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

M.C. Rodriguez-Sanchez [a,*], M.A. Moreno-Alvarez [a], E. Martin [b], S. Borromeo [a], J.A. Hernandez-Tamames [a]

[a] Electronics Department, Universidad Rey Juan Carlos, C/Tulipan, s/n., 28933 Mostoles, Madrid, Spain
[b] Languages and Computer Systems, Universidad Rey Juan Carlos, C/Tulipan, s/n., 28933 Mostoles, Madrid, Spain

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

* Corresponding author. Tel./fax: +34 914888238.
E-mail addresses: cristina.rodriguez.sanchez@urjc.es (M.C. Rodriguez-Sanchez), miguel.moreno.alvarez@urjc.es (M.A. Moreno-Alvarez), estefania.martin@urjc.es (E. Martin), susana.borromeo@urjc.es (S. Borromeo), juan.tamames@urjc.es (J.A. Hernandez-Tamames).

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 intelligent 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