Data Requirements and a Spatial Database for Personalized Wheelchair Navigation

Piyawan Kasemsuppakorn, Hassan A. Karimi
Geoinformatics Laboratory, School of Information Sciences
University of Pittsburgh
135 North Bellefield Avenue
Pittsburgh 15260, US.
412-624-8858
pik2@pitt.edu, hkarimi@sis.pitt.edu

ABSTRACT

A spatial database is an essential part of a navigation system since it provides the necessary resources to perform navigation and routing functions, among others. While generally wheelchair navigation and car navigation overlap from the functional standpoint, databases for car navigation are not suitable for wheelchair navigation. One major difference between databases for car navigation and wheelchair navigation is that operations in car navigation are centered around road networks along with road segment attributes, whereas operations in wheelchair navigation are primarily centered around sidewalk networks along with unique parameters related to accessibility information about the surrounding environment. In this paper, we discuss the data (spatial and non-spatial) requirements and a database for wheelchair navigation. We also report our experience in constructing a spatial database of the University of Pittsburgh campus area for wheelchair navigation.

Categories and Subject Descriptors

H.2.8 [**Database Management**]: Database Applications – *Spatial databases and GIS;* H.2.1 [**Database Management**]: Logical Design – *Data models;* H.2.4 [**Database Management**]: Systems – *Relational databases;* J.3 [**Life and Medical Sciences**]: Health; H.4.0 [**Information Systems Applications**]: general.

General Terms

Design, Management

Keywords

Personalized wheelchair navigation, Real-time wheelchair navigation, Sidewalk network, Sidewalk obstacles, Wheelchair navigation databases

1. INTRODUCTION

Traveling is a laborious task for wheelchair people. This is especially true in unfamiliar environments because they have to overcome an array of interpersonal, buildings and facilities, and environmental barriers [1]. The Americans with Disabilities Act (ADA) and Architectural Barriers Act developed specific accessibility guidelines for buildings and facilities that should be applied during the design, construction, and alteration of the buildings and facilities [2]. However, environmental barriers remain a problem preventing wheelchair people from participation and integration into the community [3, 4]. Therefore, there is a need for continued research on assisting people with disabilities in traveling on pedestrian networks. The personalized wheelchair navigation system proposed in [5] primarily serves two purposes: pre-planning a trip and real-time navigation. Pre-planning a trip is similar to other navigation tools such as MapQuest, or Google Maps, while real-time navigation provides dynamic routing to meet the needs of individual wheelchair users. Real-time wheelchair navigation is possible through Global Navigation Satellite System (GNSS) positioning techniques, map matching algorithms, routing techniques, and spatial database functionality.

Map matching uses GNSS data to provide an estimated position on the sidewalk where the wheelchair user is traveling. Wheelchair navigation requires positioning accuracy better than 3 meters, similar to pedestrian navigation, whereas a positioning accuracy within 10 meters is suitable for car navigation [6]. To mitigate performance degradation of GNSS receivers due to signal blockages in urban canyons or under heavy tree cover,, such techniques as Differential Global Positioning System (DGPS), Assisted GPS (AGPS), Wide Area Augmented Systems (WAAS), and Vision-Based Geopositioning can be used for wheelchair navigation. Unlike car navigation, where distance or time is generally used as a criterion to calculate a route, our personalized wheelchair navigation considers environmental barriers and user's preferences as parameters to calculate routes. These user's preferences are used to weight each segment of the sidewalk network where an optimal route is calculated from the origin to the destination and displayed on a digital map on the mobile device. Finally, a spatial database is to support positioning, map matching, routing, and user's search for point-of-interest. This spatial database is composed of a sidewalk network, buildings, landmarks, and accessibility information such as accessible entrances. Such features are not available in databases for car navigation, thus there is a need for developing a spatial database for wheelchair navigation. In this paper, we focus on data requirements and a spatial database because the data requirements (spatial and non-spatial) in personalized wheelchair navigation are unique. Contributions of this paper include identifying environmental obstacles that impact accessibility and safety of wheelchair users and providing a framework for the development of a spatial database for personalized wheelchair navigation.

The structure of the paper is as follows. In Section 2 data and parameters of sidewalk segments for personalized wheelchair navigation are analyzed. Section 3 provides the requirements of a spatial database for wheelchair navigation. Section 4 presents a case study: wheelchair users traveling around the University of Pittsburgh campus area. Finally, conclusions and future research are discussed in Section 5.

2. DATA REQUIREMENTS

Unlike car navigation, where all vehicles can traverse all segments in the road network, wheelchair users cannot pass through every segment in the sidewalk network because of such obstacles as stairs or slope in the sidewalk. We refer to attributes on a sidewalk network "sidewalk parameters" which are judged based on their degree of accessibility for wheelchair users. We have determined sidewalk parameters that are of importance to wheelchair users through: (1) informal interviews with wheelchair users, (2) compliance with the technical requirements for accessibility to building and facilities under the ADA, and (3) capturing the experience of wheelchair users from previous research projects including Magus [7], U-Access [8], and a Pilot study of environmental effects [1]. We have summarized the required sidewalk parameters that we have identified along with their data sources in Table 1.

Table1: Summary of parameters for sidewalk network

Parameters	Description	Data Source
Width	Clearance width of sidewalk	Field survey
Slope	Degree of slope(%) along each sidewalk segment	Calculate from contour data
Step	Location and number of steps	Field survey
Sidewalk surface	Surface type: concrete, asphalt, brick, cobblestone, grass, and gravel	Field survey
Sidewalk condition	Cracks, manhole cover, and uneven surface	Calculate from combination of cracks, manhole cover, uneven surface, and field survey
Sidewalk traffic	Passage of people along sidewalk segment that depends on day and time	Categorize sidewalk and determine traffic level based on day and time
Length	Length of sidewalk segment	Calculate from end nodes and chain nodes

Wheelchair users with differing fitness level and preferences may have different needs for environmental accommodations; for instance, some wheelchair users hesitate to travel along sidewalks with steep slopes, others prefer sidewalk conditions with very few cracks. In our research, all sidewalk parameters are used for determining users' preferences and calculating personalized routes.

3. SPATIAL DATABASE

A spatial database plays an important role in supporting the navigation functions which include determining a user's location, finding a route, or guiding the user to a desired destination. While generally wheelchair navigation and car navigation overlap from the functional standpoint, databases for car navigation are not suitable for wheelchair navigation. One obvious but major difference between the databases for car and wheelchair navigation is that car navigation uses a road network with road segment attributes, whereas wheelchair navigation primarily uses sidewalk networks along with unique parameters related to accessibility for the surrounding environment.

Fundamentally a spatial database is composed of spatial data and non-spatial data, where the former includes geometric data (i.e., positions and shapes of objects in space) and the latter includes data describing objects (geographical features) [9].Geometric data for wheelchair navigation is best represented by the vector model because this model is close to the user's mental perception of a sidewalk network and it allows the required computations. The vector data model is composed of basic elements: point, line, and polygon. A point is used for representing the location of objects at a certain scale; a line is represented by a series of points; and a polygon is represented by a series of lines with coinciding beginning and ending points. For the purpose of wheelchair navigation, we define a node as a "decision point" where the wheelchair user needs to make a decision with respect to the direction of travel at that node such as accessible entrance, curb cuts, and junctions, obstacles such as steps, cracks, and uneven surfaces, and accessible bus stops. We also use a line vector model to represent sidewalk segments and pedestrian traffic levels, while a polygon vector model is used to represent buildings or landmarks in the database. Figure 1 demonstrates an example spatial data (node, line, and polygon) for wheelchair navigation. The topology of the segments in the sidewalk network, to support route calculation and other topological-based computations, is modeled in a graph.

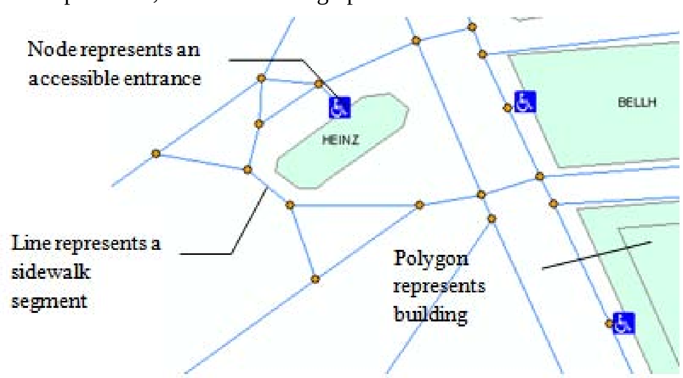

Figure1: Example nodes, lines, and polygons for wheelchair navigation

The non-spatial data contains data describing characteristics of the spatial features such as width and length. All the required data and sidewalk parameters related to the accessibility information are organized in the relational database model. In Figure 2 the Entity-Relationship (ER) diagram of the database for wheelchair navigation along with the constraints between entities is shown. This diagram illustrates integration and manipulation of geometric information.

As shown in Figure 2, the spatial database for wheelchair navigation is composed of six entities: sidewalk segments, nodes, traffic, buildings, bus stops, and obstacles. The sidewalk network is segmented into a number of sidewalk segments because the attributes of each segment along a sidewalk are different and change over time. The attributes of a sidewalk segment indicate the degree of accessibility of that segment used for navigation and routing functions, and is composed of width, length, slope, surface type, surface condition, steps, and sidewalk traffic.

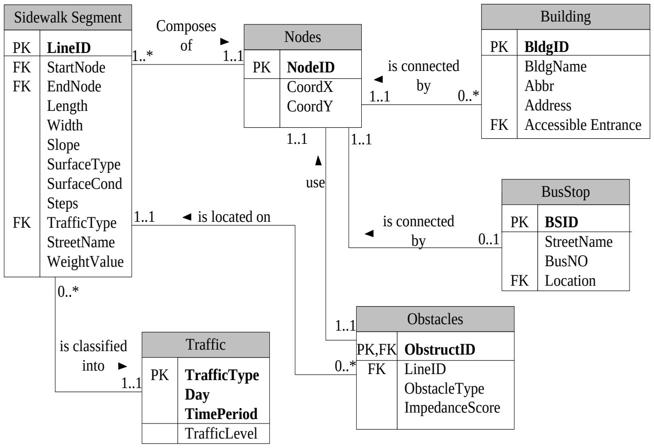

Figure2: The conceptual data model of sidewalk database

A weight value is calculated for each sidewalk segment by qualifying the sidewalk parameters in Table 1 and routing preferences by each user. With this approach, there would be a different weight value for each user on the same sidewalk segment. For traffic information, we classify sidewalks into three traffic zones: (1) main zone, (2) secondary zone; and (3) tertiary zone. We also grade the pedestrian traffic levels into three categories which are heavy, light, and no congestion. Each zone has different traffic level that depends on day and time. For example, the traffic level on a sidewalk segment could be heavy in a main zone on Monday during 12 pm to 2 pm. Entity "Node" contains a pair of x, y coordinates that indicate a location on the map. Also, as mandated by ADA [2], all accessible entrances should be connected by accessible routes to public transportation stops, to public streets or sidewalks, and to all accessible spaces or elements within buildings or facilities. Therefore, each building and accessible bus stop is connected through a node in the sidewalk network. Obstacles are composed of steps, cracks, manholes, and uneven surface. Each obstacle is represented on the corresponding sidewalk segment as a point and the impedance score of that obstacle is recorded in the attribute table. All these obstacles on the sidewalk segments are taken into account to calculate the sidewalk's condition.

4. CASE STUDY

Our personalized wheelchair navigation is intended for any wheelchair user and for any geographic area. The environmental parameters and personal parameters have impact on wheelchair navigation. In this paper, we have focused on the environmental parameters and a prototype personalized wheelchair navigation system is being developed for use within the University of Pittsburgh main campus. We are testing a spatial database, positioning techniques, map matching algorithms, and personalized routing for this navigation system. In this section, we report our experience in constructing a spatial database of the University of Pittsburgh campus area for personalized wheelchair navigation.

4.1 Campus Base Map

The campus base map is a database that contains data for the sidewalk network, buildings, accessible entrances, and bus stops within the University of Pittsburgh campus area. The sidewalk centerlines were manually digitized using satellite images. Topology between sidewalk links was verified through a field survey. This was necessary because the existence of accessible entrances as well as curb cuts at sidewalk junctions has a high impact on wheelchair mobility. Curb cuts could not be accurately identified through satellite images and required manual inspection for verification. Buildings, on- and off-campus, were represented using polygons collected by Allegheny County. Moreover, given the importance of accessible entrances for wheelchair navigation, we obtained building accessible entrances via the University of Pittsburgh Interactive campus map and field surveying. Then, we built the accessible entrance points and incorporated them into the campus base map as shown in Figure 3.

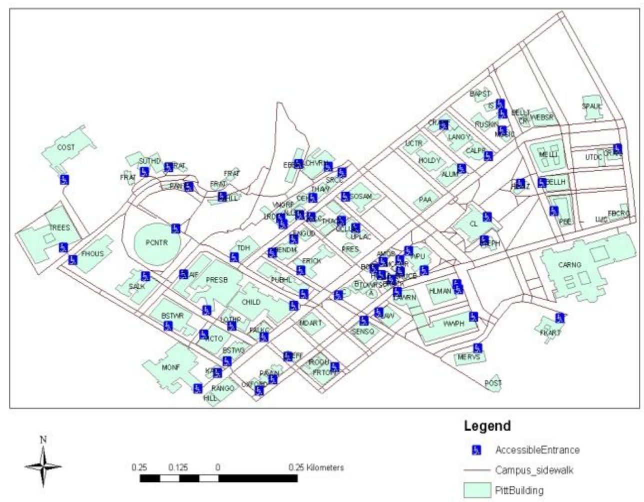

Figure 3: The University of Pittsburgh campus's base map

4.2 Obstacles on Sidewalk Network

As mentioned earlier, Table 1 shows all the required parameters for determining impedance level. Here, we discuss how to obtain these values.

We calculated the *length* of each sidewalk segment using each segment's start and end nodes and the points representing the shape of the segment. *Slope* is the steepness of a sidewalk segment represented in degrees. We utilized the contour line data in the Oakland area provided by Allegheny County to obtain the elevation value of each node and calculated the average slope value. The ADA has determined the minimum clearance width for sidewalks at a minimum of 36 inches [2]. For this, we measured the width of each sidewalk segment by using a standard tape measure. From this measurement we obtained three values: less than 36 in., about 36 in., and more than 36 in. The *sidewalk surface* is most often made of concrete, asphalt, brick, cobblestone, grass, and gravel. The ADA guidelines indicate that wheelchairs can be propelled most easily on surfaces that are hard, stable, and regular such as concrete or asphalt. Soft loose sand or gravel, wet clay, and irregular surfaces such as cobblestones can significantly impede wheelchair movement [2]. From the field survey, we found that 71.4% of sidewalk surfaces in the University of Pittsburgh campus are concrete and 23.8 % of those are asphalt. For *steps* and *sidewalk condition*, we collected data along the sidewalks using a GPS receiver and corrected these positions through a post-processing DGPS technique to improve the positioning accuracy. The data we collected include steps, cracks, manholes, and uneven surfaces. We obtained the coordinates and properties of each point and then transferred them to a personal computer for correction through a DGPS post-processing technique and overlaid them on the campus base map as shown in Figure 4.

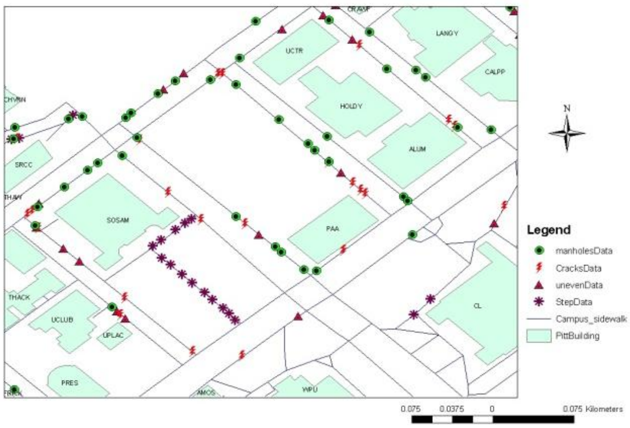

Figure 4: Sidewalk obstacles

As mentioned earlier, we categorize sidewalk traffic into three types where each type represents pedestrian traffic density. The first type, the main zone, has the highest pedestrian traffic and the third type, the tertiary zone, has the least. We determine sidewalk traffic type through surveys of campus locals who have lived in this area for more than 5 years. Figure 5 demonstrates the sidewalk zones for the University of Pittsburgh campus.

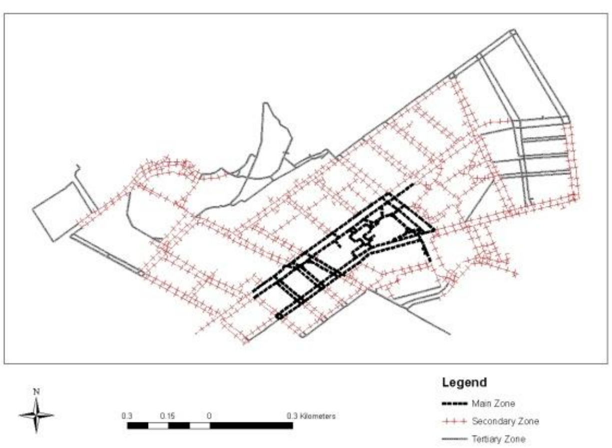

Figure 5: Sidewalk traffic zones

5. CONCLUSION AND FUTURE RESEARCH

This study includes identifying the environmental obstacles that have an impact on the accessibility and safety of wheelchair users, and the understanding of a spatial database for personalized wheelchair navigation.

Spatial databases support functionality for navigation activities. We illustrate our experience in collecting sidewalk data and constructing spatial databases. The spatial database we collected and constructed contains all the required data for a fully functional personalized navigation and assists wheelchair users in traveling along sidewalk networks. The results of our research verify the suitability of the vector data model for spatial data or geometric data and the relational data model for non-spatial data or attribute data. Future research will examine: (a) the personal parameters that have impact on wheelchair navigation; (b) the integration with positioning and map-matching techniques for real-time navigation; and (c) on transcending the mobile limitations by creating a distributed architecture for wheelchair navigation that provides remote storage, and fast, personalized, and spatially aware information retrieval.

6. ACKNOWLEDGMENTS

The authors wish to thank Allegheny County, PA for supporting contour shape file and buildings shape file in the University of Pittsburgh area and we are grateful for the assistance provided by Duangduen Roongpiboonsopit, Piyawat Chalermkanjana, and Thomas Conahan for data collection and valuable comments.

7. REFERENCES

[1] Meyers, A.R., J.J. Anderson, D.R. Miller, K. Shipp, and H. Hoenig, *Barriers, facilitators, and access for wheelchair users: substantive and methodologic lessons from a pilot study of environmental effects.* Social Science&Medicine, 2002. **55**: p. 1435-1446.

[2] *Americans with disabilities act and architectural barriers act accessibility guidelines*. 2004, United States Access Board.

[3] McClain, L., D. Beringer, H. Kuhnert, J. Priest, E. Wilkes, S. Wilkinson, and L. Wyrick, *Restaurant wheelchair accessibility* The American Journal of occupational therapy, 1993: p. 619-623.

[4] Thapal, N., G. Warner, M.-L. Drainoni, S.R. Williams, J. Wierbicky, and S. Nesathurai, *A pilot study of functional access to public building and facilities for persons with impairments.* Disability & Rehabilitation, 2004. **26**(5): p. 280-289.

[5] Ding, D., B. Parmanto, Hassan A. Karimi, D. Roongpiboonsopit, G. Pramana, T. Conahan, and P. Kasemsuppakorn, *Design Considerations for a Personalized Wheelchair Navigation System*, in *EMBC 2007*. 2007: Lyon, France.

[6] Usui, S., J. Tsuji, K. Wakimoto, S. Tanaka, J. Kanda, F. Sato, and T. Mizuno, *Evaluation of Positioning Accuracy for the Pedestrian Navigation System.* IEICE Transactions on Communications, 2005. **E88-B**: p. 2848-2855.

[7] Beale, L., K. Field, D. Briggs, P. Picton, and H. Matthews, *Mapping for Wheelchair Users: Route Navigation in Urban Spaces.* The Cartographic journal, 2006. **43**: p. 68-81.

[8] Sobek, A.D. and H.J. Miller, *U-Access: a web-based system for routing pedestrians of differing abilities.* Journal of Geographical Systems, 2006. **8**: p. 269-287.

[9] Lo, C.P. and A.K.W. Yeung, *Concepts and Techniques of Geographic Information Systems*. 2007: Prentice Hall.