Face Recognition for the Visually Impaired

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Abstract: *The inability to recognize known individuals in the absence of audio or haptic cues severely limits the visually impaired in their social interactions and puts them at risk from a security perspective. In recent years, several prototype systems have been developed to aid this population with the face recognition task. This paper aims to provide an overview of the state of the art in this domain, highlighting the strengths and weaknesses of different solutions and discusses some of the issues that need to be addressed and resolved to expedite the practical deployment and widespread acceptance of such systems.*

Keywords: Visually impaired, assistive technologies, face recognition, computer vision, survey, review

1. Introduction

Visual impairment afflicts approximately 285 million people worldwide according to recent estimates by the World Health Organization (WHO) [1] and, without additional interventions, these numbers are predicted to increase significantly [2]. One of the many challenges faced by this population is their inability to recognize the faces of known individuals when they encounter them in their daily lives. One consequence of this is that whenever a visually impaired individual arrives in a social setting (e.g., in a conference room or at a dinner party), the conversation has to be interrupted to announce which people are already present on the scene which may result in some social awkwardness. The importance of being able to view faces in social interactions is also confirmed by several studies which indicate that most of our communication takes place not through words but via non-verbal means, the majority of which consist of facial expressions [3]. Furthermore, the ability to determine if an approaching person is a friend or a stranger is essential from a security perspective and also contributes to a person's general awareness of his context and surroundings.

The exponential increase in computing power per volume coupled with the decreasing size of computing elements and sensors in recent years has opened up the possibility of running computationally demanding applications on wearable electronic devices. These advances, in conjunction with the needs specified above, have fueled research into developing wearable face recognition aids for the visually impaired in the past few years. This area of research is still in its infancy with only a few prototype systems being implemented for this purpose so far. These solutions are characterized by their emphasis on portability, convenience, intuitiveness, and cost-effectiveness. The objective of this paper is to provide an overview of the state of the art in this domain, highlighting the strengths and weaknesses of different solutions, to discuss some of the issues that need to be addressed and resolved to expedite the practical deployment and widespread acceptance of such systems, and to facilitate and inspire further research in this realm.

The rest of this paper is organized as follows: Section 2 briefly discusses previous work done on face recognition and describes other technologies that are currently being utilized to assist the visually impaired. Section 3 provides an overview of the various solutions that have been developed in recent years to aid the visually impaired in the face recognition task. Section 4 highlights several issues and challenges faced by these systems and identifies some directions for future research. Section 5 concludes the paper.

2. Related work

Automated face recognition has been the focus of extensive research for the past four decades (see [4] for a detailed survey). The approaches for this task can be broadly divided into two categories: 1) Feature-based methods [5, 6], which first process the input image to extract distinctive facial features, such as the eyes, mouth, nose, etc., as well as other fiducial marks and then compute the geometric relationships among those facial points, thus, reducing the input facial image to a vector of geometric features. Standard statistical pattern recognition techniques are then employed for matching faces using these measurements. 2) Appearance-based (or holistic) methods [7-9], which attempt to identify faces using global representations, i.e., descriptions based on the entire image rather than on local features of the face. Though face recognition methods traditionally operate on static intensity images, in recent years, much effort has also been directed towards identifying faces from video [10] as well as from other modalities such as 3-D [11] and infra-red [12].

Several computer vision-based solutions have been developed lately to assist the visually impaired in their daily activities (see [13] for a detailed survey). Most of these systems focus on navigation and obstacle detection: e.g., vision based simultaneous localization and mapping (SLAM) has been recently proposed to support blind mobility [14-16]. Extensive research has also been conducted on printed information and web access mainly by harnessing the power of OCR [17-20]. Relatively less attention has been directed towards application areas such as generic object recognition [21, 22] and face recognition but research in these domains has started gaining momentum in the past few years.

It should be noted that several alternate sensing technologies such as RFID [23], infrared [24]and sonar [25] have also been used either on their own or in conjunction with computer vision to aid the visually impaired. However, these technologies suffer from some limitations, e.g., they all require special sensing equipment while infrared and RFID require specific tags; also, sonar and infrared are not very effective in indoors environments since such surroundings tend to be cluttered and the obstacles present therein may cause the reflected echoes to become distorted resulting in unreliable information being conveyed to the user.

3. Overview of face recognition systems for the visually impaired

We will now present an overview of some of the most innovative solutions that have been developed in recent years to assist the visually impaired in recognizing faces. A summary and comparison of these approaches is provided in Table 1 at the end of this section.

3.1 iCare Interaction Assistant

Krishna et al. [3] have developed the iCare Interaction Assistant, an assistive system that acquires video from a pinhole aperture analog CCD camera embedded in a pair of eyeglasses, digitizes it and then transmits it over a USB cable to a tablet PC. The video is analyzed to detect faces using adaptive boosting [26] which are passed to a face recognition module that utilizes the Principal Components Analysis (PCA) [27] and Linear Discriminant Analysis (LDA) [28] algorithms. If a face is recognized in 5 consecutive frames, the name of the identified individual is converted from text to speech and transmitted to the user via head phones. One main concern expressed by Krishna et al. is that even though some publicly available face databases contain images captured under a range of poses and illumination angles, however, none of them use a precisely calibrated mechanism for acquiring these images, nor is each image explicitly annotated with this information. Krishna et al. have therefore, put together their own database called FacePix [29] which contains face images of 30 people with pose angles and illumination angles between -90 and +90 degrees annotated in 1-degree increments (Figure 2). An empirical evaluation of four of the most widely used face recognition algorithms – PCA [27], LDA [28], BIC (Bayesian Interpersonal Classifier) [30] and HMM (Hidden Markov Model) [31] – on this database showed the two subspace methods (i.e., PCA and LDA) to be the best performing ones with respect to both pose and illumination angle variance. These two methods were, therefore, selected for the face recognition module of the system. The system was tested with 10 known individuals and PCA's performance was found to be better than (or similar to) LDA. Since PCA's computational complexity is also lower than that of LDA, hence it is the preferred algorithm for future development work on this device.

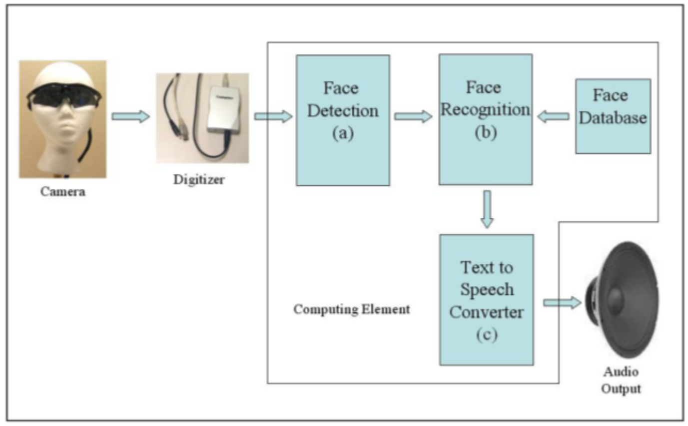

Figure 1. Block diagram of the wearable face recognition system [3] (©2005 ACM).

Figure 2. A subset of one face set taken from the FacePix(30)database, with pose and illumination angles ranging from +90 degrees to –90 degrees, in steps of 10 degrees [3] (©2005 ACM).

3.2 Balduzzi et al.'s approach

Balduzzi et al. [32] have developed a prototype for a compact PC that acquires a video stream from a small form video camera and analyzes it to detect human faces in the scene (by detecting skin-colored regions and finding faces among them using a cascade of Support Vector Machine (SVM) classifiers [33]; eye and nose detection is then applied to the face regions to select the faces in which these features are unoccluded). The face recognition module, which is based on Local Binary Patterns (LBP) [34], attempts to recognize the detected faces. To avoid audio spamming, this module aggregates the results over *N* consecutive frames and provides feedback only if the last *N* frames have provided some concrete results. If the person is identified or an unknown person is detected, in either case, an audio feedback is provided to the user via a speaker set. LBP descriptions were selected based on some initial tests that demonstrated their superiority over Local Ternary Patterns [35] and Histogram of Gradient [36]. The system was found to be robust to viewpoint changes of up to 30 degrees. Interviews conducted with prospective users of this prototype revealed that though most people were satisfied with the face detection and feedback speeds, however, the I/O interface and the face recognition capabilities need to be substantially improved to meet the users' expectations.

3.3 Kramer et al.'s approach

Kramer et al. [37] have implemented a client application for a smartphone that acquires images using the phone's built-in camera, wirelessly transmits them to a remote server for identification, receives the recognition results and then transmits them to the user via the phone's speech interface. The server application utilizes VeriLook [38], a commercially available face recognition package, with the ability to detect and recognize multiple faces per frame. To determine the robustness of the VeriLook technology to changes in viewpoint, images of 10 subjects were taken from 15 different positions with different head orientations. To make the test more realistic, images of 78 additional people were also downloaded from the CalTech and GeorgiaTech face databases and added to the database of known faces. Experiments showed that VeriLook could tolerate up to 40^o and 20^o changes in viewpoint and head tilt angles, respectively. The system has been reported to have high recognition accuracy based on initial tests conducted with 10 known users.

3.4 Blind Assistant

Blind Assistant [39] is a software platform that integrates many different functionalities for the visually impaired, namely, face recognition, text recognition (restricted to labels and short sentences), place recognition, e-mail (reading and dictating), color recognition and barcode reading. We will focus our discussion on the face recognition module of this system. This solution utilizes the *Nanodesktop*, a freely available, open-source software aimed at developing computer vision applications on embedded systems [40]. The system consists of a handheld console equipped with a pair of RISC microprocessors, a video accelerator, a wireless connection, a USB port and a slot for flash memory cards. A webcam connected to the console is used to acquire images of the scene in front of the user. The images are normalized with respect to luminosity, the faces within them are detected using the Viola-Jones algorithm [41] and recognition is performed based on the PCA algorithm. If a person is recognized, a spoken message relays his identity and average position to the user. The system was tested with 15 visually impaired users and though the PCA algorithm featured an accuracy of only around 80%, but the face recognition part was still rated as reliable and interesting by most users. The most attractive aspect of their system is that it is an open source platform running on widely available hardware and is, thus, accessible to the largest community of users and developers.

3.5 Project F.A.C.E.

Astler et al. [42] have proposed to develop a device that will communicate the names of familiar conversation partners, as well as their expression states, differentiated as six universal macroexpressions (i.e. happiness, sadness, disgust, surprise, fear, and anger) to facilitate social interaction for the visually impaired. A pair of stereovision cameras mounted either on the forehead or embedded in sunglasses, to better emulate human vision, would be used to acquire image data which will then be transmitted to a Microsoft Windows capable laptop computer (which the user can carry in a backpack) via a USB connection. Face recognition based on the PCA-SIFT algorithm [43] and expression analysis based on a parametric flow model [44] will be performed and the results will be conveyed to the user via a voice recognition and an audio feedback system with text-to-speech capabilities as well as a haptic feedback belt. The user interface will be built upon the framework already developed by Caperna et al. [45]. Astler et al. plan to conduct interviews with visually impaired users individually as well as in focus groups and intend to incorporate their feedback into the product design. They also plan to survey a group of sighted subjects in order to better understand how society may view users of their technology. The system will first be tested for accuracy and efficiency with facial images from the Cohn-Kanade Database [46] using a method similar to Krishna et al. [3] before being tested with the target population.

4. Issues and challenges

Though all the systems described in the previous section are still proof-of-concept, however, preliminary research conducted for developing these solutions has provided some valuable insights into the kind of capabilities that users expect from such a device and the minimum set of requirements that such a system should fulfill. Some of the requisites indicated by these prototypes are discussed below:

- The system should be portable allowing the user to carry it to different venues. This entails that it should be small both in terms of size and weight.
- It should be wearable. This enables constant interaction between the user and the system and also frees the user's hands allowing him to multi-task.
- It should be able to operate in real-time so that the feedback given to the user would be of immediate use to him. For instance, if a person's identity is revealed to the user 40 seconds after the person is first encountered, that information will not be of much use to him in either a social or a security scenario.
- It should be as inconspicuous as possible, preferably

Table 1. Summary of face recognition solutions for the visually impaired.

Approach	Face recognition technology/ algorithm	Input device	Output device	Number of test subjects	Number of gallery subjects	Recognition accuracy
iCare Interaction Assistant [3]	LDA [28] and PCA [27]	Glasses fitted with an analog CCD video camera	Speech output from tablet PC via headphones	10	10	PCA: 96.3% to 98.6% LDA: 96.3% to 97.8% *values estimated from the bar graph provided in the paper
Balduzzi et al. [32]	LBP representations [34] (similarity measured by histogram intersection)	A compact video camera (not specified if camera is held or worn)	Speaker set	10 known subjects + an unspecified number of unknown subjects	10	-
Kramer et al.[37]	Verilook [38]	Smartphone camera	Smartphone radio	10	88	96%
Blind Assistant [39]	PCA [27]	Webcam connected to handheld console	Speech output from console via headphones	15	10 (at the most)	Close to 80%
Project F.A.C.E. [42]	PCA-SIFT [43]	A pair of stereovision cameras mounted either on the forehead or embedded in sunglasses	Speech output and haptic feedback belt	-	-	-

hidden unobtrusively in the user's clothing since multiple studies have now indicated that the visually impaired are not eager to use devices that advertise their disability and that they rate the cosmetic acceptability of a device as more important than the actual functionality that it provides [47].

- It should be cost-effective. Since 90% of the visually impaired live in developing countries while 65% are aged 50 years or older [48], most commercial assistive devices are beyond the financial reach of this population. Hence, appropriate measures must be taken to ensure that when the system reaches the mass production stage, it will be affordable for most of its intended users. Most of the systems described in this paper seem to have taken the cost factor into account by opting to use consumer components that are widely available.
- It should be easy and intuitive to use and should require minimum technical skills and knowledge.
- It should be able to operate under a wide variety of conditions including changes in illumination, pose, and scale which constantly occur especially in group social interactions. Some of the above systems, such as the iCare Interaction Assistant [3], have explicitly taken pose and illumination angles into account and all of them implicitly or explicitly plan to improve their solutions to be better able to handle variations in these conditions.
- It should provide limited and meaningful output to the user avoiding spamming. All the above systems provide audio output to the user while Astler et al. [42] also plan to offer haptic feedback. Since visually impaired users heavily rely on their senses of hearing and touch to discern environmental cues, it is essential not to overwhelm these senses with continuous feedback from the face recognition system any time a person is spotted but rather, to alert the user only when a person has been within range for a certain number of frames and his identity is established with some degree of confidence. This also suggests that some options for customizing the output would be desirable, e.g., the user may or may not

choose to be informed every time an unknown person is encountered.

Some additional considerations pointed out by the developers of the above systems are as follows:

- The features utilized by these assistive devices may be different from those used by face recognition systems developed for security applications: e.g., algorithms for security purposes assume that the face may be disguised and thus, try to minimize the effect of glasses, facial hair, makeup, etc. when recognizing faces. However, in a social scenario, facial paraphernalia and features such as these may be a distinctive part of the person's appearance and may actually aid in recognition [3].
- On the same note, the number of individuals that need to be recognized by such an assistive device is much smaller than that for a security application. A visually impaired person needs to recognize only a handful of family members, caregivers and acquaintances in his daily life and so the face recognition algorithm does not need to match an unknown face against a database of thousands of known individuals as may be the case with a general purpose security application in a public place. This consideration can significantly impact the choice of the face recognition algorithm utilized and its complexity. As can be seen from Table 1, all the prototype systems have been tested with only 10 to 15 known persons.
- The development of face recognition aids in a work environment may be facilitated by the fact that face databases are already available in many organizations for security purposes. Moreover, an option can be provided in such systems allowing willing colleagues to self-enroll themselves by emailing their facial images with their names on the subject line [37].
- Feedback from the target population has revealed that users would prefer such a system to be able to identify individuals whom they may not have personally met but who may be of interest to them as a community, e.g., care operators at a rehabilitation facility [39].

5. Conclusion

The inability to recognize known individuals in the absence of audio or haptic cues severely limits the visually impaired in their social interactions and puts them at risk from a security perspective. An overview of several systems being developed to aid this population in the face recognition task was presented in this paper. Though all these systems are still in the prototype stage, however, the initial research, development and testing of these solutions has demonstrated their feasibility and has provided several valuable insights into requirements for assistive devices for this task. Nevertheless, several issues and challenges (which have been highlighted in the previous section) still need to be addressed and resolved to expedite the practical deployment and widespread acceptance of such systems.

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References

[1] D. Pascolini and S. P. Mariotti, "Global estimates of visual impairment: 2010," *British Journal Ophthalmology,* 2011.

[2] "Elimination of Avoidable Blindness Report by the Secretariat," World Health Organisation, Fifty-sixth World Health Assembly2003.

[3] S. Krishna, G. Little, J. Black, and S. Panchanathan, "A wearable face recognition system for individuals with visual impairments," in *Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility*, Baltimore, MD, USA, 2005, pp. 106-113.

[4] R. Jafri and H. R. Arabnia, "A Survey of Face Recognition Techniques," *Journal of Information Processing Systems,* vol. 5, pp. 41-68, 2009.

[5] I. J. Cox, J. Ghosn, and P. N. Yianilos, "Feature-based face recognition using mixture-distance," presented at the Proceedings of IEEE Conference on Computer Vision and Pattern Recognition, 1996.

[6] L. Wiskott, J.-M. Fellous, N. Krüger, and C. von der Malsburg, "Face Recognition by Elastic Bunch Graph Matching," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 19, pp. 775-779, July 1997.

[7] M. Turk and A. Pentland, "Eigenfaces For Recognition," *Journal Of Cognitive Neuroscience,* vol. 3, pp. 71-86, Winter 1991.

[8] P. N. Belhumeur, J. P. Hespanha, and D. J. Kriegman, "Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 19, pp. 711-720, July 1997.

[9] R. Jafri and H. R. Arabnia, "PCA-Based Methods for Face Recognition," in *The 2007 International Conference on Security and Management (SAM'07)*, Las Vegas, USA, 2007, pp. 534-541.

[10] S. Zhou and R. Chellappa, "Beyond a single still image: Face recognition from multiple still images and videos," in *Face Processing: Advanced Modeling and Methods*, ed: Academic Press, 2005.

[11] K. W. Bowyer, K. Chang, and P. J. Flynn, "A survey of approaches and challenges in 3D and multi-modal 3D+2D face recognition," *Computer Vision And Image Understanding,* vol. 101, pp. 1-15, 2006.

[12] S. G. Kong, J. Heo, B. R. Abidi, J. Paik, and M. A. Abidi, "Recent advances in visual and infrared face recognition - a review," *Computer Vision And Image Understanding,* vol. 97, pp. 103-135, Jan 2005.

[13] R. Manduchi and J. Coughlan, "(Computer) vision without sight," *Commun. ACM*, vol. 55, pp. 96-104, 2012.

[14] V. Pradeep, G. Medioni, and J. Weiland, "Robot vision for the visually impaired," in *Proc. Workshop on Applications of Computer Vision for the Visually Impaired*, San Francisco, CA, 2010, pp. 15-22.

[15] J. Saez and F. Escolano, "Stereo-based aerial obstacle detection for the visually impaired," in *Proc. Workshop on Computer Vision Applications for the Visually Impaired*, 2008.

[16] J. Wilson, B. N. Walker, J. Lindsay, C. Cambias, and F. Dellaert, "SWAN: System for Wearable Audio Navigation," in *Proceedings of the 11th IEEE International Symposium on Wearable Computers*, 2007, pp. 1-8.

[17] B. Leporini, P. Andronico, and M. Buzzi, "Designing search engine user interfaces for the visually impaired," in *Proceedings of the 2004 international cross-disciplinary workshop on Web accessibility (W4A)*, New York City, New York, 2004, pp. 57-66.

[18] S. Liu, W. Ma, D. Schalow, and K. Spruill, "Improving Web access for visually impaired users," *IT Professional*, vol. 6, pp. 28-33 2004.

[19] M. Tanaka and H. Goto, "Text-Tracking Wearable Camera System for Visually-Impaired People," in *International Conference on Pattern Recognition (ICPR 2008)*, Tampa, FL, 2008, pp. 1-4.

[20] T. Dumitras, M. Lee, P. Quinones, A. Smailagic, D. Siewiorek, and P. Narasimhan, "Eye of the Beholder: Phone-Based Text-Recognition for the Visually-Impaired," in *10th IEEE International Symposium on Wearable Computers*, Montreaux, 2006, pp. 145-146.

[21] J. Sudol, O. Dialameh, C. Blanchard, and T. Dorcey, "Looktel—A comprehensive platform for computer-aided visual assistance," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, San Francisco, CA, 2010, pp. 73-80.

[22] T. Winlock, E. Christiansen, and S. Belongie, "Toward real-time grocery detection for the visually impaired," in *Computer Vision Applications for the Visually Impaired (CVAVI)*, San Francisco, CA, 2010.

[23] M. Murad, A. Rehman, A. A. Shah, S. Ullah, M. Fahad, and K. M. Yahya, "RFAIDE – An RFID Based Navigation and Object Recognition Assistant for Visually Impaired People," in *7th International Conference on Emerging Technologies (ICET)*, Islamabad, Pakistan, 2011, pp. 1-4.

[24] W. Crandall, J. Brabyn, B. L. Bentzen, and L. Myers, "Remote Infrared Signage Evaluation for Transit Stations and Intersections," *Journal of Rehabilitation Research & Development*, vol. 36, pp. 341-355, 1999.

[25] "Bay Advanced Technologies Ltd. (http://www.batforblind.co.nz/).".

[26] P. Viola and M. Jones, "Robust Real-time Object Detection," in *Second International Workshop on Statistical and Computational Theories of Vision – Modeling, Learning, Computing, and Sampling*, Vancouver, Canada, 2001.

[27] M. Turk and A. Pentland, "Face recognition using Eigenfaces," in *Proc. of IEEE Conference on Computer Vision and Pattern Recognition*, 1991, pp. 586–591.

[28] K. Etemad and R. Chellappa, "Discriminant Analysis for Recognition of Human Face Images (Invited Paper)," in *Proceedings of the First International Conference on Audio- and Video-Based Biometric Person Authentication*, 1997, pp. 127-142.

[29] J. Black, M. Gargesha, K. Kahol, P. Kuchi, and S. Panchanathan, "A framework for performance evaluation of face recognition algorithms," in *ITCOM, Internet Multimedia Systems II*, 2002.

[30] B. Moghaddam and A. Pentland, "Probabilistic Visual Learning for Object Representation," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 19, pp. 696-710, 1997.

[31] A. Nefian and M. H. H. III, "Hidden markov models for face detection and recognition," in *IEEE International Conference on Image Processing*, 1998, pp. 141–145.

[32] L. Balduzzi, G. Fusco, F. Odone, S. Dini, M. Mesiti, A. Destrero, and A. Lovato, "Low-cost face biometry for visually impaired users," in *Biometric Measurements and Systems for Security and Medical Applications (BIOMS), 2010 IEEE Workshop on*, 2010, pp. 45-52.

[33] V. N. Vapnik, *Statistical Learning Theory*: Wiley, 1998.

[34] T. Ahonen, A. Hadid, and M. Pietikainen, "Face Description with Local Binary Patterns: Application to Face Recognition," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 28, pp. 2037-2041, 2006.

[35] X. Tan and B. Triggs, "Enhanced local texture feature sets for face recognition under difficult lighting conditions," in *Proceedings of the 3rd international conference on Analysis and modeling of faces and gestures*, Rio de Janeiro, Brazil, 2007, pp. 168-182.

[36] N. Dalal and B. Triggs, "Histograms of Oriented Gradients for Human Detection," in *Proceedings of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05) - Volume 1 - Volume 01*, 2005, pp. 886-893.

[37] K. M. Kramer, D. S. Hedin, and D. J. Rolkosky, "Smartphone based face recognition tool for the blind," in *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, 2010, pp. 4538-4541.

[38] "VeriLook SDK. http://www.neurotechnology.com/verilook.html."

[39] F. Battaglia and G. Iannizzotto, "An open architecture to develop a handheld device for helping visually impaired people," *Consumer Electronics, IEEE Transactions on*, vol. 58, pp. 1086-1093, 2012.

[40] F. Battaglia, G. Iannizzotto, and F. L. Rosa, "An open and portable software development kit for handheld devices with proprietary operating systems," *IEEE Trans. on Consum. Electron.*, vol. 55, pp. 2436-2444, 2009.
[41] P. Viola and M. Jones, "Rapid object detection using a boosted cascade of simple features," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2001, pp. 511-518.
[42] D. Astler, H. Chau, K. Hsu, A. Hua, A. Kannan, L. Lei, M. Nathanson, E. Paryavi, K. Ripple, M. Rosen, H. Unno, C. Wang, K. Zaidi, and X. Zhang, "A Portable Computer Vision Device for Improving Social Interactions of the Visually Impaired," University of Maryland2010.
[43] Y. Ke and R. Sukthankar, "PCA-SIFT: a more distinctive representation for local image descriptors," in *Proceedings of the 2004 IEEE computer society conference on Computer vision and pattern recognition*, Washington, D.C., USA, 2004, pp. 506-513.
[44] M. J. Black and Y. Yacoob, "Recognizing Facial Expressions in Image Sequences Using Local Parameterized Models of Image Motion," *Int. J. Comput. Vision*, vol. 25, pp. 23-48, 1997.
[45] S. Caperna, C. Cheng, J. Cho, V. Fan, A. Luthra, and B. O'Leary, "A navigation and object location device for the blind," University of Maryland, Gemstone Team Research2009.
[46] T. Kanade, Y. Tian, and J. F. Cohn, "Comprehensive Database for Facial Expression Analysis," in *Proceedings of the Fourth IEEE International Conference on Automatic Face and Gesture Recognition*, 2000, p. 46.
[47] R. Golledge, R. Klatzky, J. Loomis, and J. Marston, "Stated preferences for components of a personal guidance system for nonvisual navigation," *Journal of Visual Impairment & Blindness*, vol. 98, pp. 135-147, 2004.
[48] "Visual impairment and blindness: Fact sheet number 282. http://www.who.int/mediacentre/factsheets/fs282/en/," ed: WHO media center, 2012.