Mapping for Unknown Environment Using Incremental Triangulation

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I. INTRODUCTION

Autonomous robot exploration and map building for unknown environments is essential in a wide range of applications such as search and rescue, surveillance, military and other high risk scenarios. As the robot starts exploring its surroundings, it accumulatively builds a partial map of the environment composing of the areas that are currently known by the robot. In this work we present a new exploration and mapping solution that will capture the environment structure geometrically. The proposed Triangulation-Based exploration maps the environment using the Dynamic Triangulation Tree structure (DTT) developed in this study. Using triangles to store the geometry of the environment will significantly reduce the storage space required when compared to the occupancy grids used in many exploration and map building solutions. The efficiency of the proposed mapping structure is validated experimentally through simulations.

II. RELATED EFFORTS

Various map representations are available in the literature; some produce topological maps and some geometrical maps. Topological mapping captures the connectivity of the free space but provides no (or minimal) knowledge about its geometry. On the other hand, geometrical representations are usually concerned with the shapes and distances of the environment boundaries and mostly do not directly address the free space connectivity [1].

The majority of the exploration approaches found in the literature maps the environment using an occupancy grid. It basically divides the already explored spaces to cells of the same size labelled according to their occupancy as obstacle, free or unknown. While this representation has proved its practicality and simplicity in many solutions its main drawback is the huge memory it requires when applied to large environments. This limitation was eliminated in our proposed map representation by compressing the environment geometrical features through the use of triangles. For a given environment the number of triangles used to represent its geometry can be significantly less than the number of cells used to represent it as an occupancy grid. For a more comprehensive overview of robotics mapping see [2] and [3].

III. INCREMENTAL TRIANGULATION MAP BUILDING

During the exploration process, the robot acquires the 360 degrees *visibility region* which will be divided into a series of connected triangles arranged in the *Dynamic Triangulation Tree* (DTT), our simple yet efficient tree structure. Each triangle will encapsulate details about its geometry and its neighbouring triangles. There are mainly two types of triangles, primitive and non-primitive. Primitive triangles are those that have fixed vertices, i.e. all their vertices are existing boundary vertices from the environment. On the other hand, non-primitive triangles are those adjacent to the unexplored areas of the environment. In each exploration iteration the sensed *visibility region* is used to update the DTT structure and then chooses the next $frontier$ to explore. Exploration continues until the DTT is complete. The DTT is complete when all its triangles are *primitive* which implies that there are no unexplored frontiers. Moreover, the triangles in the DTT are connected in the formed tree structure to reflect the connectivity of the free space, allowing for easier path generation and navigation. The proposed mapping and exploration strategy is depicted in Figure 1.

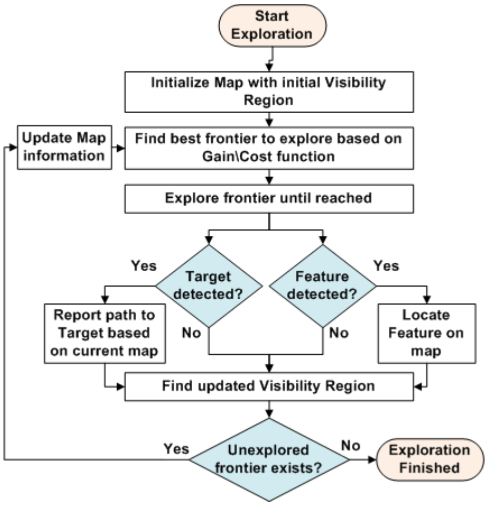

Fig. 1. Map Exploration algorithm flow chart.

Figure 2 shows the initial (left) and final (right) snapshots of the exploration process of a simple unknown environment illustrating the mapped DTT at start and end. The initial snapshot shows the initial triangulation constructed using the first acquired *visibility region* from the environment. The initial DTT contained a total of 7 triangles, 5 of which were primitive and 2 non-primitive due to their adjacency to unexplored *frontiers*. In the final snapshot, all triangles in the DTT are primitive at this stage which indicates the completion of the exploration process.

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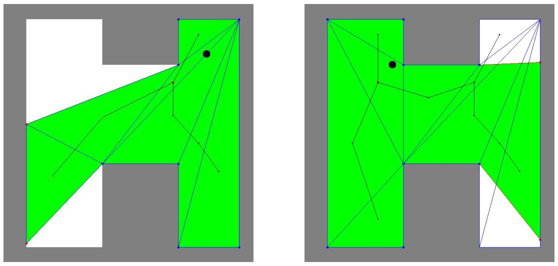

Fig. 2. Initial (left) and final (final) snapshots of the construction of the DTT for a simple environment.

IV. EXPERIMENTS

The mapping solution have been tested in various environmental setups using a testing simulation environment which was developed in Java.

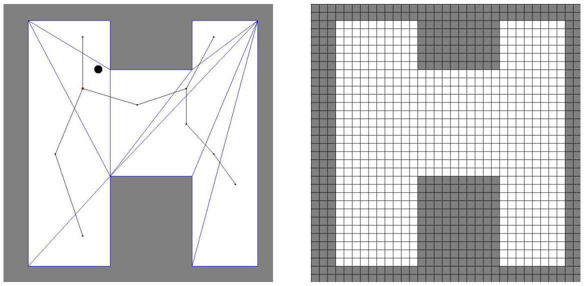

Fig. 3. The final DTT overlies the triangulated map (left) in comparison with grid decomposition (right) for the previously included simple environment shown in Figure 2.

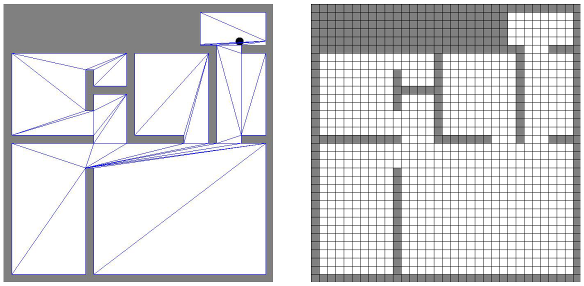

Fig. 4. The final triangulation compared to the grid decomposition of the same environment.

To prove the compactness of the DTT structure we will compare the storage space it requires to the space required by the corresponding occupancy grid since it is one of the very commonly used representations in many exploration and mapping solutions as discussed in Section II. Figure 3 shows the final triangulated map of the same environment presented in Figure 2 containing a total of only 10 triangles while the corresponding grid representation (with an approximately 0.4m x 0.4m cell size) of the same environment containing 670 free cells. This shows the compactness of the DTT in comparison to occupancy grid representation.

Figure 4 depicts both the final DTT, with a total of 91 triangles, and the corresponding grid decomposition, with a total of 817 free cells, of a more complex environment simulating a residential apartment floor plan.

Environment Type	Total Storage Size	
	DTT	Grid
Simple	10	670
Random	20	563
Maze	67	566
Simple Floor Plan	91	817
Complicated Floor Plan	115	822
Office Floor Plan	261	742

TABLE I

COMPARISON DATA OF THE DTT AND THE NUMBER OF FREE CELLS IN A MEDIUM-RESOLUTION OCCUPANCY GRID FOR VARYING COMPLEXITY SCENARIOS.

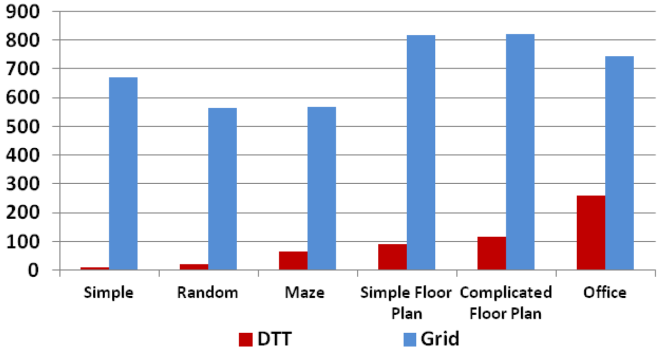

Fig. 5. Graphical representation of the comparison in Table I.

Table I and Figure 5 provides a more exhaustive comparison between DTT and occupancy grid storage size in varying complexity scenarios, namely a simple environment (Figure 3), random environment, maze-like structure, a simple floor plan (Figure 4), a more complicated floor plan, and an office environment, respectively. Further details of results can be found in [4], [5], [6].

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