Substitute Three-Dimensional Perception using Depth and Colour Sensors

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Abstract

The development of sensor-actuator systems that can provide the user with perception of the environment without any use of the eyes is a difficult task. Firstly, the sensors must work effectively under differing conditions. Secondly, the actuators (or auditory feedback) must present the environmental information to the user in a manner that is easy to understand. Thirdly, the whole system needs to be compact, efficient and robust to be practical for a blind person to use. This paper firstly reviews current research in the area of substitute vision systems and discusses their limitations. We then provide details of the substitute vision system that we have developed that is not only aimed at overcoming many of the limitations of existing substitute vision systems, but is also intended to provide the user with more comprehensive perception of the environment. This is achieved by using a combination of range and colour sensors and by delivering the environmental information to the user via electro-tactile feedback in a form that is easy for the user to understand. We provide details of the development of our Electro Neural-Vision System (ENVS) as well as the results we have achieved with various range and colour sensors.

1 Introduction

Combined sensor-actuator systems for assisting the blind to navigate the environment have been available for some time. For example, the Sonic Torch [Kay, 1964], Mowat Sensor [Pressey, 1977] , Nottingham Obstacle Detector [Bissit and Heyes, 1980] and the MiniGuide [GDP, 2005] are all hand held devices that use either sonar or laser range detectors to provide the user with auditory or haptic feedback regarding nearby objects. Although, these sensory aids can detect objects at a greater distance than a white cane, their main disadvantage is that they require the user to scan the environment with the hand holding the sensory aid. They also do not provide the user with as much detail of the detected objects as what can be achieved with a white cane due to the tactile sensations white canes provide.

Recently, similar range sensors have been fitted to white canes to increase the distance at which objects can be detected [SFS, 2004; BAY, 2005; Nurion-Raycal, 1995]. Although the incorporation of sensors into a white cane can provide additional warning of approaching objects, generally the feedback provided from just one or two range sensors is insufficient for the user to be able to construct a mental three-dimensional map of the environment or to be able to identify any familiar nearby landmarks.

The first multi-sensor blind aid capable of sensing 120 degrees of the surrounding environment, without the need for the user to scan the environment with the hand, was developed by [Borenstein, 1990]. This comprised an array of sonar sensors fitted to a belt that could be worn by the user. Feedback was provided with auditory signals whenever obstacles were detected. Later this was converted to a wheeled guide cane [Ulrich and Borenstein, 2001] that could provide the user with auditory feedback of any approaching obstacles within a 90 degree angle as well as haptic feedback of any bumps or ridges on the pathway immediately in front of the user. Although these sensory aids allow the user to detect objects within a perceivable area for the purpose of obstacle avoidance, the environmental information they provide is insufficient for enabling the user to construct a three-dimensional cognitive map of the environment suitable for navigation.

To overcome the limitations of existing substitute vision systems for the blind we have developed an Electro-Neural Vision System (ENVS) that uses an array of sensors to detect both the range and colour of objects in the environment [Meers and Ward, 2004; 2005]. This information is presented to the user in an intuitive form that enables the user to perceive the three-

dimensional profile of the environment as well as the colour of objects without any use of the eyes. In the following sections we provide details and experimental results of our basic ENVS. We also explain how we incorporated GPS into the system to enable familiar or destination landmarks to be detected and located. We follow this with details of an infrared (IR) ENVS prototype we are currently developing which is designed to simplify and miniaturise the system.

2 The Electro-Neural Vision System

Our original Electro-Neural Vision System (ENVS) can be described as a sensory substitution device that works by extracting depth and colour information from the environment using stereo cameras and delivering this information to the user via data gloves that can electrically stimulate the fingers. Our original system is shown in Figure 1.

Figure 1: The Original Electro-Neural Vision System (ENVS) Prototype

To interpret the range data the user only has to imagine that the hands are being held with fingers extended in the direction viewed by the stereo cameras or range sensors. The amount of electro-neural stimulation felt by each finger indicates the distance to objects in the approximate direction of each of the fingers as shown in Figure 2.

The data gloves are fitted with Transcutaneous Electro-Neural Stimulation (TENS) electrodes that make contact with the back of the fingers. To stimulate the fingers, electric pulses with amplitude of approximately 30V to 80V are used, depending on the user's comfort level. This arrangement also enabled us

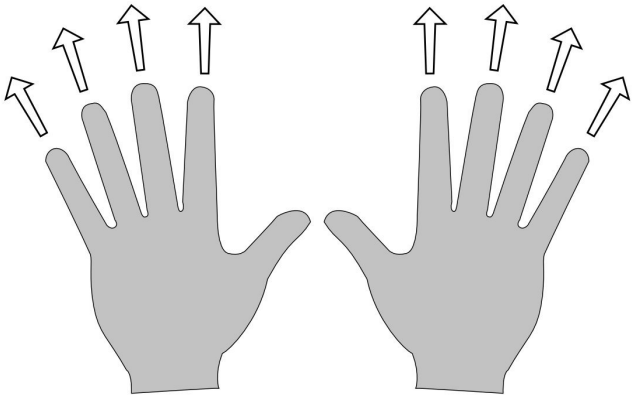


Figure 2: Interpreting the data delivered to the fingers

to use the pulse frequency for interpreting the colour of objects in the direction pointed by each finger. However, we found trying to encode and interpret the entire colour spectrum in this manner beyond the capability of the user to resolve. Instead, we encoded eight familiar colours (user-customisable) with frequencies that were relatively easy for the user to differentiate so that certain familiar landmarks could be identified by their colour.

Figure 3 illustrates the ENVS output as a blindfolded user negotiates our laboratory environment. One of the stereo video images can be seen at the top of Figure 3. The centre image shows the disparity map and sample regions, and the histogram at the bottom illustrates the level of stimulation delivered to the fingers. The central bars on the histogram show two familiar colours that have been detected by the system. In this situation the blue door and the red barrier stands near the door have been detected by their respective red and blue colours. Consequently, the user is able to determine the approximate distance and direction to the door with this information delivered to the fingers and can approach the door while avoiding objects.

3 Perceiving Landmarks with the ENVS and GPS

Although familiar nearby colours could assist a blind ENVS user to identify known landmarks in certain indoor and outdoor environments, perception of familiar landmarks at much greater distances is required to enable an ENVS user to navigate further in outdoor environments. To enable such landmarks to be perceived by the ENVS user we equipped the ENVS laptop computer with a GPS PCMCIA card and the ENVS headset with a digital compass. The digital compass on the headset is required to determine if the user is looking in the direction of specific landmarks. Figure 4 shows a photo

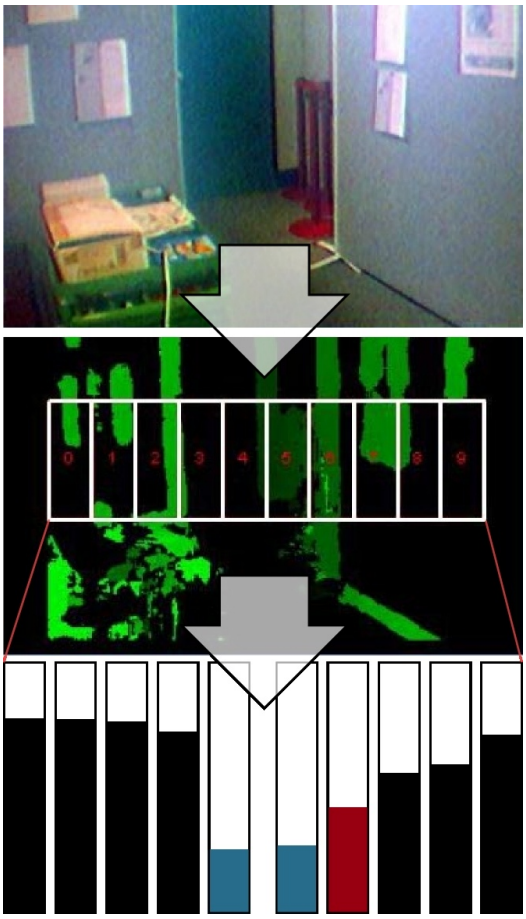
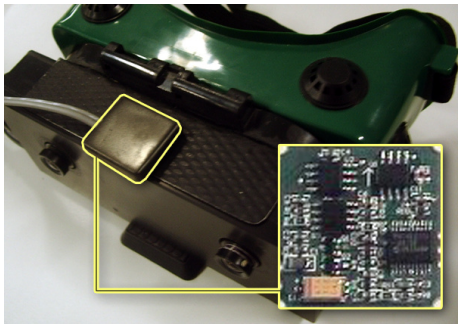


Figure 3: Stereo video frame, ENVS disparity map, and electro-neural output display whilst an ENVS user negotiates the laboratory environment.

(a)



(b)

Figure 4: (a) The ENVS - GPS setup. (b) Close up view of the compass on the ENVS headset.

of the ENVS-GPS setup and a close up of the headset fitted with the digital compass.

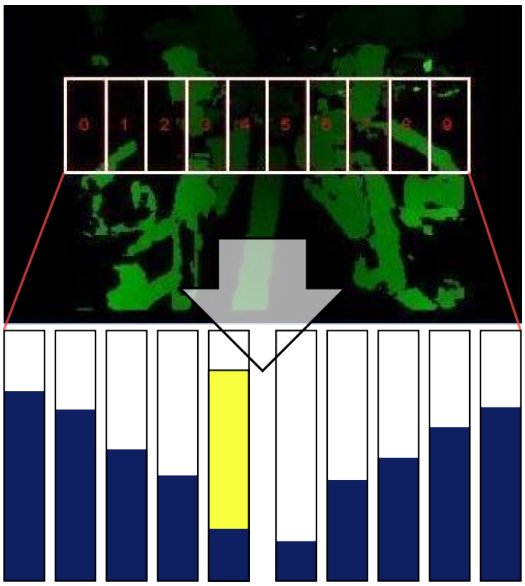
By using the GPS unit to obtain the user's location, the ENVS is able to maintain a list of direction vectors to landmarks that are within a set radius from the user. Also, the maximum landmark radius can be set to short or long range (200m or 600m) by the user via a switch on the ENVS unit. When a landmark is calculated to be within the user's ENVS visual field, (as determined by the headset compass and the set landmark radius), the perceived landmark's ID is encoded into a sequence of pulses and delivered to the user via the finger which represents the direction of the landmark. For example, if a landmark is determined to be in the far left visual field, the pulse sequence corresponding to the landmark will be felt on the left pinkie finger.

To encode the landmark's ID a five-bit sequence of dots and dashes carried by a 400Hz signal is used to represent 32 binary numbers. To avoid interfering with the range and colour readings of objects, which are also delivered to the fingers via the ENVS data gloves (see Section 2), locations are delivered to the fingers in five second intervals. Thus if the GPS is activated and if a landmark is detected, the user will receive range and colour readings via the fingers for four seconds followed by approximately one second of landmark ID information. If more than one landmark is present within the set landmark radius and the visual field of view, the landmark nearest to the centre of the visual field will be output to the user. By using this protocol, the ENVS user is able to perceive the approximate position of nearby objects as well as the location of the target destination. This enables the user to navigate to the target location while negotiating any obstacles that might be in the way.

To demonstrate this we conducted a number of successful trials in the car park shown in Figure 5(a). Here a blindfolded user is attempting negotiate the car park environment and arrive at a target vehicle by relying only on the perception provided by the ENVS. The ENVS output, shown in Figure 5(b), includes a disparity map of a narrow gap between two cars, and the corresponding output intensity histogram. The yellow bar at the left forefinger position of the finger intensity histogram, indicates that target vehicle is located slightly to the left

of where the user is looking and at a distance of approximately 40 metres. We found the GPS technology to be accurate to within a metre or two for these experiments, which was amply sufficient for long-range navigation.

(a)



(b)

Figure 5: (a) ENVS user negotiating obstacles to reach a GPS landmark. (b) Corresponding ENVS output

4 Miniaturisation of the ENVS

Although the concept of the ENVS is simple and relatively straightforward to implement with commercial stereo cameras, a laptop computer and TENS hardware; reducing the bulkiness of the system so that it is convenient to use has proven to be a more difficult task. Our experience with developing devices for blind people has convinced us that if the blind aid is awkward, bulky or inconvenient, the users will not feel comfortable with it and would prefer not to use it. Consequently, much of our recent and ongoing work has focused on miniaturisation of the ENVS and presenting it in a form that is convenient and comfortable for blind people to use. In the following paragraphs we briefly describe our prototype IR-ENVS and some preliminary test results.

As stereo cameras are bulky, computationally expensive, power hungry and need regular calibration, we have opted instead to use eight Sharp GP2D120 infrared sensors [Sharp, 2007] for measuring the range of objects. The use IR sensors in place of stereo cameras also overcomes previous limitations perceiving featureless surfaces (as can be seen by some of the black areas in the disparity maps in Figures 3 and 5(b)). The Sharp IR sensor produces an analogue voltage output proportional to the range of detected objects and is easily interfaced to low power microprocessors. Although the GP2D120 IR sensor performs poorly in sunlight, we found it to be capable of measuring 3–4 metres indoors under most artificial lighting conditions and accurate to within a 5% of the distance being measured. Furthermore, when configured as shown in Figure 6, we found very little interference or cross-talk occurring between the sensors due the narrow width of the IR detector array within each sensor. We also found that the range data and object perception achieved with the IR-headset, and our ENVS data gloves, is comparable with what we have achieved with stereo disparity cameras. Later we hope to overcome the outdoor limitations of the IR sensors by developing custom IR sensors with more powerful IR LEDs or laser diodes. We are also developing self-powered TENS electrodes that can communicate wirelessly with the IR-headset to eliminate the need for the user to where the data gloves.

Figure 6: The prototype IR-ENVS

To detect the colour of objects with our prototype IR headset we have been experimenting with miniature CMOS cameras, like the one shown in centre of the IR headset in Figure 6, and colour sensors like the TAOS TCS230 [TAOS, 2007] and the Hamamatsu S9706 [Hamamatsu, 2007]. We found the TAOS TCS230 sensor performs poorly for our application under fluorescent lighting conditions because this sensor samples the

three primary colours in sequence and receives inconsistent exposure to each primary colour due to motion or the strobe effect of fluorescent lights. Our experiments with the Hamamatsu S9706 sensor and various CMOS imagers have shown them to be suitable for our application as long as they are fitted with a suitable lens. Our current hardware prototype uses custom colour matching algorithms encoded on a PIC [Microchip, 2007] microprocessor, and our preliminary experimental results have shown that this sensor arrangement is capable of performing as well as stereo cameras for this application. We expect to finalise the development work of our IR-ENVS in the near future and will report further experimental results as they are achieved.

5 Conclusion

To overcome deficiencies in existing substitute vision systems for the blind we have been developing an Electro-Neural Vision System (ENVS) that is based on sensing the environment with range and colour sensors and delivering this information to the user via electro-tactile stimulation in a form that is easy for the user to understand. In this paper we provide results of some preliminary experiments with our ENVS and details of a miniature system currently under development for testing the concept on blind subjects. Although our substitute vision system is far from a comprehensive solution to blindness, our experimental results have shown that our system can enable the user to perceive the location of obstacles and the colour of certain objects in sufficient detail for navigation to be possible without any use of the eyes or other blind aids within certain environments.

References

[BAY, 2005] Bay Advanced Technologies Ltd. BAT-K Sonar Cane, 2005. `http://www.batforblind.co.nz`.

[Bissit and Heyes, 1980] D. Bissit and D. Heyes. Application of biofeedback in the rehabilitation of the blind. *Applied Ergonomics*, 11(1):31–33, 1980.

[Borenstein, 1990] J. Borenstein. The navbelt - a computerized multi-sensor travel aid for active guidance of the blind. In *Proceedings of CSUN's Fifth Annual Conference on Technology and Persons with Disabilities*, pages 107–116, Mar 1990.

[GDP, 2005] GDP Research Australia. MiniGuide, 2005. `http://www.gdp-research.com.au`.

[Hamamatsu, 2007] Hamamatsu corporation. s9706 digital color sensor, 2007. `http://www.sales.hamamatsu.com/en/products/solid-state-division/color_sensors/part-s9706.php`.

[Kay, 1964] Leslie Kay. An ultrasonic sensing probe as a mobility aid for the blind. *Ultrasonics*, 2:53–59, 1964.

[Meers and Ward, 2004] Simon Meers and Koren Ward. A vision system for providing 3d perception of the environment via transcutaneous electro-neural stimulation. In *Proceedings of the 8th IEEE International Conference on Information Visualisation*, pages 546–552, Jul 2004.

[Meers and Ward, 2005] Simon Meers and Koren Ward. A vision system for providing the blind with 3d colour perception of the environment. In *Proceedings of the Asia-Pacific Workshop on Visual Information Processing*, Dec 2005.

[Microchip, 2007] Microchip Technology Inc. PIC Microprocessors, 2007. `http://www.microchip.com`.

[Nurion-Raycal, 1995] Nurion-Raycal. LaserCane, 1995. `http://www.nurion.net`.

[Pressey, 1977] N. Pressey. The mowat sensor. *Focus*, 11(3):35–39, 1977.

[SFS, 2004] Sound Foresight Ltd. UltraCane, 2004. `http://www.soundforesight.co.uk`.

[Sharp, 2007] Sharp. Gp2d120 infrared sensors, 2007. `http://www.sharp-world.com/products/device`.

[TAOS, 2007] TAOS Inc. TCS230 Color Sensor, 2007. `http://www.taosinc.com/product_detail.asp?cateid=11&proid=12`.

[Ulrich and Borenstein, 2001] I. Ulrich and J. Borenstein. The GuideCane - Applying Mobile Robot Technologies to Assist the Visually Impaired. *IEEE Transactions on System, Man and Cybernetics. Part A: Systems and Humans.*, 31(2):131–136, 2001.