ONALIN: Ontology and Algorithm for Indoor Routing

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Abstract - **Much research has recently been devoted to developing approaches, techniques, and technologies which assist people with navigation within buildings. Routing is an essential technique often requested by users prior to real-time navigation, providing them with appropriate routes within buildings. A survey of the literature reveals indoor routing approaches primarily based on shortest distance or fastest travel time as the main criteria. However, such routing criteria that are common in outdoor navigation may not be as applicable to indoor navigation. Presenting users with appropriate indoor routes could be beneficial to many users in various situations. For example, people with physical, cognitive, or sensory impairments may need routes that take into account their special needs as well as preferences rather than ones that are shortest or fastest. In this paper, we present a new ontology and an algorithm (ONALIN) that provides routing for individuals with various needs and preferences. To this end, ONALIN takes the ADA (American Disability Act) standards, among other requirements, into consideration. An indoor routing algorithm based on this ontology is presented and analyzed in detail where it first finds feasible routes with respect to the special needs of the users and then from those will select the comfortable routes.**

Index terms – ADA standards, design for all, indoor routing, ontology

I. Introduction

While early research in navigation was primarily focused on outdoors, indoor navigation has gained the attention of researchers and developers in the past decade. Routes for outdoor navigation can be computed based on a variety of criteria such as travel time, travel distance, traffic, or even accidents and may incur costs, e.g., longer distance to drive or getting lost, if they are deviated. Thus, current outdoor navigation systems provide users with various routing criteria, whereas most existing indoor navigation systems support only one criterion in computing optimal routes. Similar to outdoor navigation users, indoor navigation users have different needs and preferences which need to be taken into consideration when developing routing techniques. It is worth noting that while real-time navigation in buildings typically requires costly infrastructures and technologies, such as RFID, indoor routing, which could be applied for both planning (static mode) and real-time (dynamic mode) purposes, can be implemented without a need for costly infrastructures.

The need for indoor routes can be analyzed from the standpoint of practicality and cost effectiveness, and we argue that indoor navigation is realistic and justifiable in critical situations such as in public buildings with complex structures and specially when users are unfamiliar with the structure; for individuals with permanent or temporary disability that may require special routes so that they can traverse the building in ease; in emergency situations, where people are unaccustomed to, providing users with routes for leaving the building in calm and orderly manner is essential.

While buildings built in the United States prior to the 1990's have made strides to meet with the American Disability Act (ADA) standards [1] , many still limit accessibility of people who have a disability, due to the lack of funding, neglect of the owners of the building, or because of the way the building was first constructed [2]. This means that even now, people with disabilities may take a risk by entering an unfamiliar building, which does not comply with the standards, expecting that their navigation needs will be met.

Most current indoor navigation systems do not consider the limitations of physically-, cognitively-, and sensory-impaired individuals to traverse a building in a way that is not necessarily "shortest" or "fastest". There are currently some ontologies and algorithms for indoor routing or navigation but none addresses the requirements of people with special needs specified by the ADA standards. To address

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the shortcomings of current indoor navigation/routing, in this paper we present an ontology and an algorithm, called ONALIN, which takes into consideration the needs of different groups and individuals with regard to their limitations in order to find feasible routes between POIs within a building. Furthermore, we provide an analysis of routing needs in buildings and routing use cases based on ONALIN. The contributions of the paper are: (a) a comprehensive ontology that considers the needs of all potential people traversing in buildings based on the ADA standards and (b) a routing algorithm for indoors.

The structure of the paper is as follows: Section II provides background and motivation for the proposed ontology (ONALIN). Section III describes use cases to better understand the necessity of providing routes based on user's specific need or request. Section IV describes the ontology. Section V describes our ideas for expending current approaches of indoor semantic quality to provide a user with appropriate routes. Section VI describes the proposed indoor routing algorithm. Section VII and VIII discuss the implementation consideration and future research.

II. Related Work

There have been few ontologies for building structures aiming at providing users with navigation. [3] developed an ontology, OntoNav, which addresses such factors as geometric and semantic indoor navigation. OntoNav is based on three key concepts: physical capabilities, perceptual capabilities, and routing preferences taking into account user's mobility, perceptual difficulties, familiarity with the environment, and preference for routes. [4] have proposed a spatial ontology to depict the basic elements of navigation path, which is the extended version of Indoor Navigation Ontology (INO) proposed by [3], taking into account user's preferences. INO was used to develop a hybrid rule-based navigation algorithm that considers user's preferences as well as their special needs and provides them with simplest path but not necessarily the shortest one.

To date, different indoor navigation systems have been proposed to help individuals with locating their desired destination within buildings. Some of these systems take into account a group of individuals with special needs, especially those that are visually impaired. [5] presented a hybrid indoor navigation system where indoor environment is modeled in a graph, with nodes representing turns or intersections and edges representing connection between two points. The system employs landmarks at intersection nodes to find the way. [6] presented a non-network-based indoor routing algorithm for both visually impaired and sighted individuals. The algorithm is based on a simple two-dimensional indoor environment with the objective of avoiding obstacles. It also takes into account landmarks and clues in computing an optimal route. For the sighted individuals, it returns the shortest path, but for the visually impaired it returns the safest path by avoiding obstacles. [7] presented a three-dimensional model of an indoor map. The model is shown in a graph with horizontal and vertical links. Each link is then assigned a cost, which is basically calculated by travel time from link's start node to its end node. Lastly, Dijkstra's algorithm is applied to produce the fastest path for pedestrians and real-time navigation is then accomplished by using point-to-point map matching methods. [8] developed an indoor navigation system called MNISIKLIS which is a location-based service for wayfinding inside a building. MNISIKLIS provides navigation via UHF Radio Frequency Identification (RFID) for proximity sensing, Wi-Fi positioning and dead reckoning techniques to produce the position and orientation.

Our presented approach in this paper is different than the aforementioned works in that we provide guidelines on how disabilities could be ultimately accommodated by using the ADA standards and compute optimal routes. In addition, our work is focused on indoor routing rather than real-time navigation, which is the approach taken in most other projects.

III. Use Cases

To better understand the routing requirements of a variety of users with special needs, we present four separate use cases involving someone who is either: visually impaired, paraplegic, elderly, or someone with a temporary physical disability (a broken leg). They will all start from the same location at the entrance to the same building, they will all be new to the building, so they are all unfamiliar to the people and the layout of the building, and they will all arrive at the same room at the conclusion of their routes. The purpose of these use cases is to show that while the origin-destination locations for each individual is the same, due to varying needs and preferences of each individual, each may need to take a different route.

Jess (a paraplegic), James (visually impaired), Katie (elderly, with memory issues), and Brad (who broke his foot recently) arrived at one of the local businesses for a meeting being held on the 3rd floor of a very large building built prior to 1994, so it was not required to meet the ADA standards but had updated its building layout and structure to help accommodate people who were physically, cognitively, or visually impaired. Also, all were equipped with phones that were able to access the indoor routes provided through their wireless device.

Jess was able to find a path that did not only provide her access an elevator, but also found hallways that were wider and provided more optimal maneuvering for her wheelchair. Also, she wanted a drink of water prior to the start of the meeting and the route was able to navigate her to a water fountain that was low enough to the ground for ease of use.

James was provided a path that navigated him to an elevator and destination with the most Braille signs, so he felt more comfortable about traversing the building. Also, the path took into account a walkway that had a sign that protruded from the wall and could cause him some trouble maneuvering.

Katie was provided the simplest path, so as to decrease the complexity of directions. She was also provided with a route that minimized any steps or inclines to help with mobility. Lastly, the route provided displayed signs that were easily visible for someone who had issues with his or her vision.

Finally, Brad, who would normally be able to traverse the building without difficulty but was now faced with trying to do so with a cast and crutches, needed assistance finding the best route to his destination. The route given to him was much like Jess's, but because the system is based on giving the user the most comfortable route, it provided him with options for taking a route either up the stairs (which would minimize time and distance) or to use the elevator (which would minimize effort).

IV. Ontology

To understand the issues of routing indoors as they are used by all types of users, we present an ontology (ONALIN) that includes concepts applicable for routing and that comply with the ADA standards for building layouts. ONALIN includes three main concepts: PathElement, obstacle, and landmark. PathElements are differentiated into horizontal and vertical. Horizontal paths are those routes on a single given floor, and the vertical paths are those routes that cross from one floor to another. Landmarks are employed to guide users of the routes rather than being used to actually calculate the routes. By including parameters such as direction of an escalator, capacity of an elevator, and door types, ONALIN is well-suited for computing routes for all types of users.

ONALIN also includes the ADA standards [1] that are specified for the buildings built after 1994 and the buildings that were built prior to 1994 and have since made adjustments to comply with the ADA standards. It should be noted that our intent is not to classify the building itself to be either ADA compliant or not, but simply to use the rules and standardization as metrics for computing optimal routes based on navigation needs and preferences. We believe such standards are universal so that the presented indoor ontology and algorithm are applicable to all other countries as well. These standards include capturing information such as height of stair, handrail availability, width of hallways or corridors, ramp or walkway incline, numerous numerical datasets for restrooms, permanent signs that either help the user because of its use of large readable lettering and/or Braille, or hinder the individual because protruded either low over the walkway or into the walkway from the wall. Fig. 1 shows ONALIN for indoor routing. In this ontology, concepts specified as "ADA" are classified as the ADA standards that apply for that particular concept.

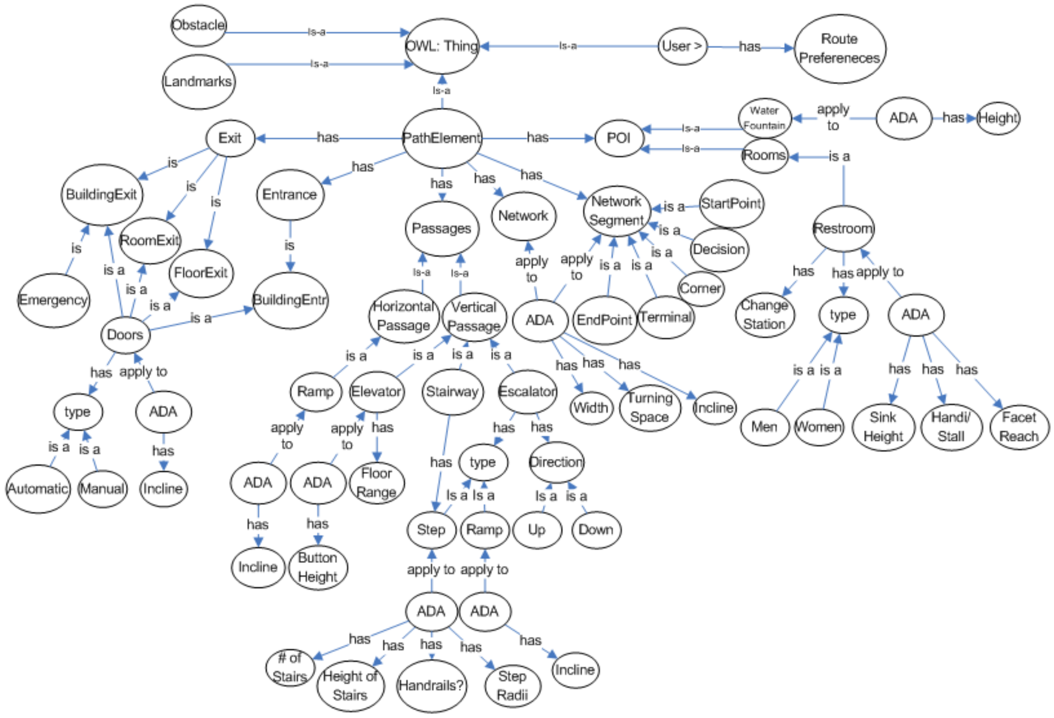

Figure 1. ONALIN

ONALIN provides the concepts and their relationships that are needed for developing algorithms for optimal routes which support navigation needs and preferences on the hallway networks. There are two steps in routing indoors: finding desired (feasible with respect to special needs) POIs and computing optimal routes. With regard to POIs, consider Jess, our paraplegic user case, who searches for a water fountain, the system must locate an accessible water fountain rather than simply the nearest one. With regard to computing optimal routes, the system must take into account both feasibility (for mobility impaired individuals) and comfortability (to meet Jess's preferences).

V. Indoor Routing

Unlike routing in outdoors, which is based on such criteria as shortest distance, shortest time, and least number of tolls, indoor routing is of practical use only when the person's ability and comfort are considered. We approach routing indoors by realizing the criteria that would meet the routing requirements of all types of users including those with special needs and preferences. To this end, we define two types of routes: feasible routes and comfortable routes. Feasible routes are routes between a pair of origin-destination in a building that the user can traverse given their constraints. For example, a route that includes stairs is not feasible for a seated wheelchair individual. Comfortable routes are a subset of feasible routes, which includes routes which are preferable by the user. For example, a user might prefer to use stairways rather than elevator. For people with special needs, feasible routes are those that would meet the ADA standards and comfortable routes are the subset which meet individual's preferences.

Computing routes within a building requires the network model of the building. Unlike road networks for outdoors which in most cases are standard, hallway networks for buildings, due to different structures and layers, are not standard. Since buildings' structures are usually represented in CAD or BIM, a technique that automatically can convert CAD or BIM of a building to the hallway network of the building is the first step in the process of developing routing algorithms within buildings.

To address the routing requirements of individuals with special needs, we present a novel approach where the obtained hallway network from the previous step, will be converted into feasible hallway networks for each groups of special needs. In other words, in order to provide each group of individuals with feasible routes, the unfeasible hallways and POIs will be removed from the hallway network taking into account the ADA standards. As a result, we will have several feasible hallway networks each suitable for a group of users with special needs. To address personalization, once feasible network is obtained, similar to outdoor navigation, users' preferences, such as shortest path, route through landmarks, etc. need to be taken into account.

VI. Traversing ONALIN for Routes

For indoor routing, we employ a hallway network that represents the layout of each floor. In this network, hallways are represented by edges. In addition, three types of nodes are defined: decision nodes, corner nodes, and terminal nodes. A decision node is an intersection that connects hallways. A corner node is where orientation is changed. A terminal node is the end of a hallway.

Furthermore, we consider two possibilities in indoor routing: single floor versus multiple floors and single destination versus multiple destinations. We analyze indoor routing based on horizontal and vertical movements that an individual needs to make in order to traverse from the origin location to the destined location. If origin and destination locations are both on the same floor, the only movement is horizontal. On the other hand, if origin and destination locations are located on different floors, movements are a sequence of horizontal and vertical movements (i.e., a horizontal movement from the origin to the entrance of a vertical passage, a vertical movement from the floor passage to another floor passage, and a horizontal movement from the floor passage to the destination.

The following formalization represents the sequence of horizontal and vertical movements in a route within a building where m is the number of floors and H and V are horizontal and vertical movements, respectively.

$$\sum_{i=0}^{m-1} V_i H_{i+1}$$

Knowledge of the sequence of movements helps the system with adapting the network model to the corresponding floor before computing any route. The larger the sequence of movements, the more complex the routing algorithm will be.

The routing algorithm addresses both feasibility and comfortability taking into account multiple destinations for both fixed and flexible sequences of intermediate destinations. Once a user requests a route from an origin to one or several destinations with their preferred order, the algorithm first retrieves the hallway network, and then prunes the hallway network based on the group under which user's special needs fall. Pruning hallway networks entails removing those inaccessible hallways and POIs for the underlying group. Once the hallway network is pruned, any route traversing the network is feasible for that group. To compute a comfortable route, in case of several destinations with specified preferred order, first a comfortable route from the origin to the first destination, then, a comfortable route from the first destination to the second destination, and so forth, are computed. On the other hand, upon a user request for a route to multiple destinations regardless of their order, except for the last destination, the algorithm computes a comfortable route from the origin to each of the intermediate destinations. Then, it chooses the destination with least cost. In the next step, the chosen destination will be considered as a new origin. The algorithm repeats the previous step until it visits all the intermediate destinations. Finally, the last chosen destination is considered as a new origin and a comfortable route is computed from it to the final destination. Fig. 2 shows our indoor routing algorithm.

```
ComputeRoute(O, D, Di, G)
O = origin, D = final destination,
Di = intermediate destinations (i =1,…,n),
G: user's group (general, visually impaired, mobility impaired,
cognitively impaired)
1.  H ← Convert CAD/BIM model to hallway network;
Switch
    Case G = "Visually Impaired"
        H ← Prune H to be feasible for visually impaired;
    Case G = "Mobility Impaired"
        H ← Prune H to be feasible for mobility impaired;
    Case G = "Cognitively Impaired" H ← Prune H to be
    feasible for cognitively impaired;
2.  If Di's are in order then
If floor_level(O) = floor_level(D1)
    Compute a comfortable route from O to D1;
Else
    Compute a comfortable route from O to the nearest elevator
    on the same floor;
    Compute a comfortable route from the elevator (on the same
    floor as D1) to D1;
For i= 2 to n do
    If floor_level(Di) =floor_level(Di+1)
        Compute a comfortable route from Di to Di+1.
    Else
        Compute a comfortable route from Di to the nearest
        elevator on the same floor;
        Compute a comfortable route from the elevator (on the
        same floor as Di+1) to Di+1;
    If floor_level(Dn) =floor_level(D)
        Compute a comfortable route from Dn to D;
    Else
        Compute a comfortable route from Dn to the nearest
        elevator on the same floor;
        Compute a comfortable route from the elevator (on the
        same floor as D) to D;
3.  Else
While there is a Di's that is not visited
```

For each D_i in the set of intermediate destinations compute the weight of the comfortable route between O and D_i
Select D_i which has the lowest weight to O; O $\leftarrow$ D_i;

Figure 2. Indoor routing algorithm.

For computing comfortable routes, Dijkstra's algorithm can be used where each edge of the feasible hallway network is assigned a weight, W_c, to represent level of comfort derived from user's preferences.

VII. Implementation Consideration

BIM is the latest generation of Object-Oriented CAD (OOCAD) in which all of the intelligent building objects are captured in a single 'project database' or 'virtual building' [9]. Recent studies show that utilizing such a standard can contribute to an easier transition from the ideas set forth in representative ontology of buildings to implementation [10]. Approaches to this paradigm have already been acknowledged to some degree of accuracy. Concepts of the ontology can be delineated to calculate and store information for computation of routes, using building layouts or blueprints. [11] explored the idea of layering attributes of the ontology to calculate and store information for the computation of a given route, where the lowest layer is produced from the building layout or blueprints. Geometric information is then stored in a spatial database via an algorithm developed by the [11]. Also, [12] have proposed frameworks for capturing and storing spatial information necessary to compute routes in emergency situations. Their proposed context-awareness approach starts with the blueprints, and then computes graphs via their ontology and building layout. Semantic information and the information provided for 3D modeling are used in parallel to compute the final building image model structure.

One approach to implement ONALIN and algorithm in public buildings is through web servers maintained by building owners. Each web server for a building would include the BIM, the ontology, the network model, and a module for computing optimal routes. Each user, either web client or a mobile client via a cell phone accessible to Internet, can obtain optimal routes in buildings. In this approach, users can plan routes in advance.

VIII. Future Research

Our future research will focus on: developing an algorithm for automatically extracting the hallway network from the CAD/BIM of a building; developing a pruning algorithm that creates a feasible network using the hallway network; developing a weight function, $W_{c,}$ to compute comfortable routes using feasible networks; and developing a metric for POIs to determine the degree of demandability by users. The idea in this last research area is to store high demandibility destinations (POIs) and comfortable routes to reach them in the database for future use.

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