Computer Vision Systems for Visually Impaired People

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Abstract

Computer Vision, as a substitute for human vision, embodies a powerful tool for the development of assistive technologies for blind and visually impaired (VI) people. Although there are very few computer vision systems currently engaged to aid blind people, some applications have employed this technique with promising results. These include: mobility, orientation, object recognition, printed access information, and social interaction. In this review, we describe some of the most successful commercial devices and laboratory prototypes based on computer vision techniques.

Keywords
Computer Vision, assistive technology, wearable devices and systems

Assistive Technologies for blind and visually impaired people

According to the World Health Organization, in June 2012, globally there were about 39 million completely blind people, and another 246 million people with some kind of moderate or severe visual impairment. If assistive technology is going to make an impact, certain trends should be considered. For example, the prototypical visually impaired person lives in an underdeveloped country (90%) and is likely to be more than 50 years old (82%). Also, while in developed countries the major causes of blindness are degenerative diseases (such as diabetic retinopathy and macular degeneration), in underdeveloped countries the problem has its origins mostly in treatable diseases (such as cataracts). In these cases, low vision is likely to be accompanied by impairment in other senses such as hearing or touch.

We, technology enthusiasts, tend to miss solutions involving only human capabilities. However, equivalent to technology sophistication, there is actually a broad range of demonstrations of outstanding skills to solve problems through cultivating human capacities. For instance, this is the case for the ability shown by some blind people to navigate using echolocation[1]. In what follows, we describe the development of computer vision-based systems for visually impaired people. Nonetheless, please bear in mind that we believe that the most fruitful results will ultimately be achieved at the fine-tuned

Digital Object Indentifier 10.1109/MC.2013.265 0018-9162/$26.00 2013 IEEE

interface between the development of the human potential and the right and appropriate technology.

Generally, assistive technologies for blind and visually impaired people have been based on ultrasonic, infrared, or laser sensors. But, as sighted people acquire most of their information through visual perception, it has been tempting to use artificial vision to achieve the same goal. However, limitations such as computing power and the lack of reliable algorithms have been the Achilles heel for computer vision in this area. Nevertheless, in the last few decades, parallel to the extraordinary advancements of computers, vision techniques have evolved and now it is possible to execute reliable real-time vision algorithms in embedded computers running on powerful multi-core processors. This has led to the development of vision-based technologies that assist blind users in several applications, including the detection of obstacles for mobility, the access to printed material, the recognition of generic objects, the location of places, and social interaction.

Electronic Travel Aids (ETAs) for blind people, have been available since the 1960s, but have had limited success among the blind and visually impaired population mainly because of an inadequate interface and usability. Such an interface can be acoustic or haptic and needs to provide a sensory substitution for vision. The problem here is that the spatial sensory bandwidth for human vision is orders of magnitude greater than those for touch and audition [2] . This means that there is much spatial information captured by the eyes that cannot be entirely provided by touch or audition. In addition, ETAs are subject to certain constraints, one of which is related to the feedback provided to the user, given the wealth of processed information. The feedback should be fast, without interfering or affecting the senses of hearing and touch. Another constraint is related to the overall hardware architecture. The system should be embedded, lightweight, and should be comfortable for the owner.

Computer Vision based systems

Computer vision, unlike ultrasonic, infrared, or laser technologies, offers a superior level of reality reproduction in exchange for processing complexity, and the proliferation of ubiquitous devices continues. For example, the integration of heterogeneous computing systems and digital cameras in smartphones and tablets has allowed the emergence of applications that assist blind people in performing several tasks. In the next section, we describe five areas where computer vision is used in mobility, orientation, printed information access, object recognition, and social interaction.

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1. Mobility

Independent travel in unknown environments is a common challenge that blind people face in their daily lives. Traditionally, blind people use a white cane to detect and avoid obstacles. More affluent people may use a guide dog. However, a white cane provides only limited knowledge of the few steps ahead and only for the lower part of the body, and an incomplete capacity to detect and to protect against sudden drop-offs along the walking surface. On the other hand, the guide dog requires significant training and may be prohibitively expensive. Clearly, these limitations provide an opportunity for the development of assistive technology for mobility.

Although there have been several commercial ETAs through the years, only a few of these use computer vision (Most of these are based on ultrasonic signals). One of the earliest computer vision-based ETAs reported in the literature is the vOICe system [3]. This system transforms an image into a sound, which is transmitted to the user via headphones. Perhaps one reason why computer vision has not flourished in commercial ETAs is because the algorithms usually require large amounts of computing power. Furthermore, while computer vision has evolved swiftly in recent years, it is still far from approaching the capabilities of human vision-in interpreting scene content at a semantic level. However, this may change due to two important factors. The first is the emergence of multimedia processors –used by smartphones— that are capable of real-time image processing. These are small enough to fit inside a wearable prototype and are powered by small batteries. The second is the presence of a growing research community dedicated to computer vision.

Unlike commercial ETAs, there are several laboratory prototypes based on computer vision. Most of these use stereo vision to generate disparity maps from which obstacles and their distances are detected. Examples of these ETAs include the Virtual Acoustic Space, developed by researches in the Instituto de Astrofísica de Canarias (IAC); ENVS (Electron-Neural Vision System) from the University of Wollongong in Australia; the TVS (Tactile Vision System) from the University of Arizona; and Tyflos from Wright State University.

As mentioned, a problem with stereo vision is that it requires a computationally expensive algorithm. This issue has been lessened with the appearance of low-cost depth cameras such as the Microsoft Kinect. An advantage is that these cameras directly provide a depth-map, thereby reducing the calculations of the main processor. A disadvantage is that these cameras typically only function properly indoors because their operation is affected by the infrared component of direct sun light. Nonetheless, in the last few years, there have been several prototypes that use these kinds of sensors. Among these are: KinDetect [4] from City College of New York, and the Vibratory Belt from Instituto Politécnico Nacional in Mexico.

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Table 1 summarizes the computer vision-based ETAs together with their advantages and disadvantages.

Table 1. Some examples of Computer Vision based ETAs

Device Year	Functionality	Interface	Components	Advantages (A:) Disadvantages (D:)	Studies and Results
vOICe 1992	Acts as a vision substitute. Provides an acoustic representation of the environment	Stereo acoustic	Digital camera mounted in eye-glasses, headphones, portable computer	A: Portable, reduced size D: Blocks user's hearing, requires considerable training	Provided enough training the results are promising.
Virtual Acoustic Space 1999	Acts as a vision substitute, allows orientation by constructing an acoustic perception of the environment	Stereo acoustic	Two cameras embedded in eye- glasses, headphones, portable computer	A: Portable, reduce form factor D: Blocks user's hearing, not tested in real environments	Six blind and six sighted, showed >75% of object and distance detection
ENVS 2005	Obstacle detection by electric stimulation in both hands. Each finger represents a zone in the frontal field of view	Two gloves with electric stimulators in each finger	Two cameras, digital compass, laptop with GPS and 2 gloves	A: Real time performance, doesn't block user's hearing D: Blocks the use of both hands, does not detect ground or head level obstacles	All one-hour trained blind-folded users were able to traverse a path avoiding obstacles
TVS 2006	Obstacle detection by vibrations across waistline through a vibrator belt	Belt with 14 vibrators	Two cameras, belt with vibrators, laptop computer	A: doesn't block hearing or hands. D: Unable to distinguish between floor level objects and hanging objects	No experiments with visually impaired people are reported
Tyflos 2008	Obstacle detection by vibrations across the chest through a vest with an array of vibrators	Vest with a 4x4 vibrators array	Two cameras, chest with 2D vibrators, laptop computer	A: Doesn't block hearing, detects obstacles at various height levels D: Needs more tests on real users	The last version of Tyflos shows no experiments with blind users
Kindetect 2012	People and obstacle detection by acoustic feedback	Acoustic	Depth sensor, computer	A: Easy to use, can detect head level obstacles D: Blocks user's hearing, limited to indoors operation	Four blind-folded users traversed an indoors path detecting obstacles
Vibratory Belt 2013	Obstacle detection by vibrations across waistline through a vibratory belt	Belt with 3 motors	Embedded computer, Kinect sensor, belt with vibrators	A: Easy to use, doesn't block hearing, can detect head level obstacles D: Typically limited to indoors operation	Blind-folded people used similar travel time using the white cane and the vibratory belt

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2. Orientation

Orientation can be defined as the capacity to know and track our own position with respect to the environment, and to find a path to the desired destination. A prototypical situation occurs when a blind person wants to cross a street. For this scenario, Ivanchenko *et al.* [5] developed a mobile application called *Crosswatch* that allows the user to find crosswalks pointing the smartphone's camera to the street. The system takes images, analyzes them with pattern recognition techniques, and produces an audible tone when it detects a crosswalk. This system is only capable of detecting crosswalks with stripes.

Another common orientation problem occurs when a person wants to know his own location and how to reach another location. For indoors orientations, Yang and Tian [6] present an algorithm to detect doors using edges, corners, and a geometric model with four connected corners. Since the algorithm only uses contours, it can detect open doors in various illuminations, deformations, and scales. Another kind of indoors application is the use of labels that can be easily detected by cameras. Tjan *et al.* [7] proposed the use of printed reflexive patterns which could be easily detected by a wearable camera inside of buildings. Coughlan and Manduchi [8] proposed the use of labels that serve as landmarks and can be robustly detected by computer vision algorithms. Such landmarks consist of figures with a defined shape and color. The idea is to help blind people locate key places such as elevators and exit doors.

An interesting project under development is the MIT Fifth sense project, supported by the Andrea Bocelli Foundation, whose objective is the creation of innovative assistive technology in order to reduce the barriers that prevent blind people to move freely in the space around them (http://www.andreabocellifoundation.org). One of the capabilities of this project is to find a safe walking surface and detect collision hazards with orientation capabilities such as the ability to know the current position, know how to get to a desired destination, infer locations (e.g. kiosk, concierge desk, elevator lobby, water fountain) through the use of surrounding cues such as text signs and features.

3. Access to Printed Information

Reading printed information is a daily activity that poses a challenge to blind and visually impaired people. To have access to books, newspapers, magazines, bills, street signs, and product information is a common activity that sighted people take for granted. Considering that only 10% of blind children learn Braille and most documents are not available in this format, the development of devices that allow reading printed information is fundamental.

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The advance of optical character recognition techniques (OCR) has led to the emergence of devices that can read printed material. The first OCR devices were large and needed to scan the entire page (e.g., the Arkenstone reader). Nowadays, we find this operation in smartphones with applications such as the kReader (www.knfbreader.com/products-kreader-mobile.php). However, aiming the camera to successfully frame the text can be difficult task for a blind user. With this problem in mind Voiceye developed a 2.5 cm^2 code that can be included on printed information. This code can store up to two complete text pages. Hence, the user only needs to aim the Voiceye scanner, or camera, to cover this small target to have access to the code content. This technique is used in schools for the blind, universities with special education, publishing companies, and local newspapers of South Korea (voiceye.viewplus.com).

Currently, the research in this field is related to the detection and recognition of non-document text such as LED and LCD displays found in many household appliances and text detection in non-uniform images that combine figures with text such as graphs, logos, and street signals. These applications are normally combined with object detection and recognition.

4. Object Recognition

Object recognition for blind and visually impaired is another practical application where the use of computer vision has shown promising results. For instance, invoice recognition is difficult for a blind person when the invoices have the same size and texture. The *Money Reader* application, developed by LookTel for smartphones, is capable of recognizing bills and reproduces their value using a voice synthesizer. Similarly, object recognition in supermarkets is difficult when the objects have the same shape. For this purpose, the *Recognizer* application, by LookTel, is capable of recognizing objects by comparing the image taken with the camera with an internal database created by the user. This application does not require an Internet connection since the entire database is stored in the internal memory. Once the object is recognized, the application reproduces the object description (previously recorded by the user). It can be used to recognize daily objects, or supermarket objects (www.looktel.com).

Non-commercial prototypes such as *Trinetra,* developed at Carnegie Mellon University, is intended to assist blind users in recognizing supermarket objects using the barcode. The problem with this approach is that the camera needs to be directed toward the barcode, which can be tricky and frustrating for a blind user. To overcome this limitation Tekin and Coughlan [9] developed an algorithm to find the bar code giving “left” or “right” indications until the camera successfully focus the bar code. The prototype developed by Winlock *et al.*

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[10] is able to recognize supermarket objects defined in a shopping list inside the smartphone. During the search, the user moves the camera through the shelves and the application notifies when an object in the list is detected. The algorithm uses SURF (Speeded Up Robust Features), which are unique features invariant to scale, and rotation that can be used to estimate the probability of a positive detection.

In addition to the aforementioned applications, another interesting example that can provide greater autonomy to blind people is the capacity to recognize public transportation without the assistance of other person. For this, Guida *et al*. [11] developed a method to identify bus numbers. This method combines geometric computer vision with machine learning to achieve robustness against reflexes, specularities, shadows, and occlusions.

5. Social Interaction

Social interaction involves acts, actions, or practices of two or more persons mutually oriented to each other. These interactions include smiling, chatting, winking, threatening, fighting, and discussing. During a social interaction, part of the conversation is sustained by non-verbal communication (given by gestures, gaze direction, and signals) to which blind people have no access. This represents a serious limitation as they could be feeling socially excluded sometimes.

In this particular area, researchers from Arizona State University have been working in a project called *iCARE Social Interaction* with the goal of allowing blind people to access visual information during social encounters. The prototype that they developed uses a camera embedded inside eyeglasses that can communicate with a smartphone [12]. By using computer vision algorithms, the iCARE detects the position of the other person and gives this information to the user through a belt with vibrators. The system can also detect seven basic emotions (happiness, sadness, surprise, anger, fear, disgust, and neutral) and to provide this information to the user through a glove made of 14 small vibratory motors.

In this kind of application the feedback pose a major challenge to the designer because there is so much information that can be gathered from the environment, which is impossible to transmit to the user by acoustic and/or vibratory means. We need intelligent algorithms to extract multiple features, but provide only the most important cues that the user needs in a particular situation. For instance, consider a social interaction where the blind user is speaking; in this case, the device can infer the degree of attention and distance of the other person or persons and provide the information only when it is needed. Consequently, if the other person shows interest in the conversation, this serves as a

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valuable clue for the blind user. However, if the person does not pay attention, the device should inform the user about this situation so he can decide whether to change or stop the conversation. Furthermore, if the other person leaves without notifying, the device should sense this and warn the user, so he can stop talking and say goodbye. A similar situation can arise when a blind user is waiting for his bus and he asks another person to tell him when this arrives (if the blind user does not have a bus detection device), since it might be expected that this person will eventually leave without further notice. The device should detect this situation and inform the user to stop waiting.

Our developments

At the Instituto Politécnico Nacional (IPN) in Mexico, we have been working with multiple prototypes to assist blind people. One prototype is the *Virtual White Cane* [13] shown in Figure 1(a). This device simulates a cane by the combination of a smartphone and a laser pointer. Figure 1(b) shows a simplified schematic of the setup. The laser is aligned with the camera with a baseline t_x, and a pan angle α. The camera captures the reflection of the laser and a smartphone application calculates the distance of the objects by active triangulation and provides feedback to the user through the vibrating motor of the smartphone. The vibration intensity is proportional to the closeness of the object where the laser is pointing.

Another prototype is the *Vibratory Belt*, whose goal is to provide to a blind user the location of obstacles without the need of using his hand. This belt contains a Kinect® camera connected to an embedded computer, an inertial measurement unit (IMU), and three small vibrating motors located around the waist (Figure 2(a)). The camera provides depth images (Figure 2(b)), and the computer calculates the distance of the closest obstacles in three positions in front of the user (Figure 2(c)). The IMU is used to calculate the orientation of the camera in order to separate the floor from the objects.

Both, the Virtual White Cane and the Vibratory Belt, rely on a haptic interface to provide feedback to the user. We performed several stimuli vs. sensation trials with multiple individuals in order to identify the relationship between the generated vibration and the user-perceived sensation, and be able to produce the right amount of vibration that represents distance.

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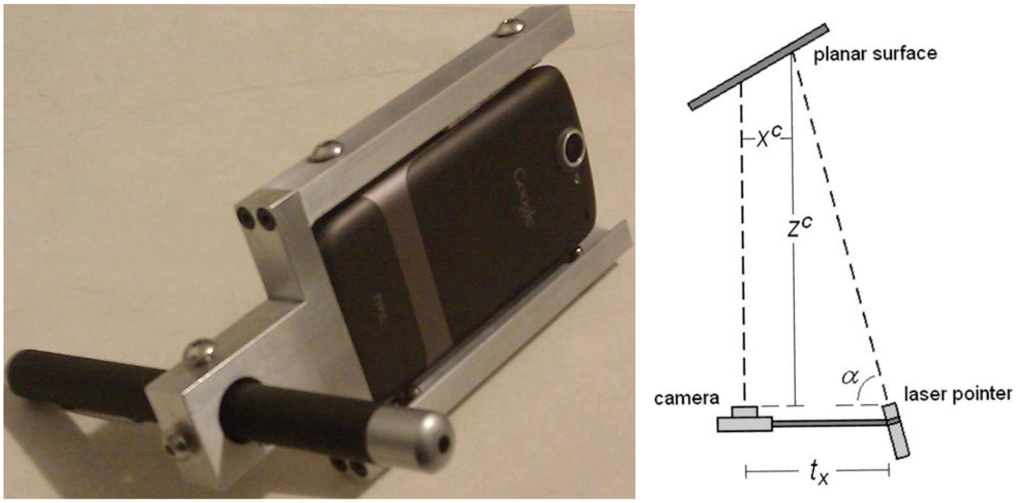
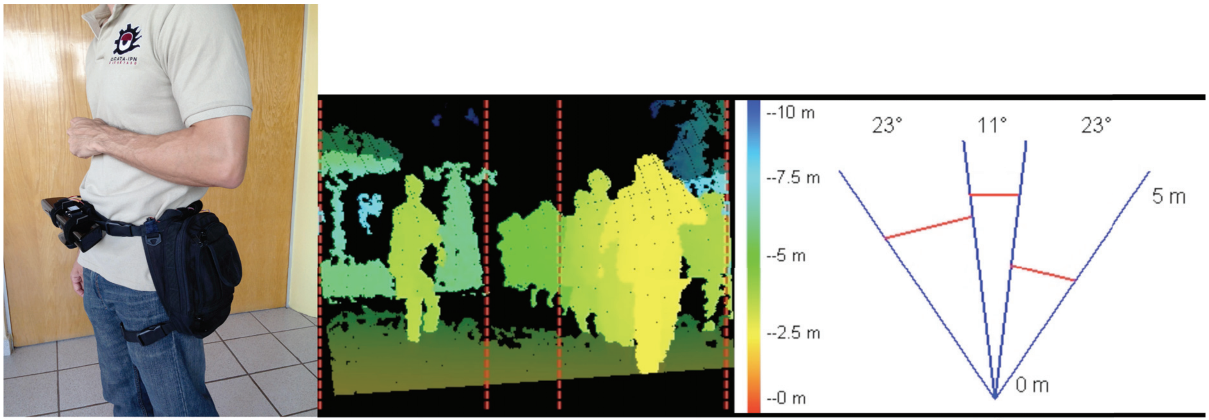


a) **b)**

Figure 1. Virtual White Cane (illustration from [12]). (a) A laser is coupled to the smartphone with a metallic structure. (b) The obstacle distance Z^C is measured by active triangulation. The vibration of the smartphone tells the user the distance of an object in the direction where she/he is pointing.



a) **b)** **c)**

Figure 2. Vibratory Belt. (a) Complete prototype worn by the user. (b) Depth map provided by the Kinect. (c) Obstacle map showing the position (horizontal axis) and the distance (vertical axis).

Given the importance and the incipient progress in the area of social interaction, we are currently working in the development of assistive technologies that support blind people in their social encounters. The idea is to detect head gestures, gaze direction, and the distance to other people in order to determine non-verbal cues that could describe the degree of attention that the other people are paying to the blind user in order to assist in situations such as those described in the social interaction section.

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Conclusion

In this review, we have found that even though computer vision has great potential as a powerful tool for the development of assistive technologies for blind people, it has not yet been fully exploited. Currently, the trends are to take advantage of existing hardware and techniques and use them to create assistive technology devices. For example, the multiple technologies existent in smartphones are used to create assistive technology applications such as Georgie (http://www.georgiephone.com). An example of using known technology in assistive devices is the case of the MIT Fifth Sense project, in which decades of robotics technology knowledge is being used to create new assistive technology devices for blind and visually impaired users (http://people.csail.mit.edu/teller/misc/bocelli.html).

We consider that the use of computer vision to assist blind people is now in an intermediate stage, one in which there is the opportunity to develop advanced algorithms that can offer a greater level of interpretation of the visual information in order to “understand” the content of an image, scene, or to interpret the attitude of the listener reliably. Moreover, despite many years of research, no general-purpose vision-to-touch translator or vision-to-audition translator has emerged that is sufficiently robust and dependable for use in everyday life [2]. Consequently, computer vision for blind people assistance is a fertile field of research.

Additionally, assistive technology is user-centered. That is, we need to know the needs and skills of blind users from the conception of the prototype, guiding each step of the design process in order to adapt the functionality to their true needs and expectations. As in the case of mobility, most users prefer the white cane instead of any type of ETA, because the cane is low-cost, reliable, and does not need batteries. These noble properties of the white cane challenge designers to develop new ideas, based on low-cost technology, state-of-the-art algorithms, and renewable energies. Furthermore, each person has a different way of learning, feeling, and perceiving. Therefore, assistive technology devices must learn from the user and adapt their parameters (such as type and intensity of feedback) to personalize the user-experience.

In this paper we showed that many assistive devices are being deployed as smartphone applications, this is due to the fact that current flagship smartphones have all the technology needed to create a computer vision-based assistive device and have many conveniences for both, designers and users. From the designer perspective, the development is highly simplified with a pure-software solution, with the free-lunch property that the application will work faster with future devices. From the user perspective, the smartphone represents an ideal assistive device because it is ubiquitous

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and does not have the stigma of an assistive device. However, for some applications, the smartphone is not the best solution. For instance, consider the use of a smartphone as a mobility device for obstacle detection; in this case, the user must point in the direction where he wants to detect the obstacles, which represents a long-term tiresome position.

As a future direction, we propose a combination of multiple technologies such as computer vision, GPS, wireless Internet, and voice recognition in a wearable platform similar to Google Glass, to deliver a single and versatile hands-free assistive device, capable of learning from the user, with multiple functions such as the five discussed in this article, and with a feedback interface based on haptic and bone-conduction audio that do not interfere with hearing.

Acknowledgements

This research was partially supported by SIP-IPN under grant 20121642. We are thankful to Paul Riley of the U.S. Peace Corps/Mexico for his comments to improve this manuscript.

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