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Design Considerations for a Personalized Wheelchair Navigation System

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***Abstract*—** Individuals with mobility impairments such as wheelchair users are often at a disadvantage when traveling to a new place, as their mobility can be easily affected by environmental barriers, and as such, even short trips can be difficult and perhaps impossible. We envision a personalized wheelchair navigation system based on a PDA equipped with wireless Internet access and GPS that can provide adaptive navigation support to wheelchair users in any geographic environment. Requirements, architectures and components of such a system are described in this paper.

Keywords – Wheelchair users, accessibility, environment barriers, wheelchair navigation, GPS.

I. Introduction

Independent mobility is an important dimension of quality of life for individuals with mobility impairments such as wheelchair users [1]. These individuals may encounter an array of environmental barriers during their activities of daily living, some of which they may overcome and others they may not. A study conducted by Meyers et al. [2] interviewed 28 adult wheelchair users and found that the barriers frequently reported included narrow aisles, no ramps or steep ramps, bad weather, door handles or door pressure, no curb cuts or blocked cuts, travel surfaces, obstructed travel, etc. The Americans with Disability Act (ADA) and Architecture Barriers Act developed specific accessibility guidelines for buildings and facilities that should be applied during the design, construction, and alteration of buildings and facilities [3]. However, environmental barriers remain to be a problem preventing wheelchair users from participation and integration into the community [4].

Many wheelchair users hesitate to visit an unfamiliar place because they have no information about the new environment and its accessibility conditions [1]. They usually have no options but rely on repetitive and regular routes with least obstructions for their daily movement in a predefined area. Still these routes, especially in a dynamic changing environment such as a university campus, are not free from unexpected obstacles and changes of accessible conditions such as icy walkway, road blockades, and a malfunctioning automatic door. These problems can be anticipated and avoided if wheelchair users are provided with accurate and reliable information about access and mobility options, and are notified about changes, which would greatly facilitate safe and effective wheelchair navigation, in particular, around unfamiliar environments.

Recent advances of modern wireless communication technology, Geographic Information Systems (GIS), Global Positioning System (GPS), and intelligent information systems have shown great promise in car navigation. Some of these technologies have been employed to develop navigation aids for the blind and visually impaired. However, there is no such systems reported for navigating people using wheelchairs. Existing car navigation systems are inappropriate for wheelchair navigation for several reasons, most important one is the lack of relevant information to wheelchair accessibility such as sidewalks, sidewalk conditions (grade, steps, smoothness) and building conditions (accessible entrance, elevators, and bathroom) in car navigation databases.

Much research has been focused on developing ‘smart’ wheelchairs for navigation assistance mainly in indoor environments [5, 6]. These wheelchairs are usually equipped with sensors to detect obstacles and use computer vision or environmental markers for localization and navigation. While some work on outdoor navigation using GPS and other sensors has been reported [7, 8], their contribution is on obstacle detection and autonomous navigation instead of on the infrastructure of the environment and accessible route planning. Several literatures report application of GPS and GIS to developing navigation maps for individuals with disabilities [9-11]. For example, Beale et al. [9] developed, tested, and applied a GIS for modeling access for wheelchair users in urban areas; Kurihara et al. [10] presented a general architecture of GIS for assisting the users in creating barrier-free street maps by using the Internet and the highly accurate GPS; and Sobek and Miller [11] developed a web-based system as a tool for routing pedestrians of differing abilities and analytical evaluation of existing infrastructure.

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However, none of these systems provides real-time navigation assistance to wheelchair users.

The personalized wheelchair navigation system proposed in this paper will provide real-time navigation support including dynamic routing functions to wheelchair users in a complex environment. The system is based on a personal digital assistant (PDA) with wireless Internet access and GPS. This paper describes the system architecture and components.

II. System Architecture

The architecture of the personalized wheelchair navigation system seeks to balance the need for mobility and computing power. To achieve mobility, most of the navigation tasks must be performed locally using the PDA. However, given the limited capacity and computing power of PDA, computationally-intensive tasks such as routing are expected to have low time performance. To achieve a feasible computing balance, the system adopts a distributed architecture as depicted in Figure 1. In this architecture, the execution of the tasks is distributed between a local navigation system on the PDA used by the wheelchair user, and a remote server as the information processing and communication center. The system utilizes publicly accessible Internet Map Server technologies such as Google Maps or Microsoft Virtual Earth along with real-time information such as weather information. With this architecture, those tasks that are not computationally-intensive will be performed by the PDA, others by the server.

Using this architecture, wheelchair users can use the PDA as a complete navigation system that includes location finder and routing modules. The navigational tasks which include position determination (using GPS), map matching and map display will be performed by the PDA, while others that computationally intensive such as routing will be performed by the server. As illustrated in Figure 1, the local navigation system is comprised of three layers: *presentation layer, core application layer, and hardware interface layer*.

The presentation layer provides users with a regular window-based screen interface and a voice-based interface. Wheelchair users can input their personal information such as age, gender, type of wheelchair used (manual or power wheelchair), fitness level, and routing preferences such as shortest time, shortest distance, minimum barriers, avoiding poor quality sidewalks, avoiding slopes with a gradient over a certain degree, etc. The hardware interface layer is responsible for abstracting data gathering and logging mechanism from a GPS device. The core application layer performs all the important computational tasks, including map matching and data integration.

The Information Center has three layers: *service layer, application layer, and data layer*. The service layer acts as a dispatcher that forwards each service request from PDA to a corresponding logic in the application layer. The application layer is responsible for providing external interface to publicly accessible infrastructure. The data layer provides transaction management/caching mechanism for all database-related operations.

III. System Components

The components of the personalized wheelchair navigation system are a digital map database, a navigation module, and a routing module, all with special features for wheelchair accessibility.

The map database component provides the navigation module with the necessary resources to perform routing and directions information. Our informal interview with three wheelchair users and preliminary analysis indicate that the map database should contain in the minimum a sidewalk network, buildings, and landmarks (see Table 1). The sidewalk network will be represented through connected lines with attributes identifying conditions of the sidewalk such as stairs, ramps, sidewalk slope, traffic, junction, bus stop, and severely damaged areas. Building data should contain location information with attributes identifying accessible entrances such as door type, i.e., automatic or manual, weight, and entrance width.

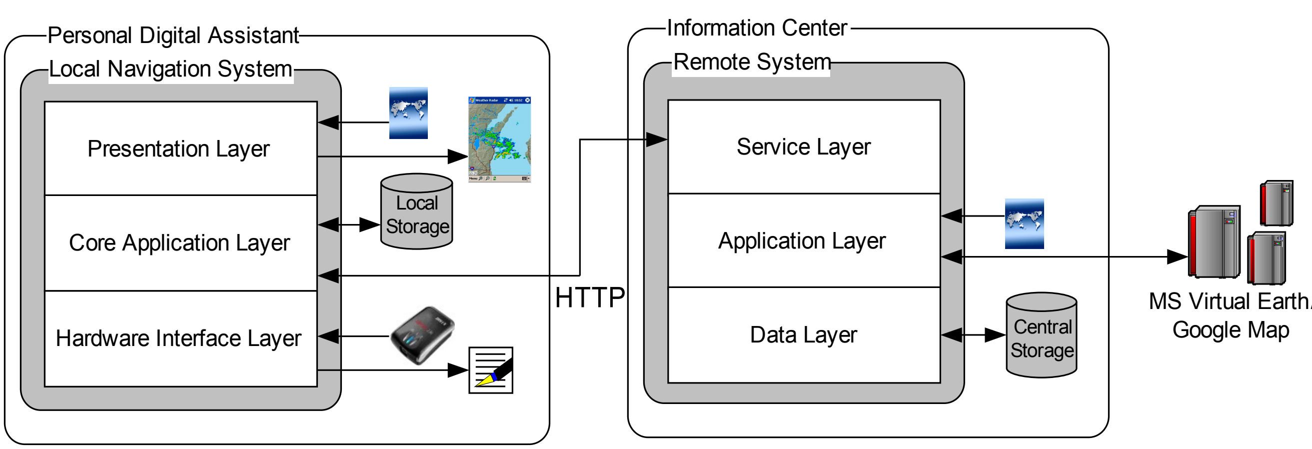

Figure 1 Distributed Architecture Model of the Personalized Wheelchair Navigation System

Table 1 Wheelchair navigation map database components

Category	Measure
Building accessibility	▪ Curb ramp ▪ Door (auto or manual)
Sidewalk	▪ Sidewalk condition (cracks, potholes, materials) ▪ Sidewalk congestion (pedestrian traffic) ▪ Sidewalk geometry (clear width, grade, cross-slope, step)
Curb	▪ Curb (height) ▪ Curb cuts (width, slope) ▪ Landing (length)
Lighting	▪ Visibility
Handicap parking	▪ Parking space (width) ▪ Passenger loading zone (width)
Bus	▪ Bus stop accessibility ▪ Bus route accessibility

The navigation module is to provide real-time navigation functions. Unlike car navigation, where position accuracy around 10 meters would be feasible, wheelchair navigation requires an accuracy of 3 meters or better, similar to pedestrian navigation [12]. The challenges with positioning include signal blockage and attenuation of Global Navigation and Satellite System (GNSS) receivers in urban canyons and under heavy tree cover resulting in inaccurate positions. Augmentations such as Differential Global Positioning Systems (DGPS), Assisted GPS (A-GPS) and Wide Area Augmentation System (WAAS) are potential alternatives for improving GNSS accuracy. Also, dead reckoning techniques could be integrated with a GNSS through a Kalman Filter technique to complement and improve the overall accuracy. Another function in the navigation module is map matching technique which can find the most probable location on the sidewalk network that user is traveling using the position received by GPS and/or other positioning techniques. Map matching assumes the user is traveling somewhere on the sidewalk network and uses specific criteria to pinpoint the most likely location. Currently, there are many map matching algorithms specifically designed to operate with vehicles traveling on a road network [13, 14]. Some features of these current techniques may work well for a wheelchair traveling on a sidewalk network. Special attention needs to be given to the increased density introduced by a sidewalk network, as sidewalks tend to be spaced closer than roads in a road network.

The routing module could be based on several existing algorithms designed for vehicles on a road network, such as Dijkstra's algorithm [15]. However, there are more parameters when choosing a route for a wheelchair than for a vehicle on a road network or a pedestrian on a sidewalk network. This is because a wheelchair is more sensitive to attributes of the transportation network, such as stairs, sidewalk slope, and sidewalk condition. Moreover, each wheelchair user has individual characteristics such as physical ability level and personal routing preferences. Therefore, the personalized attributes will be an important parameter in creating a routing function.

IV. Discussions

A prototyped personalized wheelchair navigation system will be developed for use within the University of Pittsburgh (Pitt) campus. The Pitt campus including academic buildings, mixed shops and restaurants, hilly streets, and constant special events can be characterized as a complex and dynamically changing environment. The overall goal is to develop a fully functional personalized wheelchair navigation system which will feature functions such as dynamic routing that allows the user to re-route to a new destination, or to the same destination through an alternate path, dynamic feedback notification where users can share accessibility information, and emergency response that can trigger calls to pre-specified contact persons. We also plan to explore indoor navigation techniques to facilitate smooth outdoor/indoor navigational handoffs. We believe that such a system will enable wheelchair users to experience transparent accessibility, freedom of mobility, and an improved quality of life.

Our work can be extended to support other applications such as an accessible tourist guide and the evaluation of built environments with respect to affording access for users with mobility impairments, and identifying obstacles that create routing discrepancies among people with different physical capabilities.

References

[1] N. Thapar, G. Warner, M. Drainoni, S. R. Williams, and H. Ditchfield, "A pilot study of functional access to public buildings and facilities for persons with impairments," *Disability and Rehabilitation,* vol. 26, pp. 280-289, 2004.

[2] A. R. Meyers, 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,* vol. 15, pp. 1435-1446, 2002.

[3] "Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines ": United States Access Board, 2004.

[4] L. McClain, D. Beringer, H. Kuhnert, J. Priest, E. Wilkes, S. Wilkinson, and L. Wyrick, "Restaurant wheelchair accessibility," *The American Journal of Occupantional Therapy,* pp. 619-623, 1993.

[5] S. P. Levine, D. Bell, L. Jaros, R. Simpson, Y. Koren, and J. Borenstein, "The navchair assistive wheelchair navigation system," *IEEE Transactions on Rehabilitation Engineering,* vol. 7, pp. 443-451, 1999.

[6] R. Simpson, E. LoPresti, S. Hayashi, I. Nourbakhsh, and D. Miller, "The smart wheelchair component system, ," *Journal of Rehabilitation Research & Development,* vol. 41, pp. 429-442, 2004.

[7] M. Imamura, R. Tomitaka, Y. Miyazaki, K. Kobayashi, and K. Watanabe, "Outdoor waypoint navigation for an intelligent wheelchair using differential GPS and INS," in *SICE Annual Conference*, 2004, pp. 2193-2196.

[8] Y. H. Wu, B. Y. Lu, H. Y. Chen, and Y. Ou-Yang, "The development of M3S-Based GPS NavChair and tele-monitor system," in *2005 IEEE Engineering in Medicine and Biology 27th Annual Conference*, 2005, pp. 4052-4055.

[9] L. Beale, H. Matthews, P. Picton, and D. Briggs, "Modeling access with GIS in urban systems: an application for wheelchair users in Northamptonshire," in *6th ERCIM Workshop*, 2000.

[10] M. Kurihara, H. Nonaka, and T. Yoshikawa, "Use of highly accurate GPS in network-based barrier-free street map creation system," in *IEEE*

International Conference on Systems, Man and Cybernetics, 2004, pp. 1169-1173.
[11] A. D. Sobek and H. J. Miller, "U-Access: a web-based system for routing pedestrians of differing abilities," *Journal of Geograph Syst,* vol. 8, pp. 269-287, 2006.
[12] S. Usui, "Evaluation of Positioning Accuracy for the Pedestrian Navigation System," in *IEICE Transactions on Communications*, 2005, pp. 2848-2855.
[13] W. Y. Ochieng, M. A. Quddus, and R. B. Noland, "Map-Matching in Complex Urban Road Networks," *Brazilian Journal of Cartography,* vol. 55, pp. 1-18, 2003.
[14] C. E. White, D. Berstein, and A. L. Kornhauser, "Some Map Matching Algorithms for Personal Navigation Assistants,," *Transportation Research Part C 8,* 2003.
[15] E. W. Dijkstra, "A note on two problems in connexion with graphs," *Numerische Mathematik,* pp. 269-271, 1959.