Univ Access Inf Soc (2012) 11:399–407
DOI 10.1007/s10209-011-0255-7

LONG PAPER

# Providing accessibility to blind people using GIS

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**Abstract** In everyday life, people need to move, whether in business or leisure. Navigation requires spatial knowledge and ability to make decisions based on geographic information. Recently, powerful tools have been developed, enhancing the capabilities of geographical analysis and decision-making. This work presents a platform to handle and provide geographic information, including accessibility oriented features. This geographic information system (GIS) is part of a wider project, called SmartVision. The aim of this project is to create a system that allows blind users to navigate in the University of Trás-os-Montes and Alto Douro campus. The GIS platform, together with other modules of the SmartVision system prototype, provides information to blind users, assisting their navigation and giving alerts of nearby points-of-interest or obstacles. Together with the GIS platform, this paper also describes the handling of accessibility information by the SmartVision prototype, namely the Navigation Module, the Computer Vision Module and the Interface Module.

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## 1 Introduction

Historically, human being always moved around exploring new worlds. Maps, mapping technology and orientation instruments always played a key role in the task of providing ways to get from one place to another. In modern daily life people need to move, whether in business or leisure, sightseeing or meeting. Often this is done in familiar environments, but in some cases need to find way in unfamiliar scenarios. In both cases, the recording and availability of geographical data is extremely useful.

As a new and emerging technology in the early 1970s, geographic information systems (GIS) had a profound influence in the capabilities of geographic analysis. These systems marked a turning point in the reinforcement of geography as an explicitly spatial discipline [1]. GIS are now widely accepted as powerful and integrated tools for storing, manipulating, visualizing and analyzing spatial data. GIS software has enabled users to view spatial data in its proper format. As a result, the interpretation of spatial data has become easy and increasingly simple to understand.

Besides all the developments and public acceptance of these technologies, people with disabilities still lack the real benefits that these systems could provide in accessibility oriented applications. For example, visual information is the basis for most navigational tasks and visually impaired individuals are at disadvantage because appropriate information about the environment is not available [2]. Two low technology aids for blind people are commonly used: the white cane and the guide dog [3]. These two aids are sufficiently functional and have been adopted for many years, but these are also stigmatizing symbols that have always been associated with blindness or visual impairment. Another limitation of their use is that they only give information regarding near objects or obstacles, failing to provide support for orientation/navigation and leaving the blind restricted to navigation in familiar environments. Thus, comes the necessity of developing systems that support the visually impaired in having reliable information at their disposal, so they can move around without any constraints or difficulties.

With current technology it is already possible to create systems that assist people to navigate, eliminating many of their mobility restrictions [4, 5]. The availability of GIS via Web is becoming a reality in many fields [6]. GIS and the Web are ever-evolving technologies and hold great potential for public use, allowing wider involvement in environmental decision-making. To build a successful Web GIS, it is necessary to consider the development more as a process, rather than a step. The implementation should also respect the available technology and the application requirements [7].

This paper proposes the creation of a Geographic Information System in order to assist the navigation of people with disabilities, namely blind users. First, the main project behind this initiative, the SmartVision Project, and the Geographic Information System of the University of Trás-os-Montes and Alto Douro as the GIS platform will be described. Then, the handling of accessibility information by the SmartVision prototype will be covered, namely the Navigation Module, the Computer Vision Module and the Interface Module. Finally, some considerations about future work and conclusions about the work done so far will be made.

## 2 SmartVision architecture

Currently, a system to assist the navigation of blind or visually impaired people is 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 regarding obstacles and various points-of-interest (POI) like zebra-crossings, building entrances, etc. The system is built in a modular structure, as seen in Fig. 1.

The SmartVision Module is responsible for managing and establishing communication between all 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. Radio frequency identification (RFID) and Computer Vision are common to both indoor and outdoor environments and work by detecting 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.

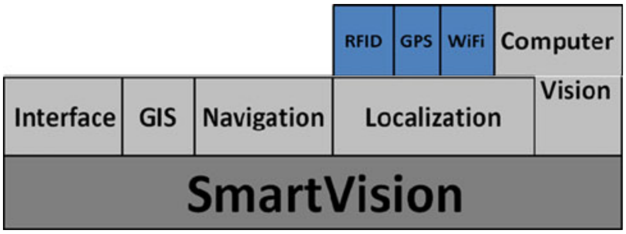

**Fig. 1** SmartVision prototype modular structure

The Navigation Module is responsible for route planning and providing information about surrounding 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 give the best instructions to the blind user.

The Computer Vision Module provides orientation instructions by detecting known landmarks in the ground and keeping the user within safe routes [8]. The camera used was the Bumblebee2 Stereo Camera, from Point Grey. Being a stereo vision system, this camera is able to provide disparity information together with the image frames. This information is used to calculate the distance between the user and detected landmarks. So, in addition to giving orientation instructions to the SmartVision Module, with this information, the Computer Vision Module is also able to feed the Location Module with location information.

Finally, the Interface Module, as the name indicates, is responsible for providing user interface. To do this it uses three resources: two outputs and one input. The two outputs are text–speech software and vibration actuators. Since the hearing sense is very important to blind user, the vibration actuators are used while navigating and the voice interface is used only when navigating the menus and giving POI information. The user provides inputs by using a small four-button device to scroll between the menus, applying the options and getting back to the previous menus.

The user interacts directly with the SmartVision 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.

This section focuses on the GIS Platform, Navigation module and Interface module. These modules will be explained in detail in the next sections.

## 3 GIS platform

This section explains how the GIS Server was developed and how it interacts with the client applications.

Given that GPS and Wi-Fi are only available in some specific spaces, all information need to navigate must be stored in the SmartVision prototype. This way it is possible to have access to information whatever the scenario, indoor or outdoor, without the need to be regularly querying the GIS. The updates to the geographic information stored in the prototype are done when Internet connection is available, through the use of web services.

The information of the different elements is stored in digital map files, or shape files [9], and a MySQL database (e.g., number of available places in car park). For the distribution of geographic information, the adopted architecture was client/server, 3-tier or *n*-tier [10]. In this model, the client application (SmartVision prototype) must have the ability to handle and give geographic information to the user. Figure 2 presents a summary of the client/server architecture.

In this type of structure, the SmartVision prototype receives requests from the user through the Interface module and makes a request to the GIS. The request is acknowledged by the Web server, which forwards it to the GIS server. The GIS server interprets the request and calls the spatial data stored in the digital map files (shape files) and database to generate the data to be returned. The generated data is divided into two groups: the digital map files and a XML file containing the results of the query made to the database. The Web Server accesses the generated data and returns it to the client, via a web service.

To improve the server's security, the GIS Server and database server are protected from external access by a firewall. A web application is also available to allow managing the geographic information stored in the server. A simplified scheme of the overall architecture is presented in Fig. 3, following the 3-tier model.

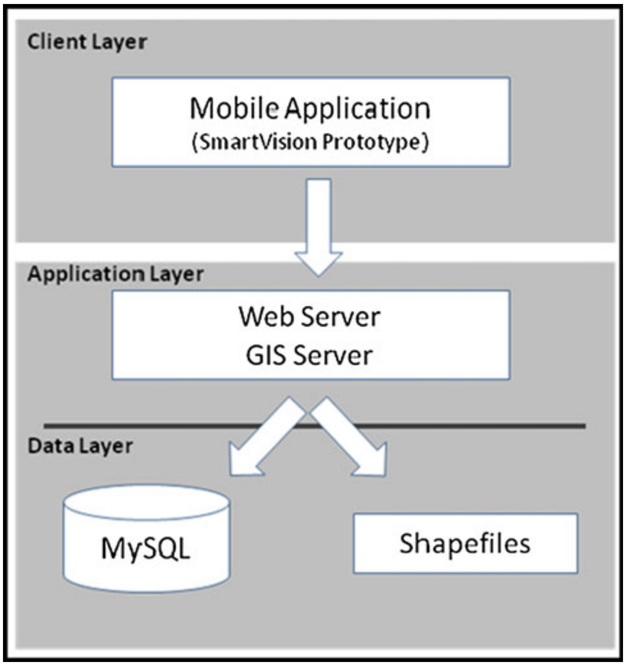

**Fig. 2** Three-tier client/server architecture

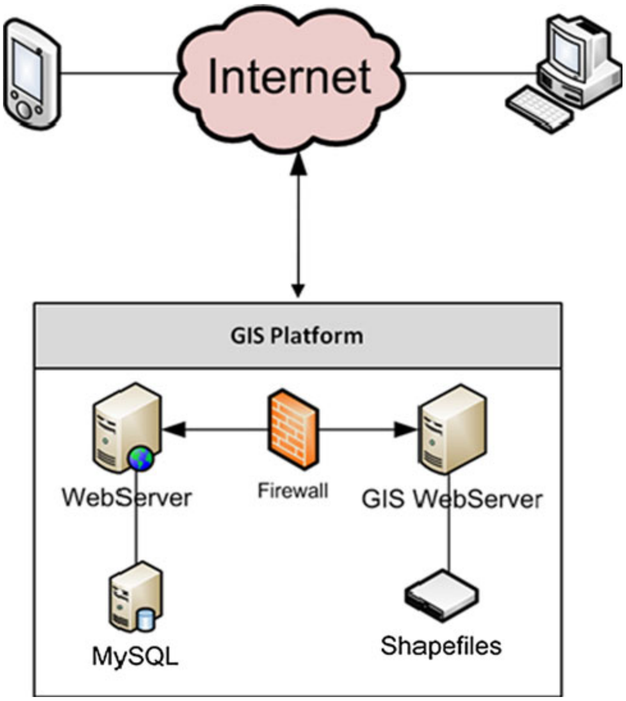

**Fig. 3** Overall architecture

Since the SmartVision prototype has support for indoor and outdoor navigation, the GIS server must store details of campus and building interiors, due to the abstraction created by the Location module. The features already mapped (outdoor) are:

| | | | | | |
|---|---|---|---|---|---|
| Roads | Buildings | Access roads | BUS stops | Car parking | Road signs |
| Crosswalks | Number of parking places | Green zones | Sport facilities | Web access facilities | |

In the case of UTAD Campus (outside of buildings), the conclusion was that the geocoding should be done manually, using an aerial view. However, this can pose some problems in getting coordinates of some specific points, due to photo resolution. GPS may be used to fix those points [11].

## 4 Navigation module

The Navigation module handles aspects related to the computation of the route that the blind user must follow from its original position to the chosen destiny. In terms of functionality, every point-of-interest (POI) in the database is transmitted to the user through the Interface module, in order to choose the desired one. Then, the operations that follow are implemented using a known routing algorithm, the Dijkstra shortest path first (SPF) routing algorithm. According to Ertl [12], this algorithm is known for being able to calculate, in a graph, the shortest path from a starting vertex to a destination vertex. The reason for using this algorithm was that, in this kind of application it provides a balanced solution between calculus efficiency and implementation simplicity. Obviously, the road layer in the map is built in a manner similar to a graph, where the points of beginning, intersection and end of the road correspond to the graph vertices and the intermediate points are the graph's edges, allowing the applicability of the algorithm to this layer. Figure 4 shows the result of the application of the algorithm to trace a route. The starting point for this calculation is obtained from the Location Module and the end point is the one chosen by the user from the POI list. Although, the blind user doesn't take advantage of the graphical interface, it is used to support development and testing.

One must note that the navigation module is the part of the system responsible for assuring that the blind user gets to his destination with the assistance of indications provided by the interface module.

At the moment, the navigation module is undergoing an improvement process, which, after the algorithm application, subdivides the route into intermediate points, using a tolerance margin to guarantee that the user gets to each point. Between two consecutive points, the algorithm tries to anticipate the movement of the user in relation to the next point, correcting the trajectory with relevant instructions. In other words, if the navigation line that the user is taking starts going out of the tolerance radius for the next route point, the navigation module sends an alert to the SmartVision module, which in turn sends an alert to the

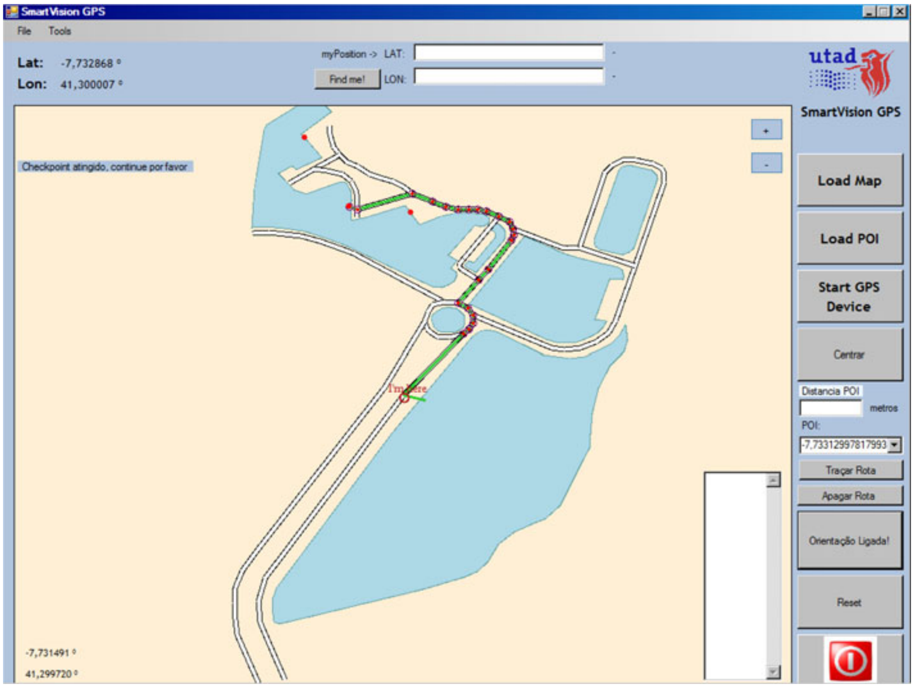

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**Fig. 4** Results of the application of the Dijkstra SPF algorithm

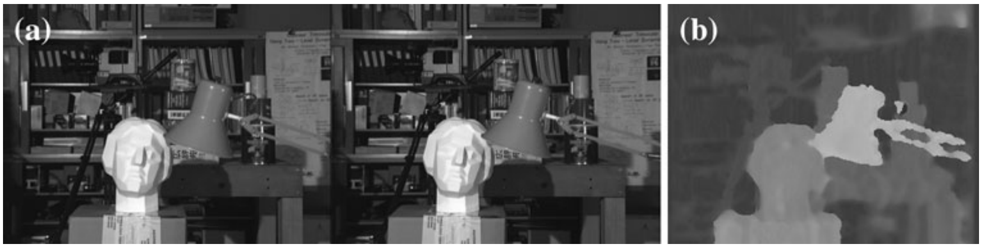

**Fig. 5** **a** Two different views of the same scene and **b** corresponding disparity map

Interface module, with the intention of correcting the trajectory of the user by the required amount of degrees to the left or right. This operation is repeated until the user gets to the desired destination.

## 5 Computer vision module

Image data can assume different forms, but typically stands as a 2-D representation of the original 3-D world. Therefore, the depth information is usually lost. Some techniques have been developed to recover the depth information after image capture, namely, stereo vision, analysis of movement, shading and texture gradient.

With two cameras it is possible to generate images suitable to extract both the position and distance of objects according to their relative brightness. These images are known as depth maps. Finding a perfect disparity map is impossible in the general case, because many points that appear in one image may not appear in the other for various reasons such as occlusions, reflections, or poor texture. Although, this process increases the computation time, it greatly decreases the information disorder in the image, as well as the chance of information overload to the user [13].

Figure 5a represents two images of the same area acquired simultaneously by a stereo vision system. The images look similar however, they have a small displacement. Based on that displacement, the system is capable of determining the distance of the objects present in the scene to the cameras.

Distance is inversely proportional to disparity. So, as seen in Fig. 5b, pixels with higher intensity values (brighter) represent objects closer to the cameras and lower intensity values (darker) represent objects far from the cameras.

The stereo vision system used in this work is the 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 12 cm, and a C/C++ Software Development Kit [PGR 2003], 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 Fly Capture SDK was used for image capture and camera control. The image size used in this work is 512 × 384 pixels. For the calculation of the disparity and the correction of the images, the Triclops SDK is used. Both this SDKs are provided together with the Bumblebee 2 stereo vision system.

Since the main objective of this work is to provide navigation assistance to blind people, the vision system must be able to detect relevant features in the scene and help the user to keep safe courses, like street walks or zebra-crossings. To achieve this, these features must have specific and constant characteristics that help the system to detect the correct path to be taken and provide corrective indications to the user in cases where he starts getting out of course. To simplify the feature detection in the captured scene, it was decided to use white circular markers in the ground representing safe paths that must be followed by the user. Due to the size of the captured image different radius of the circle were experimented, and the chosen radius was 15 cm, as seen in the last image of Fig. 6.

The image processing underwent the following steps: preprocessing, circle detection, calculation of the correction angle and, finally, output of correction instructions to the blind user.

### 5.1 Preprocessing

Since feature detection algorithms, in most cases, have several recursive and/or cyclic steps, unwanted elements in the image may cause performance drawbacks. So, before applying feature detection algorithms, preprocessing is made to select a region of interest, enhancing the performance of the system and guaranteeing that the information extracted is reliable. Another measure taken to increase performance was not to analyze all the pixels in the image, but only a portion of the image closer to the user. Figure 7 shows the preprocessing sequence applied to a captured image.

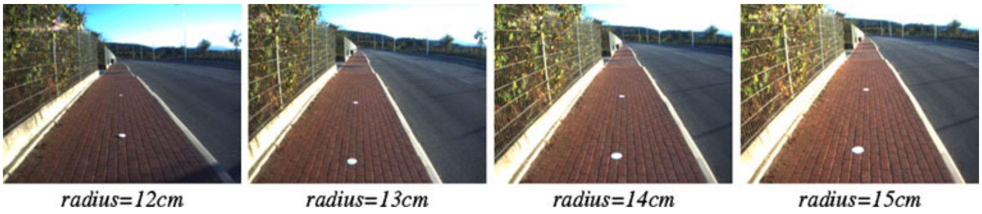

**Fig. 6** Examples of acquired images, containing *circles* of different radius

**Fig. 7** Preprocessing applied to the captured *images*: crop, binarization and edge detection

The color of the circles present in the ground is white so, after capturing the images, the circles are separated from the background through binarization. This reduces the amount of irrelevant information present in the image. After this process, a canny edge detection filter is applied. This procedure maintains the geometric information in the image, while discarding all the unneeded and redundant information.

## 5.2 Circle detection

Finding geometric features in images is a common task in a large number of image processing applications. Several algorithms have been developed to detect the presence of features with specific characteristics. In the case of circles, Hough Transform for circle detection (HCT) is a very robust and reliable method of achieving this goal [14].

A circle with radius $R$ and center $(a, b)$ can be described by the following parametric equations:

$$x = a + R \cdot \cos(\theta) \quad (1)$$

$$y = b + R \cdot \cos(\theta) \quad (2)$$

When the angle $\theta$ sweeps through the full 360° range, the points $(x, y)$ trace the perimeter of a circle. If an image contains many points, some of which fall on perimeters of circles, then the job of the search program is to find parameter triplets $(a, b, R)$ to describe each circle. If the circles present in the image are of known radius $R$, then the search can be reduced to 2-D. The problem is simplified to find the $(a, b)$ coordinates of the centers. The locus of $(a, b)$ points in the parameter space fall on a circle of radius R centered at $(x, y)$. The true center point will be common to all parameter circles, and can be found with a Hough accumulation array.

Figure 8 presents the results (detected circle and accumulation array) of the application of the HCT algorithm by the Computer Vision Module.

From the circles detected in the image, the blind user must go in the direction of the nearest circle. This ensures that the user will not get out of course.

In this system, the cameras are chest-mounted and, by being so, the user is not present in the image. Assuming that the user position is located in the center of the bottom line of the image and knowing the coordinates of both the user $(x_u, y_u)$ and the destination landmark $(x_c, y_c)$, it is possible to calculate the correction angle ($\alpha$) that the blind user must use to correct the trajectory. This is done by simple a geometric analysis, expressed by the following equations:

$$m = \frac{(y_c - y_u)}{(x_c - x_u)} \quad (3)$$

$$\theta = \tan^{-1}(m) \quad (4)$$

$$\alpha = 90 - \theta \quad (5)$$

The first step is to calculate the slope ($m$ value) of the straight line that connects the user to the destination landmark using Eq. 3. Then, from that slope value, the angle $\theta$ of the trajectory that the user must take is calculated, as defined in Eq. 4. The resulting angle must be in the interval between 0 and 180°. The correction angle, which represents the final indication to be given to the user, is found just by subtracting the trajectory angle from the

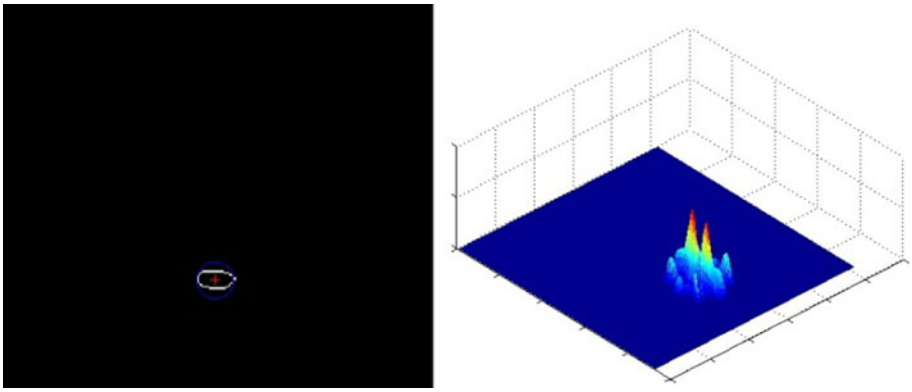

**Fig. 8** Results of the HCT

normal vector that represents the current camera heading angle, as defined in Eq. 5. In the specific case of the example presented in Fig. 8, the correction angle calculated is 7.5481°. Safe navigation is achieved by keeping this correction value under a defined, or definable, threshold.

### 5.3 Output instructions

Rather than providing correction indications in absolute values, more difficult to be understood by users without sight, the outputs are given according to angle intervals, left and right. Thus, for a specific correction angle value, an indication of whether this is a high or low value is given to the user. If this value is under a small threshold value, no indication is made at all. The correction indications fall under three categories, as follows:

- from 0 to 10°: no correction is needed;
- from 11 to 30°: small correction is needed;
- from 31 to 90°: large correction is needed;

This is done to simplify the outputs given to the user and, at the same time, prevent information overload. Respecting the architecture defined in the SmartVision system, represented in Fig. 1, this corrective information is sent to the user via the Interface Module, specifically the haptic devices (vibration actuators).

## 6 User interface

When developing a navigation interface for visual impaired users, one must consider that it has to be intuitive and easy to use, as it replaces the partial or total lost of sight [15, 16]. This kind of interface can be established through touch and/or hearing. In what concerns verbal aids, they have been widely used to provide information to blind users, and some rules and specifications have already been defined to allow functional implementations [17, 18].

In the SmartVision prototype, the interface between user and system is made using voice, vibration and a 4 push-buttons device, which is still under development. Each interface has a specific use. The voice module is used to guide the user with short information, or longer information when intentionally requested by the user. The vibration module is used, for example, when simple instructions, like "turn left" or "turn right", are needed. The pushbuttons device will work as an interface between the blind user and the SmartVision prototype. For instance, it is possible to ask for detailed information about the surrounding environment. If available, this information will be sent through the voice module.

The voice module in SmartVision was created as a dynamic link library (DLL) that uses the Microsoft speech synthesizer API. This DLL is loaded by the system's main module and provides the methods to select the voice, volume, pitch and output device.

The Microsoft API was used due to the wide range of voices in several languages available in the market that allow integration with this API. It is important to mention that these voices are made to sound as real as possible, which helps the visual impaired person to get adapted. Another important point is related to the fact that this API is already integrated in all Windows operating systems, since Windows 98.

In order to synthesize a text block, two different methods are available. In the first method, the text to be processed is directly sent to the module and synthesized, while in the second method a XML (*eXtensible Markup Language*) file is used. This file is structured in order to be able to return the text that will be processed, by selecting the respective language and identifier. It is important to refer that the language of both the voice and the text must match. The main advantage of this method is related to the fact that all information needed to inform and guide the blind is previously structured, saved and can be set in several languages, but it requires a pre-compilation of all the text blocks.

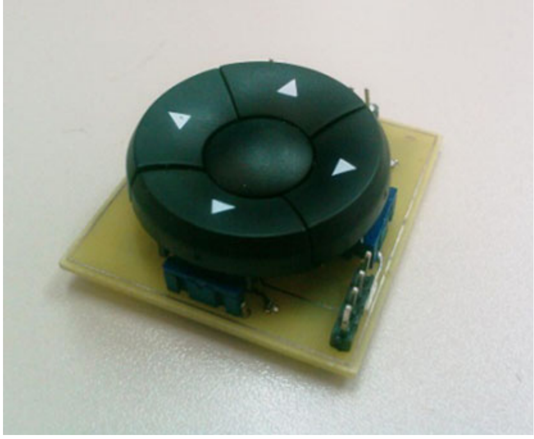

**Fig. 9** Pushbuttons interface

In spite of providing all necessary information for blind guidance, the audio interface communication is established only one way, between SmartVision and the blind user, not allowing the information to be requested by the user. To solve this problem, the interface with 4 pushbuttons was developed (Fig. 9). It enables the user to navigate in the system and to request information about some buildings or zones. To connect the buttons to the computer where the other SmartVision modules are being executed, a convertor that emulates a RS232 port through an USB interface was used. This way, the DLL is programed using the simplicity of the *RS232* protocol and the availability of the USB ports.

Regarding vibration modules, in the market there are some haptic devices for various purposes, which include assistive technologies. However, concerning blind people's spatial guiding, there is a lot to be done. Therefore, the vibration interface emerged as an alternative because it can guide the blind person without requesting any other sensorial systems. This kind of system uses one or more vibrators, which are permanently attached to the person's body and use vibration for guidance both in open or closed spaces.

The success of this kind of system depends on two very important aspects. The first one is related to the location and quantity of vibrators. They must be placed in a zone of the body where they do not interfere with the person's mobility and there must be at least two vibrators. This way the system is able to provide forward, backward, left, right and stop instructions. The sensors are usually located in the upper part of the body or in the arms, but there are some studies that suggest that they should be located in the feet [19]. The second aspect focuses on the way navigation is performed. It is therefore necessary to previously define which signals are to be sent by the vibrators and what is the meaning of each signal. The signals to be sent depend on the number of vibrators. The smaller the quantity of available vibrators, the more complex the vibration encoding will be.

This type of interfaces is very useful, since it allows the blind person to receive help from an external source without compromising any other senses, thus increasing the perception of the surrounding world.

## 7 Conclusions

One of the modules that have been proving to be very important in the task of giving information to the blind users is the GIS module. If the area to be covered is described in detail, it is possible to give information to the user better and more easily. On one hand, it is possible to provide proximity information, like a street light or a zebra-crossing in the vicinity. On the other hand, it is also possible to give information regarding more general features, like the surrounding buildings and services. The GIS of the UTAD campus has been successfully developed and it is now in a consolidation stage and loading of new information layers. The GIS module already feeds the Navigation Module with information relative to the UTAD campus, giving the possibility of finding routes and guiding the blind to the chosen destiny.

Regarding the computer vision module, with the use of circular landmarks there is no need to take into account rotation problems caused by the different viewing angles. In addition, since the area analyzed in the images is the portion closer to the user, circle deformation caused by perspective and lens distortion was reduced, while, increasing performance. With this specifications and the use of the robust HCT, the system has proven to be able to detect the defined landmarks and provide valid and simple instructions to the blind user, thus assisting navigation in a nonintrusive manner.

At the moment, the disparity information (depth maps) is not yet being used to provide distance information together with the correction indications. Since each pixel of the depth map represents the distance of the user to the objects in the corresponding pixel of the captured image, adding the distance information to the correction outputs is a close step.

The interface module is divided in three parts: audio, vibration and pushbutton device. The audio interface is now fully set and working, while the vibration and pushbutton interfaces are still in the development and test stage. The tests made to this module are encouraging, although demonstrating that the audio interface has better performance when playing messages requested by the user.

The SmartVision prototype is also composed by other modules, as seen in Sect. 2, 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.

In the future, a standalone prototype to assist the navigation of blind people will be implemented in the UTAD campus.

**Acknowledgments** This research was supported by the Portuguese Foundation for Science and Technology (FCT) through the projects PTDC/EIA/73633/2006 and RIPD/ADA/109690/2009.

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