

Review of Machine Vision-Based Electronic Travel Aids

Zixiang Fei¹, Erfu Yang¹, Huoheng Hu², Huiyu Zhou³

¹ Department of Design, Manufacture and Engineering Management, University of Strathclyde, Glasgow G1 1XJ, Scotland, UK

² School of Computer Science and Electronic Engineering, University of Essex, Colchester CO4 3SQ, England, UK

³ School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, Belfast BT7 1NN, Northern Ireland, UK

Abstract—Visual impaired people have navigation and mobility problems on the road. Up to now, many approaches have been conducted to help them navigate around using different sensing techniques. This paper reviews several machine vision-based Electronic Travel Aids (ETAs) and compares them with those using other sensing techniques. The functionalities of machine vision-based ETAs are classified from low-level image processing such as detecting the road regions and obstacles to high-level functionalities such as recognizing the digital tags and texts. In addition, the characteristics of the ETA systems for blind people are particularly discussed.

Keywords—Machine Vision, Visual impairment, Navigation System, Electronic Travel Aids

I. INTRODUCTION

According to the statistics of the World Health Organization (WHO), there are approximately 285 million people who are visually impaired worldwide [1] [2]. In fact, 39 million people are blind and 246 million people have low vision. Most of the visually impaired people live in restricted circumstances and most of the blind people are 50 years old or over. Blind people suffer from many mobility problems such as avoiding obstacles, locating position, finding a pathway and accessing information [3].

Walking canes and guide dogs are the most common navigation assistants nowadays [4]. A cane is used for obstacle detection and a dog is good at obstacle avoidance [5]. However, they both have their own disadvantages. Very little navigation information can be provided by a cane because of short range [6]. On the other hand, although a guide dog does well in navigation guide for blind people, very few patients can afford it [6] [7]. Both aids cannot communicate with blind people using natural ways such as speech. The blind people can only follow the guide dogs passively, or walk slowly using canes.

With the recent development of science and technology, more and more Electronic Travel Aids (ETAs) have been invented by researchers to help blind people. Electronic Travel Aids are devices that can convert the information obtained by vision and other sensors into the information that can be heard or touched by blind people [8] [9]. A typical ETA system could be divided into four parts: sensors as input, position beacons,

information processing and user interface and output, which are shown on Figure 1.

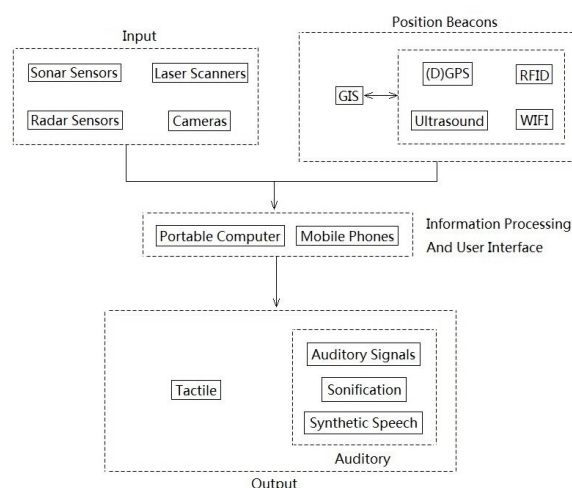


Figure 1 A Typical ETA System

In an ETA system the first part is related to different sensors. The ETA can gather navigation information using sonar sensors, laser scanners or cameras [8]. Sonar-based navigation systems cannot provide precise information such as shape and velocity of objects, but machine vision-based systems can capture the whole image of the environment [6]. Therefore, machine vision technologies could help blind users in path finding, object identification, text extraction and information acquisition [10].

The second part in an ETA system is position beacons. RFID and WIFI are normally used in indoor environments, while GPS is used outdoors. GIS could be combined with positioning technologies to find the best ways to walk towards the destination. For instance, Ran proposed a system called ‘Drishti’ which uses Differential Global Positioning System (DGPS) outdoors and ultrasound sensors in indoor situations [11]. However, some alternative methods could be used to locate positions better. For example, Treuillet [12] only used machine vision to locate position along paths which had already been learned and stored in the database.

The third part in the ETA system conducts information processing and user interaction. In order to improve the effectiveness of informing blind users of navigation information, a large amount of research work has been conducted. The users can be informed with the road situation so that they can decide if going straight ahead or turning left.

The final part of an ETA system is the system output. There are two kinds of output, namely auditory and tactile. In the survey [17], auditory assistive devices are classified into two categories: (i) ETAs that can use binary auditory signals to aid a blind user, such as a warning tone; (ii) the ETAs that can use synthetic speech to aid the blind such as telling the blind user an optimal way towards the destination. On the other hand, tactile technologies have been widely deployed to investigate the size and position of an obstacle and road situation, such as the project of on-shoe tactile display and the project of tactile belt [13] [14]. In addition, a 2D Vibration Array and a 2D Tactile Vocabulary were deployed to improve the technology of Tactile-Visual Sensory Substitution [15] [16]. Moreover, some ETAs encode information in sound parameters. For example, the Stereo Vision based Electronic Travel Aid (SVETA) could transform stereo images into stereo sounds to inform the user such as the distance and size information of obstacles on the road [18].

There are also some relevant survey papers about ETA systems. Ruxandra et al reviewed 12 ETA systems in the aspect of the functions, advantages and limitations of each system and also offered a review about the capabilities for each ETA system such as wearable, portable and reliable [9]. Karen et al reviewed some technologies to assist blind people in navigation and shopping. Also, they concluded that RFID is more suitable for pedestrian navigation than GPS. In addition, barcode and QR code identification may be used for products identification [48]. Pawel reviewed the ETA systems in major mobility tasks such as orientation, obstacle avoidance and navigation and discussed their advantages and limitations [31]. It is clear that the previous research work has been mainly focused on pathway finding, obstacle avoiding and outdoor navigation [19]. However, with the help of machine vision, a navigation system can tell blind users where they are, location of certain items, road situation, ways to the destination and texts information on the roads. The system can be portable and communicate with the blind people with sound, which is very convenient. This technology can also play important role in the robot navigation, when they need to move and know about location information. This paper is focused on the Electronic Travel Aids using machine vision only. The content covered in the paper is shown in Figure 2.

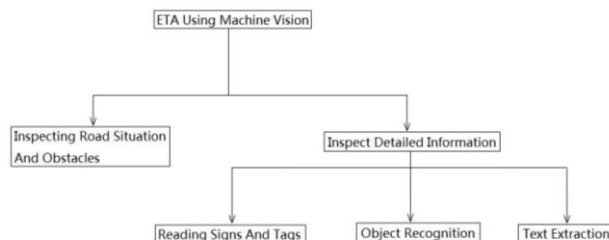


Figure 2 Review Contexts

The rest of the paper is organised as follows. After a brief introduction in Section 1, Section 2 explains how to inspect road situation and obstacles. Section 3 introduces Digital Signs, Color Markers or RFID Tags used in ETAs. In Section 4, text tracking and recognition technologies in ETAs are briefly described. Section 5 presents some object detection and recognition methods for guiding blind people. Finally, a brief summary is given in Section 6.

II. INSPECTING ROAD SITUATION AND OBSTACLES

Blind people may not be able to prevent some dangerous situations such as obstacles or holes on the road, even when they are walking alone with a cane. To detect obstacles, many kinds of sensors can be used, such as sonar, radar, infrared Intensity, laser and infrared Flight of Time [20]. However, all these methods have their own problems and conditions. For example, sonar ranging sensors have several potential sources of error such as Specularity in calculating range. With regard to radar, although the working range is long, the system using radar has blind spots in a large vertical angular range. Furthermore, a laser scanner has advantages in a long range, high accuracy and high speed, but suffers from expensive costs and narrow ranges. On the other hand, navigation systems based on machine vision seem to be more powerful and flexible than others. In general, vision based navigation systems can provide blind people with navigation information such as finding path and avoid holes, stationary or moving obstacles on the road.

A. For Normal Blind Users

Balakrishnan et al. proposed a Stereo Vision based Electronic Travel Aid (SVETA) system that was comprised of stereo earphones, stereo cameras and a computing device [21]. The system can guide blind people by informing them with situations of obstacles such as shape, size, position and distance. The time for the system to process an image and give feedback is about 1.25 seconds. However, the system may have some errors when lighting is strong. With the help of this navigation system, blind people can know the road situation well by listening to the stereo musical sound from the system. The disadvantage is that blind people need training to understand the stereo musical sound produced by the SVETA system.

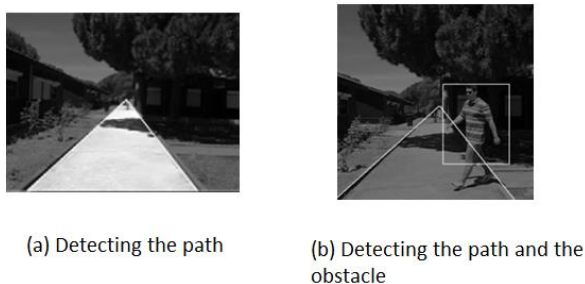


Figure 3 Detecting the path and obstacle in SmartVision [22]

Jose et al. proposed a SmartVision navigation aid for blind people [22]. The SmartVision system focuses on the local navigation for a blind user in two aspects: detecting a path and detecting obstacles. The whole system is mainly made up of the following items: the stereo camera attached at the height of the chest, the portable computer which can be worn on the shoulder or in the pocket and one earphone which can be replaced by a speaker. As shown in Figure 3, the border of the path is detected and then the path is highlighted. The SmartVision system which can work at a few frames per second can also detect static and moving objects and will alert the user if an object is detected.

Shang et al. also proposed a navigation system which is based on machine vision to guide blind people [23]. This system can provide information about road regions and help blind people avoiding stationery and moving objects. Experiments show that the system can work in real time and has a frame rate of 12 frames per second. The system is mainly focused on finding a road region, but cannot provide the user with the information such as the velocity of the moving object.

Jie et al. proposed a novel electronic travel aid for blind people which can be used to detect obstacles, recognize traffic lights and detect road edges [24]. The system consisted of two cameras, a portable computer and an earphone. The experiment of the system using 75 consecutive frames shows that the recognition rate is 96% and the processing speed is about 0.08s per frame. The main method is to compare gray values by converting image into the gray scale. As a result, if the obstacle has similar gray values to those of the road, the obstacle cannot be detected.

B. For Blind Users Who Need Wheelchair

About one in ten blind people use wheelchairs [25]. For blind wheelchair users, independent travel is difficult and using a cane or a guide dog is impractical. ETAs may play a significant role in this situation. The ETA equipment may not need to be portable, for they can be equipped on the wheelchair.

Coughlan et al. performed a research project to sense terrain features including curbs, drop-offs and shoreline for wheelchair navigation with the help of computer vision [25]. The cameras situated on the wheelchair can take images so that the developed vision algorithms can infer the visual information in real time. The audio and tactile feedback will help the user for navigation and control the wheelchair. The ground plane in the scene is

estimated first and the range map is converted to an elevation map in order to find the terrain features including drop-offs and curbs. However, the performance of the elevation map influenced by noise such as the presence of a curb is signaled by a relatively small elevation discontinuity.

Ivanchenko et al. also proposed a system to alert a blind user with the terrain information, who needs a wheelchair to support [26]. The system aims to extend the reach of the walking cane. In the system, the user can know the situation of the environment by sweeping a cane with the help of computer vision. Moreover, the system will alert the user in sound if a terrain feature (such as an obstacle, wall or curb) is detected in the direction that the cane is pointing. This method can be limited in the working area.

Nguyen proposed a semi-autonomous wheelchair system named as TIM (Thought-controlled Intelligent Machine), which uses stereoscopic vision for 3D depth perception along with a spherical camera for 360-degrees of monocular vision [27]. The vision system can help the user avoid the collisions with other people or obstacles during the autonomous navigation. The experiment is conducted in crowded places with people moving around. The experiment shows a good performance in obstacle avoiding with the help of machine vision technology.

III. USING DIGITAL SIGNS, COLOR MARKERS OR RFID TAGS

It is convenient to scan the barcode of a product when one is shopping in a supermarket. To help blind people, many researchers are working towards an optimal solution for scanning or recognition barcode, color markers or RFID information grid which includes information of locations and descriptions of navigation and wayfinding [28] [29]. These special markers can work as landmarks and signs in the navigation process.

Both digital tags using machine vision and RFID tags have their own problems and conditions. Computer vision will make it easier and cost effective [30]. However, computer vision techniques may suffer from motion blur, image quality or conditions such as illumination and orientation. On the other side, RFID tags may have a weakness in their working range. According to Karen Duarte, active tags need external power supply although they have a greater range [31].

A. Using RFID

Willis and Helal proposed a RFID based navigation system which contains location information and other descriptive information [32]. It has a low cost and is easy for installation and maintenance. One possible practical usage for this system is to help navigation of blind students in college buildings where outdoor corridor, hallways and rooms are installed with RFID tags. In this system, a blind user will be able to navigate by scanning RFID tags at the corridor with a RFID reader attached to the shoe or the cane. Each tag can store information about 2000 bits and the time for reading the tags is short enough and will not influence walking. However, in order to locate direction, 2 or more tags need to be detected. In

addition, in order to read the tags, the distance between the reader and the tags need to be less than 100mm unless a large antenna and strong RF signals are used.

The layout of the installation of the RFID tags in a building is also important. Tsirmpas created the scenarios with the installation of RFID tags to test if the system can help blind people travel in an unknown place [28]. Experiments show that the success rate of avoiding obstacles is about 99%.

Szeto researched on extending the range of RFID tags [29]. They have ideas such as creating active RFID tags which use solar power and will not need any battery. Furthermore, by installing multiple directional antennas on a jacket, scanning the environment will be no longer needed. However, this work still seems to be in a research stage.

B. Using Machine Vision

Although there is a significant development in RFID technology, its major weak point is the short distance between the reader and the passive RFID tags. Tjan et al. proposed an indoor navigation system using inexpensive digital signs for vision impaired people providing location, heading and other information within a distance of 3 meters [33]. The digital tags can be found by using a hand-hold device called Magic Flashlight which contains an array of infrared emitters. The Magic Flashlight uses a camera to identify a tag using a machine vision technique when the tags are in the field of view. The tag is slightly larger than a credit card and contains a 16-bit number which will provide navigation information by checking the 16-bit number in the database.

Machine vision is used to translate the pattern on the retro-reflective tag to a 16-bit number. Reading digital tags using machine vision is better than detecting the RFID signals with regard to working distance. However, the tag identification process will be affected by sunlight. Furthermore, experiments show that the tags identification takes about 20 seconds which is difficult for real time navigation, though it can be improved.

Different blind people may have different navigation behaviors and the best navigation technology may change to fit different situations [5]. Manduchi et al. presented a usability study of a navigation system for blind people by detecting color markers [3]. In the study, a normal mobile phone uses its onboard camera to detect some color makers placed in the environment in order to locate their positions. There will be a beeping sound to inform the user if the color makers are detected. In addition, the beeping sound would repeat more frequently if the distance between the color maker and the mobile phone is less than 4.5 meters. Three blind participants took part in the test in different indoor places. Only one participant succeeded in all the tests. The experiment showed that the field of view is an important factor in this navigation process. It was clear that some navigation technology may not meet all the blind people with different navigation behaviors.

In summary, RFID tags or digital signs can help blind people recognize objects or landmarks and be alternative

methods to provide position and heading information. However, compared with the GPS location technology in outdoor conditions and location technology using a WIFI technology which may be less accurate, RFID tags or digital signs may be more expensive.

IV. TEXT TRACKING AND RECOGNITION

Without the help of text information when traveling, important information will be missed such as the name of roads and important signs. In order to inform blind people of text information when traveling, the system needs to be small enough to take or wear, whilst the system can recognize the text information in real time and uses an appropriate way to inform the user. In practice, researchers work on extracting text information from the environment and converting them into forms that most off-shelf OCR products can process. In general, there are two kinds of problems: (i) selecting good frames that are unblurred and contain text information from videos and (ii) extracting text information that most OCR products can process from image frames.

A. Text Extraction

Tian et al. developed a text extraction and recognition algorithm in a navigation system for blind people [34] [35]. The system can extract text regions from signs in complex backgrounds and then use topological analysis to filter out interference. The text information from a sign can be used as landmarks in the global navigation. They conducted experiments by selecting 420 images containing compatible text information and achieved the accuracy of about 71%. However, there are some limitations in the system. For instance, if the color of the background is similar to that of the text, the interference cannot be filtered out. The algorithm would also fail if the text information is in different colors or the texts are less than 3 letters.

Most off-shelf OCR products cannot recognize texts which are skew or slant seriously. Hairuman proposed an improved OCR signage recognition model for blind people to recognize a text which is skew or slant [36]. If the text is skew, the Shearing Transformation will be applied. The model is tested using 15 different samples of texts in 5 subjects and achieved a recognition rate of 82.7%.

Yi et al. developed a prototype system to read text information on an object which can be held in hand by blind people [37]. The object of interest is located by blind people using a motion-based method. To extract the text information from the background containing colorful noise, a text localization algorithm was proposed by using the stroke orientations and edge distributions. In order to let the system focus on an object of interest in a complicated environment, the user needs to shake the object. Figure 4 shows the flowchart of reading text information from objects for blind users. In addition, the experiments showed that the method had low accuracy and took about 2 seconds to process every image.

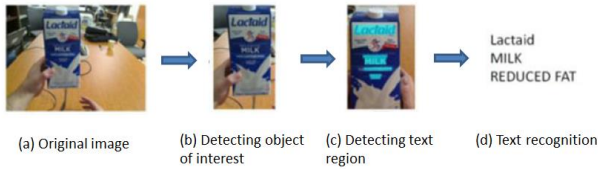


Figure 4 Flowchart of Reading Text Information from Objects for Blind Users [37]

Public transport systems play an important role in people's traveling from one place to another. However, it is difficult for vision impaired people to notice the coming buses and recognize route numbers of buses. Pan et al. [38] proposed a primary framework to detect and recognize the bus route number using the images taken from a camera and notify the user in speech. The image containing bus numbers is captured by a blind user's device. The text region is located and the non-text region is removed by using the layout analysis and applying a text classifier. The experiment shows that only part of the text regions are detected using bus images containing 438 text regions. This algorithm seems to be specific to the layout of a bus.

Karacst also invented a Bionic Eyeglass using machine vision to guide blind people to recognize a bus number [39]. The system can tell blind people with the bus number by detecting the bus number from the recorded video. The video is recorded at least 15 frames per second. They have tested the Bionic Eyeglass using 35 videos with lengths between 15 and 90 seconds, containing bus numbers and achieve a recognition rate of about 83%.

B. Selecting the Appropriate Images for Text Extracting

Most researchers prefer to use the off-shelf OCR products in their systems. In general, a navigation system using OCR for blind people consist of three parts: extracting text information, using OCR products to recognize texts and informing the user of the text information in voice. In practice, extracting text information can be divided into two steps: to acquire an image of a small area of the object of interest from a video and to extract the text information in images. Most of researchers work on the second part by designing an algorithm to extract texts from complex backgrounds. However, in real world an advanced and qualified OCR system for blind people needs to be able to extract the text information from videos in real time. It will involve selecting appropriate images for text extraction from videos.

Tian proposed a method to detect unblurred frames in a video taken by blind users [40]. Four types of features which are based on edges and luminance information are used to check if the image frame is blurred. In order to evaluate the method, 17 videos are captured both indoors and outdoors when the user was moving. The accuracy is 84.1% after they have tested 233 frames.

Goto and Tanaka proposed a prototype system which was equipped with a video camera to extract text information in natural scenes in real time [41] [42]. They noticed that the movement of the user is usually

unpredictable and a robust text tracking method is needed. Meanwhile, some text information may appear in consecutive image frames which are repeated. Recognition of the text information in all images is unnecessary and impractical. Furthermore, the user may want to know the text information in the appropriate moment such as when the user is near to the text instead of passing the text. In practice, the text regions were extracted using a revised DCT-based method. In addition, similar text regions were grouped into images chains using a particle filter based method and the best image is selected from each image chain in order to avoid recognizing repeated text information.

In summary, the system showed above succeeded in detecting and tracking the text region in video sequences, grouping image frames containing the same text information and selecting proper text images which can be used for text recognition. They have tested their system using 1730 image frames and reduced the images of text candidate regions to 1.47% at the rate of about 10 fps. The future work is to recognizing texts from images and presenting the user of the information in an appropriate way.

V. OBJECT DETECTION AND RECOGNITION

When visual impaired people are walking around, a navigation system can be used to detect landmarks or amenities such as door and elevator. Recognizing objects by comparing two images using image features may be effective for identifying part of the object.

A. 3D Template Match

Tian et al. proposed a wayfinding aid for blind people using computer vision to find landmarks and some building amenities such as an elevator or an exit [34] [35]. They proposed an algorithm to detect the doors by using a general door model containing features such as edges and corners of a door. The experiment with 221 door images showed that the algorithm was robust to various light conditions, sizes, color, text information, viewpoints and occlusions and achieved a successful rate of about 90%. Using the edge and text information to detect a door is shown on Figure 5.

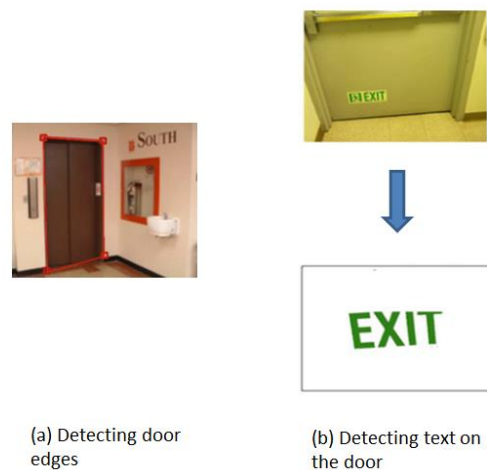


Figure 5 Using edge and text information to detect a door [34]

Serrao et al. presented a system using a camera to find landmarks and localize the user [4] [43] [44]. The system was integrated with an indoor GIS which includes landmarks and objects in order that it helps trace and validate a route for the user's navigation. The open SURF(Speeded-up Robust Features) library was used. This algorithm recognizes the objects by finding the correlations with the defined templates regardless of rotations and locations. It is not computationally expensive, but it works better to search for a small area instead of the entire image. The system can operate in real time by both the sighted and blind people and show the good results in a range of about five meters, but the system performance deteriorates in background noise and light condition.

Wang proposed a framework to detect stairs and pedestrian crosswalks which are normally comprised of parallel lines using a RGBD camera which includes depth information [45]. The experiment shows that the proposed method can achieve a recognition rate of about 90% for detecting stairs and pedestrian crosswalks and the system can work in real time. However, some items which contain parallel lines such as bookshelves could be misclassified as stairs and pedestrian crosswalks. Moreover, the depth information is hard to obtain when lighting changes.

The attempts shown above are based on machine vision and are used for blind people to recognize objects regardless of size, color, position and so on. However, they have some weaknesses. The recognition performance could be influenced by motion blur, light condition and image quality. A lot of work needs to be done to build the 3D templates of the objects and make these algorithms be computationally demanding.

B. 2D Image Matching

Matusiak et al. proposed a software module for blind people to recognize objects which can run on an Android smartphone [46]. This software can recognize the objects by matching the images taken by the mobile phones against a database of objects. In order to recognize the object which is insensitive to image parameters such as scale, rotation and brightness and recognize the object robustly, the Scale-Invariant Feature Transform (SIFT) computer vision algorithm was applied. In addition, this software was also able to detect the major color of the image and locate the brightest place. The experiment showed that the accuracy of recognizing the front side of 30 products was 90%. Although the object recognition performance was promising, this algorithm can only recognize objects in 2D instead of 3D. Moreover, the average time for object comparison was about 30 seconds which was quite long. Certainly, the performance of the system would also be affected by the quality of the images and the light condition.

C. Using Other Sensors

Object recognition could also be conducted by using other methods. Scherlen proposed a new concept named RecognizeCane which can be used to recognize some common objects [47]. RecognizeCane used brilliance, infrared or water sensors to detect subjects such as a water

puddle or a zebra crossing. However, one sensor is only capable to detect one type of subject in this system. In order to detect several subjects, several sensors may be needed. For instance, a water detector is fitted at the end of the cane to detect water puddle, and a brilliance sensor equipped with an infrared transmitter and a receiver is used to detect zebra crossing as it can differentiate a white surface from a black one.

VI. CONCLUSIONS

This paper has reviewed several Electronic Travel Aids, especially for helping blind people navigation using machine vision technologies. It classifies the navigation functionalities provided by vision- based ETAs from low-level image processing such as detecting road regions and avoiding obstacles to high- level functionalities such as navigation using digital tags and recognizing object or text.

With the continuous development of sensor technology, vision-based ETAs will have significant improvement in the near future. It is clear that vision-based navigation systems can provide blind users with the navigation information such as location, the best way to the destination, road situation, important landmarks, items and text information. In addition, it will also be portable, reliable, real time, low cost, and robust. Finally, it could be used to aid sighted people or even robots such as searching specific items in complex environments and telling users text information on a distant notice board.

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