Data Structures for Landmark-based Navigation of Blind Pedestrians

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Abstract. Current GIS based navigation systems lack specific landmarks blind pedestrian use. To address this issue we present a data structure for landmark-based navigation. The data structure supports definition of specific landmarks such as surface, acoustic, olfactory properties of environment same as definition of important landmarks along a route. Routing algorithm takes in account specific preferences and abilities of blind travelers such as inability to cross large open spaces or preference to use underpass from unmarked pedestrian crossing. Resulting step-by-step navigation instructions enable users to navigate independently along the route.

Keywords: visually impaired; landmark-based navigation; data structures

1 Introduction

Mobility as a key aspect of independent living is primarily restricted by visual impairment. It has been observed that 30% of blind people never leave their homes and this number has remained constant over decades [1, 2]. An efficient navigation aid is needed to change this situation. Unfortunately currently available navigation systems do not take into consideration specific route description needed by blind pedestrians for efficient and safe wayfinding.

2 Related Work

We can see several attempts to adapt navigation systems to meet the blind pedestrians' needs, but these solutions do not solve the wayfinding task systematically and thoroughly. Some use cameras [3], RFID based systems [4], others are based on concept [5] using some kind of positioning system (e.g. GPS) in combination with GIS system (Ariadne GPS, BlindSqure). The wayfinding process consists of two parts: first is immediate environment sensing i.e. avoiding obstacles and hazards; second is navigation to remote destination [6]. Both parts of the wayfinding process can be supported by technology that will assist visually impaired. The basic criteria for evaluation of navigation aids [7] were defined as safety, efficiency and stress level. The study by Wycher?ley and Nicklin [8] shows that visually impaired people experience higher stress levels than sighted ones whenever they travel independently. This finding was also confirmed by research conducted by Peake and Leonard [9]. It has been shown that the usage of landmarks in description of the route reduces the stress level and increases confidence of travelers [10]. The research by Rehrl [11] has shown that participants preferences landmark-enhanced voice-only guidance.

2.1 Specific Landmarks for Navigation of Visually Impaired

The navigation aids based on major GIS systems such as Google, Apple, OSM maps, or Nokia HERE, suffer from lack of specific description of the environment for visually impaired pedestrians. The available description may be imprecise, ambiguous, or may ignore specific navigation cues (e.g. missing sidewalks, missings handrails, specific sound of a passage, the traffic of busy route, or other sensory landmarks such as smell of bakery). In addition, routing algorithms do not take into account specific preferences and abilities of visually impaired people (e.g. inability to cross open spaces such as large squares). Although several papers were written on the topic of landmarks used in navigation of visually impaired, it proved to be difficult to identify all necessary attributes [12] as they depend also on cultural and architectural context of the environment.

In our work we focus on the problem of creating data structure that enable storing of the specific landmarks and routing in accordance to preferences and abilities of visually impaired pedestrians.

3 Navigation Data Structure

Based on the analysis of dialogs collected during experiments on remote navigation of blind pedestrians we have identified specific landmarks which are important for navigation. These landmarks are of various modality, e.g. acoustic or surface (material, haptic characteristics, inclination), and various shape, e.g. area or point. The data structure should take it into consideration.

3.1 Data Model

Formally the data structure for the first layer comprises of 4 classes and 3 enums (see Fig. 1).

Landmark. The landmarks represent the basic building blocks of the entire navigation system. We have identified two types of landmarks. Area landmarks that cover an area of polygonal shape and point landmarks. Both of them hold spatial information that is needed in queries. Modern databases support spatial types and operations with them which is reflected in our design so landmarks can virtually hold any geometric shape in a single attribute called Shape. Landmarks are created from different sources which can be updated independently. In our system we have used OpenStreetMap database to create a basic layer and custom collected data with attributes for visually impaired pedestrians. Nodes in OpenStreetMap database are special types of Landmarks – point Landmarks. To support updates each landmark contains reference to an original source described by DataSource and SourceId.

WalkEdge. Subset of point landmarks are connected to form an edge that can create routable network. By connecting two point landmarks we can create an entity called WalkEdge. WalkEdge represents the smallest routable part e.g. sidewalk between two junctions. Each WalkEdge has a certain geometric shape and passability. While most WalkEdges are passable from both directions there exist situations where only one direction is allowed e.g. an escalator. Each WalkEdge is stored with a certain orientation which is determined by source and target landmarks. Passability then tells whether edge is navigable from source, target or from both landmarks. WalkEdges are used in process of generating routing graph.

EdgePassability. EdgePassability is an enumeration that describes the passability of WalkEdge. Each WalkEdge is stored with certain geographical orientation that may not respect the actual passability from pedestrian point of view. We have defined the following values: None: edge is not passable, this might be useful to temporarily forbid travel along this edge e.g. work on pavement; Forward: edge is passable from Source to Target landmark; Backward: edge is passable from Target to Source; Both: edge is passable in both directions.

WalkEdgePoint. Remaining subset of point landmarks are used to describe important orientation cues along the route. To describe this situation we have designed an entity called WalkEdgePoint that creates relationship between point landmark and WalkEdge. Cues can be located on either side of the WalkEdge at specific distance from the source landmark. Each edge has polyline shape and distance is calculated to the closest point on polyline. Some cues can be observed only when traveling at certain direction. By adding Observability attribute we can filter these cues after the route and travel direction is calculated.

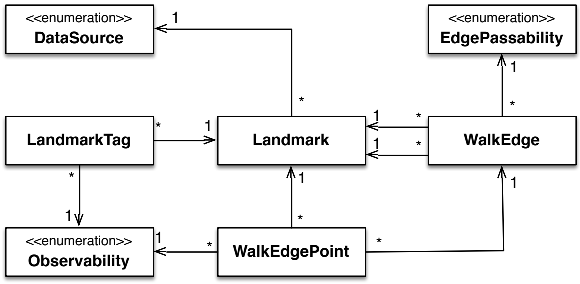

Fig. 1. Diagram of the primary database entities that are used to store and update data from multiple sources.

LandmarkTag. Each landmark can have multiple tags that carry additional information for generating multiple criteria values of routable networks and for building route description. In our model it is represented by LandmarkTag entity. We have decided to approach the problem of categorisation of landmark attributes by using key-value attributes that are easily extendible. On the other hand it is necessary to rigorously use predefined set of keys and values that can be reasonably processed by other algorithms. Similarly to the point landmarks, LandmarkTags can also be observed based on the travel direction.

Observability. Observability works similarly as EdgePassability but in the context of observing tags and landmarks. We have defined the following values: None: tag or landmark is temporarily disabled and cannot be observed; Forward: tag or entire landmark is observed only when travelling from source to target; Backward: tag or entire landmark is observed only when travelling from target to source; Both: tag or entire landmark is observed in both directions.

3.2 Data Import

Creation of routable network consists of several steps. At first it is required to import all source data into presented data structures.

For OpenStreetMap data it means to parse PBF or XML format. Both of these formats contain the same data but PBF file is smaller and faster to read. OpenStreetMap format consists of three entities - nodes, ways and relationships. We are interested in ways that have tag highway. Although this tag might sound confusing it also contains ways and data for pedestrian (pavements, steps). Ways that are primarily designated only for cars are filtered out. Each way also contains reference to nodes that define the actual shape. This subset of ways and nodes are transformed and imported into our database using WalkEdge and point Landmarks entities.

Second step consists of collecting landmarks that help visually impaired pedestrians with orientation. These can actually consist of either spatial landmarks or point landmarks along the WalkEdges. These landmarks are collected from actual pedestrians or professionals helping them. It is expected to be a long running process and that database would be updated periodically.

3.3 Routing

To efficiently solve routing queries it is necessary to transform primary database into a secondary database that consists of routable network, data structure to identify source and target points of Dijkstra algorithm [13] and data structure that contain spatial landmarks (see Fig. 2). WalkEdges serve as the main source to build network topology for Dijkstra algorithm. Cost vector is calculated from distance and landmark tags. Finding source and target point Landmarks and spatial Landmarks is a spatial search problem that can be efficiently solved by using R-Tree [14] data structure.

By using cost vector we can search for multiple routes. Multi-criteria variant of Dijkstra algorithm [15] can find a pareto optimal solution which potentially contains multiple routes. These routes are sorted and presented based on user preference. We have implemented heuristic to reduce running time of this algorithm by stopping Dijkstra expansion at solutions that would not be interesting for a user.

For each route we find all WalkEdgePoints and all intersecting spatial Landmarks. Then for each of these landmarks we fetch landmark tags. At this point we already know the direction of travel along the edge and landmarks and tags are filtered accordingly. By having all this information we can prepare a model for route description generation.

3.4 Route Description Generation

Once we have the data model of the route we can start to generate the description. For successful navigation it is important to provide user with clear and structured instruction and description of important landmarks. As the description can be longer than the user can remember, the description has to be split into several parts called segments [16].

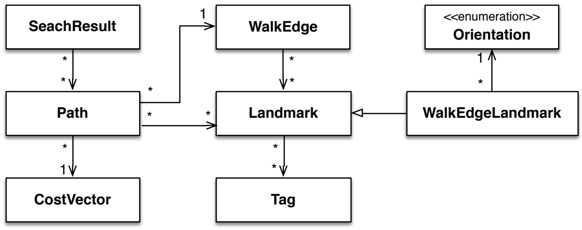

Fig. 2. Diagram describes the secondary database entities that are used for navigation instruction generation.

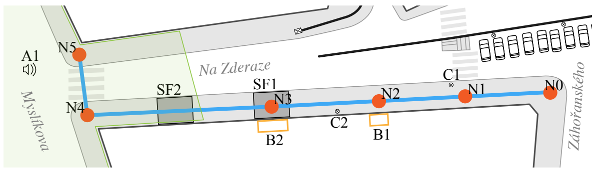

Fig. 3. The illustration depicts a part of urban environment with selected landmarks: B1, B2 – restaurant, courtyard door respectively, Cx – traffic signs, SFx – cobblestones, green area A1 – sounds from a busy street, Nx – point landmarks connected by navigable edges. Blue line represents a route found between N0 and N5.

The first of the problems to solve is the optimal length of the segments. Typically the segments starts and end at a Landmark, although this is not optimal solution if Landmarks are located on one straight line (see N0 – N1, N1 – N2, , N3 – N4 in Fig. 3. In this case it is necessary to merge these segments and mention these Landmarks as being passed by, e.g. create one segment N0 – N4.

Another problem is whether to mention a Landmark in the route description. For this purpose we use the Observability attribute and the direction in which the pedestrian travels i.e. the Landmark description is mentioned in case when the Landmark is observable in the direction of pedestrian walk.

The orientation on the starting point is essential for successful navigation. As the visually impaired persons tend to use egocentric frames for their orientation it is important to relate their position to the environment. This can be typically solved by instructing the user to have a building (or any other leading line) on a desired hand side or back side. However, this becomes extremely difficult in a such case when the visually impaired pedestrian starts the navigation on a corner.

Finally, each segment is composed of two parts – environment description and navigation instruction. First one is description of current location based on the Landmarks in vicinity and Landmarks along the current segment. Second, is the navigation instruction (e.g. go approximately 50 meters until you reach a crossroad). There can also be optional part describing imminent dangers on the route (e.g. reconstruction work on a pavement).

The generated route description for route in Figure 3 is separated into 2 segments:

1. You are at corner of Zahoranskeho street and Na Zderaze Street. Go approximately 50 meters towards the corner of Na Zderaze street and Myslikova street. The building will be on your left hand side. You will pass traffic sign on your right hand side, entrance to the restaurant B1, traffic sign on your left hand side, entrance to the courtyard paved with cobblestones on your left hand side, and second cobblestones. When approaching the corner you will hear sound from a busy street.
2. You are at corner of Na Zderaze street and Myslikova street. Turn right 90° and cross the pedestrian crossing to the other side of Na Zderaze street.

Each segment contains environment description and action. There are several possibilities how to order Landmarks in the environment description. We can use an order in which the pedestrian approaches the Landmarks without distinction of LandmarkTag (i.e. doors, surface landmarks or columns). Another approach is to cluster Landmarks by its LandmarkTag (i.e. first describe all doors, next all surface landmarks, etc.).

4 Results and Discussion

We have designed a multi-layer data structure and routing algorithm for efficient navigation of blind pedestrians.

Although part of the data model is generated from OpenStreetMaps, it strongly depends on specific landmarks used by visually impaired travelers. They can be obtained by trained orientation and mobility (O&M) experts, by visually impaired travelers with help of O&M experts and by crowdsourcing from interested parties (e.g. relatives or friends of visually impaired persons).

5 Conclusion

Our data structure and routing algorithm allow efficient selection of suitable route by means of summary description of offered alternatives. Capability to describe specific landmarks ensures more efficient and safer navigation. In the future we will focus on the problem of better distinguishing of similar routes and offline navigation.

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