floor mat with pressure sensors [6] [7]. We then used the data from the sensors perpendicular to walking to calculate the velocity using the Least-Squares Method (LSM) and on the left and right data from the parallel sensors to perform machine learning. The key points of this equipment are twofold: privacy is ensured owing to the use of a floor mat, and health conditions are assessed without the use of vital sign measurements. In the future, it will be possible to measure the motion speed unconsciously in daily life without having to switch the equipment on and off. We have previously studied patients on dialysis using this equipment [8].

This report presents a study on the availability of the developed floor mat sensor in the rehabilitation field. We compared the results of the Timed Up and Go test (TUG), which is often used as a gait ability assessment, with those of our floor mat sensor. TUG and floor mat walking speeds were measured with the participant wearing an older person experience set to simulate motor dysfunction. In addition, an occupational therapist evaluated the video recordings and developed a new speed -calculation method. This study was approved by the Ethics Committee on Research with Humans as Subjects of the Teikyo University of Science. Section II describes the experimental methods for measurement and analysis, Section III describes the results, Section IV presents the discussion, and Section V presents the conclusion.

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II. Experimental Method

Three subjects wore the older person experience set to measure the walking speeds in TUG and on a floor mat with grid array sensors. Walking speed was analyzed using the existing programming LSM and new methods, along with the assessment of walking by an occupational therapist. The experimental procedure is as follows:

A. Measurement

- Equipment

  The study used a floor mat with a grid array of eight pressure sensors, each perpendicular and parallel to the direction of walking. Eight sensors (P0–P7) are perpendicular to the walking direction, and eight sensors (Q0–Q7) are parallel to the walking direction (see Figure 1). Parallel sensors Q are 1.5 cm apart and are a set of two. They are arranged with four in the front and four in the back. Perpendicular sensors are 10 cm apart only at the initial P0–P1 sensor interval and 15 cm apart at the other sensor intervals. The length of the sensor was 62 cm, and it measures approximately 120 cm in the direction of walking. The equipment size allows its use and placement at home. The surface is protected by a clear plastic sheet so that the position of the sensor position can be checked. The sampling frequency of the equipment is 100 Hz.

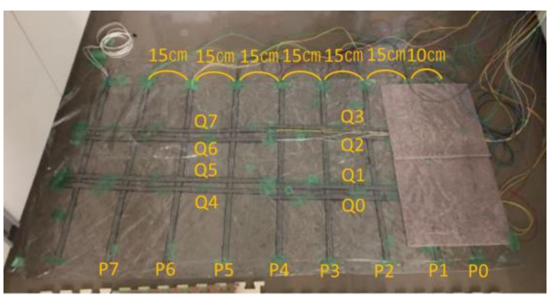

Figure 1. Floor mat-type equipment with pressure sensor array.

- Walking measurements

  Three subjects in their 50s to 70s (Cases A, B, and C) performed TUG and walked on the sensor array floor mat under simulated restricted motion while wearing the older person experience set (see Figure 2). The TUG measures the time it takes to get up from a chair, go around a cone 3 meters away, walk back to the chair, and sit down. We measured the time taken. TUG is often used in walking assessment during rehabilitation. We performed the test not only with comfortable walking, which is standard practice, but also with fast walking.

  The motion restrictions varied by subject. Subject A wore tinted eye glasses in addition to (1) trunk weighted, and left upper and lower limb restrictions, followed by (2) trunk weighted and right upper and lower limb restrictions. Subject B was (3) weighted on the trunk and had both legs restricted. Subject C was (4) weighted on the trunk.

  The subjects then walked on the sensor array floor mat without motion restrictions. Comfortable and fast walking were performed. Videotaping and ankle joint Range Of Motion (ROM) measurements were also conducted by an occupational therapist. The ROM of the ankle joint is shown in Table I, with plantar flexion and dorsiflexion. R and L represent the right and the left sides.

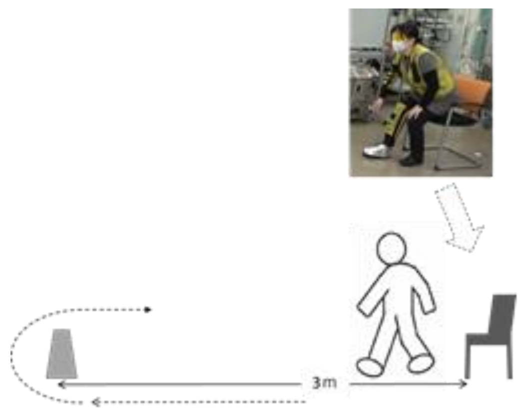

Figure 2. Timed Up and Go test.

TABLE I. Range Of Motion of cases A, B, and C

		Subjects		
Direction of motions	**R / L Side**	Case A	Case B	Case C
plantar flexion	R	50	60	45
	L	55	50	50
dorsi flexion	R	20	10	20
	L	20	5	-5

B. Analysis

- Speed calculation by the LSM

  Speed was calculated by programming using the LSM. This is the same analysis method that has already been used for patients undergoing dialysis.

$$y_i = a x_i + b \tag{1}$$

xi is the time when the P sensor is stepped on and yi is the distance from P0 to the stepped-on P sensor.

Figures 3 and 4 show examples of a graphical representation of the output data for P0–P7 and Q0–Q7.

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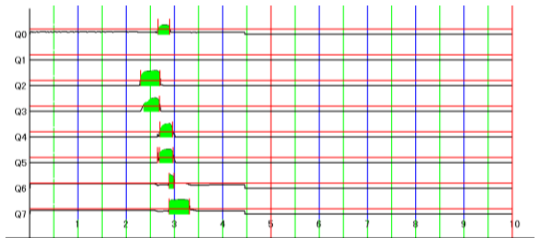

Figure 3. Q sensor output data.

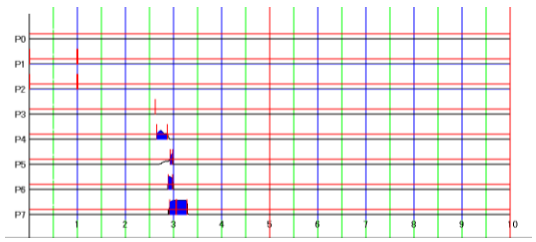

Figure 4. P sensor output data.

For the LSM calculation, data over half the height of the highest signal were used. In addition, data with very few continuous signals were judged to be noise and were not used. Figure 5 shows the time (s) and distance (sensor position), where the inclination of the red line is the speed.

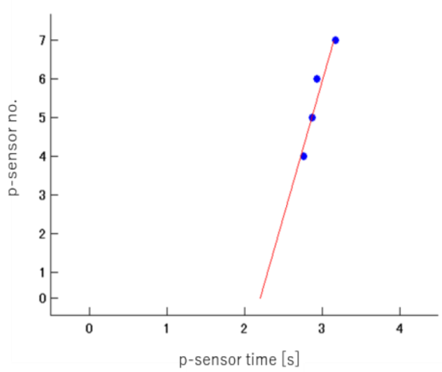

Figure 5. Speed by the least-Squares Method.

- Speed by direct calculation

A footprint diagram was drawn by looking at the raw data from the P and Q sensors, plantar ground contact was determined, and the speed was calculated (see Figure 6). When two sensors were stepped on simultaneously at the same time by a single sole, it was assumed to be a single ground contact, and the position and time that was the middle of the two sensors were used to determine the speed. It was calculated directly by manual process (Direct Calculation: DC).

The terms of judgment were as follows: (1) If there was an output that appeared to be noise that was not understood for a short time, the plantar ground contacts were judged to be grounded when 10 consecutive pieces of data were obtained. (2) Data with <2.0% of the maximum value 10 times in a row were excluded from sole grounding. (3) When two front and rear sensor data responded simultaneously, the same plantar contact was assumed when >70% of the front sensor data overlapped with the rear data. (4) When adjacent P-sensors did not respond consecutively, that is, there was one or more unresponsive P sensors in between, we assumed a different plantar ground contact.

Two major differences were noted between the LSM and DC of speed using footprint diagrams. First, the LSM calculates the speed based on the position and time of each sensor, regardless of whether the two sensors are stepped on simultaneously. The speed by the DC is calculated by judging when two sensors are outputting simultaneously, whether they are one footprint or two footprints, that is, the same grounding. Second, this is whether to use data with small values or responses in the calculation or to exclude them and treat them as noise.

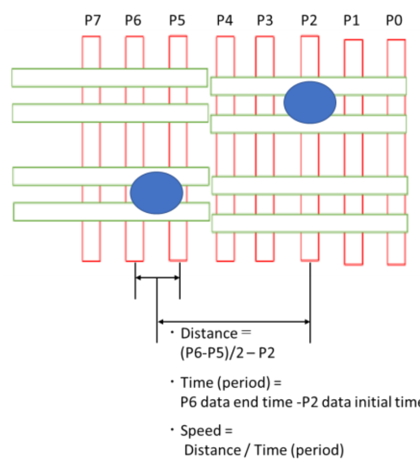

Figure 6. Footprints and direct calculation.

- Comparison with rehabilitation assessment

(1) We compared the TUG results to the sensor array data. (2) Occupational therapists assessed and validated the results by watching the video (see Figure 7).

Figure 7. Assessed video screen.

On the sensor array, subjects walked straight ahead, whereas on TUG, subjects walk straight ahead and then U-turn. The speeds on the TUG were converted and compared with the LSM and DC results on the sensor array data.

III. RESULTS

A. *Speed by Calculation Method*

The speed results were compared to determine the difference in the calculation method between the programming LSM and DC with footprint diagrams. Figures 8–10 represent the speed in meters per second. Data blanks in the LSM were those that could not be calculated because the number of data points was less than 2. In the graph, subjects A, B, and C correspond to 1, 2, and 3, respectively. The letters following the numbers are “Rr for right upper and lower limb restriction, “Lr” for left upper and lower limb restriction, “W” for weight loading, “E” for wearing tinted eye glasses, “c” for comfortable walking, and “f” for fast walking.

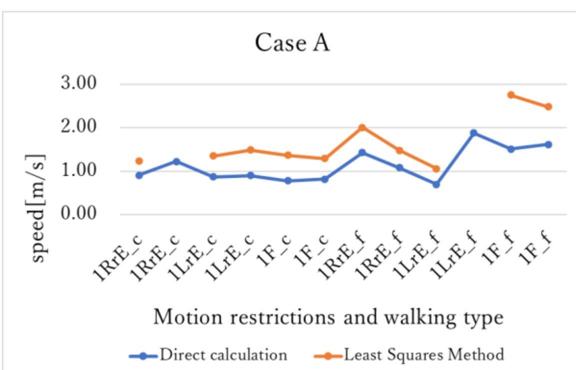

Figure 8. Walking speed by motion restrictions of subject A.

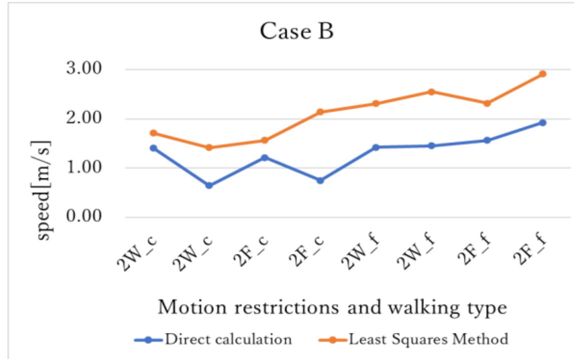

Figure 9. Walking speed by motion restrictions of subject B.

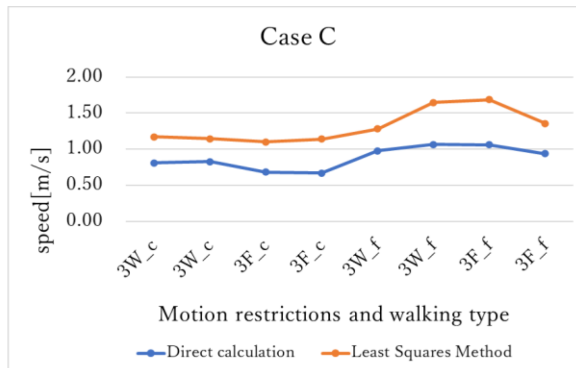

Figure 10. Walking speed by motion restrictions of subject C.

The results show that LSM tends to be judged as walking faster than DC.

B. *TUG and Walking on Sensor Array Floor Mat*

The speed of the TUG was compared with that of walking on a sensor array floor mat. The walking speed on the sensor-placed floor mat was calculated using two methods: LSM and DC. The mean speeds of subjects A, B, and C were calculated when they walked comfortably and fast with restricted motion. Figure11 shows the results for the TUG, LMS, and DC. The figure is graphed in ascending order of the TUG speed.

The calculation results from the pressure sensor array differed according to two calculation methods: LSM by programming and DC by manual calculation using a footprint diagram. In the LSM, the calculation result showed that the speed was slower by 3 of 7 times than the slowest speed in the “left upper and lower limbs and eye limits (1LrE_c)” TUG in Case A. In DC, the calculation result shows that only 1 of 7 times the speed was slower than the slowest speed in the “1LrE_c” TUG in Case A. The relationship between TUG and DC is higher, which is a manual calculation using footprint diagrams, than between TUG and LSM using programming. In the sensor array, walking is measured only straight ahead, whereas in TUG, walking is measured both straight ahead and U-turns. Therefore, the speed of TUG walking would be slower than that of the sensor array walking.

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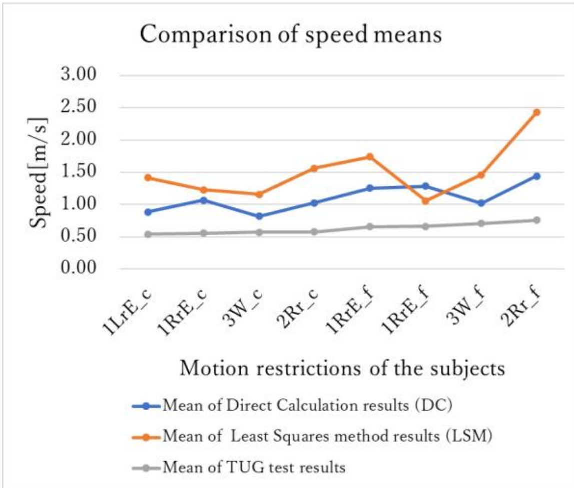

Figure 11. Speed comparison between TUG and sensor array walking.

The two discrepancies between TUG and DC were 3 W_c and 3 W_f for subject C. Subject C's walking was assessed on video by an occupational therapist, and a left-right difference was judged. Both 3 W_c and 3 W_f was observed during plantar grounding of the left foot. The ankle joint ROM in case C was R20/45 and L-5/50, with a left–right difference.

C. *Judgment of Left and Right Foot Speed*

The results of the speeds calculated by the DC for the simulated left and right upper and lower limb movements when restricted are shown in Figures 12 and 13, respectively; Figure 12 shows the right motion restrictions, and Figure 13 shows the left motion restrictions, x-axis is the plantar-grounded side of the foot, and y-axis is the speed. Only in case A the right and left upper and lower limbs were restricted.

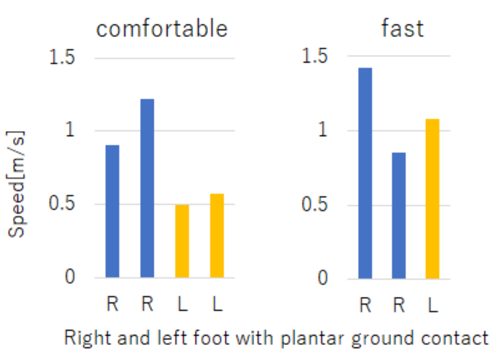

Figure 12. Right upper and lower limb restrictions.

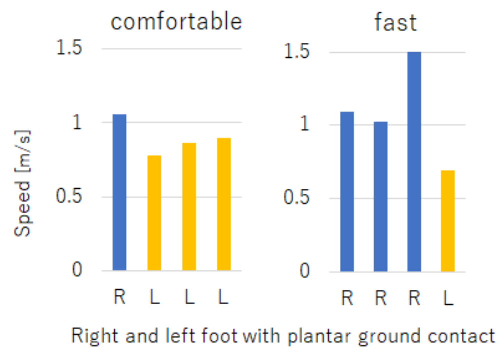

Figure 13. Left upper and lower limb restrictions.

The right-side walking tended to be faster than that of the left side regardless of whether the motions were restricted to the left or right side.

IV. Discussion

The equipment for monitoring health conditions up to now usually measures vital signs, and the monitoring care system captures movements. In this study, we used a floor mat that provides privacy while monitoring movements and enables assessment of health status based on walking patterns. However, the reliability of walking assessment using this device has not been compared with that of conventional assessments. In this study, we compared this device with TUG, which is commonly used for walking assessment. Owing to simulated motor limitations with only three subjects, it is not yet possible to generalize the results to people with disabilities. However, there was a tendency toward a relationship with conventional TUG.

In addition to the LSM of calculating walking speed that we have been using, we performed manual calculation using footprints, which showed a higher relationship with TUG. Data with low relationships were considered possibly influenced by left－right differences in the ankle joints. Footprints were created and calculated directly and manually according to the four requirements. The calculation requirements are related to whether it is a one- or two-footprint diagram, that is, the same plantar ground contact, and to determine whether data with small values or responses should be used in the calculation or excluded and treated as noise. In this study, 10 consecutive datasets were used: in the case of simultaneous response by two sensors (front and rear), the same plantar contact was considered when at least 70% of the front sensor data overlapped with the rear sensor data, but this number may vary depending on the distance between sensors and walking speed. Although the measurements were obtained with simulated motor impairment, some older people and those with disabilities were slower than others. If there is no output from the P sensor, data from the front and rear P sensors can be judged as different plantar ground contacts; therefore, it is effective to narrow the sensor interval. The LSM programming analysis was probably faster speed because two sensor data from the same plantar, that is, one footprint, were treated the

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same way as two data from different plantar contacts, that is, two footprints. Although the speed calculated by LSM had a low correlation with TUG, it was similar to the speed calculated by manual DC. Because this study was based on a small amount of data, the correlation may be higher in the future when huge data are used for analysis in daily life measurements.

The length of the equipment was set at approximately 120 cm, which is too small for determining the walking speed. However, as the equipment can be placed at home at all times considering its size, anything larger than this is not considered practical. Even with the 120-cm equipment, differences between the left and right feet could be detected. Suppose the width of Q is narrowed so that it can automatically determine whether the left or right sole is grounded. The speed at which the left and right soles are grounded can be calculated, and changes in walking ability by left and right can be detected.

V. CONCLUSION

In this study, we investigated three subjects using a small amount of data. Therefore, the results of this study cannot be generalized. However, a relationship was suggested between TUG and array sensors, that is, the floor mat-type array sensors could be used for walking condition assessments. Occupational and physical therapists routinely assess walking conditions, but do not always use measuring devices or quantify them. They observed and assessed their interactions with the patients. Health conditions were expressed as a state of walking. If walking conditions can be measured naturally in daily life, it will be possible to assess walking ability without a therapist. This also leads to objective data showing the therapist’s tacit knowledge of experience. Motion speed measurement with pressure sensors has already been studied, as well as getting up out of the bed. The use of machine learning has also begun. We plan to study both walking and getting up from bed in the future.

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