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A Fast On-line Global Path Planning Algorithm Based on Regionalized Roadmap for Robot Navigation ⋆

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Abstract: Inspired by the 'fine-to-coarse' way-finding strategy that human utilized in the process of navigation, the paper proposed a fast on-line global path planning algorithm based on regionalized roadmap. First, a regionalized roadmap(RRM) that has a multi-layered structure is proposed for representing environments. Then, the RRM based FTC-A* algorithm is designed to plan an FTC-route('fine-to-coarse' route) with being fine in vicinity yet coarse at a distance. This algorithm can be applied to on-line global path planning in navigation system of mobile robots or vehicles. Finally, the simulation and physical experiments have been carried out to show the efficacy of the proposed path planning algorithm which can be applied to such occasions as large-scale environment and dynamic changes of the destination.

Keywords: Navigation,Path Planning,Regionalized Roadmap

1. INTRODUCTION

Robot navigation can be regarded as a process that combines global path planning with local motion planning. According to the priori environmental map, global path planning plans a path which is often consist of a series of position nodes. Then the robot can move from one position to another along the path before arriving at the end point. Therefore, global path planning functions as a guide of the robot's movements. However, when the robot begins to move along the established path, it carries out local motion planning online based on the local environment information so that the robot is able to avoid any obstacle to ensure safe and reliable movement. Still, if the target or the destination changes during the motion, then the robot has to employ a priori environment model to rapidly plan the global path from the current position to the new destination online, making the robot quickly move by responding to the new instruction. On-line global path planning holds strict limitation on the time taken by path planning.

The on-line global route planning process involves two aspects: environment map and path planning algorithm. As to map modeling, metric map(Rudan et al. (2010)), topological map(Ranganathan and Dellaert (2011)) and the hybrid map(Wu et al. (2014)Schmuck et al. (2016)) serve as the commonly-used map modeling methods. As one common type of metric map, grid map has been widely applied into the area of robot map modeling, but there are serious problems about its performance when the environment scale is very big, because the number of grids increases rapidly with the size of the environment(Augustine et al. (2012)). Therefore, to reduce the computation complexity, multi-layer map structure and hierarchical search algorithm are proposed, such as HA*(Holte et al. (1996)), HPA*(Botea et al. (2004)) and CFA*(Lee and Yu (2009)). These algorithms improve their efficiency through narrowing down the size of search space.

The above path planning algorithms return to a complete global path. But in actual process of navigation, a complete global path is not a must. It is enough to quickly plan out an incomplete yet effective path that can guide the robot to move immediately to the right direction. Studies find out that human beings are planning an incomplete path on-line to guide their own motion in the process of navigation, which allows them to quickly plan out paths and move to the destination under the circumstances of big-scale environment and change of targets(Wiener and Mallot (2003)Wiener et al. (2004)). In the process of navigation, human has used the regionalized spatial model and adopted the 'fine-to-coarse' way-finding strategy to plan an incomplete route from the current position to the destination, called 'fine-to-coarse' route(FTC-route).

Inspired by human way-finding strategy, we seek to build a robot navigation system that integrates regionalized spatial representation and efficient path planner to try to find a solution of on-line global path planning problem. First, we present a regionalized roadmap(RRM) to describe the search environment. Then, an innovative on-line global incomplete path planning algorithm is proposed, called 'fine-to-coarse' A* algorithm(FTC-A*). Based on the prior

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regionalized spatial information, described by RRM, FTC-A* algorithm plan a global incomplete ‘fine-to-coarse’ route(FTC-route). The route is temporarily stored and can be fetched by the target generator to produce the next closest goal for the goal executor to execute until the closest goal is reached. By updating robot’s location and then re-planning the FTC-route, the robot always have the ability to develop a detailed plan for movement decisions along the route. In navigation, mobile robots operate in the alternate mode of “plan-move-plan-move...”. They move to the next position according to the planned path and then plan the path from this position to the target position. Under the guidance of path planning, mobile robots finally reach the target position.

The rest of the paper is organized as follows. In SectionII, a regionalized spatial representation model to describe the environment is presented, called regionalized roadmap(RRM). In Section III, inspired by human’s way-finding mechanism, a FTC-A* algorithm is presented. Simulation and physical experiments are given in section IV. Finally, the conclusion is made in Section V.

2. REGIONALIZED ROADMAP

Abundant research results(Wiener et al. (2004)Wiener and Mallot (2003)) have led to the hierarchical theories that the structure of spatial information in the memory system is regionalized and nested with multi-levels. Hierarchical theories demonstrated that the environments are divided into regions and smaller regions are grouped together to form superordinate regions at the next hierarchy level which yields a tree-like structure. But there are other relations between different spatial objects, making the whole spatial representation model more like a graph-like structure. This section proposes a new model, i.e. the regionalized roadmap(RRM), which is used to describe the environment representation. Fig. 1 uses the RRM to describe a simple environment. From this figure, one can see that the simple environment is divided into 4 big regions and each region consists of 4 places each, altogether 16 places in the environment, as shown in Fig.1(b). The places were interconnected by road. Fig.1(a) uses a RRM to describe the small environment. We can see from Fig.1(a) that RRM, which describes the environment in an abstract way, consists of two primary types of components: the spatial nodes and the relations between them. The spatial nodes denote the recognizable units in the space, such as bed, room, house, city, and so on. The RRM needs to be nested, which means that a spatial node can include other spatial nodes. For instance, the spatial node 17 includes 1, 2, 3 and 4, and itself is included in the node 21. Thus, RRM can be defined as follows.

***Definition** 1.* (RRM). Let C be a set of spatial objects. Then a spatial node O can be described as a couple $O = (N, R)$, in which:

(1) $N = \{O_1, O_2, \cdots, O_k\}$ is a set of spatial nodes included directly by O and this set is connected, and meets the condition that $\forall i(O_i \in O)$ and $O \in C$.

(2) R is a set of the relations owned by node O, and $R \subseteq (N \cup O) \times C$.

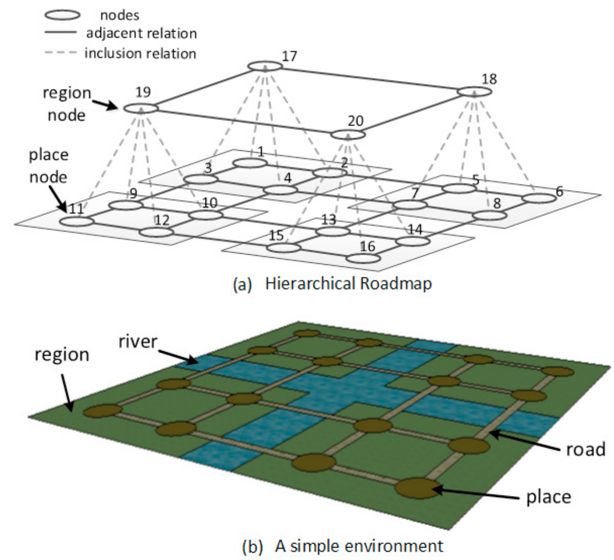

Fig. 1. An example of a regionalized roadmap of a simple environment

A spatial node is denoted as $O = (N, R)$, according to the Definition1, where N is a set of spatial nodes included directly by O and R is a set of relations owned by node O. O is called a **parent node** of each node in the set N. Each node in N can be called a **child node** of the node O. Therefore, it can be seen that RRM is a nested model. The expression $R \subseteq (N \cup O) \times C$ allows relation R to be able to represent not only the mutual relations inside the region(just like there is a route linking spatial nodes 11 and 12), but also the relations with spatial nodes outside the region (like there is a road linking 19 and 20), thus the cross-regional connections can be described. The spatial nodes can be divided into two categories. In the first category, the node, whose child nodes are empty ($N = \emptyset$), is called *place node*, such as the node 11 in Fig.1(a). In the other category, the node, whose child noes are not empty ($N \neq \emptyset$), is called *region node*, such as the node 19.

In this paper, the grid method is employed to divide the experimental environment and to build the regionalized roadmap. To build RRM, there are three main steps: first, the road information expressed in terms of discrete GPS points can be collected by driving the robot along the road; second, based on the road data collected in the environment, a road network is generated using Growing Neural Gas(GNG) algorithm; and third, the whole environment is divided into regions by grid segment method and represented into a RRM with two-layer structures in this paper. The sub-layer is the road network, and the up-layer is the connective relation layer of regions.

3. “FINE-TO-COARSE” ROUTE AND ITS PLANNING ALGORITHM

Previous sections focus on representation of regionalized spatial environments. The following subsections integrate its application into robot navigation system. This section starts with a description of the ‘fine-to-coarse’ route(FTC-route), and then presents a innovative FTC-A* algorithm to plan the FTC-route.