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An object-oriented data model built for blind navigation in outdoor space

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ABSTRACT

Increasing research has been conducted to improve navigation services for the blind when they are moving through an outdoor space. This article aims to propose a formal modeling approach helps facilitate decision making about navigation pathways. The proposed data model is based on an objective orientation idea. City features, such as street features, buildings and environmental areas, are organized as a series of function objects that meet the various needs of the blind. They are linked by paths with obstacles and irregular surface objects. A complex function object is composed of several inner function objects and paths; thus, it can reflect the spatial layout at various levels. Detailed semantic content can be added into the objects as an extension that enhances the representation and facilitates spatial learning. The geometric shapes of the proposed objects and their topological information are also recorded for local navigation and comprehensive path planning. To examine the usability of the data model, a prototype system was developed using the Chinese university of Hong Kong as a study area, and test cases are illustrated for a typical designed scenario.

Introduction

It is well known that vision is one of the most important senses for human beings. People with weak sight, especially the blind, are challenged by outdoor travel because it is difficult to acquire surrounding environmental information through vision. Significant advancements have occurred in studies on object detection to help the blind find obstacles in their paths, such as using infrared, Bluetooth, and WiFi to detect a nearby barrier (e.g., Alhajri, Al-Salihi, Garaj, & Balachandran, 2008; Bohonos, Lee, Malik, Thai, & Manduchi, 2007; Ganz, Gandhi, Wilson, & Mullett, 2010; Hashino & Yamada, 2010; Hatakeyama et al., 2004; Willis & Helal, 2005; Wilson, Walker, Lindsay, Cambias, & Dellaert, 2007). However, questions still remain, including “what is the relationship between the obstacle and the entrance?”, and “among these paths, which one is safer with fewer obstacles?” In these situations, geospatial information and related technologies play an important role, such as providing an accessible mapping portal with a data model underneath for deep spatial learning (e.g., http://pinhel.proasolutions.pt/).

Early in 1991, Coulsen, Riger, and Wheate (1991) proposed that geographic information systems could be used for assisting blind pedestrians in diverse navigation and path finding tasks. Since then, the research on this topic has continued. During the next decade and a half, Prof. Reginald Golledge, who is a pioneer in this field, and his team were engaged in using geospatial technologies as an innovative way to provide technological navigation aids for the blind. A review of their research reveals that they were not only focused on technical issues, but also interested in the outdoor travel behavior of the blind. For the first objective, the Personal Guidance System (PGS) and related technologies (e.g., user interface design) were proposed (Golledge, 2005; Golledge, Klatzky, Loomis, Speigle, & Tietz, 1998; Loomis, Golledge, & Klatzky, 2001; Loomis, Marston,

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Table 1
Examples of software design in recently years based on geospatial technologies.

Research group	Research focus
Wasserburger, Neuschmid, and Schrenk (2011)	Build their map based on OpenStreet Map, and add semantic labels to the node.
Fernandes et al. (2012)	Build an object-oriented data model for blind navigation.
Rice et al. (2011, 2012), Rice, Curtin, et al. (2013)	Use volunteered geographic information (VGI) and an Open Source system to provide updates of local infrastructure.
Karimi and Kasemsuppakorn (2013), Karimi, Zhang, and Benner (2014)	Generate network map/accessibility map for the disabled (including the blind).

Golledge, & Klatzky, 2005; Marston, Loomis, Klatzky, Golledge, & Smith, 2006). For the second objective, the team suggested that five types of geospatial knowledge are needed for the blind: specific information and positive identification at locations, geospatial information accessed from a distance, directional cues to distant locations, self-orientation and location, and an integrated model of the space (Marston, 2002). Additionally, six types of detailed information are needed: landmarks, street information, route information, destination information, building information, and transit information (Golledge, Marston, Loomis, & Klatzky, 2004; Marston & Golledge, 2003). Later, studies of both system design and exploration of geospatial requirements emerged. These studies are increasingly being improved upon to help the blind overcome vision-related limitations. Table 1 provides some examples of recent software design that are based on geospatial technologies (excluding human–machine interaction designs). Table 2 summarizes the related analysis of geospatial information requirements of the blind for their outdoor travel. It has been argued that the blind subject's view of the world should be given greater emphasis (Perkins, 2002), thus the research tends to focus on the type of geospatial information that the blind actually need because a user needs study is always the first step in developing a practical system (Strothotte, Petrie, Johnson, & Reichert, 1995). However, to date, many assistance systems cannot provide required and suitable detail or information that would be of use to the blind according to their requirements (Chandler & Worsfold, 2013). Chandler and Worsfold (2013) attributed this issue to three causes: the limitations of the current Global Navigation Satellite System (GNSS), the limitations of geographical information representation, and the difficulty in capturing and manipulating geographic data. Regarding the last point, in addition to the difficulty in obtaining highly accurate geographic data, managing temporary/transient events, managing the diverse spatial information in the system is another challenge. In this respect, a data model is needed (e.g., Laakso, Sarjakoski, & Sarjakoski, 2011; Laakso, Sarjakoski, Lehto, & Sarjakoski, 2013). Golledge et al. (1998) suggested that an object-oriented data model is the most "realistic" because of its capacity to conform well to the precepts of cognitive behavior. However, designing object classes according to each of the various objects in the real world will produce redundant classes and complicate the extension process.

To bridge the gap between the demanded geospatial information of the blind and related assistance systems, this article focuses on building an object-oriented data model that can be used to manipulate geospatial information for system design. The goal of this article is not to provide a fixed model that can be used to record every type of information for the blind at the current stage but to provide a basic model that can easily be extended when additional needs of the blind should be tracked. The characteristics of the proposed data model are the following: (1) the required geospatial information is represented using several city objects according to their various impacts on the blind travel process; (2) the model can be extended with detailed semantic content using customized XML schema, and (3) topological information is recorded to identify the relationships among different objects and can further be used for global path planning and local navigation. The remainder of this article is organized as follows. Based on the analysis of previous research on the geospatial information requirements of the blind, the basic, object-oriented data model is proposed in Basic data model design section. Extension strategies based on semantic content section describes the detailed extension strategies using semantic content to enhance the description ability, whereas The strategy for recording topological information section illustrates the strategy to record the topological information based on the designed data model. A prototype system is developed in Operation and usage of the data model section. Using data acquired from the

Table 2
Related analysis about geospatial information requirements of the blind for their outdoor traveling.

Research method	Research group	Summary of spatial information requirements of the blind
Mental representations analysis	Bentzen, Barlow, and Bond (2004)	The information about road intersections
	Gaunet (2006)	Route information between 5 and 10 m before each action to be accomplished, Environmental information in 30 m before in the case of road intersections and 5 m before for other cases.
	Yaagoubi and Edwards (2008, 2009), Yaagoubi, Edwards, Badard, and Mostafavi (2012)	Based on the five basic factors (paths, limits, districts, nodes and landmark) in outdoor space proposed by Lynch (1960), they mainly argued that: The requirement of spatial information of blind is not constant at one level, but in a hierarchical structure, The relationships of street objects are very important.
Analyses based on travel tools	Yerassimou (2002), Nzegwu (2006), Pavey et al. (2009)	Information at bus stops regarding timings and identifying bus routes/numbers and information on buses regarding the next stop and where they are, when they get off
	Polzerova and Fraser (2009)	Information related to the train and taxi (e.g., location, platform)
Analyses based on scenario design and questionnaire survey	Liao, Rakauskas, and Rayankula (2011)	Information about transit, street, destination, landmarks, route, building
Task analysis	Chandler and Worsfold (2013)	Information about designated crossing points, type of road junction/intersection, footpaths/pavements, paths attributes, accurate address locations, availability of assistive technology solutions, road type, relevant POIs