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Assessment of walking condition using pressure sensors in the floor mat

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Profile

Tomoko　Funayama

- Occupational therapist.
- Experience with Therapy: For the disabled and older people in hospitals, nursing homes, and their homes, I worked.
- Current affiliation: Department of Occupational Therapy, Faculty of Medical Sciences, Teikyo University of Science.
- Research: I have been researching with engineering specialists on the use of digital wearable devices to support people with disabilities.

  - Monitoring of Daily Health-condition with WearableDevice and Network, T. Funayama, Y. Uchida, Y. Kogure, Rehabilitation International 24th World Congress,2022
  - Application of the human-machine interface technology to occupational therapy, T. Funayama, N. homma, Y. Kogure, Y. Uchida, 16th International Congress of the World Federation of Occupational Therapists, 2014

Our Projects

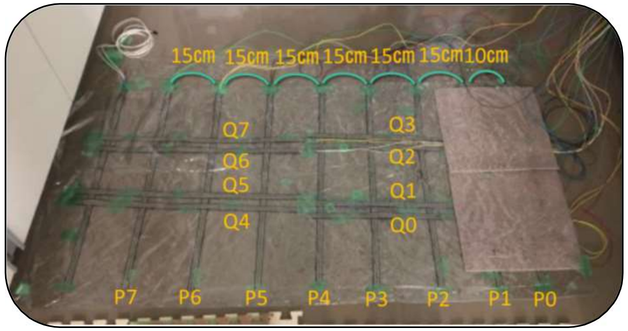


Figure 1. Floor mat type pressure sensor

We have been investigating activity assessment with digital devices for people with disabilities and health issues, in collaboration with occupational and physical therapists working in hospitals, human-machine interfaces (HMIs) experts, data processing specialist, medical doctors, and others.

Figure 2. Wristwatch type optical and acceleration sensors

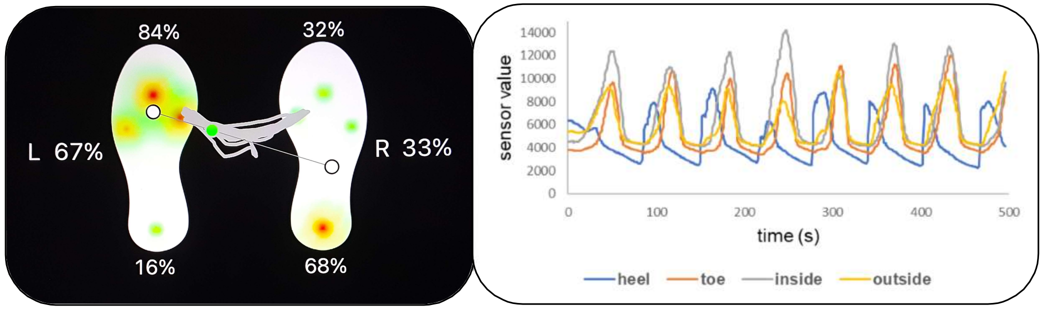


Figure 3. Smart Insoles

Introduction / Purpose

- 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.

- 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.

- Purpose: In this study, to confirm the usefulness of walking assessments with this equipment. We simulated visual and motion restrictions due to weight loading on the trunk and upper and lower limbs and compared the results with the timed up and go test (TUG) used in rehabilitation assessments.

Experimental Method

Equipment

- The floor mat consists of a grid of pressure sensors.
- Perpendicular sensors (P0-P7) and parallel sensors (Q0-Q7) are arranged eight each.
- 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 is 62 cm, 120 cm in the walking direction.
- The size is available for home use.
- The sampling frequency is 100 Hz.

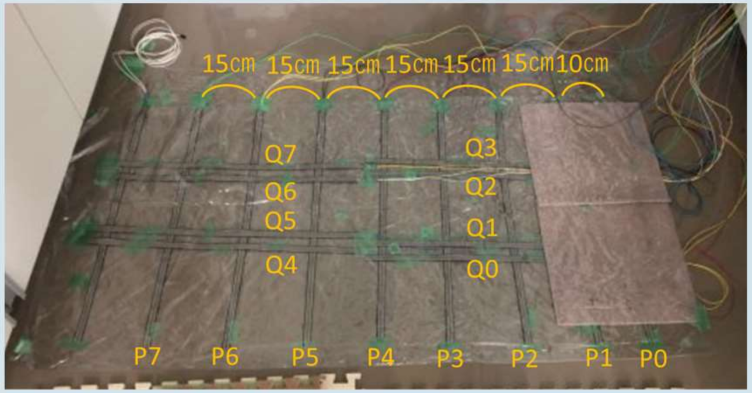


Figure 4. Floor mat-type equipment with pressure sensor array.

Walking measurements

Three subjects wore the older person experience set to measure the walking speeds in TUG and on a floor mat with grid array sensors. Comfortable and fast walking were performed. Walking speed was analyzed using the existing programming least-squares method (LSM) and new methods (DC), along with the assessment of walking by an occupational therapist.

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.

Figure 5. Walking measurements

Motion restrictions

Using the older peoples' experience set

Subject A

- Eye glasses, trunk weighted, and left upper and lower limb restrictions
- Eye glasses, trunk weighted and right upper and lower limb restrictions.

Only Case A restricted the left and right sides separately.

Subject B

- Weighted on the trunk and had both legs restricted

Subject C

- Weighted on the trunk.

Output data of P and Q sensors

Examples of a graphical representation of the output data for P0–P7 and Q0–Q7

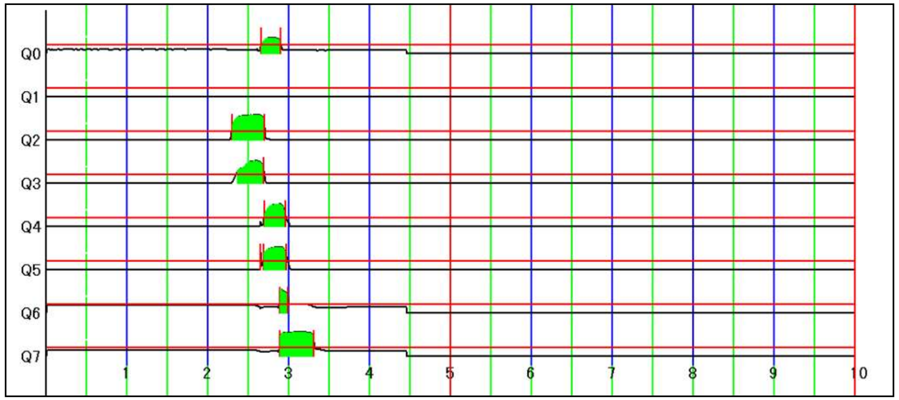


Figure 6. Q sensor output data.

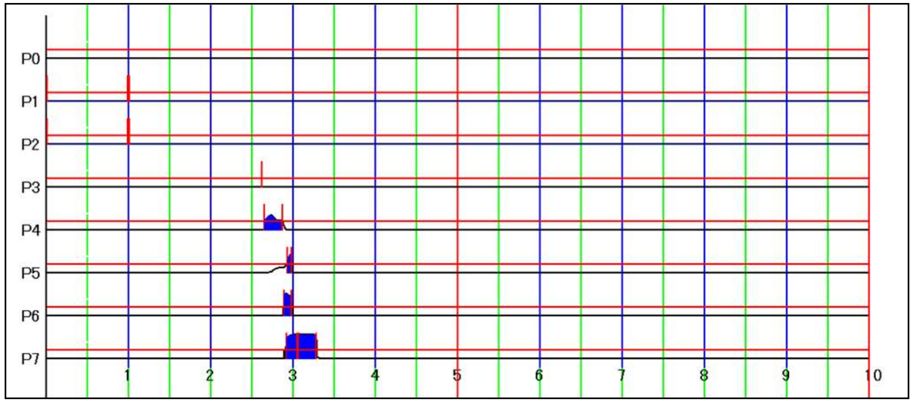


Figure 7. P sensor output data

Multiple sensors are reacting at the same time.

Speed by the least-squares method

examples

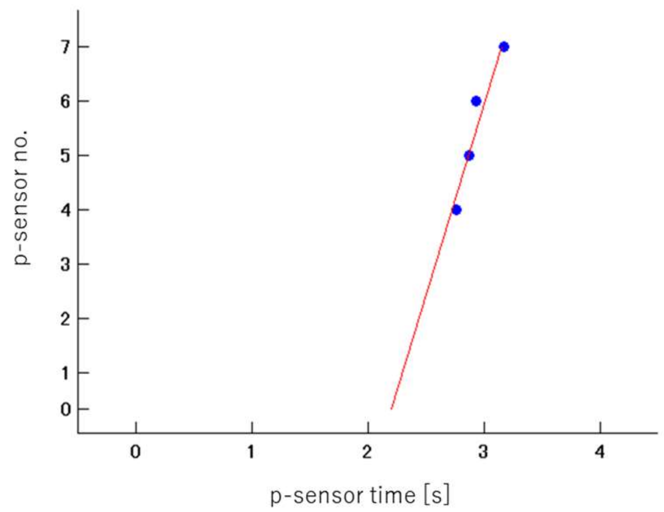
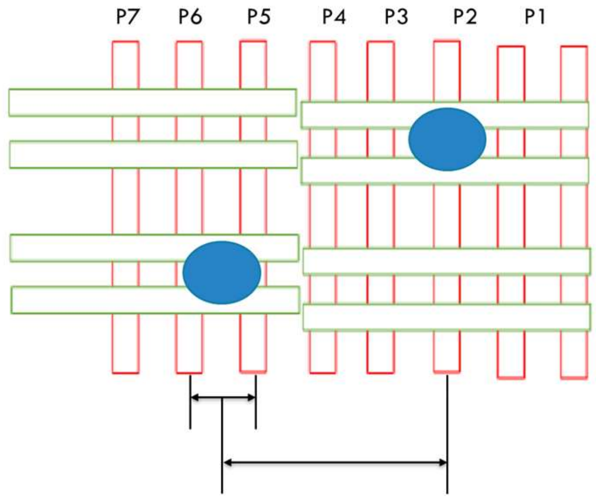


Figure 8. Speed by the least-squares method.

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 8 shows the time (s) and distance (sensor position), where the inclination of the red line is the speed.

Speed by direct calculation

examples



- Distance＝(P6-P5)/2 – P2
- Time (period) = P6 data end time – P2 data initial time
- Speed = Distance / Time (period)

Figure 9. Footprints and direct calculation.

The new method was calculated directly by manual process (Direct Calculation: DC).

DC 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. 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.

Difference between LSM and DC

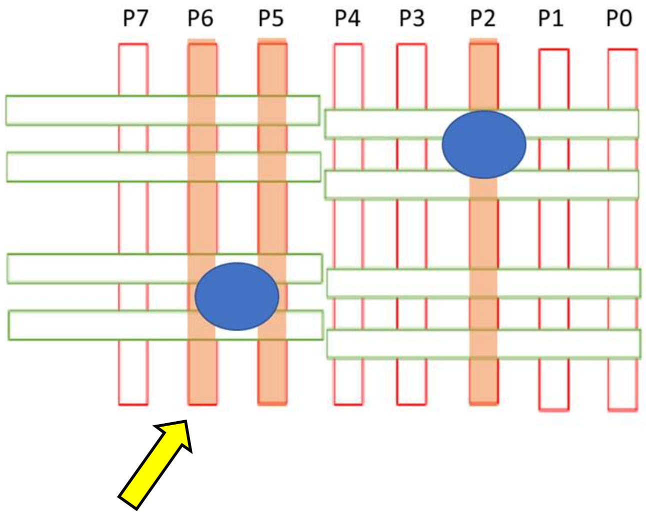
1. Detection of one or two plantar contacts.

- 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.

2. Judgment of Noise.

- Whether to use data with small values or responses in the calculation or to exclude them and treat them as noise.

examples



Although it was a single plantar contact, two sensors (P6 and P5) responded.

Terms of judgment when data is used in DC.

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 plantar 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.

Results of LSM and DC in Case A, B and C

Walking speed by motion restrictions of subject

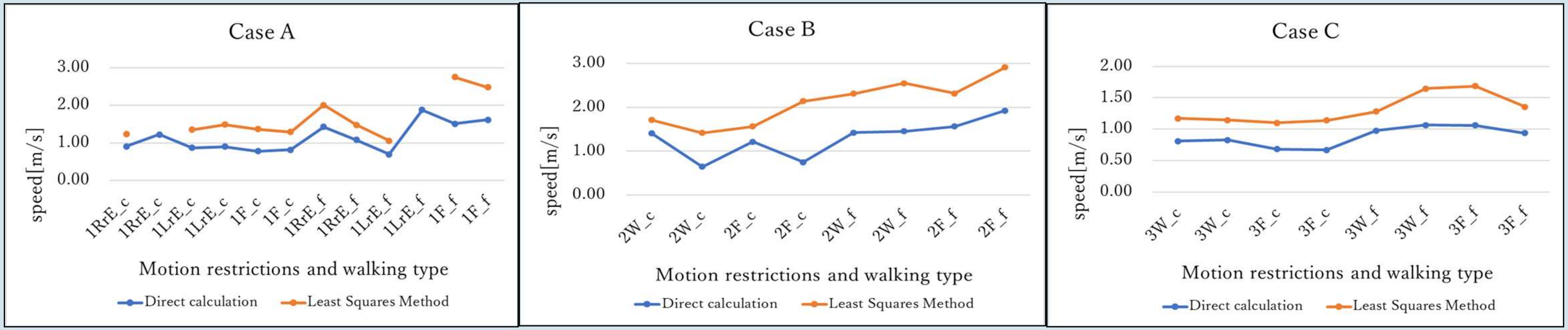


Figure 10. subject A,B and C.

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

※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.

Comparison of LSM and DC

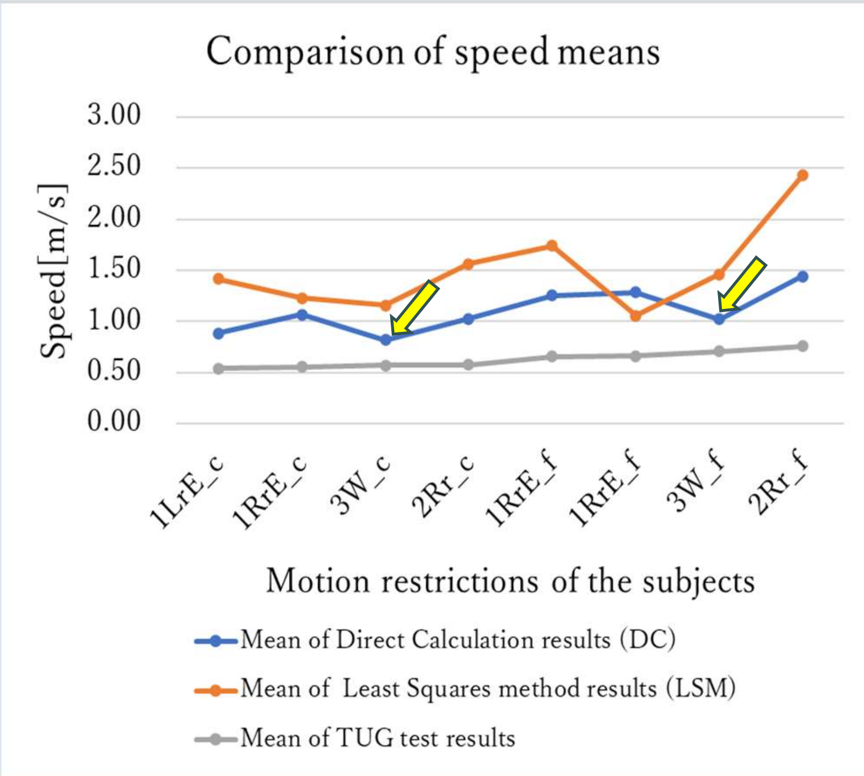


Figure 11. Speed comparison between TUG and sensor array walking.

The relationship between TUG and DC is higher, than between TUG and LSM. Case C's walking was assessed on video to judge left and right plantar grounding. Both 3 W_c and 3 W_f was observed during plantar grounding of the left foot. The ankle joint ROM is shown in the table below. There was a left-right difference in Case 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

Figure 11. Ankle joint range of motion in Cases A, B, and C.

Comparison of LSM and DC in Case A

x-axis is the plantar-grounded side of the foot, and y-axis is the speed.

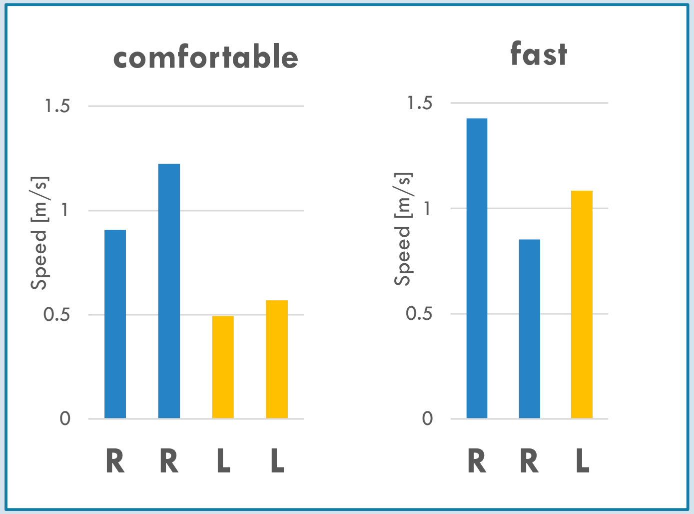


Figure 12. Right U/L motion restrictions

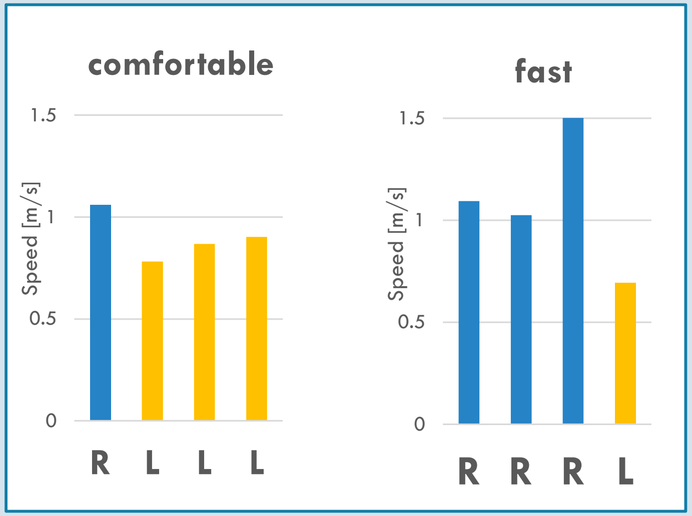


Figure 13. Left U/L motion restrictions

The left foot tends to be slower than the right foot,
regardless of whether the left or right upper or lower limb is restricted

Discussion

The results show that LSM tends to be judged as walking faster than DC. And TUG is slower than sensor array walking.

- The reason was assumed to be that the LSM treated the data from the two sensors with the same plantar contact as if they were different plantar contacts.
- TUG includes U-turns, whereas sensor arrays only go straight, hence TUG walking was slower.

The left foot tends to be slower than the right foot, regardless of whether the left or right upper or lower limb is restricted.

- Although the floor mat was only 120 cm long, the possibility of detecting the subject's features was shown.

Importance of determining whether two sensor responses are the same plantar contact.

- With DC, four terms were used: 1. judgment of noise based on the number of consecutive outputs; 2. exclusion of very small values compared to the maximum value; 3. judgment based on the overlap rate between the previous and next data; 4. When adjacent P-sensors did not respond consecutively.(Explained on the next slide)

Using the Terms used in DC that should be changed depending on the situation.

Terms used in DC	Terms to be adjusted
1 • 10 consecutive datasets were used.	The values should be adjusted according to the distance between sensors and walking speed.
2 • 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.	
3 • 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	Some older people and those with disabilities were slower than others therefore, it is effective to narrow the sensor interval.

Conclusion

1. 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.
2. Which showed a higher relationship with TUG. Data with low relationships were considered possibly influenced by left–right differences in the ankle joints.
3. Possibility to assess health conditions expressed in gait. Useful for rehabilitation therapists.
4. 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.

Acknowledgments

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