Future route presentation to autonomous mobile wheelchair passengers using the movement of vibrotactile stimuli

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Abstract: While autonomous wheelchairs reduce the burden on the passenger, the automation of the operation may make it difficult for the passenger to understand the route the wheelchair will take in the future. In this case, passengers may feel anxious or uncomfortable due to unexpected movements of the wheelchair. To reduce passengers' anxiety and discomfort, it is important to present information to passengers about the future route of the wheelchair when obstacles or pedestrians approach from the front. In previous studies, only the distance and direction to the next turning point were presented. We propose a comfortable and easy-to-understand route presentation method that presents the direction and avoidance width of the wheelchair's turn by changing the length of the haptic apparent motion according to the width of the wheelchair's turn. Preliminary simulated wheelchair driving experiments have confirmed the potential of the proposed method to improve passenger comfort.

Keywords: autonomous wheelchair, preliminary announcement, vibrotactile display

1. INTRODUCTION

Automated wheelchairs have been studied to extend the range of activities and improve the quality of life of people with mobility impairments [1] [2] [3]. Autonomous wheelchairs expand mobility possibilities for people who are not comfortable driving, prevent accidents caused by human error, and reduce the burden of driving operations. Due to these advantages, autonomous wheelchairs are expected to become popular, especially among the elderly and physically challenged.

Since the passenger is not involved in driving, one problem with autonomous wheelchairs is that the future behavior of the wheelchair is unpredictable, causing anxiety and discomfort. Watanabe et al. [4] argued that it is important for an autonomous wheelchair to share its future behavior with its surroundings. Research in the field of automated driving has also pointed out the importance of driver comfort [5] and the driver's understanding of the driving situation [6]. So far, many methods have been proposed for presenting information to passengers of autonomous vehicles using visual [7] and auditory devices [8]. The problem with the audiovisual presentation of information is that visual route presentation requires passengers to gaze at the display, making it difficult to understand what is going on around them. Auditory presentation in a wheelchair may be difficult to hear with loud ambient noise.

The effectiveness of tactile presentation has been shown to address this problem [9][10]. In a study of tactile information presentation to self-driving passengers, Erp et al. [11] showed tactile information presented direction and distance and reduced cognitive load compared to visual presentation. Scott et al. [12] showed that the mean reaction time was shorter than that of auditory and visual information [12]. In order to convey navigation information to passengers, which consists of the distance and direction to the next turning point, vibration devices installed on the seat [13] [14] and tactile-waist belts [15] [16] have been proposed. In a study of information presentation to wheelchair passengers, Devigne et al. [17] presented navigation information and distance to obstacles to a passenger who drives an electric wheelchair with a vibration device attached to the arm.

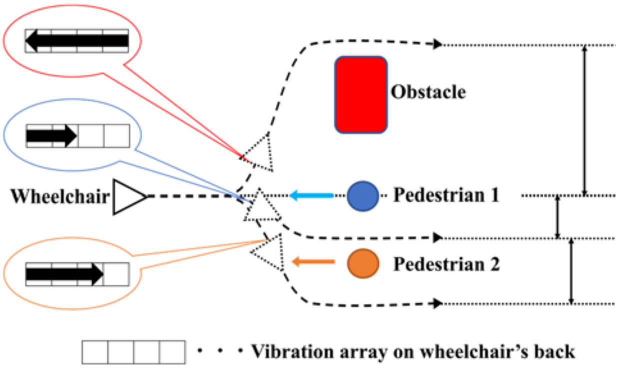


Fig.1 Array of vibrating elements on the back of the wheelchair

However, autonomous wheelchair passengers need more detailed route information. Wheelchairs mainly travel on sidewalks and public spaces, avoiding pedestrians and obstacles and taking a more diverse range of routes than cars. Fig. 1 shows a scene in which a wheelchair is traveling in a public space, with two pedestrians approaching from in front of the wheelchair and an obstacle on the left side. The possible future routes for the wheelchair could be a route around the left side of the obstacle, a route between the two pedestrians, or a route around the right side of pedestrian 2. For a wheelchair that moves autonomously in a lane-less area, sharing more detailed route information with the passenger would be effective, such as the side the wheelchair avoids and what route it avoids. Conventional studies on tactile information presentation to passengers have been focused on the side and distance to the next turn, which is not sufficient for passengers of

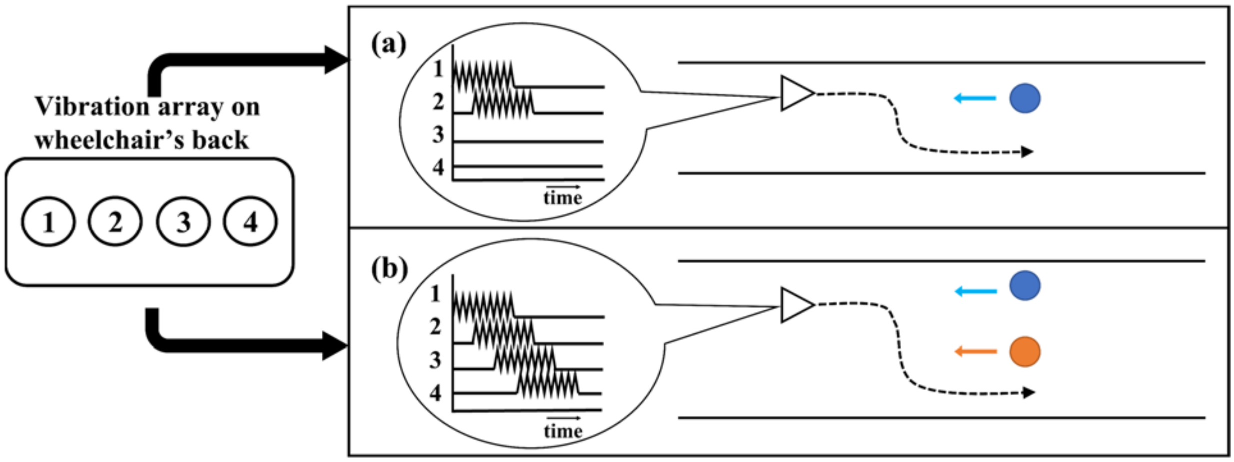


Fig.2 Mechanism of the proposed method (e.g., right avoidance)

autonomous wheelchair. In addition, there is little experimental knowledge of the appropriate timing of the presentation.

This paper proposes a method of conveying detailed future route information to a passenger of an autonomous wheelchair using vibration presentation (Fig. 1). We place an array of vibrating devices on the seat of a wheelchair, which in turn vibrates to represent the future trajectory of the wheelchair. We also investigate the appropriate presentation timing for actual wheelchair avoidance.

2. FUTURE ROUTE PRESENTATION USING VIBROTACTILE DISPLAY

2.1 Presentation of future routes to passengers in autonomous wheelchairs

This section proposes a method to present a future travel route to a passenger of an autonomous wheelchair in the situation shown in Fig. 1. In these changing surrounding conditions, passengers have the problem of feeling uneasy about the sudden change of the autonomous wheelchair's route or not knowing whether it will perform evasive maneuvers. In order to present a route in the situation, it is important to inform the passenger of the timing of the wheelchair's evasive action and the side and avoidance width of the route. In the proposed method, an array of vibration devices installed on the back of the wheelchair vibrates in sequence at an appropriate timing to share the route with the passenger.

2.2 Route presentation method using haptic display

Conventional route presentation methods using vibration devices only tell the passenger the side of the turn and the distance. The problem with this presentation method is that the passenger does not understand in detail what avoidance route the wheelchair will take in a lane-less environment.

The proposed method presents a route by vibrating an array of devices attached to the back of a wheelchair in sequence. Following previous studies, the direction of avoidance is indicated by the position of the vibrating device; specifically, the device on the right side vibrates when presenting avoidance behavior to the right side. Furthermore, in the proposed method, the array of devices on the right side vibrates in turn, and the distance traveled by the vibration presents the avoidance width.

Fig. 2 shows examples of runs with different avoidance widths and the vibrations presented. The vibrations of the array of devices move over the back of the wheelchair depending on the avoidance width of the wheelchair. In Fig. 2 (a), only two devices vibrate because of the short avoidance width, and the vibration on the back moves short. In Fig. 2 (b), the four vibrating devices vibrate in turn to present a large avoidance, and the passenger feels a large evasive path. This allows the passenger to understand the future travel route of the wheelchair.

Here, when the devices vibrate in turn, the timing of the presentation is based on the haptic apparent motion. Haptic apparent motion is one of the perceptual phenomena in which a stimulus with a fixed time interval between two points on the skin is perceived as moving from the first stimulus point to the subsequent stimulus point [18]. Specifically, by overlapping the time of vibration of adjacent vibrating devices, a continuous vibration movement is perceived from a discrete arrangement of vibrating devices. With this method, the passenger is expected to experience a more continuous range of avoidance.

2.3 Timing of future route presentation using haptic sensation

When presenting a future route to a passenger in an autonomous wheelchair, the timing of the presentation is considered important. If the presentation is too early, the passenger may not know when the avoidance behavior actually starts, which may cause anxiety. In contrast, if the presentation is too close to the point of avoidance, the passenger has difficulty predicting the wheelchair's behavior.

We hypothesize that the timing of vibrotactile route presentation to the passenger is most easily understood when the avoidance behavior starts immediately after the presentation is over. By having the wheelchair start its avoidance maneuver at the end of the route presentation, there is no danger of the passenger becoming uncertain about when the wheelchair will perform the avoidance maneuver. In the experiment, we compared several different timings to find the most obvious presentation timing to the passenger.

3. EXPERIMENT 1

When presenting an autonomous wheelchair route, it would be desirable to inform the passenger of the route before the wheelchair actually changes routes. The question is which timing is appropriate. This section reports on an experiment to compare the impression of the route presentation timing when a wheelchair moves autonomously along the same route and presents the same vibration stimulus.

3.1 Apparatus and Environment

Autonomous mobile wheelchair

Fig. 3 shows the electric wheelchair used in the experiment (Nissin Medical Instrument NEO-PR). The wheelchair runs autonomously on the given route under computer control using two range sensors (Hokuyo Automatic UTM-30LX) installed at the height of 34 cm. It localizes its position and posture by matching the observation with the grid map of the environment acquired in advance based on a particle filter [19].

Tactile vibration devices

Eight vibration devices (Foster Electric Company 602760) were installed in a wheelchair, and a microcontroller (STMicroelectronics Nucleo-f446re) controlled the timing and frequency of vibration. We mounted a row of vibration devices on a 300 mm by 210 mm thin and soft board (Fig. 5(a)). We placed it on the seat of the wheelchair so that the backside of the board faces the passenger, preventing the vibration device from coming into direct contact with the passenger (Fig. 4).

The tactile vibration device was vibrated with the time-series pattern described in section 2.3. Vibration devices on the side of avoidance were vibrated in turn based on haptic apparent motion with a vibration time of 200 ms and a delay time of 100 ms between vibration elements (Fig. 5(b)). The vibration frequency was set at 200 Hz. Under the condition of small avoidance width, vibrating elements 1 to 3 in Fig. 5 (a) oscillated. Under the condition of large avoidance width in Experiment 2, vibrating elements 1 to 4 oscillated.

Environment

Fig. 6 shows the 13m by 5m environment in which the running experiment was conducted. The wheelchair repeatedly traveled along with a specific route with a small avoidance to the right.

3.2 Conditions

The wheelchair traveled an identical route avoiding the obstacle ahead by 0.75 m to the right (Fig. 6). The vibration was presented at a fixed time before the

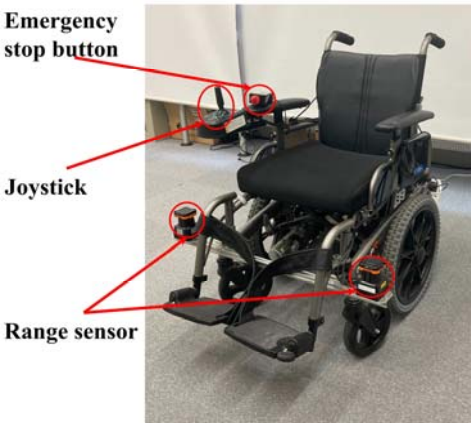


Fig.3 Autonomous wheelchair robot used in experiments

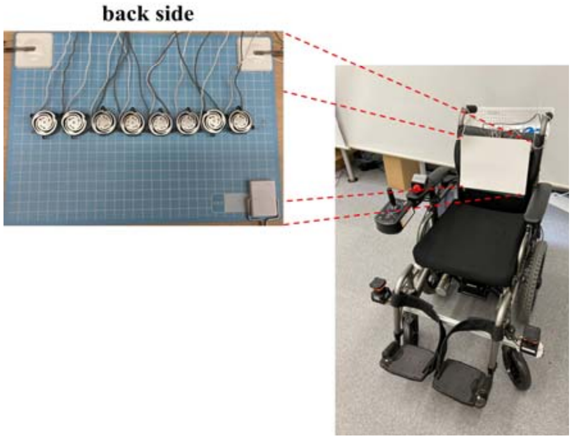
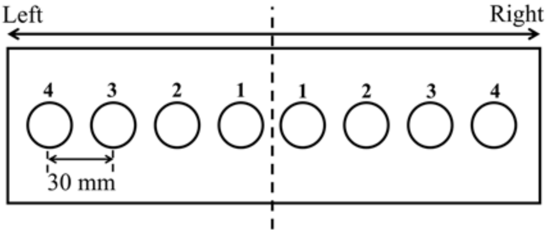
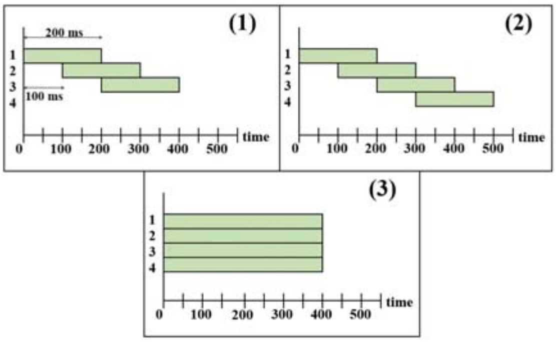


Fig.4 Vibration elements array and installation on a wheelchair



(a) Dimensions of vibrating element array, arrangement of vibrating elements



(b) Created vibration pattern

Fig.5 Vibration element array and vibration pattern

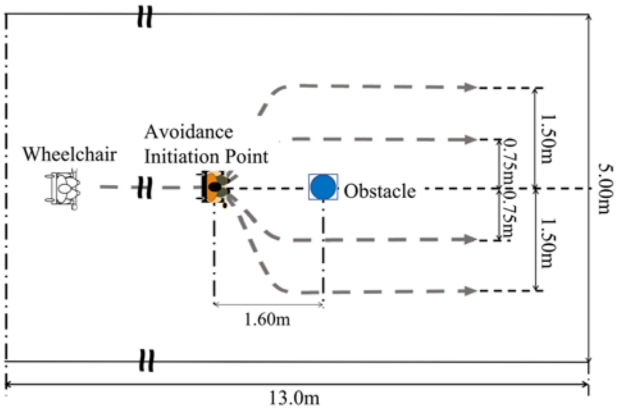


Fig.6 Experiment environment

Table 1 Experiment conditions (Experiment 1)

Condition	timing of route presentation[sec]
A	0
B	2
C	4

wheelchair started avoidance behavior. We compared three different timings shown in Table 1.

3.3 Participants

Seven healthy male adults (mean age was 22.0 years) participated in our experiment. All procedures used in this research were approved by the Ethical Committee of Hiroshima City University. Written, informed consent was obtained from all the participants in our study.

3.4 Procedure

After receiving an explanation of the task, participants experienced once the wheelchair traveled in a small avoidance to the right with vibration. Participants then experienced wheelchair travel in three conditions and completed an evaluation questionnaire after each run. Each condition was presented in a pseudo-randomized order.

3.5 Measurements

Fig. 7 shows the questionnaire items. Participants responded to each item on a 7-point scale. After completing all conditions, participants answered which condition they preferred the most.

Q1. Did you feel comfortable with the automation driving?
Q2. Were you able to predict when wheelchair would avoid?
Q3. Did you feel any discomfort with the timing of the presentation?

Fig.7 Subjective evaluation (Experiment 1)

3.6 Results and discussion

Figs. 8 to 10 show the distribution of responses to the survey questions. For all questions in Q1-Q3, the best results were obtained when the wheelchair presented the route two seconds before avoidance in Condition B. In the post-experiment evaluation, five of the seven participants indicated that condition B was the best. Participants' comments on Condition B included responses such as "It was easy to predict when the turn would occur" and "I had a degree of relief because the turn occurred right after the vibration ended."

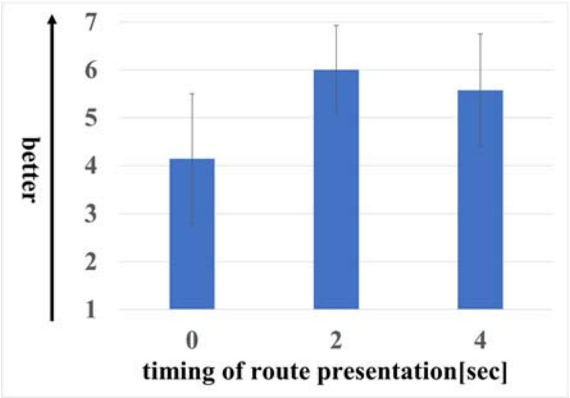


Fig.8 Sense of security in automation driving

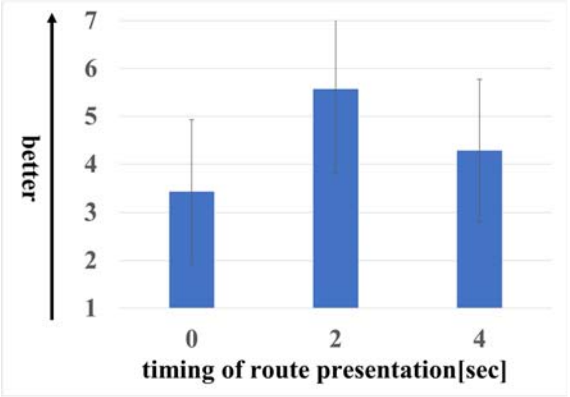


Fig.9 Predictability of when wheelchair will avoid

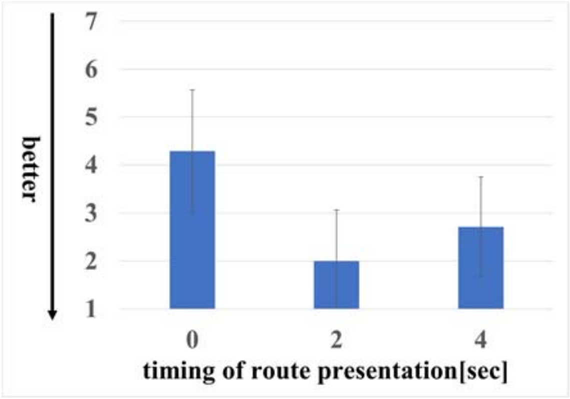


Fig.10 Discomfort with timing of route presentation

In condition B, the route presentation started two seconds before the start of avoidance, and the wheelchair started avoidance as soon as the route presentation ended. This timing may have made it easier to understand when the wheelchair was to be avoided, and this may have made the two-second presentation the most preferred.

4. EXPERIMENT 2

This section reports the preliminary results of evaluating the proposed route presentation method when a wheelchair traveled along several different paths, avoiding obstacles in front of it. The experiment was conducted in the same environment as Experiment 1.

4.1 Conditions

The autonomous wheelchair moved to the destination by avoiding obstacles in front of it. There were two information presentation conditions. In the proposed method, the width and direction of the wheelchair's future movement route were presented to the passenger. The vibration patterns (1) and (2) in Fig. 5(b) were presented. In the conventional method, only the left and right directions of the movement route were presented. The vibration pattern was used in which all vibration elements on the side to be avoided started and ended vibrating simultaneously (Fig. 5 (b)(3)).

4.2 Participants

Four healthy male adults (mean age was 22.0 years) participated in our experiment. All participants were those who took part in Experiment 1. The same ethical procedures were followed as in Experiment 1.

4.3 Procedure

After receiving an explanation of the task, participants agreed to participate in the experiment. Participants were briefed on how to evaluate the presentation of future pathways by wheelchair by filling out a questionnaire. Participants then experienced all routes and vibration patterns of the wheelchair before the experiment. Then, participants experienced the information presentation by driving through the four routes shown in Fig. 6 in random order and completed an evaluation questionnaire after each run. The timing of presentation was the two-second condition that most participants answered as the best in Experiment 1.

4.4 Measurements

Fig. 11 shows the questionnaire items. Participants responded to each item on a 7-point scale.

Q1. Did you feel the vibration clearly?
Q2. Was it easy to understand the avoidance width of the wheelchair?
Q3. Was it easy to understand the direction to avoid the wheelchair?
Q4. Did you feel comfortable with the automation driving?
Q5. Was the vibration in your back uncomfortable?
Q6. Was the future route easy to understand?

Fig.11 Subjective evaluation (Experiment 2)

4.5 Results and discussion

The means and variances of the responses to the survey questions are shown in Figs. 12 to 17. No significant differences were found for all questions.

Condition
A … Proposed method
B … Existing method

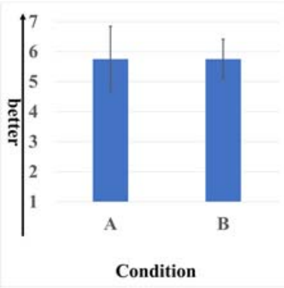


Fig.12 Ease of feel the vibration clearly

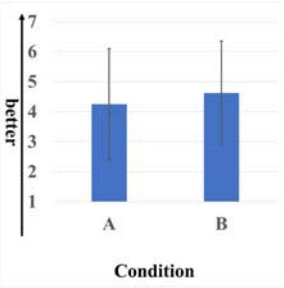


Fig.13 Ease of understanding the width of avoidance

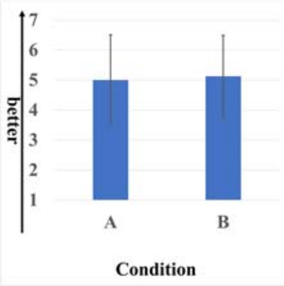


Fig.14 Ease of understanding the direction of avoidance

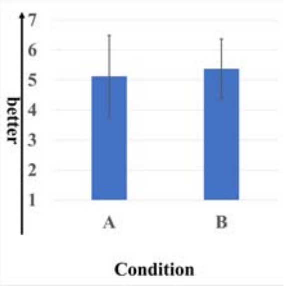


Fig.15 Sense of security in automation driving

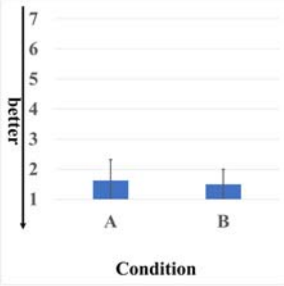


Fig.16 Vibration discomfort

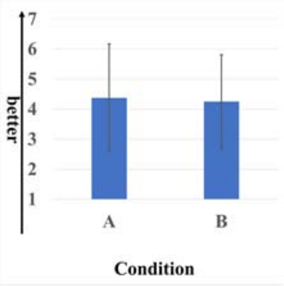


Fig.17 Ease of understanding future route

The first possible reason for this result is the arrangement of the vibrating elements. While the two-point discrimination threshold of the human back is reported to be 40 mm, in this study, eight vibration elements were placed in a row with a spacing of 30 mm to arrange in a row. This would have prevented the two stimuli from being perceived as different, even under the condition in which the stimuli were presented in sequence, and thus would have resulted in no difference in the evaluation of the two stimuli.

Another possible reason is the intensity of the vibration. The placement of the vibrating element between the backrest of the wheelchair and the passenger's mid-back caused the element to be compressed, and the passenger could not feel the vibrations with satisfactory intensity. For future issues, we would like to review the hardware design and installation method and improve them so that the proposed presentation can be sufficiently conveyed to passengers.

5. CONCLUSION

The contribution of this paper is to propose a method of presenting future travel routes to a passenger of an autonomous mobile wheelchair using vibration stimuli to reduce the passenger's sense of anxiety and discomfort. We conducted preliminary experiments on a method of presenting changes in the direction and width of a route by sequentially vibrating an array of vibrators.

We also evaluated the appropriate timing of the presentation based on subjective evaluation. Our limitations are that we evaluated with a small number of experiment participants and did not evaluate with actual wheelchair passengers. We also found issues with the hardware design and installation method, which prevented us from effectively using the proposed method of presentation. We would like to validate the effectiveness of the proposed method with improved hardware configuration by evaluating with a larger number of participants.

As a future plan, we would like to verify the proposed method by driving the wheelchair in a real environment with pedestrians and obstacles around the wheelchair and confirm the effectiveness of the proposed method by conducting experiments on actual wheelchair users.

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