Accessible Maps for the Visually Impaired

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Abstract. Map systems for the visually impaired are designed for pre-journey and mobile use. Both indoor and outdoor systems are known and systems become web-based. We discuss their design issues and review some of the missing features for better acceptance of such systems, like interactive interfaces and social web features.

Keywords: visually impaired, tactile map, virtual map, GPS-based map, multi-line Braille display.

1 Introduction

Maps have been evolving together with the development of science and technology. From the ancient parchment map to explore the continents, to cheap and portable paper-based maps, and then to today's maps rendered on computers and mobile devices, the functions of maps are extended by a large number of applications. An electronic map represents enormous data via vision such as a satellite view, real-time traffic layer as well as route path, rather than basic functions to explore the geographical world.

Although there are various new technologies applied in map production, people who are blind and visually impaired still have various challenges to access maps and relevant applications, and most of them wouldn't know the layout of the earth, the cities and streets where they lived. In the WWW maps are considered as images. However it is difficult to provide an alternative description for this class of images in order to make them accessible. Orientation development or routes are based on graphical representations. At the same time, those citizens are unable to travel safely and independently, and restricted to take part in everyday social activities. Furthermore, owing to the issue of aging worldwide, in 2009 the World Health Organization (WHO) reported there are about 314 million people visually impaired, and 65% of them are age 50 and older, specifically about 19 million are children below age 15[1]. While it is an urgent issue to make maps accessible for users who are blind and visually impaired, solutions suitable for elderly people must be found.

In this article, we review existing approaches in maps for the visually impaired individuals, applicable guidelines of design, and methodologies of evaluation. From the perspective of mobility, we distinguish two types of maps, desktop-based maps including paper-based maps, computer-based virtual maps and novel Braille tactile maps, and mobile maps mainly focusing upon GPS-based maps. New features become possible in both types, which should be integrated into future map systems like interactive user interfaces and social interaction, in order to take into account different user requirements in desktop and mobile environment.

2 Research on design accessible maps

In order to investigate different methods to design accessible maps for the visually impaired, we distinguish two types: desktop-based maps and non-visual mobile maps, most of which are GPS-based. Printed tactile maps may be carried by blind pedestrians on the move, they compete with electronic devices. While designing an accessible map, in addition to the representation of geographical features (e.g. streets, bus lines, bus stops, etc) via different media, it is crucial to design the user interface to ensure input/output information without barriers for people with visual impairments. In previous work there are 3 kinds of methods to explore maps with non-visual interaction, which are though tactile perception, acoustic perception, and by audio-haptic channels.

2.1 Desktop-based accessible maps

Printable tactile map

Printable tactile maps are maps produced by swell (or microcapsule) paper, thermoform diagrams, Braille embossers and similar technologies, which offer haptic perception to the fingers. A number of guidelines of designing a tactile map have been published [2],[3],[4]. Edman described the design of tactile maps from the perspective of tactile graphics[4], and packs of map symbols were provided in Nottingham Kit and Euro-town-kit from early studies to promote standardization of textures. In an international survey study [5],[6] it is mentioned, swell paper and thermoform are the two most popular methods to produce tactile maps, and various suggestions on size, tactile symbols, labels, legends and other map elements are given. Due to the limited haptic sensitivity of fingers, researchers conducted user experiments to investigate distinguishable lines and symbols in design process [7], [8], [9].

Most production methods of printed tactile maps are manual, and hence labor intensive and time-consuming. Thus, aiming at enhancing efficiency of production, a couple of automatic approaches have been implemented. Most of them obtain map data from geographic information system (GIS), and then render map elements in different styles. The TMAP project (Tactile Map Automated

Production) [10] creates larger tactile street maps for towns or cities in the USA from a GIS, consisting of numerous roads and streets. Labeling on tactile street maps automatically is one of the most challenging tasks, a special labeling algorithm in TMAP project has been employed to calculate the best position of street names in a large printed tactile map [11].
As a result, regardless of materials (e.g. swell paper, thermoform diagrams and Braille embossers), most design principles are similar. For instance, maps should contain main map elements, such as roads, streets, buildings, points of interest and other elements like legend and orientation, and label them in Braille text. Because it's impossible to overlay map elements other than thermoform, there is few content available to be rendered on the printable tactile maps. On the other hand, tactile maps support haptic perception by fingertips. This helps to establish a mental map easily with distances and orientations.

Virtual acoustic map
The limitations of paper-based tactile maps to overlay any geographic data and integrate a legend may be avoided by acoustic output. Verbal and non-verbal audio output has the capability of representing information in quantity from a visual map. While designing it doesn't require extra tasks to render a digital map from GIS, and design the acoustic rendering module, such as sonification of sounds and control of a speech synthesizer. For instance, Zhao proposed an interactive sonification to access census data on a visual USA map [12], and a 3D sonification of city maps has been implemented to transform the map elements (e.g. lakes, parks) into different acoustic signals[13].

Virtual tactile map
In order to overcome the disadvantages of paper-based tactile maps, the concept of a virtual tactile map has been proposed to render more information and let users explore flexibly tactile displays through a computer [14],[15]. Other than paper-based tactile maps, virtual tactile maps are not presented on real printed maps, however, instead with computer-based devices, where map elements are from off-the-shelf GIS mostly. Thereby, users don't need a great deal of burden to design special map elements to explore larger spatial areas more effectively. As input/output channels, a number of haptic devices are employed (e.g. joystick, Phantom haptic mouse [16],[17],[18]. Meanwhile, their auditory output represents not only simple sonification but also various geographic data, such as the names of cities.

Augmented paper-based tactile map
A combination of paper-based tactile maps and virtual tactile maps are audio-haptic tactile maps. It requires a both a tactile printer to produce maps, and touchable pad for exploration. There are 4 steps needed to produce and utilize an augmented paper-based tactile map, as shown in Fig. 1. At first, an algorithm to automatically generate map elements from GIS such as TMAP [10] or from map

images [19] should be carried out to create tactile street maps. After production of maps via Braille printers, the paper-based maps can be mounted on a touch-sensitive pad. In the end, users explore maps with their fingers, and obtain more detailed information with the help of auditory representation [19, 20].

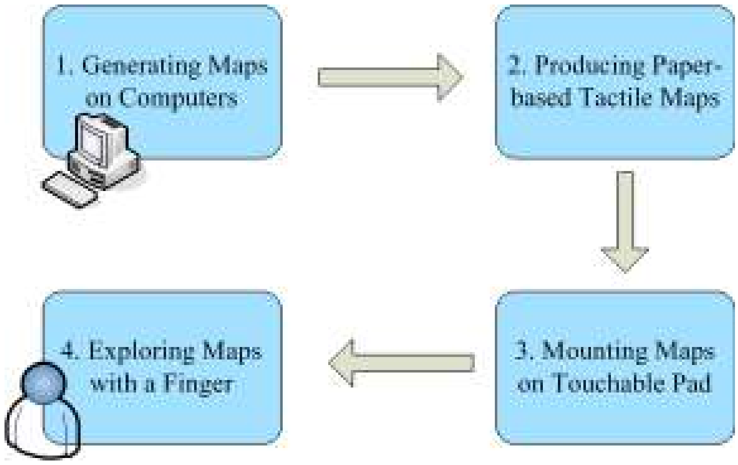

Fig. 1: Augmented paper-based tactile maps in 4 steps

Recently multi-touch displays such as the iPhone are utilized without tactile feedback but through kinaesthetic control and spoken feedback alone.

Braille tactile map

Although augmented paper-based tactile maps increase information density, they are restricted to the size of the touchable device. Furthermore, the process needed to produce printed tactile maps is contradicting to the concept of multiple exploring geographical regions and not suitable for web browsers.

Novel tactile and touch-enabled Braille displays offer a new opportunity to design a completely automatic tactile map system for the visually impaired. Map elements are presented through raised pins. In [21] an audio-haptic map system has been developed to access geographic data on a HyperBraille[1] display, in which a set of tactile symbols is employed to represent points of interest and several manners to explore maps (e.g. panning, zooming, search, etc).

Discussion on future features of accessible desktop-based maps

From traditional paper-based tactile map to latest multi-line Braille display, currently individuals with lack of a vision are able to select suitable solutions to explore geographic maps at desktop-based environments, while few paper-based ones are available for mobile requirements. However, which features should be

[1] www.hyperbraille.de

promoted for future desktop-based accessible maps in the digital era? Simplicity of maps is still one of the most important general guidelines. As illustrated in Table 1, different features of various desktop-based accessible maps are possible.

Table 1. The comparison of various desktop-based accessible maps

Map Type	Device/ Material	Map Size	Amount of Information	Representation	Production	Interaction
Printable Tactile Map	swell paper, thermoform, embossing, Braille printer, etc	small	small	raised lines, symbols, etc	by Hand	tactile perception against fingertips
Virtual Acoustic Map	computer, earphone	large	large	visual map	automatic	audio output
Virtual Tactile Map	computer, earphone, mouse, joystick, force feedback devices, etc	large	large	visual map	automatic	haptic and audio output
Augmented Paper-based Tactile Map	swell paper, Braille printer, earphone, touchable pad, computer, etc	small	medium	raised lines, symbols, etc	semi-automatic	tactile and audio output against fingertips
Braille Tactile Map	computer, multi-line Braille display, earphone	large	large	raised pins	automatic	tactile and audio output against fingertips

Maps created by virtual approaches need fewer attentions to be designed, as map elements are rendered more automatically and follow different style sets, e.g.

streets in different styles, and from families of map symbols. Involvement of kinaesthetic perception may help to match spatial geographic data with the tactile interaction against fingertips (e.g. distances, orientation). The advantage of audio output is the provision of geographic data in detail and may be both verbal and non-verbal.

Tactile maps on multi-line refreshable Braille display meet many of the recommended capabilities, they should be a very promising solution in the future. New multi-line Braille displays will be developed to support different applications and in particular are suitable for mobile use.

2.2 Non-visual Mobile Maps

Maps for mobile use provide individuals with visual impairments to access maps flexibly on their journey through mobile devices. At the same time, mobile maps mostly focus on rendering the surrounding areas where the users is and instructions for navigation, rather than exploring a large geographic area.

2.2.1 GPS-based Maps

GPS-based maps are the most common of non-visual mobile maps as they have evolved since the 1990's when the GPS was used to guide the blind outdoor [22], [23],[24]. The design of representation of map data is often more simple on mobile devices than on tactile maps. Most of them avoid rendering streets and symbols, but connect to an off-the-shelf GIS to inquire place names, like "where you are", "nearby POIs". The verbalization of landmarks will allow individuals with vision impairments to locate themselves precisely in the contextual surroundings[25].

Another significant task to implement an accessible GPS-based map is the design of user interfaces suitable for mobile non-visual interaction. The acoustic channel is considered as a reliable and convenient output for the visually impaired, and has been used in almost all of current GPS systems to deliver detailed map information, e.g. Trekker GPS[2], Kapten[3]. Furthermore, a few systems support to transmit data via Braille displays, like BrailleNote GPS[4]. Apart from obtaining map data via pressing a pre-defined button or menu, in recent years, the booming touch screen mobile devices provide new opportunities to read map through moving fingers against the surfaces. For instance, a smart phone-based application named Ariadne GPS[5] enables users to explore city maps to get the names of streets or POIs while touching the display. Specifically, for younger blind people a playful game-oriented interface will enhance their learning and

2 http://www.humanware.com/
3 http://www.kapsys.com
4 http://www.senderogroup.com/
5 http://itunes.apple.com/en/app/id441063072?affId=1777033

utilizing more effectively[25].

2.2.2 Maps on Portable Tactile Displays

Due to the smooth surface of touch-sensitive mobile devices, they are full of challenges that users would not percieve map elements explicitly and promptly, if exploration of the whole screen is not careful enough. Portable tactile displays combine the mobility features with explicit tactile features and offer a better solution. Already in [26] researchers represented a simple obstacle map on a tactile display equipped by 8 x 8 vibrating microcoils. This indicates the possibility to render more complex map on a larger tactile display. Thereby, the design of this kind of maps considers not only how to render tactile map symbols on the small display, but also suitable interaction in mobile environment, such as the user's changing position, speech recognition interface or selectable audio output.

2.2.3 Discussion on future features of non-visual mobile maps

Evidently, there do exists fewer types of accessible mobile maps for the visually impaired at present, in addition to mainstream GPS-based maps. However, due to the increasing number of users interested in better mobility and a large number of new devices it is predictable that various kinds of mobile maps will be applied, aiming at satisfying users on the go. In consequence, which features are to be integrated into the future accessible mobile maps? The acoustic output channel is determined to deliver map data as detailed as possible. Exploration of maps on touchable mobile devices is another new promising feature to obtain map information immediately. Meanwhile, Braille output would be an alternative method to enhance outdoor safety because audio output might interrupt users' perception of surroundings, especially when passing streets and crossings. In particular, the explicit perception of map symbols via raised pins will enable users to explore maps rapidly and establish more precise cognitive maps than on smooth surfaces. Furthermore, beyond as one part of guidance systems the wearable equipment will comprise of various novel applications.

3 Research on evaluate accessible maps

The sighted map readers gain information through visual text descriptions, a variety of colors and styles, as well as boldness of particular lines. Visually impaired persons have to depend on their ears and fingers to explore the maps and gain all information involved simultaneously. Efficiency and effectiveness of maps require to develop geographic tasks and measuring appropriate criteria.

3.1 Desktop-based map

Tactile map on fingertips

The tactile map is a very common form of accessible map for the visually impaired, especially on microcapsule and thermoform materials. Criterions have not been changed enormously in evaluations of thermoformed[27], microcapsule-formed maps[28], comparison of both[29], and electronic tactile maps [19],[20],[21].

Being an essential part of tactile maps, individual symbols such as tactile directional symbols[8] are assessed against minimal perceptible distance between tactile features and optimal elevation through adjustment of corresponding parameters[7]. Accuracy of recognition of symbols is one of the most important criterions.

Evaluations of tactile maps are full of challenges due to their complexity and participants' rare map experiences. The method of re-creation of mental maps and locating map elements after a training task is considered as one effective way to evaluate how the subjects learn from the tactile maps and understand relationships among map elements. In [19] the blind participants were asked to find out two pre-defined landmarks, and [9] let the users re-create maps as much as possible in five minutes. In addition to accuracy, recall is another criteria to assess how much the participants grasp the maps, as well as their elements.

Another major task is to find a route from start to destination. The evaluation of a route building is a more complex than locating individual symbols and re-creation maps. It requires the participants to locate the starting point and destination, and then form a possible route along related streets and points of interest. In [19] researchers simply tested subjects to trace the route between two landmarks at a desk-top environment. A Levenshtein distance can be calculated to measure the difference between routes formed by users and the optimal route based on the nodes and edges visited.

The speed of reading a route also impedes the recognition rate of landmarks along the routes. The time spent to find a route is sometimes a useful indication to illustrate how long the subjects need to get an overview[19], [30].

3.1.2 Virtual map

The virtual map is representing map features as part of a selection task through acoustic output and haptic devices (e.g. force feedback devices, vibration, joysticks). The main task in virtual maps focus upon how to explore whole maps and comprehend all information[13], [16],[17],[18]. The angular error, subjects create to locate themselves on a sea map while navigating a sailboat is a more specific measure. But recall of angles itself is error prone. Evaluation suffer also from finding sufficient number of subjects, and often pilot studies are reported with one or two subjects [15],[16],[18]. Blindfolded participants [13], however, have not acquired the necessary orientation and mobility skills as blind people have.

3.2 GPS-based mobile map

Similar to virtual maps, the evaluation of GPS-based mobile maps needs to isolate the usability of the representation of map elements from the user's understanding of the real world. In addition, the user's own position or even route has to be incorporated. Establishing ground truth becomes even harder if the user is moving. If the user has no mental map (in other words never has been there or heard about the place), the system's capabilities are evaluated only for a subset of scenarios.
While navigating, the users are enabled to establish a cognitive map from the real environments as precise as reading a physical map[32],[33], and mapping the mental model of the geographical features such as current location, street name where walking on, nearby landmarks[34] may be evaluated from classic think aloud protocols or reported by a sighted follower.
The very common criteria to assess interfaces in the real world people without isolating some features are scores from users' subjective feedback, e.g. [31]. It is still the most effective methods to evaluate how the users perform by observing blind individuals' behaviors in an uncontrolled/controlled environment. Due to the inaccurate location of GPS, [35] employed a reference station to improve the accuracy at level about one meter, when participants made annotations on a campus map. The audio-based GPS[36] proposed so called "hour system" to assess accurate heading directions and counted steps to estimate distances from the starting points to destinations. As a subjective measurement, the time needed is usually a criterion used to evaluate how long the subjects complete routes, e.g. [37],[38].

4 General Discussions

Standardization of Braille map symbols: New developments of hardware such as multi-line refreshable Braille displays or vibrating touch displays improve access to graph-based contents (e.g. digital maps). Tactile maps might be the type of accessible map for the visually impaired in coming future. Therefore, it is necessary to consider how to design a standardized Braille map symbol set consisting of raised pins or other haptic cues.
More desktop applications: There are a number of interactive map-based applications on desktop computers through visual representation of geographic data. Evaluation of their accessibility should be developed. In order to satisfy increasing requirements of visually disabled individuals more and more individualized map features should be integrated, such as color settings, font selection and route verbalisation.
Mobile map exploration: Although millions of users with vision impairments benefit from mobile maps within wayfinding systems, it's still full of various challenges to explore maps freely rather than mechanical turn-by-turn commands. The booming touch-sensitive mobile devices will play a more important role in the future, specifically the portable multi-line Braille display. Meanwhile, how to

investigate the accuracy and effectiveness of mapping a mental mode of outdoor surroundings (e.g. nearby POIs) presented on touch-enable devices, should be compared with the methodologies applied on paper-based tactile maps.

5 Conclusions

There are several accessible maps satisfying different requirements from individuals who are blind and low vision at a desk-top and mobile environment. In recent decades the users have been used to low-cost paper-based tactile maps (e.g. thermoform-forming and microcapsule-forming). Those maps have disadvantages and do not meet increased needs. Various new solutions through electronic equipments have been implemented, from the computer-based virtual maps to novel Braille tactile maps. In particular the GPS-based maps extremely help users go travel independently.

Design guidelines have not been adapted and specific map designs depended on the particular features, materials and platforms. For instance, the standardization of map symbols on microcapsule maps isn't suitable on refreshable Braille displays which only have two status of each pin, raised or lowered.

More and more new features will be integrated into the current map-based applications such as interactive interfaces (e.g. zooming, panning, and searching), and social interaction, in order to extend the manners to make use of maps. At the same time, different map solutions require new strategies of evaluation. Evaluation should be more flexible through subjective and objective measurements (e.g. time, accuracy, error), and for truly user centered design the analysis of evaluation results must be directly effective and convincing to developers.

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