Fiducials Marks Detection to Assist Visually Impaired People Navigation

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doi:10.4156/jdcta.vol5.issue5.38

Abstract

Assistive technology enables people to achieve independence in the accomplishment of their daily tasks and enhance their quality of life. Visual information is the basis for most navigational tasks, so visually impaired individuals are at disadvantage due to the lack of information or given unsufficient information about their surrounding environment. With the recent advances in inclusive technology it is possible to extend the support given to people with visual disabilities during their mobility. In this context we propose and describe the SmartVision project, whose global objective is to assist visually impaired people in their navigation through unknown indoor and outdoor environments. This paper is focused mainly on the Computer Vision module of the SmartVision prototype, were we propose a new algorithm to recognise fiducials marks suitably placed on sidewalks, revealing to be a promising solution.

Keywords*: Accessibility, Blind Navigation, Computer Vision, Ensemble Empirical Mode Decomposition*

1. Introduction

Assistive technology enables people with disabilities to accomplish daily living tasks and assists them in communication, education, work and recreation activities. Principally though, it can help them to achieve greater independence and enhance their quality of life. Of the various assistive technologies available, a special focus was put on those that help blind or visually impaired people with their mobility.

The World Health Organization estimates that there are about 314 million people visually impaired worldwide, 45 million of them are blind [1]. Blind or visually impaired people have a considerable disadvantage, as they need information for bypassing obstacles and have relatively little information about landmarks, heading, and self-velocity. The main issue on using assistive technologies is to provide additional information useful to blind people during their mobility process, i.e. walking.

Human mobility can be distinguished between Orientation and Navigation. Orientation can be thought of as knowledge of the basic spatial relationships between objects within the environment. Information about position, direction, desired location, route, route planning etc, are all bound up with the concept of orientation. Navigation, in contrast, suggests an ability to move within the local environment. This navigation implies the knowledge of immediate objects and obstacles, of the formation of the ground (holes, stairs, flooring etc.), and of dangers both moving and stationary.

The aim of the present work is to propose a new algorithm for the computer vision (CV) module that will be integrated with the SmartVision project, described later. The new image processing algorithm is intended to extract useful information from an outdoor scene in the University of Trás-os-Montes and Alto Douro (UTAD) campus, and put the blind user correctly positioned on the sidewalk along a predefined route. In order to reduce the image complexity features for extraction/detection fiducial marks were placed along the sidewalks. The algorithm we propose uses Ensemble Empirical mode decomposition (EEMD) for image processing and basic correlation for template matching.

The paper is organized as follows. Section 2 presents a classification of navigation systems to assist visually impaired people. Some projects that represent the state of the art are presented. Section 3 presents the proposed algorithm and the related techniques used. Section 4 presents and discusses the results. Finally, section 5 concludes the paper.

2. Navigation system to assist visually impaired people

An Electronic Travel Assistant (ETA) has to supply the visually impaired with the necessary routing information to overcome obstacles in the near environment with minimum errors. This displacement between the origin and the destination is varies according to the programmed route. A distinction must be made between primary support systems such as guide cane and guide dogs, and the secondary ones that use the most recent technologies.

These secondary systems are the focus of current study and consist of a wearable or handheld computer with a Global Positioning System (GPS) responsible for the macro navigation. In order to prevent collision with obstacles (micro navigation) these secondary systems also make use of the services of primary navigation systems. In the mid eighties, Collins and Loomis independently proposed the use of GPS to assist navigation for the visually impaired, in their navigation systems [2].

According to the proposed model by Loomis [2] a system to assist navigation for visually impaired people is organized in three basic components: **1) The position unit and orientation** is responsible for supplying the navigation system with the user's spatial location, in the form of local and global coordinates. Due to the strong dependence on the environment in which the system is used, this is the functional block that more specifically characterizes the navigation systems; **2) The geographic Information System (GIS)** contains main geo-referenced database system data. This functional block is an essential component of the navigation systems. Its main function is to store additional information about user's position, navigation maps, object positions and possible dangers; **3) The user interface** is the most critical component in the navigation system for assisting the visually impaired because it acts as a substitute for vision sensing (or attempts to). The user interface must be user-friendly in such a way that the user does not encounter difficulties which would impede daily use. Typically interaction with the visually impaired is through audio interfaces, like Text-To-Speech (TTS) or virtual audio (sonification) and tactile displays like Braille keyboards or vibrotactile devices.

Figure 1 shows the Loomis's proposed block diagrams for his navigation systems. The position unit and the orientation block can be seen, with several sensors for macro and micro navigation, the GIS block for route planning and the user interface block to provide feedback to the blind.

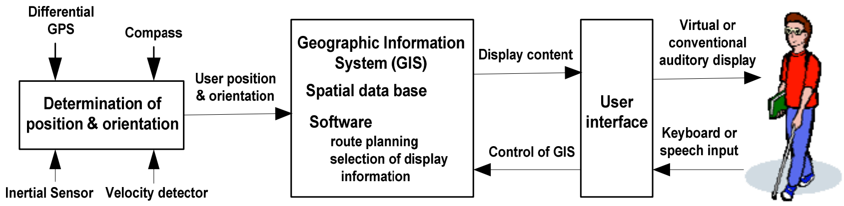

Figure 1. Functional block diagram of the navigation system proposed by Loomis et al, adapted from [2].

2.1. Navigation Systems and related work

Navigation systems to assist visually impaired people can be classified in three groups based on their usage. The indoor systems are to be used in structured environments with less complex scenes, typically inside buildings or in isolated controlled campuses. The outdoor navigation systems are intended to be used in exterior open space, typically on the street. The indoor/outdoor systems can be used in both indoor and outdoor spaces, switching functionalities based on environment operation.

The following presents some commercial research and development (R&D) projects that currently describe the state of the art in outdoor navigation systems for assisting visually impaired people.

1) Navigation systems without local obstacle information, the systems BrailleNote GPS [3], StreetTalk [4], Trekker [5], Navigator [6] and Drishti [7] and [8] are GPS based systems to assist the navigation of visually impaired people. Their primary components are a PDA or Laptop especially designed/adapted for people with visual disabilities, a Bluetooth GPS receiver and specially developed software for configuration, orientation and route mapping. The output user interaction can be from Braille display or a speech synthesizer.

2) Navigation systems with local obstacle information provide better knowledge of the local scenario, increasing the information quality provided to the blind user to overcome local obstacles.

Several techniques are used to detect and measure object distances, multiple ultrasonic sensors (sonar) [9], Laser Range Scanner (LRS) [10] and computer vision (CV) techniques [11], [12], [13], [14] and [15].

2.2. The SmartVision: active vision for the blind

A system to assist the navigation of blind or visually impaired people is currently being developed at the University of Trás-os-Montes and Alto Douro (UTAD). This project is named SmartVision and its main objective is to develop a system that helps visually impaired people to navigate, providing ways to get to a desired location and, while doing so, giving information about obstacles and various points-of-interest (POI) like zebra-crossings, building entrances, etc. The system is built in a modular structure, combining several technologies, as seen in Figure 2.

The SmartVision Module is responsible for managing and establishing communication between all the available modules. This module also receives inputs from the user and makes decisions on what information the user should get from the system.

The Location Module is responsible for providing regular updates on the user’s current geographic coordinates to the SmartVision Module. To provide this information both in indoor and outdoor environments, this module makes use of different technologies: Global Positioning System (GPS) for outdoor environments and Wi-Fi for indoor environments.

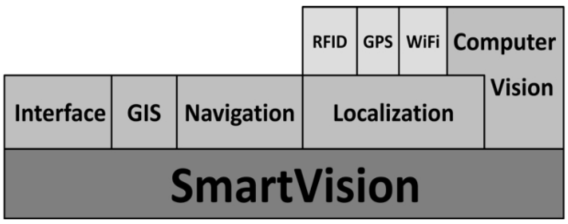

Figure 2. SmartVision modular structure

Radio-Frequency Identification (RFID) and Computer Vision are common to both indoor and outdoor environments and are based on the detection of landmarks placed in the ground. Each location technology has a specific accuracy and the Location Module always chooses the one with the best accuracy from the ones available in each moment. In terms of hardware, the RFID reader is placed in the white cane and the camera is chest-mounted. The GPS antenna is connected via Bluetooth and the Wi-Fi antenna is a built-in component of the mobile computer.

The Navigation Module is responsible for route planning and providing information about surrounding points-of-interest (POI). It connects to the SmartVision Module and requests two different data inputs: GIS data and location data. To get the GIS data, the SmartVision module queries the GIS server in order to get maps and POIs. The user location is fed from the Location Module. After analyzing the requested data, the Navigation Module feeds back the SmartVision Module with navigation instructions. The amount and accuracy of the GIS data stored in the GIS server is critical in order to feed the blind user with the most appropriate instructions.

The Computer Vision Module provides orientation instructions by detecting known landmarks in the ground and keeping the user within safe routes. Using a stereo vision system, disparity information is extracted from the captured image frames and can be used to create a depth map. This information is useful to know the distance between the user and detected landmarks. So, in addition to giving orientation instructions to the SmartVision Module, with this distance information, the Computer Vision Module has the possibility to feed the Location Module with location information.

Finally, the Interface Module provides user interface using two outputs and one input. The two outputs are text-to-speech software and vibration actuators. Since the hearing sense is very important to blind users, the vibration actuators are used for navigation guidance and the voice interface is used for menu interaction and to provide POI information. The user gives inputs to the system by using a small four-button device to scroll between the menus, apply the options and go back to the previous menus.

The user interacts directly with the SmartVision Module through the Interface Module and all other modules are independent. This way, the user can get information even when some modules are not available, or cannot provide information. For example, if GPS is not available or if the user is in an indoor environment, the Location Module can get information from the RFID tags, Wi-Fi or Computer Vision Module. Redundancy is, therefore a very important factor to increase the reliability of the system.

2.3. Computer Vision Model for SmartVision

Several image processing techniques are used to extract useful information from the scene, i.e., object identification, recognition and scene description. This information is very important for tracing a route between the scene objects.

In the context of assisting visually impaired people, the computer vision model must deal with the large amounts of image data acquired (high bandwidth process) and provide useful scene information to the user (Human Computer Interaction - HCI) which is typically a low bandwidth process.

Several Computer vision techniques have been used in navigation systems to assist people with visual disabilities. The Principal Component Analysis (PCA) was used in ASMONC [9], the Tyflos system [10] uses Fuzzy Like Reasoning segmentation technique, Expectation-Maximization (EM) algorithm was used by Zelek [12], stereo images for measuring distance from object were used by Meers [14] and Hadjileontiadis [15], a Neural Network technique was used in NAVI [16], and later the same project authors also tested Fuzzy Learning Vector Quantification (FLVQ) to classify objects in the scene.

The computer vision model of the SmartVision is one of the most critical because it deals with large and heterogeneous amount of data and in general requires a high computing power. All the computations are made on a laptop computer and for image acquisition we use the stereo vision Bumblebee 2 developed by Point Grey Research.

The Bumblebee is a packaged system that includes two pre-calibrated digital progressive scan Sony ICX084 CCD cameras with a baseline (the distance between cameras) of 12cm, and a C/C++ Software Development Kit, and a 400 Mbps IEEE-1394 Firewire interface for high speed communication of the digital video signal. Gain and shutter control can be set to automatic or adjustable manually. The calibration information is preloaded into the camera allowing the computer software to retrieve it for XYZ coordinate calculations and image correction.

The FlyCapture SDK was used for image capture and camera control. The image size used in this work is 512 by 384 pixels. For the calculation of the disparity and the correction of the images we used the Triclops SDK, and will be used for future improvements. Both this SDKs are provided together with the Bumblebee 2 stereo vision system.

3. Empirical Mode Decomposition

In the real world, data from natural phenomena like life science, social and economic systems, are mostly non-linear and non-stationary. Fourier and wavelet transform (built upon predefined basis functions) are traditional methods that sometimes have difficulty in revealing the nature of real life complex data. The adoption of adaptive basis functions introduced by Huang et al. [17] provided the means for creating intrinsic a posteriori base functions with meaningful instantaneous frequency in the form of Hilbert spectrum expansion [17]. This approach is embedded into a new decomposition algorithm, namely Empirical Mode Decomposition (EMD) [17], which provides a powerful tool for adaptive multi-scale analysis of non-linear and non-stationary signals. EMD is a method of breaking down the signal without leaving the time domain; it filters out functions which form a complete and nearly orthogonal basis for the signal being analysed. These functions, known as Intrinsic Mode Functions (IMFs), are sufficient to describe the signal, even though they are not necessarily orthogonal [17]. IMFs, computed via an iterative 'sifting process' (SP), are functions with zero local mean [17], having symmetric upper and lower envelopes. The SP depends both on an interpolation method and on a stopping criterion that ends the procedure. Some updates of the 1D-EMD have been proposed which address the mode mixing effect that sometimes occurs in the EMD domain. In this vein, 1D-Ensemble EMD (1D-EEMD) has been proposed [18], where the objective is to obtain a mean ensemble of IMFs with mixed mode cancelation due to input signal noise addition.

3.1. D-Empirical Mode Decomposition (1D-EMD)

1D-EMD considers a signal $x(t)$ at the scale of its local oscillations [17]. Locally, under the EMD concept the signal $x(t)$ is assumed as the sum of fast oscillations superimposed to slow oscillations. On each decomposition step of the EMD, the upper and lower envelopes are initially unknown; thus, an interactive sifting process is applied for their approximation to obtain the IMFs and the residue. The 1D-EMD scheme is realized according to the following steps [17]:

1) Identify the successive extrema of $x(t)$ based on the sign alterations across the derivative of $x(t)$;

2) Extract the upper and lower envelopes by interpolation; that is, the local maxima (minima) are connected by a cubic spline interpolation to produce the upper (lower) envelope. These envelopes should cover all the data between them;

3) Compute the average of upper and lower envelopes, $m_1(t)$;

4) Calculate the first component $h_1(t) = x(t) - m_1(t)$;

5) Ideally, $h_1(t)$ should be an IMF. In reality, however, overshoots and undershoots are common, which also generate new extrema or exaggerate the existing ones [17]. To correct this, the sifting process has to be repeated as many times as is required to reduce the extracted signal as an IMF. To this end, treat $h_1(t)$ as a new set of data, and repeat steps 1-4 up to k times (e.g., $k = 7$) until $h_{1k}(t)$ becomes a true IMF. Then set $c_1(t) = h_{1k}(t)$. Overall, $c_1(t)$ should contain the finest scale or the shortest period component of the signal;

6) Obtain the residue $r_1(t) = x(t) - c_1(t)$;

7) Treat $r_1(t)$ as a new set of data and repeat steps 1-6 up to N times until the residue $r_N(t)$ becomes a constant, a monotonic function, or a function with only one cycle from which no more IMFs can be extracted. Note that even for data with zero mean, $r_N(t)$ still can differ from zero;

8) Finally,

$$x(t) = \sum_{i=1}^{N} c_i(t) + r_N(t), \tag{1}$$

where $c_i(t)$ is the i-th IMF and $r_N(t)$ the final residue.

3.2. D-Ensemble Empirical Mode Decomposition (1D-EEMD)

One of the major drawbacks of the original 1D-EMD is the appearance of mode mixing, which is defined as a single IMF consisting of signals of widely disparate scales, or a signal of similar scale residing in different IMF components. The effect of adding white noise scales uniformly through the whole time-scale or time-frequency space, will provide a reference distribution to facilitate the decomposition method. The added white noise may also help to extract the true signals in the data, a truly Noise-Assisted Data Analysis [18]. The 1D-EEMD is implemented as follows:

1) Add white noise series w(t) to the data x(t), X(t) = x(t) + w(t);
2) Decompose the X(t) data with white noise into IMFs, $X(t) = \sum_{j=1}^{N} c_j(t) + r_N(t);$
3) Repeat step 1 and step 2 several times with different noise series wi(t), Xi(t) = x(t) + wi(t), and obtain corresponding IMFs, $X_i(t) = \sum_{j=1}^{N} c_{ij}(t) + r_{iN}(t);$
4) Finally, the ensemble means of corresponding IMFs of the decomposition are

$$c_j(t) = \frac{1}{N} \sum_{i=1}^{N} c_{ij}(t), \qquad (2)$$

where N is the ensemble members.

3.3. D-Empirical Mode Decomposition (2D-EMD)

The sifting notion is essentially identical in 1D and 2D cases. Nevertheless, due to the nature of the 2D data of the images, some issues should be handled with care.

In particular, in a 1D space, the number of local extrema and zero crossings of an IMF must be the same or differ by one [17]. In a 2D space, the IMFs typically use the definition of symmetry of upper and lower envelopes related to local mean [19]. There, many ways of defining the extrema are in use; hence, different local extrema detection algorithms could be applied. Fast algorithms use the comparison of the candidate extreme with its nearest 8-connected neighbours [20], while more sophisticated methods, like morphological reconstruction, are based on geodesic operators [21]. Furthermore, the interpolation method should rely on proper 2D spline interpolation of the scattered extrema points. In [19] the thin-plate smoothing spline interpolation is used. In Bi-dimensional Empirical Mode Decomposition (BEMD) [21] Radial Basis Functions are used for surface interpolation. This combination of 2D extrema extraction and 2D surface interpolation represents very heavy computation power, suitable neither for real-time implementations, nor for use in portable devices.

3.4. The proposed algorithm for fiducials marks detection

In order to provide useful information to blind people navigation the vision system must be able to detect relevant features in the scene and help the blind user to keep safe courses. The first approach was intended to reduce the image complexity for the processing algorithms and enhance the detection. Fiducial marks were made on sidewalks representing safe paths along the user route. From several geometric marks, circles were adopted because in this application they are scale and rotational invariants. Several captured images with different circle radius were tested and to minimize the size and maximize de detection rate the 15 cm circle radius were chosen.

The proposed CV phases are described as follows:

1) Decompose the captured image with Ensemble Empirical Mode Decomposition

2) Image filtering to eliminate higher frequencies containing noise and fine details. This process is achieved in the EEMD reconstruction phase (1) by eliminating the first two IMFs according to a criterion of root mean square error (RMSE) minimization. Figure 3 represents the RMSE during the reconstruction phase of the image which was corrupted by Gaussian white noise ($\sigma = 0.1$). The minimum error occurs when removing the first two IMFs, where the reconstruction is $x(t) = \sum_{i=3}^{N} c_i(t) + r_N(t),$ were i starts at 3 IMF.

3) Define a region of interest (ROI) near the blind user, in our case we chose to analyze the first half of the image and a quarter image size for each side of the blind user. Data outside the ROI area is set to zero.

4) Perform a data binarization of the ROI image using a global threshold using Otsu's method [22], followed by canny edge detection.

5) Finally the ROI image is passed to a circle detection procedure using a simple correlation template matching.

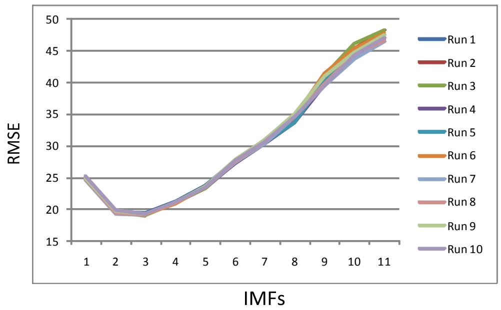

Figure 3. Reconstruction error of a image corrupted with white noise

4. Experimental results and discussion

In order to test the proposed algorithm to detect fiducial marks in the sidewalk a set of different images were taken on UTAD campus. We present two images that represent different areas of the campus as can be seen in Figure 4a) and Figure 4e), the second one represents a more difficult task for any image processing algorithm. Figure 4b) and Figure 4f) are the EEMD filtered images as can be seen the higher frequencies were removed, with this procedure prior image binarization image artifacts were minimized. Figure 4c) and Figure 4g) are the ROI near the user that are processed to circle detection, consider that the user is centered at the image bottom. Finally Figure 4d) and Figure 4h) represents the circle detection of the respective images, all circle detected are marked with a rectangle. In order to improve the visualisation results these two images are at a bigger scale.

From the circles detected in the image, the blind user must go in the direction of the nearest circle. This ensures that he/she will not get out of course. Based on the relative position of the blind user and the detected nearest circle it’s possible to compute the trajectory correction and output it to the blind user. The interface to the user uses five microvibrators corresponding to the five directions, i.e. left, left-diagonally, straight, right diagonally and right.

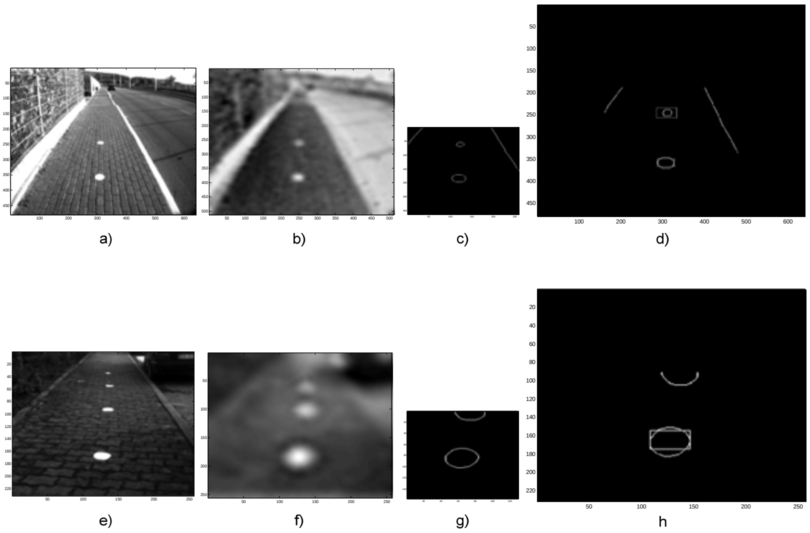

Figure 4. Results of the proposed algorithm for fiducial marks detection

5. Conclusions

In the present work a Computer Vision module for the SmartVision project was proposed. For an efficient assistance to blind user's navigation the CV must detect accurately specific features in the environment. In outdoor navigation due to very different scenarios we adopted to mark sidewalks with fiducial marks to improve the CV feature detection efficiency. To the fiducial mark detection the EMD Template Matching method was implemented and the system has proven to be able to detect the defined landmarks and provide valid and simple instructions to the blind user.

The SmartVision prototype is also composed by other modules, as seen in section II, and, at the moment, they are all being integrated. A set of tests done to the assembled system by blind users will be performed in order to validate and improve the system.

Further work is needed to enhance the method accuracy, future improvements will continue to use EMD image analysis. Range image information (disparity map) will be integrated into CV model to add the obstacle detection feature.

6. Acknowledgments

This research was supported by the Portuguese Foundation for Science and Technology (FCT), through the FCT project PTDC/EIA/73633/2006 - SmartVision: active vision for the blind.

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