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Exploiting the Haptic and Audio Channels to Improve Orientation and Mobility Apps for the Visually Impaired.

Maria Teresa Paratore and Barbara Leporini

ISTI-CNR Area della Ricerca di Pisa, 56124 Pisa, Italy

`mariateresa.paratore@isti.cnr.it`
`barbara.leporini@ isti.cnr.it`

Abstract. Orientation and mobility apps for visually impaired people are well known as effective means to improve the quality of life for this target group. A mobile application that guides a visually impaired person step by step through a physical space is a valuable aid, however, it does not allow to get an overview of a complex environment "at a glance", as a traditional hard-copy tactile map does. The aim of this study is to investigate whether a smartphone GPS map, enriched with haptic and audio hints, is an effective tool to facilitate cognitive mapping for visually impaired users. Encouraged by a preliminary study conducted in co-operation with two visually impaired volunteers, we designed and developed an Android prototype for the exploration of an urban area. Our goal was to provide an affordable, portable and versatile solution to help users gain awareness of an environment through the positions of its landmarks and points of interest. Vibro-tactile and audio hints were linked to the coordinates on the map via the GeoJson data format, and were issued exploiting the text-to-speech and vibration capabilities of the mobile device, as they were exposed through the operating system's APIs. Test sessions and interviews with visually impaired users produced encouraging results. Results obtained, although to be verified by more extensive testing, overall confirm the validity of our approach and are in line with those found in the literature.

Keywords: Haptic Feedback, User Interfaces, Accessibility, Mobile Applications, Navigation and Mobility, Cognitive Maps.

1 Introduction

Almost every public environment nowadays provides visitors with aids for navigation (digital signage, websites or mobile apps), however these aids are generally not accessible for visually impaired users; also maps embedded in mobile applications, which rely on online providers, typically do not include support for accessibility. Accessible navigation apps, however, have proven to be effective assistive solutions for persons with visual impairments, helping them achieve better social inclusion and autonomy. Kahn et al. [1] summarized the main challenges faced by visually impaired persons during their daily activities, and pointed out how ICT, and more specifically assistive technologies, may help them. Pathfinding, location tracking and orientation in outdoor and indoor environments are among the main needs that visually impaired users satisfy through the use of mobile devices [14]. Users can rely on navigation apps to get real-time information about their actual position, route planning, and accessibility warnings in a physical environment. Applications such as Lazarillo and BlindSquare, explicitly designed for blind and partially sighted users, provide them with vocal instructions as they navigate through an outdoor or indoor environment [28, 32]. Besides step-by-step navigation, anyway, a map may also be useful to provide an overview of an environment, e.g. when planning a visit.

The terms "orientation" and "mobility" are used in the visual impairment literature to identify, respectively, the concepts of wayfinding and locomotion, which, according to Montello [20], are the two components of spatial decision-making. Mobility refers to the activities that a visually impaired subject performs as real-time responses to physical features while traversing an environment (e.g., avoiding an obstacle, walking up a step or crossing a street). Orientation, on the other hand, is related to the skill of planning a route from a person's current position to a given destination. While mobility depends only on the perception of the immediate surroundings at a certain moment, orientation requires also a knowledge of the whole area, and the relevant landmarks, and hence involves an enduring mental representation of the environment. Such a representation is referred to as a "mental" or "cognitive" map [9].

Developing a cognitive map involves tasks such as spatial coding, landmark anchoring and route planning; the purpose of a cognitive map, in fact, is to facilitate the awareness of one's position in the space in relation to the landmarks and elaborate a route to reach a given point of interest (POI). Building a cognitive map requires skills to understand the structure of an environment, to describe its organization and to understand its relations with other physical spaces; these skills are not strictly related to vision, and involve different neurological processes depending on whether an individual is visually impaired or not [10, 12, 18]. Thinus-Blanc et al. [19] provided a thorough insight about how blind persons build mental map. In particular, authors have proved that sensory modalities other than vision are exploited by the visually impaired in order to gain spatial knowledge and consequently develop orientation skills.

Popular mobile apps for the orientation and navigation of the visually impaired lack in providing a means to build a fast overview of the environment and the POIs; such a functionality might be very useful for a preliminary exploration of the space (e.g. when planning a visit), playing a role similar to that of hardcopy maps for sighted users. The goal of this study is to investigate if vibration patterns and verbal hints can be successfully used to help visually impaired users build a cognitive map; in particular, we will adopt the haptic channel not only to convey information about the positions of the POIs, but also about their function. We will first describe a preliminary study conducted on a simple indoor environment, then we will show how we applied the preliminary findings to build a new prototype based on georeferenced, downloadable maps. User testing procedures will be described, and test results will be discussed. Finally, we will analyze the open issues and future perspectives of the proposed approach.

2 Related Work

The role of non-visual stimuli in the development of spatial knowledge has been a subject of research for many years. Ottink .et al. [10] provided an overview of neurological studies about the role of auditory and haptic stimuli in the formation of cognitive maps for both sighted and visually impaired persons. Authors have pointed out that, although visually impaired people have a slower learning rate, using non-visual hints facilitates the process of learning, and, after an adequate training phase, they can build a faithful mental map of a physical space.

An allocentric representation of the space encodes information about mutual locations of landmarks in an environment, the location of a landmark in the space is thus defined relative to the locations of other landmarks. Conversely, an egocentric representation provides a perception of the space from the explorer’s perspective. Tactile maps have proved effective in allowing satisfying allocentric layout representations in persons with visual impairments [4, 22]. Locations and distances, as well as directions, can also be approximated [4, 19, 22]. Some difficulties occur when rotation comes into play [24]. Recognizing a rotated environment, in fact, requires an additional cognitive load that may hinder the performance. It must be pointed out that individual differences occur when assessing the effectiveness of a tactile map for visually impaired persons. In blind subjects, it mainly depends on the onset of blindness, while in the severe visually impaired the characteristics of residual sight can make the difference. According to some studies [14, 22, 21] tactile maps are effective means to improve navigation and wayfinding in a real environment. This is particularly true for small-scale tactile maps, since their exploration allows for a simplified yet effective allocentric overview of the environment which is much faster than direct experience.

Hardcopy tactile maps, based on raised line paper or other ad-hoc stiff materials, have become a traditional alternative to visual maps for visually impaired users. Espinosa.et al. [14] investigated the effectiveness of a tactile map in familiarizing with an unknown urban area. Authors compared the learning performances of different groups of blind users subjected to direct exploration of the environment, some of whom were provided with a tactile map of the environment and others with verbal descriptions. Tactile maps contained a representation of the route and the significant landmarks, other details of the environment were provided verbally or as braille text. Test results showed that participants with tactile maps achieved better results.

Large-scale adoption of tactile maps suffers from a very complex creation and authoring process, which leads to high production costs. Other limitations arise from the fact that these maps necessarily provide static information from both a spatial and a temporal point of view. In fact, a hardcopy map cannot be zoomed in or out, nor can it be modified depending on the user's orientation; moreover, changes in the physical environment cannot be reproduced on the map in real-time. Finally, conveying descriptive information with only the tactile channel may result in an overwhelming amount of stimuli for the users [8]. Much effort has therefore been expended over the years on finding more effective alternatives based on electronic devices.

Digital counterparts of tactile hardcopy maps, which leverage electronic devices' haptic and audio capabilities, are the subject of several studies. Lahav et al. [11], for instance, developed a digital user interface with haptic feedback to build a virtual representation of a physical environment. Authors carried out test sessions in which visually impaired participants were first immersed in the virtual environment and then directly explored it. Test results showed that the haptic-based virtual environment allowed participants to develop faithful cognitive maps. Similar results were achieved by Poppinga et al. [16], in which the use of haptic and speech feedbacks was proposed to improve the usability of a map rendered by a touchscreen; in particular, vibrations issued by the device were used to trace the road network. Papadopoulos et al. [6] compared three modalities of exploration in a simulated urban area, namely, verbal description, audio-tactile rendering, and audio description combined with haptic-feedbacks. Their study highlighted that tactile and haptic feedbacks associated with the audio channel facilitated the process of building a mental representation of the environment. Finally, Palani et al. [4] conducted a series of tests, which involved both sighted and visually impaired users, on an experimental prototype of a digital map based on haptic and audio channels. The map was implemented as a multimodal user interface built on top of an Android tablet, in which different vibro-tactile feedbacks were used to distinguish between lines and polygons, while audio cues and verbal messages were used to signal landmarks. Results showed that, for both categories of users, the digital multisensory map provided equivalent performances compared with a hardcopy tactile one. Another attempt to overcome the issues of versatility and flexibility posed by hardcopy tactile maps was made by Brayda et al. [27], which used a programmable pin array matrix (PAM) connected to a laptop, to obtain a small scale map of a simple indoor environment (i.e. the perimeter of a room and some landmarks). The PAM's configuration was controlled via a dedicated software, and the study was conducted in a laboratory. Participants to the study were provided with the PAM tactile map and a synthetized audio description of the real environment. Tests results showed that the tactile map proved an effective aid in orientation tasks.

As smartphones have become more powerful and pervasive, their popularity has grown as means of increasing the autonomy of visually impaired persons [1]. Smartphones' vibration motors, Text To Speech (TTS) capabilities and accessibility services can be used as low-cost solutions to convey enriched information through the haptic and audio channels. Besides their affordability, solutions based on mobile devices' native capabilities share that they can be easily distributed to large groups of users via mobile app stores on the Web.

Vibration patterns have been identified as a valuable aid for both sighted and visually impaired users. They have proven effective in conveying the priority level associated with notifications [2], moreover, they were successfully adopted to identify logical partitions, icons and functions of a smartphone's graphical user interface, possibly coupled with audio hints [7, 3], thus fulfilling the function of aiding in the construction of an allocentric perception of the graphical interface's elements.

3 Method

3.1 Preliminary Phase

A preliminary study was carried with a digital map of an indoor environment (namely, a shopping mall) enriched with verbal and haptic hints. The digital map was developed for an Android platform, and was obtained from a PNG image of the floor plan of a mall, to whom a transparent "semantic" layer was superimposed. The semantic layer made it possible to issue vibro-tactile hints as the user's finger hovered over a functional area. Figures 1, 2 and 3 show how the digital map worked. In Figure 1, a floor plan is shown, as it was rendered on the screen of the mobile device, while Figure 2 shows the functional areas as they were rendered on the semantic layer. The RGB color encoding was used to identify each functional area, i.e. providing information about POIs categories. Each POI category corresponded in fact to a fixed couple of red and green levels, and was associated to a vibration pattern and a text label (e.g. "Restaurant") while the blue component was used to precisely identify the area by its name (the name of the restaurant itself). According to this strategy, hence, each category could account for up to 256 different POIs. A category was announced via a text-to-speech (TTS) vocal message and a vibration pattern issued via the device's native APIs. The final result is shown in Figure 3, in which three POIs are highlighted, with the corresponding audio and vibration hints. Vibration patterns were designed so that they were as distinguishable as possible, while keeping a low level of intrusiveness. Android does not always allow full control over the vibration motor, in fact APIs to control features such as the waveform or intensity of a vibration are available only for some devices [25]. In order to provide the same user experience for every user, we decided not to involve these factors in the vibration patterns' design.

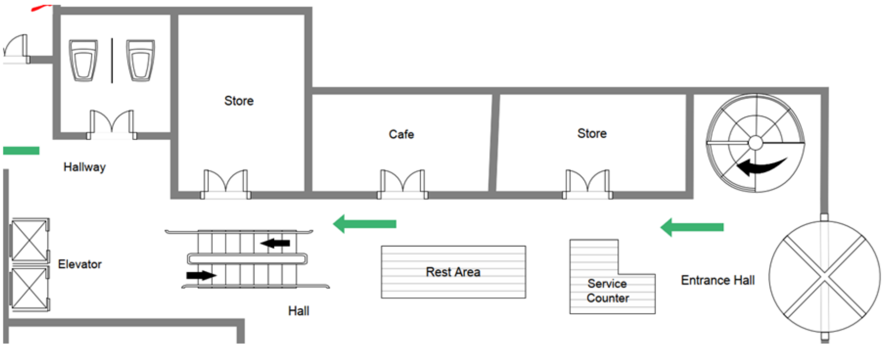


Fig. 1. The floor plan as it appears on the screen of the mobile device, with its different functional areas

Fig. 2. The layer that is superimposed to the floor plan, in which different colored squares account for different categories of functional areas. Each category is identified by a couple of Red and Green color levels. This layer is not visualized on the screen.

In order to evaluate the effectiveness of this approach, two blind users were involved in co-design sessions with a prototype application that was developed specifically for this purpose. The prototype showed a digital map which was composed of 15 different areas pertaining to seven categories. In order to avoid bias, at each session the areas were placed differently. Control buttons (also highlighted in the picture) were added in order to toggle each modality of interaction and evaluate the impact of the audio and haptic channels separately.

Sessions were held remotely via Skype calls, due to Covid-19 restrictions. Participants were preliminarily sent an e-mail containing a link from which they could install the prototype app, and detailed instructions of its functioning. Overall, three sessions of about forty minutes were held, in which Users were asked to practice with the different types of feedback and then explore the map for about ten minutes in order to identify as many POI categories as possible. Finally, they were asked to indicate four specific POIs. Users were invited to think aloud during the exploration, and at the end of each session they were asked to provide us with their impressions and criticisms. Their suggestions were collected in order to refine the prototype and identify strengths and weaknesses of our approach. Figure 4 shows a screenshot of the prototype as it was at the end of the three sessions, in which different POI categories are highlighted.

Sessions with users showed that vibro-tactile hints were appreciated and deemed useful to build a mental map of the mall; the different areas in the map were successfully recognized through the associated vibrations, and users were able to find the POIs they were required to. A concern arose that the cognitive load may become too heavy with very narrow and close areas or for certain categories of users, such as the elderly. It was hence suggested to add a filtering function to the map, so to allow users to receive hints only for chosen subsets of categories. For the same reason, a zooming function was suggested as a way to better distinguish among close POIs. These functionalities were taken into consideration for further evolutions of the digital map.

Although during sessions vibrations alone were sufficient to them to recognize POI categories, users stated that the best feedback configuration was the one combining the audio and haptic channels together, since if a person could not feel the vibration, they could understand the spoken description and vice versa. It was stressed that, depending on the type of disability, not all visually impaired subjects may be equally responsive when it comes to the sense of touch.

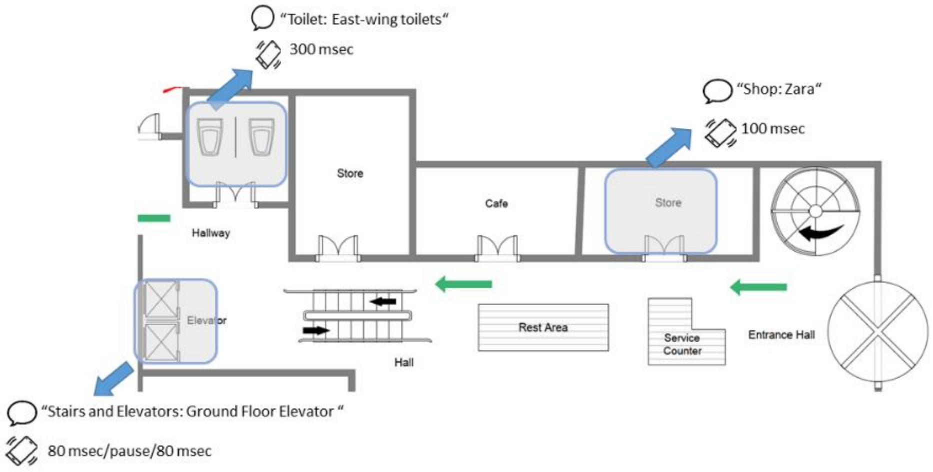


Fig. 3. When the finger swipes over an area identified in the semantic layer, Android's Vibration API and its TTS engine will announce the corresponding category.

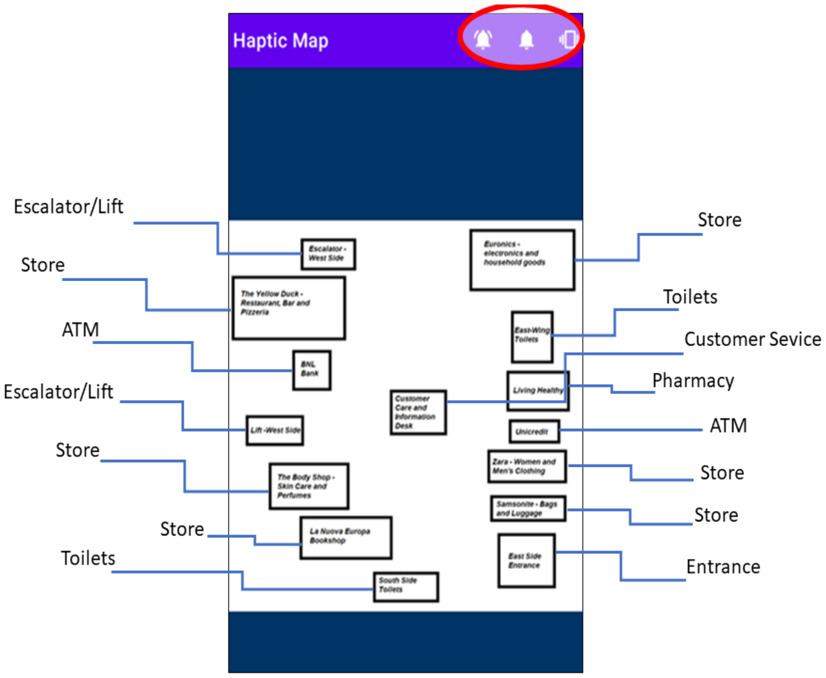


Fig. 4. The prototype used for testing; different categories of POIs are highlighted, as well as buttons to toggle interaction modality.

3.2 Enriching a Downloadable GPS Map

The results of our preliminary study encouraged us to adopt a similar approach with downloadable GPS maps, such as those obtained from Google Maps or OpenStreet Map [29, 31]. Metadata provided by these platforms do not natively support accessibility, hence we had to come up with a strategy to enrich them in analogy with the hidden coloured layer of our early prototype. Our goal was to enrich a GPS map with information to make landmarks and POIs easily discoverable by visually impaired users, possibly in a customisable way. We needed a framework for location and orientation with APIs that would allow to build a customized interaction layer on top of the map's default canvas; this led us to use the Mapbox framework [34], which offers excellent customization capabilities when it comes to define user interactions, and allows to define multiple map layers for data presentation. Mapbox web services and APIs, moreover, provide geospatial data in the GeoJson format [30], an intuitive open standard file format for representing POIs, which can be easily integrated with customized metadata. Figure 5 shows a GeoJson file, and how it is related to two POIs highlighted on a map. The complete metadata file is formed by a sequence of *Feature* objects, in which each Feature consists of a pair of objects, named *Properties* and *Geometry*. We designed the *Properties* object in order to contain metadata related to accessibility hints, while *Geometry* defined the POI on the map in terms of its GPS

coordinates. A *Properties* object contained an *objectId*, a *category* and a *name*. *objectId* was the unique identifier assigned to a POI; *category* was the numerical code assigned to the POI type, and finally *name* was the textual denomination of the POI. C*ategory* fields were used programmatically to issue vibration patterns and TTS announcements related to a specific type, while the POI's *name* was announced by the TTS engine soon after its type.
The following convention was used to define vibration and pauses;

- SHORT_VIB = 100 msec vibration
- LONG_VIB = 200 msec vibration
- LONGER_VIB = 300 msec vibration
- PAUSE = 100 msec silence

An additional 400 msec vibration was used to signal when the user's finger reached the edge of the map, beyond which the focus was lost and then it was necessary to reposition the finger and resume exploration.

Figure 5 better explains the metadata structure. Table 1 shows the patterns used for each POI category and the related spoken labels.

Table 1. The six POI categories and the related vibration patterns and TTS labels.

Category	**UID**	**Vibration Pattern**	**TTS Label**
Shop	200	{SHORT_VIB}	"Shop"
Bar/Restaurant	300	{LONGER_VIB}	"Bar or Restaurant"
ATM	400	{SHORT_VIB,PAUSE,LONGER_VIB}	"ATM"
Public Transportation	500	{LONGER_VIB,PAUSE,SHORT_VIB, PAUSE,LONGER_VIB}	"Public Transportation"
Church	600	{SHORT_VIB,PAUSE,SHORT_VIB, PAUSE,SHORT_VIB}	"Church"
Historical Building	700	{LONGER_VIB,PAUSE,LONG_VIB}	"Historical Site"

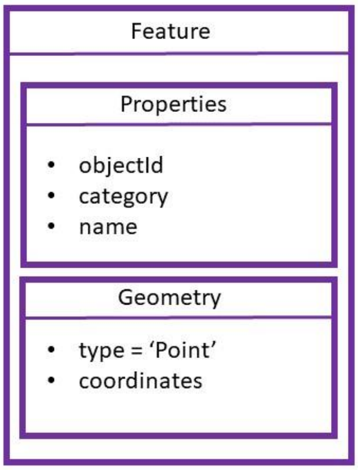
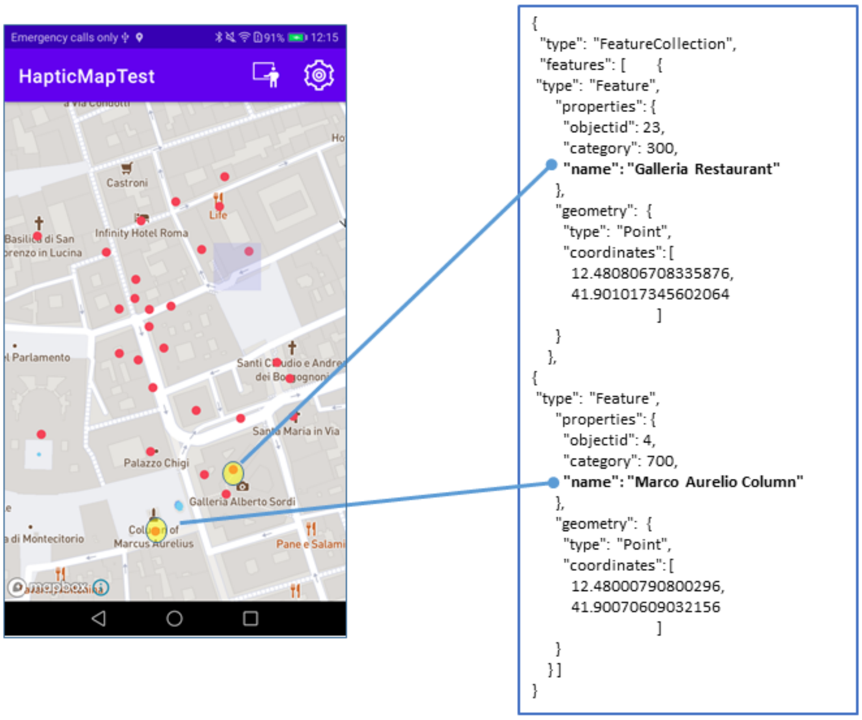


Fig. 5. The nested structure of a Feature GeoJson object, in which the Properties object contains descriptive information about the POI, and the Geometry object pertains to the positioning of the POI onto the map.



```
{
  "type": "FeatureCollection",
  "features": [      {
 "type": "Feature",
     "properties": {
       "objectid": 23,
       "category": 300,
       "name": "Galleria Restaurant"
     },
     "geometry": {
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         12.480806708335876,
         41.901017345602064
                       ]
     }
   },
{
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     "properties": {
       "objectid": 4,
       "category": 700,
       "name": "Marco Aurelio Column"
     },
     "geometry": {
       "type": "Point",
       "coordinates": [
         12.48000790800296,
         41.90070609032156
                       ]
     }
   }]
}
```
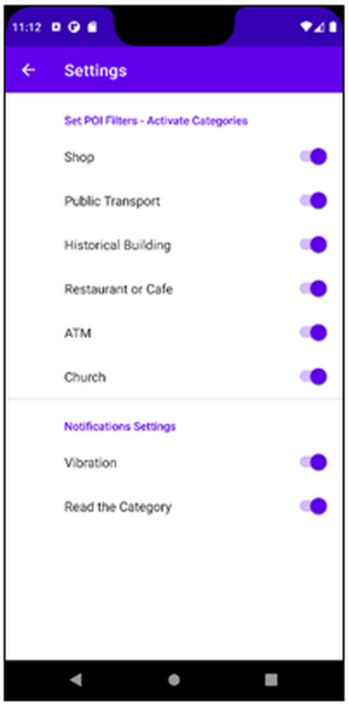

Fig. 6. Correspondences between two points of interest on a map and the related GeoJson metadata

In order to evaluate the enriched map, an Android mobile app was developed. Zooming, category-filtering and feedback preferences were integrated, in accordance with the findings of our preliminary study. Figures 7 and 8 show screenshots of the app that highlight these functionalities.



Set POI Filters - Activate Categories

Shop ●
Public Transport ●
Historical Building ●
Restaurant or Cafe ●
ATM ●
Church ●

Notifications Settings

Vibration ●
Read the Category ●

Fig. 7. A screenshot of the POI Filtering function and the Notification settings.

In order to meet the needs of visually impaired users, we modified MapBox's default interaction modes and controls. We defined an "ad-hoc" layer in which a 48-by-48 pixel draggable square could be moved and issued haptic or audio feedbacks whenever a point of the map related to a POI entered its perimeter. A single tap on the screen caused the draggable square to appear right under the position of the finger, and a special sound notified the user that the square was focused and ready to be dragged around; whenever the finger was lifted, the focus was lost. In order to prevent the map from involuntary panning, which could lead users to lose spatial references [26], we disabled the default gesture for this function. We developed special "pagination" buttons to show adjacent portions of the map, but for simplicity's sake we did not include these buttons in the prototype used for testing. Zooming was associated, as per default, to the "pinch" gesture. A sound indicated when the map was being zoomed in or out, and a TTS message announced the new zooming level at the end of the procedure. In order to limit problems of map shifting as a result of rescaling, we rescaled the surroundings and repositioned the map after each zooming action, in such a way that the last focused POIs were always visible. Unfortunately, for POIs located near the borders of the screen, problems persisted. Finally, to prevent ambiguities due to rotation, we kept the map orientation fixed to north.

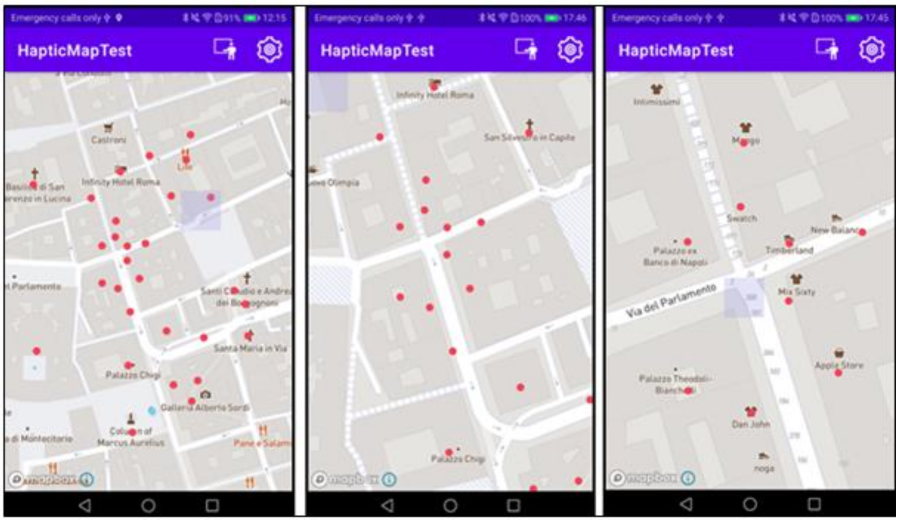


Fig. 8. A zooming sequence; red dots are the POIs rendered in accordance with the GeoJson description.

3.3 The Testing Procedure

Tests were carried out with seven volunteers, 5 females and 2 males, aged 42 to 65, recruited in Pisa, Italy, via the Italian Association for the Visually Impaired (UICI) [36]. Among them, four were affected by severe binocular visual impairment, while three were affected by binocular blindness. All participants provided written informed consent. Table 2 summarizes the main characteristics for each participant; degrees of visual impairment are defined according to the WHO visual impairments classification [35].All of the participants had experiences of use with navigation and mobility apps.

At first, we had considered to set up the tasks by assigning them a time limit for the execution. During the first sessions with the participants, however, we found that they were more comfortable performing the tasks in a less restrictive manner, particularly by talking with the researchers to satisfy their curiosities and express their thoughts. We hence decided to leave each participant free to perform the assigned tasks without setting time limits, but observing whether each one was able to complete the task smoothly, i.e. by interacting with the map without the need for external help, or conversely whether they had noticeable difficulties during the interaction. Non-blind participants were left free to interact with the app using their residual view, but screen magnification was disabled on the devices, since it hindered the correct functioning of the prototype.

After an initial training phase of about ten minutes, nine tasks were sequentially assigned, that were focused on assessing the users' ability to distinguish among different POI categories and locate their relative positions on the map. In order to collect information about the participants' user experiences, they were invited to think aloud during the training phase and while executing the tasks; in the meanwhile, we took note of their observations, questions and difficulties.

Tasks were carried out using two Huawei MediaPad T5 tablets, running Android 8 and an Oppo A74 running Android 12. After all the tasks were performed, the System Usability Scale (SUS) standard questionnaire [25] was administered, and participants were asked which kind of hint they were more comfortable with, between audio, vibration, or the combination of both. Finally, we asked their opinion about using a digital map like the one they had tested on a regular basis in a typical scenario such as looking for a store in a shopping district.

Table 2. An overview of the participants recruited for the test sessions.

Participant	**Age**	**Gender**	**Visual Impairment**	**Familiarity with Mobile Technologies**
P1	52	M	H54.1	High
P2	48	M	H54.1	Medium
P3	65	F	H54.1	Low
P4	54	M	H54.0	Low
P5	42	F	H54.0	High
P6	49	M	H54.0	High
P7	48	M	H54.1	High

Table 3. The tasks proposed during our test sessions.

Task	**Zoom**	**Audio Feedback**	**Haptic Feedback**	**POI Filters**	**Description**
1	Max	OFF	ON	None	How many categories can you detect?

2	Max	OFF	ON	Bus stops, Churches, Shops	How many categories can you detect?
3	Min	OFF	ON	None	How many categories can you detect?
4	Min	OFF	ON	Bus stops, Churches, Shops	How many categories can you detect?
5	Min	ON	ON	None	How many historical buildings can you detect? Can you recall their relative locations?
6	Min	OFF	ON	None	How many historical buildings can you detect? Can you recall their relative locations?
7	*Use case* – Short trip planning: "You are about to travel to Rome for a business meeting. At the end of the meeting, you would like to visit a couple of historic buildings in the centre of the city, withdraw some money from an ATM, and get something to eat before taking a bus to the station. Use the map and the app features to find the most convenient places to pursue your plan."				
8	*Use case* – Recall the relative position of POIs: "Can you remember where the historical buildings are placed on the map? Can you name them?"				

3.4 Test Results

Most of the participants were able to complete the required tasks autonomously, anyway, age and familiarity with electronic devices did play a role. In particular, P3, a 65-year-old who had developed severe vision loss during the past two years, and who was not particularly used to using assistive technologies, needed additional assistance to interact with the map, just as P4, a 54-year-old, blind since birth, who explicitly declared that he rarely used technology "as a sight substitute", preferring human interactions (i.e., asking people for help and information). Two of the non-blind participants, P1 and P2, were not used to rely on the sense of touch, as they habitually used the screen magnification function of the smartphone to interact with its interfaces.

All the participants agreed that tactile hardcopy maps are outdated nowadays, and they greatly appreciated the ability to interact with a digital map on their mobile devices via the vibro-tactile channel. All of them accorded their preference to the haptic channel when coupled with the audio channel, thus confirming what had emerged during co-design sessions of our preliminary study and the findings in [10]; they considered in fact this composite feedback as the most reliable. The haptic channel was mostly appreciated by blind participants, whom proved more skilled at feeling the vibration patterns correctly, and discriminating among different patterns. Among the non-blind, P1 and P2 in particular showed more difficulty relying on the haptic channel, since magnification had been disabled. They both claimed: "*I find it extremely difficult to get information relying on different kinds of vibrations. If I need to check something on the screen, I just use the magnifier and search*." Pattern recognition tasks (i.e. tasks 1 to 6) showed that out of the 6 patterns present, participants were only able to remember between 3 and 4. However, all the participants pointed out that probably with more training they could have done better. Pattern recognition was more precise when category filtering was enabled, and with a proper use of the zooming function, which augments distances between POIs on the screen, again confirming what had emerged during our preliminary study. Participants that experienced particular difficulties in perceiving vibrations were asked to repeat tasks 1 to 6 by using the smartphone, holding it in their hands while exploring the screen. This modality of interaction proved much more effective in conveying the haptic channel, due to the fact that the vibrations were perceived also by the palm of the hand holding the device. Tasks 7 and 8 were successfully accomplished by all the participants but P4. P4 explicitly stated "*I hate to relate with the external world via an electronic device. I'd rather communicate with people and ask for directions and information*", while the other participants, albeit with different levels of difficulty, completed the tasks.

Concerning the use of the enriched map as a support for real-world navigation, all of the participants stated that it could be a valuable support before visiting an unfamiliar environment, maybe integrated in one of the existing apps for orientation and mobility as an "overview" functionality.

SUS scores per user are shown in Figure 9, in which different colors identify different visual disabilities.

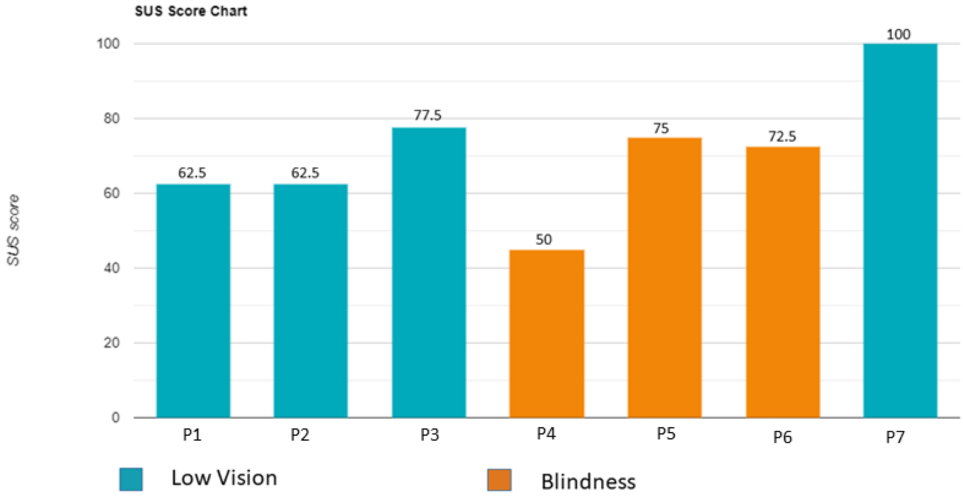


Fig. 9. SUS scores assigned by participants at the end of the test sessions.

4 Conclusions and Future Work

We have described an approach to exploit the haptic and audio channels in order to make GPS-based mobile maps more accessible for users with visual impairments. Our goal was to enable the target users to derive an allocentric mental representation of a physical space from a downloadable GPS map. For this purpose, we developed an Android prototype for a georeferenced map, described by the GeoJson data format, upon which we superimposed tactile and audio hints to indicate locations, categories and descriptions of relevant points of interest. The prototype underwent test sessions with volunteers affected by severe visual impairments or total blindness. Test users highlighted the validity of our approach as an evolution of traditional hardcopy tactile maps. In order to derive more meaningful usage and liking statistics, we are planning to perform more tests with a wider audience. These tests will also be necessary to allow a better insight of the problems related to different users' needs based on factors such as age, or the kind of visual impairment. Functionalities such as panning and rotation also need to be integrated in a future release of the prototype and tested. At the time of writing, well known issues persist between Android's assistive technology (TalkBack), touch interactions and apps that use the vibration service. In the case of our prototype, this produced unpredictable interaction problems when TalkBack was activated. If these bugs will not be fixed in the near future, effective workarounds must be found before developing a new prototype for a wider audience, especially if it will be meant to allow for tests without supervision. We are also planning to do further research on vibro-tactile hints design, to find possible strategies (e.g. pattern personalization) for easing their memorization. Finally, in order to enhance POI descriptions, interoperability with FourSquare may be considered.

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6 Author Information

6.1 Funding and Competing Interests

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6.2 Contributions

MP conceived the idea on the basis of this study and took the lead in writing the manuscript. BL contributed in the editing and revision process. MP conceived the prototype, BL recruited the participants for the test sessions and planned the user tests with MP. MP developed the prototype and carried out tests and interviews with participants *in situ*.

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