Personalized Accessibility Maps (PAMs) for Communities with Special Needs

Hassan A. Karimi, Lei Zhang, and Jessica G. Benner

Geoinformatics Laboratory, School of Information Sciences,
University of Pittsburgh, Pittsburgh PA, USA
{hkarimi,lez13,jgb14}@pitt.edu

Abstract. Accessibility data/information is necessary to support the everyday mobility of people with special needs. As a means to accommodate mobility of students with special needs, universities and colleges provide maps with accessibility data/information for their campus, where some are static and others are interactive. In this paper, we describe the concept of Personalized Accessibility Maps (PAMs) and discuss the development of a PAM for the University of Pittsburgh's main campus as a representative PAM. As a result of this development, there is a better understanding of the technologies and techniques needed for PAMs along with challenges and future research directions.

Keywords: accessibility map, social navigation network, special needs, pedestrian navigation service.

1 Introduction

Mobility is a common and routine activity performed by all people. As people travel to unfamiliar locations, they commonly rely on online services (e.g., Google Maps, Bing Maps) and/or navigation systems/services (e.g., Garmin, TomTom) to find their way in new locations. For these systems and services, and the maps produced by them, to address mobility of people with special needs (e.g., people with mobility and visual impairments), they need to contain accessibility data/information. However, containing only accessibility data/information, while necessary, is insufficient to address the range of mobility challenges faced by special needs communities. For systems and services to be of value to special needs communities, they must: (a) contain useful accessibility data/information; (b) utilize accessibility data/information in meaningful ways (such as for trip planning and real-time navigation) that address specific special needs; and (c) present accessibility data/information, or their utilization, through easy-to-access and easy-to-use interfaces.

Accessibility is essential for the quality of life of people with disabilities [12]. Aspects of the built environment, public transport, and levels of shopper activity present a range of difficulties restricting the physical mobility of wheelchair users [2]. Provisions for accessible infrastructure are regulated through legislation such as the Americans with Disabilities Act (ADA) in the U.S. and the Disability Discrimination Act (DDA) in the U.K [2], [18]. The term *accessible* is defined by the Uniform Federal

S. Liang, X. Wang, and C. Claramunt (Eds.): W2GIS 2013, LNCS 7820, pp. 199–213, 2013.

Accessibility Standards (UFAS) as "[describing] a site, building, facility, or portion thereof that complies with [UFAS] standards and that can be approached, entered, and used by physically disabled people" [19].

In compliance with the ADA standards, universities and colleges aim to provide students with maps that highlight accessibility of their campus taking different approaches where some provide static maps and others support interaction with their maps. These maps are usually hosted by a designated unit in a university or college whose main objective is to provide special resources that aid students with special needs with their learning activities on campus.

In this paper, we present the concept of Personalized Accessibility Maps (PAMs) which feature an interactive map with specific functions suitable for students with special needs. To better understand PAMs, the development of a PAM for the University of Pittsburgh's main campus (PAM-Pitt), as a representative PAM, is described. Users of PAM-Pitt can locate accessible entrances of campus buildings, find shortest paths between campus buildings, request personalized optimal paths between campus buildings (e.g., a path personalized for a wheelchair user) based on their requirements, and find and locate university shuttles for travelling between campus locations.

The contributions of this paper are: (a) recognition of existing services which provide accessibility data/information; (b) conceptualization of a new geo-web system, called Personalized Accessibility Map (PAM), and its components; and (c) realization of theoretical gaps and research challenges in PAMs by developing a representative PAM for the University of Pittsburgh's main campus (PAM-Pitt). For the latter contribution, we have used, as much as possible, existing data, technologies, techniques, and tools (some based on our prior works), to develop a representative PAM.

The rest of the paper is structured as follows. Section 2 gives a background to specialized navigation services and tools and university accessibility maps focused on communities of users with special needs. The architecture and components of PAM-Pitt is detailed in Section 3. Section 4 discusses advanced features and functions in PAMs. Section 5 highlights challenges and future research directions. Section 6 provides a summary of the paper.

2 Background

2.1 Navigation Services for Communities with Special Needs

[10] have developed an algorithm to personalize routes for wheelchair users that employs individual preferences and sidewalk parameters obtained through interviews with wheelchair users, ADA guidelines, and relevant research literature. [14-17] have developed different map matching algorithms suitable for pedestrian and wheelchair navigation.

Other research projects integrate geo-crowdsourcing and routing techniques. OurWay is a prototype system that allows users to rate road segments in terms of accessibility and use the ratings for route planning [4-6]. The system is focused on physically impaired users such as wheelchair users and parents with strollers [5]. The basic road network is from OpenStreetMap and users are provided a map-based interface on which they can rate the quality of streets, sidewalks, and paths, create new segments for the underlying network, and engage in route planning [5].

[20] have developed algorithms for utilizing multi-modal annotation in personalized multi-criteria routing for blind and wheelchair pedestrians. These algorithms utilize predefined user group profiles that are adapted by users as they rate segments on a 5-point Likert scale. The prototype system, RouteCheckr, includes an underlying geographic network from a local land surveying office and is evaluated using two criteria: safety for blind users and accessibility for wheelchair users [20].

2.2 University Accessibility Maps

Maps of accessibility can be generated for any area. As the focus of this work is university accessibility maps, it is important to understand existing accessibility maps created by universities in the US. A search of accessibility maps provided to students resulted in 20 universities (Table 1). We categorized the map types as static and interactive in which the former is either an image or a PDF map and the latter is a web map that allows users to select information to be displayed.

Of the 20 universities, seven provide students with an *interactive* web map. Of the remaining 13 universities, 11 offer detailed maps of the accessibility of the campus as a *static* PDF and two offer the same type of map as a JPEG image. The universities in which map type is marked with an asterisk offer both map types to students. None of the interactive university maps searched offers any geo-crowdsourcing features that allow students to contribute data to the maps. The data layers displayed on a map are important in determining the usefulness of the data for specific populations of users. We divide the data layers available in each university's map into two categories: basic data layers and accessibility data layers.

One other aspect of these maps that is useful to report is their support for indoor vs. outdoor information. All of the maps include accessibility information useful for outdoor navigation while 13 include both indoor and outdoor accessibility information. While the seven interactive maps searched include more data layers than PAM-Pitt, none offers interactive features that support trip planning and navigation which is at the core of PAMs. Some interactive maps have accessible paths displayed on a map but the maps do not allow any interactivity between the map and the users.

3 Personalized Accessibility Maps

3.1 Architecture and Components

The architecture of PAM-Pitt is used as a representative PAM for any campus. PAM-Pitt is designed based on a web-based client-server architecture. The client is a web browser that communicates with an internal web server and an external web server over the Internet. The client is developed using Javascript and other basic web authoring tools to receive user requests, communicate requests to the two servers and render the map and

Table 1. University accessibility maps characteristics

Campus	Map Type	Data Layers	*Accessibility* Data Layers	Environment
Allegheny College	Static	Street network, Campus buildings, Building number, Parking lot numbers, Emergency call box	Accessible buildings, Non-accessible buildings, Barrier-free routes, Accessible entrances, Automatic entrances, Accessible restrooms, Elevators, Van accessible parking, Accessible parking	Indoor and Outdoor Features
California State University at Fresno	Static	Street network, Sidewalk, Campus buildings, Public transit stop, Emergency phones, Pay phones, Drinking fountains	Accessible Routes, Bus stops, Services for students with disabilities, Telephone devices for the deaf, Blue curb, Rest area, Automatic doors, Elevators, Entrances, Ramp, Accessible restrooms	Indoor and Outdoor Features
Harvard University	Interactive*	Campus Buildings, Street Network, Green space	Accessible entrances, Entrances accessible with assistance, Accessible paths, Intra-University phones, Accessible parking, Construction areas	Indoor and Outdoor Features
MIT	Interactive*	Street network, Buildings, Campus buildings, Waterbodies, Emergency phones, Public Art, Bike racks	Accessible Entrances, Accessible ramps	Outdoor Features
North Carolina State University	Static	Street network, Railways	Accessible buildings, Partially-accessible buildings, Inaccessible buildings, Future accessible building, Access routes, Handrails, Elevation change, Steep grade, Accessible facility entrances, Accessible facility entrances with door opener, Passenger elevator, inaccessible tunnel, Accessible parking, Accessible public transit, Emergency phone	Outdoor Features
Northern Kentucky University	Static	Street network, Campus buildings, Visitor parking, Student parking, Faculty/staff parking, Open parking, Restricted parking, Tank bus stops, Emergency phones	Accessible routes (plaza level), Accessible routes (ground level), Accessible entrance (power door), Accessible parking	Indoor and Outdoor Features
Ohio University	Static	Street network, Campus buildings, Buildings, Waterbodies, Occupied and Vacant campus buildings	Handicap Parking, Accessible entrance, Construction fence, Accessible walkway, Accessible raised walkway, Difficult route, Inaccessible route, Inaccessible campus buildings	Indoor and Outdoor Features

Table 1. (*contiued*)

Purdue University	Static	Street network, Campus buildings	Accessbile buildings, Partially-accessible buildings, Non-accessible buildings, Ramps or grade-level entrances, Ramps or grade-level entrances with a door opener, TTY text telephones, Non-accessible ramps, Passenger elevators, Service elevators, Entrances with a lift, Wheel-chair-accessible restrooms, Accessible tunnels, Inaccessible tunnels	Indoor and Outdoor Features
Rice University	Static	Campus Streets, Bus stop, Information center, Campus entrance, Visitor's entrance	Accessible buildings, Automatic accessible entrances, Accessible entrances, Ramps, Curb cuts, Accessible parking, Wheelchair lift, Assistive listening devices, TTY available, Accessible restrooms	Indoor and Outdoor Features
St. Olaf College	Static	Street network, Campus buildings	Accessible parking, Accessible entrances	Indoor and Outdoor Features
Tufts University	Interactive*	Street network, Buildings, Public transit stops	Accessible parking, Accessible restrooms, Fully accessible buildings, Buildings accessible with assistance	Indoor and Outdoor Features
University of Missouri	Interactive	Athletic Fields,Campus Buildings, Campus Streets, Parking Lots, Walkways, Non-University Buildings, Construction layers.	Accessible Entrances, Automatic Entrances, Ramps, Elevators, Chair Lifts, CurbCuts, Cross-walks, TTYs, Access Barriers, Barrier-free Sidewalks, Stairs on Walkways, Accessible Parking	Indoor and Outdoor Features
University of Montana	Interactive	Street network, Campus buildings	ADA accessible parking, Entrances with no opener, Entrances with automatic opener, Priority snow routes, Curb cuts	Indoor and Outdoor Features
University of North Carolina	Static	Street network, Campus buildings	Ramps, Staff power entrances, Staff non-power entrances, Entrances with power door, Entrances with non-power door, Elevators/lifts, Restrooms	Outdoor Features
University of Richmond	Interactive*	Street network, Walkways, Visitor parking, Building numbers, Campus information	Accessible buildings, Accessible walkways, Accessible doors, Handicapped parking	Indoor and Outdoor Features
University of Texas at Austin	Static	Street network, Campus boundary	Automatic door, Manual door, Curb cut, Ramp	Outdoor Features
University of Wisconsin at Green Bay	Interactive	Google Map layers	Buildings with text description about accessibility and links to floor plans	Outdoor Features

Table 1. (*contiued*)

Wesleyan University	Static	Street network, Campus buildings	Accessible entrances, Accessible walkways, Automatic door openers, Accessible entrance to first floor, Ramps, Accessible classrooms, Elevators, ADA accessible restrooms, ADA parking	Indoor and Outdoor Features
Western Michigan University	Static	Street network, Campus buildings, Campus boundary, Waterbodies, Emergency call boxes	Parking availability, Curb cuts/ramps, Ramp or grade level entrances, Ramp or grade level entrances with door opener, Restrooms, Passenger elevators/lifts, service elevators, wheelchair lifts, Accessible, partially-accessible, and inaccessible buildings	Outdoor Features
Yale University	Static	Street network, Principal building entrance, Restricted parking, Public parking	Accessible routes w/in city blocks, Indoor routes from accessible to otherwise inaccessible buildings, Accessible entrances, Accessible entrances with automatic door, Accessible entrances normally locked, Entrances accessible via wheelchair lift, Elevator, Curb cut or driveway	Outdoor Features

other interface components to the display. The external web map server, which is Google, is accessed using the application programming interface (API) provided for the Google Maps application. The client sends a request for map data to the external server each time the page is loaded into the client. Once the requested data is returned to the client, it is rendered to the display as the background map for PAM-Pitt. The internal web server, maintained by the Geoinformatics Laboratory in the School of Information Sciences, is a web server containing the local PAM-Pitt database and PAM-Pitt's routing and mapping functions. All computations, coded in PHP, are performed in the internal web server and the client is used for map rendering and presentation.

PAM-Pitt's components include a data layer, a control layer, and a view layer (see Figure 1). The data layer, shown in the bottom of Figure 1, represents the database used by PAM-Pitt. The control layer includes the map functions and routing module to support map presentation, routing features and audio presentation modules, a module for communication with the external web map server and a module for managing user information. This layer connects the data layer to the interface layer and provides the basic procedures for data retrieval, presentation and computation. The view layer is the interactive layer designed for user interaction. In summary, the main components of PAM-Pitt are a user interface, a routing module, map functions, an audio module, and a database, each described in the remainder of this section.

User Interface. The user requests accessibility data/information and submits navigational requirements and personalized settings to PAM-Pitt through its user interface. The interface consists of a web map with interactive controls for displaying data layers, selecting origin/destination pairs, and searching for specific locations (see Figure 2).

Routing Module. The routing module in PAM-Pitt provides a user with optimized routes from origin/destination pairs using the underlying sidewalk network. Optimized routes are shortest paths and personalized routes for wheelchair users. Shortest path, which is the default route choice in PAM-Pitt, is a commonly employed route criterion in navigation systems and services and the use of distance as a criterion is motivated by user preference for the shortest possible journey between locations [13]. Personalized routing is based on individual preferences which include type of wheelchair, age, and fitness level and on sidewalk parameters such as segment length, width, slope, sidewalk condition, sidewalk traffic, and steps [10].

The routing module, in addition to the shortest and personalized routes, provides a suitable University shuttle that is close to user's origin and destination locations. In this option, PAM-Pitt finds the nearest shuttle bus stops to the origin and destination locations and links to the University's shuttle tracking system so that a user can view the selected shuttle traveling along their chosen route and the shuttle's current location. The real-time shuttle position updating consists of two parts, shuttle's position through GPS data and schedule information on the web page using Javascript. We use a server push technology called long-polling for obtaining real-time data every three seconds in the browser and reorganize the data for navigational needs. After obtaining the real-time data, the position of the shuttle is displayed and the time a shuttle will pass the stop closest to the origin is estimated. Figure 3 shows a shuttle route between a pair of origin and destination and several views of the shuttle's real-time location over several minutes.

Another important feature of PAM-Pitt's routing module is the directions provided to the users. The first requirement for providing users with turn-by-turn directions is to know the street name for each segment in the underlying network. Since PAM-Pitt uses a sidewalk network to calculate optimal routes, the use of traditional directions based on a road network is inadequate. Figure 4 shows an example sidewalk intersection. In this example, it can easily be identified that segments AI, HL, JD and KE belong to Street Alpha, and that segments BI, CJ, LG and KF belong to Avenue Beta. The remaining segments IJ, LK, IL and JK represent potential crosswalk areas that are less straightforward for identification.

Visually, IJ and LK seem to belong to Street Alpha, but when directing a user to cross Street Alpha neither IJ nor LK is useful. For instance, if a user is walking from point A to point I, the instruction "keep walking on Street Alpha" would be fine, but when the user comes to point I, "go straight on Street Alpha" is the only option. However, "cross Avenue Beta" is a better instruction for this intersection. In addition to using cross streets when providing directions at an intersection, we divide sidewalk segments into 3 different categories: sidewalk along a street, crosswalk along a building, and sidewalk along a building (see Figure 5). These different sidewalk categories have distinct attributes necessary for turn-by-turn instructions for pedestrian navigation. An example of each sidewalk category is shown in Figure 5.

Map Presentation. The map presentation module retrieves and displays the background map data from the external map server using functions from the Google Maps API and the local PAM-Pitt data layers from the internal server. Examples of the presentation of routing results and the internal data layers are shown in Figure 6.

Database. PAM-Pitt uses PostgreSQL database to store map data, data about users, and weights for route calculation. PAM-Pitt's database includes segment and node entities defining the sidewalk network, user entity that defines user characteristics, personalized parameters, ranking parameters and cost entities utilized in the routing module, and buildings and accessible entrances entities. [11] developed the sidewalk network, the backbone for routing in PAMs, for the University of Pittsburgh. A coordinate pair (i.e., latitude and longitude) represents the nodes of the sidewalk network (Figure 6d) in the database. The segments are represented by using a from-node and to-node structure and include several attributes. The attributes include street name, slope, surface type, surface condition, traffic, number of steps, width and distance.

The database also contains the campus buildings, where users can select them as origin and destination locations, and the accessible entrances (Figure 6b) to the buildings whose locations are described in texts and images (the building and the entrance). One additional layer is the University service boundary (Figure 6c) that defines the extent of University services.

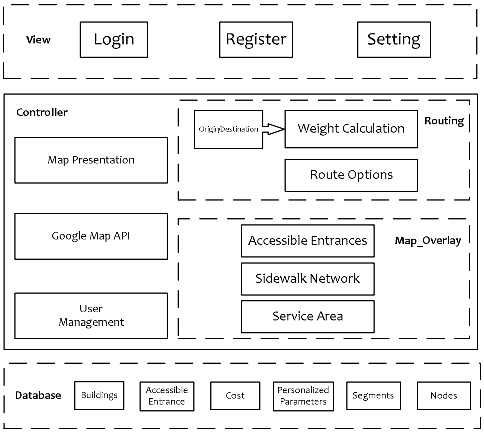

Fig. 1. PAM-Pitt's components

Fig. 2. PAM-Pitt's user interface

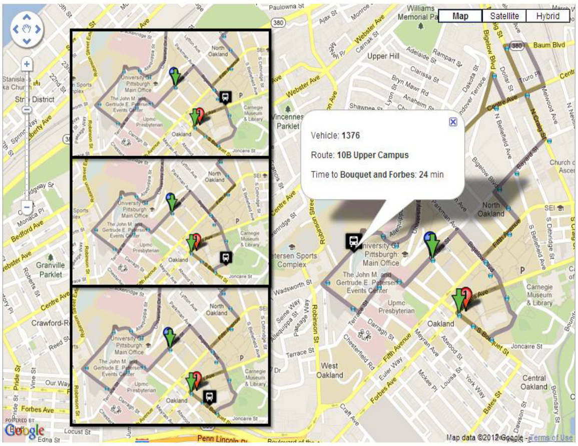

Fig. 3. Real-time shuttle location

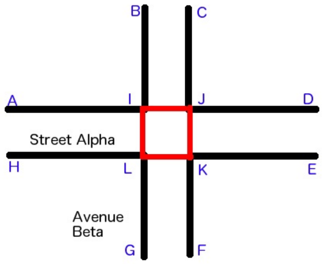

Fig. 4. Example sidewalk intersection

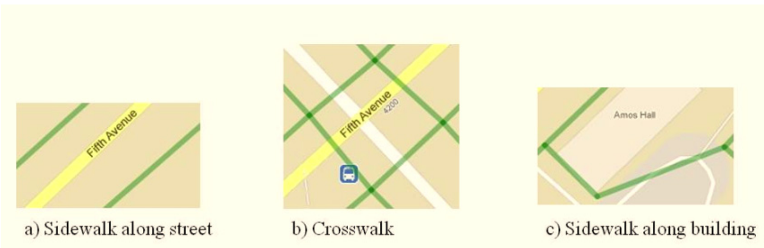

Fig. 5. Sidewalk segment categories

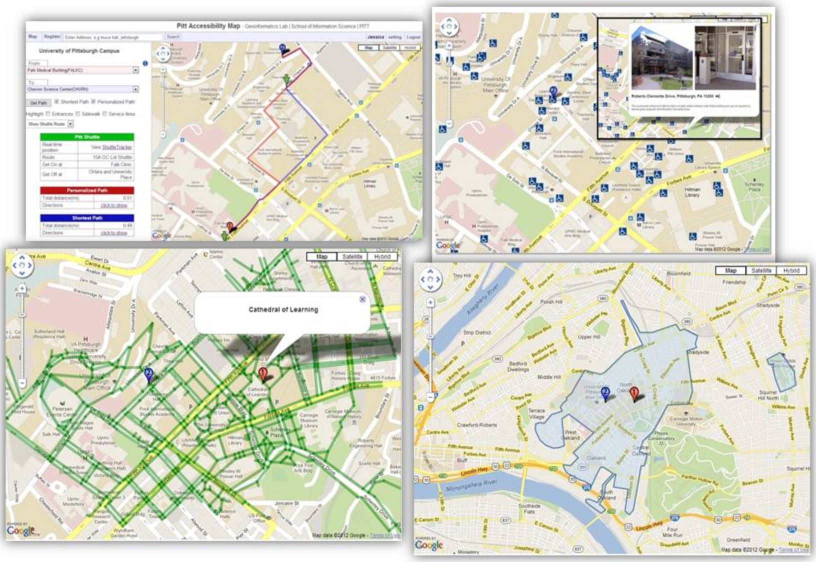

Fig. 6. Accessibility functions and data presentation. Clockwise from top left: (a) routing result presentation, (b) accessible entrances, (c) university's service boundary, (d) sidewalk network.

4 Advanced Features and Functions

Our current plan is to deploy PAM-Pitt for the University of Pittsburgh, described above, as the first version and make it available to the campus community of students, faculty, and staff. Our future plan for PAM-Pitt is to deploy new versions while gathering feedback on the first version. In this section, we describe the platform, features, and functions in future versions of PAM-Pitt.

4.1 Mobile PAM-Pitt and Data Extension

Our immediate next step is to extend the first version in consultation with the Disability Resources and Services office and implement a mobile version of PAM-Pitt, on the mobile web, to enable the widest access to potential users and allow students to access the system through their mobile devices such as iPhone, Android, iPad, among other mobile devices. We also plan to determine the basic set of accessibility data/information that a PAM must contain. We have identified an initial set of new data necessary for PAM-Pitt (see Table 2); however, the type of data the basic data set must contain remains an open question.

Table 2. Additional data for PAM-Pitt

Environment	Data	Community Relevance
Outdoor	Extension of sidewalk network to the extent of the service boundary	All
	Entrances and entrance images for all campus buildings	Mobility
	Power entrance doors	Mobility
	Manual entrance doors	Mobility
	Accessible parking lots	Mobility
	Intersections with assistive technology (APS - accessible pedestrian signals)	Vision
	Curb cuts	Mobility
	Tactile Warnings at Intersections (truncated domes)	Vision
	Alleys	Vision
	Ramps	Mobility
	Landmarks	All
Indoor	Elevator locations	All
	Accessible restrooms	Mobility
	Areas of narrow turning	Mobility
	Building floor plans for campus buildings	All

4.2 Integration of PAM-Pitt with SoNavNet and PNS

We plan to integrate PAM-Pitt with a Social Navigation Network (SoNavNet) and a Pedestrian Navigation System (PNS); both have been developed in the Geoinformatics Laboratory. These integrations will allow the full features of PAMs to be achieved. In the integrated system, students (members of SoNavNet) can share their experiences about POIs/routes/directions with other students who face same/similar mobility challenges. These POIs/routes/directions can then be recommended to other users of SoNavNet. In addition, students can receive real-time guidance from PNS for travelling on computed/recommended as well as on personalized routes. The next two sections briefly describe SoNavNet and PNS.

SoNavNet. SoNavNet is a location-based social navigation network (LBSN) that can address the navigational needs and preferences of any user, anywhere, anytime [7-8]. SoNavNet is a personalized navigation assistance provided through members' experiences. SoNavNet has a high potential for assisting people with disabilities, both indoors and outdoors, by providing a platform for users to share new and personalized data/information. SoNavNet is based on a link between the real world in which navigation occurs and the virtual world of an interactive map. In the real world, there are people who navigate the environment using different modes of transportation. These people become users of a SoNavNet and can participate by sharing and recommending POIs/routes/directions with other users. The vehicle for receiving or sharing recommendations is the interactive map in which users can add POIs, routes, directions, areas and GPS traces.

SoNavNet offers three main functions. The first allows the user to manipulate a map of their surrounding area and to place POIs, routes, directions, and areas on it, thus letting them trace places they visit and how they get there. The second and third functions are request and recommend services. Members seeking navigation recommendations are able to message their friends with a map on which they can mark off an area and request a POI/route/direction within it. The system searches the recommended POIs/routes/directions stored in its database and sends a match POI/route/direction to the user. While SoNavNet is applicable to all communities, users with special needs have unique navigational needs that can be aided by the contributions of other users and SoNavNet offers an ideal medium for capturing the details of the unique navigational needs of these communities.

Pedestrian Navigation Service (PNS). The PNS is focused on providing navigation guidance to pedestrians on walking paths. A pedestrian network, a topological map that describes the geometric relationship between pedestrian path segments, is the key component in any PNS. Pedestrian network data is currently not available (or partly available) for many areas and in many countries compared to road network data. [9] investigated and developed techniques for automatically constructing pedestrian networks using three approaches: network buffering, collaborative mapping, and image processing. To evaluate the three approaches for automatically constructing pedestrian networks, [11] collected and constructed the pedestrian network of the University of Pittsburgh's main campus as the baseline. Different types of a pedestrian path in this network are sidewalk, crosswalk, walking trail, entrance to POI, pedestrian bridge, and pedestrian tunnel [9].

Other components of the PNS are geocoding, map matching, routing, and direction. The PNS is based on a client/server architecture where the servers provide map data (Google Maps) and render maps, compute map matching, compute routes, and generate directions. The client is an Android mobile phone which performs the following main functions: obtaining GPS data on the Android device, sending the new GPS data to the server, and receiving a map showing a computed route and the current location. The map matching module, which uses GPS data and a pedestrian network to map match newly updated GPS data, is based on a chain-coding technique [14]. The routing module is currently based on shortest distance criterion but the plans are in place to include an option for wheelchair users taking into account such criteria as shortest distance, minimum barriers, fewest slopes, avoiding bad surfaces, using only controlled crossings, and limited road crossing [10]. The direction module presents step-by-step instructions guiding the user to travel on the computed route using both text and audio on the Android phone.

5 Challenges and Future Research Directions

PAM-Pitt is the first of its kind and the first attempt at developing such a system for a university campus. This development, described above, however, has helped us realize several challenges and issues that developers of PAMs must address. Below each of these challenges along with future research directions are described.

Considering the advances and interest in geo-crowdsourcing [1], it is expected that updated and new accessible data/information will increasingly become available through existing and new geo-crowdsourcing services. An example of data update is information about a new construction on a sidewalk segment which makes the segment impassible for a period of time. An example of new data/information is an accessible entrance to a newly constructed building or previously unmapped entrance. Updating a PAM's database with new data and updates, whenever they become available, requires routinely searching for updates in existing and new geo-crowdsourcing services. This routine checking will become a challenge for the developers of PAMs and if it is not addressed properly may result in outdated data being used with PAMs. To address this challenge, there is a need for development of techniques/tools to continually search existing geo-crowdsouring services and identify new services as they become available, and for procedures to download the required data/information.

Once adequate methods for retrieving new data and updates from geo-crowdsourcing services are determined, the next challenge is to determine an automatic means for updating PAM's database with the new accessible data/information. To address this challenge, there is a need for development of techniques/tools that: (a) convert heterogeneous data/information (current geo-crowdsourcing services do not adhere to a specific agreed upon standard type and format) to the underlying data/information type and format supported by a PAM; (b) integrate data/information using a suitable data schemas supported by a PAM's database; and (c) populate a PAM's database with new data/information.

Considering that currently there are no standards with respect to accessible data/information quality, understanding the quality of the new data and updates downloaded and populated in a PAM's database is another challenge. To address this challenge, development of techniques/tools to automatically validate the quality of accessible data/information in a PAM is needed.

6 Summary

In this paper, we introduced the concept of PAMs and discussed the development of PAM-Pitt. We have shown that PAM-Pitt is novel compared to existing accessibility maps provided at 20 university campuses in the US in that it offers navigation services, such as routing, in addition to displaying a map of accessibility at certain locations. We discussed advanced features and functions for the representative PAM that include development of a mobile PAM-Pitt and integration of PAM-Pitt with SoNavNet (a social navigation network system) and PNS (a pedestrian navigation service). The purpose of SoNavNet in PAM-Pitt is to allow users to share personal POIs/routes/directions experiences with the members of a university community and the purpose of PNS in PAM-Pitt is to facilitate real-time guidance on the computed/recommend routes within the campus area. We also discussed some challenges and future research directions such as development of techniques and tools for automatically finding updated and new accessible data/information, populating PAMs' databases, and determining quality of accessible data/information.

Acknowledgements. The work presented in this article is the result of collaboration between the Geoinformatics Laboratory in the School of Information Sciences and the

Disability Resources and Services office at the University of Pittsburgh. The authors would like to thank Ms. Piyawan Kasemsuppakorn for making the base software for an interactive map available for this work. We also thank the Disability Resources and Services at the University of Pittsburgh for providing data regarding the accessible entrances as well as consultations on the various aspects of the project.

References

1. Benner, J.G., Karimi, H.A.: Geo-Crowdsourcing. In: Karimi, H.A. (ed.) Advanced Location-Based Technologies and Services. Taylor & Francis (2013)
2. Bromley, R.D.F., Matthews, D.L., Thomas, C.J.: City Centre Accessibility for Wheelchair Users: The Consumer Perspective and the Planning Implications. Cities 24(3), 229–241 (2007)
3. Elwood, S.: Geographic Information Science: Emerging Research on the Societal Implications of the Geospatial Web. Progress in Human Geography 34(3), 349–357 (2010); First published on (July 28, 2009)
4. Holone, H., Misund, G.: People Helping Computers Helping People: Navigation for People with Mobility Problems by Sharing Accessibility Annotations. In: Miesenberger, K., Klaus, J., Zagler, W.L., Karshmer, A.I. (eds.) ICCHP 2008. LNCS, vol. 5105, pp. 1093–1100. Springer, Heidelberg (2008)
5. Holone, H., Misund, G., Holmstedt, H.: Users Are Doing It for Themselves: Pedestrian Navigation with User Generated Content. In: Next Generation Mobile Applications, Services and Technologies (NGMAST 2007), pp. 91–99. IEEE Press, Cardiff (2007)
6. Holone, H., Misund, G., Tolsby, H., Kristoffersen, S.: Aspects of Personal Navigation with Collaborative User Feedback. In: NordiCHI 2008: Using Bridges, pp. 182–191. ACM Press, Lund (2008)
7. Karimi, H.A., Zimmerman, B., Ozcelik, A., Roongpiboonsopit, D.: Sonavnet: A Framework for Social Navigation Networks. In: International Workshop on Location Based Social Networks (LBSN 2009), Seattle, WA (2009a)
8. Karimi, H.A., Nawn, D., Zimmerman, B.: Navigation Assistance Through "Models" or "Experiences"? GIM International 23(12) (2009b)
9. Karimi, H.A., Kasemsuppakorn, P.: Pedestrian Network Construction Approaches and Recommendation. International Journal of Geographical Information Science (2012) (in press)
10. Kasemsuppakorn, P., Karimi, H.A.: Personalized Routing for Wheelchair Navigation. Journal of Location Based Services 3(1), 24–54 (2009)
11. Kasemsuppakorn, P., Karimi, H.A.: Data Requirements and Spatial Database for Personalized Wheelchair Navigation. In: 2nd International Convention on Rehabilitation Engineering & Assistive Technology, Bangkok, Thailand (2008)
12. Matthews, H., Beale, L., Picton, P., Briggs, D.: Modelling Access with Gis in Urban Systems (Magus): Capturing the Experiences of Wheelchair Users. Area 35(1), 34–45 (2003)
13. Pang, G.K.H., Takahashi, K., Yokota, T., Takenaga, H.: Intelligent Route Selection for in-Vehicle Navigation Systems. Transportation Planning and Technology 25, 175–213 (2002)
14. Ren, M., Karimi, H.A.: A Chain-Code-Based Map Matching Algorithm for Wheelchair Navigation. Transactions in GIS 13(2), 197–214 (2009a)
15. Ren, M., Karimi, H.A.: A Hidden Markov Model Map Matching Algorithm for Wheelchair Navigation. The Journal of Navigation 62(3), 383–395 (2009b)

16. Ren, M., Karimi, H.A.: A Fuzzy Logic Map Matching for Wheelchair Navigation. GPS Solutions 16(3), 273–282 (2012a)
17. Ren, M., Karimi, H.A.: Movement Pattern Recognition Assisted Map Matching for Pedestrian/Wheelchair Navigation. Journal of Navigation 65(4), 617–633 (2012b)
18. U.S. Access Board: ADA Guidelines, `http://www.access-board.gov/ada/index.htm`
19. Uniform Federal Accessibility Standards: 24 C.F.R. § 40 (1984)
20. Völkel, T., Weber, G.: Routecheckr: Personalized Multicriteria Routing for Mobility Impaired Pedestrians. In: ASSETS 2008, pp. 185–192. Halifax, Nova Scotia (2008)