Towards a Situation Awareness Design to Improve Visually Impaired Orientation in Unfamiliar Buildings: Requirements Elicitation Study

Abdulrhman Alkhanifer
Computing and Information Science Program
Rochester Institute of Technology (RIT)
Rochester, New York 14623, USA.
akhnaifer@mail.rit.edu

Stephanie Ludi
Software Engineering Department
Rochester Institute of Technology (RIT)
Rochester, New York 14623, USA.
salvse@rit.edu

***Abstract*—Requirements elicitation can be a challenging process in many systems. This challenge can be greater with a non-standard user population, such as visually impaired users. In this work, we report our experience and results of eliciting user requirements for a situation awareness indoor orientation system dedicated to the visually impaired. We elicited our initial system requirements through three different studies that focus on users along with orientation and mobility instructors. Also, we performed a knowledge elicitation through our studies to formulate our system's situation awareness requirements.**

***Index Terms*—Visual impairment, requirements elicitation, situation awareness requirements, assistive technology, and qualitative analysis.**

I. Introduction

The World Health Organization (WHO) estimated that there are currently 285 million people who have a visual impairment [4]. Visually impaired (VI) persons can be either legally or totally blind. Legally blind means having the visual acuity of 20/200 in the better eye due to a vision problem that cannot be corrected, a limited vision field, or a visual disorder [3]. While sighted people rely on their vision to understand and orient themselves in unfamiliar indoor environments, VI persons rely on their other senses to understand such environments. This reliance, however, causes many challenges that this class of users faces. For instance, VI users might get distracted and veer from their path in any unfamiliar, noisy indoor environment. VI challenges in the unfamiliar buildings motivate us to develop an assistive orientation technology that helps to raise their environmental situation awareness of unfamiliar indoor environments, and therefore accommodate user's orientation. Situation awareness (SA) is known as the "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [16]. Due to the scope of this paper, we will not discuss the SA design.

Orientation is "the ability to use one's remaining senses to understand one's location in the environment at any given time [1]." Visually impaired users face many orientation challenges when they enter unfamiliar indoor environments. Tasks, like for example, realizing the surrounding important landmarks, can be difficult in unknown environments as users try to pick up cues and comprehend them to build their mental model. A mental model is a cognitive term that refers to the phenomenon of having an imaginary mental image that depends on a person's knowledge and experiences [7].

The SA design approach was selected for this work for two reasons. First, the SA design approach is useful for systems that support user's decisions. Second, SA design helps in deciding what and when to present information to the users, while maintaining an acceptable information flow that allows the users to comprehend presented information [5]. The VI need to be able to focus on the environment while using our system.

Requirements elicitation with a non-standard population poses many challenges as software engineers need to understand the problem domain. With VI users, many challenges are presented such as the absence of visual aids to discuss user's needs. In this study, we discussed our work with two different stakeholder populations to elicit and define initial requirements for an SA orientation assistive technology to enhance VI orientation in unfamiliar indoor environments. The system goal is to enhance VI user's performance in unfamiliar indoor environments by providing them with an assistive technology that helps in raising their SA of the surrounding environment. To elicit the system requirements we performed a series of three requirement elicitation studies: domain understanding, orientation and mobility (O&M) recommendations, and survey-based studies. O&M is defined as teaching VI persons the required skills to be able to travel safely and efficiently in any environment [2]. Eliciting O&M instructors' knowledge is very important for our design as they can provide recommended guidelines that help in enhancing VI user's mobility and safety when orienting in unfamiliar indoor environments. Our elicitation studies' goal is to realize user's problems and to elicit initial user and SA requirements.

Our contribution in this paper can be summarized as conduction of the SA requirements' elicitation and analysis of VI users' orientation in unfamiliar indoor environments. Our results can help other researchers who are conducting further

SA applications in the field. The rest of this paper will discuss in detail our elicitation process and results of this research. Section two will provide a literature review of the field of requirements elicitation for VI indoor orientation. Section three will illustrate our methodology that captured and elicited the initial requirements. Sections four, five, and six will discuss our elicitation study phases in details. Section seven will briefly outline some user's needs diversity based on the geographical location. Section eight will discuss users profile. Section nine will overview our elicited SA requirements, and section ten will discuss lessons learned from our work.

II. Literature Review

Previous research has been conducted to elicit VI user's requirements for assistive technologies to raise the user understanding or guide him/her through different indoor and outdoor environments. However, to the best of our knowledge, none of the previous work has been addressed to elicit SA requirements for VI indoor orientation. SA requirements help when designing systems that support user's decisions and actions, such as orientation assistive technologies dedicated to the VI. We also performed semi-structured interviews with six O&M instructors, which provided us with critical insight to help design our system. The rest of this section will discuss some of the previous work in requirements elicitation with VI users for the purpose of providing an aid to the users when orienting in indoor environments. Also, we will discuss one related work in the field of goals and requirements analysis for assistive technologies.

Miao, et al. [12] reviewed their conducted requirements for an indoor navigation system dedicated to the blind users. Their motivation was to enable blind users to be independent travelers by providing them with an indoor navigation system. To decide their user profile, they surveyed six blind users. They also interviewed one mobility instructor and investigated two environments where blind users travel. For their users' requirements, they conducted structured interviews with six blind users. Through the interviews, they investigated what functionality could be offered by their system and how to present the system information. Authors elicited user requirements through structured interviews, which might restrict users to elaborate on related issues to the questions being asked. Also, the authors interviewed only one mobility instructor. In our work, we used semi-structured interviews where users elaborated upon our interview questions, which generated some important ideas. Also, we interviewed six O&M instructors and got their insights on the recommended ways to tackle the orientation problem in unfamiliar environments.

Rafael, et al. [11] explained their development of a prototype to enable VI users to identify people around them using a mobile-based Bluetooth. Before conducting their prototype, they elicited user requirements through interviews with 19 blind users. Interviews were focused to realize user problems in identifying objects and people around in both indoor and outdoor environments. In their elicitation findings, they reported user needs towards identification of objects and people in the environment. The authors' work was directed to assist blind users to dynamically identify other people in the surrounding environment. This, however, is different than our focus, which is on raising VI user's SA in unfamiliar indoor environments by enabling them to understand the environment dynamically as they travel in it.

Strothotte, et al. [8] and Johnson and Petrie [9] discussed the elicitation study for the MoBIC (Mobility of Blind and Elderly People Interacting with Computers) project. They performed their elicitation with the help of 24 VI users, and instructors. Some of the VI users were cane users, while the rest were guide-dog users. Their study's goal was to identify the habits and problems that exist with VI users traveling in familiar and unfamiliar environments. The authors used interviews to elicit user requirements, which consisted of open and close-ended questions. Their study shows a high VI demand for an assistance detecting indoor and outdoor obstacles, and for help crossing streets. While this work focuses on the safety travel of VI users in any environment, it does not discuss orientation and obstacles in the unfamiliar indoor environments. In our work, we focused on the VI orientation in unfamiliar indoor buildings as users behave differently as opposed to known environments.

O'Neill, et al. [10] and Engelbrektsson, et al. [14] discussed the Personal Adaptive Mobility Aid (PAM-AID) project, which is intended to support indoor mobility and navigation of elderly and frail VI users. Their goal was to make users independent of caregivers by providing users with the physical support as well as guidance. They performed an initial requirement elicitation study in three countries: Ireland, Sweden, and the UK. The authors performed face-to-face interviews with 38 users who live in 14 care facilities. They also interviewed 14 professionals who work in the care and rehabilitation centers as their secondary stakeholders. Their interviews focused on two aspects. First were the current available assistive technologies and aids. Second was user's preference for his/her system's input/output interactions. This work is dedicated to serve a special group of VI users: elderly and frail. Elderly and frail VI users can navigate unfamiliar indoors with the help of care persons, or using an equipped wheelchair. In our work, we focus on a different class of users: VI cane users who are able to walk unassisted and not hard of hearing or deaf. Also, we performed a domain analysis using O&M instructors' interviews, as they provided us with how to tackle orientation problems in unfamiliar indoor.

Sutcliffe, et al. [17] proposed a three-layer requirement's analysis framework that focuses on user's personal goals as well as how a system achieves user's goals. The first layer focuses on the general goals of stakeholders. The second layer focuses on user characteristics such as physical context details. The third layer focuses on specific personal goals that vary from one user to another. The authors performed two assistive technology case studies where they used their proposed framework to perform the requirements analysis: email and a navigational support application. Their navigational support application was addressed to support users who suffer from traumatic brain injuries, which sometimes result in short-term memory loss. In this case study, authors identified requirements under three levels. The first level focuses on the general goal of users who need assistance when traveling to public transit modes. The second focuses on user characteristics such as the memory loss. The third focuses on users' personal goals such as travel purpose. The framework provided by the authors is beneficial for systems that need to be customized on a personal level to the needs of each user. In our work, we identified users' goals using SA analysis and then identified decisions and information that assist each goal. SA design provides a good method to support user decisions.

III. METHODOLOGY

Our methodology relies first on qualitative analysis that uses the content analysis [13], and second on an open-coding technique, which is a part of the grounded theory method [1]. We used an iterative fashion to re-evaluate and re-define our research questions and user's problems. In the rest of this section we will discuss briefly our elicitation process and SA requirement analysis methodology. To minimize the bias in the elicitation process, we designed our questions in a way that does not lead the participants to specific answers. Also, each interview results (phase 1 and 2) were validated and expanded in the following phase.

A. Requirements Elicitation

We used an ethnographic interview method [18] as well as surveys to elicit system's requirements. Two of our elicitation studies were in the form of semi-structured phone interviews, and the other one was an online survey. Our studies focused on users as our primary stakeholders and O&M instructors as our secondary stakeholders. Eliciting requirements from different stakeholders can bring diversity to our system's requirements, as users provide their needs and O&M instructors provide us with the domain efficient and safe practices in indoor orientation.

Every elicitation phase's results were fed into the next one to tailor the questions towards elaboration on user's reported requirements. The questions were designed not to lead users to any preferences; instead, they explore the problems from the stakeholders' point-of-view. All questions that were presented to the users during the course of elicitation corresponded to our research questions and goals. Our study was designed to investigate many aspects that relate to orientation in unfamiliar indoor environments, such as: user's orientation issues, past experience with indoor navigation systems, experience with obstacles detecting technologies, familiarity and experience with smartphones, and user's preferences towards system interaction.

To analyze open-ended questions responses, we analyzed their content and looked for similarities. Then, using the open-coding method [1] we developed a set of codes that represent ideas or problems that were reported through our interviews. Afterwards, we started assigning codes to each participant's answers. Later, codes were calculated depending on the number of their occurrences. Higher occurrences indicate higher importance or demand.

With participants' permissions, we recorded our interviews while maintaining participants' anonymity. Each interview took between 40-60 minutes. Participants were recruited randomly through online mailing lists dedicated to the VI users. The recruiting process for each phase was performed independently.

B. Situation Awareness Requirements

The approach we use for our SA requirement analysis is based on the method described by Endsley and Jones [5]. They recommend the use of Goal-Directed Task Analysis (GDTA) as a method to elicit user's knowledge. This knowledge includes user goals, decisions, and information that is needed to support each goal and sub-goals. Crandall, et al. [7] describes GDTA method as one of the ways to conduct Cognitive Task Analysis (CTA) that allows the elicitation of user's knowledge. In our study, while eliciting system requirements, we focused on user goals when entering unfamiliar indoor environments. Goals were divided into sub-goals that make it easier to identify the required information that supports them. In our approach, we defined user's goals and sub-goals when entering unfamiliar indoor environments, and associated each sub-goal with the corresponding information needed to achieve it. This analysis was performed in parallel with our system requirements elicitation. While system requirements define the needed requirements to build the system, SA requirements help in knowing what information is needed by users for each goal and how important each piece of information is when reaching each goal.

IV. DOMAIN UNDERSTANDING PHASE

The domain understanding is an important part of our study as it helps researchers to understand the challenges that persist with VI users in unfamiliar indoor environments in different parts of the world. To achieve that, we designed an interview that focuses on the problem and allows us to discuss and elaborate on user problems in such environments. Our designed interview was comprised of 45 close-ended questions and 21 open-ended questions. We interviewed 24 VI across six different countries: US, Canada, UK, Italy, Australia, and New Zealand. Interview questions focused on many topics that relate to the VI orientation in unfamiliar indoors such as: orientation and navigation tasks, users' orientation problems, users' experience with orientation assistive technologies, and system interaction preferences. Interviews were conducted on a one-to-one basis. Each interview took about an hour. There were 10 males and 14 females. The mean age was 49.2 years with a 14.8 years standard deviation.

To understand user needs, participants were asked to discuss and explain scenarios where they navigate an unfamiliar indoor environment. When needed, researchers asked elaboration questions to unveil any unclear points. User scenarios were transformed later in the form of Hierarchal Tasks Analysis (HTA) [7] that models and describes the required steps to perform orientation and mobility tasks in unfamiliar buildings.

Another part that we focused on in our domain understanding study was to measure user acceptance to different orientation assistive technology forms. This is an important step to our initial requirements, as it will provide us with insight into the user technology preferences for such technology. The rest of this section will explain our results in details.

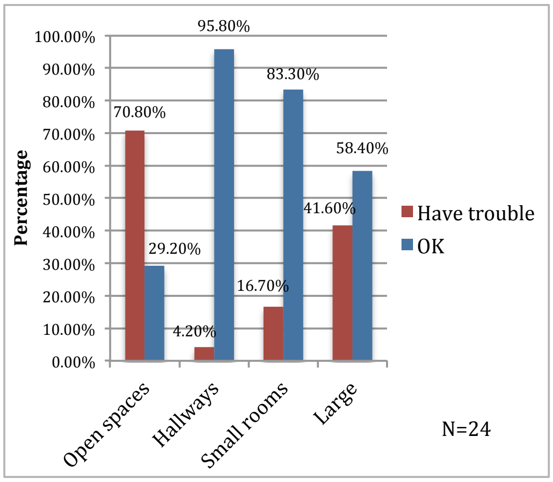

Figure 1. Users expressed their comfort level navigating different unfamiliar indoor setups.

A. Navigating Different Indoor Setups

To focus our design on an indoor setup, we discussed with our interviewed users what indoor setups are most challenging to them. Our results suggest that indoor open spaces represent one of the greatest challenges. Figure 1 illustrates what VI users think about different indoor setups. Absence of landmarks in open spaces was reported as the major reason why open spaces, such as atrium areas, are considered more challenging to navigate through than other indoor setups.

B. User Needs

Users expressed their need for an assistive technology that enables them to navigate unfamiliar indoor environments. In fact, 75% of users who participated in this study stated that they will use any indoor navigation assistive technology, while around 21% said they may use it. Through this study, we captured many user needs when navigating unfamiliar buildings. Primary user needs can be classified as the follows:

- Building information: many users expressed the need for a system to provide them with the unfamiliar building information such as: building layout, number of floors, availability of Americans with Disabilities Act (ADA) bathrooms
- Orientation information: another discussed need was user orientation when the user is in motion. This is vital for users to understand building context as opposed to their position when in motion
- Surrounding important landmarks: users would like to know about the existence and location of important landmarks when the user is in motion. Important landmarks include but are not limited to staircases, elevators, hallways, and bathrooms
- Guidance directions: all users expressed their need of a guiding medium to direct them to their indoor destination. While most of the users preferred one-to-one instructions that are similar to the Global Positioning System (GPS) devices, two users preferred a descriptive guidance that explains user's path and its context
- Obstacles information: users have reported that they need to know more about obstacles in their way. While they can detect many obstacles with their canes or guide-dogs, some obstacles are hard to detect. Examples of these hard-to-find obstacles are obstacles above the user's waist and safety signs such as wet floor signs

C. Assistive Technology Forms

Another area that we focused our elicitation study on was the orientation assistive technology form. Such technologies can be designed in different forms to suit VI users. Examples of the available forms are: wearable, and smartphone-based technologies. User acceptance was measured through interview questions that assess the user's desire to use such technology. System's forms were explained to the participants using different verbal scenarios. Figure 2 shows user preferences towards different orientation assistive technology forms that were presented to the users during the interviews. Users were able to choose more than one preferred technology form.

Another aspect that we looked at was to define our user profiles. At the level of the domain understanding, we were targeting any VI user; however, by looking at our conducted HTA, we discovered different user needs between those who use a guide-dog and those who use a cane. A fundamental difference was that guide-dog users were able to navigate unfamiliar indoor environments in a faster and easier way than cane users. The reason behind that is the ability of guide-dogs to explore and navigate areas. Guide-dog owners can instruct their guide-dogs to search for most of the important landmarks around. For example, a user can instruct his/her guide-dog to find the nearest stairs or elevators. On the other hand, cane users rely on their other senses to understand the environment.

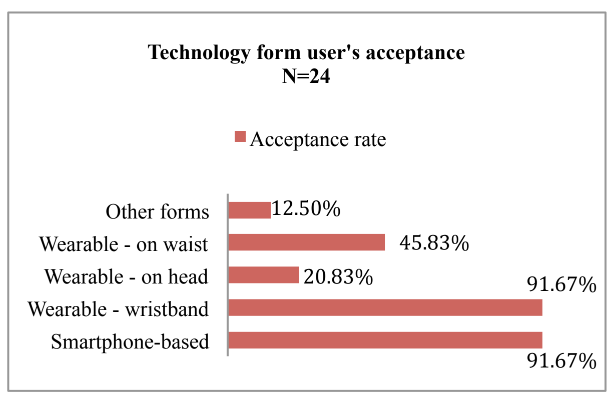

Figure 2. Users acceptance rates to different orientation assistive technology forms that was presented to them through the interviews

Due to the high need for a system from users who use a cane compared to guide-dog users, we decided to dedicate our system to fit this group of users. Another consideration was to consider developing a hands-free assistive device. The reason behind our consideration is that it is extremely dangerous for VI cane users to use anything in their other hand if they were to fall they can protect themselves. This means that they need to interact with a hands-free-device when they are in motion. Also, we considered narrowing our user profiles to any VI users who are able to walk unassisted except hard of hearing and deaf. We excluded hard of hearing and deaf VI users as they need a different way to interact with the system. On the other hand, the ability to walk unassisted was preferred due to the researchers' desire to test the system with users at a later stage.

V. Phase 2: Orientation & Mobility Recommendations

As we started the requirement elicitation by conducting the domain understanding and initial user needs from our system's primary stakeholders, we had to look from a different angle and realize the system requirements from secondary stakeholders' point-of-view. This is an important step, as the system should accommodate VI users with information that supports O&M goals to maintain their safety and to enhance their performance. O&M training is offered by O&M certified instructors who spend months with VI students, teaching them the required skills. Therefore, we designed our second elicitation study to target O&M instructors and elicit system requirements from their point-of-view.

We interviewed six O&M instructors who live in the US. Instructors were distributed around five different geographical locations. We designed interview questions to capture the instructors' point of view of which O&M training techniques are recommended to enhance VI orientation in unfamiliar indoor buildings. Three of the instructors are female, and three are male. Instructors' mean age was 50.5 years with 11.9 years standard deviation. Except one, all instructors were experienced instructors who had more than three years O&M teaching experience. The exception was a new instructor who had an experience of less than one year. Interviews were one-to-one, which took between 45-60 minutes for each. There were 22 interview questions, where 12 of them were close-ended and 10 were elaborative open-ended. Instructors were engaged in scenarios about students trying to orient themselves in unfamiliar indoor environments. While instructors may deviate from our scope and express their frustration with other related issues, researchers try to focus on the scope by following the designed questions.

The described O&M best practices were transformed into initial system requirements that match each of the recommendations. For example, a recommendation of the importance of paying attention to the environmental cues such as floor texture can be transformed into a system requirement that says that the system should provide information about floor textures and their types in the open space areas.

VI. Phase 3: Remote Elicitation with Primary Stakeholders

To elaborate on our gathered initial requirements, we conducted a remote requirement gathering and validation. We wanted to validate our previous initial requirements, and elaborate on them. We designed an online survey, which was intended to validate and extend our gathered requirements. We hosted the survey on an online survey engine that belongs to our university. The online survey was accessible through screen readers to allow visually impaired users to read and interact with them. Users were invited to fill out the survey through social news site (reddit.com/r/blind) and online mailing lists. As mentioned before, we invited VI users who are cane users, able to walk unassisted, and not hard of hearing or deaf to participate in the survey.

The survey consists of 27 questions. Questions have different variations such as: demographics, multiple choice, discussion and attitudinal questions. Survey questions discuss many issues such as orientation enhancement in unfamiliar indoor environments, disorientation factors, and input/output user preferences.

In this survey, we received 65 responses. Our participants' mean age was 53.26 with 11.29 years standard deviation. The male-female ratio was about half where 32 were female, 31 male, and two preferred not to answer. In terms of the geographical locations, we had participants from 27 different geographical locations inside and outside the United States (US). Table 2 illustrates the participants' geographical locations. In terms of the visual impairment types, 41 (63.1%) of our sample reported that they are totally blind while 24 (36.9%) of them reported being legally blind.

TABLE I. A SAMPLE OF THE INITIAL REQUIREMENTS BASED ON O&M INSTRUCTORS POINT OF VIEW

No.	Requirement
R1	The system should provide information to the user about floor texture types in the open spaces
R2	The system should provide the user with information about the surrounding landmarks
R2.1	When a user arrive at an open space area, the system should explain and describe to the user what and where the nearby landmarks are
R2.2	When user is in motion, the system should provide information about the availability of a landmark
R3	The system should provide information about the open space (how big and how far)
R4	The system should not block user's ears, as a user needs her hearing ability at all times

TABLE II. NUMBER OF PARTICIPANTS GEOGRAPHICALLY

ID	Country/State	Count
1	United States	56
2	Canada	4
3	England	2
4	Australia	1
5	Did not answer	2
In the United States		**56 (86.2%)**
Out of the United States		**7 (10.8%)**
Did not answer		**2 (3.0%)**
Total		**65**

TABLE III. SMARTPHONE OWNERSHIP AND BRAND

Smartphone	Count (N=65)
iOS device (iPhone)	42 (65.6%)
Android phone	4 (6.2%)
Nokia Symbian	1 (1.5%)
Jitterbug	1 (1.5%)
Use smartphone	45 (69.2%)
Do not use smartphone	16 (24.6%)
Did not answer	4 (6.2%)

TABLE IV. EXAMPLES OF USER'S REPORTED INFORMATION NEEDS ABOUT LANDMARKS IN THE UNFAMILIAR OPEN INDOOR SPACES

Information type	Number and percentage (N=65)
Availability and location of reception desk	60 (92.3%)
Bathrooms locations	59 (90.8%)
Elevators and staircases locations	56 (86.2%)
Number of floors	48 (73.85%)
Location of office space	47 (72.3%)
Availability and location of ADA-compliant bathrooms	11 (16.9%)
Did not answer	4 (6.2%)

To help us to decide a mobile-based platform for our proposed orientation assistive technology, we asked the users to answer questions regarding their use of smartphones. The majority of our participants use iOS devices (iPhone). Two of our participants reported using more than one smartphone regularly. Table 3 shows participants' ownership of smartphones. Reporting smartphone's ownership and brands can help other software engineers when designing smartphone-based applications for VI users.

To realize user's needs in terms of the needed information, we asked users two different types of questions, those that relate to disorientation factors, and those related to the information needs. Disorientation factors were asked because some users realize their challenges, but may not know what required information should be presented. For example, one of the reported challenges was the difficulties users face to understand what and where are the landmarks around them. This, however, can be transformed into a very key insight to the system requirements that "*a system needs to present information about the surrounding landmarks upon user request.*" Table 4 shows examples of the top information needs for orientation assistive technologies in unfamiliar indoor open spaces to be taken into account.

While a system needs to present information about landmarks in unfamiliar buildings, referencing a landmark can be done using various systems such as cardinal, clock-based, degree, and relative systems. We measure user acceptance to the previous systems in different questions. Figure 3 shows user acceptance to different landmark location reference forms where two of our participants did not answer this question. Learning referencing systems is part of the O&M training; however, we added a description for each system in the survey. The clock-based system was the most preferred way by our participants to explain any landmark position in relation to users' current position. This however, can give insight when designing a system that involves referencing for this class of users. Figure 4 illustrates the clock-positioning system. In that system, the front of the user's position is 12 O'clock.

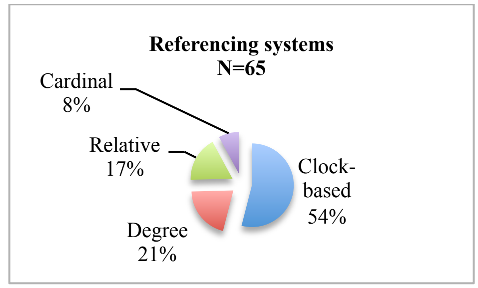

Figure 3. User preferences towards landmark's referencing system

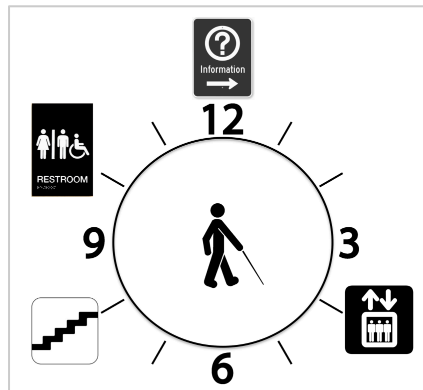

Figure 4. Clock-positioning system explains landmarks around VI user in a clock shape

A. Technology and Interaction Requirements

Through this part of the study, we investigated and elicited user preferences towards the preferred form of technology and user interface, depending on the environment. Users discussed their preference towards voice-based interaction and an easy-to-use interface. Users can query the system using their own voice, and hear the system feedback in a speech form. While voice is the preferred form of interaction, users expressed their need to keep their ears open to pick up environmental sounds while listening to the system feedback. Thus, the use of a special headphone such as bone-conduction technology was recommended. Table 5 shows examples of our top user's initial requirements for the technology and user interface for our proposed orientation assistive technology.

VII. GEOGRAPHICAL REQUIREMENTS DIVERSITY

In our requirement elicitation process, we interviewed and surveyed VI users from different countries around the world. Through the course of the elicitation, we recorded diversity in terms of needs between users from different countries. For example, VI users from Europe have less need for assistance when entering unfamiliar buildings due to the small size of atrium areas, or the structure of buildings. On the other hand, users from the United States (US) reported an urgent need for assistance when entering unfamiliar buildings. Another example was the need for braille office signs in Australia and New Zealand in contrast to users from US, Canada, and Europe who did not discuss that as a need.

TABLE V. TECHNOLOGY AND USER INTERFACE REQUIREMENTS

No.	Requirement
R1	The system should provide voice feedback to the user
R2	When in motion, user can query the system using voice
R3	When not in motion, users can interact with the system using tabs and gestures
R4	To alert user, the system should provide alert information in haptic form (vibration)
R5	The system should provide voice feedback delivered through headphones
R6	User headphones should not block user's ears (use special headphones)
R7	User should be able to adjust system's volume at any time
R8	The system should provide vibration feedback through a vibrating wristband
R9	The system should run on a user's smartphone
R10	The system should work as a hands-free device

VIII. User Profile

To design our system, we need to understand our targeted user's profile, as the system should accommodate their needs. In this section, we will overview the most important user characteristics that profile our targeted system's users.

A. Demographics

We expect our system to be used by adult VI users, as our domain study included only adults. Another user demographic is the O&M training. We expect that our users have received an O&M training and know how to travel using their cane. Our users are expected to use their cane in addition to our system when entering unfamiliar indoor environments.

B. Visual Impairment

VI users are classified under two visual impairment types: legal and total blindness [3]. As mentioned before, legal blind users have some visual perception of no more than 20/200 in the better eye. This perception can allow them to identify some visual changes in the environment; however, it's not enough for them to travel only using their sight.

C. Ability to Hear

Due to our intended user interface design, we decided to consider VI users who are not hard of hearing or deaf. The reason behind this decision is that deaf-blind users communicate with systems using only a figure-braille method [15]. Additionally, deaf-blind users were not included in our domain understanding.

D. Cane Users

VI persons can vary from people who can travel unaided or with aid. Users who travel with aid use two aids: canes and guide-dogs. In our domain understanding elicitation study, we discovered less need towards an additional assistive tool to the VI users who use guide-dog in contrast to cane users. This led our decision to specify our system to the cane users.

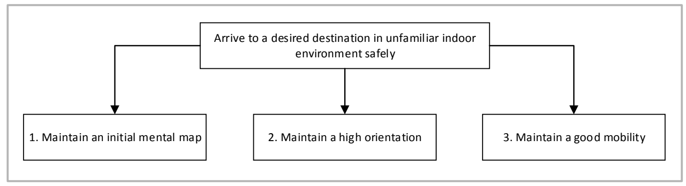

Figure 5. A high-level analysis of user's goals that was conducted using GDTA analysis.

E. Ability to Walk Unassisted

The ability of VI users to walk unassisted when orienting in unfamiliar indoor environments is one of the characteristics that we selected for our system's users. The reason behind selecting it was the desire of conducting controlled experiments to test the system at a later stage. Our potential controlled experiment environments are not suitable to accommodate VI users who are not able to walk. Also, VI users who are assisted by humans have no use for an orientation tools as their assistants can lead them through different environments.

IX. Situation Awareness Requirements

For the purpose of our design, we elicited SA requirements in parallel with system requirements. As mentioned before in the methodology section, SA requirements can be conducted through identifying user goals. We used GDTA as our method to elaborate on each user goal and divided each goal into sub-goals as needed. Also, we've attached to each goal the associated user decision and the required information to make that decision. Information required to maintain each identified goal can be obtained either from the environment or from a system. Our analysis was conducted using our elicited requirements from our interview studies: VI users and O&M instructor interviews.

SA requirements can help in forming design decisions as they show what information can be presented to the user and when. Some systems can present unneeded information in different situations, which might overwhelm the user.

When visiting an unfamiliar building, VI users have a common goal of "*arriving to a desired destination in an unfamiliar indoor environment safely.*" Using this goal, we elicited, and elaborated with users to identify what are the sub-goals, and what information is needed to achieve each. Figure 5 shows a high-level elaboration of user goals when entering unfamiliar indoor environments.

A. User's Initial Mental Map

Building user's mental map at the beginning of orientation tasks in any unfamiliar buildings is crucial to user's performance and safety. VI users use their prior knowledge such as a descriptive information about the environment to build an initial mental map about the environment. Prior knowledge, however, is not enough for VI users to have a good mental map and be able to orient themselves in such environments. Through our interview's elaboration, we explored with our users and instructors different scenarios when a VI user enters an unfamiliar indoor environment. Using our gathered data, we've conducted an in-depth GDTA analysis that presents what information is needed to assist VI user's initial mental map when entering unfamiliar indoor environments. Figure 6 shows a brief view of goal (1) analysis. Note that the provided sub-goals are not ordered. Figure 9 shows the SA requirement blocks that explain each of the information needs.

Determining and understanding the surrounding important landmarks (goal 1.1) are so crucial as they help VI users to visualize the surrounding environment and make their travel decisions based on the availability of landmarks. We described what are the important landmarks earlier in the domain understanding section.

One of the goals that help VI users to maintain a good initial mental map of the environment is the sense of direction (goal 1.2). Users need to know their direction, as they need to maintain their understanding of the changes in their direction when they travel in indoor environments. This is an important step, as they need to reverse the order of the previous directions to know their way back when exiting the building or any part of it.

As VI users need to travel through unfamiliar indoor environments, they need to plan their path (goal 1.3). To plan their path, users need to use their prior knowledge of the environment and decide the easiest path to follow. Planning user's path, however, needs environmental information such as what landmarks are available in the environment and where they are located. Depending on the environmental information available to the user, a user can plan an initial path to follow when traveling.

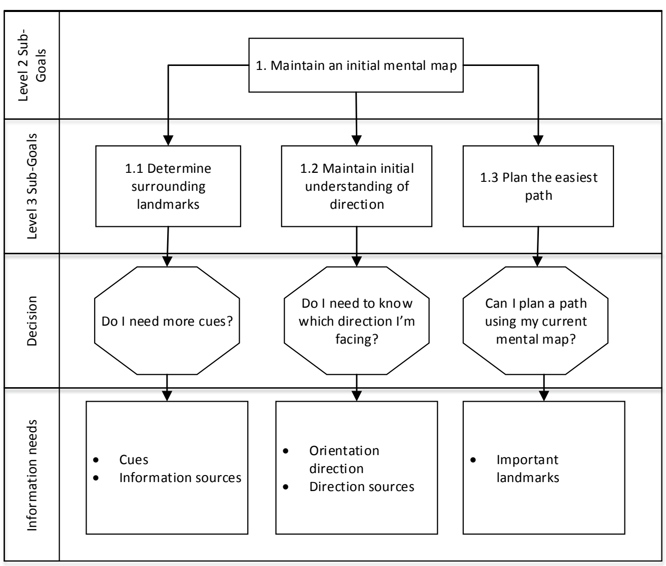

Figure 6. A Goal-Directed Task Analysis for goal number (1)

B. User's Orientation

The second core sub-goal of VI user's goals when entering unfamiliar indoor environments is to maintain a high orientation. This is an important goal, as users need to be able to change their path due to any changes in the environment. Using our interviews' data, we divided this goal into three sub-goals. Figure 7 illustrates our GDTA analysis for *"maintaining a high orientation"* goal. Figure 9 shows SA requirements blocks of information needs listed here.

In the previous section, we mentioned the importance of the initial understanding of the direction that a user is facing. This is extended here to understand the direction that a user is facing when traveling indoors (goal 2.1). This goal is important, as a user need to maintain a relational path of the environment in order to be able to travel back and exit the building or any part of it.

While a user is traveling through an unfamiliar indoor environment, the initial user's mental map is not enough. A user needs to maintain and update the initial mental map to be able to travel efficiently. Goal 2.2 illustrates the user desire to understand the environment in a continuous manner. This means that a user needs to acquire information about landmarks' locations, in addition to understanding where the previous landmarks are that a user passed by, and to predict what landmarks will be in the user's way.

Although VI users need to maintain their path planning when traveling in unfamiliar indoor environments, they also need to maintain their safety. Detecting obstacles in the user's way (goal 2.3) is an important goal to maintain a safe orientation. Users need to be able to identify obstacles on their way using their assistive tools.

C. User's Mobility

While orientation is an important factor in the VI travel in unfamiliar indoor environments, maintaining that orientation when traveling is yet another goal that VI users need to maintain. Figure 8 shows our conducted GDTA for goal 3: "*maintain a good mobility.*" Figure 9 shows the SA requirements blocks that can explain each of users' information needs.

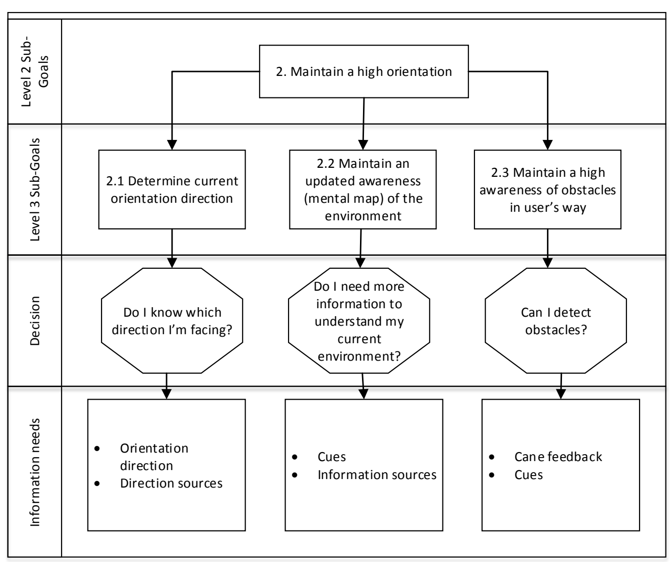

Figure 7. A Goal-Directed Task Analysis for goal number (2)

User's need to avoid anything that may affect their indoor travel such as dead-ends. Goal 3.1 illustrates user's desire to avoid any dead-end paths. Information about a path, such as environmental cues, obstacles that cannot be traveled around and closed doors, can provide an indicator to the VI user to change the travel path immediately.

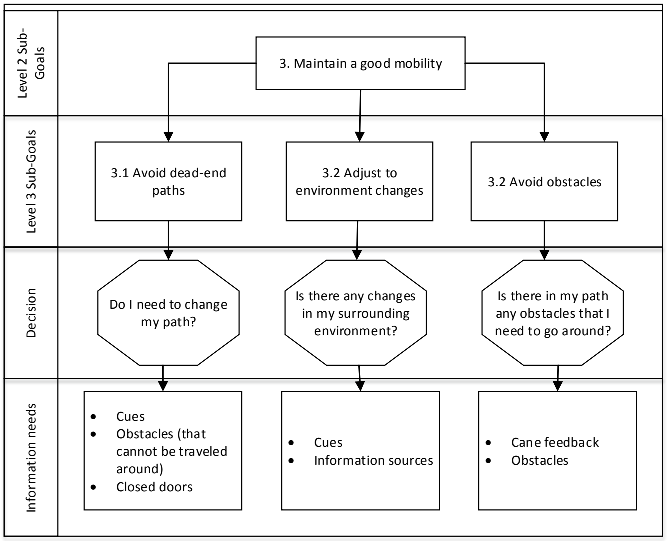

Figure 8. A Goal-Directed Task Analysis for goal number (3)

Adjusting to environmental changes is another crucial user's goal (goal 3.2) that the VI user needs to maintain. Pedestrian traffic, for example, can lead users to decide changing their path when traveling.

As mentioned before, users need to be able to detect obstacles when they are traveling unfamiliar indoor environments. However, this is not enough to maintain user's safety. Avoiding obstacles is another safety goal (goal 3.3) when user is in motion. This goal helps in maintaining user's safety as well as knowing obstacles in the user's way.

X. Lessons Learned

Through our requirement elicitation stage, we learned lessons that could help the future elicitation studies that work in the field. Our lessons learned can be classified into two categories: first, lessons learned from the elicitation process; second, lessons learned from the knowledge elicitation and the combination of different stakeholders' views.

A. Elicitation Process

When working with non-standard user population, software engineers need to take into account that the standard ways of conveying ideas may not always be ideal. In this work, we faced three elicitation challenges that can be categorized as the following:

- Domain challenges: since our intended solution is aimed for the domain of visual impairment, we had to learn how VI individuals travel indoors and what their needs are when traveling unfamiliar environments. This knowledge, however, should be combined with domain experts' opinion from the same domain. Domain experts can provide a different view of the same needs. They also help in elaborating upon the previous elicited requirements.

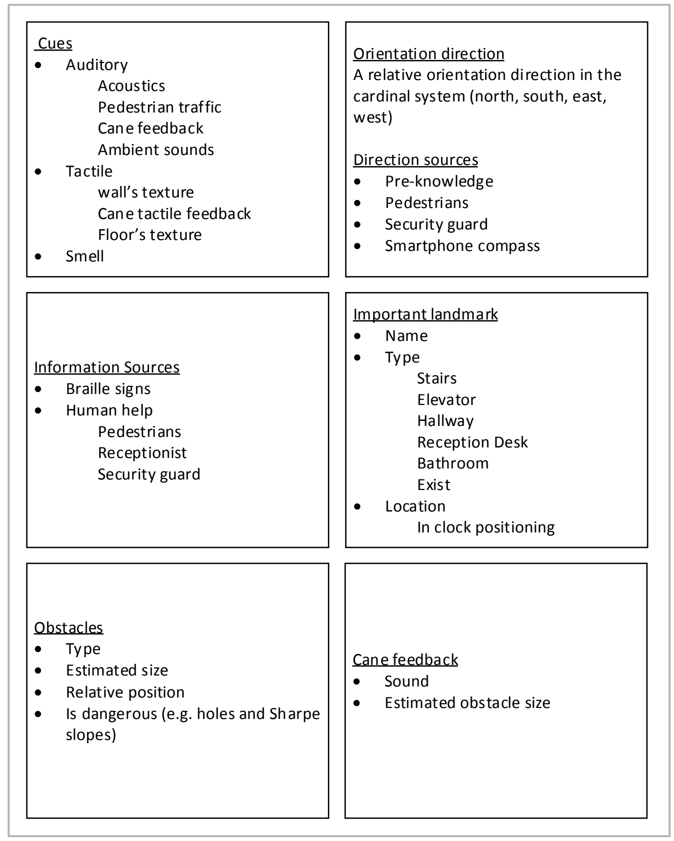

Figure 9. SA requirements blocks

- Remote elicitation: remote elicitation can provide great feedback to software engineers who want their design to work in different geographical areas. In our elicitation study, we sought VI participants from different geographical locations worldwide. This helped us to formulate the system needs based on different views. Accommodating the preferred time for interviews in remote locations was a challenge. In some countries far east, it was difficult to find a time that suits participants and researchers. Remote elicitation process could involve working out of the normal working hours.
- Non-visual elicitation: eliciting requirements from VI stakeholders indicates that visual aids cannot be used. To work this out, we developed a scenario-based explanation of features and properties that we discuss with users.

B. Combining Different Stakeholders' Views

In some cases, VI stakeholders and domain experts do not share the same opinions when it comes to system features and interactions. In this work, we faced a challenge of eliciting requirements from the primary stakeholders that conflict secondary stakeholders' (domain experts) point-of-view. An example of this is when some users told us that they would like to hold their smartphones and communicate with an embedded orientation assistive technology that resides in them. On the other hand, O&M instructors stressed that holding the smartphone when traveling may result in unwanted consequences such as injuries. To resolve these conflicts in the initial requirements, we further asked the users in the online survey about the conflicting requirements while stressing the issues that were raised by the secondary stakeholders. This provided a good context for us to elicit user's response to such conflicting requirements.

XI. Conclusion and Future Work

VI users strive to understand unfamiliar indoor environments when they travel through them. Maintaining a high SA level of VI users in such environments is crucial as it helps to enhance their orientation abilities and safety. In this paper, we discussed our elicitation process and results to gather user and knowledge requirements for an SA orientation assistive technology dedicated to the VI users. We discussed our process in eliciting requirements from remote stakeholders distributed among different geographical locations. We used interviews and surveys to elicit our initial requirements. Also, we showed the vital environmental information in the unfamiliar indoor environments such as landmark locations that need to be taken into account when designing an assistive orientation technology for the VI. Our work provides a foundation for SA applications that are dedicated to support VI orientation indoors.

Our next step is to validate and finalize our users' requirements using a participatory design (PD) approach [6]. Using this method, we will involve four VI users in the requirement and design processes. In PD, users along with software engineers can perform many software engineering activities, such as requirements analysis, design, and prototyping. We will perform the PD with our users in an iterative manner to enhance our final system design.

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References

[1] A. Strauss and J. Corbin, *Basics of Qualitative Research (3rd ed.): Techniques and Procedures for Developing Grounded Theory*, vol. 3. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc., 2008, p. 379.

[2] W. H. Jacobson, *The Art and Science of Teaching Orientation and Mobility to Persons with Visual Impairments*. New York: AFB Press, 1993.

[3] "Disability Evaluation Under Social Security: special senses and speech - adult." [Online]. Available: http://www.ssa.gov/disability/professionals/bluebook/2.00-SpecialSensesandSpeech-Adult.htm. [Accessed: 19-June-2014].

[4] "Visual impairment and blindness: key facts." [Online]. Available: http://www.who.int/mediacentre/factsheets/fs282/en/. [Accessed: 13-Feb-2014].

[5] M. R. Endsley, *Designing for Situation Awareness: An Approach to User-Centered Design*, Second Edi. Boca Raton, FL, USA: CRC Press, Inc., 2011.

[6] M. J. Muller, "Participatory design: The third space in HCI," in *Human-Computer Interaction Handbook*, J. Jacko and A. Sears, Eds. L. Erlbaum Associates Inc., 2003, pp. 1051–1068.

[7] B. Crandall, G. Klein, and R. Hoffman, *Working minds: A practitioner's guide to cognitive task analysis*. Cambridge, MA: MIT Press, 2006.

[8] T. Strothotte, H. Petrie, V. Johnson, and L. Reichert, "MoBIC : user needs and preliminary design for a mobility aid for blind and elderly travellers," *Computer (Long. Beach. Calif).*, vol. 1, pp. 348–351, 1995.

[9] V. Johnson and H. Petrie, "Travelling safely: the problems and concerns of blind pedestrians," *Br. J. Vis. Impair.*, vol. 16, no. 1, pp. 27–31, Jan. 1998.

[10] A. M. O'Neill, H. Petrie, G. Lacey, N. Katevas, M. A. Karlson, P. Engelbrektsson, B. Gallagher, H. Hunter, and D. Zoldan, "Establishing initial user requirements for PAM-AID: a mobility and support device to assist frail and elderly visually impaired persons," in *Improving the Quality of Life for the European Citizen*, I. P. Porrero and E. Ballabio, Eds. IOS PRESS, 1998, pp. 292–295.

[11] I. Rafael, L. Duarte, L. Carriço, and T. J. V. Guerreiro, "Towards ubiquitous awareness tools for blind people," in *BCS HCI*, 2013, p. 38.

[12] M. Miao, M. Spindler, and G. Weber, "Requirements of Indoor Navigation System from Blind Users," in *Information Quality in e-Health SE - 48*, vol. 7058, A. Holzinger and K.-M. Simonic, Eds. Springer Berlin Heidelberg, 2011, pp. 673–679.

[13] J. Lazar, J. H. Feng, and H. Hochheiser, *Research Methods in Human-Computer Interaction*. Wiley Publishing, 2010.

[14] P. Engelbrektsson, I. C. M. Karlsson, B. Gallagher, H. Hunter, H. Petrie, and A.-M. O'Neill, "Developing a navigation aid for the frail and visually impaired," *Univers. Access Inf. Soc.*, vol. 3, no. 3–4, pp. 194–201, 2004.

[15] M. Hirose and T. Amemiya, "Wearable Finger-Braille Interface for Navigation of Deaf-Blind in Ubiquitous Barrier-Free Space," in *Proceedings of the Tenth International Conference on Human-Computer Interaction*, 2003, pp. 1417–1421.

[16] M. R. Endsley, "Design And Evaluation For Situation Awareness Enhancement," *Hum. Factors Ergon. Soc. Annu. Meet. Proc.*, pp. 97–101, 1988.

[17] A. Sutcliffe, S. Fickas, and M. M. Sohlberg, "Personal and contextual requirements engineering," in *13th IEEE International Conference on Requirements Engineering (RE'05)*, 2005, pp. 19–28.

[18] J. T. Hackos and J. C. Redish, *User and Task Analysis for Interface Design*. New York, NY, USA: John Wiley & Sons, Inc., 1998.