Modelling Indoor Spaces to Support Vision Impaired Navigation Using an Ontology Based Approach

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Abstract. An ontology representation of indoor spaces useful for electronic navigation tools for the vision impaired community is presented here. The specific needs and how the building environment, features and their attributes contribute to safe and efficient navigation is explored from an orientation and mobility perspective, comparing with standard building models. The limitations of standard building models in addressing the unique requirements of the vision impaired community is addressed in this approach. The ontology forms the basis for defining a navigation model suitable for the vision impaired community, serving the needs of different groups of vision impaired individuals to derive user centric, context aware route determination and navigation instructor formation.

Keywords: Vision Impairment, Building Information, Indoor Navigation, Electronic Navigation Aids, Ontology

1 Introduction

Navigating in large complex buildings becomes a necessity in fulfilling life needs in the modern civilization for everybody, including vision impaired (VI) individuals. However, with impaired vision, the human orientation and mobility abilities are heavily affected and wayfinding becomes an extensively challenging task. Electronic indoor navigation aids specific for the VI community are being developed complementing traditional aids such as white canes or guide dogs, to support the navigation needs of the VI community. Navigation is a process which requires constant negotiation with the environment. Therefore the built environment representation is considered as a main module in such travel aids [1].

The environmental features which can be easily negotiated with vision become serious safety concerns for VI navigators. For example, fine grained information, such as direction of a door opening, virtually irrelevant for a sighted person, becomes useful information while visually rich landmarks, notable by a sighted person, become meaningless for a VI person. Therefore, how the built environment is modelled and represented becomes an important step for realising a successful VI navigation aid.

Though common building models support general navigation needs, they have limitations related to VI navigation; the type of features modelled may not capture required information such as barriers or landmarks; the level of detail would not be enough for safety concerns; the representations may not suitable for satisfying VI mobility needs. In the absence of properly defined knowledge on building information requirements for VI navigation, this work defines a VI indoor space ontology aimed at providing a sufficient level of information for navigation models and navigation tools.

2 Background and Related Work

The concepts of building are well documented from a construction and architectural point of view via national building codes (ex: Australian building codes [2]) and comprehensive standards such as industry foundation class (IFC) [3]. There are two Open Geopatial Consortium (OGC) standards, CityGML[4] and IndoorGML[5], related to building information. The former is for modelling city information which defines cities with five levels of details (LODs) and LOD4 is providing a means to represent indoor environment features. Instead of looking at the building from an architectural point of view, IndoorGML[5] looks at the building from a navigational point of view and the indoor space is semantically defined as cell spaces and cell boundaries. Open Street Maps (OSM), a leading crowd source map data platform, supports indoor data modelling though it is not used as widely as their outdoor data [6].

An example of how IndoorGML can be extended for VI navigation is presented as a use case in [7], where landmarks are attached to edges to provide navigation instruction. Accessible BIM modelling [8] and building constructs classification for VI navigation [9] are some approaches adopted by researches to solve the VI navigation building information modelling problem. [10] compares three different specifications about taxonomies for environmental semantic information and, with a user study, highlight that information requirement can greatly vary across users.

Ontologies are an effective approach to represent the knowledge of a domain using objects, relationships and descriptions so it can be used by different resources, perform semantic queries on the information and infer new knowledge. There are studies on using an ontological approach in general navigation modelling [11] and vision impaired navigation [12, 13] as well.

3 Methodology

Skills, techniques and guidelines, collectively called Orientation and Mobility (O & M) guidelines are a key resource for a VI individual in learning independent navigation skills. Therefore, first, the information required from the environment in VI navigation activity is identified from the O & M point of view. For that the O & M domain is explored, referring to standard O & M guidelines [14, 15], requirements from electronic travel needs proposed by experts in the field [16], research outputs [17, 18] and authors' experiences working with VI individuals. Then, specific building features which fulfil those requirements are identified by mapping the requirements to the standard building terminology. Third, the identified vocabulary is analysed against the IndoorGML [5], CityGML [4] and indoor OSM [6] to identify how the required information is covered in such specifications and to identify gaps. A conceptualization of the building information requirements is then carried out, based on the previous steps' results and the ontology is derived. Protégé [19] is used for the ontology modelling using the OWL2 language combined with GeoSPARQL [20] standards to represent the geometric nature of the features.

4 VI Navigation and Building Information

4.1 Information Required from a VI Indoor Navigation Tool

The listing below summarizes the main environmental information expected from a VI navigation tool by a typical VI user as per the O & M domain.

1. Identification of obstacle at front from ground level to head height and over a wide enough area horizontally to cover the width of the traveler's body
2. Identification of the nature of the walking path and the surface nature (e.g. slippery, tiled, carpeted etc.) including abrupt elevation changes with safety concerns(e.g. split floors, steps, down stairs)
3. Detect objects at sides, including doorways, walls etc. which forms shoreline on either side of the path
4. Detect walls at side of the walking areas which can be used for wall training
5. Information to know about heading and direction of movement, distant landmarks to support maintaining the course
6. Information to allow the traveller to build up a mental map, image, or schema for the chosen route to be followed, including turns and other discontinuities
7. Landmarks in immediate surrounding referring to specific building features
8. Identification of challenging transit features between floors (e.g. staircases)
9. Identification of connecting features within floors such as doors with sufficient details for safely opening

Items 1-3, 5-7 are based on [16] and revised to represent the indoor environment and modern travel aids sensing capabilities. In conventional turn by turn navigation tools for VI users, there is less concern for requirements 2, 4, 6, 7, 9. Obstacle avoidance is integrated in many applications, though the level of details may not be sufficient.

4.2 Building Features Needed for VI Navigation

Based on the requirements defined above, the building features needed to be modelled are identified and presented in the Table 1. Contrast and light sensitivity also can be reduced with certain forms of vision loss and affects environment sensing hence included. Most of the features identified have architectural meaning but need some additional information explicitly.

Table 1. Building Features Useful for VI Navigation Tools from user Perspective

	Requirement in VI terms	Description
Possibility to use		
1	shorelining techniques	Follow the vertical surface adjoin to the walking floor using white cane techniques to maintain walking direction or obstacle checking
2	Wall-trailing techniques	Trail a wall using the cane or hand to obtain parallel line of travel or locate a specific object
Know about		
3	fixed or temporary hazards on the way	For safety as well as for landmarks; support cognitive map building also; may prefer to avoid paths cluttered with them
4	abrupt elevation changes	For safety; split floors, down-stairs etc.need to be notified to avoid injuries
5	Floor type	For safety as well as for landmarks
6	Escalators	Guide dog user would have less preference for escalators
7	elevators	User preference would vary
8	staircases	Strong safety concern; some with higher gradient, unconventional shapes or small width would be difficult to travese; sufficient information to locate the first step and the railing should be provided
9	ramps	Ramp, if available, would be preferred over steps; if the gradient is high, it would be difficult to traverse
10	large open spaces	Normally difficult to traverse and easy to get lost; walking alone the wall would be safer than crossing the open space
11	human traffic	High level of human traffic may be difficult to negotiate
12	doors and openings	Door type can be vary hence how to open them; the opening direction and space needed to open are useful for safety
13	food serving places served	Guide dogs may be distracted with the food smells
14	landmarks	Useful for orientation, verifying the path; mental map building
	a.visual landmarks	With reduced vision but having some level of light perception; prominent visual landmarks would be detectable;
	b.tactile landmarks	Features which can be sensed via the long cane, a touch of hand, foot
	c.olfactory landmarks	Features which can be smelled and help to differentiate a place
	d.audio landmarks	Features which can be heard and help to differentiate a place
15	Contrast levels of a the area	User preference would vary; high contrast setting would enable functional vision ; low contrast areas may affect safety
16	Lighting levels of a the area	User preference would vary; better lighting enable functioning vision

4.3 Conceptualize the Indoor Space for Navigation

The features identified above are conceptualized based on the idea of VI navigation in the indoor environment. For example, a landmark should be alone the path even to be detected by a tactile mean; a wall should be presented along the navigation path to it to be used for shorelining or wall-trailing.

The notion of cellular space, which is adopted by IndoorGML [5] is extended to define the navigation spaces for VI community as well. Following the cell subdivision concept of IndoorGML [5], we propose cell sections, which can be created by tesselating cell space to smaller cells in a separate VI navigation layer. Then for a corridor, it would be possible to identify several cell sections, where some are adjoining to walls and some not. By this conceptualization we can identify whether cell space sections are having supporting boundaries or features which can support the navigation.

Accordingly, we define two hypothetical disjoint constructs, *VICellSpaceSection* and *VICellSectionBoundary*, which can be linked to actual cell spaces of the indoor environment via a grid based partitioning for the indoor space. *VICellSectionBoundary*, which constitutes of both navigable and non-navigable boundaries define the boundary of the cell section.

5 Developing the VI Building Ontology

Fig. 1 shows the top-level visualization of the defined ontology. The ontology defined has four types of classes; (a) core feature classes (b) supporting classes to define core feature details (c) space division classes (d) geometry classes. All features can be a *VIIndoorLandmark*. Eight top level classes of the taxonomy which define the core features are as follows:

- *VIindoorLandmark:* any indoor feature which can support developing mental map or establish orientation for a VI navigator
- *VIIndoorObstacle:* any indoor feature which can become a safety concern for a VI navigator
- *VIIndoorFloorConnectionSpace:* any indoor construct used to connect two levels of floors or split floors
- *VIIndoorOpening:* an opening in a wall or boundary of a passage which may or may not be having a door
- *VIIndoorFloorSection:* floor of an indoor walking area
- *VIIndoorWallSection:* wall bounding any indoor space
- *VIIndoorBuildingInstallation:* any fixture such as fire equipment in indoor which are relatively fixed
- *VIIndoorfurniture:* furniture items in indoor space.

Some supportive classes are:

- *VIIndoorMaterial:* define the material or textures use in indoor floor sections or walls sections
- *VIContrastValuePartition:* define the contrast levels which can affect the environment sensing with four variations.

As staircases, elevators, ramps, escalators and steps are a major challenge for VI community and need more details each of them are modelled as separate classes as subclasses of *VIFloorConnectingSpace*. How these features and attributes are represented in compared standards are considered to reuse of the vocabulary where possible.

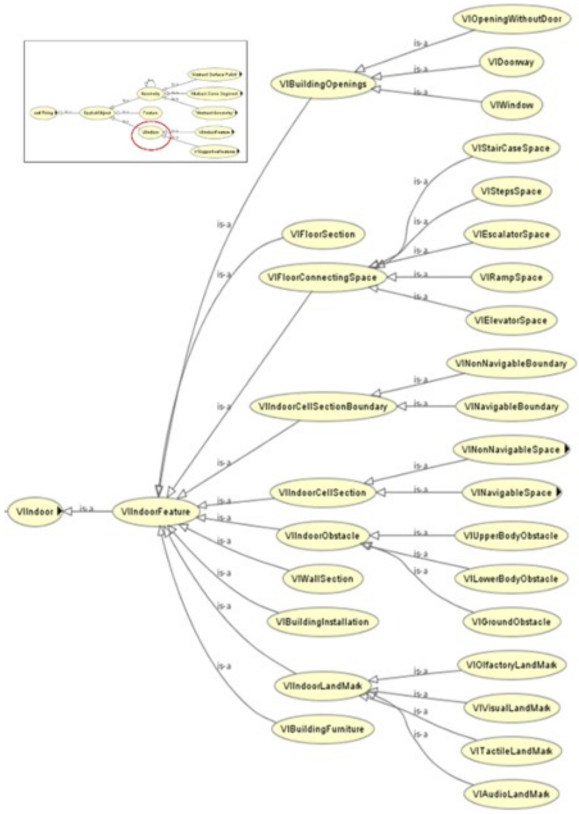

Fig. 1. Top Level Ontology for VI building features (inset shows the link with geometry class)

Three obstacle types are defined based on the part of the body it would affect and from which side it can affect. *VIObstacle* can be either a *VIBuildingInstallations*, *VIBuildingFurniture, VIHumanClutter* or a *VIRandomItems*.

6 Discussion

The ontology defined can be used in different ways to support the concerned community. First, formal queries based on SPARQL or GeoSPARQL[20] can be derived , by integrating with user preferences, to answer questions such as whether a particular room in a building is easily accessible by a VI user who has lost the central vision. Second, the building data models and data collection platforms can consider this ontology when defining indoor data schemes so that sufficient levels of data are recorded. With the increasing possibilities of recording indoor building data via LIDAR, mobile mapping, Indoor OSM and real-time object identification, the ontology defined can assist in identifying what data to capture and store to support VI navigation.

Third, VI navigation models could be derived based on the ontology as the foundation. As the building space is conceptualized with a space model coupled with se-mantic information and relationships, a VI navigation focused building model can be defined which can later be utilised for navigation modelling. Such a model would be useful in route determination and navigation instruction formation which would include landmarks, obstacles and other VI user specific constructs as inputs.

Though the ontology is attempted to be comprehensive, there are features which are not addressed; some of the features modelled would have attributes which vary with time (e.g: human clutter); the requirements of the VI community as well as building features can vary between geographic areas (e.g: tactile markers).The proposed ontology is influenced by the IndoorGML specification [5], however it differs in the (a) way the indoor space is conceptualized and represented and (b) in the classification of building features, properties and relationships.

Finally, comprehensive rules should be derived and tested to verify the ontology and check the consistency before it is used for actual instances of complex building data. The next stage of this work is to look at (a) formal testing and deriving route determination rules with the defined ontology (b) deriving navigation model for VI people, especially as an extension for IndoorGML using the derived ontology as the basis.

7 Conclusion

A building ontology specifically serving VI navigation needs is defined in this study. The unique requirements of the VI community is identified by analysing the VI information requirement from O & M perspective and conceptualized the indoor areas accordingly. It is capable of representing building feature semantics and use hypothetical constructs to model navigable areas for VI users. The ontology defined would be useful in different ways to develop more useful indoor navigation tools for VI community and open for enhancements as well.

Acknowledgment

This study is initially supported by COPRS scholarship from the Curtin University, as per its affiliation with SLIIT, Sri Lanka and now being supported by the Research Training Program (RTP), Australian Government. Support provided by the Association for the Blind,WA and Ms. Manique Gunaratne , EFC's ICT Training Centre for the Visually Impaired, Colombo are kindly acknowledged.

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