Guidelines for Electronic Systems Designed for Aiding the Visually Impaired People in Metro Networks

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Abstract. The research described herein sought to contribute to the theoretical field pertaining assistive technology systems for the visual impaired. It aimed to investigate by what means the visual impaired interact within the metro environment, seeking to understand their abilities, limitations and fears, in light of their cognitive variables. The study was conducted through participant observation of users with visual impairment and also survey questionnaires to specialists, instructors of orientation and mobility for the visual impaired, and members of the focused users, in São Paulo (Brazil), and Porto (Portugal), which include, respectively, the assessment of two electronic guidance systems, NavGATe and Navmetro. It resulted in a set of guidelines for design, implementation and operation of mobile based assistive systems for the visual impaired within metro networks that fill existing gaps in current knowledge.

Keywords: Visually impaired · Spatial awareness · Navigation · Metro

1 Introduction

Public spaces in general, and transportation and information systems in particular, are still generally inaccessible to the visual impaired, despite this being the most common personal disability worldwide. In Brazil, the last National Census [1] verified that 18.8% of the population have some degree of visual impairment, while motor, hearing and mental/intellectual impairment account less, respectively 7.0%, 5.1% and 1.4%. Visual impaired persons have greater difficulty in understanding large public spaces, because of the lack of visual references commonly used by sighted people [2].

Metro networks account for the commute of millions of passengers daily. Metro stations are designed as transition spaces within such systems. In order to cope with such high flows and gatherings of passengers, intersecting service lines and other urban infrastructures, stations become non-standard complex buildings. Flow of passengers vary, not only, daily, but over time, as there are changes to the network. Also, different metro car dimensions, layouts, and door mechanisms makes metro networks confusing to the autonomous movement of the visual impaired.

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Adaptation of existing metro networks as well as making of accessible new stations and lines is a major challenge, as verified in the day to day work of technical and customer support teams of the São Paulo Metropolitan Company (CMSP) [3]. In Brazil, despite the adjustments made, as dictated by legislation [4] and norms [5, 6], one notes that many visual impaired users feel unsafe and require the aid of personnel while moving within metro stations [7]. Current specifications comprise basically, installation of tactile mats, Braille plates or raised lettering as alternatives to the existing visual cues.

In recent years, visual impaired users have asked metro companies to provide electronic means of guidance. Although there are no official records of such claims, they can be easily related to widespread use of the Internet, accessible software, and availability of mobile phones. Such technology has enabled the visual impaired to access information and to interact with the rest of the world, greatly reducing their dependency on other people, allowing them to experiment a desired freedom.

Such state of things was the motivation for the research project [8] described herein, that investigated the means the visual impaired interact with the environment while travelling inside metro systems. The study involved the assessment of the São Paulo (Brazil) and Porto (Portugal) metro systems. The Porto metro system assessment included a review of Navmetro, an electronic information and navigation system for the visual impaired, in operation since 2009 [9].

This paper also includes the continuity of the research, mainly the assessment of NavGATe [10], a proposed orientation and navigation system for the visually impaired, under evaluation by CMSP.

2 Method

Use of a transportation system is a socially organized activity, in which, real behaviour can differ from stated preference. According to Flick [11], qualitative research is best indicated to interpret and identify user needs, not acknowledged by themselves, and to identify peculiarities not covered in academic publications. Also, Creswell [12] affirms that qualitative research provides for the investigation of complex problems, also for situations involving the visual impaired. And, according to Moresi [13], qualitative research must be used when seeking to understand in detail why an individual exhibits a particular behaviour. Therefore a qualitative approach was adopted in this study. This was also influenced by Angrosino [14] who recommends such an approach when the experiments occur in their natural context, which was the case.

This research was oriented by instruments observation and interviews, of qualitative research, favorably used by Cohen [15], Valentini [16], Queiroz [17] and Barbosa [18].

In face of the difficulty in finding specific significant data compilations, research on the problem domain sought the multidisciplinary information specific to researchers and other concerned on the subject. It was necessary to build a cognitive map of the targeted users, identify the relevant characteristics of metro networks, and investigate the available technology, of interest to orientation and navigation for the visually impaired.

Descriptive analysis was made by systematic reading of the data to seek for emerging behavioral patterns, as proposed by Angrosino [14], so as for them to be organized in categories for the analysis.

Content analysis was done by reading the transcriptions of spoken interviews, testimonials and observation protocols. This material is summarized after treatment and classification, to guide the selection of the relevant information in the recorded transcripts, as indicated by Gerhardt and Silveira [19]. A similar procedure was applied by Rose [20] to contribute to the categorization of results, from moving images. The analysis of the interviews considered the interpretive context, since, according to Gill [21], all discourse is circumstantial.

3 Previous Work

Previous work considered are Hatwell [22]; Bradley and Dunlop [23]; Taylor, Peplau and Sears [24]; Bins Ely [25]; Rogers, Sharp and Preece [26]; WHO [27]. Based on these studies it was identified that visually impaired people exhibit particular corporal structure. They organize their world according to the ways they walk, their routes and its access points are configured by their bodies in movement.

In order to orient themselves and move in a quick, efficient and independent manner, the visual impaired rely on a cognitive process that includes perception, coding, learning and environmental information memory [28]. However, ACAPO [29] observes that 70 to 80% of the visual impaired are not completely blind, and, according to Harper [30] and Honorato [31], this influences the way they interact with public circulation spaces. According to WHO [27] and Lora [32], despite using other means of perception, like aural, haptic, kinesthetic, muscular memory, vestibular (or labyrinthine) and/or olfactive, people tend to use as much as possible whatever visual capability they possess.

In order to learn how to orientate themselves without the visual sense special training is necessary and courses exist, on using the remaining senses, through systematic learning techniques. These are referred to as Orientation and Mobility (OM) [33]. In addition, Almeida [34] proposes the use of audio guides, especially in the case of congenital visual impairment, as many cannot pinpoint their location based spatial information, e.g. tactile maps.

Notable experiences on the design and use of electronic guidance systems, especially for indoor environments, are Crandall, Bentzen, Myers and Mitchell [35]; Du Buf et al. [36]; Almeida, Orduña and Castillejo [37]; López-De-Ipiña et al. [38]; Virtanen and Koskinen [39]. Although prototypes may have been produced and tested, the great majority of these devices did not reach production. Hersch and Johnson [40] speculate on the possible reasons for this: (a) excessive complexity of operation allied to insufficient training; (b) odd-looking device; (c) cumbersome or too heavy to carry; (d) fails to address the user's needs or even; (e) less useful than the walking stick.

The key aspect regarding safety and reliability is to secure a user's next steps. Blindness or reduced vision makes all spaces hazardous to some degree. The issue for any electronic guidance system is the instantaneous determination a user's position, as emphasized by Hersh and Johnson [40]. According to them, this is a complex process because: (a) references are to be acquired through sensors, and this can involve communication between devices, possibly of differing technology; (b) references are subject to changes, i.e., new construction and placement of objects that become interventions to the original design; and (c) interpretation of reference information data can be quite complex.

The majority of navigation devices studied are based on radio waves. However, radio triangulation errors can be of several meters, according to Furukawa and Bruno [41]; and Pereira [42], and this is unacceptable regarding a metro system.

In what regards comfort, devices must carried with ease, most importantly, they mustn't require permanent handling during use, e.g. holding in one hand, considering that the other is already in charge of the walking stick. One hand should be free for other interactions, as recalls ONCE [43].

For studies on navigation, those of Harper [30] and Hersh and Johnson [40] stand out. Harper's findings, despite almost twenty years, are still up to date, regarding navigation, because they refer to the natural behavior of people; and the scarcity of newer references.

The contemporary meaning for navigation, used also as the determination of the route through terrestrial paths and built environment was explored in [8] with significant importance, as, according to Rogers, Sharp and Preece [26], the ways in which a person is oriented is crucial to a well succeeded trip. In this sense, navigation comprises a few simple actions: (a) route planning; (b) orientation based on reference points; (c) orientation during dislocation; and (d) detecting/avoiding obstacles and hazards.

Yatani et al. [44] verified that the most effective communication interface is one that combines audible and tactile (or haptic) information, but that further studies are necessary to determine communication style preferences before actual usage.

Almeida [34], based on Harper [30], summarized some concepts related to non-visual navigation, two of which are noteworthy: (a) a route to be followed will require more segments in relation to what would be described for sighted people; (b) despite the necessity for more information, they must simple and objective.

Hersh and Johnson [40] also state that a navigation system should provide information in all situations, both normal and abnormal or in face of an emergency.

Gedawy [45] studied navigation instructions based on necessities of the visually impaired, and emphasizes that some instructions can be stated in different ways, according to user preference. Booch et al. [46] recommend that such systems be designed to adapt to user expertise.

Rogers, Sharp and Preece [26, p. 85] recommend that "provide additional hidden information that is easy to access for users who wish to understand more about how to carry out an activity more effectively". And also that menus and voice instructions be minimal, as people find it hard to deal with menus having more than three or four options, as well as remembering multipart instructions.

4 Development

The research was initiated by the study of the perceptive experience of the target users. In this first phase, that culminated in [8], defined the objectives: (a) identify and analyse the senses and references used by the visually impaired when moving in metro stations and trains; (b) understand how they perceive space, train arrivals and departures, and other people, in order to orientate themselves; (c) observe user experience in the use of a orientation and navigation system when moving inside a metro station.

The instruments used in the first phase were observation and interviews, organized as follows:

(a) São Paulo (Brazil) metro, from September to October, 2015

- Individual observation, without researcher interference, of six frequent users, with different types of visual impairment, going through different stations, on their usual routes to work and/or education;
- Individual interviews, semi-structured and face-to-face, with eleven operational or station design staff of CMSP, and two orientation and mobility instructors;

(b) Porto (Portugal) metro, in March, 2015

- Group interview with two architects, employees of the *Metro do Porto* (Porto metro company) and developers of the Navmetro orientation and navigation system; and an individual interview with its project leader, also lecturer at FEUP – Faculty of Engineering of the University of Porto;
- Observation, without researcher interference, of a frequent user on his usual route, oriented by the Navmetro system inside a station.

Navmetro is a free orientation and guidance system for use in the Porto metro, which provides information such as lines, schedules and fares, through the use of voice commands on a regular mobile phone. Orientation is provided separately through bird sounds emitted at different points inside stations.

Observations compiled [8] were of fundamental importance to the understanding of the ways visually impaired people: do to know metro itineraries, locate entrances and exits; manage to reach a station not known to them and perceive their spatial location, among others, for the development of electronic guidance systems.

The second phase of the research, occurred from June to August, 2016, made use of the instruments of observation and interview of seven voluntary participants for testing NavGATe [10], an integrated system in which users carry receivers of information transmitted to them from devices distributed inside stations. The system provides exact user location and directions to follow. It consists of several transmitters conveniently placed inside stations, marked as (A) on Fig. 1. A receiver provided to each user, marked as (B) on Fig. 1, captures the location or other information, in the form of short range light signals; and sends them to his smart-phone via Bluetooth, where an application software transforms them into audible form. The smart-phone need not be handled during the whole of the course.

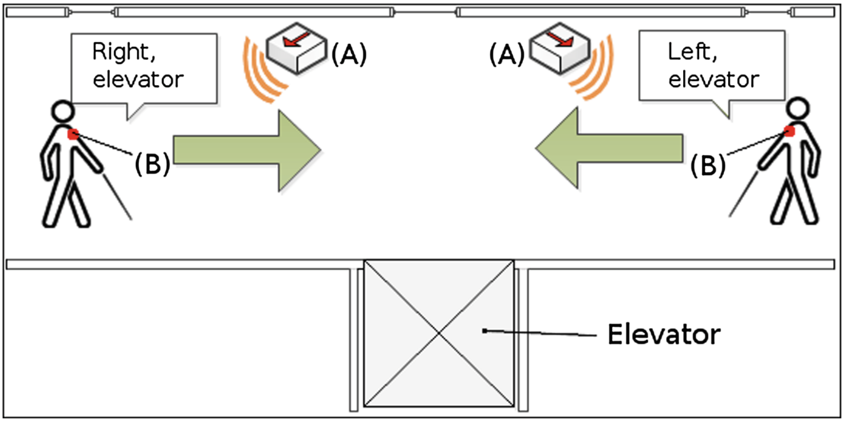

Fig. 1. NavGATe working example.

Fig. 2. Visual impaired participant using NavGATe to find a staircase, not reachable via tactile mat.

In this experiment, NavGATe was programmed to orient users in a manner consistent with information already provided by tactile mats, while offering added information and alternative paths, from the alighting from trains at Vergueiro station, to one of its exits to the São Paulo Cultural Center, that hosts a library (with books in Braille) much used by visually impaired people.

Figure 2 illustrates a participant using such system to reach a staircase that cannot be reached through tactile mat. In this station, the tactile mat is directed towards an elevator on the platform (Fig. 2 "A"). However, at an appropriate point during the course, NavGATe informs the user of the alternative use of stairs, to her left, which she accepts (Fig. 2 "B"). Beyond this point, having no tactile mat, the user relies only on NavGATe (Fig. 2 "C") and manages to reach the stair case (Fig. 2 "D")

5 Results

Results and discussions comprise the whole of the research, including [8]. The interviews with metro operation staff and systems designers came to the conclusion that metro stations are great circulation spaces, and flows vary during the day and also in time, and this is an important factor in their design. In addition, metro stations embody systems not perceived by its users, but that can affect and be affected by any new system that may be introduced. This requires careful planning regarding the choice of electromagnetic frequencies, cabling or transmission systems used. Another important consideration is the diversity of users, and their varied needs.

Based on the above, plus observation and interviews with visual impaired users, further conclusions are that any such system design must seek to achieve: (a) safety and reliable information; (b) effectiveness – provide the relevant information and; (c) comfort – ease of use and customizable.

The interviews with the orientation and mobility instructors [8] showed favourable opinions to the use of electronic systems as orientation and navigation aids. These instructors also provided useful information, regarding spatial perception and cognition, not found in literature and that hadn't been identified through user observation.

In the assessment of the existing Navmetro in the Porto metro [8], the interviews of personnel and the faculty researcher involved in its implementation, and observation of a visual impaired user, evidenced both the necessity and the difficulty in creating a system capable of determining the exact location of the user in order to provide proper guidance; also the possibility of use of differentiated sounds (e.g. bird sounds), that are clearly identified by the visually impaired, while not disturbing others; the importance of flexible user interfaces that enable users to refer to places in different ways.

In the Porto assessment, the respondents, involved in its implementation, also revealed the limitations of the use of Wi-Fi and Bluetooth in metro environments, due to its inherent inaccuracy in positioning, as well as the interference it potentially causes and suffers from other systems required in normal operation. This corroborates the affirmations of Furukawa and Bruno [41]; and Pereira [42], regarding the use of radio wave technology.

The respondents also informed that Navmetro needed improvements, the ability to adapt to user preferences and expertise. Such had been, respectively, cited by Gedawy

[45], and Booch et al. [46]. This was confirmed during the observation of an experienced user who got annoyed at having to repeat always the same steps in its operation.

Other important conclusions, from literature review, user and specialists (in metro operations and design) interviews, and user observation, that form the first phase of this research [8], were that, for any proposed user orientation and navigation system:

(a) user safety comes first;
(b) its usage mustn't cause perturbation to existing systems nor disturbance to other users;
(c) there mustn't be a limit to the number of simultaneous users;
(d) if a device is to be carried by the user, it should be of simple use, able to provide information through audio, preferably (though not mandatory) using vibration - as recommended by Yatani et al. [44] and stated in user and mobility instructors interviews - to confirm commands, indicate left or right, etc.;
(e) it must include information regarding trains; their destination, door states, next station and, alert users on platforms of existing gaps between cars;
(f) it must be planned for continuous evaluation and updates;
(g) its boundaries are station entrances and exits and it must encompass all possible paths, in association or not with tactile mats; also inside trains and in transfers between trains;
(h) user location must be given accurately;
(i) any possible interference to or from existing systems must be foreseen and avoided;

Guiding visual impaired people through metro stations and in and out of trains is a complex and challenging real time task, which can be tackled by dividing its path into segments derived from orientation and mobility requirements. This was cited by Harper [30] and confirmed in the observations of Navmetro and NavGATe users. In this regard the second phase of the research confirmed earlier findings considering the design of electronic guidance systems:

(a) it must inform users of the correct direction of escalators, elevator door status, escape routes and other operational information – as stated in the users and specialists interviews;
(b) it must be able to detect route deviations and provide the necessary corrective instructions – from observations of the use of Navmetro and NavGATe;
(c) if a device is to be carried by the user, e.g. a smart-phone, it mustn't require to be held full time, i.e., one hand must be free for other needs - as stated by ONCE [43] and verified in the experiments using Navmetro [8] and NavGATe - as stated in user and mobility instructors interviews and during all user observations;
(d) the advantages of adding the needed functionality to the user's own smart-phone; choice of narrator voices; usage of a single earphone, for guidance or other uses, e.g., listen to music, or receive calls – as stated in user and mobility instructors interviews and during all user observations;
(e) and function also as an audio guide – as recommended by Almeida [34], verified through the interviews in [8] and also experimentally while testing NavGATe.

6 Conclusion

Despite the difficulties posed by current metro systems to the visually impaired, which leads to 85% of these users resorting to CMSP staff in helping them, 72% of whom would rather be independent [8]. It was initially thought that this can be achieved through the use of electronic orientation and navigation systems, since people have become accustomed to smart-phones and apt to absorb information technology. However, there were few and inconclusive studies in the field.

Navmetro, in the city of Porto metro, is one of the very few examples of systems that made it out of the drawing board, were produced and that are actually in use. Other systems for indoor use were assessed, because of the similar environmental conditions. The possibility of interfering with other systems required for metro operation was appraised in each case.

The list of directives obtained through this study, novel or confirmation of earlier works, compiled into a single text, is an important resource for planners and designers regarding such systems. Also, since it comprises a thorough assessment of the different visual impairment types and their abilities, and, the design of information, and navigation systems, its findings could benefit also other transportation systems and the use of electronic guides for use in public spaces in general.

NavGATe is scheduled for validation tests and homologation within the São Paulo metro. As of March 2017 it is being fully installed on the station where previous testing were done.

Further research should deepen knowledge of navigation aspects, notably: sound and voice communication; determine best phrases and vocabulary used in commands and most appropriate moment to emit a command, as well as best receiver design (e.g. shape and handling), considering the diversity of user needs.

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