TECHNICAL NOTE

An embedded system for aiding navigation of visually impaired persons

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Visually impaired individuals find navigation difficult as they often lack the much needed information for bypassing obstacles and hazards in their path. In order to help blind people navigate safely and quickly, an obstacle detection system using ultrasonic sensors and USB camera-based visual navigation has been considered. The proposed system detects obstacles up to 300 cm via sonar and sends audio feedback to inform the person about their location. In addition, a USB webcam is connected with eBox 2300™ Embedded System for capturing the field-of-view of the user, for finding the properties of the obstacle in particular, in the context of this work, locating a human being. Identification of human presence is based on face detection and cloth texture analysis. The major constraints for these algorithms to run on the Embedded System are small image frame (160 × 120) having reduced faces, limited memory and very less processing time available to achieve real-time image-processing requirements. Prototype of an electronic travel aid device has been developed and experimentally verified on blind-folded persons to analyse the device performance in a laboratory set-up.

Mobility is one of the main problems encountered by visually impaired persons in their daily lives. In particular, orientation and navigation in unknown environment seems impossible without external help. According to the World Health Organization (WHO) census, around 314 million people worldwide are visually impaired, among which 45 million are totally blind. Almost 82% of visually impaired persons are of age 50 or above, representing 19% of the world's population[1]. Over 90% of these visually impaired people live in developing countries like India, less than 15% of them have access to vision enhancement or vision rehabilitation services that could help change their lives. There are over 1.4 million visually impaired children aged 0–14 years[2]. The vast majority of visually impaired children with low vision conditions in developing countries are sent to blind schools despite having usable vision because they do not have access to or cannot afford vision enhancement or vision rehabilitation services. Over time, blind and visually impaired people have used some methods and devices, such as long white cane or guide dog, to aid in mobility and to increase safe and independent travel. Electronic travel aid (ETA) is one of the new approaches to the solution of this problem, allowing the visually impaired to live a more independent life. ETA devices for visually impaired are developed to convey information of the environment to the user to reconstruct a scenario alternative to the visual one. This information is generally conveyed through the haptic and auditory channels.

Long white cane is a traditional mobility tool used to detect obstacles in the path of a blind person. The length of a white cane depends upon height of the user and extends from the ground to the user's sternum. On the other hand, guide dogs are assistance dogs, trained to lead visually impaired around obstacles. Due to the development of modern technology, many different types of navigational aids are now available to assist the blinds[3]. They are commonly known as ETAs.

Some of these aids are Sonic Pathfinder[4], Mowat-Sensor[5] and Guide-Cane[6]; but they have narrow directivity. However, Sonic-Guide[7], NavBelt[8] and other ETA devices[9,10] have wide directivity and are able to search several obstacles at the same time. These devices are all based on producing beams of ultrasound or laser light. In such a system, the device receives reflected waves and produces either an audio or vibration in response to nearby objects, but its market acceptance is rather low as useful information obtainable from it is not significantly more than that from the long cane and responses received from it are not user-friendly. So recent research efforts are being directed to produce new navigational systems in which a digital video camera is used as vision sensor. Some of these ETA devices are vOICe[11], NAVI[12], SVETA[13] and CASBLIP[14].

In vOICe, the image is captured using a single video camera mounted on a headgear and the captured image is scanned from left to right for sound generation. The loudness of sound depends on the brightness of the pixels. Similar work has been carried out in NAVI, where the processed captured image is converted into stereo sound and the amplitude of the sound is directly proportional to the intensity of image pixels and the frequency of sound is inversely proportional to vertical orientation of the pixels. In SVETA, an improved area-based stereo matching is performed over the transformed images to compute dense disparity image. To map the disparity image to stereo musical sound, sonification procedure is used. In CASBLIP, the object is detected through sensors and stereo vision. In addition, orientation is computed using GPS system. This system is embedded on the field programmable gate array (FPGA).

The most important factors which enable blind users to accept these devices readily are portability, low cost and simplicity of control. Hence, ETA devices should be small in size and lightweight for portability. Since a blind person will not able to see the display panel or control buttons, the device should be easily controllable. Moreover, the ETA device should be of low cost so as to be affordable by a common man. Considering all these requirements, eBox 2300™ is used as a processing unit in the proposed system. The processing of the ETA device is performed on this embedded system. It controls all the modules which are used to navigate the user.

Proposed electronic travel aid

The device is based on an embedded system eBox 2300™, a small (4.5″ × 4.5″) low cost, X86 processor-based embedded computer system[15]. The ultrasonic sensors are connected with the sensor circuit. It feeds the distance data to eBox 2300™ through a RS-232 serial cable. A USB webcam is connected with eBox 2300™ for capturing the field-of-view of the person, which is used for locating a human being. A headphone is connected with eBox 2300™ to get the audio feedback (beep sound) of the obstacle distance and presence of human beings. The eBox 2300™ is powered by a 5 V, 3 A DC adapter and the sensor circuit is powered by two 9 V alkaline batteries. The algorithms are implemented in C++ using Visual Studio 5.0 IDE, which runs on WinCE environment.

Figure 1 depicts the proposed ETA system. For better field of view, the USB webcam is mounted on a helmet and ultrasonic sensors are placed on the user's belt. Three easy control switches are provided to control the ultrasound-based distance measurement system, human detection system and motion detection system respectively. The eBox 2300™ and sensor circuit are kept in a bag which will be held around the waist of the user. The user has to operate the system manually and he/she will get the auditory feedback till the switches are pressed.

Figure 1. Proposed electronic travel aid.

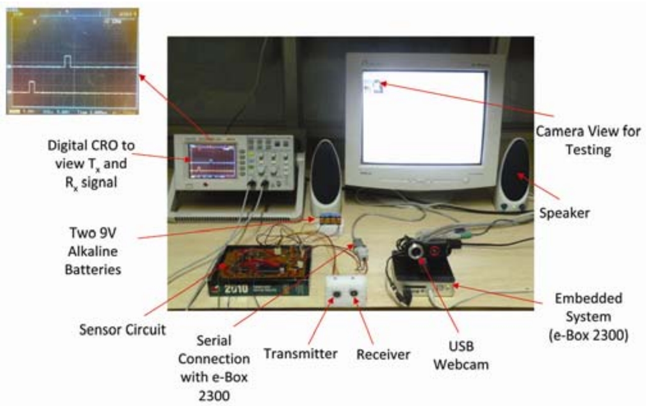

Figure 2. Experimental set-up of the electronic travel aid.

Ultrasound-based distance measurement

In this work ultrasonic sensors are used to detect the obstacles in the path of a blind person. The overall operation is divided into two parts. The first part consists of development of sensor unit and the other part deals with processing of sensor circuit data (distance data) in eBox 2300™. The sensor unit has three subunits: transmitter, receiver and processing units. The transmitter unit generates 40 kHz ultrasonic signal and the receiver unit receives the reflected echo signal. Finally, the processing unit computes the time difference between the transmitting and receiving pulses. The sensor unit provides the raw distance data in the form of pulse count as its output. These counts are used to compute actual distance through processing in eBox 2300™. ICOP-eBox 2300™ and Windows Embedded™ are respective Trademarks of Microsoft Corporation and ICOP Technology.

The pulse count data are obtained as raw data for computation of distance of the object from the sensor unit through RS232 cable. These data are processed in the eBox 2300™ embedded system. The eBox 2300™ generates a temporary file to store the serial data coming through its COM port. A C++ program running on eBox 2300™ reads this file to process the data. Finally, the object distance is calculated and accordingly the feedback (beep sound) is provided to the user.

The performance of the ultrasound-based measurement system has been evaluated using the experimental set-up as shown in Figure 2. The system is calibrated by placing an obstacle at a measured distance in front of the sensor. The calibrated distance (d_cal) is measured using first-order interpolation and the mapping between pulse count and distance. This calibrated distance is compared with distance computed from the velocity of sound (d_v). From the experimental data it is found that for distances 15–150 cm, there is no error between the two distances (d_cal and d_v). However, after a distance of 150 cm, due to one-to-many mapping, there is error in the calibrated distance. In order to reduce this error, average of three consecutive calibrated distances has been considered. The system detects obstacles up to 300 cm. It is also inert to background noises since the ultrasound frequency (40 kHz) is well beyond the audible frequency range (20 Hz–20 kHz).

Detection of human presence

Human presence is detected by the human face. However, there are situations when the face is not present in the field-of-view of the camera in spite of the presence of a human being in front of the visually impaired person. Such type of presence of human beings may be asserted by detecting cloth and human skin. To detect the presence of humans, if cloth is found in the vicinity of human skin and face is not detected (side faces), then it will be considered as human.

Table 1. Summary statistics and control limits of the features

Feature	Lower threshold	Upper threshold	Type-I error
F_{be}	1	1.5	0.06
F_{ab}	1.5	2.4	0.1
F_{oe}	1.05	1.15	0.1

Table 2. Summary statistics and control limits of the features

Feature	Mean (μ)	SD (σ)	$\mu - 3\sigma$	$\mu + 3\sigma$	*P*-value
eA	99.5233	0.8274	97.0411	102.0055	0.0011
eH	0.0480	0.0829	–0.2007	0.2967	0.0000
eV	0.4234	0.8140	–2.0186	2.8654	0.0027
eD	0.0052	0.0113	–0.0287	0.0391	4.159×10^{-11}

Face detection

Face detection method consists of three main processing blocks: segmentation of skin regions, computation of shape features and classification based on thresholding. In segmentation of skin region, the input RGB image is transformed to YC_rC_b colour space and the skin pixels are detected based on their chrominance values. A connected component labelling algorithm using contour tracing technique is used to find the largest skin region in the image frame. This is followed by the computation of shape features of the largest skin region.

The computed shape features for making decisions are as follows: (a) F_{be}: Ratio between area of bounding box and area of fitted ellipse. (b) F_{ab}: Ratio between semi-major and semi-minor axes of fitted ellipse. (c) F_{oe}: Ratio between total number of pixels in skin region and number of pixels inside the fitted ellipse of that skin region.

Classification of human face is performed by thresholding different shape parameters. The feature values are summarized into mean (μ), standard deviation (σ) and the 3σ-control limits are taken as threshold. To analyse the features, our in-house database is used, where 240 frontal face images of size 160×120 of 12 individuals have been taken at distances 30, 60, 90 and 120 cm. To examine the accuracy of the algorithm, 60 object images (non-face) have been taken randomly.

The final threshold values of each feature are given in Table 1. Considering normal distribution of the features, the probabilities of misclassification or error (Type-I error)[16] are calculated and given in Table 1. Constrained by real-time requirements of processing, the proposed methodology is based on simple heuristics; yet it is found to be more effective than other existing algorithms in the given scenario. This algorithm is implemented on Windows CE-based eBox 2300™ embedded system.

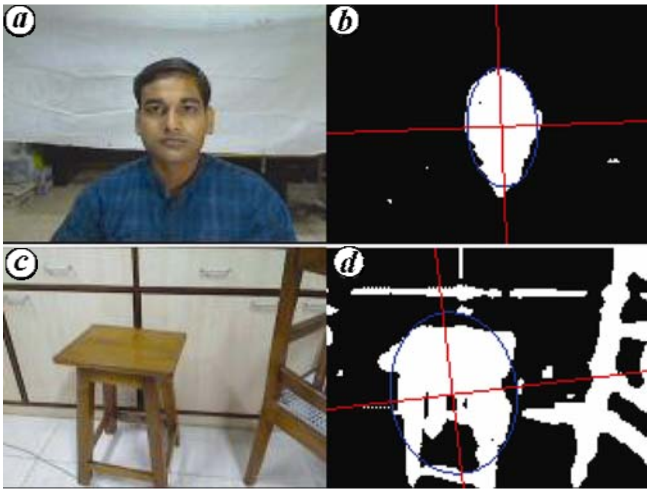

Figure 3. ***a***, ***c***, Input images. ***b***, ***d***, Result of ellipse-fitting on skin region.

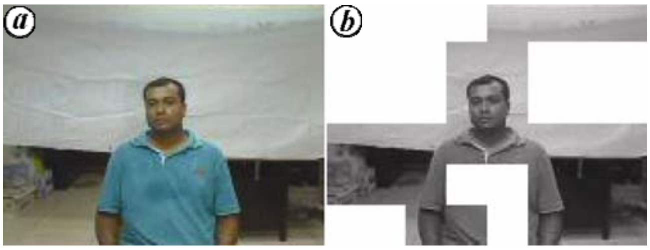

Figure 4. Results of cloth detection algorithm for cloth at a distance 120 cm. ***a***, Input image; ***b***, Resultant image.

The major constraints for this algorithm to run on the embedded system are small image frame (160×120) having reduced faces, limited memory and very less processing time available to achieve real-time image-processing requirements. The USB webcam connected with eBox 2300™ embedded system provides image frames at a rate of 15 fps, which restricts the execution time of the algorithm within 66 ms. Taking all the above constraints into consideration, the proposed face detection algorithm targets the basic shape features of objects to classify human face to reduce computational complexity. The execution time of the proposed algorithm is 20 ms.

Figure 3 represents one face and one non-face object images and their results. In the non-face image though false skin region has been segmented out, its feature values do not satisfy all three conditions ($F_{be} = 1.48$, $F_{ab} = 1.28$ and $F_{oe} = 1.188$). Hence it is classified as non-face.

Detection of cloth

The image is subdivided into 48 non-overlapping subimages of size 20×20 pixels and these subimages are processed using ‘Haar’ wavelet decomposition at level 1. The energy values of the approximate (eA) and detail coefficients (eH for horizontal, eV for vertical and eD for diagonal) are computed for each subimage. These energy values are considered as features to classify cloth texture.

Figure 5. Prototype of the electronic travel aid device.

Table 3. Performance analysis of the electronic travel aid device

	User type	Obstacles	Human presence	Cleared obstacles	Travel speed (m/s)
Test 1	Novice	5	No	5	0.40
Test 2	Novice	5	No	5	0.45
Test 3	Trained	5	No	5	0.90
Test 4	Novice	5	No	3	X
Test 5	Trained	5	No	5	0.83
Test 6	Trained	5	No	5	0.77
Test 7	Novice	7	Yes	7	0.66
Test 8	Trained	7	Yes	7	0.86

Table 4. Response of ETA device for different type of obstacles

	Detection range (cm)				
Obstacle	Test 1	Test 2	Test 3	Test 4	Test 5
Concrete wall	185	210	195	205	200
Human body (static)	120	95	155	105	160
Cardboard box	230	210	285	245	225
Wooden material	150	185	160	190	210
Human presence by face detection	85	135	155	105	90

Table 5. Price of items purchased

Item	Price (US$)
eBox 2300™	104
USB webcam (Logitech pro 9000)	95
Helmet	2
Headphone	3
Ultrasonic sensors	3
Circuit components	8
Two AA size batteries (Duracell)	8
Total cost	223

Prices are rounded to the nearest dollar.

The feature values are summarized into mean (μ) and standard deviation (σ) and the 3σ-control limits are taken as threshold (Table 2). The reason behind taking 3σ-control limits is that, irrespective of the sampling distribution of the feature, the probability of having values in the interval ($\mu - 3\sigma$, $\mu + 3\sigma$) is very large (nearly 0.9973). Prior to classification, the significance of the features is tested using unpaired Student's t-test[16] and the P-values are given in Table 2.

It is observed from the Table 2 that all the features are significant at 1% level of significance. Using these thresholds, the decision is made whether the texture is cloth or not.

The results of the cloth detection algorithm are shown in Figure 4. The input image has different cloth textures at 120 cm distance. In the resultant image white, 20×20 pixel blocks (subimages) are the detected cloth regions. Along with the T-shirt of the person, the algorithm also detects the cloth in the background of the image.

Results and discussion

In order to test the ETA device on blindfolded persons, a system prototype is developed as shown in Figure 5, where the USB webcam is mounted on a helmet and ultrasonic sensors are placed on the user's belt. Sensor circuit unit and eBox 2300™ are carried by the user in a bag.

To evaluate the performance of the ETA device, it is tested on trained and novice people in the laboratory environment. Three easy control switches are provided to manually operate the device. The first switch is to find the obstacles in the path of the blind person, the second is used to find human presence in the field-of-view of the camera and the last switch is used to detect any movement in front of the person. The device provides auditory feedback to the user in response to the switch pressed. For example, if the user presses the first button to find the obstacles on his/her path, the device will produce a beep sound whose loudness will increase or decrease with respect to the obstacle distance. To easily operate the device and to understand the auditory feedback, proper training is required.

A total of eight tests have been carried out in the laboratory environment and outside on three blind-folded persons, two of them being trained subjects and one a novice. After blindfolding the person, he/she is asked to walk through the corridor where different types of obstacles have been placed within 10 m range. During the experiment, the user's walking motion is recorded using a video camera. The time taken by the users (trained and novice) for successfully walking through the obstacles is measured and travel speed for each test is calculated (Table 3).

It is apparent from Table 3 that average speed of the trained and novice users is 0.84 and 0.50 m/s respectively. In comparison with the travelling speed of sighted people (1.3 m/s), this result is acceptable. The accuracy of the device in finding obstacles is 95.45%. This result shows that training of the user is one of the important factors for gaining high travelling speed and also to increase the user's confidence to choose an optimal path.

To evaluate the detection range of the system, five tests have been performed in the laboratory environment. The response of the proposed ETA device for different types of obstacles is shown in Table 4. It is observed from Table 4 that the range of detection of a cardboard box is 210–285 cm, whereas that of human body is

Figure 6. Blind-folded volunteers walking in different environments. ***a***, Laboratory; ***b***, Department corridor.

Table 6. Price and weight comparison with currently available ETA devices

ETA device	Price (US$)	Weight (g)
Sonic Pathfinder	1695	325
Laser Cane	2500	500
Mowat-Sensor	775	185
Guide-Cane	Prototype	–
KASPA:Sonic-Guide	3300	–
vOICe learning edition	0	–
Wheelchair Pathfinder	2500–4500	–
Polaron	870	257
Our proposed ETA	Prototype	< 500

95–160 cm. It is apparent from this result that the reflection or obstacle detection depends on the object surface; more smooth the surface, higher will be the detection range. In addition, detection range of human presence by face detection is also tested, which is 85–150 cm. The reason behind the low range for this is the small face size, which will be reduced further as the distance between the human and the device increases.

Figure 6 shows the ETA device testing, which has been performed on blind-folded volunteers in different environments. Figure 6 *a* shows that a blind-folded volunteer is crossing the hazards (pillars and cartons) successfully in the laboratory environment and Figure 6 *b* shows a blind-folded volunteer walking through obstacles in the corridor.

The proposed ETA prototype is much cheaper and lighter compared to other currently available ETA devices. The total cost of our prototype experiment is approximately US$ 223. The prices of items purchased are listed Table 5. A list of price and weight of ETA devices that are currently available in the market is shown in Table 6 (ref. 3).

Conclusion

An ETA to navigate visually impaired persons has been proposed here. The aid has been tested on blind-folded volunteers in laboratory environment. Using this ETA device blind users can pass through the unknown environment independently. The major issues for the users to accept these aids are that they should be unobtrusive, easy to carry, small and light weight. The proposed system is designed considering all these factors. The user needs to wear a helmet in which the camera and headphone are mounted. The user has to carry eBox 2300™ and sensor unit of nearly 500 g. This device can detect obstacles up to 300 cm and human presence within 120 cm. Thus, a portable ETA device has been developed taking into account the blind users' requirements. It fills the gap between these requirements and the presently available aids.

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