StepByWatch: A Smartwatch-based Enhanced Navigation System for Visually Impaired Users

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***Abstract*—The worldwide diffusion of mobile technology has opened the door to a new era of distributed sensing. Indeed, mobile sensing and wireless technology can be exploited to create new information and services that have the potential to improve our lives in many ways. This becomes even more interesting if the benefits could reach the whole community, even people with disadvantages that are often left out by the digital divide. To this aim, we have developed a system able to offer an enhanced route navigation system, while at the same time gathering quality data through smartwatches. Even more interesting, we have endowed our system with an interaction paradigm based on vibration patterns so as to guide the user without the need for looking at the device. Our proposal avoids user distraction and field trials demonstrate its effectiveness when employed by visually impaired people.**

***Index Terms*—blind user, good technology, mobile application, smartwatch**

I. Introduction

In the recent years, smartphone devices have known an incredible success. They are no longer considered simple communication devices: they can entertain the user with games or videos, they allow to share experience through the social networks, to take pictures or video clips, to remember appointments and other important events, to read newspapers, books and so on. Smartphones can be used to remember medical treatments or to practice physical exercises. They are a sort of, quite silent, companion of user's life, which follows him/her ubiquitously.

Even if they are almost always very useful instruments, sometimes their use can become the cause of problems, as in the case of drivers. But this is not the only case: the widespread of *augmented reality* technology fostered the development of new applications, with different purposes, but also potentially dangerous. This is the case of *Pokemon Go*, an apparently harmless game but that can cause incidents if used while driving, cycling, or even, walking. Many GPS navigation systems suffer of similar problems.

For this reason, in this paper we propose a new interaction paradigm, based on the use of smartwatches. We defined a vibration alphabet that can be used to notify the user through the use of vibrations, which can be sensed without looking away from the current activity. This new interaction paradigm has two interesting advantages: as already said, it does not need the use of the sight, thus not significantly distracting the users and, even more important, allowing to be used by visually impaired people.

We have integrated the vibration alphabet into the *PathS* system [3], an augmented navigation application which offers an enhanced pedestrian route navigation system, while at the same time gathering quality data through the devices. The application allows to enrich geographical maps on the web with historical data about brightness and noise levels, and to provide pedestrians with an improved navigation. In this paper we extend *Paths* with a smartwatch application, named *StepByWatch*, for three reasons:

- the smartwatch can collect more precise environmental data since it is always on the user's wrist rather than in a pocket or a bag;
- the use of vibrations of the smartwatch avoid to distract the user, especially if he/she is driving or cycling;
- the use of vibrations is accessible to visually impaired people and preserve the user's privacy.

The paper is organized as follows: background and related works are discussed in Section II. The system is described in Section III. Section IV reports the results obtained with a questionnaire submitted to visually impaired users. Finally, we conclude in Section V.

II. Related Work

Nowadays, the popularity of smartphones endowed with a multitude of sensors and ubiquitous connectivity has attracted the attention of many researchers who are eager to explore the potential of this scenario. In particular, it is clear that gathering environmental data has become a feasible option in any location with users and their smartphones. The people-centric sensing paradigm has been around for some years now, ranging from algorithms and techniques proposed to measure specific environmental properties to hierarchical system architectures and communication paradigms [4], [6].

For instance, PRISM [7] is a framework enabling distributed data acquisition of environmental data using off-the-shelf mobile devices. PRISM provides both an orchestrator of the mobile nodes taking part in the data acquisition process and a mobile component deployed on smartphones that autonomously collects data from the environment. Even more

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general, Mirri *et al*. present an architecture to help designing and deploying smart mobility applications specifically tailored for crowdsourcing and sensing related to urban barriers and facilities [12].

Kanhere in [11] presents several future research directions for data acquisition using smartphones in urban environments. They can involve the use of GPS sensors and the analysis of moving patterns and traffic statistics to generate a real-time map of traffic jam in cities. Furthermore, audio samples of streets could be collected by pedestrians to generate a noise map.

Considering smartphone-based sensing systems, Aram *et al*. [14] consider the use of specialized low cost sensors to acquire temperature and humidity values. The proposed system exploits Bluetooth connectivity to forward the gathered data to a smartphone, which may act as data collector or forward them toward a central node. Also, the proposed solution could achieve higher coverage distances by adopting Wi-Fi as transmission technology. Gathered data could be used to raise alarms in case of unhealthy conditions or other critical events.

Similar to the previous example, but tailored for a wider environment, the work in [1] focuses on an application that determines pollution exposure indexes for people carrying mobile devices. The authors in [5], instead, propose a pattern recognition method employing smartphones that could transparently and automatically detect crossroads accessible to blind people.

Benjamin Gotow *et al*. in [10] investigate the challenges faced when developing Augmented Reality (AR) applications for smartphones. The main focus of this work is on three main issues: data acquisition (i.e., how to manage raw data coming from smartphone sensors), the implementation of the *magic lens* that adds the overlay to the simple underlying environment, and how to fetch the points of interest from an online server.

Even our work aims at gathering environmental data through smart mobile devices. To reach this goal, the end-user is provided with a route guidance system that also include a vibration-based navigation so as to allow its use by people with sight impairments or that simply cannot look at the device because driving or cycling.

Focusing on the last part, we have to mention as related work the electronic white cane, which provides blind users with the ability to move around in unfamiliar environments thanks to the use of RFID technology [9] or sonar [2]. Yet both these solutions are limited by short-range communication.

A different kind of approach for transmitting information to blind people is represented by electronic gloves [8]. One of the most interesting examples is represented by GlovePi, which is a tool that allows communication with deaf-blind people through the use of the Malossi alphabet [13].

III. System description and implementation

A. System description

As already introduced in Section I, *StepByWatch* aims at providing an innovative navigation system, able to provide customized services to different type of users.

In particular, the primary idea is to offer a customized experience depending on which are the user's preferences or characteristics. For example, let us consider a student moving to a new city that has to attend a lecture in the afternoon and does not know how to reach the university campus. Moreover, it is summer and very hot, and the student would like to arrive in good conditions to make a good impression. It is clear that, he/she would like to receive the shortest path for his/her destination, but he/she would like even to maximize the amount of path made under the shadow of plants or buildings. This information, that is not available using standard maps, can be collected using daily commuters or residents, that every day walk along the same streets and can collect/provide information about the environmental conditions through the sensors of their mobile devices.

Furthermore, another important aspect of environmental data collection is related to people with disabilities or that have mobility problems, e. g., they are blind or cannot walk. Current maps do not contain information about obstacles, stairs, audible traffic lights or other accessibility-related issues. The system aims at collecting information even about the general conditions of the path and the different spaces of the road, in order to understand and to provide the best solution for people with special needs. An even higher attention should be given to blind people, since visual indication are completely useless for them.

The description of these two simple use cases is able to highlight which are the main characteristics of the system. First of all, it is necessary to collect data about the streets of a city, retrieving information about environmental properties that could be useful to provide customized experience. Moreover, even timing aspects are extremely important, as environment conditions at 8am could be really different than at 5pm. Moreover, the system has to take into account the possibility of annotating obstacles or obstructions along the path (that can be provided by the user if not automatically detectable). Finally, the system has to provide the possibility to different users to select different preferences for their path, as for example the shadow, the noise, the maximum deviation acceptable from the shortest path, etc.

To automatically collect data, smartphones can be considered the most ubiquitous sensors, as users carry them along the day and along their walks. For this reason, and since every smartphone is equipped with a bunch of sensors, this type of device is the perfect tool to collect environmental data. Moreover, in the recent years, we have seen an explosion of smartwatches, that people use in combination with their smartphones [15]. The peculiarity of these devices is that they are equipped with their own sensors, e.g., luminosity sensor, accelerometer, microphone, etc., and, differently from

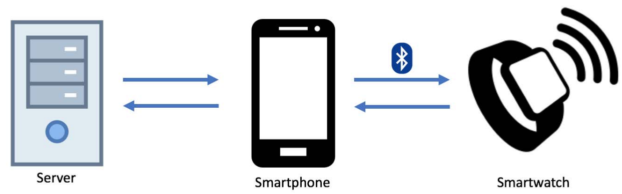

Fig. 1: System architecture

the smartphone, they are exposed on the wrist; thereby, they can be continuously used as data collectors, differently from smartphones that cannot collect useful information about ambient light or ambient noise when hidden in pockets, bags, purses and backpacks.

Moreover, smartwatches can provide a better user experience: e.g., it can be easier for the user to look at the smartwatch and receive information and notification on it, instead of keeping the smartphone out and constantly look at it to receive information about the path. Smartwatches can therefore provide a new interaction modality. For example different vibration patterns can indicate which are the roads to follow (e.g., one vibration pattern to turn right, two to turn left). Moreover, this new interaction based on vibration patterns has two interesting features: first, it is suitable for blind people or with visual impairments, since interaction based on vibrations can overtake the problem of visual suggestions, and can leave ears free to the person to "sense" their surrounding environment and second, it preserves the user's privacy.

B. System implementation

The description of the system provided in the previous section highlights how the system is mainly based on two different components: the server component, that stores the data collected by users and calculates the personalized paths, and the mobile component, that is based on a smartphone and a smartwatch.

The mobile component, on its turn, is also based on two different parts, the smartphone and the smartwatch application, that communicate together and exchange data in both directions, as depicted in Figure 1. The smartphone application has been developed using the Android OS, while the smartwatch version of the application has been developed using Android Wear OS. Moreover, the smartphone version of the application uses the Wikitude SDK to provide augmented reality features[1].

The smartphone application has several purposes. First of all, it permits to request to the server a path from an origin point to a destination, then it shows the path provided by the server (Figure 2a). Before searching for a path, the user can select his/her preferences. The selection of the profile lets the application know which point of interest around the current location of the user should be provided to him/her. We defined three different profiles: athlete, tourist and manager. For the athlete profile, we suggest places like parks (where the user

[1]https://www.wikitude.com/products/wikitude-sdk/

(a) Smartphone interface. (b) Smartwatch navigation interface

Fig. 2: Smartphone and smartwatch interface

can run and do physical exercises), gyms, sport shops, etc. On the other hand, the system suggests to tourist profiles museums, historical buildings, churches, etc. In this way, recommended places are better suited depending on the user. Moreover, we conducted a questionnaire with 350 different people to understand which is the maximum deviation, from the original path, accepted by people to reach a point of interested suggested by the application. The results showed that people would like to increase their walk of around 500 meters to reach a place they consider interesting. For this reason, the system is able to suggest interesting places around the path of the user that extend the original path of, at most, 500 meters.

The smartphone is even responsible to upload data to the server, and this data comes mostly from the smartwatch application. As said before, the first task of the smartwatch is to collect data while the person is walking along the streets, in order to collect information about the environmental conditions. The data is sent through Bluetooth to the smartphone, that then upload them to the server. Thanks to the different sensors available on the smartwatch, we can collect data about the luminosity of the streets (to identify shady or sunny places and paths) and the noise of the street, that can identify places with lots of cars, hence dangerous or not healthy for the high presence of smog.

The second task of the smartwatch is to provide indication about the path to follow (Figure 2b). As mentioned before, despite the standard visual indications that are shown on the screen of the smartwatch to turn right or left or to continue straight, we felt the necessity to develop a navigation system that could be useful even for blinded people. The usage of sounds for people with this kind of disability should be used carefully and possibly avoided, since ears are the main input

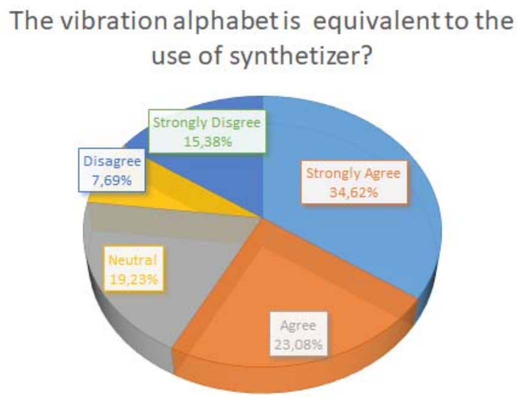

Fig. 3: Answer to the question: “Do you consider the vibration alphabet equivalent to the use of synthesizer?”

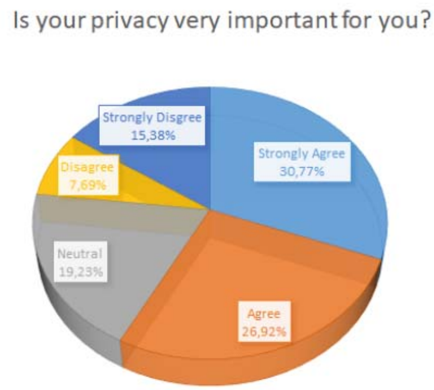

Fig. 4: Answer to the question: “Do you consider your privacy very important and you use the earphones to preserve it?”

sense to understand an open environment for these users, hence other solutions should be found. For this reason, we defined an indication alphabet based on different vibration patters depending on whether the user has to turn right, left, or go straight. In this way, ears are free and can be used by the blind person as a basic support for walking and living, while vibrations are used to provide them suggestions about the path.

Finally, the server component is responsible to receive data from the smartphone of the different users and to store all the variables and information provided by the smartwatch. Beyond the data coming from the different sensors of smartphone and smartwatch, the server stores even an evaluation manually provided by the users. This evaluations aims at identifying the quality of the path, e.g., if it was easy to follow, or appreciated by the user, etc., and if during the walk the user encountered any obstacle or difficulty. This information, especially the last one, is very important for people with disabilities, e.g., blind people or people on a wheelchair, since the presence of obstacles can reduce the easiness of the path. Storing this manually provided information makes the system even more able to adapt to the different users, especially for the ones that have any disabilities and need special attention.

The server is based on the first implementation of the system called *PathS* [3], but has been evolved to support the new introduced features. First of all, it is based on the Play! Framework[2], used to deploy the general structure of the system and for the development of the website used to monitor the collected and processed data. On the other hand, the server uses a PostgresSQL database, in order to be able to store temporal data, since every data collected from the user with a timestamp that indicates the moment of the day when the data was collected, and the ability to manage and to analyze geographical data.

IV. User study

At the current state of implementation, our navigation system cannot be used autonomously by visually impaired people due to many reasons, among which the insufficient accuracy of the European GPS system. For this reason, we cnould not perform any field trial with visually impaired subjects; instead, we have asked them to answer a questionnaire. The aim of the questionnaire is to learn more about the target users and to understand the level of acceptability of StepByWatch.

The questionnaire is composed by nine 5-point Likert questions with possible answers ranging from “Strongly disagree” to “Strongly agree” and two multiple choice questions. Finally, the participants can leave comments in a text area.

26 visually impaired participants anonymously answered to the questionnaire. This number may seem low, but we must note here that, according to the World Health Organization, 39 million people in the world are blind [16], so only the 0.5% of the world population which makes hard to find candidates. Moreover, four organizations of visually impaired users have been contacted to spread the questionnaire among members.

The results of the questionnaire confirm the limited use of off-the-shelf navigation systems among visually impaired users: only one participant declared to use a GPS system, 46.2% uses the white walking stick, 23.1% is guided by a human and 19.2% of the participants is guided by dog. A participant explained with a comment that the reason to not use a navigation systen is the low accuracy: blind people ask for an accuracy lower than two meters, whereas the accuracy of regular GPS is about ten meters.

The participants have really appreciated the use of vibration to communicate the direction: only 23% of the participants do not consider the vibration alphabet equivalent, in term of expressive power, to the use of synthesizer, as depicted in Figure 3, and 95% of them prefers to receive direction through vibrations to increase their security. The use of earphones in fact preserves their privacy, but occupies their ears, which are no longer able to capture what is happening around the user, thus jeopardizing safety.

One participant commented the preference explaining that the hearing sense does not allow to hear, and comprehend, more than one sound at the same time. For this reason, according to 96.2% of the participants, the use of earphones

[2]https://www.playframework.com/

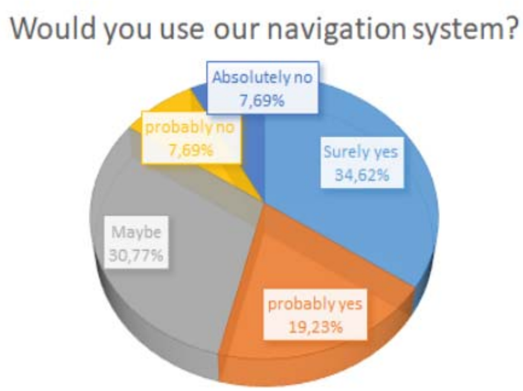

Fig. 5: Answer to the question: "Would you like to use a navigation system which gives you you indication through vibration of the smartphone?"

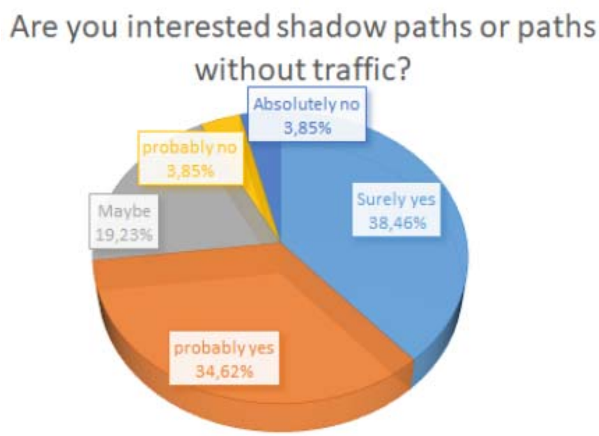

Fig. 6: Answer to the question: "Are you interested in a navigation system which suggest shadow paths of paths without traffic?"

is essential in crowded locations to understand synthesizer. Moreover, both earphones and the vibration alphabet allows to preserve the user privacy, which is a very important issue for 57.9% of the participants (see Figure 4).

Finally, 84.6% of the participants declared they would potentially favor the use of StepByWatch (see Figure 5), 80.7% evaluated the system as useful and 92.4% expressed a potential interest in paths with particular features like few traffic or shadow (see Figure 6).

V. Conclusions

The widespread adoption of mobile devices with sensing and communication capabilities has opened the door to a new era for innovative services based on distributed sensing. To this aim, we have developed a system able to offer an enhanced route navigation system, providing routes based on distance as well as on luminosity and noise along the path. Our proposal transparently gathers environmental information through the smartwatch while keeping the user informed along the path. The adopted interaction, notification paradigm is based on smartphone vibration patterns so as to guide the user without the need for looking at the device. Preliminary field trials demonstrate the feasibility of the approach.

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