BotBeep — An Affordable Warning Device for Wheelchair Rearward Safety

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***Abstract*—As the rear of a wheelchair is often in a wheelchair user's blind spot, an innovative and low-cost device, BotBeep, was developed to warn the user of elevation changes behind the wheelchair corresponding to holes, steep slopes, and staircases. Thus, BotBeep reduces the risk of falling and turning over. Tests were conducted using a smartphone as a computing device via an image processing technique. Elderly volunteers from the Suang-Lien Elderly Center participated in these tests. This research studies the possibility of incorporating BotBeep into the daily lives of Taiwan's elderly population.**

***Keywords*—wheelchair, sensing device, laser, smartphone.**

I. Introduction

Improving assistive devices for elderly or disabled people has become an important area of research. For example, a mobile transportation robot has been developed for people with a lazy eye or poor vision [1], which can carry their body weight, avoid obstacles, and provide safe transportation. The general definition of an "assistive device" is a machine or device that can help elderly or disabled people live more independently, with more convenience, and a better quality of life. The design concept of an assistive device not only improves individual mobility in daily situations, but also increases autonomy and decreases their dependency on other people [2]. For instance, installing a robot arm on a wheelchair can provide the ability to grip objects, allowing people to perform daily tasks such as shaving, holding things, and drinking water [3].

Currently, many assistive devices are available on the market; among these devices, manual and motorized wheelchairs are widely used for elderly or disabled persons. Based on wheelchair accident research by the School of Occupational Therapy in the College of Medicine of the National Taiwan University, overturning accounts for 53.9% of all wheelchair accidents; among these accidents, 75.6% are forward or backward overturning, and this causes injuries in 56.6% of users [4]. A review of wheelchairs on the market shows that the price of a wheelchair with accident-proof (Fig. 1) devices is higher than that of a manual wheelchair. There are also no accident-proof devices for manual wheelchairs or low-cost electric wheelchairs. Therefore, most wheelchair users are not aware of gaps, obstacles, and blind spots when they are moving backwards, as shown in Fig. 2.

Fig. 1. A wheelchair with an accident-proof device (circled) to prevent overturning [5].

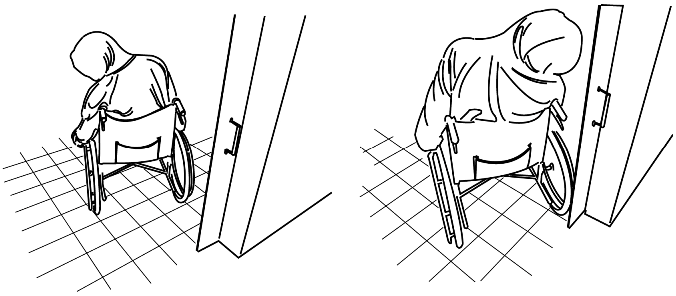

Fig. 2. A dangerous scenario for a wheelchair moving backwards.

In this study, we focused on improving safety when elderly or disabled persons are moving backwards in a wheelchair. We used the Taiwanese version of the Quebec User Evaluation Satisfaction with Assistive Technology (QUEST-T) to evaluate the special needs of wheelchair users in terms of safety, durability, and maintainability. The results are given below.

In our survey, we collected 19 questionnaires from wheelchair users (6 male, 13 female). Sixteen participants (84%) would leave their homes by themselves every week, and nine of them (47%) more than 5 times a week. The following is a summary of the results of the 16 wheelchair users:

- Participants left their homes for working, eating, shopping, visiting friends, journeying outside, going to the hospital, going to the bank, watching a movie, and traveling.
- 13 users (81%) considered going outside by themselves unsafe.
- The frequency of accidents was 8 users once a year, 2 users once every half-year, and one user once every month, while 69% of users had at least one accident every year.
- 14 users (88%) stated that a device providing information of the environment behind the wheelchair would be convenient and would let them feel more safe and at ease when using the wheelchair.
- 15 users (94%) responded that if the price of the aforementioned device was lower than NT$1,000, and it was easy to install, they would probably like to buy the device, and 10 users (62%) would definitely buy the device.

The questionnaire results show a common problem among wheelchair users. Even those who regularly and independently leave their homes consider this action unsafe. Wheelchair accidents, which are caused by obstacles or terrain, are a universal problem. Although these wheelchair users had not seen the BotBeep device, they believe it would make them feel safer and give them greater convenience and relief. If the price of the BotBeep device was less than NT$1,000, more than 50% of wheelchair users said they would buy one, even though they had not yet seen the device.

II. Methodology

We started by gaining practice with the wheelchair in order to familiarize ourselves with the kinds of situations that cause wheelchair accidents. Then we defined the problem, considered different kinds of solutions, and selected the optimal solution. Next, we developed the hardware and software for BotBeep. Finally, we implemented user tests in the Suang-Lien Elderly Center to verify the feasibility of the device.

III. Development

Based on our experience with the wheelchair, we divided the barriers that may cause wheelchair accidents into three categories: (1) height differences in the terrain, such as stairs or ramps, may cause the wheelchair to overturn; (2) broken terrain, such as potholes or ditch covers, may cause the wheels to become stuck; and (3) large obstacles, such as vehicles or walls, may block the wheelchair. Fig. 3 shows each of these barriers.

From this categorization, we discovered that if the wheels could smoothly pass the barrier, the accident would not happen. Thus, the core of the solution is to monitor the terrain a short distance behind the wheelchair, and determine whether it is flat. We found two main ways to solve this problem: a geometry method and a force distribution method. The geometry method uses image processing, distance sensing, or contact to monitor and calculate the variation of the geometric distribution. The force distribution method monitors the wheelchair's weight distribution and determines whether it will overturn. After estimation, we decided to use the distance sensing and image processing methods in a feasibility study.

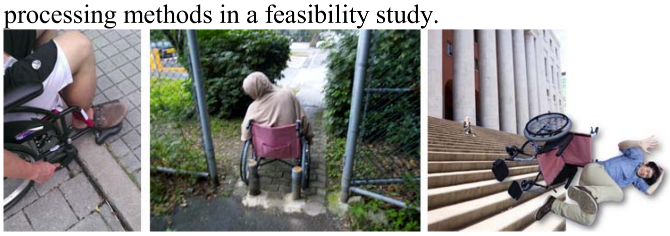

Fig. 3. Three kinds of barrier responsible for wheelchair accidents.

In the distance sensing method, we utilize many kinds of sensing devices, including infrared ray sensors, ultrasonic sensors, and a Kinect, to measure the range. In the image processing method, we utilize a laser light generator and a camera to detect the variation of the ground. We will discuss these methods in the following sections.

A. Kinect

We connected the depth sensor from an Xbox 360 Kinect to the back of the wheelchair in order to analyze the level of flatness. The depth sensor can sense the two-dimensional depth data of an object. Fig. 4 shows the data for a flat area and a ditch cover. Since the sensor could not capture data on the area of the ditch cover, the readings there are the maximum distance values, and are easily identifiable. We implemented a median filter to eliminate noise in the data signal. In the case of a flat surface, the median filter result will be a straight line; in the case of a barrier, the result will be a convoluted curve. Comparing with data for different kinds of environments, we adopted a linear regression method to ascertain whether the terrain was flat behind the wheelchair. Fig. 5 shows the real-time test result. Fig. 5(a) is the result of the algorithm and Fig. 5(b) is the environment. When the wheelchair encounters a barrier, the median filter line will be more convoluted, influencing the linear regression line and changing the slope and the value of the coefficient of determination. We can determine if it is flat behind the wheelchair using the value of the coefficient of determination.

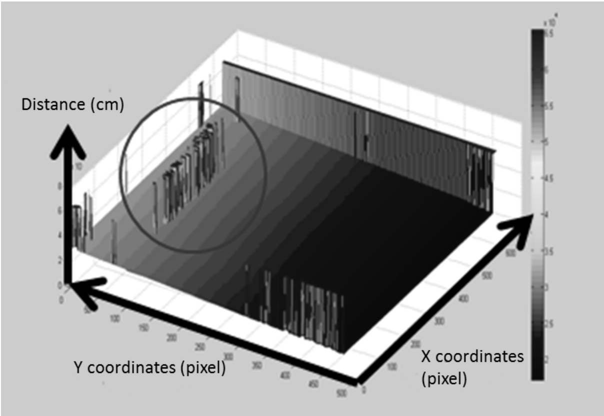

Fig. 4. Depth data for a flat area and a ditch cover. The circled part is the ditch cover.

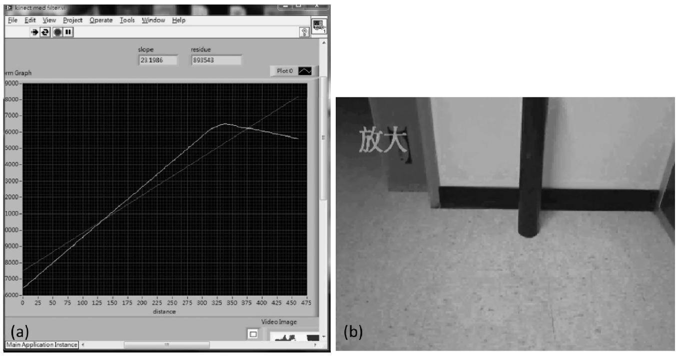

Fig. 5. (a) The results of the linear regression algorithm, and (b) the environment behind the wheelchair.

B. Infrared Ray Sensor

The infrared ray (IR) sensor is a distance sensing device. We installed two IR sensors on the back of the wheelchair. Each sensor monitors the ground 50 cm behind each wheel. The IR sensors detect the distance from themselves to the target position with a period of 2 seconds.

The IR sensors are very sensitive to the change in terrain; however, there are many sources of noise in the IR sensor signals. The accuracy is affected by the material of the ground. Furthermore, we cannot rely on the IR sensor as it can only detect obstacles on the sensing line.

C. Image Processing Method

We used a laser light generator to project laser points on the ground, and a camera to scan the image. The pattern produced by the laser points will be different for different kinds of terrain. For example, the laser points will shift in the case of stairs due to the projection principle. Fig. 6 compares the laser pattern on flat terrain with that on terrain with a height difference. We found the coordinates of each laser point, and summed the *x* and *y* coordinates to observe the divergence. In Fig. 7, we see that the value of the summation will change noticeably if the wheelchair approaches a barrier. With the linear regression algorithm, the BotBeep clip can determine whether it is dangerous behind the wheelchair.

Table 1 compares these three sensors. After the feasibility test, we decided to use the image processing method to develop the BotBeep clip.

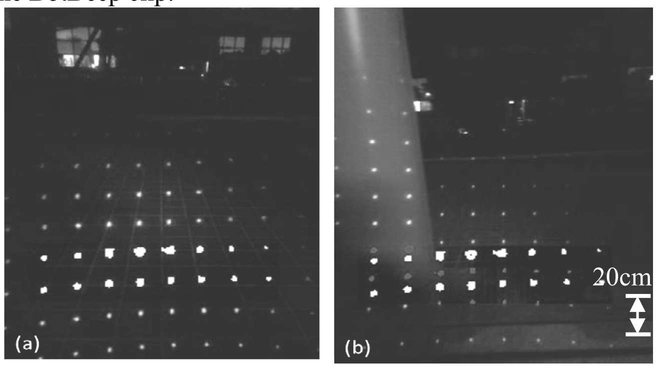

Fig. 6. Laser point patterns of (a) flat terrain and (b) terrain with a height difference.

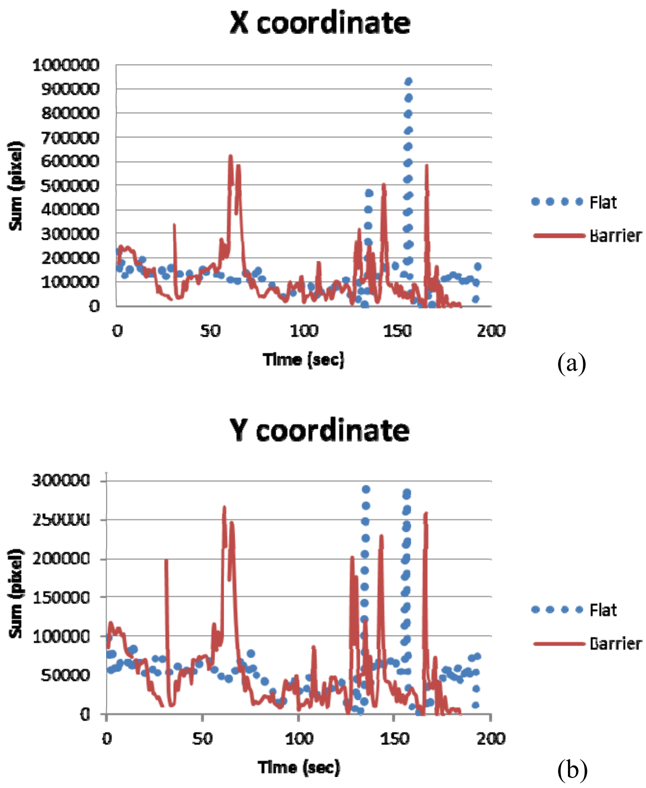

Fig. 7. Summations of *x* and *y* coordinates in (a) a flat environment and (b) an environment with a barrier.

Fig. 8 The appearance of the BotBeep clip.

Table 1: Comparison between the Kinect, IR sensor and image processing approaches.

	Kinect	IR sensor	Image processing
Under sunlight	NG	NG	OK
Device volume	Large	Small	Small
Accuracy	Superior Outcome	Too Sensitive	High
Price	Expensive	Cheap	Medium
Algorithm	Built-in	Too complex	Needs to be developed
Overall result			Recommended

IV. Implementation

The implementation phase of the BotBeep clip includes hardware and software.

A. Hardware

The BotBeep clip uses a smartphone as its main computational device. This is combined with a Bluetooth module and a laser module to create a system that directly scans the environment, performs calculations, and notifies the user of danger. The smartphone connects with the laser module via Bluetooth to control the laser to reduce the consumption of electricity and avoid the use of additional chips and complex circuitry. This can increase the efficiency of the computation and the stability of the system.

The key feature of the device's appearance is its clip shape, as shown in Fig. 8. The smartphone is embedded in the BotBeep clip so that it is not ostensibly visible. The camera can scan through the glass on the clip, and the user can still operate the smartphone through the window in the clip.

B. Software

We utilized an Android application to operate the system. The system operates by scanning the environment, calculating dangers, and notifying the user. The smartphone continuously records video and performs calculations. We used the C programming language to compile an algorithm that processes images and performs calculations for the laser point shifts. If the system detects a dangerous environment behind the wheelchair, it will play an alarm sound to notify the user.

The user only needs to download and install the application, which contains a tutorial describing the installation procedure of the BotBeep clip. Once the user finishes the installation, the system will automatically operate.

V. User Tests

The user tests were held at the Suang-Lien Elderly Center. Two elderly people took part in the research. The first participant was an 80-year-old grandmother. She could easily install the equipment by herself and moved her wheelchair backward without looking behind. The second participant was a 76-year-old grandmother. She had a small problem installing the equipment, but she could also move her wheelchair backward without looking behind. As a result, it is clear that even elderly people with little knowledge of electronic devices can still use the BotBeep clip.

VI. Conclusions

We have developed a warning device, BotBeep clip, for wheelchair safety. This clip is suitable for almost every kind of wheelchairs in the market because it can clip onto the rear bag of the wheelchair. The utilization of an Android application allows easy development and operation. Moreover, it can control the laser light to reduce the consumption of electricity and prevent temperature spikes. As the BotBeep clip can be used with different smartphones, the user can select a suitable phone to use, and only needs to install the application. This can decrease the cost of production and give greater flexibility in usage.

The essence of the BotBeep clip is the care and concern with which it is designed. In this study, we not only focused on reducing the number of wheelchair accidents, but also on providing services showing care for safety and health. In particular for a society with an increasingly aging population, it is important to pay attention to elderly care.

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