ROBOT PATH PLANNING WITH MULTIRESOLUTION PROBABILISTIC REPRESENTATIONS: A COMPARATIVE STUDY

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Abstract

Path planning is an essential step in robotic applications; it allows the robot to execute the task successfully, without any collisions with neighbouring objects. As path planning performances directly depend on the nature and the encoding of an environment representation, various approaches can be considered. In this paper new strategies are studied and compared with classical ones: multi-resolution vs standard occupancy grids and probabilistic vs deterministic datasets. The goal is to identify the best solutions for path planning and collision avoidance in semi autonomous robotic systems operating in complex environments.

Keywords: *Path Planning, robotics, collision avoidance, occupancy maps.*

1. INTRODUCTION

Avoiding collisions during the movement of a mobile robot is a critical issue that implies efficient path planning strategies. Numerous approaches have been proposed in the literature. However, few of them demonstrate sufficient reliability to operate in very complex environments, especially in 3D cases.

Multi-resolution occupancy grids [1] and their compact encoding structures known as quadtrees (in 2D) and octrees (in 3D) eliminate much of the redundancy existing between neighbouring clusters. Results obtained in this research work also demonstrate that path planning delays can be significantly reduced when multi-resolution maps are used due to an important reduction in the number of steps needed to identify a sequence of collision-free regions to traverse.

Furthermore, datasets containing obstacle information can be defined in different formats. The standard empty/occupied representation has been widely used. Unfortunately, it does not encode measurement and registration errors that could lead to erroneous mapping of the environment. A probabilistic approach has been introduced [2] which demonstrates important advantages over binary (empty/occupied) representations by allowing a direct computation of potential fields as uncertainty is already encoded in the dataset.

This paper presents a comparative study between classical occupancy representations and the latest probabilistic techniques under various resolution mappings in the context of mobile robot path planning. Experiments that are reported in this paper demonstrate the superiority of these modern environment-mapping schemes over classical representations.

2. OVERVIEW OF TECHNIQUES

2.1 Multi-resolution grids

The objective of using multi-resolution grids is to reduce the number of steps in the robot path. By grouping together large regions of similar occupancy state, we can lower the number of steps required when finding the trajectory and reduce memory requirements. The comparison done here is between two tree-like structures: one where all the cells are of fixed size and one of multi-resolution. Figure 1a illustrates a simple environment with fixed-sized cells; when compared with a multi-resolution encoding (as shown in Figure 1b), there are much more cells to process in the standard representation. As a consequence, using a multi-resolution scheme significantly reduces model computation.

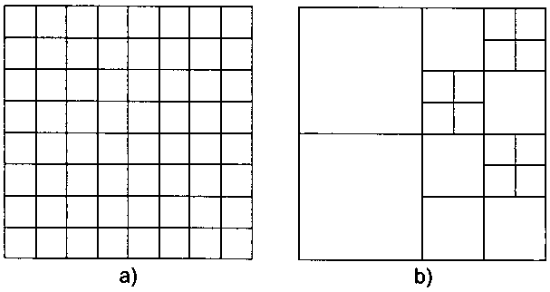

Fig. 1. a) Standard fixed-size grid; b) multi-resolution grid.

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2.2 Probabilistic datasets

Even the most accurate range sensors are often error-prone. Therefore, obtaining many samples of the same data point is important for the robustness of the environment model. Inspired by a 2D approach introduced by Elfes [2], Payeur *et al.* have proposed a method of 3D data fusion [3] where a probability (with 0.0 representing empty space and 1.0 corresponding to occupied space) is used to encode the occupancy of a given cell, as opposed to discrete occupancy levels (occupied, empty or unknown). This probability is based on the number of measurements and the fusion of those readings. A probabilistic model of a simple environment is shown in Figure 2. For clarity, only 5 levels of probability are used and mapped as grey levels ranging from black (occupied space) to white (empty space).

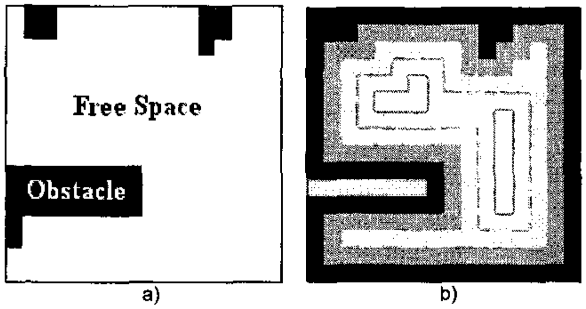


Fig. 2. Probabilistic encoding of a workspace.

The occupancy of cells inside obstacles is unknown and given a probability of 50% (shown with the middle shade of grey). Outward from the obstacle edges, the probability lowers as the certainty that cells are empty increases.

2.3 Potential fields

Potential fields have been used for nearly 20 years in robotic applications [4]. They give an efficient representation of an environment to be used in path planning. The process can be seen as letting a marble fall from a hill and reaching the lowest point of a valley. It usually relies on two distinct artificial fields: a repulsive field that pushes the robot away from obstacles and an attractive field that pulls the robot towards the goal. The combination of these fields is used for path planning.

However, the main drawback of this approach is the appearance of local minima: places in the environment that lead the robot to be trapped before it reaches the goal position. Many researchers have proposed ways to overcome this [5][6][7], but an appealing approach remains that of Laliberté and Gosselin [8], which discretizes the fields. The attractive field is computed by means of wave propagation from the target position. This yields a model that is exempt of local minima. When combined with probabilistic datasets, this approach simplifies the calculations of the repulsive field as the free space can be determined by applying a threshold on the probability of occupancy [9].

3. EXPERIMENTAL STEPS

The four approaches that are examined result from the combination of standard or multi-resolution grids with deterministic or probabilistic datasets. All approaches use the same basic steps: find the free space beyond a security margin from obstacles, determine the attractive field by calculating the distance to the goal position and calculate the collision-free path by following the down slope from the start to the goal position. The resulting output paths are shown and analyzed in the following subsections.

3.1 Standard grids and deterministic datasets

This combination is the classical approach found in the literature. Its performances are used here as a comparison to the other methods. It uses simple, discrete occupancy grids that are represented in the form of binary images. The image is encoded into a tree structure where the cells are all of the same size. Here, the repulsive field is calculated by finding the distance (in number of empty cells) from the nearest object for every cell in the grid. A threshold is then applied over these distances to obtain the representation of empty space as shown in Figure 3b.

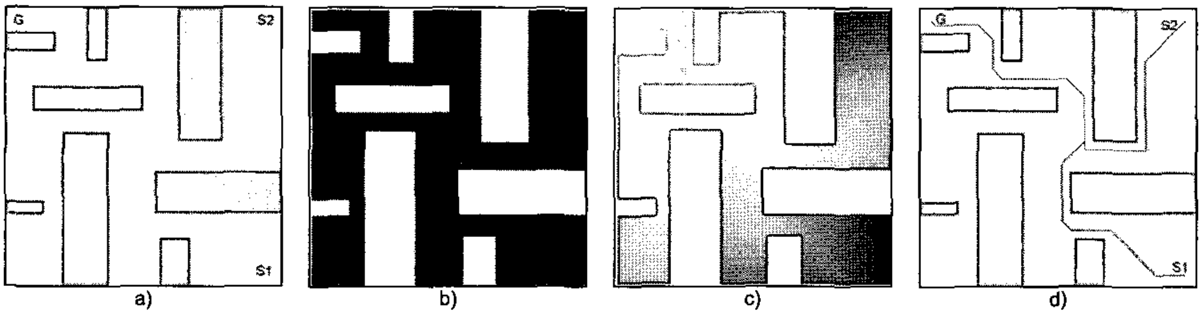


Fig. 3. Determination of free space and collision-free paths between a set of obstacles:
a) sample space, b) free space, c) attractive field computed on the free space, d) resulting paths.

By wave propagation starting from the goal position (near the top left corner, denoted "G"), the attractive field is computed for the cells inside the free space. Each cell is assigned a distance (in number of cells) to the target position, this is shown in Figure 3c, where the farthest distance is displayed in black and gradually becomes lighter towards the target position. The output path is simply calculated by taking the gradient of this field and following the "down slope". Here, paths are presented for two starting positions (denoted S1 and S2) and are superimposed unto the original image of obstacles as shown in Figure 3d. The space left between the robot trajectories and the obstacles results from the addition of a safety margin all around the obstacles.

3.2 Multi-resolution grids and deterministic datasets

In our second set of experiments, the same path planning method is applied but with multi-resolution representation of the free space. The attractive field is now calculated in the number of multi-resolution cells rather than in the number of pixels. This drastically reduces the amount of searches to determine a safe path. The resulting paths computed on the same environment are illustrated in Figure 4a. The black cells are those that are to be visited by the robot.

3.3 Standard grids and probabilistic datasets

With probabilistic datasets, the environment description is no longer discrete (occupied or empty), but rather provides a probability between 0 (white) and 1 (black) that a given area is occupied. The free space between obstacles is determined by thresholding the probabilistic dataset (usually a value under 50% is preferable since it excludes the insides of obstacles). This procedure saves the expensive computation of distances all around the obstacles and automatically implies a proper safety margin around all obstacles. In the example shown in Figure 4b, a threshold of 33% has been applied. The "fuzziness" around the obstacle boundaries illustrates the progressive variation of the occupancy probability that typically results from the uncertainty of sensor readings. When the potential field path planning approach is applied on this space representation, the collision-free paths are not significantly modified in comparison with their deterministic counterparts.

3.4 Multi-resolution grids and probabilistic datasets

For the fourth part of our experiments, probabilistic occupancy representations similar to those used in section 3.3 have been encoded in a multi-resolution grid on which the potential field path planning strategy has been applied. The resulting occupancy representation and collision-free paths are shown in Figure 4c. This combination leads to significant improvements in the calculation of the potential fields and of similar safe trajectories.

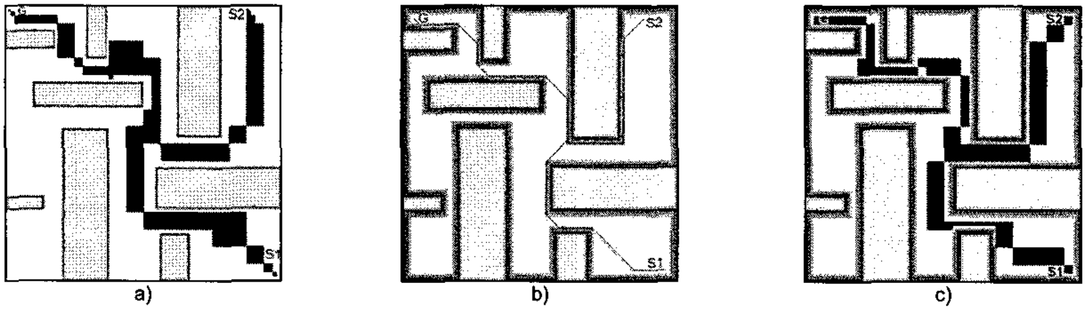
4. RESULTS

The efficiency of the four combinations has been analyzed based on several tests performed on different environment configurations with various starting and goal positions. The results presented below represent an average of all experiments for each of the four approaches. The environments are defined as binary images of 512x512 pixels. Simulations were run on a 600 MHz SGI 320 workstation.

In Table 1, a comparison of the time required for determining the free space (computing repulsive field and encoding it in a tree structure) from the environment description is shown. We observe that the use of multi-resolution grids allow to reduce computation times by 40% on average when compared to standard grids while probabilistic datasets offer a 30% reduction. When probabilistic datasets and multi-resolution grids are used in conjunction, the computation times have been reduced by a factor of 3.5 (70% reduction on computation time).

Table 1: Free space computation times (seconds)

	Deterministic	Probabilistic
Standard grid	6.97	4.49
Multi-resolution grid	4.32	1.98



a) b) c)

Fig. 4. Collision-free paths computed from a) a multi-resolution grid with deterministic dataset, b) a standard grid with probabilistic dataset, c) a multi-resolution grid with probabilistic dataset.

As path planning is the most critical step in many autonomous robotic applications, Table 2 displays the computational times required for path planning. We observe that the multi-resolution grids reduce path planning time by 30% on average while the use of probabilistic datasets results only in marginal variations.

Table 2: Path planning computation times (seconds).

	Deterministic	Probabilistic
Standard grid	3.22	3.37
Multi-resolution grid	2.25	2.25

Table 3 presents an indication of the efficiency of the entire process including free space calculation, attractive field computation and path planning. We observe that the use of multi-resolution grids tends to reduce computation time by about 30% with respect to standard grids. The introduction of probabilistic encoding generates an extra 15% saving on computation time.

Table 3: Full program computation times (seconds)

	Deterministic	Probabilistic
Standard grid	17.08	14.82
Multi-resolution grid	12.45	10.05

The average path length (number of cells from start to goal) is another important factor in path planning. Experimental path lengths are summarized in Table 4. On average, paths computed with a multi-resolution representation count 20 times less steps than those based on a standard grid. On the other hand, datasets encoding does not influence the number of steps along the paths..

Table 4: Path steps count (number of cells visited)

	Deterministic	Probabilistic
Standard grid	948.2	948.2
Multi-resolution grid	45.7	45.7

5. ANALYSIS

Computation times and path lengths are significantly improved by the use of multi-resolution grids in comparison with path planning based on standard fixed-sized grids. This mainly results from the lower number of searches that need to be performed since multi-resolution cells cover larger uniform areas. In combination with the important reduction of computation times spent on data fusion when using multi-resolution grids [3], the benefits of a strategy based on multi-resolution models are clear.

The introduction of probabilistic datasets in replacement of deterministic ones mainly influences the computation of repulsive potential fields and the determination of free space. As expected, it has a marginal effect on the path planning performance as well as on the location of the trajectory in general. However, in environments where narrow corridors have to be traversed, the richness of a probabilistic representation provides knowledge on the reliability of the environment model. In a deterministic representation, this uncertainty can at best be encoded into fixed safety margins around each obstacle and therefore does not provide any flexibility to the path planning operation.

The experiments presented here have been performed on a 2D environment to provide a clearer analysis of robot behaviours. The research is currently generalized to 3D environments and manipulators trajectory planning. Due to the computational explosion associated with the addition of the third dimension, it is expected that improvements in computational times will be more significant in 3D space.

6. CONCLUSION

In this research work, potential field path planning based on four different encoding schemes has been studied and performances have been compared. Multi-resolution grids reveal to offer a significant advantage on almost all aspects of the path planning process in comparison with standard grids. Similarly, using probabilistic datasets also contributes to reduce computational times while improving the flexibility of the path determination. This demonstrates that it is worth to pursue research efforts on robot path planning with multi-resolution probabilistic representations.

References

[1] H. Samet and R.E. Webber, "Hierarchical Data Structures and Algorithms for Computer Graphics Part I: Fundamentals", in *IEEE Computer Graphics and Applications*, pp. 48-68, 1988.

[2] A. Elfes, "Using Occupancy Grids for Mobile Robots Perception and Navigation", in *IEEE Computer*, Vol. 22, No 6, pp. 46-57, 1989.

[3] P. Payeur, D. Laurendeau, C.M. Gosselin, "Range Data Merging for Probabilistic Octree Modelling of 3-D Workspaces ", in *Proc. of the IEEE Int. Conf. on Robotics and Automation*, vol.4, pp. 3071-3078, Belgium, 1998.

[4] O. Khatib, "Real-time Obstacle Avoidance for Manipulator and Mobile Robots", in *Proc. of the IEEE Int. Conf. on Robotics and Automation*, pp. 500-505, 1985.

[5] S. Caselli, M. Reggiani and R Rocchi. "Heuristic Methods for Randomized Path Planning in Potential Fields", in *Proc. of the IEEE Symp. on Computational Intelligence in Robotics and Automation*, pp. 426-431, 2001.

[6] Y. Kitamura, T. Tanaka, F. Kishino and M. Yachida. "3-D Planning in a Dynamic Environment Using an Octree and an Artificial Potential Field", in *Proc. of the IEEE Int. Conf. on Intelligent Robots and Systems*, pp.474-479, 1995.

[7] Y. Wang and G.S. Chirikjian. "A New Potential Field Method for Robot Path Planning", in *Proc. of the IEEE Int. Conf. on Robotics and Automation*, pp. 977-982, 2000.

[8] T. Laliberté and C.M. Gosselin. "Efficient Algorithms for the Trajectory Planning of Redundant Manipulators with Obstacle Avoidance", in *Proc. of the IEEE Int. Conf. on Robotics and Automation*, pp. 2044-2049, San Diego, 1994.

[9] P. Payeur, C.M. Gosselin, D. Laurendeau, "Application of 3-D Probabilistic Occupancy Models for Potential Field Based Collision Free Path Planning", in *Proc. of the IEEE IMDSP Workshop '98*, pp. 175-178, Austria, 1998.