Auto-Creation and Navigation of the Multi-area Topological Map for 3D Large-Scale Environment

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Abstract. The widely used topological map is quite essential to localization and navigation for mobile robot, especially in large-scale environment. In this paper, a new structure of topological map is presented and applied in robot navigation. This kind of map, compared to occupancy grid map and conventional topological map, can better represent the environment with certain features, such as multi-floor and multi-type, and reduce time and space complexity to a degree. In this case, it will be more convenient for the creation and maintenance of topological map, and the navigation based on this kind of map become more efficient and robust. Finally, certain experiments demonstrate that this approach is very effective.

Keywords: Topological Map, Multi-area, Navigation, Laser Sensor, Mobile Robot.

1 Introduction

Navigation is one of the most challenging capacities for mobile robots. Over the past two decades, it has made great progress and received considerable attention on the problem of robot localization and navigation in mobile robots community. Thus far, map can be divided into continuous map and discrete map. The continuous map is mainly about the geometrical map [1][2], which represent the geometrical feature with feature points such as lines and points. It is easy for identification and localization, but with poor anti-interference performance. Discrete map includes grid map [3], topological map [4][5] and hybrid map [8] and so on. The grid map is concise and flexible, but consuming large memory resource. Topological map represents a specific location with node, and represents the passage with link. It is with high abstractness but low specification about the details of the environment [6][7]. In this paper, the topological map is more suitable for describing large-scale environment for its flexibility, robustness and low memory consumption. In the navigation process, a variety of properties are set on the topological nodes, including

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orientation, size, landmark, stopFlag, etc. These attributes can remedy the inaccuracy of the topological map and improve the ability of the localization and navigation.

In practical, mobile robots usually work indoors with multi-floor and multi-room environment. There is presented by some researchers a fusion algorithm dealing with multi-floor problem [9]. However, in large-scale environment, the robot doesn't have to search the entire map when doing path plan, which will rise the searching difficulty, increase the searching time. This paper presents a multi-area topology map structure. It can effectively organize the information under large-scale, multi-floor situation. Furthermore, a path plan approach based on the multi-area topology map is presented.

2 Robot and Map Editor

2.1 Mobile Robot for Home Service

At present, service robots are expanding towards agriculture, services, military and other non-industrial areas at amazing speed. Particularly in our daily lives, service robots have a promising future and its commercialization becomes more and more practical.

In this paper, the study is based on the dual-arm robot *SmartPal* cooperatively produced by Shanghai Jiaotong University and Yaskawa Electric cooperation, and focus on the map building and navigation problems in large-scale environment. *SmartPal* collects information through the laser sensor, and then build a grid map automatically. After that, a topological map is created in 3D Map Editor.

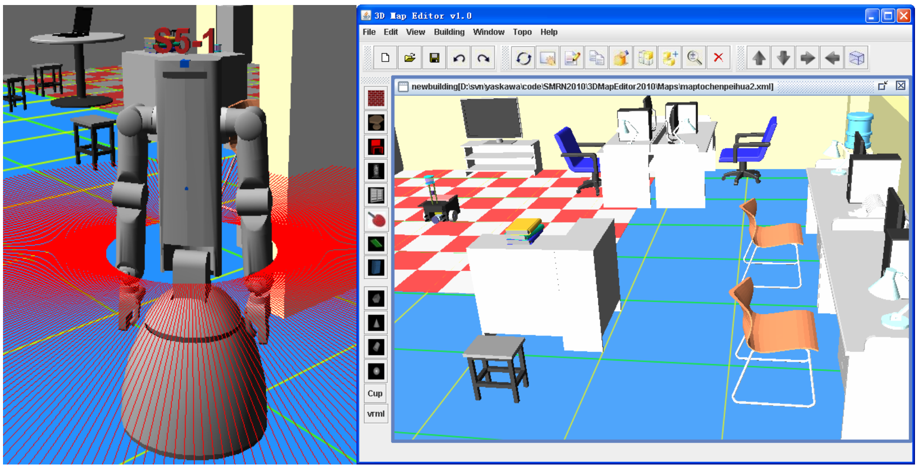

Fig. 1. The left figure show the 3D simulation model of the mobile service robot: Smartpal. Laser sensor is represented by the rays around the robot. The right figure is the 3D environment 3D Map Editor.

2.2 3D Map Editor

We use 3D Map Editor to model the environment and testify our map-creating algorithm. 3D Map Editor provides us with the functions of building geometrical map, grid map and topological map. The whole program is based on Java3D language.

3 The Topological Modeling and Multi-area Structure

3.1 Topological Node Model

Topological nodes represent the accessible points for robots on the map, especially some turning points and other critical points. On an topological node, the robot probably need to complete some specific actions, such as opening the door, turning around, picking up objects or taking an elevator and so on. Therefore topological nodes should contain certain information, such as size, orientation, landmark and some other special properties. We record the information in XML format, which is a cross-platform language with hierarchy structure. The node structure is shown in Figure 2.

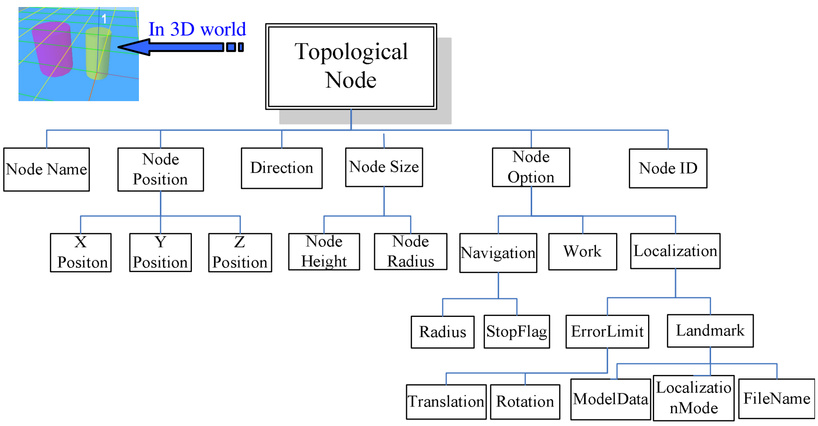

Fig. 2. This shows the structure of Topological node

3.2 Topological Link Model

Topological links represent a continuous region through the area. Usually, through the topological link, the robot just needs to complete some simple motions as translation or rotation. Therefore, the model of the topological link is relatively simple. It includes the information of start and end nodes, time cost, velocity, angular velocity, width and so on. Figure 3 shows the structure of topological link.

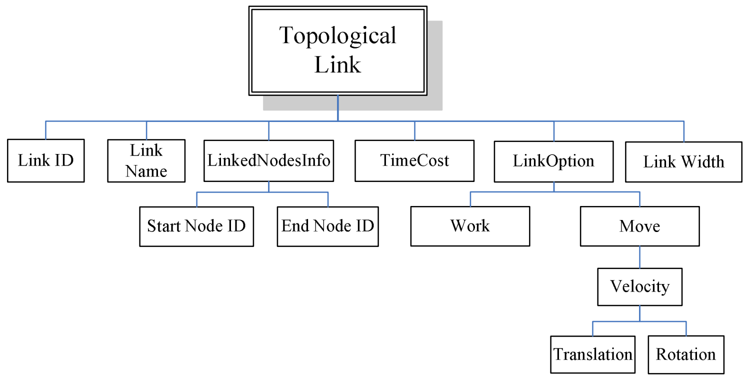

Fig. 3. This shows the structure of Topological link

3.3 Multi-area Structure

This paper addressed a topological map with multi-area structure in the large-scale environment. Different floors, different rooms can be divided into different areas. Each area can be regarded as an independent topological map. At the same time, each area is also connected by the special topological link based on actual situation. Usually the connections between two areas are likely to be the elevator between different floors and the passage between different rooms. Figure 4 shows the basic structure of multi-area structure of the topological map.

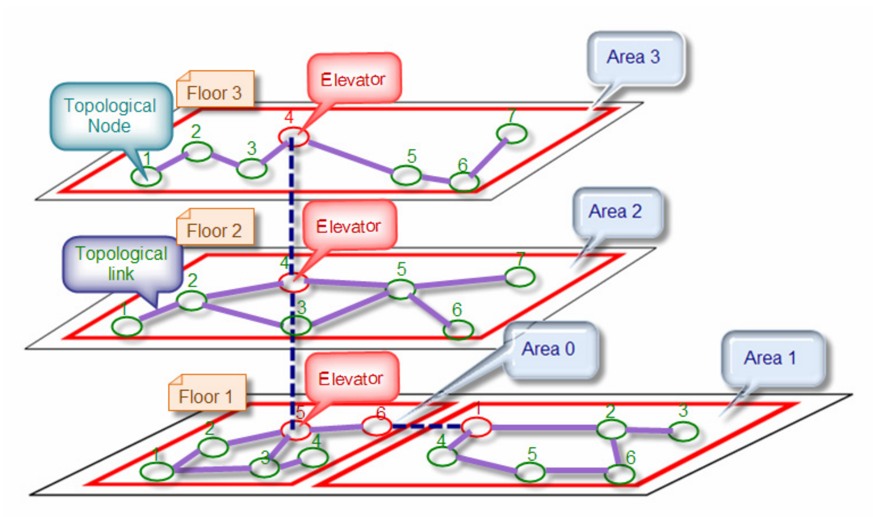

Fig. 4. This shows the architecture of multi-area topological map. It depicts a three-floor building, which is constructed to four areas.

There are three major advantages of this structure:

I. Simple structure and clear hierarchy. In a large-scale complex environment, such as modern high-rise building, or exhibition hall, it is hardly possible to build the entire environment into a complete map and use it in navigation. With a regional approach, it would be easy to solve this problem.

II. Modular explanation and good maintainability. When a local environment changes, it only need to modify a specific area, which in the case of large scale situation, would greatly reduce the calculating workload.

III. Easy positioning and navigation. When using topological map for path planning, if the start node and goal node are in the same area, it just need to search in that particular area, which will greatly simplify the problem. If the start and goal nodes are not in the same area, the task can be done by traveling through the topological links between areas.

4 Auto-creating and Editing Topological Map

In the 3D Map Editor, the data collected by the laser module is converted to a grid map. Then, the skeleton of the map is extracted using a graphics algorithm. Finally, the non-critical topological nodes are replaced by links. This automatically process of topological map building is shown as below:

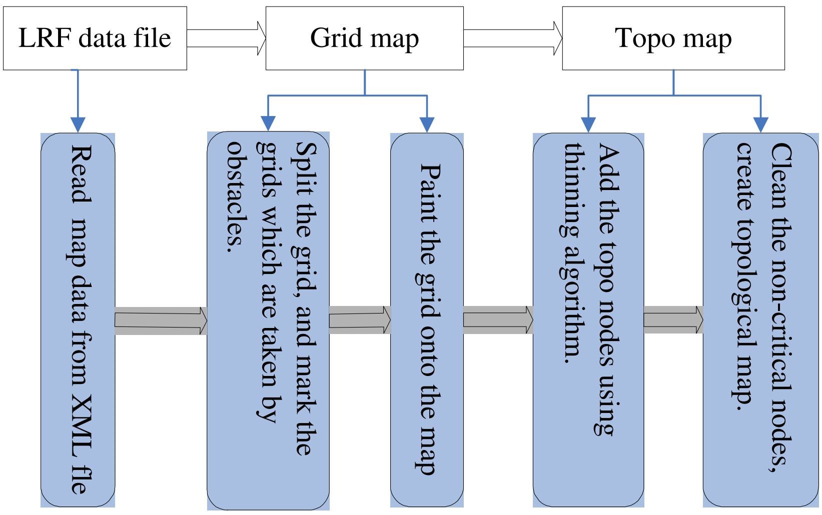

Fig. 5. This shows the process of creating topological map

It is very convenient to display and create the map in 3D Map Editor. The entire process can be visualized and is easy to modify and improve. In addition, 3D Map Editor supports vrml model. This allows us to use Solid Works and other 3D software to establish a precise environment model. In fact, we made a copy of our laboratory in the virtual world, and achieve a realistic effect. This combination of the real world and the simulation is very helpful to our study.

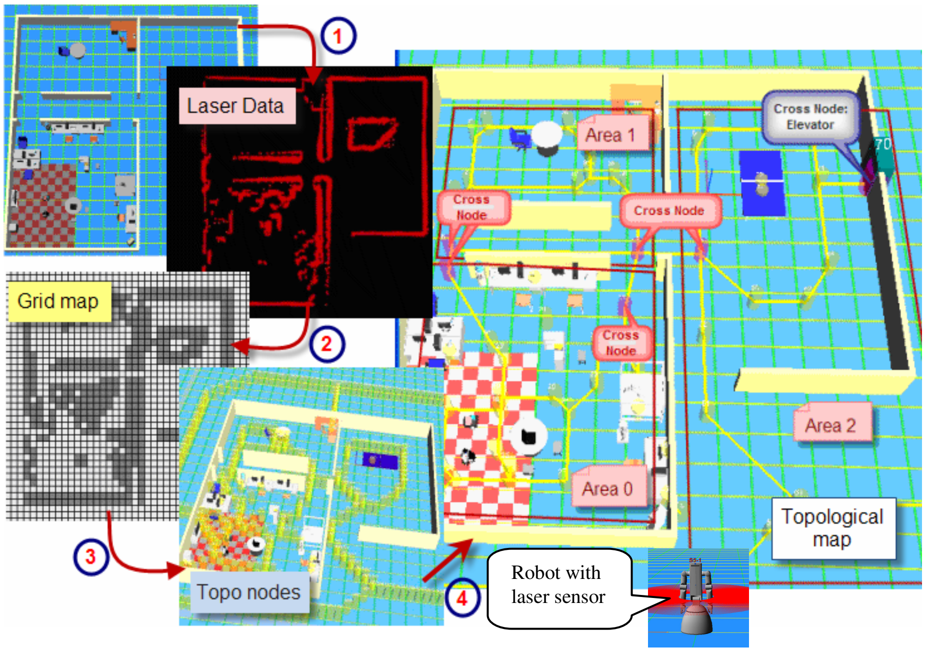

Fig. 6. This shows the experiment result of creating topological map in 3D Map Editor. There are several steps as shown in the figure. 1) Collecting laser data in the 3D environment. 2) Creating grid map. 3) Build the map with topological nodes using thinning algorithm. 4) Creating topological map.

5 Multi-area Navigation

The topological map is used on navigation when the robots get the commands from people, who specify the start node and the end node on the topological map. Then the path planner works out the path with minimum cost if exists, and the robot can follow the path to the destination. There are mainly three problems about the planning algorithm.

I. The algorithm should be good at real-timing. That is, the planner should take as little time as possible when navigation.

II. The algorithm should avoid infinite loops. There may be a lot of circles on the topological map, the robot should avoid running into the same node again.

III. The algorithm should adapt to the multi-area structure of the map.

For the real-timing, the algorithm should be as simple as possible. We consider the heuristic searching algorithm to solve this problem. Let $f(n)$ be defined as the actual cost of the optimal path constrained to go through n. And $f(n)$ is consisted of two parts:

$$f(n) = g(n) + h(n). \tag{1}$$

Where $g(n)$ is the actual cost of an optimal path from the start point s to n. And $h(n)$ is the actual cost of an optimal path from n to the goal point. The evaluation function $\hat{f}(n)$ is defined as the sum of $\hat{g}(n)$ and $\hat{h}(n)$, where $\hat{g}(n)$ is an estimate of $g(n)$, and $\hat{h}(n)$ is an estimate of $h(n)$. In this case, $\hat{g}(n)$ can be defined as the minimum cost of the path from s to n. And then the problem is how to define the $\hat{h}(n)$ to form the heuristic function, and adapt to this multi-area situation. There are several basic principles to follow.

I. The estimated cost must be lower than the actual cost [12].
II. The cost should be less if the current node is in the same area with the end node.
III. The robot may only search one certain part of the map depending on the navigation task.

Based on the above three principles, the heuristic function is designed like this:

$$\hat{f}(n) = g(n) + \hat{h}(n) \tag{2}$$

$$\hat{h}(n) = d(n) + \delta \cdot l(n) \tag{3}$$

Where $d(n)$ is the distance of the n and the goal node, and $l(n)$ is an additional value of the area cost, and $\delta \in (0,1)$ is the impact factor.

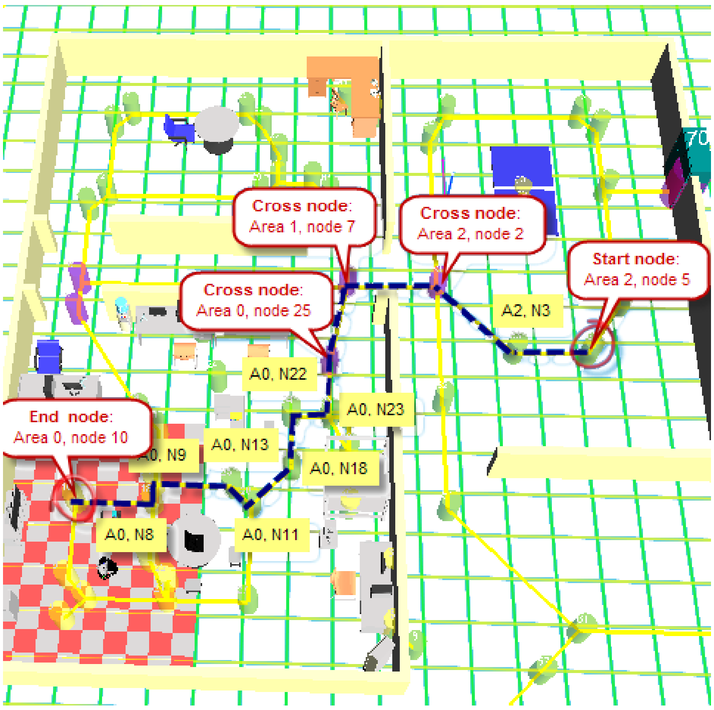

Fig. 7. This shows the experiment result of the navigation result. The task for robot is traveling from node 5 in area 2 to node 10 in area 0. It totally passes 13 nodes all through the path, especially three *cross nodes*, those are node 2 in area 2, node 7 in area 1 and node 25 in area 0.

This algorithm is tested on the map showed in figure 6. The start node is set to node 5 in area 2, and the end node is set to node 10 in area 0. Figure 7 shows the result of the path plan, where dash line indicates the optimal path calculated by path plan unit.

The result of simulation figures that the path planner can handle the large-scale navigation efficiently and can well adapt to the multi-area situation. Besides, compare with non-area map, which build the whole environment into one map, this approach appears a better performance on calculating efficiency.

6 Conclusion

The paper addressed a multi-area structure of topological map to deal with the map-building and navigation in the large-scale 3D environment. A new model of topological node and link is developed to achieve better navigation results. The map-building process is successfully accomplished in 3D Map Editor. The path plan algorithm and the simulation result are show in 3D Viewer. The encouraging result of the simulation shows the improved topological map can be used for map-building and navigation in large-scale environment.

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