Computer Vision-Based Terrain Sensors for Blind Wheelchair Users

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Introduction

Approximately one in ten blind persons uses a wheelchair, and independent travel is currently next to impossible for this population. Conventional blind wayfinding techniques – cane or guide dog – become extremely difficult or impractical in a wheelchair, requiring great physical dexterity and coordination. As a result, independent travel is so difficult that few attempt it, resulting in a widespread lack of awareness of this severely disadvantaged population.

We have begun a research project to develop computer vision technology for sensing important terrain features as an aid to wheelchair navigation. These features include drop-offs, curbs/curb cuts and the shoreline (i.e. edge of the sidewalk bordering grass or other terrain, or adjoining a wall). We are developing computer vision algorithms for interpreting visual scenes to infer this visual information, in real time, obtained from images collected by video cameras mounted to the wheelchair. This information will be communicated to the traveler using synthesized speech, audible tones and/or tactile feedback, and is meant to *augment* rather than *replace* the information from existing wayfinding skills. The traveler will use this information in controlling the wheelchair himself/herself (rather than relying on robotic control of the chair).

State of the Art and Related Technology

The specific problems of visually impaired wheelchair riders have received little study (Greenbaum et al, 1998). Indeed, the only commercial device targeted at this population is a version of the laser cane by Nurion Inc., mounted on the arm of a wheelchair (Gill, 2000). The laser's fixed pencil beam drastically limits its "field of view," while four added ultrasonic sensors detect only large, tall obstacles within one foot. Several "smart wheelchair" projects have emerged from mobile robotics research (Levine et al, 1999), mainly directed at persons with severe physical, cognitive and neurological rather than visual disabilities. However, the robotic approach in general removes control from the user, and operation is restricted to controlled environments (e.g. Nisbet et al, 1995).

Some technology developed in robotics and autonomous vehicle navigation research may eventually be useful in the design of navigation aids for wheelchairs, but has limitations that prevent it from being adopted in the near future. For instance, 3-D sensing for environmental mapping in robotics is performed using a single or double axis lidar (similar to radar but using laser light rather than radio waves). Although lidars produce very accurate distance measurements, they are still expensive and bulky; moreover, they cannot acquire surface color information, which can be very useful for recognition. Curb detection over short distances for safe driving has been demonstrated at CMU with a laser striper and a calibrated camera, which makes for a very economical system (Thorpe 2002). The problem with a fixed laser striper is that the resulting viewing geometry is very limited, while our task requires the ability to detect features over a rather wide field of view.

Research and Methodological Approach

In our experiments, one or more pairs of stereo video cameras are mounted on the wheelchair and connected to a laptop computer to produce range estimates throughout the image. We are currently using the Videre Design MEGA-DCS color stereo system, which produces range maps at several frames per second using a simple but fast correlation-based stereo algorithm (see Scharstein and Szeliski 2002 for a comparative survey of stereo algorithms).

In order to find important terrain features such as drop-offs and curbs it is useful to first estimate the ground plane in the scene and then use this information to convert the range map into an *elevation map* (Mandelbaum et al 1998), which indicates the height of points in the scene relative to the ground plane (see Figure 1b). Since stereo range estimates are often noisy or missing in parts of the image, it is important to develop robust techniques for estimating ground planes and other specific features of interest even when some of the range estimates are unreliable.

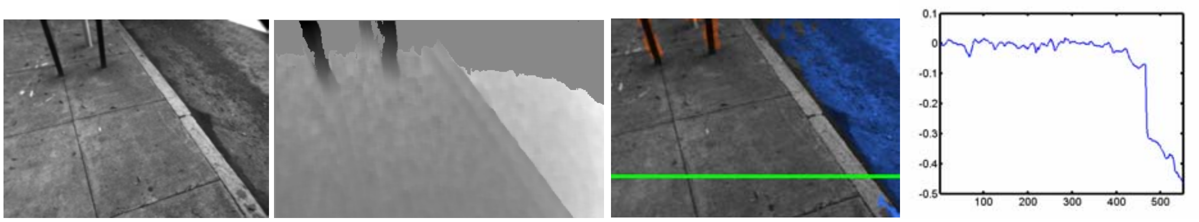

Figure 1. Stereo input and output. Left to right: (a) Image from left camera. (b) Elevation map (darker = higher). (c) Areas classified as above (red), below (blue) and on (no color) ground plane. (d) Graph of elevation across the green slice in panel in (c) is roughly constant except for the discontinuity at the curb.

Findings

In order to improve the accuracy of the elevation map, we have implemented a version of the “V-disparity” algorithm (Labayrade et al 2002) that reliably estimates the ground plane in real time, at a rate of about four frames per second. The algorithm exploits the fact that, in much of the scene, the range is nearly constant along horizontal lines in the image, except at structures that do not lie on the ground plane (see Figure 1d). This assumption, which our preliminary experiments show to be reasonable in practice, allows the algorithm to reduce the noise in its estimate of the ground plane. We can then use knowledge of the ground plane to detect positive obstacles (visible surface protruding above the ground plane) and negative obstacles, i.e. drop-offs (signaled by discontinuity in the elevation profile, as in Bellutta et al 2000).

However, the elevation estimates are still sufficiently noisy that additional information should be used to find certain features. For instance, the presence of a curb is signaled by a relatively small elevation discontinuity which may be swamped by noise. We will draw on past work in stereo-based curb and stairway detection (Lu and Manduchi 2005, Se and Brady 1997), which uses both elevation and (monocular) intensity discontinuities to identify potential curb candidates.

Future Plans

After refining and testing the algorithms for finding the ground plane, drop-offs and curbs, we will design algorithms for finding curb cuts and other ramps and for locating the shoreline. The detection of curb cuts and other ramps will require the ability to reason about different elevation slopes, and may be simplified by the fact that many such ramps are required to be colored yellow (in the US). The shoreline will be detected by tracking a roughly straight line to the side of the wheelchair that separates regions with different elevation or slope, texture (e.g. grass vs. pavement) and/or color.

We will test the algorithms both offline using previously recorded image sequences and in real time running on the wheelchair. Appropriate modalities for conveying the information extracted by the algorithms – including synthesized speech, audio tones and tactile vibration – will be determined by consulting with blind engineers working at Smith-Kettlewell, who will also help to determine the appropriate algorithm parameters (e.g. how close should a drop-off detected by the algorithm be before its presence is signaled to the wheelchair traveler?). We will also explore possible ways of integrating the algorithm outputs into an overall "clear path indicator," which reports information on where the obstacle-free path ahead is.

Acknowledgments

We would like to thank Bill Gerrey for many helpful discussions. The authors were supported by the National Science Foundation (grant no. IIS0415310).

References

P. Bellutta, R. Manduchi, L. Matthies, K. Owens and A. Rankin. “Terrain Perception for DEMO III.” Intelligent Vehicle Symposium 2000.

J. Gill. (2000). Personal electronic mobility devices. In Information for Professionals Working with Visually Disabled People. http://www.tiresias.org

M.G. Greenbaum, S. Fernandes and S.F. Wainapel. Use of a motorized wheelchair in conjunction with a guide dog for the legally blind and physically disabled. Arch Phys Med Rehabil. 1998 Feb, 79(2), 216-7.

R. Labayrade, D. Aubert and J.P. Tarel. "Real Time Obstacle Detection in Stereo Vision on Non Flat Road Geometry Through 'V-disparity' Representation." Proceedings of IEEE Intelligent Vehicle Symposium. Versailles, France. June 18-20. 2002.

S.P. Levine, D.A. Bell, L.A. Jaros, R.C. Simpson, Y. Koren and J. Borenstein. The NavChair Assistive Wheelchair Navigation System. IEEE Trans Rehabilitation Engineering, 1999 Dec; 7(4):443-51.

X. Lu and R. Manduchi, "Detection and Localization of Curbs and Stairways Using Stereo Vision", IEEE International Conference on Robotics and Automation (ICRA '05), Barcelona, April 2005.

R. Mandelbaum, L. McDowell, L. Bogoni, B. Reich and M. Hansen. "Real-Time Stereo Processing, Obstacle Detection, and Terrain Estimation from Vehicle-Mounted Stereo Cameras." Proc. 4th IEEE Workshop on Applications of Computer Vision (WACV'98), Princeton, New Jersey, October 1998.

P. Nisbet, J. Craig, P. Odor and S. Aitken. "Smart" wheelchairs for mobility training. Technology & Disability, 5, 49-62, 1995.

D. Scharstein and R. Szeliski. A Taxonomy and Evaluation of Dense Two-Frame Stereo Correspondence Algorithms. International Journal of Computer Vision, 47(1/2/3):7-42, April-June 2002.

S. Se and M. Brady, "Road Feature Detection and Estimation", Machine Vision and Applications, 14:157--65, 2003.

C. Thorpe et al., "Driving in Traffic: Short-Range Sensing for Urban Collision Avoidance", Proc. SPIE: UGV Tech. IV, Vol. 4715, April 2002.