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Topological Map Generation from Simplified Map for Mobile Robot Navigation

Vachirasuk Setalaphruk Takashi Uneno Yasuyuki Kono Masatsugu Kidode

Graduate School of Information Science
Nara Institute of Science and Technology(NAIST)

For an autonomous mobile robot to be able to navigate efficiently from current position to a given destination, it needs a model of the environment, or a "map." We are studying a new robot navigation system that can operate on simplified maps, similar to floor plans commonly found in buildings. This paper proposes a method for generating from such simplified map a topological map that will be used in our system.

1. Introduction

Our research group is interested in developing an autonomous robot system to be used in indoor environment. One of the requisitions for such robot is the ability to navigate inside the building. Generally, for an autonomous mobile robot to be able to navigate efficiently to a given destination, it needs a model of the environment, which is also called a "map." This information can either be obtained by active exploration of the environment, or be supplied by human.

A lot of works has been done in the area of active exploration and environment mapping, such as [Blanco 00] [Thrun 98]. These methods enable robot to gain knowledge of its environment, hopefully without need of human intervention. However, this also means that the robot cannot be used until the mapping process is over. Also, since there is no initial knowledge of the environment, the process is prone to confusion and may require help from human in some situations. Furthermore, it will need to spend time learning the map each time it enters new environment.

Alternatively, robot can use a map provided by human, but such map usually requires a lot of details, some of which are not easily accessible by human, such as exact length of corridor. Moreover, the map has to be provided in accordance with sensor model of the robot. Creating such a map can be a laborious task for human.

Our aim is to create a robot navigation system that can operate on simplified maps, similar to floor plans commonly found in buildings and can be created easily by human. In the following sections, we describe what a simplified map is, and propose an algorithm for creating topological map, to be used for navigation, from the simplified map given by users.

2. Simplified Map

A simplified map is an abstract map of the environment that shows only important (from human's perspective) structural information of the building. Figure 1 shows a sample map of a building at NAIST. This kind of map can be created easily with a simple drawing tool. It consists of the following components:

- *Walls*, denoted as black pixels, are obstacles that robot cannot move through.
- *Corridors*, which robot can move along, are simply free space between the walls.
- *Rooms* are space enclosed by convex polygon of walls. It can be assigned as destination. In our current work, we simply model rooms as space enclosed by four walls for simplicity.
- *Doors* which robot can move through, are modeled as red lines (but shown in Figure 1 as thick black lines).

Human can use this kind of map to navigate inside the building efficiently, but it is difficult for robot to use, because of the lack of information and accuracy. Specifically, we assume the following constraints:

- *Scale of the map is unknown.* We usually do not know the exact scale of the map, thus cannot relate distance on the map and real distance before runtime.
- *Scale is not uniform across the map.* The map is usually partially deformed, so scale of the map computed at runtime on one part of the map may not apply exactly to other parts.
- *Real world and the map is different in minor details.* Details such as irregularities of the walls or exact places of branching are usually inaccurate.
- *The map lacks information about some obstacles.* Obstacles such as pillars are usually omitted from the map, making localization difficult.

3. Algorithm

So far, generation of topological map that can be used in robot navigation either requires a geometric map with sufficient accuracy, or requires the robot to move around and gather data in real environment, for examples, [Shatkay 97] [Thrun 96] [Winters 00]. Our proposed algorithm produced topological map from an easy-to-create image of simplified map, enable users to easily give knowledge about environment to robots.

3.1 Structure Extraction using Voronoi Diagram

Let $\mathcal{C}$, the "free space," be a set of non-black pixels inside a given bitmap image. Black pixels then form an occupied space, denoted by $\bar{\mathcal{C}}$. The definition of Voronoi diagram generated by $\bar{\mathcal{C}}$ is as followed [Thrun 96]. Consider an arbitrary point p in $\mathcal{C}$. A *basis point* of p is a point $c \in \bar{\mathcal{C}}$ that has minimal Euclid

Contact: Vachirasuk Setalaphruk, Graduate School of Information Science, Nara Institute of Science and Technology, 8916-5 Takayamacho Ikomashi Nara, 0743-72-5265, setalav@is.aist-nara.ac.jp

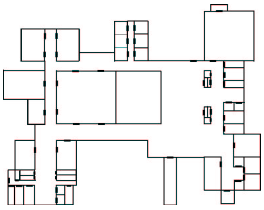

Figure 1: Floor Plan

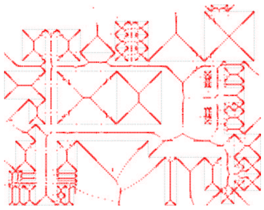

Figure 2: Voronoi Points

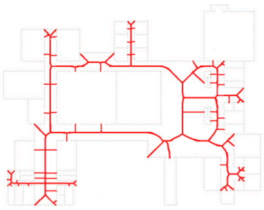

Figure 3: Masked Voronoi Diagram

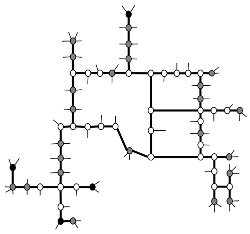

Figure 4: Topological Map

distance to p. The Voronoi diagram is the set of points in $\mathcal{C}$ that have at least 2 different basis points.

Voronoi diagram is used as a mathematical tool to extract the structural information from simplified maps. We want the diagram to be a skeleton of the corridors and also shows the configuration of doors along them. We used the following algorithm to produce such diagram.

1. **Down Sampling.** To reduce the complexity of calculating Voronoi diagram, the given map is down sampled by averaging all the coordinates of occupied pixels in each 5x5 block and take the result as a sample pixel for that block.
2. **Delaunay Triangulation.** We created Voronoi diagram by performing *Delaunay triangulation*. A set of 3 points $P = \{p_1, p_2, p_3\} \subset \bar{\mathcal{C}}$ form a Delaunay triangle if and only if there is a point c in the plane equidistant to each point in P and no other points in $\bar{\mathcal{C}}$ is nearer to c. In other words, c is the center of the circumcircle that pass through p_1, p_2, and p_3 and has no other points inside it. This qualifies c as a Voronoi point, since it has 3 basis points. Delaunay triangulation is performed on the set of points generated by the down sampling process and obtains a set $\mathcal{V}$ of center points from circumcircles of each Delaunay triangles. $\mathcal{V}$ is shown in Figure 2.
3. **Masking Rooms.** The Voronoi diagram inside a room in the simplified map is not very useful since it does not represent the real configuration of obstacle inside the room We omit those points in $\mathcal{V}$ that is found to be inside a room, obtaining $\hat{\mathcal{V}}$, a set of points on Voronoi Diagram inside the corridor.
4. **Creating Voronoi Diagram.** Joining the centers of adjacent circumcircles gives us Voronoi diagram that depict the structure of corridors and configuration of doors along it. Figure 3 shows the resulted Voronoi diagram.

3.2 Topological Map Generation

Topological map is a graph representation of the environment, where nodes correspond to distinct places that can be recognized by robot and arcs represent adjacency. The following features are extract from the Voronoi diagram using hints from the given simplified map. They are used as nodes in the topological map.

- **Branch points** are Voronoi points that have more than two neighbors.
- **Dead ends** are branch points that all but one of its branches ended at black pixels, which represent walls.
- **Doorways** are branch points that at least one of its branches ended at red pixels, which represent doors.

A pair of nodes is connected by an arc if there is a direct path between them. However, due to the inaccuracy of the simplified map, exact position of branching of corridors cannot be totally trusted. Consider a situation where a robot is moving along a corridor, and, according to the topological map, it expects to find a left branch slightly before a right branch. However, it might find the reverse in the real environment, due to human error when drawing the map, leading to confusing situation. For this reason, we proposed that branch points that appear tight together on Voronoi diagram be grouped together as a single node, and marked as *grouped features*. This will let the robot expect features near each other, but don't take their positional relations into account. The result is shown in Figure 4.

4. Conclusion

The simplified map of the environment, which can be easily created, is obviously useful as an easy way to give information about the environment to the robot, enable it to navigate efficiently without having to spend time wandering around learning the map. In this paper, we proposed a method to create a topological map that can be used in robot navigation, from a given simplified map.

The work described in this paper is still fairly preliminary. There are problems still unaddressed. One of them is that topological map generated from Voronoi diagram does not have any information about spatial property of the map. This is a problem when navigate in a large free space like a hall. One of the solution would be a distinction between large halls and narrow passages during map generation. Another problem is that the simplified map's inadequacy of odometric information and lack of information about obstacles might create confusing situation during navigation. However we believe that these problems can be covered with a proper navigation strategy. In the near future, we plan to develop a such a strategy that can be used to overcome these problems, and test it on our robot navigation system.

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