Computer Vision-Based Clear Path Guidance for Blind Wheelchair Users

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ABSTRACT
We describe a system for guiding blind and visually impaired wheelchair users along a clear path that uses computer vision to sense the presence of obstacles or other terrain features and warn the user accordingly. Since multiple terrain features can be distributed anywhere on the ground, and their locations relative to a moving wheelchair are continually changing, it is challenging to communicate this wealth of spatial information in a way that is rapidly comprehensible to the user. The main contribution of our system is the development of a novel user interface that allows the user to interrogate the environment by sweeping a standard (unmodified) white cane back and forth: the system continuously tracks the cane location and sounds an alert if a terrain feature is detected in the direction the cane is pointing. Experiments are described demonstrating the feasibility of the approach.

Categories and Subject Descriptors
I.5.4 [**Pattern Recognition**]: Applications: *Computer Vision*.

General Terms
Algorithms, Performance, Experimentation, Human Factors.

Keywords
Orientation, Mobility, Wheelchair, Blindness.

1. INTRODUCTION
Approximately one in ten blind persons uses a wheelchair, and independent travel is extremely difficult for this population. However, little research has been conducted on the specific problems of visually impaired wheelchair riders [1]. One of the few commercial devices targeted at this population is a version of the laser cane by Nurion Inc., which is rigidly mounted on the arm of a wheelchair [2]. The laser's fixed pencil beam severely limits its field of view, while four added ultrasonic sensors detect only large, tall obstacles within one foot.

White canes are often used by visually impaired wheelchair riders, who scan the area around the chair while it is moving [3]. However, the cane's detection range is limited by its length, which means that riders are often unaware of hazards until too late. Flexible curb feelers may also be used, which gently scrape obstacles alongside a wheelchair (before they can scrape or injure the user's hand). Even with such adaptations, visually impaired users still face challenges in "maintaining orientation to the environment and following a straight line of travel" [4].

There is growing interest in applying emerging technologies such as lidar (similar to radar but using laser light rather than radio waves) or computer vision to the problem of sensing terrain in vehicles such as robots and cars [5]. Indeed, such technologies may one day lead to the development of fully autonomous, robotically controlled wheelchairs [6]. In the meantime, we propose [7] the more modest goal of using computer vision technology to *augment* (rather than replace) the information that visually impaired wheelchair users already obtain from their existing orientation and mobility skills; the traveler will use this information to control the wheelchair himself/herself (rather than relying on robotic control of the chair).

The focus of this paper is a novel user interface we have developed for efficiently and intuitively communicating terrain information from a computer vision-based range sensor to a wheelchair user (Fig. 1a). This interface continuously tracks the location of the user's white cane and sounds an alert if a terrain feature (such as an obstacle, wall or curb) is detected in the direction the cane is pointing. The goal is to provide an intuitive method for extending the "reach" of the cane, without requiring any alterations to the cane or the environment.

Figure 1. (a) Wheelchair system. (b) Close-up of stereo camera, which is mounted above wheelchair rider's head. (c) Elevation map estimated by system shows corridor walls (long blue lines) and the cane (long white line near bottom).

2. COMPUTER VISION APPROACH
Our system uses stereo vision [5,6,7], which is a powerful computer vision technique for inferring 3-D scene structure by comparing the differences between images taken by two cameras placed a short distance apart (like human eyes). We use the Point Grey Bumblebee 2 stereo camera, which contains two stereo

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video cameras housed in a single package (Fig. 1b). The camera is mounted above the rider's head and is connected to a laptop computer mounted on a manual wheelchair. The computer analyzes the images and produces range images in real time, at a rate of up to 20 or more frames per second.

It is convenient to represent range image data relative to the dominant ground plane in the scene. Given knowledge of the ground plane (which is fixed relative to the stereo camera once it has been rigidly mounted to the wheelchair, and can be measured in advance), the elevation of every point in the scene is easily calculated, i.e. how high (in meters) each point lies above or below the ground plane. Terrain features such as curbs, walls and obstacles may be detected by the presence of points with elevation significantly different from zero (Fig. 1c).

A clear path ahead of the wheelchair is present whenever any such features are absent within a narrow corridor region centered on, and oriented directly ahead of, the wheelchair. In the next section we describe a user interface for alerting the rider to the presence of any terrain features entering the clear path.

3. USER INTERFACE

We devised a user interface that is compatible with the way a rider already uses his/her regular (unmodified) white cane, scanning the area in front of the chair for any hazards or important terrain features. Our system continuously tracks the location and direction of the cane (Fig. 1c) and sounds a brief, high-pitched audio tone if any features are detected in the cane direction up to a pre-specified range (currently within 1.8 – 3 meters from the hand, measured along the ground). Note that the system monitors the location of the cane in 3-D and is programmed not to report the presence of the cane itself as a terrain feature, even though it is directly in front of the chair and lies well above the ground.

In this way, we are able to extend the "reach" of the cane by a few meters, giving the user more time to react to any hazards or other terrain features ahead. At the same time, the rider retains full use of the cane for acquiring detailed information at short range. In addition, the information is reported in a way that is very easy to understand, even while the wheelchair is moving (and possibly experiencing bumps and vibration). This method of reporting information may be easier to interpret, and more convenient to use, than other forms of directional/spatial feedback, such as binaural feedback, force feedback trackballs/mice and other forms of tactile feedback.

4. USER TESTING

Preliminary tests of our system were conducted with blindfolded, able-bodied volunteer subjects riding a manual wheelchair with a white cane. Experiments were conducted both in indoor corridors and on outdoor sidewalks. The processing required for our computer vision algorithms reduced the processing speed to approximately 5 frames per second, which was adequate for our purposes. (Optimizations of the computer vision algorithms and the use of a faster computer would increase this speed, if necessary.)

Subjects were able to use the system to detect and avoid obstacles at longer range than when the system was turned off. In particular, the system aided them in maintaining a straight direction in a corridor or other straight path. Performance of the system was good but limited by errors made in stereo processing, which led to occasional false positives and false negatives (i.e. "hallucinating" terrain features where there are none, and failing to detect actual features, respectively). Many of these errors stem from illumination conditions that degrade image quality – primarily scenes containing both very bright and very dark regions (e.g. dscenes with sunlight and shadows), which we hope to better cope with using optical contrast filters.

5. CONCLUSION

In the future we plan to improve our computer vision system to minimize false positives and false negatives and to experiment with various enhancements and alterations to the user interface (as well as comparisons with other interfaces, e.g. using tactile feedback). An important question to investigate is whether our "cane interrogation" mode should be combined with a simple "go-no-go" interface that simply alerts the user if any terrain features are present anywhere in the path ahead (without specifying the directions of such features). Extensive subject testing is required, involving blind users and quantitative measures of performance.

Finally, we emphasize that our proposed system is only intended as *one component* of a complete wheelchair wayfinding system, which will ultimately employ redundant sources of information from multiple sensor technologies (including computer vision, ultrasound and laser) covering all sides of the chair.

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