Basic Research on the Method of Presenting Distance Information to the Blind by Means of Gait Measurement

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Abstract

In order to realize a navigation system for the blind, there are two main problems to be solved: one is to measure the present position of a blind person, and the other is to notify the blind on the route to his/her desired destination. As for the first problem, we are developing a measuring device by means of which gait information can be obtained that cannot be obtained by existing devices in order to assist walking rehabilitation. Our newly developed device is able to measure the step length and present position. As for the second problem, a new notification method is proposed. According to past results, this notification method, which counts the number of steps remaining until the blind reaches the destination, can guide the blind easily because the number of steps is easy to count. Based on the abovementioned considerations, we tried to realize a new guidance system which would inform the blind of the remaining distance to the destination as the number of remaining steps after measuring the present position. In this paper, we propose a new guidance system and describe our assessment of the feasibility of this new method. The experimental results indicate that our device could measure the step length with a small measurement error, and that our new guidance method guided the subjects correctly. We conclude that our new guidance method would be useful and that it can be realized.

Keywords: Distance, Blind person, Gait analysis

1. Introduction

To date, many devices for guiding blind persons have been developed, and some have been commercialized. Those devices first identify the present position of blind person, then find the optimal route to the desired destination, and finally inform the blind person regarding which way to go.

For identifying the present position, most devices use Global Positioning System (GPS) [1] or radio frequency identification (RFID) tags [2] to measure the present position of the blind person. However, using GPS inside a building or underground is impossible because of signal loss, while using GPS in a place surrounded by high-rise buildings is impossible because of signal reflection. On the other hand, using RFID tags everywhere is impossible because of the costs involved in installing tags. So, we thought it was necessary to develop a method of identifying the present position regardless of where that might be, in order to realize a truly effective and helpful navigation system for the blind.

In the meantime, we have been developing a system which assists walking rehabilitation [3]. Several kinds of sensors are mounted on the rehabilitation shoes and certain types of information, such as the step length, walking speed and pressure distribution, can be obtained by means of this shoe-type device. A similar system for rehabilitation, called “GaitShoe,” has already been developed [4]. The difference between that system and ours is the purpose. That is to say, the purpose of GaitShoe is to evaluate the gait, whereas the purpose of our system is to give the user information about feet movement and pressure on the feet during walking in addition to evaluating the gait. In our system, the information about the feet is transmitted by a wireless system to a signal processing unit, and the foot position and pressure distribution are displayed in real time. Thus, we hypothesized that we would be able to measure the present position accurately by using our

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shoe-type device if the position was impossible to identify by GPS and RFID. Moreover, we expected to be able to assess the remaining distance to the destination if information about the destination had already been received by GPS or RFID.

Next, regarding the method of notifying the blind person on the route to take, in most such devices, voice instruction is used to inform the device user of the direction and distance to the destination [5]. Most currently available devices use expressions such as “The destination is 5 meters ahead” or “Make a left turn at the corner 5 meters in front of you.” However, long-term training is necessary to be able to use these devices, and some of the information given by the devices can confuse the user. For example, the device user might not be able to estimate the distance precisely while walking if the distance is presented in length units, as in “5 meters ahead” [6]. We define this method, in which distance is presented in length units, as the “length expression” method.

Some blind persons naturally utilize the number of steps in order to assess distance. This is an effective method of assessing distance because personal ability is irrelevant if a small number of steps are taken. So, we developed a method which would inform the blind person of the remaining distance to the destination or corner in the form of the number of remaining steps to be taken. We define this method, in which distance is presented as the number of steps, as the “step expression” method. In a previous study, we investigated which expression method, the length expression method or the step expression method, was more effective in precisely guiding the user to the destination [7]. The results show that the subjects arrived at the destination more precisely when they were given the information on the remaining distance to destination through step expressions such as “The destination is 3 steps ahead.” So, the device user might be able to estimate the distance precisely while walking if the distance is presented in step expressions.

If we combined our shoe-type device with the findings regarding the effectiveness of the step expression method, we would be able to inform the blind person of the remaining distance more precisely and in a more easily understandable manner. In this paper, we would like to introduce the most recent results obtained in experiments using our shoe-type device and discuss the possibility of distance presentation based on step expressions.

2. Shoe-type distance measurement device

Figure 1 shows the outline of our system for walking rehabilitation (named as “GaitGuide”). Our device consists of a shoe-type device onto which sensor units (gyro sensor, acceleration sensor, ultrasonic sensor and pressure sensor), a wireless module and a display for the gait information are installed. The shoe-type device collects gait information (step length, step width, pressure, etc.). The collected data are sent to a personal computer through the wireless module. The gait information necessary for rehabilitation is displayed on the screen based on the collected data. This gait information comprises the step length, step width, step timing, foot rotation, height of the raised foot, pressure of the foot and pressure distribution. These data are displayed in graphic form, which was designed based on the opinions of physicians, physical therapists and patients. This makes it easier to understand the state of the gait based on the information shown on the screen [8].

![Figure 1. Outline of our walking rehabilitation system.](image1)

With our device, we first measured the foot position during the swing phase by combining the data of a gyro sensor and an acceleration sensor (Fig. 2). A triple-axis gyro sensor (ADIS16355AMLZ, Analog Devices, Inc.) was installed at the toe, and was set to measure 300 deg/s of foot rotation during walking. A triple-axis acceleration sensor (ADIS16355AMLZ, Analog Devices, Inc.) was also installed at the toe, and was set to measure 10g of foot acceleration during walking. The maximum values (300 deg/s and 10g) were determined in a preliminary examination. Both types of sensor data were integrated twice to calculate the rotational angle and the moving distance of the foot. The 3D foot position and foot rotation were acquired every 30 ms.

![Figure 2. Foot position measurement method of our shoe-type device.](image2)

However, the integral calculation of the data sent by gyro sensor and acceleration sensor generated an integral error. Thus, we used our device to measure the distance between the two feet by means of an ultrasonic sensor and a gyro sensor during the double-support phase in order to correct the integral error. Triangulation by combining the data from one ultrasonic transmitter (MA40S4S, Murata Manufacturing Co., Ltd.) and two ultrasonic receivers (MA40S4R, Murata Manufacturing Co., Ltd) made it possible to measure the distance. Incidentally, according to physicians, the average step length of patients who...
need walking rehabilitation is around 0.6 m. In order to measure a step length of about 0.6 m during walking, we decided that four ultrasonic receivers must be arranged on the inside of the shoe and two around the heel on each foot, according to the results of geometrical analysis. After our device is turned on and before the distance is measured, the ultrasonic transmitters and receivers are synchronized. After the synchronization, one transmitter sends an ultrasonic wave and the arrival times of the wave to the four receivers are measured during the double-support phase. Then, another transmitter sends a wave and the arrival time is measured. Two arrival times with similar values are selected and the distance between the feet is calculated. Moreover, the gyro sensor measures the foot rotation when the foot lands on the ground.

We used eight pressure sensors (Flexi Force Button Sensor, Tekscan, Inc.) which were installed on the insole, and those sensors were arranged to measure the track of the COP (center of pressure) inside the sole. Also, the timing of ground contact of the foot was determined from the pressure change. Before starting to walk, the device user wearing the shoe-type device was asked to stand with both feet for a moment to allow the measurement of his/her body weight by means of all the pressure sensors. While walking, if the total amount of pressure on the swing-phase foot was over 2 kgf, the swing-phase foot was judged to have landed on the ground and an ultrasonic wave was transmitted to evaluate the distance. Inversely, if the total amount of pressure on the stance-phase foot was under 2 kgf, the stance-phase foot was judged to have been lifted from the ground. Here, the value of 2 kgf was adopted based on trial and error.

Figure 3 shows the trial shoe-type device. The data were transmitted to the screen by a wireless module at a sampling rate of 30 Hz, and data transmission up to a distance of 15 m could be achieved.

3. Distance-presentation method

In order to investigate the possibility of distance presentation based on the number of steps, we set up the following experimental system: the step length was measured by our shoe-type device in real time, and the remaining distance to the destination was presented by voice instruction using step expressions at the beginning of the double-support phase.

The step length was measured at a sampling rate of 30 Hz. The average step length was calculated based on the latest three step lengths. Voice instruction on the remaining distance was given based on the remaining distance divided by the average step length.

Figure 4 shows the experimental procedure. First, the subjects were asked to wear the shoe-type devices. Next, they were asked to start walking from the starting point with their stronger, dominant leg. Three starting points were prepared, 7, 8 and 9 m away from the destination, in order to prevent the subjects from memorizing the destination. When the remaining distance was 3, 4 or 5 steps, a voice instruction (“3 steps”, “4 steps” or “5 steps”) was given to the subjects during their double-support phase through a speaker placed behind them. From the preliminary experiments, voice instructions were decided to 3-5 steps because the subjects felt hasty for 2 steps and felt anxious for 6 steps. The subjects were asked to follow the voice instruction and stop walking after the designated number of steps. Also the subjects were asked to try to keep the same walking speed and same step length after voice instruction. For example, when the subjects heard “3 steps” , they had to walk three more steps and stop walking.

In this experiment, the destination was the middle of a door leading into a corridor. After the subjects stopped walking, the distance between the middle of the door and the stopping point was measured. This distance was defined as the “guidance error.”

The subjects were 9 non-visually impaired people ranging from 23 to 31 years of age, and they were asked to wear sleeping masks. Before the start of the experiment, the subjects were asked to practice walking straight without using their sight. Ten trials were executed for each walking distance. The starting points and voice instructions were changed randomly. Before joining the experiment, all the subjects were given a detailed explanation about the experiment, and they gave their informed consent.
4. Results and discussions

4.1 Foot position measurement

In order to investigate the measurement accuracy, we compared the foot position as given by our device with the position given by a 3D positioning sensor and a 3D motion capture system. The 3D positioning sensor was the Fastrak system (Polhemus, Inc.), and the measurement accuracy was under 1 mm. The 3D motion capture system was the commercial product of Ditect Co., Ltd., and the accuracy was under 1 cm for the area measured in our walking experiment.

Figure 5 shows the foot-position measurement error when a pair of shoe-type devices was placed on a plane. The horizontal axis shows the rightward-leftward position, and the vertical axis shows the forward-backward position. First, the left shoe-type device was placed so that the heel was on the origin of the coordinate system. Next, after the heel of the right shoe-type device was placed on a lattice point (black/white dots in Fig. 5), the distance between the two devices was measured. The location of the two devices was also measured by the Fastrak system, and the distance between the two devices was calculated. The measurement was repeated ten times for each lattice point. In Fig. 5, the black dots indicate that the measurement error was within 5 cm at those lattice points, while the white circles indicate that the error was greater than 5 cm at those lattice points (maximum error: 10 cm). The results suggest that our device was able to measure the distance with an error of around 5 cm most of the time. It was also found that our device could measure distances within the range of 0.1 m to 0.6 m.

Figure 6 shows one example of a result with a measuring error obtained by our device during walking. In this experiment, the foot position was measured by both our device and the 3D motion capture system. Before walking, both feet were aligned side by side because of the limitation of our device (Fig. 6, bottom left). After that, the subject was asked to walk for about 3 m, shown as footprints on the left side in Fig. 6. The right side of Fig. 6 shows the result mentioned. The black/white dots show the heel positions of the shoe-type device. The white dots show the heel position as obtained by the motion capture system, while the black dots show the heel position as obtained by our device. Our device could measure distance with a relatively small discrepancy. After 10 rounds of walking, the average discrepancy was calculated to be 3.3 cm (standard deviation: 2.5 cm) for the step length and 3.2 cm (SD: 3.7 cm) for the step width. This means that our device gives a maximum error of about 4 cm error for the step length, considering the measurement error of the motion capture system.

The specifications of our trial shoe-type device are as follows: weight, 490 g for each foot; measurement error, about 4 cm for the double-support phase; pressure measurement points, 8 points for each foot; data sampling frequency, 30 Hz; battery, three AA size batteries for a pair of shoes; battery lasting time, 360 minutes for continuous measurement; transmitting power, 1 mW; measurement distance, 0.1 m to 0.6 m for both the step length and the step width.

Based on our experimental results, our device can measure the foot position with an error of about 4 cm. Also, our device has a limitation, in that the maximum step length that can be measured is 0.6 m. Namely, our device can measure the foot position with an error of about 4 cm if the device user walks with a step length within 0.6 m. Because this navigation system can pinpoint the destination easily by GPS or RFID, the system, which combines our device and GPS/RIFD, can accurately calculate the remaining distance to the destination if the step length is within 0.6m. Nevertheless to say, increasing the measurable step length is a future problem to be solved.

4.2 Effectiveness of distance-presentation method

Figure 7 shows the experimental results for all the subjects. The left column shows the results when the remaining distance was 3 steps and the voice instruction “3 steps” was given. The middle and the right columns of Fig. 7 show the results for 4 and 5 steps, respectively. The vertical axis shows the guidance error. The horizontal axis shows the voice instruction. In the preliminary experiment, it was found that the subjects could find the door by using their hands without any visual information if they stood within 0.5 m of the middle of the door. So, we stipulated the area between -0.5 m and + 0.5 m away...
from the middle of the door as the target area in which guidance was deemed successful. This area was defined as “the allowable area” (shaded in Fig. 7).

In the left column of Fig. 7, it can be seen that only a few results were outside the allowable area in the case of 3 steps. Guidance was successful in 74 tries out of 90 (82%) in the case of 3 steps. Similarly, guidance was successful 78 times out of 90 (86%) in the case of 4 steps and 81 times out of 90 (90%) in the case of 5 steps. In this experiment, it was found that the subjects could reach the destination with the highest precision when the voice instruction was “5 steps.” Our method guided the subjects to the destination with a success rate of 90% and within a maximum guidance error of 1 meter when “5 steps” was used as the voice instruction. However, it was found that any number of steps could be used, because there were only slight differences between 3, 4 and 5 steps. So, we suggested to the device user to choose 3 steps if he/she wanted to know the destination as late as possible. Conversely, the device user was suggested to choose 5 steps if he/she wanted to have sufficient time. However, the walking speed of the blind person increased as preview of environment by an obstacle detection device such as the Laser Cane was prolonged and optimum preview was decided to be 3.5 m from the experimental results [9]. In our experiment, average step length was about 0.6 m. Then, we thought 5 steps, which was equivalent to 3.5 m, would be best for voice instruction. Nevertheless to say, although there are some differences in gait parameters, such as step length between non-visually impaired person and blind person [10], our method would be applicable to the blind person because our method used not average gait characteristics of blind persons but the step length of an individual.

5. Conclusions

In this paper, we have described the outline of our new gait measuring system and our distance presentation method for helping the blind navigate. Based on the results, our shoe-type device could measure the foot position with an error of about 4 cm if the step length was within 0.6 m. Moreover, our distance presentation method guided subjects to the destination with a success rate of 90% and within a maximum guidance error of 1 m when “5 steps” was used as the voice instruction. Therefore, we concluded that our system can guide the blind to the destination if the destination is first pinpointed by GPS or RFID. However, there are still problems to be solved, such as the measurement limitation mentioned above. After solving these problems, a fully functional commercial navigation system for the blind can be developed.

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References
