Assessment of Semantic Taxonomies for Blind Indoor Navigation Based on a Shopping Center Use Case

J. Eduardo Pérez [a] [b]
juaneduardo.perez@ehu.eus

Myriam Arrue [b]
myriam.arrue@ehu.eus

Masatomo Kobayashi [a]
mstm@jp.ibm.com

Hironobu Takagi [a]
takagih@jp.ibm.com

Chieko Asakawa [a]
chie@jp.ibm.com

[a] IBM Research – Tokyo
19-21 Nihombashi, Hakozaki-cho, Chuo-ku
Tokyo, 103-8510 Japan

[b] EGOKITUZ: Laboratory of HCI for Special Needs
University of the Basque Country (UPV/EHU)
School of Computer Science, 20018 Donostia, Spain

ABSTRACT

Despite the growing availability of location-based services (LBS) to support pedestrian activities, we know little about the effectiveness of existing geographical web information to assist the indoor navigation of people with special needs such as the visually impaired. To characterize these indoor environments, we surveyed three different specifications about taxonomies for environmental semantic information. Survey results show that even having different scopes, the three studied specifications share considerable environmental semantic information. In order to evaluate the validity of survey results, we created a set of environmental semantic information for a shopping center, and then performed a navigation experiment with 9 visually impaired participants in the same indoor location. A smartphone-based system providing audio navigation assistance based on accurate real-time localization in the shopping center was used to complete navigational tasks. Experiment results show an overall positive assessment from participants about the usefulness of the audio messages used. We present further findings about the assessment of the different audio messages by the study participants.

CCS Concepts

• Human-centered computing ~ Accessibility design and evaluation methods • Human-centered computing ~ Accessibility technologies

Keywords

Indoor environments; semantic taxonomy; navigation assistance; visually impaired; real world accessibility.

1. INTRODUCTION

Nowadays, countless number of location-based services (LBS) are available based on geographical information shared through the World Wide Web. For instance, *Google Maps* [3] transformed the way people interact with maps by sharing geographical information via web services, and grew as a basis for various types of LBSs including pedestrian navigation support. LBSs are used to provide personalized assistance, in any location, and for a huge variety of applications. Such geographical information architecture can be applied to support indoor LBSs. Especially intended to assist people with mobility and orientation impairments, such as the visually impaired and wheelchair users, it is hoped that LBSs will change the daily lives of these people, making them more active and independent.

However, existing geographical information on the Web is not meaningful enough to create effective indoor LBSs that are able to meet the needs of people with disabilities. For instance, navigation for people who are visually impaired requires information about tactile and sound cues, whereas wheelchair users require information about the width of corridors, and the location of gaps and elevators. Nowadays, there is no defined and proved taxonomy to enable such services. It is necessary to figure out a necessary semantic taxonomy to enable large-scale information structure for LBSs.

In this paper, we focus on characterizing indoor environments by surveying three real world semantic taxonomies. Based on these findings, we created a set of environmental semantic information from a large-scale shopping center comprising 98 stores distributed over 14 floors of 3 connected buildings. Then we performed a navigation experiment with 9 visually impaired participants in this location, in order to evaluate the effectiveness of navigation assistance based on defined semantic information.

2. SURVEY OF SEMANTIC TAXONOMIES FOR INDOOR ENVIRONMENTS

Despite the many LBS available nowadays, there are very few specifications including semantic taxonomies of real world information. These taxonomies are even more limited when referring to indoor environments, with only working drafts or proposals. In this section, we present a survey of environmental semantic taxonomies based on three different draft specifications proposed by: the OpenStreetMap project (OSM), the Wayfinder organization (WFD) and the Japanese Ministry of Land, Infrastructure, Transport and Tourism (JMLITT). Table 1 summarizes and classifies the main environmental semantic information defined by the referenced works, focusing our survey on indoor routing and navigation applications for pedestrians.

OSM forms the most popular collaborative community aiming to create a free editable map of the world. Supported data by OSM mainly focuses on outdoor environments, although the OSM community also works on proposals to include indoor mapping in the future [5] [2]. A set of the latest indoor elements and features proposed within the OSM community was studied in this survey.

W4A 2017, April 02-04, 2017, Perth, Western Australia, Australia
ISBN 978-1-4503-4900-0/17/04...$15.00
DOI: http://dx.doi.org/10.1145/3058555.3058575

Table 1. Comparison of environmental elements and features considered by three real world specifications (shared entries bolded).

	OpenStreetMap [5]	**Wayfindr** [6]	**JMLITT** [4]
Pathways	▪ **type of pathway** ▪ **width** ▪ **access restrictions** ▪ **tactile paving availability** ▪ **slope (wheelchair access)**	▪ **type of pathway** ▪ **length** ▪ **tactile paving availability** ▪ junctions, significant curve, type of tactile paving	▪ **type of pathway** ▪ **width, length** ▪ **access restrictions** ▪ **tactile paving availability** ▪ **slope (gradient, wheelchair access)** ▪ surface condition, direction of travel, open hours, name
Doorways	▪ **type of doorway** ▪ **width** ▪ **wheelchair accessible** ▪ **steps counts** ▪ **entrance name** ▪ handle type, opening direction, ramp, handrail, access restrictions, level	▪ **type of doorway** ▪ **venues connected** ▪ opening button (door side and height)	▪ **type of doorway** ▪ **width** ▪ **step height** (only one) ▪ **entrance name**
Elevators	▪ **tactile/braille support** ▪ **levels connected** ▪ **wheelchair accessible** ▪ access restrictions, opening hours	▪ **audible announcements** ▪ **tactile/braille support** ▪ **levels connected** ▪ call buttons location (side and height) side doors open (if more than 1 door)	*- defined as type of pathway* ▪ **audible announcements** ▪ **braille support** ▪ **wheelchair accessible**
Escalators	▪ **direction of travel** ▪ **tactile paving availability** ▪ width, incline, lanes, access restrictions	▪ **direction of travel** (may change - peak hours) ▪ **tactile paving availability** ▪ handrail location, side to stand during travel	*- defined as type of pathway* ▪ **direction of travel** (pathway feature) ▪ **tactile paving availability**
Stairs	▪ **number of steps** ▪ **handrail location** ▪ **levels connected** ▪ **tactile paving availability** ▪ width, incline, ramp (for wheelchair), name	▪ **number of steps** ▪ **handrail location** ▪ **levels connected** ▪ **tactile paving availability** ▪ type of stairs, landing/flight of stairs	*- defined as type of pathway* ▪ **number of steps** ▪ **handrail location** ▪ **tactile paving availability** ▪ assistive mechanism available
Public toilets	▪ **wheelchair accessible** ▪ **gender** ▪ **opening hours** ▪ access restrictions, diaper changing table, drinking water, hand washing, paper supply	NOT INCLUDED	▪ **accessibility level** (wheelchair accessible and colostomy support) ▪ **gender** ▪ **opening hours** ▪ crib
Buildings / facilities	▪ **name** ▪ **address** ▪ purpose, levels, entrance, access restrictions	NOT INCLUDED	▪ **name** ▪ **address** ▪ phone number, opening hours, toilets accessibility level
Rooms / venues	▪ **name** ▪ **purpose** ▪ level	▪ **name** ▪ **purpose**	NOT INCLUDED

WFD published their first working draft on an open standard for audio-based wayfinding assistance [6]. The presented guidelines aim to assist with navigation of people with visual impairments within built-environments by means of audio instructions. To inform this specification draft, tests with real users were conducted at two underground stations in London and one train station in Sydney. In addition to the information listed in Table 1, the document published by WFD also includes details about two main elements from train and metro stations: *ticket barriers* and *platforms*. The JMLITT proposed a data specification for modeling outdoor pedestrian spaces [4]. The purpose of this work is to enable the creation of barrier free pedestrian maps and route searches, as well as the provision of navigation assistance services for different groups of people who encounter barriers, for example the elderly and people with different disabilities.

3. SHOPPING CENTER USE CASE

In order to assess the effectiveness of the resulting semantic taxonomy for indoor navigational assistance purposes, we performed a voice-based navigation experiment with 9 visually impaired participants in a large-scale shopping center. Previously, we had defined the environmental semantic information for this area, and used it to revise the *NavCog* tool [1]. This voice-based navigation assistant was used by experiment participants to complete navigation tasks in the shopping center.

3.1 Environmental semantic information

The shopping center where the experiment took place consists of three towers of five story buildings, from the basement to the fourth floor. The area has 98 stores, including restaurants, food shops, fashion stores, miscellaneous stores and cinemas. Each tower has an elevator to access all floors of the shopping center, and all elevators include audible announcements in the interior as well as buttons with braille support. Escalators are installed consistently throughout each tower enabling travel across all floors. Each tower has several entrances to the shopping center from the street and basement. There are two adjacent automatic doors at each entrance. Between the three towers there is an open area in the basement that includes tactile paving support, and connects the shopping center with an adjacent metro station. Figure 1 shows a detailed section of the shopping center map tagged with the following environmental semantic information. A street level entrance to the shopping center on the right, two automatic doors (both circles in the middle of the corridor), a corridor with two junctions (leading first to an accessible toilet and to an elevator later –tagged with the location of buttons both outside and inside), doorways to four different stores, and obstacles along the corridor against each side of the walls.

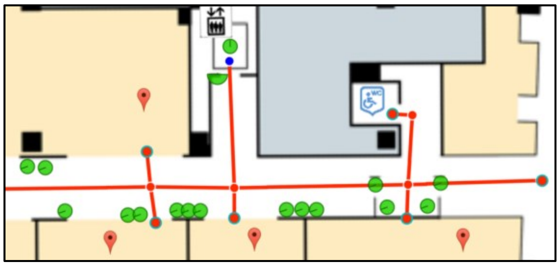

Figure 1. Network route editor view showing a corridor with tagged diverse environmental semantic information.

The set of environmental semantic information used to characterize the shopping center where the experiment took place is listed in Table 2. We selected the JMLITT specification as the basic taxonomy and data structure, as this was the only one to include all required features for the first revised version of the *NavCog* tool (non-bolded data in Table 2). Based on iterative on-site testing we added necessary vocabularies from the other specifications, as well as creating a new category for obstacles due to the huge number of these in some corridors. Obstacles were described by heading and angle attributes in order to warn about their location in relation to users' direction of movement.

Table 2. Set of environmental semantic information defined for the shopping center use case (later included in bold).

Pathways	▪ Type of pathway [corridors, elevators] ▪ length, width ▪ tactile paving availability
Doorways	▪ type of doorway [automatic doors]
Elevators	▪ **outside & inside buttons location – door side, height** ▪ buttons with braille/tactile support ▪ audible announcement availability ▪ wheelchair accessible
Obstacles	▪ **heading, angle**
Stores	▪ proper noun of store, doorway entrance

3.1.1 *Voice-based navigation assistance*

The *NavCog* tool [1] is a smartphone-based system that provides turn-by-turn navigation assistance through vocal messages and sonification based on accurate real-time localization. To achieve this, two different kinds of vocal messages are provided to the user during the route: distance announcements to inform about the distance remaining until the next node along the current straight edge (e.g., *"10 meters left"* ... *"approaching"*), and action instructions once the user reaches a node in order to align correctly with respect to the next edge of the route (e.g., *"turn right"*, *"arrived, destination on your right"*). Once the user is aligned correctly (a distinctive sound is played when facing the correct direction) the next message is forwarded to continue the route (e.g., *"proceed 9 meters and turn right"*).

The revised version of NavCog followed the same previously explained navigation assistance and included additional semantic information about the shopping center environment (Table 2) to enhance navigation. Thus, the new vocal messages added information along the route about: tactile paving support (e.g., *"proceed 35 meters on Braille blocks and turn left"*, *"turn right… Braille blocks will no longer be available"*), location of elevator buttons (e.g., *"elevator call button is right side of the door with Braille"*, *"go to the 3rd floor, control buttons with Braille are right side of the exit"*), elevator navigation (e.g., *"proceed 13 meters and go down to the 1st floor by the elevator on your left"*, *"after getting off the elevator turn right"*), and presence of obstacles (e.g., *"turn left… there are obstacles on both sides"*), stores (e.g., *"Vinos Yamakazi is on your left"*) and doorways along the route (e.g., *"there are 2 automatic doors"*).

3.2 Experiment

3.2.1 *Participants*

Nine subjects with a visual impairment took part in the study. Some participants had previously visited the shopping center but unanimously confirmed not remembering or having visited the traveled routes during the experimental sessions. Table 3 shows detailed information on each participant, including gender, age, visual condition, mobility aid used and previous experience with smartphones (SMA) and voice navigation apps (VNA).

Table 3. Detailed information about experiment participants.

Subject	*Gender*	*Age*	*Visual Condition*	*Mobility Aid*	*SMA*	*VNA*
U1	male	65	totally blind	white cane	no	no
U2	female	42	residual vision	white cane	4y	no
U3	male	54	totally blind	white cane	4y	yes
U4	female	44	totally blind	guide dog	1w	no
U5	male	48	residual vision	white cane	3y	yes
U6	male	38	totally blind	white cane	no	no
U7	female	40	totally blind	white cane	no	yes
U8	male	42	residual vision	white cane	no	no
U9	female	46	residual vision	white cane	1.5y	no

3.2.2 *Apparatus*

All participants used the same equipment during experiments: an *iPhone 6* smartphone running the revised version of the *NavCog* app, and bone conduction headphones to listen to audio messages during experimental route. Participants' and system's behaviors along the shopping center route were recorded in an event log. All participants were video recorded from behind with a 360º camera.

3.2.3 *Procedure*

First, participants were briefed on the purpose of the experiment and signed a consent form. Before starting with the experiment, the navigation system was introduced to participants through a training session. The navigation tasks in the shopping center were divided into three different routes. Selected routes included diverse representative indoor areas such as the underground open space connecting a nearby metro station with the shopping center entrances, a main entrance to the shopping center, corridors (featuring diverse widths, junctions' complexity, number of obstacles and passers-by), elevators and the cinema hall. Escalators use during the experiment was avoided this time for security reasons. After finishing the experimental navigation, a walking interview was performed with each participant retracing experimental routes, in order to gain subjective insights from them. Finally, participants were asked to rate the usefulness of the vocal messages during experimental navigation on a 7 point Likert scale based on the following five categories: locate tactile paving, find elevator buttons, travel by elevator, predict nearby obstacles along route, and recognize nearby stores along route.

3.3 Subjective ratings

Figure 2 and Figure 3 show mean ratings about usefulness of the different vocal messages used by *NavCog* to assist navigation, grouped by participants' characteristics (mobility aid used and visual condition first, and experience with SMA and VNA next). Likert scale ranges from 1 (strongly negative) to 7 (strongly positive). Figure 2 also shows mean ratings of all participants (N=9), containing generally positive responses (71.1%) except for few cases (15.6% negative, 13.3% neutral). Overall, the preferred messages were those assisting elevator navigation (mean=5.89, SD=1.27), whereas less preferred messages were those announcing obstacles (mean=4.33, SD=1.94).

On average white cane users (N=8) rated equally as preferred messages those about elevator navigation and tactile paving (mean=5.75, SD=1.28), whereas the less preferred messages remained those announcing obstacles (m=4.75, SD=1.58). Among white cane users, subjects who were totally blind (N=4) preferred, on average, messages about tactile paving (m=6, SD=1.41), followed by messages about elevator navigation (m=5.5, SD=1.29), about elevator buttons (m=5.25, SD=0.96) and stores (m=5.25, SD=1.5), and lastly about obstacles (m=4.75, SD=1.26). Among white cane users, subjects with residual vision (N=4) preferred, on average, messages about elevator navigation (m=6,

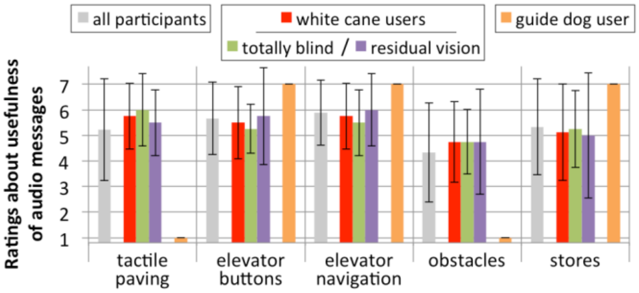

Figure 2. Mean ratings about usefulness of messages, grouped by mobility aid used and visual condition. Error bars represent ±1 SD.

SD=1.41), followed by messages about elevator buttons (m=5.75, SD=1.89), about tactile paving (m=5.50, SD=1.29), about stores (m=5, SD=2.45), and lastly about obstacles (m=4.75, SD=2.06). The participant accompanied by a guide dog (N=1) rated messages about elevator and those announcing stores with the highest score, and those messages about tactile paving and announcing obstacles with the lowest score.

On average white cane users with previous experience using SMA (N=4), VNA (N=3) or any of both (N=5), rated the different vocal messages with higher scores than participants without previous experience using SMA (N=4), VNA (N=5), or neither of both (N=3). This fact was more noticeable for messages about elevator buttons, elevator navigation and tactile paving, than for messages announcing obstacles and stores. For instance, white cane users with SMA experience rated, on average, with 2 points more, messages about elevator buttons (m=6.5, SD=0.58) and elevator navigation (m=6.75, SD=0.5) than those with no SMA experience (m=4.5, SD=1.29 and m=4.75, SD=0.96 respectively).

4. DISCUSSION

Overall, positive assessments about the usefulness of vocal messages used during experiment show a high level of acceptance for audio-based navigation assistive technology from the visually impaired people that participate in the study.

Messages about the elevator were considered, on average, very useful by all groups of participants. However, there were notable differences between the assessments given by experienced participants with SMA and VNA and those who had no prior experience with these technologies. Lower ratings given by these latter participants may be due to several reasons, such as for instance: issues caused by inexperienced use of the experimental devices, due to certain reluctance by participants to use these technologies, or due to inaccurate localization estimations. To identify the possible reasons, it will be necessary to study the participants' interaction with the system, as well as review the interviewee responses. Messages about tactile paving were also considered, on average, very useful by white cane users participating in the study.

Messages about obstacles were considered, on average, the less useful by all groups of participants. Sometimes it was difficult to define the position of obstacles (e.g., chairs), and therefore localization issues occurred during experiments, leading to lower assessments and opposing opinions from participants. Despite this, white cane users demonstrated an interest in these messages. An image recognition approach could be a possible way to improve this issue. On the other hand, the participant with a guide dog (U4) suggested turning off messages about obstacles and tactile paving, as these were unnecessary and confusing for her.

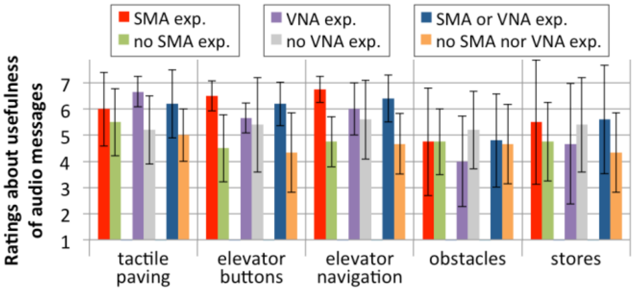

Figure 3. Mean ratings from white cane users about usefulness of messages, grouped by previous experience with SMA and VNA. Error bars represent ±1 SD.

Even if the presented information about stores only included names, assessments from participants were generally positive (66.7%) although opposing opinions were given (mean=5.33, SD=1.94). Tagging further information about stores could be of great value for people with vision impairment, although it would be tedious and time consuming. The retrieval of this data from owners' directories or other sources should be studied.

5. CONCLUSIONS AND FUTURE WORK

Overall, environmental information used to guide visually impaired participants has proved to be useful, although some information presented was not useful for some participants, other information was too brief, and certain information requires new technical approaches to achieve effective usage during navigation guidance. In order to gain further knowledge from this experiment and contribute towards real world accessibility for assisting blind indoor navigation, we are studying participants' behaviors during experimental tasks through system logs and video analysis.

6. ACKNOWLEDGMENTS

We thank all study participants, as well as the Japan Blind Library for their collaboration. J. E. Pérez holds a research fellowship from the Canon Foundation in Europe. This research work was partially supported by the Department of Education, Universities and Research of the Basque Government under Grant IT980-16.

7. REFERENCES

[1] Ahmetovic, D., Gleason, C., Ruan, C., Kitani, K., Takagi, H., and Asakawa, C. 2016. NavCog: a navigational cognitive assistant for the blind. In *Proceedings of the 18th Internat. Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI'16), ACM, pp. 90-99.

[2] Goetz, M., and Zipf, A. 2011. Extending OpenStreetMap to indoor environments: bringing volunteered geographic information to the next level. *Urban and regional data management* (UDMS'11), Taylor & Francis, pp. 47-58.

[3] Google Maps APIs (last accessed: December 2016) https://developers.google.com/maps/web-services

[4] Ministry of Land, Infrastructure, Transport and Tourism, Japan 2010. Proposed draft of pedestrian network data specification (last accessed: 17 November 2016) www.mlit.go.jp/common/000124059.pdf

[5] OpenStreetMap collaborative project (last accessed: 17 November 2016) wiki.openstreetmap.org

[6] Wayfindr 2016. Open Standard for audio-based wayfinding. *Working Draft ver. 1.0 (last accessed: 16 November 2016):* www.wayfindr.net/wp-content/uploads/2016/07/Wayfindr-Open-Standard-Working-Draft-1.0.pdf