Expert Systems with Applications 41 (2014) 7210–7222

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Accessible smartphones for blind users: A case study for a wayfinding system

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ARTICLE INFO

Article history:
Available online 2 June 2014

Keywords:
Accessibility
Visually impaired users
User interfaces
Touch screens
Wayfinding

ABSTRACT

While progress on assistive technologies have been made, some blind users still face several problems opening and using basic functionalities when interacting with touch interfaces. Sometimes, people with visual impairments may also have problems navigating autonomously, without personal assistance, especially in unknown environments. This paper presents a complete solution to manage the basic functions of a smartphone and to guide users using a wayfinding application. This way, a blind user could go to work from his home in an autonomous way using an adaptable wayfinding application on his smartphone. The wayfinding application combines text, map, auditory and tactile feedback for providing the information. Eighteen visually impaired users tested the application. Preliminary results from this study show that blind people and limited vision users can effectively use the wayfinding application without help. The evaluation also confirms the usefulness of extending the vibration feedback to convey distance information as well as directional information. The validation was successful for iOS and Android devices.

1. Introduction

The use of mobile technologies has increased in the last years. As mobile battery life and capabilities of phones continue to grow, there are supporting increasingly complex applications that leverage information about wayfinding functionalities. This kind of service should be adapted to the environment with high levels of heterogeneity (network topology, physical connections, objects, devices, and user preferences). Moreover, the accessibility and mobility are key issues in this kind of scenario (Martín, Haya, & Carro, 2013). Disabled people may be a significant market segment for the tourism industry. However, many tourism sites are not well suited to serve disabled tourists (Chang, Tsai, & Wang, 2008; Manduchi, 2012). This heterogeneity should be constantly recomputed and adapted, especially using wayfinding system. For this purpose, ubiquitous computing has emerged, which, according to Mark Weiser, can be described as "*by making many computers available through the physical environment, while making them effectively invisible to the user*" (Lee, Lim, & Kim, 2009; Weiser, 1993).

In this paper, we focus on wayfinding systems for visually impaired users. Sometimes people with visual impairments have difficulties navigating freely and without personal assistance in unknown environments. In many cases, blind users lack much of the information needed for planning routes around obstacles and hazards and have little information about distant landmarks, the direction they are heading and the distance that remains between them and their destination. This kind of information is essential when they are traveling through unfamiliar environments with a basis of maps and verbal directions.

Over the last decade, considerable efforts have been made to solve these issues in different wayfinding systems for disability users. There is also recent research showing how to make use of non-visual feedback (Jones et al., 2008; Magnusson, Rassmus-Gröhn, & Breidegard, 2009; McGookin, Brewster, & Priego, 2009; Robinson, Eslambolchilar, & Jones, 2009; Williamson et al., 2010). At the present work, we will show a universal solution that visually impaired users can use.

1.1. Related work

With the success of smartphones, navigation systems for pedestrians have reached the end consumer market. One of the typical navigation applications is a map-based system showing the current position of the user. Optionally, the route to the destination

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http://dx.doi.org/10.1016/j.eswa.2014.05.031
0957-4174/

is displayed on the map. Other navigation applications offer audio feedback for guiding to users. Some projects related to context-aware and wayfinding mobile applications use multimedia technologies in the fields of cultural organizations for interactive tourism (Lehn & Heath, 2003; Rodriguez-Sanchez, Martinez-Romo, Borromeo, & Hernandez-Tamames, 2013; Wilson, 2004; Woodruff, Aoki, Hurst, & Szymanski, 2004) oriented to people without disabilities. Mobidenk (Baldzer et al., 2004), O', Lola (Michlmayr, 2002), CRUMPET (Poslad et al., 2001) and GUIDE (Cheverst, Davies, Mitchell, Friday, & Efstratiou, 2000) provide information delivery services for a far more heterogeneous tourist population. They use location, device, network and user context properties. Most of them use GPS and Web Services for outdoor location. Additionally, previous solutions require a permanent network connection to receive information, thus taking a longer response time. To minimize user waiting and enable affordable usage, the access to content and services should not require constant network connection.

A wayfinding application consists of two very different functions: sensing of the immediate environment for obstacles and hazards and navigating to remote destinations beyond the immediately perceptible environment (Allen, 1999; Golledge, 1999; Kettani & Moulin, 1999; Timpf, Volta, Pollock, & Egenhofer, 1992). The research of several groups is focused on the use of special tactile displays for wayfinding systems (Pielot & Boll, 2009, 2010). PocketNavigator (Pielot, Poppinga, & Boll, 2010) is a simple map-based navigation system only for Android phones. The route is drawn on the map and the next waypoint is highlighted. Once the route has entered, the user can walk with the device in his pocket. This system employs the built-in vibration motors of the smartphone. However, the interface could be less available to the wider public. Another works present investigations into pedestrian's routing behaviors within outdoor and indoor environments (Liu et al., 2014; Nasir, Lim, Nahavandi, & Creighton, 2014). In Nasir et al. (2014), the main contribution is the formulation of an appropriate utility function that allows an effective application of dynamic programming to predict a series of consecutive waypoints only within indoor environments. However, the usability is not valid for outdoor environment and the accessibility criterion for this study is not applied. Most systems do not research about personalized routes for different purposes and accessibility paths with information related to physical references.

When a blind user walks around a city, she usually needs physical references and information about the environment. Other systems have been devised using sound as guidance. Early attempts were the Audio GPS (Holland, Morse, & Gedenryd, 2002), Personal Guidance System (Loomis, Reginald Golledge, & Roberta Klatzky, 2001) and Soundcrumbs (Magnusson et al., 2009), which use headphones. The Swan project (Wilson, Walker, Lindsay, Cambias, & Dellaert, 2007) gives auditory feedback related to routes and context for visually impaired users. The OnTrack project (Jones et al., 2008) uses 3D audio and music to guide the user. However, these examples present some problems. Most systems use a computer with a GIS system to provide a guidance service using audio channel. An example of guidance for blind users is provided in Spindler et al. (2012). On one hand, this kind of solution is not scalable and not portable. On the other hand, when the user is in a noisy environment, the use of the audio channel could require wearing headphones. However, in many instances this would be not recommended. For example, not hearing the honking of a horn would be dangerous, when a user is crossing at a pedestrian crossing. This could be a problem for visually impaired users because it could cut off the user's environment, which could disturb bystanders. PointNav (Magnusson, Molina, Rassmus-Gröhn, & Szymczak, 2010) describes a wayfinding application for a specific environment like a park. The system combines functionalities of Pocket Navigator project, vibration functionality and augmented reality scanning. However, the accuracy of location and guidance for this solution is not enough. Also, the user only can choose a close destination. A wayfinding application could allow the user to choose different points of interest in an environment, a city, a university, etc. For example, a user who would want to go from the subway to a museum, could need to walk a long distance. In the context of elderly people there are some examples such as where a platform can guide and assist using multisensory monitoring and inteligent assistance (Costa, Castillo, Novais, Fernández-Caballero, & Simoes, 2012). However, this work is only for home environment.

While progress on assistive technologies have been made, some blind users still face several problems opening and using basic functionalities when interacting with touch interfaces. For instance, there are problems opening an application in some platforms for blind users. The majority of their interfaces do not have a universal and intuitive design. Although there are some touch screens with accessibility features, some blind users may have problems using their mobile phone to search a contact, to make a call, or to write and send text a message. According to Oliveira, Guerreiro, Nicolau, Jorge, and Gonçalves (2011), "*current mobile devices force users to conform to inflexible interfaces, despite their wide range of capabilities*". Both the blind community and technology manufacturers are still working in progress on improving touch screen interfaces and functionalities. In Burzagli, Emiliani, and Gabbanini (2009), Chen, Yang, and Zhang (2010), present the importance of content adaptation based on user preferences and their context. Burzagli et al. shows a platform that makes it possible to build service, that are accessible from anywhere and at anytime. Although this study is only oriented for characteristics implemented in the web site, all principles can be used for a wide range of mobile and wired communication devices.

Due to the fact that most user interface designers are usually people without disabilities, they have a limited understanding of how blind people experience technology. It is important that designers better understand how blind people actually use touch screens (Kane, Wobbrock, & Ladner, 2011). Furthermore, a designer who wishes to provide motions in their application must consider whether the gestures will be appropriate for blind users or not. Although people with disabilities may use the same hardware as their peers, it is possible that they prefer to use different gestures, or that they will perform the same gestures differently than a user without disabilities (Tinwala & MacKenzie, 2010). A context evaluation of an audio-tactile interactive tourist guide is reported by Szymczak, Rassmus-Gröhn, Magnusson, and Hedvall (2012). This project allows blind people to be guided along a historical trail and experience sounds from the past. However, the applications reproduce the information using a sound file. The problem is that this solution is not scalable and dynamic.

Several design approaches have highlighted this issue in order to offer users better and more adequate interfaces (Oliveira et al., 2011). The user interface needs to be adapted to those conditions to meet the accessibility requirements, multimodal functionalities in different situations (Heuten & Klante, 2005). Some projects proposed new input and output methods (Bonner, Brudvik, Abowd, & Edwards, 2010; Guerreiro, Lagoa, Nicolau, Gonalves, & Jorge, 2008; Yfantidis & Evreinov, 2006) to write messages, comments or a contact. The interface layout and letter management can be edited to accommodate the users' textbox based on the user preferences (gesture approach or adapted notes are some examples). In Oliveira et al. (2011), a proposal to identify and quantify the individual attributes that make a difference in a blind user when interacting with a mobile touch screen is presented. In De Oliveira, Bacha, Mnasser, and Abed (2013) present a study about user interface personalization in the development of transportation interactive systems. However, one weaknesses of this proposal is that this mapping requires a deep knowledge of the application domain in order to choose which concept should be mapped. Besides, the parameters for interface and for mobility issues related people with sensorial and cognitive impairments are not included.

Most of these previous studies are only focused on the phone capabilities for text entry. One of the major issues is related to text-entry and how to choose a screen element. This is one of the most visually demanding tasks, yet common in numerous mobile applications (text messages, email, contacts, etc.). Other authors propose techniques and rules for accessibility oriented to blind users using touch screens (Kane, Bigham, & Wobbrock, 2008). They concluded that they "*may be used to improve the accessibility of current and future touch screens*". Moreover, in the recent years, several screen reading software in tactile devices such as smartphones (Symbian, iOS, Android, etc.) have emerged. Existing solutions resort to assistive screen reading software to make up for the lack of sight to manage and use the applications installed at the phone. Apple's VoiceOver software or Talkback for Android are successful examples. This software allows exploring the interface layout to users by dragging their finger on the screen while receiving audio feedback. To select the item, the user rests a finger on it and taps with a second finger or alternatively lifts up the first finger and then double-taps anywhere on the screen.

Furthermore, each user could have different capabilities and preferences. Other abilities, as many other individual attributes like age, age of blindness onset, or tactile sensibility are often forgotten. According to Zajicek and Brewster, 82% of blind people are aged 50 or over (Zajicek & Brewster, 2004). The magnitude of this problem increases as the screen contains multiple elements such as icons to execute applications, different horizontal and vertical menus, and so on. Accessible touch screens still present challenges to blind users. Users must be able to learn new touch screen applications quickly and effectively. The cognitive capabilities such as short-term memory, attention and spatial ability should also be meaningful when developing interfaces for the blind. Persad et al. also acknowledge this diversity and propose an analytical evaluation framework based on the Capability-Demand theory, were users' capabilities at sensory, cognitive and motor levels, are matched with products demands (Persad, Langdon, & Clarkson, 2007). More recently, Wobbrock et al. introduced the concept of ability-based design, which is in an effort to create systems that leverage the full range of human potential (Wobbrock, Kane, Gajos, Harada, & Froehlich, 2011). Most of this literature reports only on prototype systems and applications based on specific architectures. USE-IT, a knowledge-based tool for automating the design of interactions at the physical level, so as to ensure accessibility of the target user interface by different user groups, includes people with disabilities (Guerreiro et al., 2008).

1.2. Our approach

Our research is motivated by prior attempts to create accessible touch screen user interfaces and to support guidance applications for blind people, as well as a universal design. The goal is to create an adaptable wayfinding application for smartphones which design will be accessible for all users independently of the age, blindness or preferences of the user. Most wayfinding applications described before present at least one of the following problems: the information is not dynamic, the design is not universal, the interface is not adapted to different users and preferences, blind users need assistance to open the application, the typical screen reader is not applicable, they need to install a special screen reader or the auditory feedback is not enough.

This paper presents a complete accessible solution to guide people using a wayfinding application (both iOS and Android devices). This application is continuously looking for closest waypoints inside the route and it provides the navigational feedback. Routes and information provided about points of interest can be adapted and personalized avoiding obstacles depending on the user needs and providing information about physical helpful references. They can also be provided by Google Maps application as other previous works used before. Furthermore, this approach combines static and dynamic information. Static information is stored in the own smartphone and it is available anytime and anywhere. Therefore, it is not required a permanent network connection. The information stored in the devices could be updated with dynamic information when the network connection is available.

Other important aspect to be considered is that the application is accessible for a huge number of people independently of the users' needs and abilities thanks to the use of different sensory channels (visual, auditory and tactile) for providing information. The Blind-Launcher and the wayfinding application operate in noisy environment to help people with visual impairments regardless of age. For giving information to users with visual impairments, the best combination is both auditory and tactile feedback. When tactile feedback is provided, the application vibrates when the user walks in the suitable direction. Furthermore, if the user is close to the destination, the smartphones vibrates quickly. The guidance process is performed by the combination of DGPS, the compass and the route information. Its accuracy is around 1–3 meters. Additionally, other one that allows managing the basic functionalities of old Android devices without assistance to blind users complements this application.

This application has been evaluated by end-users (blind users and people with limited vision).

The results obtained are also presented in this paper. These results show that a user, independent of age and disability, could use a smartphone (iOS or Android) and the guidance application developed.

2. User interface design for visually impaired users

In the present context, user interface adaptability means that user interfaces can be adapted based on requirements and preferences of different user groups as well as the specifications of a particular development platform. With the goal of creating a universal design, it is important to include users with visual impairments in the design of the system at an early stage (Dix, Finlay, Abowd, & Beale, 2004). The "Program of Support for people with Disabilities" of Universidad Rey Juan Carlos, ONCE (National Organization for blind people) volunteers of Mostoles (Madrid, Spain) and "Vodafone Spain Foundation I+D" (Spain) collaborated in this stage. Feedback on early interface prototypes provided useful insights into the effectiveness of both the interface and the functionalities.

The first step was to analyze the available screen reading software and its limitations. Voiceover is a screen reading software to navigate among applications, menus and execute actions in Apple devices. However, Android devices do not have similar software that supports accessible interfaces for these devices from version 2.1 to 4.0. The version 4.0 adds accessible functionalities thanks to Talkback but most of the user devices are running under earlier versions. In order to know the limitations of these two options for visually impaired users, we have evaluated both screen reading software with 10 users with screen reading software knowledge (5 blind users and 5 people with limited vision). In this preliminary evaluation, they have been tested with an iPhone and an Android phone during 3 h using the most common functionalities of the smartphones. The most preferred option was Voiceover, selected by 7 users: only 2 people preferred the Talkback. One user specified he did not have a clear preference. Although new Android devices include some accessibility options thanks to Talkback software, it is not enough for visually impaired users. This fact led to our development of an adapted interface for blind users in order to use any Android devices regardless of the version before creating the wayfinding application. With this aim, the first step was to develop an approach called Blind-App Launcher which characteristics are detailed in the next subsection.

2.1. A screen reading software for Android devices – Blind-App Launcher

Based on some rules proposed by Kane et al. (2008), we have developed an adapted blind desktop for Android devices since version 2.1. It allows browsing a menu by performing a series of discrete directional flicks to move the cursor, and selecting a menu item by double tapping on the screen. The Blind-App Launcher combines diverse interaction techniques based on menu browsing through discrete gestures and fixed regions. On one hand, the menu browsing allows navigation through the options through vertical and horizontal movements. For this choice, each item is a full screen option. The user moves the cursor up and down for browsing between the applications installed in his smartphone. On the other hand, when the user interface of the screen is structured in fixed regions, the applications are accessible by touching the screen. Application maps specific regions of the screen to predefined functions, as if the screen were in fact a set of discrete hardware buttons.

Fig. 1 presents an example of using a fixed regions interface. This interface can be split in one to four regions. A region represents an option in the application. Each region is situated around the physical corner of the smartphone for helping blind users to know where they are. When the user chooses one region (an option), the related region is spoken. The user manages the application moving his finger from right to left to advance to the next options. The navigation among windows and choices is based on gestures made from left to right. The functionality is similar to VoiceOver. If the user wants to go back, he can move his finger from left to right. Anther example of an application that uses fixed regions is Mobile Messenger for the Blind (Sánchez & Aguayo, 2007).

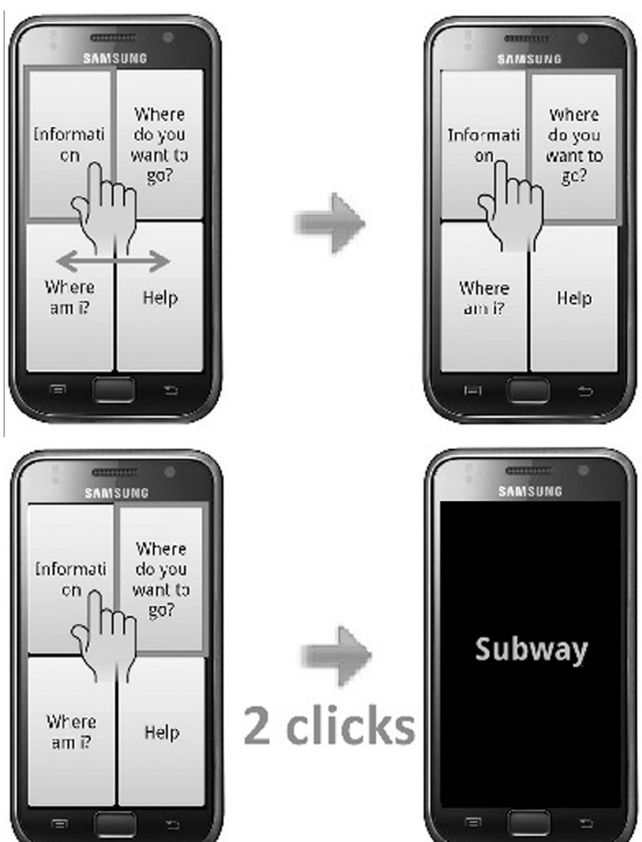

Fig. 1. Example of the Blind-App Launcher using fixed regions in the wayfinding application.

For both interfaces, users can separate the fingers or perform double tap to select the current option. The user continuously receives an auditory feedback about what he is touching. A short vibration is felt as you move from one button to the next. This allows you to feel the borders between the different buttons. If you rest your finger on an option, the speech feedback will provide you with the name of the button. The two kinds of interfaces based on menu browsing and fixed regions were developed to research the most adaptable for visually impaired users when they are using the wayfinding application. All methods provide text-to-speech, vibration and audio feedback for users' interactions.

When this screen software was developed, we evaluated it with final users. In this evaluation, 18 visually impaired users participated. 9 people were blind users and 9 people have impaired vision (10–20%). In this group of participants, there were 11 males and 7 females aged between 20 and 77. The goal of this evaluation is to check the accessibility to the basic functionality of the smartphone using Android devices and the screen reading software developed. First, participants use Android devices to access basic functionalities such as to text a message, call a person and run a specific application, among others. The actions of the users were recorded by direct observation. All the users navigated without difficulties among the applications of the device. The average time spent for the execution of the activities was slightly higher for blind users (10 s more than impaired vision users). In general, when users needed to execute a certain application, blind users had some problems to coordinate their fingers to double tap. 4 blind users have no experience with a smartphone or computer in their daily life. Therefore, they needed to practice the movements allowed previously in order to execute the applications. After 10 attempts, they understood the possible movements.

After testing the access to the basic functionalities of the Android smartphone, users filled a short questionnaire with a five-level Likert scale. The questions are related to the previous and future use of the smartphone in their daily life, if they could use this devices without help in the future, if the interface is easy to use for visually impaired people and if it is easy to know the applications installed on the smartphone, and to execute the menu option for doing basic tasks such as calling or sending messages.

Regarding the use of smartphones before and after the evaluation, 4 blind users of GUP participants did not use a smartphone in the daily activities before. However, after that, all the users want to incorporate these devices into their life. They have realized the advantage of the smartphones in their daily life. In respect to the use of basic functionalities, two blind users would need help when they use the application. Only 7 blind users would be able to use the basic functionalities without help. People with impaired vision would have no problems using the application. Furthermore, all participants agreed or strongly agreed with the ease of use in both devices and they always knew which applications were installed in the devices. Lastly, most of them thought that browsing between the options and executing the basic functionalities were also easy (7 blind people and 8 impaired vision users selected the strongly agree option or agree option).

Once there was a solution of screen reading software for both iOS and Android devices, we started to design and to develop the wayfinding application that is the goal of this work. The details are presented in the next section.

2.2. Design of the wayfinding application

The goal of the wayfinding application is to guide visually impaired people from one place to other providing directional, compass-like information in a universal way. As it will be presented in the following section, this application was tested in a university. The application consists of building's information, location and wayfinding options (see Fig. 2). This interface can be used with typical screen reading software.

The "information" functionality offers news, contents, multimedia files, etc., related to a point of interest. The "location" functionality explains where the user is. If the user is a person with limited vision, he can activate the visual map or he can use magnification software to help better navigate a visual interface. The map follows the criteria of chromatic color scheme for limited vision users. The visual map shows the location of the user and the destination with a highlighted itinerary.

The "wayfinding" functionality consists of a tactile compass and a guide for orientation. In contrast to Magnusson et al. (2010), our application can have information and guidance functionalities related to many interest points of a city, environment, park, university, etc. In contrast to De Oliveira et al. (2013), the information and points of the route for this applications is integrated using the GAT system (Rodriguez-Sanchez et al., 2013). Additionally, we follow a simple information structure and interaction design based on typical screen readers such as VoiceOver. We have included a set of instructions for the navigation functionality. For example, the application guide to the user about how to turn at each crosswalk that is provided by text or by speech. The compass uses an auditory and tactile feedback through audio and vibration phone functionalities. The tactile feedback is used to encode the correct direction of the destination, similar to a compass. This compass functionality is continuously available when the guide mode is activated. Besides providing turning directions, the application presents the information in the display and speaks the direction and distance to the next waypoint.

The wayfinding functionality is presented in the Fig. 3. The user chooses a destination (Point Of Interest – POI). The application calculates the accuracy. The accuracy is an important issue in wayfinding systems due to the fact that precision of GPS is limited to 20 m. However, higher accuracy is afforded by differential correction (DGPS) and sensors of the smartphone, in which correction signals from a GPS receiver at a known fixed location are transmitted by radio link to the mobile device for beginning the guide and orientation service to the next point. Applying DGPS, the accuracy could be around 1–3 m. When the accuracy is between 2 and 3 m, the navigation is ready. The application is continuously looking for the closest waypoints inside the route. In contrast to other solutions, this wayfinding application contains routes that can be adapted and personalized. Most applications only use the generated routes of "Google maps" by default. This application also supports customized routes and the routes provides by "Google maps" in a XML file. This XML file is structured to contain points of interest (and waypoints) with coordinates and destinations, step by step. This information could be managed by the GAT system. For every waypoint in the route, the application informs the user and calculates the distance to the destination point. This information is also stored in the XML file. The application is continuously reading this information to provide instructions to the end-user. The navigational feedback is continuously provided so the user knows

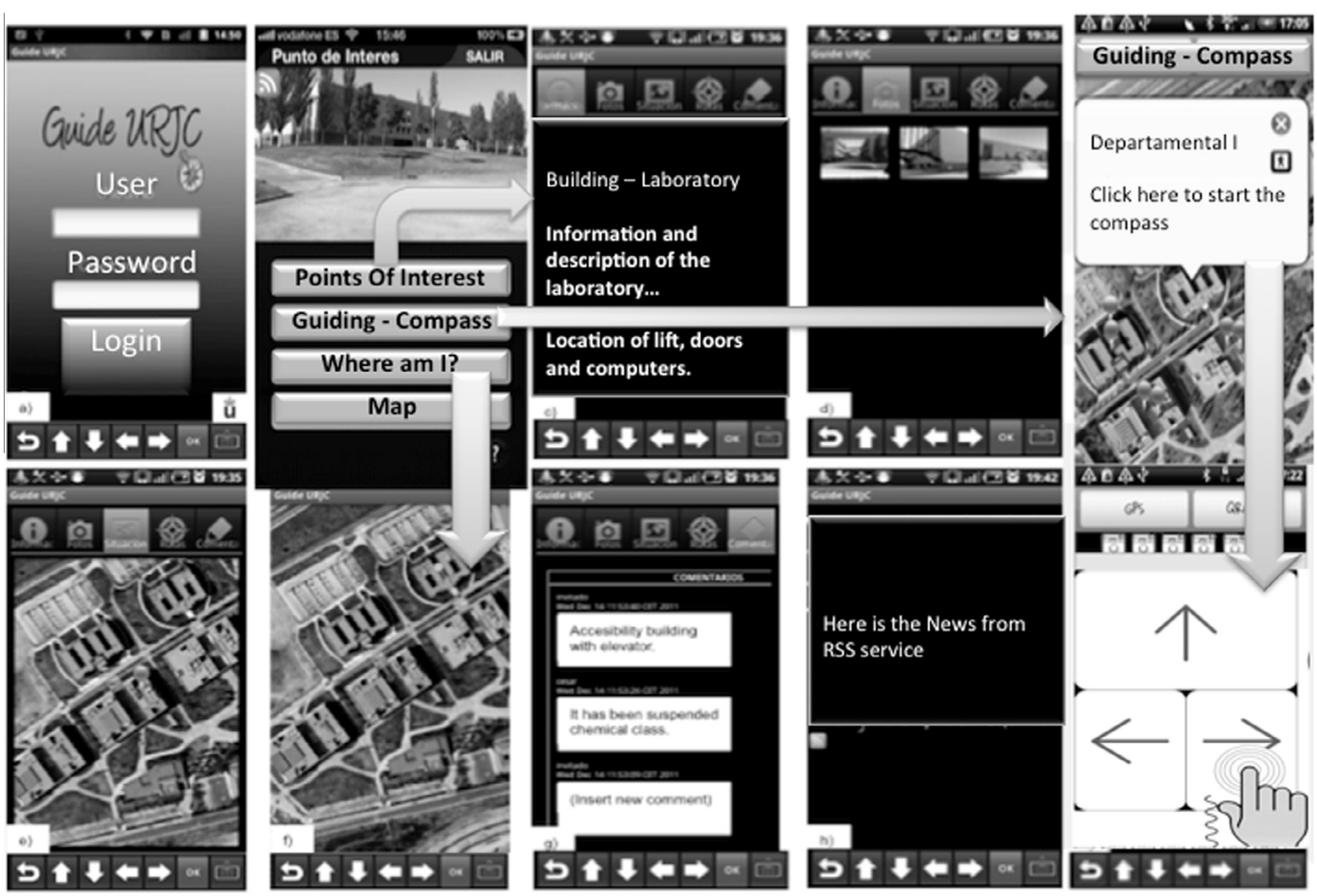

Fig. 2. Design of wayfinding application using a screen reading software.

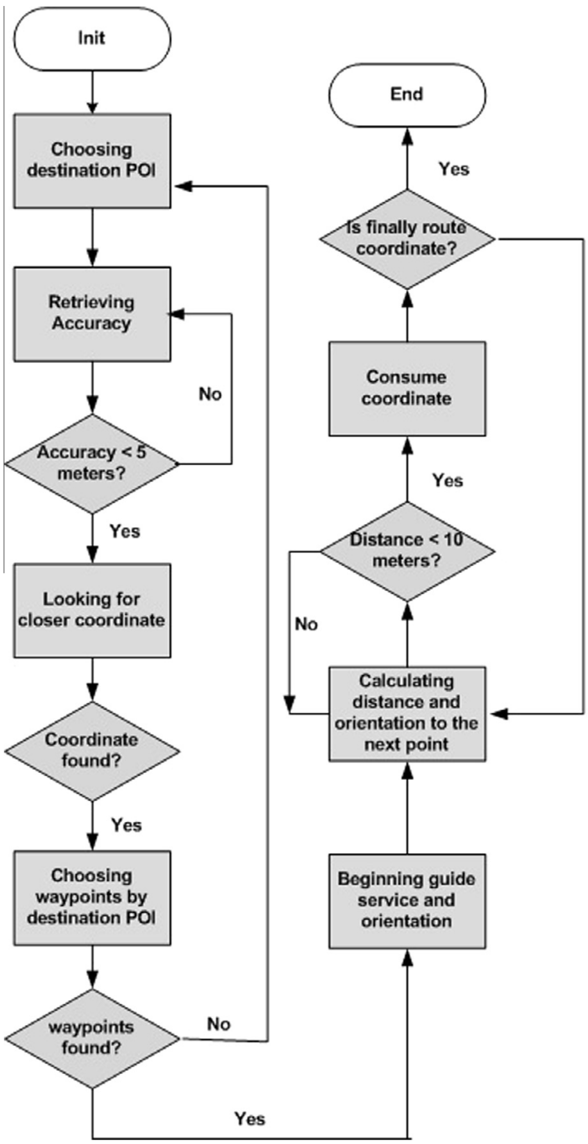

Fig. 3. Location and navigation among waypoints.

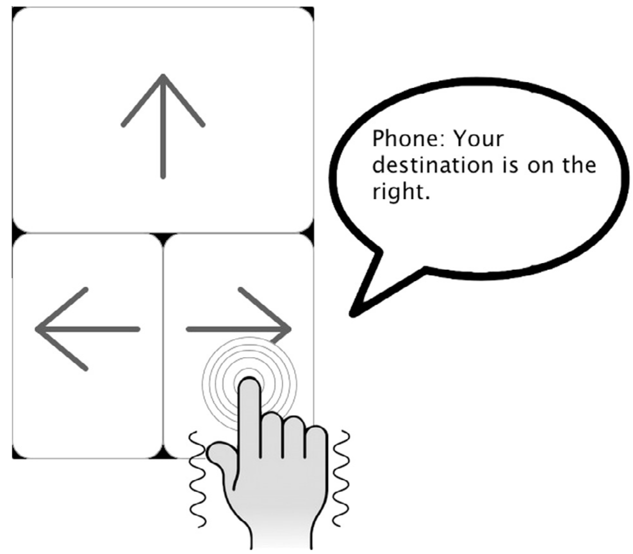

Fig. 4. Compass and fixed regions of the wayfinding application.

the direction to follow. Also, the application only vibrates when the user walks in the suitable direction. Furthermore, when the user is close to the destination, the vibration frequency increases in such way that the smartphone vibrates quickly. The compass and accelerometer method returns a vibration feedback and auditory feedback when the user is in the correct orientation and he is using the wayfinding application.

As Dix et al. states, the information will be provided through more than one mode of interaction for a universal design (Dix et al., 2004). If this application only provided auditory feedback and the user is in a noisy environment, the instructions about the path to follow could be not heard by the user. With the aim to solve this potential issue, the application also uses the compass functionality of the smartphone. Fig. 4 presents an example of the compass-screen. Each region symbolizes a possible direction. A specific region only vibrates according to the destination address. For example, let us suppose that the user is walking to a specific destination. The destination is on the right in 100 m. The phone provides instructions to the user about the direction to follow. However the user does not listen to this information and then, he presses the left region. In this case, the phone will not vibrate because it is not the proper direction. But when the user presses on the right region, the phone will vibrate.

Therefore, the vibration of the smartphone allows users to know the correct orientation. Furthermore, the smartphone vibrates more quickly when the destination is near. On the one hand, when the user is close to the destination, the vibration mode has a pattern that is repeated more times. The advantage of this mode is that the feedback simplifies both the location and the guide. Conversely, if the user is walking in the wrong direction or he is disoriented, the system alerts him by providing a new route to the destination. To get more feedback, the application alerts the user about different points in the route (other buildings, services, physical obstacles, benches, litter baskets, etc.) Therefore, the user receives constant feedback related to the best way for reaching the destination.

In summary, the application combines GPS, AGPS (Assisted GPS), compass and accelerometer in order to guide the user among different points of interest and to provide the suitable feedback according to the user's orientation. The tactile and auditory functionality improve the feedback provided to the user. The accuracy measurement is between 1 and 3 m.

Moreover, this application was designed to minimize the hesitance of the user and to enable an affordable usage. A constant network connection is unnecessary to access the content and services, due to static and dynamic possibilities of the information of the user. The static information is stored in the phone, which can be accessed at anytime and anywhere without network connection. Meanwhile, the dynamic information can be provided and updated by the person in charge for the specific environment. Users of the application can also comment on the points of interest on the route. These comments can be accessed by other users of the application and enriches the information of the environment.

3. Experimental evaluation

With the goal of evaluating the wayfinding application developed, we performed two trials with visually impaired people. Each trial was structured in two sessions: one session for testing the application using Android devices and other for testing the application using iOS devices. At the beginning of the trial, participants were split in two groups. First, half of each group used the Android platform and the other half used the iOS devices. In the next round, they changed the phones. The objective was to test the wayfinding application in both platforms.

One of the key points for these trials is to obtain feedback related to which is the best option when the application provides information to users. For this reason, we have used two ways of providing feedback to validate the navigation functionality. The first one is the "audio and touch screen" mode. In this case, the application guides the users towards a specific destination point only in an auditory form. The orientation is obtained whenever the user presses on the device's screen. The second one is the "auditory, touch screen, and tactile" mode. The application guides the user via audio and vibration functionalities. The screen is split in fixed regions described in the previous section. We chose this interface in order to validate the fixed regions functionality. After the procedure, we asked the participants for their preferences regarding the wayfinding application.

Two months passed between the two trials. In the first trial, participants evaluated the first mode and two months later, they used the second mode. The structure of each trial was the same for both. The following sections describe the devices used, the participants and the methodology in these two trials.

3.1. Platform constraints and participants

We used different smartphones to validate the application: the Samsung Galaxy S and SII, HTC Desire and Motorola Delphi using Android platform. These Android devices have a 4-inch capacitive touch screen with multi-touch support. Furthermore, we also used iPhone 3G, 4G and 4GS although both applications can also be installed in the iPhone 5.

The system has been evaluated in the Rey Juan Carlos University. Seventeen visually impaired people (light perception at most) were recruited from a learning center for visually impaired people from the Spanish organization for blind people (ONCE) and one participant is a blind student from the university.

The participant group was composed of 11 males and 7 females with ages between 20 and 77 (25% within the range of 21–30 years, 50% of 31–50 years and 25% 51–77 years). They were divided in two groups: users with limited vision (10–20%) and blind users. There were 9 users in each group. There were two born blind participants who are expert users on the daily use of smartphones. Four limited vision users had never used a computer or a smartphone with screen reading software, although all users had experience with a mobile phone.

3.2. Procedure

At the beginning of the trials, a short introduction to the smartphones and the case study was provided to the participants. They were seated at a desk in front of a smartphone (Android or iOS). The participants were introduced to these devices, the screen reading software (Voiceover, Talkback and Blind-Launcher) and the wayfinding application.

Once users were familiar with the devices and the screen reading software, they started to test the wayfinding application outside. The goal was to test if the application is easy to use and users can effectively interpret the vibration patterns. The route starts from a student building to the subway stop near the university. When a person without disabilities walks from the starting point to the destination, the first time he can spend 9–10 min for 450 m. The route was designed taking into account the physical references of the walk to help blind people (see Fig. 5). Furthermore, physical obstacles were avoided thanks to the static information from the wayfinding application. The part A of the route has physical references (a sidewalk curb) for blind people that help them when they are using a walking stick and the wayfinding application at the same time. The part B has no physical references between points 1 and 3. Finally, the part C has physical references although the environmental noise is higher owing to the traffic. The point 4 is the subway station and it is located outside of the campus. Users had to complete this route from point 1 to 4 and the other way round.

While participants were using the wayfinding application, observers were taking notes about the success rate for each task and the time to complete the activity. Specifically, the elements observed and recorded are summarized below:

- Selecting wayfinding option from the building entrance to the destination.
- Measure of route points were followed to a destination.
- Time spent from the starting point (building) to the subway.
- Time spent from the subway to the starting point.

When the users finished the activities proposed in the two trials, they completed a usability test in order to evaluate the wayfinding application. The questions were the following:

- Q1. After the training, do you think the wayfinding application software is easy to use for blind users?
- Q2. Is it easy to choose a specific destination?
- Q3. Is it useful that the wayfinding application contains physical references on the route?
- Q4. Is there enough auditory feedback?
- Q5. When the auditory and tactile feedbacks are activated, is the navigation better than when you are using only audio?

We also asked if they often used a smartphone and if after this experience they will use one in their lives.

4. Results

This section presents the results of the case study summarizing the key results. First, the results extracted from direct observation are presented and then we summarize the results obtained from usability tests.

4.1. Direct observation

The wayfinding application has different choices of environment (city, university, etc.). The interface to choose the options for the navigation functionality uses fixed regions. The list items screen is used only to choose the destination waypoint. Blind users had problems understanding that this menu is not a list. They only needed a shorttime longer than limited vision users to understand the use of fixed regions. Apart from that, one limited vision user had problems because the screen reading software had problems due to the presence of sweat on the screen. From this activity, the average time spent was 35 s for blind people and 20 s for limited vision users.

Regarding the navigational activities, all users executed the navigational choice of reaching a destination without problems. At this point all users tested the application for the two feedback modes. The first was the "audio and touch screen", and the second was the "audio, touch screen and tactile" feedback. Regarding the performance of the guidance, the results were similar for both trials since users were able to reach the destination in both cases. The route points from the starting point to destination were reached in most cases. There were only a few problems for blind users due to if they used the physical references sidewalk curbs with the walking stick to follow the indications from navigation system. In the route proposed, only the first part of the route has this type

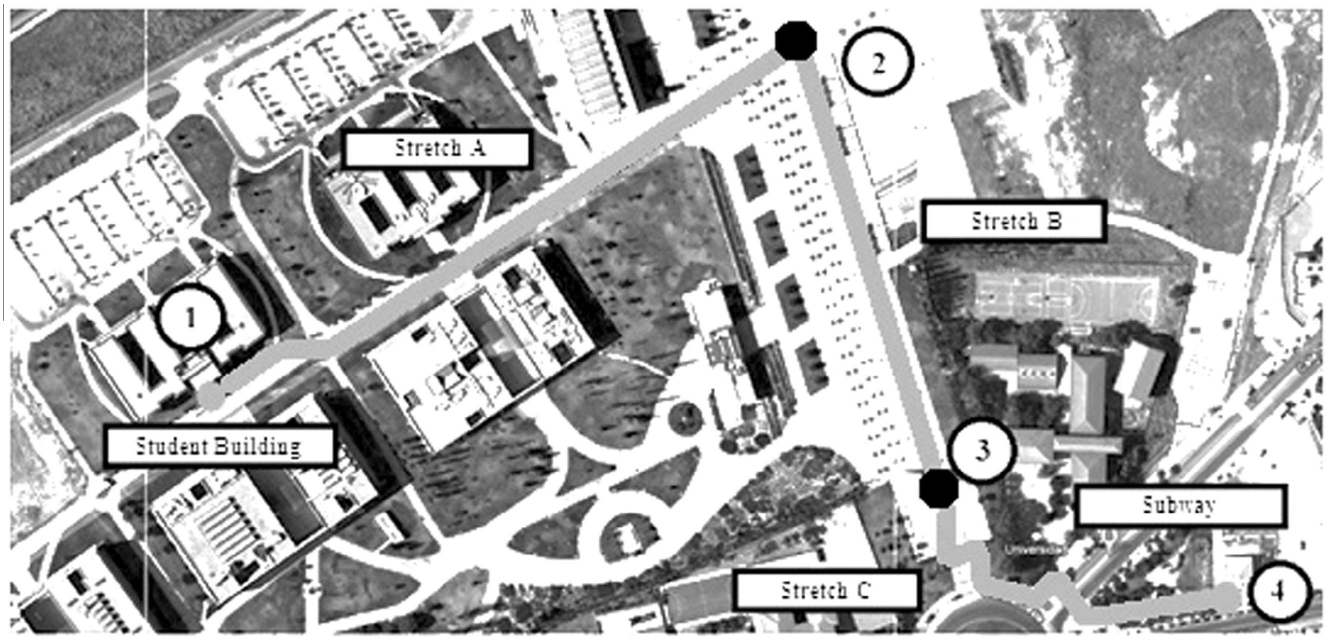

Fig. 5. Picture of the route at the University (430 m).

of references. This fact was a problem for blind users because they diverted from the path but the application helped them to solve this problem. The application provides alarms to the user and it redirects the user to the correct orientation. This lack of physical references was the cause of 29% of the route points that were not followed accordingly. However, limited vision users do not usually need many physical references and they had no problems to reach all the route points.

In the last part of the route, users had several problems using the "audio and touch screen" feedback. Although, this stretch has sidewalk curb and a pedestrian crossing, there was noise from car traffic and many environmental noises. The noise is a problem for both types of users because the indications of the smartphone cannot be heard appropriately. The users need more time to complete this stretch using the first mode. This problem could be solved by wearing headphones. However, many blind people do not like this solution due since their main sensory channel would be occupied by the indications of the mobile devices and they could lose other important information. We have improved this measure time using physical references alerts in the wayfinding application using the second mode based on the vibration of the phone. The user receives auditory and vibration information about physical references in the route among different points without the influence of the noise of the environment. Therefore, this mode is more efficient.

If the time to complete the routes is analyzed, users spent more time in the first route from a building of the campus to the subway station than in the reverse path. For the first mode, blind people and limited vision users spent 18 and 12 min respectively from the starting point to the subway station. Whereas in the reverse path, the average time decreased down to 10 min for blind people and 8 min for limited vision users. Furthermore, when users were using the second mode (audio, touch screen and tactile feedback) in the second trial, the time spent also decreased: 14 min for blind people and 12 min for limited vision users when they are walking from the building to the subway and the reverse path was the half the time for both types of users. This fact is due to the users learning both the path to follow and how to interact with the wayfinding application of the smartphone. In this last trial, blind users did not have problems with being guided thanks to the accuracy of the application.

4.2. Users' feedback

Users' feedback was registered through a brief usability questionnaire at the end of the trials. The questionnaire uses a five-level Likert scale. The different choices are: strongly disagree (SD), disagree (D), neither agree nor disagree (NAD), agree (A) and strongly agree (SA). Table 1 shows the results of this questionnaire. With the goal of clarifying the obtained results, we have removed the disagree option and strongly disagree from these tables. The reason is neither of these options were selected by the users. Both tables present the number of users who selected each option. Although these tables present the results classified by the platform (Android or iOS), similar results have been obtained for both platforms.

The results presented in this table are successful. The navigation among menus in the wayfinding application is easy for the most users. 18 of the participants agree or strongly agree (see row Q1 in Table 1). The majority of users could select the destination without problems in both platforms. Only two participants spent more time to select the destination (see row Q2 in Table 1). Regarding the usefulness of physical references on the route in the wayfinding application most of the blind people are strongly agree (see Q3 in Table 1). For blind people, it is really important that the guidance not only provide indications related to the route but also the physical references to avoid obstacles. Similar results were obtained for limited vision users. Finally, regarding the most suitable feedback for visually impaired people, all of the participants prefer the combination of auditory and tactile feedback (see row Q5 in Table 1) before only audio (see row Q4 in Table 1) specifically, this preference is a need for blind people who demand the inclusion of this type of information. The evaluation also confirms the usefulness of extending the vibration feedback to convey distance information as well as directional information. We can conclude that the wayfinding application is well designed; it is usable and accessible for visually impaired people.

Furthermore, the questionnaire included open questions where users expressed their preferences related to the most suitable

Table 1
Results of usability questionnaire regarding wayfinding application.

Item	GUC (Android)	GUC (iOS)	GUP (Android)	GUP (iOS)
Q1	SA: 6, A: 3, NAD: 0	SA: 7, A: 2, NAD: 0	SA: 7, A: 2, NAD: 0	SA: 7, A: 2, NAD: 0
Q2	SA: 4, A: 3, NAD: 2	SA: 4, A: 5, NAD: 0	SA: 5, A: 4, NAD: 0	SA: 5, A: 4, NAD: 0
Q3	SA: 7, A: 2, NAD: 0	SA: 7, A: 2, NAD: 0	SA: 4, A: 4, NAD: 1	SA: 5, A: 4, NAD: 0
Q4	SA: 5, A: 3, NAD: 1	SA: 5, A: 3, NAD: 1	SA: 2, A: 6, NAD: 1	SA: 2, A: 6, NAD: 1
Q5	SA: 9 A: 0, NAD: 0	SA: 9, A: 0, NAD: 0	SA: 7 A: 2, NAD: 0	SA: 7, A: 2, NAD: 0

interaction for selecting the options (fixed regions vs. menu browsing) and the two types of feedback provided by the application ("audio and touch screen" vs. "audio, touch screen and tactile"). In the next section, we have included a discussion about this results, open questions and related-works.

4.3. Research method

We proposed a solution for people with visual impairments regardless age. The study about the fixed regions has provided many advantages to design and implement the management of Blind-Launcher and the wayfinding application. We obtained positive results for our study with the final users. Besides, we can conclude that elderly people without visual impairments could use this solution to improve their use of the smartphone and the navigation services.

For the wayfinding service, the usefulness of the vibration feedback is based on distance and directional information. The users can follow the routes without looking or listening the phone, they provide more mobility and liberty in their movements. However, it could be necessary to analyze this function for people with motor impairments.

The study related to the messages of physical references concluded that the users feel more comfortable with this functionality.

Although, the number of participants involved in the study presented in this paper is higher than other previous studies, it would be interesting to evaluate the wayfinding application with more users. Moreover, users with other disabilities could test the application and validate its usefulness thanks to the multimodal interaction provided.

One weakness of our method could be multimodal awareness. We could improve the multimodal interaction of the application with icons and pictograms to be helpful for deaf people and people with cognitive impairments.

4.4. Results

Navigation tasks and wayfinding applications through an environment represent an essential activity in our daily lives. Many investigations have emerged to improve the management of pedestrian routes and navigation activities based on user preferences. There is variety of domains for this issue such as public design, geo-positioning, navigation, wayfinding, cultural planning, tourist planning, social inclusion, urban planning and environmental design. However, people with disabilities, people with visual impairments, need help when moving in a physical environment, known or unknown. For this reason, it is important the development, testing, implementation, and/or management of a wayfinding system and a context-aware interface. The proposed wayfinding application improves their mobility and social integration.

The study of design for interfaces in mobile applications is basic key to develop accessibility services. In this work, the first analysis is about the kind of interfaces using fixed regions. On the one hand, although blind people spent more time understanding the fixed regions; all participants preferred the fixed regions. This is easier because they only need to touch any part of the screen to listen to the contents. Blind people use the regions of the brain for visual processing when they are reading Braille or they are performing other spatial tasks. Other studies have shown that both early-blind people (those blind people at birth or at an early stage) and late-blind people have higher tactile sensitivity in their fingers than sighted people (Goldreich & Kanics, 2003). Also, late-blind adults can trace tactile shapes faster and more accurately than sighted adults (Heller, Wilson, Steffen, Yoneyama, & Brackett, 2003). Limited vision users chose a fixed regions interface because they better remembered the options based on their location on the screen. When there are few options, the users usually prefer fixed regions because the access to the choices is faster and easier to remember. This was more significant for users between 50 and 77 years.

On the other hand, users prefer the second mode of information that combines audio and vibration feedback. The information only provided by audio could have problems in noisy environments. Furthermore, a user had problems with the guide dog with the auditory feedback. When the dog was barking, the blind user could not hear the audio of the application. The audio feedback also disturbs the guide dog and it alarms the owner because he is not following its signals. Some projects propose the use of headphones or earphones (Loomis et al., 2001), but this solution obstructs the auditory sense. It cuts the user off the environment (chatting with a friend, the sound of a car, alarms, and so on), or it requires speakers, which may disturb bystanders and/or embarrass the user. For the second type of feedback, the application offers the user continuous auditory and tactile information. The feedback about the proper direction is constantly provided and the phone vibrates when the direction is the correct. Firstly, the application speaks to the user about the route, hotspots and physical obstacles in the route. Second, the application vibrates based on the user's orientation. Therefore, the previous problems with noisy environments are solved.

For the analysis of the wayfinding application using accessibility criteria for the designed and implemented interfaces. Burzagli et al. (2009), Chen et al. (2010) and Oliveira et al. (2011) present the importance of content adaptation based on user preferences and their activity at the environment. A solution with multimodal channel of communications could be the solution to make accessibility services for everybody regardless their preferences. We focused on different parameters of users: visual impairments, age and known about technologies In contrast to other authors (Heller et al., 2003; Pielot & Boll, 2010), in the present proposal, younger users and older users can use the same wayfinding application in the same way. The Tactile Wayfinder (Pielot & Boll, 2010) explores the use of a vibrating belt to give directional information. Additionally, its interface is very simple. It uses several types of pulses to identify the direction of destination. However, these different modes are not easy to understand and remember for most of users (most problems for elderly people). We propose an interface and application for users regardless age based on the same time to familiarize themselves with the interface and how to interact with it. The participants needed less time to learn with the training. This allows to familiarize with more functionalities demanded in the guidance process (calling, mailing, messaging, contacts, and so on).

Fig. 6. Blind participants using the wayfinding application to go from one point of interest to other in the university (near pedestrian crossing, entrance of the university and entrance of a building).

Some works present investigations into pedestrian's routing behaviors within outdoor and indoor environments. PointNav includes a combination of different technologies (Magnusson, Molina, Rassmus-Gröhn, & Szymczak, 2010). However, the application is not oriented for any point of interest. It is oriented for specific interest points that there are nearby the user. Moreover, in contrast to PointNav, or other projects (Jones et al., 2008; Magnusson et al., 2009; McGookin et al., 2009; Robinson et al., 2009), we have performed an evaluation with more participants. Therefore, we have obtained more feedback in the results. Also, our proposal is a complete solution. The application presented by Szymczak et al. (2012) is not designed specially to be more accessible for visually impaired people. Also, the application plays sound files about the point of interest. These sound files need to be previously installed on the phone with any information about the point of interest in the guide. This could be a problem in terms of storage, scalability and dynamic information. In Nasir et al. (2014) proposes solutions only for waypoints within indoor environments. Another disadvantage is that the usability is not valid for outdoor environment and the accessibility criterion for this study is not applied. Another works like (Costa et al., 2012) has proposed guidance system to help elderly people in their homes. However, the problem to integrate all people to enjoy a city, cultural routes and outdoor navigation is still an important key to be solved. Thus, after results of the proposed work, we can conclude that we have could solve this issue. In the work for a guidance based on transportation interactive systems (De Oliveira et al., 2013), there are not parameters oriented to people with sensorial and cognitive impairments. it is oriented to transportation interactive systems. Besides, another weaknesses is that the mapping requires a deep knowledge of the application domain. We solve this issue, because our wayfinding application only requires that data of XML file, described previously, can be changed with new point of interest and waypoints.

In conclusion, related to design of applications, the user interface needs to be adapted to the user preferences and conditions to meet the accessibility requirements. Results presented previously show that the different methods offer advantages and disadvantages, and these are related to users' individual abilities. We have obtained useful indications of the most suitable methods for each person and groups. There were not significant differences in the accessibility options between iOS or Android devices. Therefore, the participants did not present any preference for a specific smartphone.

To sum up, most wayfinding applications described before present more problems such as blind users need another person to open the application for them. Most systems do not research about personalized routes for different purposes and accessibility paths with information related to physical references. The typical screen reader is not applicable or they need to install a special screen reader, and some interfaces are not adapted using a universal design. At this work, a visually impaired user can navigate among basic functionalities of the smartphone and open the navigation application in an autonomous way thanks to the Blind-App Launcher and the screen reading software such as Talkback and VoiceOver. The wayfinding application guides users through an adapted interface and the users will get feedback in which direction to walk to arrive at a destination using tactile, audio and text functionalities. Even a map could be displayed with dynamic information of the route. In this kind of services, the information and feedback in real time is very important for the users. The usefulness of the vibration feedback is based on distance and directional information was validated in the results, the user feel very comfortable using the application with this functionality. Moreover, the accuracy of the location allows alerting users about the physical references, obstacles, things like street signs, doors, litter bins, a perimeter fence or pedestrian crossing (see Fig. 6) are messages to improve the mobility and interaction with the environment. Another important aspect to be considered is that the application is accessible for a huge number of people independently of the users' needs and abilities thanks to the use of different sensory channels (visual, auditory and tactile) for providing information. Therefore, we work in order to offer mechanisms for the universal and accessibility design. Moreover, we considered very important to have access to the information and navigation anywhere and anytime, in fact, this solution work in online and offline mode to operate properly.

5. Conclusions and future research

Wayfinding systems are very important in order to improve the guidance of people between unknown places, especially for people with visual impairments. The accessibility and mobility are key issues in this kind of scenarios. However, some smartphones and touch-based interfaces still pose several challenges for blind users. A large number of efforts have been made to make these devices more accessible. Smartphones can be accessible for visually impaired people if they contain the correct screen reading software. VoiceOver is a powerful application that allows users to listen the information displayed in the screen. However, most of Android devices and design of applications present a lack of appropriate software for using the basic functionalities of the phone in an easy and accessible way.

Our research was motivated by prior attempts to create accessible touch screen user interfaces and a universal guide application for blind people designed and validated by real visually impaired users. In this way, a user could travel from his home to his work or university using an adaptable wayfinding application. Everything is available through a smartphone, which is already in most users' pockets. Our approach is universal and accessible because, according to the results we obtained, blind people and people with limited vision had the same successful results regardless of age and knowledge of screen reading software and smartphones.

The application and interfaces have been designed, developed and validated thanks to people with limited vision, blind users and sighted people. Also, the interface is compatible with other screen reading software. This is the best way to obtain the most suitable solution for everybody.

Furthermore, our wayfinding application improves previous solutions described in the first section. A key feature of this proposal is the tactile compass that provides continuous directional information through vibration, audio and interfaces patterns for blind users. Besides, the results of the case study presented in this paper are preliminary but they bring light about the suitability of this feedback combination for blind users. These results indicate that the tactile compass allows reaching a displayed location without any notable disadvantage compared to a map while offering more adaptability for blind users. The accuracy was between 1 and 3 meters. All users could go to the destination using the screen reading software and the wayfinding application for both iOS and Android devices. The measured time for blind user was only 30% more than a typical user with limited vision. Besides, the age was not a problem if there was a short training process. Any user could use the interface and application between 5 and 15 min even if he has not previous experience with smartphones. Moreover, this wayfinding application will be useful for other type of users since it provide the information in different formats (e.g. audio instructions will be useful for people driving or deaf people can be guided by tactile feedback).

Moreover, the proposal application integrates the elements that are not visible to them in the world such as street signs, pedestrian crossing, or points of reference, among others. This information could give them this missing information that has been useful for visually impaired users. Finally, according to the evaluation done, most of blind users would prefer the fixed regions to navigate among applications whereas people with limited vision prefer the menu browsing and a list of menu items because it is faster for them. Therefore, although the number of users who evaluated the application is small, the solution developed is accessible since people with limited vision as well as blind people can use it and can choose the type of interfaces.

To sum up, most wayfinding applications described before present more problems such as blind users need another person to open the application for them. The typical screen reader is not applicable or they need to install a special screen reader, and some interfaces are not adapted using a universal design. At this work, a visually impaired user can navigate among basic functionalities of the smartphone and open the navigation application in an autonomous way thanks to the Blind-App Launcher and the screen reading software such as Talkback and VoiceOver. The wayfinding application guides users through an adapted interface and the users will get feedback in which direction to walk to arrive at a destination using tactile, audio and text functionalities. Even a map could be displayed with dynamic information of the route. In this kind of services, the information and feedback in real time is very important for the users. The usefulness of the vibration feedback is based on distance and directional information was validated in the results, the user feel very comfortable using the application with this functionality. Moreover, the accuracy of the location allows alerting users about the physical references, obstacles, things like street signs, doors, litter bins, a perimeter fence or pedestrian crossing (see Fig. 6) are messages to improve the mobility and interaction with the environment. Another important aspect to be considered is that the application is accessible for a huge number of people independently of the users' needs and abilities thanks to the use of different sensory channels (visual, auditory and tactile) for providing information. Therefore, we work in order to offer mechanisms for the universal and accessibility design. Moreover, we considered very important to have access to the information and navigation anywhere and anytime, in fact, this solution work in online and offline mode to operate properly.

As a future work, we would integrate an evaluation toolkit into the application for Android and iOS. This toolkit allows storing logs about the use of the navigation functionalities and recognition methods to understand better the requirements from the users such as the studies presented by Pielot, Henze, and Boll (2009), Pielot et al. (2010). For this case, we could use the functionality of comments from users in the application about point of interests. For this proposal, we also want to improve the management of the routes and accessibility points by integrating the present proposal into the GAT systems (Rodriguez-Sanchez et al., 2013). The objective is to manage the information, contents, applications and routes by people with disabilities using accessibility resources and criteria for web interfaces. This means that people with disabilities can manage their own routes and applications to distribute and to share; therefore this is a facility to social integration.

For this proposal, we developed the interface to improve the interaction with basic applications and the wayfinding application for people with visual impairments. However, the application is accessible for a huge number of people independently of the users' needs and abilities thanks to the use of different sensory channels (visual, auditory and tactile). We are working on validating the wayfinding application for people with motor, hearing, speech impairments and cognitive limitations. For this purpose, we are analyzing functionality for a multimodal design to improve the universal design of the application.

Finally, we would start some studies to validate the interface and the wayfinding application for a new context: labor inclusion. Steering and navigation tasks through an environment constitute an essential activity in our daily lives. It has a high practical value in a variety of domains, such as public area design, architectural wayfinding, geo-positioning and navigation, as well as urban planning and environment design. This proposal would help people with disabilities to learn the path to their works with autonomy. For example, we could focus on people with visual impairments and people with cognitive limitations, including learning disabilities. They could follow the path to their works using the interface and the application. In this way, related of issues of ageing the application could be a tool to follow routes with physical exercises. Our wayfinding application has functionality to send messages to the users about the physical references (litter bins or pedestrian crossing), we can imagine that we could integrate messages in different points in a route with different tasks and exercises. This kind of activities could be a tool monitoring of people with chronic diseases. They could different routes among different places in a city, for example, the application could monitor this route and interact with the users in different points with adapted exercises for each user. This kind of improvements could be integrated in some systems of De Marisco, Sterbini, and Temperine (2010), to improve social activities and interaction with the environment.

Acknowledgments

We acknowledge URJC (Universidad Rey Juan Carlos for this research), the ''Programs of Support for people with Disabilities'' in the URJC and ONCE (National Organization for blind people) volunteers of Mostoles (Madrid, Spain).

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