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Practical Indoor Mobile Robot Navigation Using Hybrid Maps

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Abstract—**This paper presents a practical navigation scheme for indoor mobile robots using hybrid maps. The method makes use of metric maps for local navigation and a topological map for global path planning. Metric maps are generated as 2D occupancy grids by a range sensor to represent local information about partial areas. The global topological map is used to indicate the connectivity of the 'places-of-interests' in the environment and the interconnectivity of the local maps. Visual tags on the ceiling to be detected by the robot provide valuable information and contribute to reliable localization. The navigation scheme based on the hybrid metric-topological maps is scalable and adaptable since new local maps can be easily added to the global topology, and the method can be deployed with minimum amount of modification if new areas are to be explored. The method is implemented successfully on a physical robot and evaluated in a hospital environment.**

I. Introduction

Map-based navigation has been an active field of research since very early days of mobile robotics, and a number of map-based methods have been introduced to solve the problem of navigation. Representation of the environment, or modeling the world, is the key feature in map-based navigation, and it depends on several factors such as sensing capabilities, processing capabilities and the environment itself.

In this paper, we propose a practical indoor mobile robot navigation method using hybrid maps. A Hybrid map, in general, combines multiple maps of same or different kind to represent the same environment.

The method uses metric-topological hybrid maps are to represent indoor environments. Metric maps, in the form of occupancy grids represents local environment accurately for localization and obstacle avoidance. The topological map abstracts the environmental representation with nodes and edges, which is useful for global path planning and symbolic problem solving. Finally, use of visual tags in topological map allows efficient means for localization in both local metric maps and in global topology map.

Rest of the paper is organized as follows. In the next section, the background of the proposed method is presented. In the third section the method is described and typical usage scenario is explained. In the fourth section, physical experiments and evaluations are given, and in the final sections, discussion of the method is depicted and concluding remarks are presented.

II. Background

Autonomous navigation of indoor mobile robots has been a popular topic both in industry and research community. Many solutions has been proposed and implemented for autonomous navigation in industrial settings, where the environment is controllable and usually significant modifications are necessary. Automatic guided vehicles (AGV) traditionally used deterministic methods for navigation, such as magnets embedded in the floor [1], tracks painted with fluorescent ink [2], reflector strips attached to the wall [3] and recently, RFID tags [4] or optical markers placed on the floor[5].

On the other hand, with the influence of deliberate control paradigms and statistical theory; several methods has been developed by the research community for map based robot navigation, which did not require extensive environmental modifications.

A number of map types are in use today for mobile robot navigation. In the order of

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popularity, these can be classified as; metric maps[6], topological maps [7], sensor-level maps [8], appearance-based maps [9] and semantic maps [10].

Simply put, metric maps represent the environment in terms of distances that correspond to actually distances of the objects in the real environment. Occupancy grid maps [11] are the most commonly used metric maps, where the environment is represented as a matrix of cells and each cell has a value that correspond to the probability of its occupancy.

In contrast, topology maps represents the environment in terms of its constituents and their connectivity without using metric information. Therefore, topology maps mainly describe the structure of the environment, and how places or objects (nodes) are related to each other (edges).

Metric and topological maps are alternative ways of representing environments, and they have complementary strengths and weaknesses. Metric maps are easy to build, represent and maintain for small environments [12]. They can be used for accurate localization and for optimal route planning. Metric maps also layout the environment in an easily readable way for humans [13]. Topological maps are very suitable for planning, and they are easy to scale up for large environments. Sensor precision is not as important, since there is no need for precise position estimation for map building [14]. Topological maps are also good interfaces for symbolic problem solvers.

Hybrid metric-topological maps simply combine these advantages by utilizing the appropriate type of map for different tasks. The idea of hybrid maps was already suggested in early works ([8],[15],[16]), but a number of new methods and implementations (such as [17-21]) are introduced in the last decade.

III. Method

The method consists of two phases; map generation and actual navigation. Map generation principally takes place offline, pre-recorded environmental data is processed together with user input. At the end of this phase, a hybrid (metric-topological) map is obtained.

During navigation phase, the map generated in the mapping phase is used for local and global navigation. Structural information about the environment in the topology map is also used for user interaction by extracting the 'places-of-interest' and prompting them to the user to select a destination.

A significant characteristic of the method is the use of visual tags to aid navigation. Visual tags are basically artificial landmarks, that are easy to deploy and easy to distinguish and detect, and they correspond to certain nodes of the topology map.

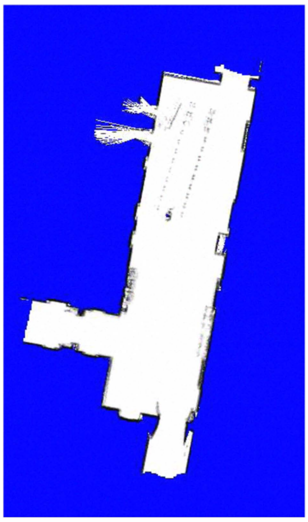

Figure 1, Occupancy grid map of Waiting room at Building 60, Bispebjerg Hospital, Denmark

A. Map Generation

In this phase, metric-topological map that is required for navigation is generated. The resulting hybrid map is hierarchical in the sense that; in the lower level, metric maps represent a number of regions in the environment and in the higher level, the topology map represent the interconnectivity of these regions.

Map generation is divided into 3 stages: Metric map generation, annotation and topology generation.

1) Metric map generation

Metric maps in this method are simply occupancy grids that represent static, local knowledge of certain regions in the environment.

Generation of these maps require pre-recorded datasets of these regions. Datasets are collected by manually guiding the robot in these regions. To be able to create connectivity in the topology generation step of this phase, it is assumed that a metric map partially overlaps with at least one other metric map. Therefore certain places in regions need to be visited more than once during data collection.

Datasets consist of odometry correlated range data and sequence of images that comes from onboard sensors of the robot. A number of sensor systems, such as monocular/stereo cameras, acoustic or infrared sensors can be used to record range data, but laser range finders are the most common sensors to generate occupancy grid maps, due to their superior range and accuracy.

Datasets can be collected by a single robot over the time, or by a group of robots simultaneously. The only important consideration is the partial overlap, which is significant enough do correlation. Consequently, it is also assumed that the environment is relatively static around the overlapping areas, i.e. no significant changes occur between revisits during data collection.

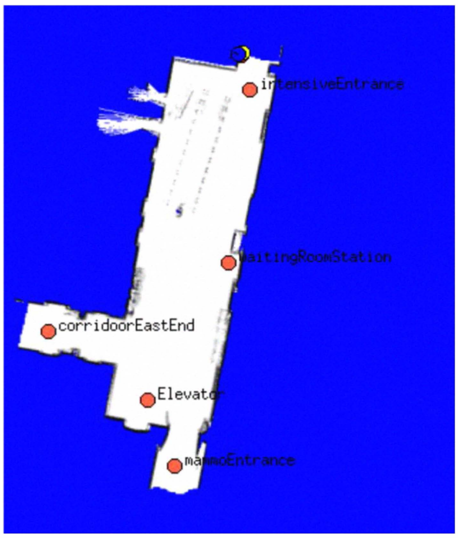

Figure 2, Annotated version of the map in Figure 1

After obtaining a group of datasets, occupancy grid maps are generated. This is essentially a simultaneous localization and mapping process where probabilistic methods are utilized to represent the region as a grid and estimate the occupancy likelihood of each cell. Occupancy grid maps can be graphically represented where darker pixels account for high probability of occupancy.

Metric map generation is an offline process. At the end of this process, a set of metric maps (such as in Figure 1) is obtained.

2) Annotation

Annotation is the consequent phase to metric mapping, in which semantic information is manually added to existing metric maps. The main reason for having this phase is to address the following question: '*where* the robot should go?'. To elaborate, consider the following usage scenario of an indoor service robot; where the user would like to send a robot to a certain 'place-of-interest'. While this place-of-interest has a meaning for the human user in terms of natural language, such as 'storage room', it only correspond to a certain pixel of the grid map, or to latitude longitude and orientation of a pose in the metric map. Annotation phase merely creates a link between semantic knowledge about the environment and its representation in robot coordinates.

During annotation, two types of information are added to metric maps; actual places-of-interests, i.e. names of the places that can be reached by the robot and 'switching nodes' where two or more maps overlap. These overlaps are also marked with distinct visual tags, which act as artificial landmarks. Both types of additions correspond to a certain position in the map, whereas switching nodes additionally refer to the distinct ID of the visual tag at that node.

Implicitly, an annotated map also depicts local topology (Figure 3). As all the nodes of a local topology map reside in the same metric map, any local node can be reached from any other local node. At the end of this phase, a set of annotated metric maps (such as in Figure 2) are obtained.

3) Global topology generation

Global topology is generated by creating symbolic links between metric maps through switching nodes. For simplicity, all the edges of the topology map are assumed to have unit weights.

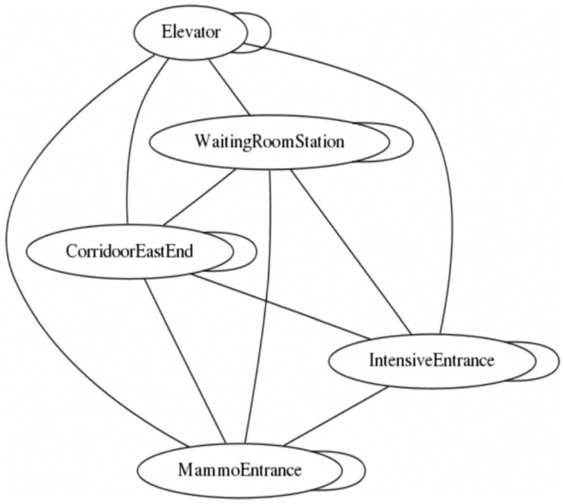

Figure 3, Local topology of the annotated map in Figure 2

Topology generation can be done online, because only the local topology information is used. The major advantage of online global topology generation is scalability. If a new annotated map of a new region is added to the existing set of annotated maps, global topology will be automatically extended and the robot will be able to reach to new points-of-interests in this region. Moreover, modifications to existing metric maps, such as adding or deleting places-of-interests, can be handled transparently, as the global topology is regenerated each time it is needed.

B. Navigation

Navigation process starts with a user request. The user specifies a destination for the robot from the list of all places-of-interest in the given set of annotated maps. Knowing the initial position of the robot on the global topology map, a global path is calculated using A* algorithm. The global path is a sequence of nodes, starting with the initial node, followed by a number of switching nodes (if the destination is not in the same local map), and destination node.

Initial position also determines the current local metric map. This is due to the fact that robot is initially at a particular place-of-interest, each place-of-interest is unique and only present in a single local metric map.

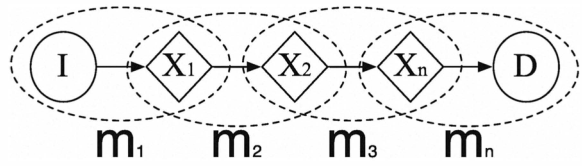

Figure 5, A global path consist of an initial node, a number of switching nodes and a destination node. Each two consecutive nodes reside in a single metric map

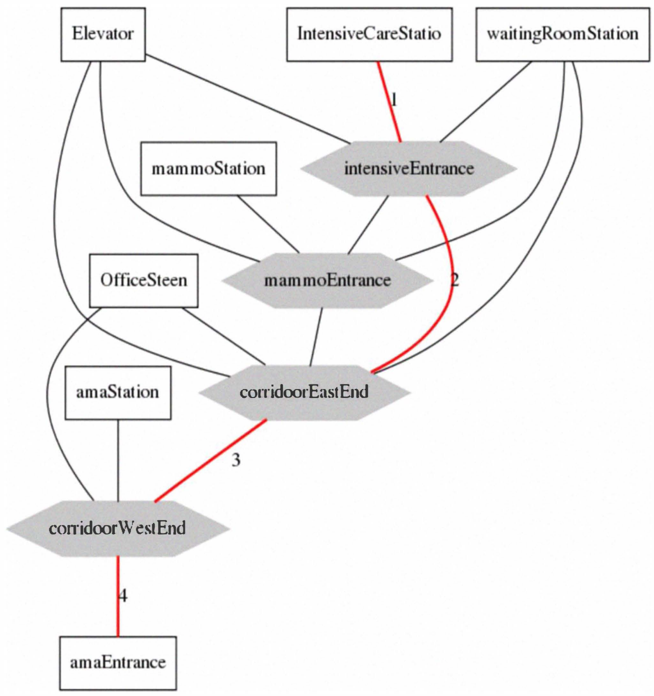

Figure 6, Global path from 'Intensive Care Station' to 'AMA Entrance'. Robot passes through 3 switching nodes; 4 local maps will be used

The second node in the global path is also in the same local metric map with the initial position. If the given destination is in the same local map with the initial position, global path is only composed of these two nodes. If the destination is not in the same local map with the initial node, the robot must pass through at least one switching node, as shown in Figure 5.

It is possible to plan and execute a local path from the first to the second node of the global path, using the local metric map. Robot can localize itself in the local metric map. As the robot approaches to the switching node, its expectation to observe the associated visual tag increases.

Therefore, robot can determine whether a switching node is reached based on metric-map based localization and visual tag detection. When the robot reaches a switching node, the new local metric map is needed. Any two consecutive nodes in the global path can only exist in one single metric map, so the new local map can be traced by using the current and the next nodes in the global path.

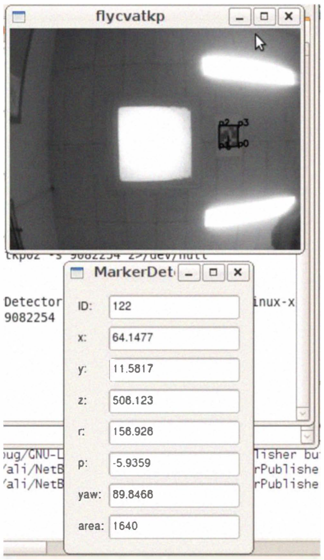

Figure 7, Artoolkit Plus [25] visual tags are detected at a switching node.

IV. Experiments

The described method is developed as a software library and tested in a real hospital setting. CARMEN [22] is used as the software framework for the experiments. Gmapping [23] is used to generate metric maps. Based on a recent survey[24], Artoolkit Plus [25] markers (Figure 7) placed on the ceiling are used as visual tags at the switching nodes.

Physical experiments are conducted on a Pioneer-3dx platform, which is equipped with a Sick-LMS200 laser range finder, upward-looking PointGrey Firefly-MV cameras and a laptop computer running Linux operating system.

Experimental tests took place in the first floor of building 60, Bispebjerg Hospital, Copenhagen, Denmark. The environment is roughly 4500 m^2, and it is divided into five regions: Acute Medical Attention (AMA) unit, Offices, Waiting Room, Intensive Care Unit and Mammography Unit. Seven points-of-interest were identified in the environment, and there are four switching nodes in the global topologic map (Figure 6).

After initialization at a given place-of-interest, the robot was requested to randomly given places-of-interest in the environment. Several experiments were conducted, over a period of a month, at different times of the day, with different intensities of crowdedness.

Experiments demonstrated that the robot can successfully navigate in-between any point-of-interest inside the environment, handling the map transition effectively. It is also shown that providing an additional annotated map can easily extend the area covered for navigation. This map is handled automatically by the system, and becomes available immediately for navigation, due to online global topology generation.

A short video of the experiments can be seen in [26].

V. Discussion and conclusion

The proposed scheme provides a practical framework for indoor mobile robot navigation, where the robot is required to operate between certain places of interest in the environment. This framework is targeted for service robot applications, and it is especially useful in logistics tasks such as [27]; where the robot is used for transportation of goods between different units of a hospital.

There are three salient advantages of the method. First, the method provides reliable navigation. The use of simple visual tags provide makes it possible to redundantly localize the robot. Visual tags are distinct and easily recognizable, allowing absolute localization in topology map. They also make it possible to improve metric localization, as they act as landmarks in the local metric map.

Secondly, the method allows scalable mapping and navigation. The use of the global topology map reduces memory requirements significantly because local metric maps are only symbolically linked through the topology map. New local maps can be easily added over the time, and the existing ones can be changed or modified individually.

Finally, the method can be easily adapted to new environments. Environmental modification is needed, but it is very easy and minimal. Building metric maps of smaller regions of the environment is also an easier task compared to mapping the entire environment, and visual tags will provide valuable information, especially in relatively featureless areas of the metric map.

VI. Conclusion

In this paper, an indoor mobile robot navigation scheme based on the hybrid metric-topological maps is presented. The method is developed as a software library, and it was implemented on a physical robot for empirical evaluation in a real hospital environment.

The method is developed to address the navigational requirements of a service robot, and it provides a practical solution for indoor mobile robot navigation.

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