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Automatic Pre-Journey Indoor Map Generation Using AutoCAD Floor Plan

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Abstract

Accessible maps are very useful for the visually impaired because they can learn maps and routes prior to their upcoming journeys. These maps are usually generated by an existing GIS database, e.g. Google Maps or ArcGIS, which are popular in outdoor environments. Though a pre-journey on an indoor map is useful and encourages the visually impaired to travel independently, the generation of accessible indoor maps still involves a lot of manual work, which makes pre-journey task inconvenient to the users. In this project, we propose a hybrid method to automatically generate indoor maps, from AutoCAD architecture floor plans, which are usually available for buildings made within three decades. Our approach extracts semantic information from AutoCAD files, e.g. location of rooms, exits, other landmarks, etc., which could help to further analyze the 2D floor plan images. It then generates both graph-based topological and traversable maps, which are useful for constructing accessible maps that can be used in pre-journey tasks. Experiments have been performed in an indoor facility to test the performance of the system.

Keywords

Assistive Technology, AutoCAD, Accessible Map, Pre-Journey, Visually Impaired, Computer Vision.

Introduction

Visually impaired people have a need for an easy way to navigate themselves in new indoor environments. Various efforts have been made to develop indoor navigation software for the visually impaired people (Fallah et al. 21-33, Ganz et al. 19, Zhang et al. 159–162), but many of them rely on other infrastructures or sensors and are also costly, therefore are not easy to scale up. As a supplementary solution, a pre-journey approach allows visually impaired people learn spatial environments or plan route priors to their travels. The solution only need accessible maps of the indoor facility, hence it’s economic and effective (Ishikawa et al., 74–82). Accessible maps (Zeng and Weber 290–298, Kumar 1) are usually generated by an existing GIS database, e.g. Google Maps or ArcGIS, which are popular in outdoor environments. The generation of accessible indoor maps still involves some manual work and is a non-trivial task, therefore, automated process of accessible indoor map generation can ease the spatial knowledge acquisition and pre-journey task, and hence improve the life quality of the visually impaired. Such work can also be useful in the task of robot rescue or autonomous navigation in indoor environments.

In this paper, a hybrid algorithm is proposed to automatically convert an architectural floor map into an accessible indoor map, which eases pre-journey tasks to many visually impaired users. Fig. 1 shows the system work flow. Given an AutoCAD floor map, two output maps are generated using our proposed algorithm, where Fig. 1(a) shows the original AutoCAD floor plan. Fig. 1(b) is a topological map and it shows the geometric relations among different rooms in the building, which can be used to generate a navigation brief that provides a simple summary of a route and Fig. 1(c) is a 3D floor map that can be used to calculate turn-by-turn directions in pre-journey tasks. How the algorithm works is shown in Fig. 2: (1) the system reads an architectural floor plan (such as an AutoCAD file), extracts information of each entity (room, corridor and so on) and layers, and then stores them into a database; (2) an image-based analytics method is applied to extract each room's layout–entity polygon; (3) the system identifies the geometric relations between neighborhood rooms and corridors, which allows a topological graph of the entire building to be computed; (4) a 3D floor map and a traversable map are finally generated.

Discussion

Related Work

Many outdoor GPS-based accessible navigation systems are available, such as Ariadne GPS, BlindSquare and Sendero Seeing Eye GPS, which provide normal navigation features to blind users. However, none of them works in indoors since there is no accurate GPS signal available. Research shows that on average people spend around 87% of their time in indoor environments (Klepeis et al., 2001), hence indoor spatial knowledge acquisition plays a very important role to improve the quality of daily life of the visually impaired. In the last decade, researchers have been working on WiFi or Bluetooth-based navigation approaches, and a few public facilities have tested such approaches (e.g. SFO airport, The American Museum of Natural History). These approaches, however, usually require large-scale infrastructure changes and tedious sensor installations and calibrations procedures, thus making such kinds of requirements very costly and not easy to scale up.

Pre-journey learning is the process of learning spatial environment or plan travel route prior to an actual travel. The process helps cognitive map development and encourages visually impaired people travel independently (Ivanchev, Francis, and Ulrike 81-88; Meneghetti et al 165-178). Research (Ishikawa et al., 74–82) shows cognitive map development using a map can help people to understand the 3D space, and it’s even more effective than a navigation system, which only provides passive spatial learning.

Outdoor accessible map generation can be done by converting existing GIS database into accessible map, e.g. Google Map and ArcGIS. However, not many existing GIS indoor databases are available, and hence the generation of indoor accessible map still requires a lot of manual work. As such, automated process of accessible indoor map generation will be very useful to ease the development of pre-journey systems and help the visually impaired on spatial knowledge acquisition.

System design and implementation

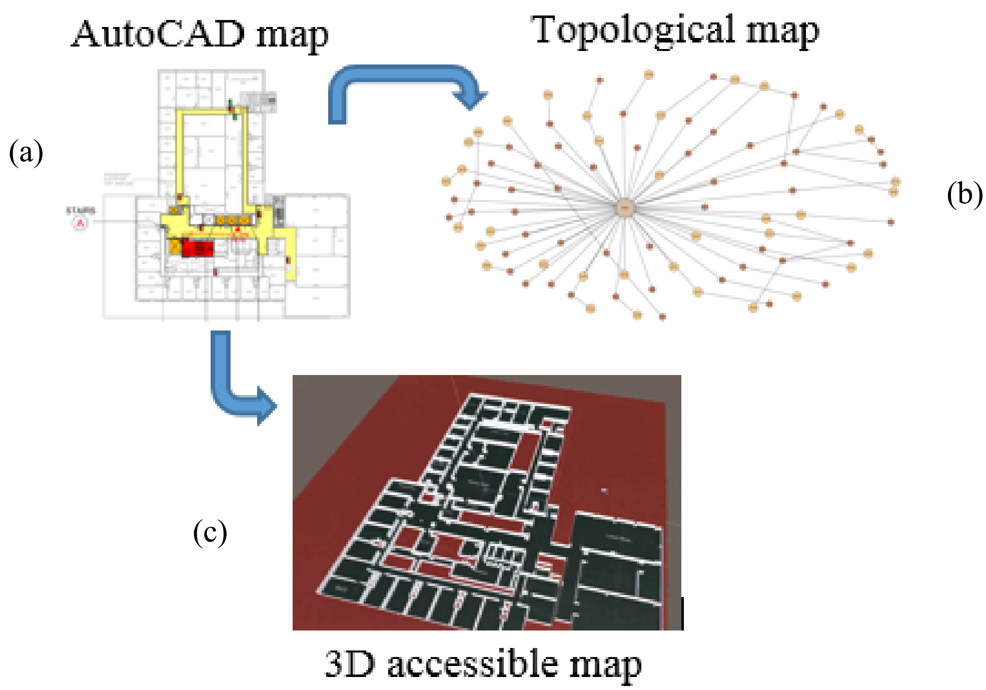


Fig. 1. The proposed system.

In this project, we aim to develop a system to automatically generate accessible maps of indoor facilities from architectural floor plans (such as AutoCAD files). The accessible maps comprises basic entity and layout of indoor environments. The entity includes the entrances and exits of the building and each floor (e.g. escalators, elevators and staircases), rooms, corridors and landmarks (restrooms, water fountain, information desks, public safety office, etc.) The layout includes the locations of entities and the geometric relations among different entities. In order to use the maps in the pre-journey tasks (Ivanchev, Francis, and Ulrike 81-88; Meneghetti et al 165-178), both the navigation brief and turn-by-turn navigation guidance are needed.

The turn-by-turn navigation can be calculated, with a 2D or 3D traversable map with each entity and its occupied region labeled in the image. In the traversable map, traversable and non-traversable area are labeled and the A* algorithm (Hart, Nils and Bertram, 100–107) is used to calculate an optimal route given both source and destination entity locations. Therefore, our system needs to automatically produce a traversable map.

The navigation brief includes a summary of the optimal route. For example, if an visually impaired person starts with the building entrance and plans to go to the Computer Science Department at F930, the brief only includes a list of entities on the route, for example, hallway, elevator, the 9th floor, and the room F930. Therefore, a topological map, a graph with the connection among neighborhood entities (as shown in Fig. 1), needs to be constructed. In the graph, a line (edge) connects two (entities) if they directly connected.

Each entity (rooms, corridors, exits and landmarks) is defined as a polygon in the image. An accessible image needs the label of each polygon in the image. Though the floor plan in AutoCAD is a vector image (e.g. lines, arcs and other simple geometric shapes), the entity polygons is not available. So the correspondences between the geometric shapes and the entities are unknown when the architectural floor map is drawn. Therefore, we first need to extract entity polygons from the AutoCAD file and then analyze the geometric relations among different entity polygons to build the topological map. Some simple computer vision algorithms are applied to complete the above tasks.

The proposed algorithm consists of four steps (as shown in Fig. 2):

- Parse the AutoCAD floor plan and extract useful layers and semantic information.
- Detect entities (e.g. rooms, corridors, exits and landmarks) using a region growing algorithm.
- Build geometric relations among different entities and construct a topological graph, with the entities as vertices and connections (doors or opening) as edges.
- Extract the contour of the entity polygons and build a 3D accessible map.

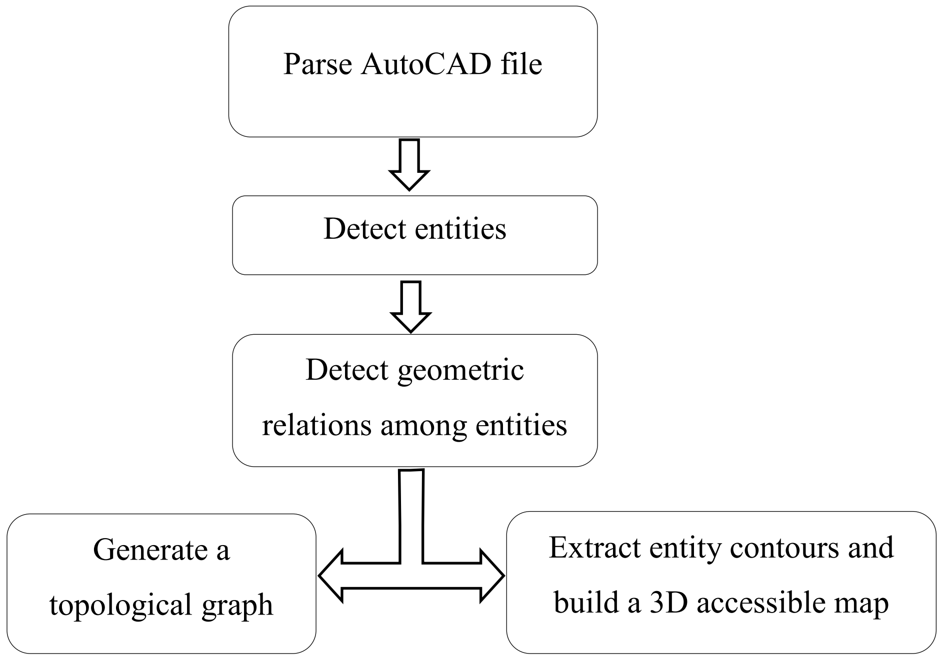
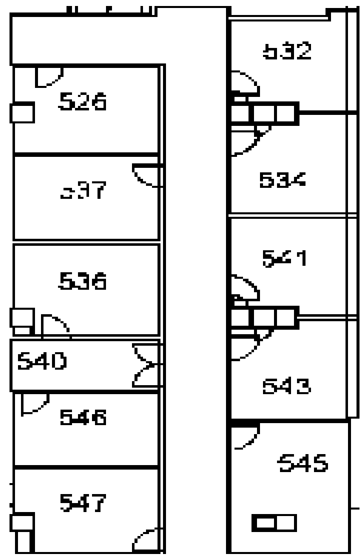


Fig. 2. The flowchart of the proposed algorithm.

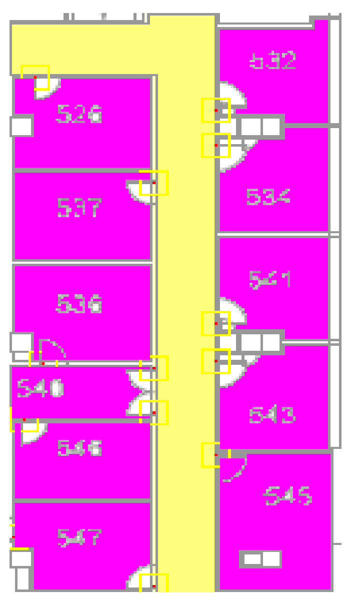
We will discuss each step in the following subsections.

Parse the AutoCAD floor plans and extract useful layers and semantic information.

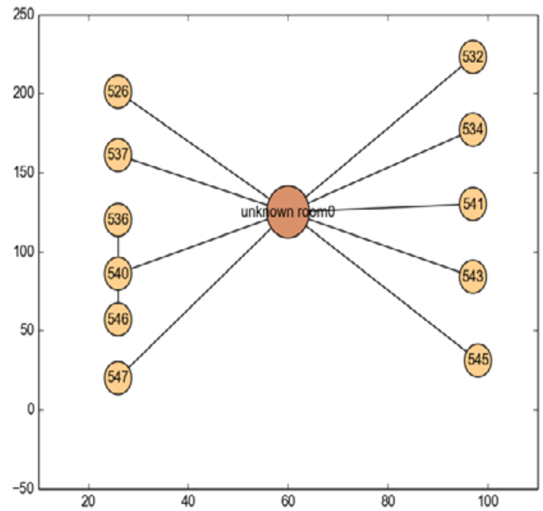
We first extract layers from a DXF file, based on the DXF specifications on the Autodesk website, for example, a layer is text annotations that includes the room numbers, and another layer provides the locations of room centers in the floor map. In addition, we extract semantic information from the AutoCAD file, which are the locations of entities, including rooms, exits, elevators, restrooms and some landmarks. All the above information are stored into a database. Note that some layers are not needed in the pre-journey task, for example, electricity map, which is therefore removed in this step.



3(a)



3(b)



3(c)

Fig. 3. Results of the region growing algorithm. (a) Small section of the original floor plan; (b) The result of region growing: purple area are pixels detected within each room; (c) The corresponding graph, where the "Unknown room0" is the corridor.

Detect entities using a region growing algorithm.

In the second step, we first render a floor image, as shown in Fig. 3(a) from the database. Note, only useful information is drawn, and all unnecessary information are not rendered in this image. We then create the entity polygons using a simple computer vision algorithm – region growing.

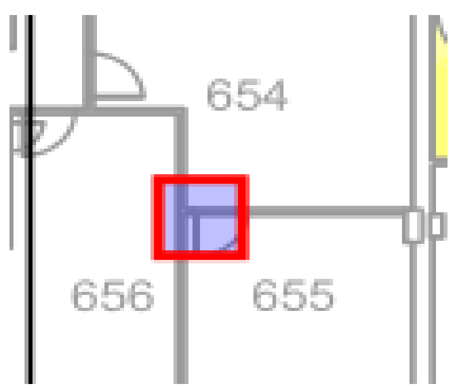
First the floor map image is converted into a binary image and wall partitions are drawn in black, and open space, such as rooms and corridors are empty, as shown in Fig. 3(a). Then we query semantic information obtained in the first step to obtain the entity number and centroid of an entity. Starting with the centroid, we apply a region growing approach (Rosen 798), to scan through the empty space in the entity and hence the image region of each entity is obtained. The process is repeated until all known entities (in the database) have been processed and the labeled entry is saved into the entity list.

Because some entities may not be available in the database, for example, corridors may not be identified in the database, they are still empty in the image. Then we can scan each pixel in the floor image. For any empty pixel, we run the same region growing method. We store the labeled entity into the entity list if its area is greater than a threshold (>50 sq. feet). The above process is repeated until there are no more empty area in the floor image. Fig. 3(b) shows the result after region growing is applied.

Build geometric relations among different entities and construct a topological graph.

In this step, the labeled entities are connected with neighborhood entities to build a topological graph. We first query the semantic information for the position of doors, since doors connect and separate rooms and corridors, and then we start to process and extract relationships between rooms and corridors. Note, the corridors are usually not marked in the AutoCAD files so we declare any open space connecting multiple rooms as a corridor.

A simple computer vision algorithm to identify the geometric relations between two entities works as follows. For each door position d (x, y) (Fig. 4(a)), we create a region of interest (ROI) (x - p, y - p, x + p, y + p) where p is the padding initialized to 1, in the lookup table (an image where each pixel value is equal to the entity the pixel belongs to). Pixels with the value 0 do not belong to any entity.). If there is only 1 unique nonzero pixels, then we increase p by 1 and create a larger ROI until the ROI contains at least 2 unique nonzero pixels (a door connects two entities, represented by the two unique nonzero pixels). In order to make sure only two entities connected through the door, two entities with the smallest distance from the ROI's center (the door) are identified. Fig. 4 shows an example, the room 654 and 655 are connected through the door in the Fig. 4(a).



4(a)

```
[   0 654 654 654 654]
[   0   0   0   0   0]
[   0   0   0   0   0]
[   0 655 655   0 655]
[   0 655 655   0 655]
```

4(b)

```
[   0 654 654 654 654]
[   0   0   0   0   0]
[   0   0   0   0   0]
[   0 655 655   0 655]
[   0 655 655   0 655]
```

4(c)

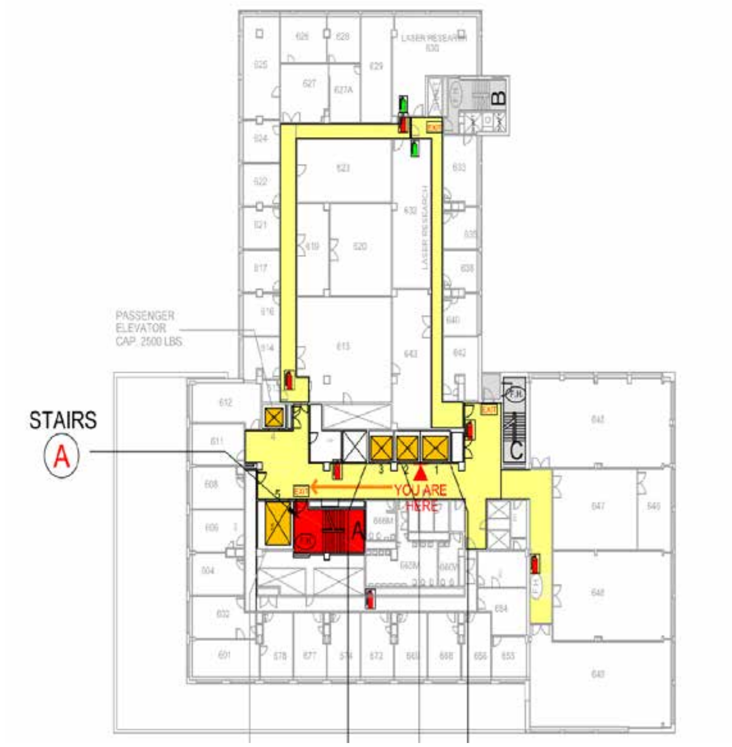
Fig. 4: (a) A small section of a map. The red box shows the ROI around a door of the room 655; (b) The pixel values within the ROI; (c) The two unique room numbers nearest to the ROI's center are identified, and room 654 and 655 are connected in the topological graph.

The above process is repeated on all doors in the database, hence the geometric relations among entities are built. A topological graph is then constructed, with each entity as a vertex and each door connecting with two entities as an edge. Fig. 3(c) shows the graph generated from Fig. 3(a). The navigation brief problem can be modeled as searching the shortest path in the graph and can be calculated using the Dijkstra's algorithm (Dijkstra, 269-271).

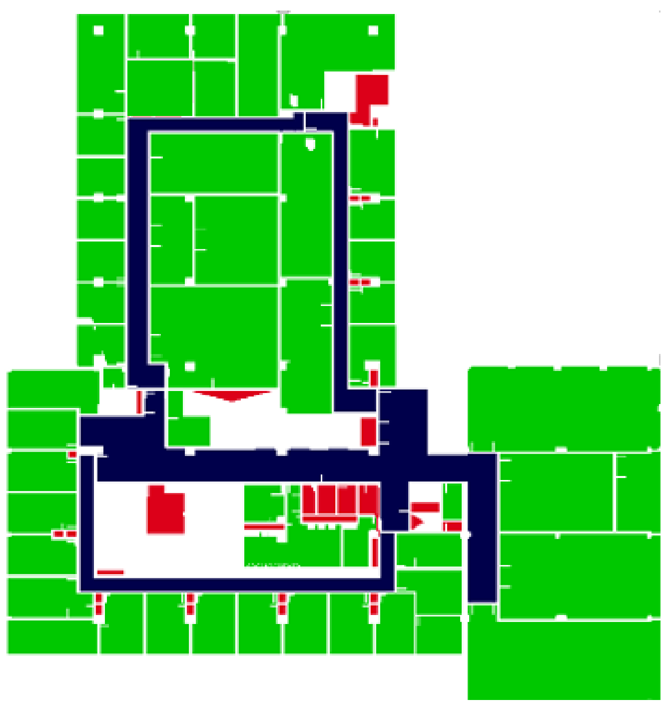
Extract contour of the entity polygons and build a 3D accessible map.

After we perform the region growing method and find the shape of each entity, we perform contour extraction using Open Computer Vision library, which computes the contours of each entity polygon. Each contour is simply a list of vertices of the polygon. We iterate over each vertex and insert them into a file (using JSON format.) The content of the JSON file is structured in the following way, for each entity.

Entity n: {the coordinates of polygon vertices, the coordinates of door(s)}

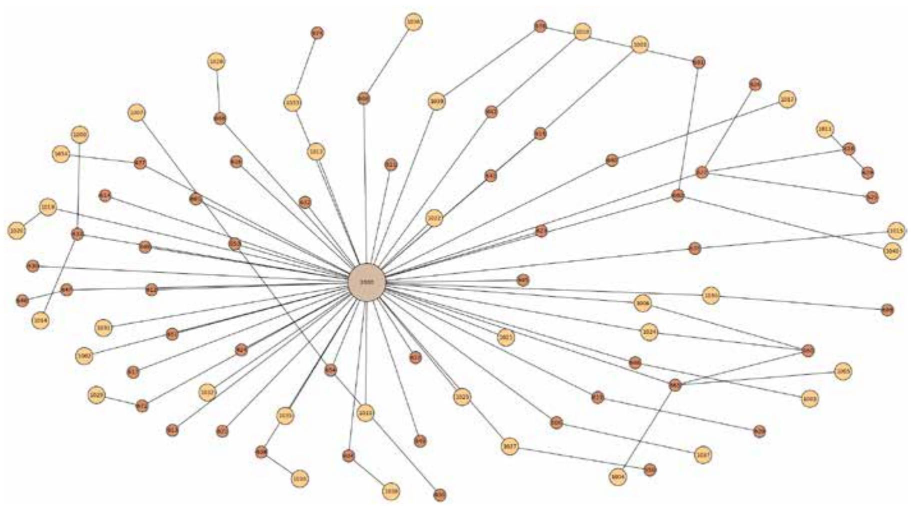


5(a)



5(b)

5(c)



5(d)

Fig. 5: (a) A map of one floor of a campus building. (b) A visualization of the lookup table after region growing is performed. (c) The 3D traversable map rendered in Unity3D. (d) The topological map, each node is represented by a note and an edge represent the connectivity between two entities.

The JSON file is loaded into the Unity3D engine and a 3D floor map is constructed automatically. The traversable map is built and an optimal route can be computed by using A* algorithm (Hart, Nils and Bertram, 100-107).

Experiments

We have performed the proposed algorithm on an AutoCAD file of a complex campus building. Fig. 5(a) shows the input AutoCAD map (the image only shows the map of one floor). We first parse the AutoCAD file, and extract useful layer and semantic information, which are stored into a database. We then render a new floor image that only includes wall structures from the database. The region growing method is applied into the new floor image and entities are identified from the image. In Fig. 5(b), the green regions represent rooms and blue regions represent corridors. Once the entities are extracted, the geometric relations among entities are calculated and a topological map is successfully built. Furthermore, the contour of entity polygons in the floor image is extracted and saved into a JSON file. A 3D traversable floor map is built in the Unity3D game development environment (Fig. 5(c)) and a turn-by-turn navigation direction can be calculated.

We manually verify the accuracy of the topological and traversable maps. For the topological map, we compare it with the original AutoCAD map. We derive a topological map from the AutoCAD map and compare it with the one generated by our proposed algorithm. They match correctly. For the 3D traversable map, we project it into a 2D space and it aligns with the original AutoCAD map correctly as well.

To test the performance of the topological and the 3D traversable maps, each time we randomly select two entities from the AutoCAD map and we manually calculate the shortest path between two entities. We then compute the navigation summary (using the Dijkstra's algorithm) from the topological map, and the turn-by-turn directions (using A* algorithm) from the 3D traversable map. We compare the three paths and they match correctly. The above test is repeated several times, the paths are all consistent.

Conclusions

In this project, we designed a hybrid approach to automatically generate indoor accessible maps from AutoCAD architectural floor maps, which are available for buildings built in the past three decades. Both the topological map and the traversable map of the indoor environment are constructed, which could be used to create a navigation summary, and an accessible map of the facility. The visually impaired can learn the spatial layout of indoor environments on the accessible map. In addition, a pre-journey application can be developed on the accessible map that allows visually impaired plan routes prior to their travels on a tablet or a smartphone, which is our current ongoing project.

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