A New Approach for Pedestrian Navigation for Mobility Impaired Users Based on Multimodal Annotation of Geographical Data

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Abstract. Although much effort is spent in developing navigation systems for pedestrians, many users with special needs are mostly excluded due to a lack of appropriate geographical data such as landmarks, waypoints, or obstacles. Such data is necessary for computing suitable routes which might differ from being the shortest or fastest one. In this paper, the concept of multimodal annotation of geographical data for personalized navigation is described. Direct input by the user is combined with data derived from the observation of the user's LOM-Modality (Location, Orientation, and Movement) to annotate geographical data. Based on this data and data derived from other users of the same user group, suitable routes even in unknown territory can be calculated.

Keywords: multimodal annotation, pedestrian navigation, mobility impairment.

1 Introduction

Carrying out an independent and autonomous life seems usual for most people around us. However, many disabled and elderly people face immense problems in overcoming difficulties imposed by our common environment. For example, for people restricted in their mobility due to impairment, a task such as covering a specific distance for buying daily life products may become a heavy burden. In this context, the navigation problem is divided into two parts, namely, micro-navigation and macro-navigation. Distances up to 10 meters are covered within micro-navigation which includes the avoidance of nearby hazards and obstacles whereas all distances above are covered within macro-navigation. The navigation to a remote destination which is not perceivable by the traveller is thus a task including both micro-navigation and macro-navigation.

Travel aids and assistive technologies have been developed to guide elderly and visually impaired people in unknown environments. For example, the MOBIC travel aid [19] is based on geographical information systems (GIS) and the Global Positioning System (GPS) for guidance for distances greater than 50 meters which has

C. Stephanidis (Ed.): Universal Access in HCI, Part II, HCII 2007, LNCS 4555, pp. 575–584, 2007.
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been defined as the starting distance for macro-navigation at the time of system development. The difference to the distances used within the introduction for macro-navigation is due to a higher accuracy of state-of-the-art GPS systems.

MOBIC also provides a component for pre-journey planning, on which the later navigation relies. The MOBIC system proved successful for distances over 50 meters; however, there is a gap between the immediate environment of the traveller which can be sensed by other travel aids such as the long cane and the provided support for long distances. Approaches to close this gap, which are also used for indoor navigation, incorporate beacons which provide additional information about the environment. Although promising results have been reported [16], such systems require immense investments regarding necessary infrastructure and are therefore only available at special places.

Using current GPS systems, promising results have been reported to support navigation for instance for visually impaired people [13]. However, one of the most important problems – as was also reported for the MOBIC system – is the acquisition of specific data including obstacles, specific waypoints, and landmarks [5, 14]. The additional information is necessary to adaptively calculate the best route for people with special needs and provide accurate route descriptions. Although the direct and shortest route might seem the best choice for people without impairments, for instance blind people try to avoid crowded cross-ways. Consequently, a route avoiding such cross-ways – though it might be of longer distance – becomes more suitable. A recently developed solution [11] uses machine learning methods for route planning and takes additional information into account to fit the requirements of disabled travellers. User specific information such as the type of handicap is derived from a user model and used within a fuzzy decision system where an appropriate route is calculated using a modified version of the A*-Algorithm. Although additional data is used for the calculation of appropriate routes, the problem of the acquisition of specific geographical data remains an untreated problem.

The paper is structured as follows. An extensive overview of assistive technologies for navigational support for mobility impaired and in particular visually impaired travellers is given in section 2. The requirements of mobility impaired travellers regarding pedestrian wayfinding are presented in section 3 together with a discussion of standard route calculation algorithms and their adaptation to the specific needs of the intended user group as discussed in the following. In section 4, the concept of multimodal annotation of geographical data is introduced which is used to acquire necessary data for the calculation of optimal routes. Finally, a conclusion is given in section 5.

2 Travel Aids for Navigational Support

The navigation and wayfinding problem for mobility impaired and particularly visually impaired people has been tackled by many research projects and commercial product developments. Most systems have been developed to solve one specific part of the wayfinding problem, namely either micro-navigation or macro-navigation. Electronic travel aids can thus be classified in the following schema:

- primary vs. complementary travel aids,
- support for micro-navigation and / or macro-navigation,
- dependencies upon environmental installations.

Considering the first classification, primary travel aids can be used on their own. Consequently, primary travel aids must offer support for micro-navigation for travellers who are not able to sense their direct environment directly. For instance, blind travellers need a travel aid such as a long cane or a guide dog to avoid nearby obstacles and hazards. Long canes and guide dogs are thus primary travel aids; the Ultrasonic Cane [9] is an example for a primary electronic travel aid respectively.

Complementary electronic travel aids normally support the part of the navigational task related to reaching a remote destination beyond the immediate perceivable environment (macro-navigation). Examples for complementary travel aids include GPS-based systems such as the MoBIC travel aid [19], Trekker [10], and Drishti [15]. Other complementary electronic travel aids which rely upon environmental installations include Talking Signs [4] which is discussed in detail below, and Talking Braille [16], being mainly a solution for the problem of ‘where am I?’ by providing environmental information accessible within short distances from RFID beacons.

The MoBIC travel aid and Trekker are complementary travel aids which do not rely upon environmental installations. The MoBIC travel aid is based on a geographical information system (GIS) and the Global Positioning System (GPS). It is intended to increase the mobility of blind and elderly travellers. The MoBIC travel aid is mainly used for macro-navigation, thus it can be classified as complementary to primary travel aids including the long cane or guide dog which are used to avoid obstacles and hazards within micro-navigation distances. The MoBIC travel aid consists of two components, namely the MoBIC Pre-Journey System (MoPS) and the MoBIC Outdoor System (MoODS). The MoPS allows travellers to plan their routes and to access information about the environment using a standard PC. The system uses different digital maps which have to be enriched by additional information bein particularly important for blind and elderly travellers such as the type of surface underfoot, or entrances usable by wheelchairs. During route planning, user preferences such as choosing the safest route instead of simply following the shortest path where incorporated into the route calculation.

The pre-planned route is used by the MoODS to assist the traveller during the navigational task. The system provides information and feedback to the traveller whenever a change in direction is needed or when the traveller explicitly asks for it. Field trials revealed promising results for elderly and blind travellers. Main drawbacks of the system include the exclusive support for great distances above 50 meters and the lack of additional specific geographical data for optimal route calculation. Consequently, only pre-planned routes could be used without the possibility for a dynamic adoption to changing parameters.

Trekker is a commercially available complementary system developed by the New Zealand based company Humanware. Trekker offers GPS based navigation support for blind travellers based on map data and personal points of interest stored on a PDA. This data can be updated by using internet based resources, for example, points of interest of other users can be imported and used. Additionally, Trekker offers an offline mode for travellers to explore routes in advance comparable with the functionality of the MoPS. Although Trekker is one of the most sophisticated systems on the market, it does not support an adaptation of the underlying geographical data by the user. Consequently, the functionality regarding the calculation of optimal routes is restricted.

Examples for systems relying upon environmental installations include Talking Signs and Talking Braille. The Talking Signs system relies upon remote infrared signage deployed at important locations or public transportation means. The traveller uses a receiver which must be pointed towards the direction of the signage to access the specific information. The information is then presented using synthetic speech. Consequently, the traveller receives information about location itself and the direction where the place is located.

The Talking Braille system also conveys information about specific locations by using a receiver and synthetic speech. However, Talking Braille uses RF signals to transmit the information which does not permit to obtain the direction of the specific location. The main drawback of both systems, although they offer many benefits to make cities more accessible, is the need to deploy beacons within the environment which is additionally very cost intensive. A usage of the system in environments without preliminary installations is also not possible.

To sum up, regarding current electronic travel aids, the main problem is lack of appropriate geographical data to fit the requirements of disabled people. Most systems still rely upon inappropriate map data; an acquisition of additional geographical data or related annotations is not possible. Consequently, a methodology for the acquisition of such data is needed.

3 Pedestrian Navigation for Mobility Impaired People

Mobility impaired people form a very heterogeneous user group with a broad range of different requirements concerning pedestrian navigation and wayfinding. A definition of the term "mobility impairment" in a way that fits in the context of the discussion is needed to narrow the user group. In most cases, mobility impairment is defined as a motion impairment limiting the movement of parts of the body [21]. This definition must be broadened to include the intended user groups. We thus will rely upon the following practical definition for mobility impairments for the following discussion:

> *Mobility impairments include all functional limitations which affect the ability of a person to reach a remote destination independently. A physical, cognitive, or sensory impairment or a combination of them may lead to mobility impairment.*

The above definition allows a broader context regarding the term of 'mobility impairment'. Although wheelchair bound people are the most prominent group of mobility impaired users, our definition allows for inclusion of other users such as blind people who are limited in their mobility by the inability to sense their environment visually. However, part of the mobility impairment of blind people can be compensated by the use of specific travel aids such as the white cane or a guide dog. Additionally, many elderly people have problems when navigating in an unknown environment due to a slight loss of sight or cognitive disabilities such as dementia [1]. These people are hence mobility impaired and can benefit significantly when travel aids offering appropriate navigational instructions in a suitable presentation form are available [6].

Pedestrian navigation in particular concerning mobility impaired travellers imposes additional requirements upon navigation systems compared to car navigation. Car navigation mostly relies upon a network of well-known streets whereas pedestrian navigation is more complex due to an increased network size as pedestrians are able to use paths that are not accessible for cars. Assuming that the available map data is sufficient, pedestrian navigation is then reduced to the problem of finding a route in a network from one initial point *S* to a destination point *D* with minimum cost. This problem has been treated extensively within the past decades and is referred to as the shortest path problem.

The most well-known algorithm for solving the shortest path problem is Dijkstra's algorithm [2] which calculates the shortest path from one starting location to all other locations in the network. This calculation can be accelerated when only the shortest path from one starting point to one destination point is of interest. The corresponding algorithm is called the A*-Algorithm [7] and is the most commonly used shortest path algorithm in geographical networks. As the result of these algorithms is the route with minimal costs, it strongly depends on the weightings associated with the branches of the network graph. The weightings are normally correlated with the distance of the real path section or the time necessary to traverse it. Fig. 1 shows a simple example of a network graph with weights associated with the branches.

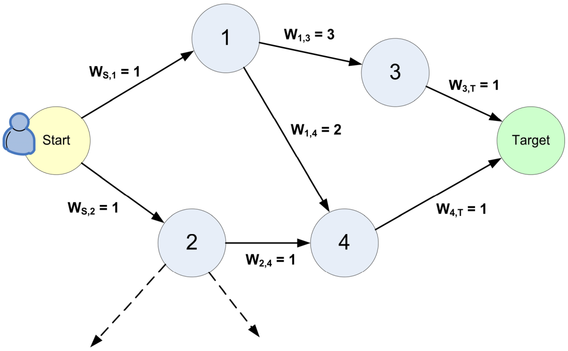

Fig. 1. Example for a simple network graph

The above presented distance metrics provide appropriate results for most pedestrians navigating in unfamiliar environment. However, they do not fit the heterogeneous requirements of mobility impaired travellers, as the assumption that the suitability of a path only depends upon distance or traversing time cannot be adhered. For example, people bound to a wheelchair are not able to surpass stairs. Therefore, a route including a section which can only be passed by traversing stairs must not be the result of the route calculation algorithm. On the other hand, regarding blind travellers, it even depends on the current situation which routes are appropriate. If a blind traveller is accompanied by a guide dog, escalators must be avoided as the guide dog is not able to use them. In this case, stairs or elevators are suitable alternatives. In contrast, if the blind traveller uses only a long cane, escalators are a suitable option.

The complexity of route calculation increases significantly when additional means of public transportation such as busses, railways, or tramways are considered. The inclusion of these transportation means leads to an increased network graph. In this context, the navigation is sometimes referred to as multimodal [3], meaning the availability of different modes of transportation. The usage of public transportation also leads to new constraints regarding the convenience rating of routes. Although a bus stop might be closest with respect to a desired destination, taking the next bus stop might be a better choice for a traveller using a wheelchair if the way backwards goes downhill instead of uphill. Furthermore, big squares and plazas impose additional problems upon navigation systems. As specific fine grained geographical data are normally not available, only poor support for micro-navigation is offered by most navigation systems.

Routes calculated by currently available navigation systems do not provide optimal routes for mobility impaired travellers regarding the above mentioned requirements. Consequently, we need an adapted definition of 'optimal route' before the aspect of missing geographical data is discussed in more detail in the next section. We thus defined the term 'optimal route' in the context of pedestrian navigation for mobility impaired travellers as follows:

> *A route from an initial location S to a destination D is optimal if the value of a specified cost function is minimal compared to the value of other possible routes. The specified cost function expresses a metric depending on the parameters distance, time, convenience as well as other related parameters derived from the individual requirements of the specific user.*

The definition allows a broad interpretation of what requirements must be fulfilled by an optimal route as the cost function is not specified in detail. However, it also constricts the cost function as these parameters must be included. In contrast to most navigation systems which only use metrics such as distance or time, the here defined cost function relies on additional parameters. To illustrate the creation of suitable cost functions, consider the following simple example:

$$W_{Path} = \sum_{i,j} f_{i,j}(w_{i,j}^{u}, w_{i,j}^{c}, d_{i,j}^{\sim})$$

The function W_{Path} calculates the value of the cost for the whole path as the sum of the cost $f_{i,j}$ of each section / branch linking intermediate locations i and j. The cost $f_{i,j}$ of a section depends on a convenience weighting $w_{i,j}^{u}$ derived from the personal profile of the user, on a collaborative convenience rating $w_{i,j}^{c}$ which is accessed remotely and associated with the user group of the traveller, and on a temporal / distance metric $d_{i,j}^{\sim}$ for the section. The last parameter is used to verify calculations which are based on the previous convenience parameters. Although a route might lead to a maximum convenience rating (which would result in a minimum cost value), it might have a very high distance rating, that is the distance of the resulting route is comparably high. Consequently, a very high value of the distance metric might lead to an exclusion of specific routes as it is not reasonable for a traveller to traverse a very long route to reach a nearby destination.

The convenience ratings indicate a measurement of appropriateness for the individual traveller and the associated user group. Consequently, the result of the cost function represents a metric which depends on the correlation of all parameters required by a specific user. The cost function thus varies dependent on the current user's profile and situation.

4 Multimodal Annotation of Geographical Data

To enable navigation systems to calculate optimal routes for mobility impaired travellers, additional geographical data are necessary. In the majority of cases, these specific data are neither part of the underlying maps nor of the geographical database. One of the biggest problems is the acquisition of the geographical data including obstacles, specific waypoints and landmarks as well as their annotation with metadata, which is particularly important regarding the derivation of parameters for the cost function used to calculate optimal routes.

The here introduced technique of multimodal annotation builds a conceptual framework for both the acquisition and application of specific geographical data and corresponding metadata. The general concept is to annotate and enrich the basic geographical data with additional information associated with predefined user profiles. The concept is based on two integral parts. Firstly, annotation data is derived semi-automatically by analyzing the user's LOM-Modality. The LOM-Modality combines the user's location, orientation and movement into one modality which allows for drawing conclusions using arbitrary combinations of all three spatial dimensions to annotate the underlying geographical data. Secondly, direct input by the user is used to derive geographic information. This approach stands in contrast to classical approaches where spatial information is solely considered as context [17, 18] but offers many benefits as the user's location, orientation, and movement can be comprehended as an integral part of the interaction.

Annotation examples derived via direct input include information about the ground surface, the slope of a path section, specific points of interest (POI), small sound samples, or even images. Considering the last example, especially elderly people benefit substantially when guided along a route using photographs of landmarks compared to the use of standard paper based maps [6]. Automatically derived annotations using the LOM-Modality include specific convenience weights for path sections indicating the suitability for specific user groups. For instance, if a user needs significantly longer than the average for covering a specific distance, the route might therefore not be appropriate. Additionally, specific paths which are used more often than others by different users can be associated with a high convenience rating. However, annotations derived by analyzing the user's LOM-Modality might lead to improper conclusions regarding in particular the weighting of path sections. As the system is not able to determine the reason of the time difference which varies significantly from the average, direct input by the user is needed to decrease the grade of uncertainty. Combining information derived from the LOM-Modality and from direct user input thus leads to a semi-automatic annotation procedure.

Annotated data is related to the user from whom it was derived. However, this data is only suitable within the known environment of the user and does not permit the navigation in unknown terrain. Derived data is therefore transmitted to a central database where the annotations of all users are assembled and associated with specific user group profiles. A traveller navigating in unknown environment is then able to access the data remotely to broaden the data basis for the calculation of an optimal route concerning his specific requirements. The usage of collaboratively derived annotations in combination with personal annotations leads to the concept of stereotype based navigation.

The resulting system consists of a mobile device carried by the traveller and a central server where the collaborative annotation data is stored. The software of the mobile component is build on top of a standard PDA phone such as the generally available T-Mobile MDA [20]. A central server part is responsible for the management of collaboratively acquired annotation data. The overall system architecture is presented in Fig. 2.

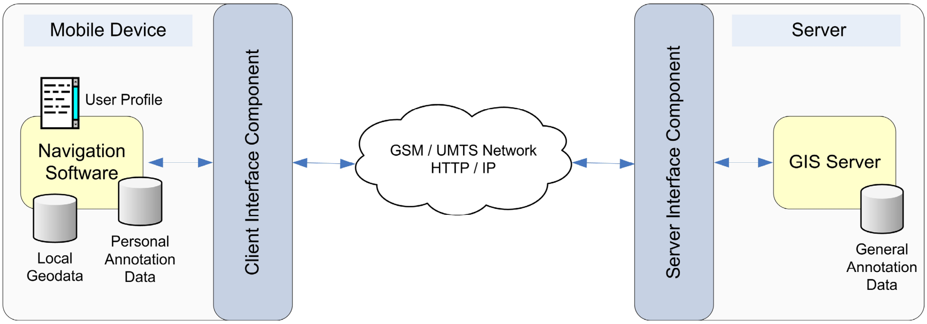

Fig. 2. Overall System Architecture

The presented approach has some important advantages compared to the assembly of proprietary hardware. For example, by using the standard PDA phone, GSM and UMTS channels are available to access the central database remotely without the need to connect to any WLAN hotspots. The central server is thus accessible in all areas where a normal mobile network is available. Additionally, a lower financial investment is necessary which makes such devices affordable for many mobility impaired people. The comparably low price and the fact that the device is not noticed as obtrusive assistive technology might decrease the inhibition threshold for many mobility impaired people regarding its usage.

5 Conclusion and Future Work

In this paper, the concept of multimodal annotation of geographical data is presented which leads to a data based allowing for the calculation of optimal routes for mobility impaired travellers. The annotation data is acquired by using direct input from the user in conjunction with an analysis of the user's LOM-Modality. Additional information is requested from the user in case results of the automatically acquired data are contradicting. The calculated routes are not necessarily optimal in terms of distance or time needed to pass them but rather in terms of a predefined convenience rating derived from a personal user profile of the traveller and a central server component.

Standard GPS receivers are used for the localization of the traveller. Although the GPS systems matured significantly, the accuracy of the localization is in particular in urban environments still unsteady. Concerning pedestrian navigation, this fact might lead to annotations related to false locations and improper navigational instructions. One possible solution is the application of step sensors in conjunction with a digital compass to build a hypothesis about the current location of the traveller as has successfully been shown in [8]. This approach is similar to techniques used in actual car navigation systems which combine the sensor data of a GPS receiver with the velocity of the car and the steering of the driver to calculate the most likely location of the car. However, user tests can also be carried out without the application of additional sensors as the standard Wizard-of-Oz technique can be applied to the evaluation of navigation systems as has been shown recently for an indoor navigation system [12].

As yet, a conceptual model has been build within our ongoing research. We are currently gathering additional user requirements while the system is being implemented. Future research includes the refinement of the system and evaluation phases with users to verify the benefits of the here presented concept of multimodal annotation of geographical data.

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