GeoCoach: A cross-device hypermedia system to assist visually impaired people to gain environmental accessibility

Limin Zeng · Gerhard Weber

Introduction

During the past decades, a huge amount of geographic data has been collected by geographers, governments, and professional corporations in GIS, and is becoming one of the foundational elements of location-based services (LBS), such as navigation and map exploration services. It is conceivable that without detailed information about environmental accessibility in GIS, however, LBS would have trouble in satisfying the requirements of people with special needs. For instance, wheelchair users cannot use routes consisting of many stairs/curbs, and visually impaired people might end up in a dangerous situation when walking on routes that include streets under repair or construction. To provide suitable LBS for them, it is important to collect such environmental accessibility data as much and in as much detail as possible.

It is evident that it is a cost and a time-consuming task for geographers, governments, and professional corporations to collect such environmental accessibility information with traditional methods. To provide environmental accessibility in cities for citizens and tourists, many cities spend a huge amount of money and time on collecting accessibility information by a large number of employees. For instance, building the smart and accessible city of Berlin, the project "*Mobility for All*" employed about 200 workers to collect information on disabled access for over 35,000 facilities[1]. Furthermore, much more extra effort is required while updating this accessibility information.

As an efficient method, the crowd-sourcing approach has been employed in a large number of applications for gathering data from users, such as the free worldwide map data provider *OpenStreetMap*[2] (OSM, [9]). Although there are a number of applications that allow sharing environmental accessibility information, most of them focus on wheelchair users and pay little attention to the visually impaired. In addition to collecting specific information for visually impaired people, it is essential to implement accessible non-visual user interfaces in various assistive tools.

In this paper, we present an accessible and cross-device system to help visually impaired people access and share environmental accessibility via volunteered geographic information (VGI). The system, namely GeoCoach, adopts adaptive user interfaces to support users to acquire such geographic based accessibility information on three different devices, i. e., desktop computers, smart phones, and tactile pin-matrix displays. The evaluation results with visually impaired participants indicate the effectiveness of the proposed GeoCoach system.

Related work

Accessible maps for visually impaired people

Compared to the traditional productions of accessible maps for visually impaired people, such as those on swell paper and embossing paper, computer-based methods have been applied widely in the last decades due to their advanced features, such as, e. g.,

[1] Mobidat: http://www.mobidat.net, last accessed on 8.1.2017.

[2] OpenStreetMap: https://www.openstreetmap.org/.

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Abstract

Benefiting from today's global positioning systems (GPS) and geographic information systems (GIS), visually impaired individuals are able to travel more independently than before. However, due to a lack of accessibility information about geographic features, those navigation systems fail to satisfy their special requirements. To help visually impaired people access and share environmental accessibility information in cities ubiquitously, this paper presents a collaborative and cross-device hypermedia system, namely GeoCoach. In addition to desktop computers, visually impaired people are able to access environmental accessibility on a pin-arrayed display and on mobile phones. The two user studies conducted with visually impaired users indicate that the proposed system was effective.

importing map data from GIS, automatic production, and the provision of rich interactions while accessing [7]. The augmented paper-based method allows users to acquire auditory descriptions of tactile graphics via touching a map overlay coated on a touchpad; however, a separate Braille printer is required to produce tactile graphics, like the ViewPlus IVEO-based map system [5, 20]. The Talking Tactile Tablet (TTT) system develops an automatic method to create a street map by processing map data from GIS, but its maps do not contain various POIs [15]. Due to a lack of explicit representation of tactile graphics and with only a single point of contact, virtual maps hardly support the use of multiple fingers or two hands [12, 17]. Although touchscreen devices provide the chance for blind people to access auditory maps [13], users' performances are not good due to lack of explicit tactile sensation [25]. Although [25] developed a pin-matrix display-based geographic data explorer, there are few studies that investigate how to represent other types of geographic data for the visually impaired, such as environmental accessibility information.

Collaborative accessibility applications for visually impaired people

Since the last decade, the concept of collaborative accessibility has been proposed to improve information accessibility for blind and visually impaired people. The base concept of collaborative accessibility is to use a crowdsourcing approach to collect various types of accessibility information by volunteers and end users [4]. In a social accessibility project, independent sighted volunteers create alternative text descriptions for images in inaccessible web pages for blind users [18]. The research in [2] indicates that the collaborative approach would make alternative text with higher quality through many volunteers' efforts than using artificial intelligence-based methods. Moreover, Bigham et al. developed the VizWiz system to allow sighted community to nearly real-time answer visually impaired users' daily questions described by photos [3], as well as the TapTapSee[3] software for mobile devices. The GoBraille system allows blind and blind-deaf people to access real-time bus information and bus stop accessibility information, which is sourced from the end users [1]. However, there is little attention being paid to developing a cross-device platform to support users to access services in desktop and mobile scenarios.

Collaborative environmental accessibility for visually impaired people

As Goodchild pointed out the concept of "citizens as sensors" to create the world of volunteered geography [8], i. e., the collaborative approach, has become a solution for acquiring information on environmental accessibility for disabled people. The WheelMap system, an OSM-based system, helps wheelchair users find which places are accessible or inaccessible in cities, and accepts new reports on environmental accessibility. The Talking Points system [22] provides environmental information on POIs along routes and applies a universal collaborative approach for both sighted and non-sighted users. [10] addressed a crowdsourcing method to collect accessibility of bus stops by exploring maps in Google Street View. Most of existing applications for visually impaired people rely on auditory output, either text-to-speech (TTS) or sonification; nevertheless, the auditory output is not good enough to represent geographic data. Different tactile representations of geographic data and environmental accessibility information should be considered. Although the mPASS system collects accessibility information from sensors, users, and experts, there is

[3] TapTapSee: http://www.taptapseeapp.com/.

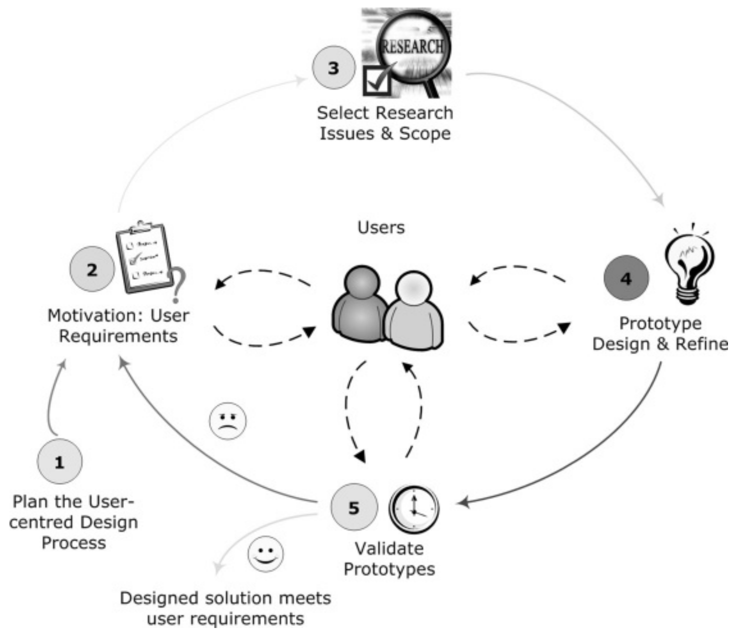


***Fig. 1** The user-centered design process of the GeoCoach system*

no detailed description of the categories for visually impaired people [16].

VGI on environmental accessibility

While annotating VGI on environmental accessibility, in general, there are two different types of content: structured and unstructured annotations. A structured annotation uses a structured rating mechanism to assess the accessibility of geographic features and can be used in route planners. For instance, the Wheelmap system lets participants update accessibility status of POIs through four simple structured levels (i. e., yes, limited, no, and unknown). Besides, the Ourway system [11] and the RouteCheckr system [19] make use of structured annotations to generate personalized routes for people with special needs. An unstructured annotation describes detailed environmental accessibility. The Navatar indoor navigation system augments the indoor environment for the visually impaired by annotating indoor landmarks via unrestricted descriptions, such as "Follow the wall to your left until you reach a hallway intersection" [6]. ClickAndGo[4] and SoNavNet [14] employ unstructured verbal or text description. Nonetheless, there are few systems that combine both of the two types of environmental accessibility information together, as well as multimedia annotations.

GeoCoach system

User-centered design

According to the ISO 9241-210 Standard, a user-centered design strategy will be adopted (see Fig. 1). To acquire the requirements of outdoor mobility by blind and visually impaired people, an international survey has been conducted. After analyzing their responses, we selected the research issues related to environmental accessibility, which has been paid less research attention in the last decade. Furthermore, blind and visually impaired users were involved in the evaluation of the proposed system, and their feedback was collected towards an improved system.

User requirements

64 blind subjects and 33 people with low vision from 13 countries (e. g., Germany, UK, China, etc.) participated the survey [23]. In the study, we found that 35.0 % of the blind subjects mostly needed a partner while travelling outdoors, as well as 21.2 % of the low vision subjects. There are many barriers preventing them from an independent journey, such as public transport stops or facilities lacking audio information, various obstacles, and complex situations in unfamiliar areas. Mobile phones (including

[4] http://www.clickandgomaps.com/.

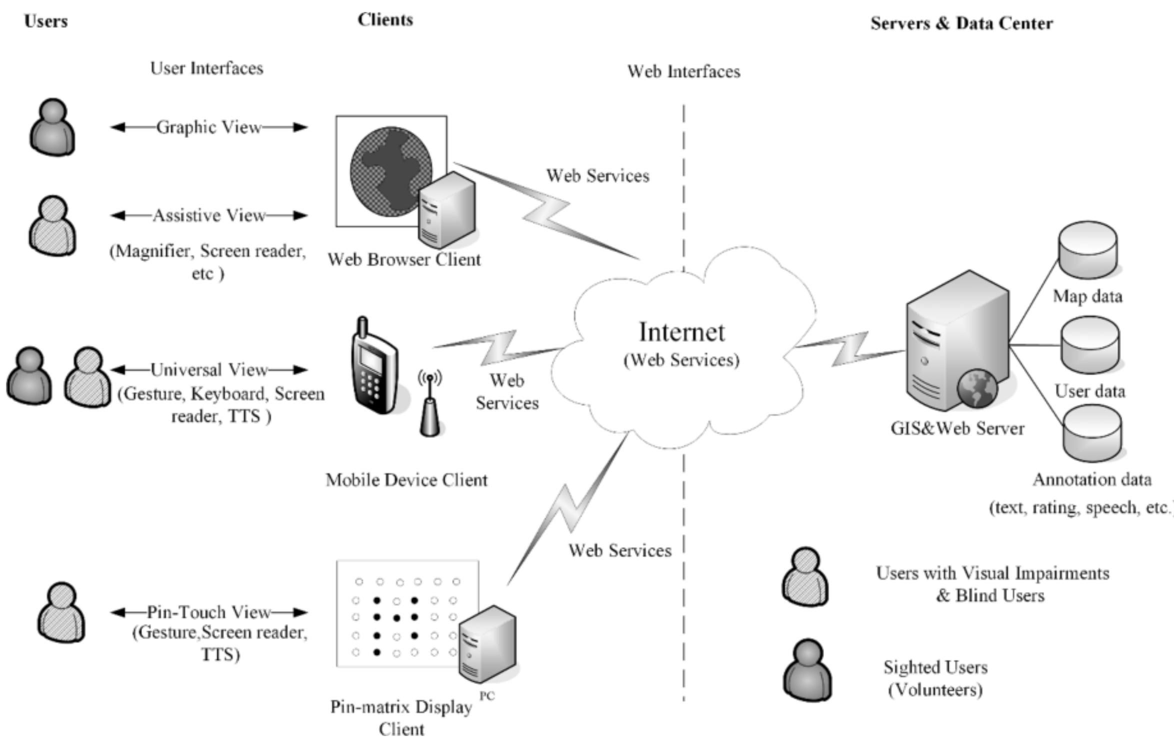


Fig. 2 The overview architecture of the GeoCoach system

smart phones) have a high acceptance (97.7 %) in the community. Although GPS navigation systems are helpful for these people to pursue independent journeys, those navigation systems still cannot satisfy their specific needs. The survey indicated that 69.7 % reported the most important shortcoming of current navigation systems was the lack of environmental accessibility information, for instance, whether the unknown building has tactile sidewalks leading to the entrance to which street the entrance connected.

Environmental accessibility information describes how geographic features are accessible to people with special needs. In addition to collecting and sharing the accessibility information via the crowdsourcing approach [3], however, at present there is little research on how blind and visually impaired users would access that geographic information via non-visual user interface, specifically by the users of different devices (e. g., desktop computers and mobile devices). Furthermore, it is unclear whether and how users would interact with the environmental accessibility information while accessing tactile street maps on pin-matrix displays.

System design and development

In this section, we address our proposed GeoCoach system in detail, from the aspects of system design, the concept of collaborative environmental accessibility, and non-visual user interfaces for various devices.

The overview system structure. The GeoCoach system consists of three clients for desktop and mobile devices (i. e., a web browser client, a smart phone client and a pin-matrix display-based client), central servers including various databases, as well as web service interfaces to connect clients and servers, as shown in Fig. 2. The role of the central servers (e. g., map database server, annotation server) is twofold: they provide communication services for the whole system and manage essential databases, including a geographic database and a user-contributed annotation database that stores environmental accessibility information. The system accepts several types of content media as annotations, like text descriptions, audio recordings, photos, as well as alternative text. The GeoCoach system focuses on collecting and sharing environmental accessibility annotations for various POIs.

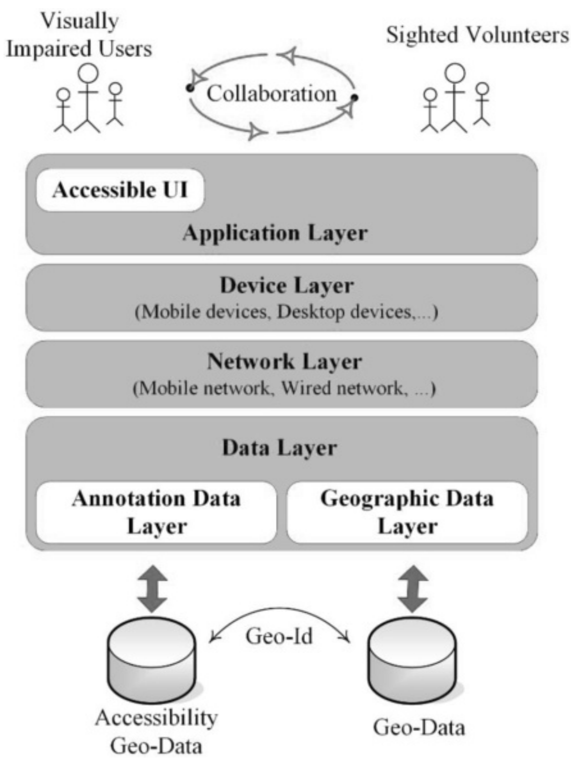


Fig. 3 The concept of the GeoCoach system

Collaborative annotations to share environmental accessibility. To help visually impaired people acquire environmental accessibility information in a low-cost way, a collaborative approach has been proposed. In general, sighted volunteers are encouraged to contribute accessibility information for geographic features with which they are familiar. Besides, visually impaired people would contribute their experience as well. An independent annotation layer is used to store the user-contributed environmental accessibility information and connects to the geographic data layer via the unique identification of geographic features (e. g., osm_id in OSM). To support different types of devices, the adaptive user interface layer of the GeoCoach system provides different accessible user interfaces for visually impaired users and sighted volunteers (see Fig. 3).

Due to the different disabilities, it is important to collect necessary environmental accessibility information for people with special needs, as well as for guiding sighted volunteers while annotating [24]. By summarizing from previous studies [21], the GeoCoach system proposes a series of features for visually impaired people to better acquire accessibility information about common geographic features, including buildings, service paths, entrances, stations, intersections, traffic lights, and temporary constructions. A combination of structured and unstructured environmental accessibility has been proposed in the GeoCoach system (See Table 1).

Non-visual user interfaces for different devices.

(1) Web browser client for desktop computers

Visually impaired users can make use of a web browser to access and share annotations on environmental accessibility. A keyword search function is supported (see Fig. 4) in the web browser client to search target POIs from the database. With the help of assistive tools (e. g., screen readers, Braille displays), users would search POI names and reading the results from an accessible table. As shown in Fig. 5, users read detailed geographic information and annotations of POIs through the web links involved, as well as edit or create annotations. Additionally, sighted volunteers can locate target POIs by searching keywords or exploring on a visual map, which is inaccessible for visually impaired users.

(2) The smart mobile client

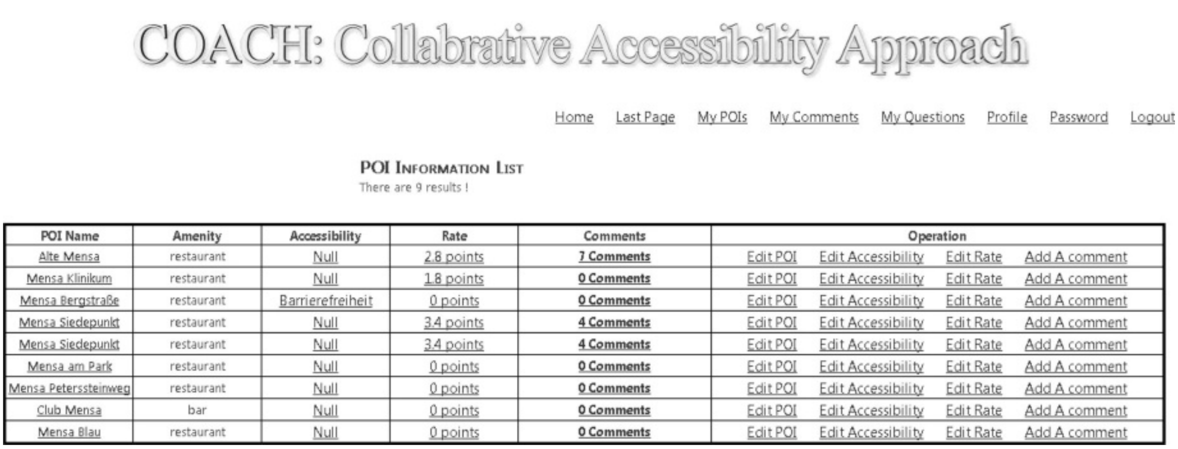
The mobile client of the GeoCoach system is demonstrated on two kinds of Android-based smart phones, one with a touch screen and a physical QWERTY keyboard, and another one with a common touch screen only (see Fig. 6). The two mobile clients provide location-based services to search nearby POIs while on the move. Via assistive screen-reader software on the smart phones, blind and visually impaired people can acquire auditory in-

Fig. 4 An example to search POIs with keywords

Table 1

Examples of structured and unstructured environmental accessibility

	Structured Mapping Features	Unstructured Descriptions
Buildings	Location (on which street) The number of entrances The number of floors With/without elevator Elevator with/without Braille Elevator with/without audio reminder	Explanation of detailed location
Service Paths	With/without tactile paving Rough length The number of branched paths	Target of each path Surrounding environment
Entrances	The name of a connected street With/without automatic door Type of manual door (e. g., revolving, sliding or folding) The level of entrance With/without attached stairs	Surrounding environment (e. g., special sounds, smells)
Stations	The (bus/tram) line no. and direction Capacities of the platforms With/without gap on the platform	Detailed descriptions at complex stations
Intersections	Connected streets Type (X-type, Y-type or T-type) With/without traffic lights With/without attached island	Detailed descriptions about complex intersections
Traffic Lights	With/without sound reminder With/without vibration reminder With/without tactile indicator	Detailed descriptions about how to active traffic lights
Temporary Constructions	Location (latitude and longitude) Status (existing or removed) Dangerous level	Detailed descriptions of the construction, like purpose and size



COACH: Collaborative Accessibility Approach

Home Last Page My POIs My Comments My Questions Profile Password Logout

POI Information List
There are 9 results !

POI Name	Amenity	Accessibility	Rate	Comments	Operation			
Alte Mensa	restaurant	Null	2.8 points	7 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa Klinikum	restaurant	Null	1.8 points	0 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa Bergstraße	restaurant	Barrierefreiheit	0 points	0 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa Siedepunkt	restaurant	Null	3.4 points	4 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa Siedepunkt	restaurant	Null	3.4 points	4 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa am Park	restaurant	Null	0 points	0 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa Petersteinweg	restaurant	Null	0 points	0 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Club Mensa	bar	Null	0 points	0 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment
Mensa Blau	restaurant	Null	0 points	0 Comments	Edit POI	Edit Accessibility	Edit Rate	Add A comment

Fig. 5 A screenshot of an accessible table with listed search results

Table 2

Interactions with POIs for annotating on each client

	Web Browser Client	Smart Phone Client	Pin-matrix Client
POI Name Search	✓	✓	✓
Nearby-POI Search	✓ (mouse-click for sighted users)	✓ (GPS location)	✓ (touch point)
Audio-haptic Exploration	–	– (audio only)	✓ (touch point)

formation. Specifically, the system stores the context automatically while making the annotations through the mobile clients, like current GPS location and heading orientation. Sighted volunteers would contribute their annotations through the mobile clients, by typing or voice recording.

***Fig. 6** The GeoCoach mobile clients on two types of smart phones*

(3) The pin-matrix display client

Differently to the two previous clients, the pin-matrix display client is designed for people who are blind or visually impaired only. This client allows users not only to explore audio-haptic city maps [25], but also to access or share annotations for POIs. There are two methods available for locating the target POI conveniently: either by searching for a POI name or searching a nearby area by tapping the target POI with a finger. For instance, when planning to go to an unknown destination beforehand, a user would explore the surroundings of the destination on the maps, and read environmental accessibility annotations of the nearby POIs within 500 meters via screen-reader software or Braille descriptions (see Fig. 7).

Table 2 summarizes the different user interfaces which support blind and visually impaired people

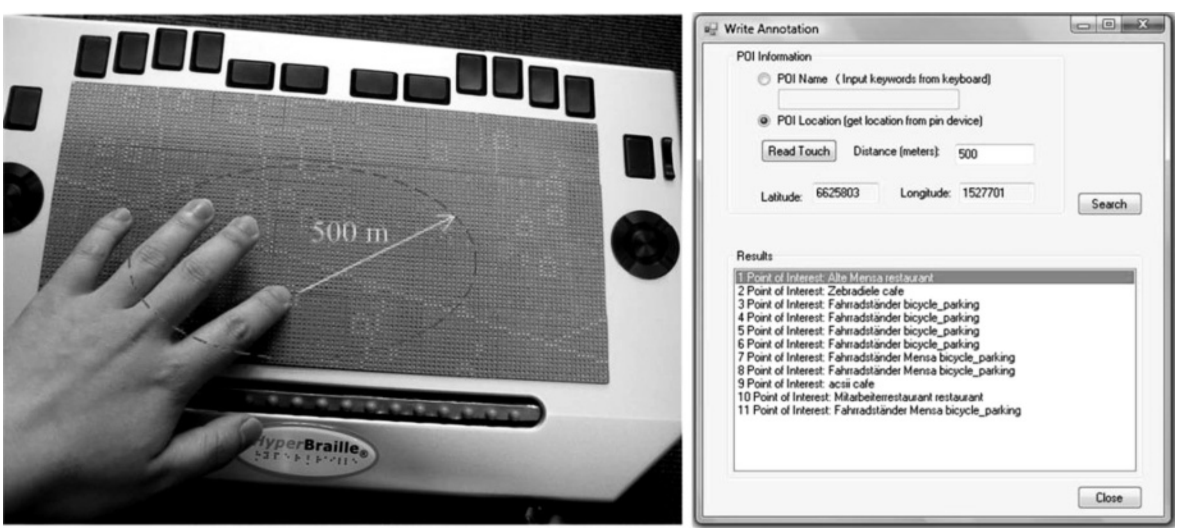


***Fig. 7** An example of the nearby-POI search on a pin-matrix display (**left**: locating the destination by a finger and searching nearby POIs in 500 meters; **right**: the resulting POIs)*

Fig. 8 A blind participant evaluating the web browser client **(left)** *and the mobile client* **(right)**

to interact with POIs while accessing and sharing annotations.

Evaluation

In this section, two user studies with visually impaired participants are addressed in detail, to validate the effectiveness of the proposed GeoCoach system.

User Study 1: Accessing environmental accessibility with the GeoCoach system

The preliminary pilot study introduces how visually impaired users create and read environmental accessibility annotations on the three clients. Four blind participants and one severely low vision participant were invited, aged between 28 and 50 years (mean age: 37.2). All participants had many years of experience with using computers and mobile phones, and four of them had some experience with pin-matrix display.

Procedures and instruments used. Before the evaluation, sufficient training was provided, including manual training for each client, a description of the keyboard layout on the mobile phone, and how to explore maps and locate POIs on the pin-matrix display. A training task test, where the participants had to create and read annotations on a selected POI, was conducted before the real trial. The following instruments were used: a desktop computer with the screen reader Jaws[5] and one 80-cell Braille display, a smart phone, and a HyperBraille display. Figure 8 shows one blind participant evaluating the web browser client with a Braille display (80 cells) and the mobile client. The subjects were informed that they could leave the experiment at any time, and they consented to a video recording of the evaluation being made. In the training tasks and the formal tasks, the subjects needed to find the targeted POIs with the supported methods on the three clients, and had to create text descriptions, and even edit geographic metadata of POIs such as street names or POI name as annotations. When evaluating the smart phone client, participants were led outside the buildings to receive a GPS signal.

Results and findings. Each subject prepared at least 12 annotations, in addition to the training tasks. The participants annotated for 25 POIs in all, including a railway/bus station, a tourist spot, a church, and a restaurant. Users commented on those POIs via their own previous experience, for instance, what you would do in a bus/railway station, or favorable food in a restaurant. At unknown places they mostly left questions, like about the POI or where the entrance was. We found that all subjects were able to create or read annotations for POIs successfully, where the results indicated a 100 % of task completion rate and a 100 % success rate. Typically, writing an annotation took 1–2 minutes, all subjects wrote only a few words.

When subjects annotated on POIs in a different user interface, different editing errors occurred. Not as many problems were observed when a desired POI was searched by using keywords in the web browser client. On the mobile client, participants made many mistakes when typing POI names using the *QWERTY* keyboard, however, few mistakes occurred when locating nearby POIs from a GPS signal. While using the pin-matrix display-based client, users were able to find nearby POIs easily by scanning the screen with their fingers. All the blind subjects indicated in their feedback that they were interested in the tactile display, because they could interact with the POIs on

[5] Jaws screen reader: http://www.freedomscientific.com/Products/Blindness/JAWS.

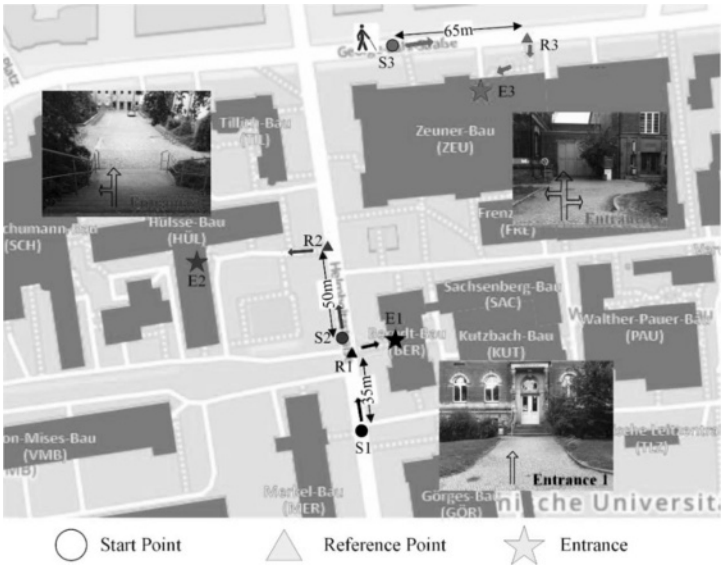


Fig. 9 The evaluation map and entrances in User Study 2 (the three images show the entrances at their reference points)

the tactile maps while acquiring the environmental accessibility information. The study also indicated that the presentation of tactile mobile maps [27] and environmental accessibility information on potable pin-matrix displays is a promising approach in the near future.

User Study 2: Guidance to entrances with environmental accessibility

Since GPS signals are frequently blocked by surrounding high buildings, it is difficult to guide users to find entrances by using turn-by-turn audible instructions, especially for entrances located in irregular areas. Thus, this user study investigates how the combination of environmental accessibility annotations and the current context (e. g., GPS and heading) can help visually impaired people navigate to entrances in the last 10 to 20 meters.

The basic idea is firstly to navigate users to the corresponding reference point that is close to a target entrance and usually located at the intersection point between a main street and a pedestrian path leading to the entrance, more importantly, at these points reliable GPS location data can be acquired [26]. Secondly, at the reference point users need to access existing annotations on environmental accessibility and be guided to the entrance by their understanding of those collaborative annotations. One hypothesis of this study is that each entrance in the system needs at least one close-by reference point. At each reference point several annotations should be added in advance to describe how to reach corresponding entrances, in addition to environmental information.

Ten subjects were recruited for the evaluation, in which five were blind (two female) and five were blindfolded (two female). They were divided into two groups (i. e., the blind group and the blindfolded group), and aged between 20 and 52 (average age: 30.0). Three blind subjects had had some experience with touchscreen phones. All blindfolded subjects had some mobility skills while blindfolded. All subjects walked with white canes. The participants' main tasks of this study were to find the reference points first (e. g., via GPS navigation) from nearby starting points, and then walk to find out the entrances with the help of existing collaborative annotations rather than GPS devices. Note that in this evaluation, participants only used the mobile client for touchscreen smart phones.

Preparation. Two preparation tasks must be completed before the evaluation: creating the reference points and collecting environmental accessibility information.

– *Creating reference points for the test entrances*

In this study, three entrances of three buildings were selected as destinations, and three reference points were created manually for the three target entrances (Fig. 9). To ensure that the three entrances were un-

Table 3

The abstract environmental accessibility annotated for the three entrances

Entrance	Annotated Basic Mapping Info.	Annotated Audio Description[1]
E1	Main entrance: Yes	The path is about 3 m in width
	Swing door: Yes	A bicycle is parked on the right
	At the ground level: Yes	A garbage bin on the left
	With steps: Yes	Entrance with six ascending stairs
	Distance[2]: 9 m	Stairs with hand rails both sides
E2	Main entrance: Yes	A two-level drop-off stair in 5 m
	Swing door: Yes	A wide, coarse cobblestones path after the stairs,
	At the ground level: Yes	and both sides with a long bicycle parking area
	With steps: Yes	A temporary construction site on the left
	Distance: 50 m	Only one ascending step in front of the entrance
E3	Main entrance: Yes	The path is 3 m wide, tri-forked at the end,
	Swing door: Yes	coarse cobblestones
	At the ground level: Yes	A big iron door in the front, and the targeted entrance
	With steps: Yes	on the right
	Distance: 11 m	The entrance has 3 ascending steps, and one garbage bin on each side

[1] The descriptions are abstracted from the volunteer's audio annotations via the mobile client.
[2] The distance is between the entrance and its corresponding reference point.

known to the participants, the three target buildings and their surrounding streets and POIs were renamed as general names in the map database, like "Building 1", "Street L", etc. The nearby main streets were about 10 meters in width, with the surrounding buildings being mostly three to four floors high (this ensured enough open space to receive GPS signals). Moreover, the three target entrances had different features: Entrance 1 had only one path leading to it, Entrance 2 had an additional path on the left of its test path with drop-off stairs, while Entrance 3 was the most complex one with a three-branched path.

– *Creating environmental accessibility*

We invited sighted volunteers to collect environmental accessibility information for this evaluation. Table 3 indicates the abstract content of annotations, made by the volunteers while standing at the reference points and facing the entrances. The duration of these three auditory descriptions were 20, 30, and 42 seconds, respectively.

Procedure. At the beginning of the study, all subjects received systematic training on the mobile client, including a brief introduction, the functions of the mobile client, and their tasks. They spent time on learning how to use the accessibility tools on the Android-based smart phones. A video recording permitted by the subjects, was performed for further analysis. If participants failed to reach the reference points or they went too far away from the reference area, a failure was recorded and they were then guided to the reference points to continue with the next steps. The system allowed participants to add new annotations. At the end of the evaluation, they had to ask four 5-point rating scale questions (1 – the most negative, 5 – the most positive). The questions are listed below:

Q1: How easy was it to reach the entrances by using the reference points?
Q2: In general, how useful were the accessibility related annotations of POIs (including mapping information and unstructured descriptions)?
Q3: How useful was the structured basic mapping information on the accessibility of the entrances?
Q4: How useful were the auditory descriptions on the accessibility of the entrances?

Instruments used and assessment. In User Study 2, only the client on a touch-screen smart phone was evaluated, and the Android (Version 4.2)-based smart phone had built-in screen reader software. The subjects were allowed to make use of earphones or the speakers of the phone. Figure 10 illustrates how subjects evaluated the mobile application on the move.

To assess the subjects' performance, we chose three main metrics:

- Success rate: how successfully did the subjects find the three target entrances;
- Completion time: the time required by the subjects to find the reference points and the target entrances, respectively;
- Subjective feedback: the participants' feedback for Q1–Q4.

Results and Findings.

- Success rate

Due to inaccurate GPS data from time to time, several subjects failed to reach the reference points and stopped walking, and the success rate of locating the reference points with mobile devices was 90 %. More importantly, most of the blind participants (success rate: 93.3 %) arrived at the three entrances, which were unfamiliar to them, except one fail trial by P3 on Route 3. However, three trials of the blindfolded subjects failed (success rate: 80 %). All in all, the total success rate was 86.7 %.

- Completion time

The subjects spent about one and half hours completing the whole evaluation, including the training

Fig. 10 Two blind subjects testing the mobile app outdoor

Table 4

The mean time spent (unit in seconds) to find out the three entrances[1]

	S_1-R_1	R_1-E_1	S_2-R_2	R_2-E_2	S_3-R_3	R_3-E_3
B	49.8	32.0	66.0	85.4	128.8	46.6
BF	163.8	85.4	215.0	274.0	269.7	99.8

[1] B: blind subjects; BF: blindfolded subjects. The mean time did not calculate the time spent by subjects who failed in the sub-trial

task and the time for finding out the three entrances. Table 4 shows the mean time spent on walking to the reference points (Step 1) and walking to the entrances from the corresponding reference points (Step 2). The blindfolded subjects required more time than the blind subjects. The two-way ANOVA (at the 95 % confidence level) found the two user groups had significant differences for the mean time spent on Step 1 ($F(1,21) = 18.19$, $p < 0.001$) and Step 3 ($F(1,23) = 13.74, p = 0.001$). The test map had a main effect for the mean time spent on Step 3 (Step 3 ($F(2,23) = 9.62$, $p = 0.001$)). In Step 2, the blind group and the blindfolded group took about 132.1 seconds and 195.0 seconds to read annotations about accessibility information, and no significant difference was found.

- Subjective feedback

As shown in Fig. 11, the two groups graded the four questions. The blindfolded subjects preferred

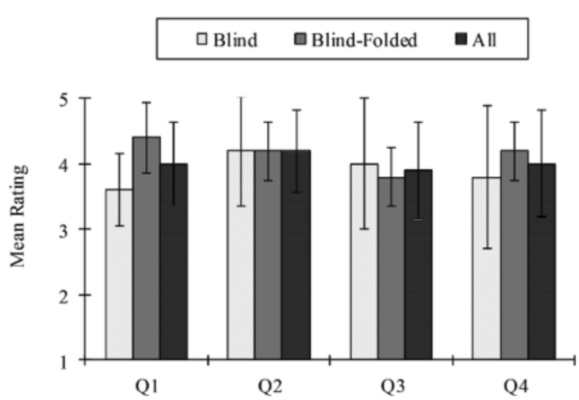


Fig. 11 Subject's mean grade of the four questions in the post-questionnaire

the reference points of entrances in Q1 (mean rating: 4.4) compared to the blind subjects (mean rating: 3.6). All of them had positive responses to the accessibility information acquired from structured and unstructured annotations (in Q2, Q3, and Q4).

The high success rate of finding entrances in unfamiliar regions indicate the effectiveness of the proposed approach. The participants walked at normal speed to find the reference points with the vibration alert; however, they had to walk slowly to follow the environmental accessibility annotations to find the entrances from the reference points, which required a considerable number of cognitive loads. A simple and structured spatial description model might be necessary and helpful to help reduce cognitive loads while understanding and following these annotations in the future. The positive evaluation results of User Study 2 might encourage an integration of the proposed approach into the existing assistive mobility applications, like *Blindsquare*[6].

Conclusions

In this paper, as the main contribution we present an accessible and cross-device platform, namely GeoCoach, to assist visually impaired people to access and share environmental accessibility information. In addition to a collaborative approach that allows sighted and visually impaired volunteers to contribute accessibility information, a series of accessible non-visual user interfaces has been developed for desktop and mobile devices; specifically users are able to acquire accessibility information about POIs while interacting with tactile street maps on pin-matrix displays. Two user studies have been conducted to investigate the effectiveness of the proposed GeoCoach system. The first user evaluation showed that visually impaired participants were able to access and share environmental accessibility information via the accessible and adaptive user interfaces for desktop and mobile devices. In the second study, visually impaired users navigated to unfamiliar entrances via user-contributed environmental accessibility, even in areas with imprecise GPS signals. The insights presented in this paper might be helpful to develop future inclusive and smart navigation services for all.

[6] BlindSquare system, http://blindsquare.com/.

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