Frontier Based Exploration for an Autonomous Robot

JINTO JOSE

ABSTRACT

A mobile robot is one that can navigate through a given space. But an Autonomous mobile robot is one which can navigate through space without supervision. Autonomous Navigation can be done efficiently, once the robot has mapped the environment around it and localized itself within the environment it mapped. This paper focuses on the exploration and mapping of the environment around the robot. There have been many algorithms that have come up for the mapping of an unknown space. Frontier based exploration is one such algorithm that is the focus of this paper. The idea of Frontier based Exploration is for the robot to move to the Frontiers to explore further, Frontier being the boundary between the explored and unexplored world. This fastens the process of exploration as the robot spends most of its time exploring the unknown part of its environment. The exploration stops when there are no frontiers left to explore.

I. INTRODUCTION

Having a map and then finding a location or landmark in it is not a big hassle since maximum certainty is achieved at a point allowing the robot to know its location with a high probability of accuracy. This allows the robot to navigate through the world easily. But a robot without a prior map cannot navigate its path, rendering it virtually useless for moving from one point to another. Hence a robot being able to map the world that it does not know about is one such problem that needs to be solved with a maximum probability of success. One such approach to solving this challenge is the frontier based exploration. Exploration is the act of moving through an unknown space and building a map of the space to improve the accuracy of navigation and localization.

The process of exploration of the environment by an Autonomous robot consists of three steps:

1. Exploring the region around the robot to the extent to which the robot's sensors can reach.
2. Next is to find the location to which the robot should move to explore further.
3. Check whether the environment is mapped completely to know when to stop the exploration.

Frontier based exploration encompasses of these steps.

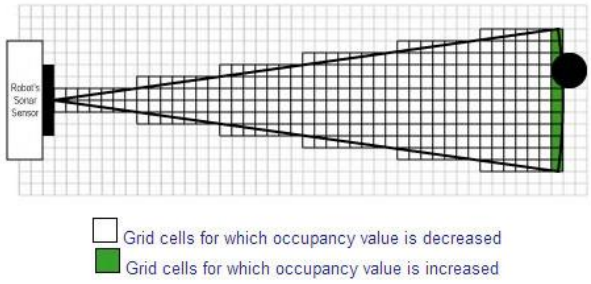
II. PROJECT DESCRIPTION

The idea of the frontier based exploration is to use borders between the explored and unexplored areas.
An evidence grid is used to define the map. A prior probability is given to each cell in the grid, since initially it cannot be determined if the grid is occupied or not.

$$p(c_{(x, y)}) = 0.5$$

This is the probability of a cell at position x, y. Initially all of it is 0.5. The sensor reading then updates the probability of the cell. As per the approach determined by Brian Yamauchi [1], the cells are classified into 3 categories.

A cell is said to be occupied when probability of the cell being occupied is more than the prior probability. An open cell is one where the probability of the cell occupancy is less than the prior probability. If the probability of the cell occupancy is equal to the prior probability, the cell is said to be unknown i.e. the occupancy of the cell has not be determined.



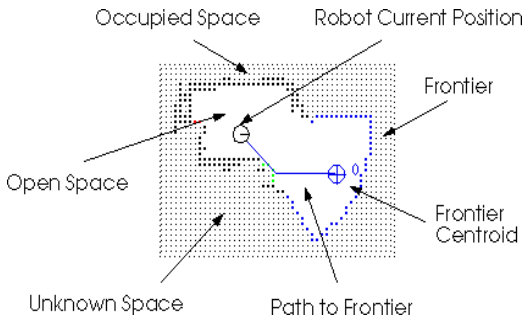
Frontier Detection:

An algorithm just like the edge detection is used to determine the boundaries between open space and the unknown space. The unknown cell next to an open cell is taken as the frontier edge. A frontier is a group of adjacent cells that are found from the frontier edge. A minimum size is taken randomly and a region above this size is a frontier. A robot can detect any number of frontiers at a given time. This depends on the range of the sensor. A frontier may not be accessible to the robot i.e. it can be in between areas that the robot cannot reach. In such cases the robot keeps trying for a finite amount of time and determines that it is inaccessible or unreachable. The path to the frontier is a traversable path.

Frontier Navigation:

The closest frontier is chosen, and the robot navigates to this frontier. A* algorithm provides an accurate path. Waypoints are found along this path and the robot is given then end point along with the waypoints which helps it to navigate to the nearest frontier.

This exploration technique allows the map to be explored in a finite time. The frontier is then added to the list of known frontiers. The robot sensor detection is usually done by rotating 360 degrees. At the new frontier the robot updates its grid and then does the sweep to determine the new frontiers.
This process is repeated till every unexplored area is determined as reachable or unreachable.



III. Related Work

Yamauchi, Brian. "A Frontier-Based Approach for Autonomous Exploration." states that "A good exploration strategy is one that generates a complete or nearly complete map in a reasonable amount of time." Finding such a strategy is challenging since the noise corruption of data cannot be accounted for always. He proposed that using a laser-limited sonar reduces this issue significantly. A sonar sensor may cause specular reflections. Combining it with a laser sensor allows it to reduce the error caused by specular reflections.

TOTO, a robot built by Mataric uses a path planner along with reactive exploration and obstacle avoidance. The issue with this robot is that it follows the wall to do so which is inefficient in case of a complex map. Reactive exploration is also hindered in a complex map. Implementation of the frontier based approach will allow it to increase the efficiency of the exploration. *Mataric, Maja J.. "Integration of representation into goal-driven behavior-based robots." IEEE Trans. Robotics and Automation 8 (1992): 304-312.*

A ROS implementation of the frontier based exploration was done by *Uslu, Erkan, et al. "Implementation of frontier-Based exploration algorithm for an autonomous robot." 2015 International Symposium on Innovations in Intelligent SysTems and Applications (INISTA), 2015*. Using the ROS framework, they implemented this strategy in a real and stimulated environment. Various runs were to generate optimal parameters for a clear map of the area. They proposed segmentation based extraction to prevent multiple visits to partially explored areas.

Wurm, K.m., et al. *"Coordinated multi-Robot exploration using a segmentation of the environment." 2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2008*, focuses on investigation of how to coordinate between multiple robots using a probabilistic approach. A trade-off between the costs of reaching a target and utility of reaching the target is determined. When a target point is assigned to a specific robot, the utility of unexplored area will be reduced for other robots from the coordinates of

the robot to which the target point has been introduced. A frontier detection is carried out only when a new target is allocated on any of the robots.

K. Wurm, C. Stachniss, and W. Burgard. "Coordinated multi-robot exploration using a segmentation of the environment." IROS-08, Nice, France, Sept. 2008 proposes to divide the map into segments corresponding to features of the map. Each robot is assigned a segment and is explored by that segment only. The frontier detection algorithm is called at every step of the coordination algorithm. Once the map is updated about a segment, every robot included the robot which updates the map gets the new information and updated map. It is suggested that whenever a new target is asked for the algorithm is executed.

Communication between the robots is important for the success completion of map exploration is given time. During the target selection process, wireless constraints are to be taken into consideration. Recomputation of the frontiers at every 3-4 meters can be done to improve the accuracy of the algorithm as suggested by *A. Visser and B. A. Slamet." Including communication success in the estimation of information gain for multi-robot exploration." In WiOpt-08, pages 680–687, 2008.*

One of the other ways that the frontier based algorithm can be increased is by finding ways to reach the frontier faster and to find the closest frontier more accurately. *Dirk Holz1, Nicola Basilico2, Francesco Amigoni2 and Sven Behnke1. "Evaluating the Efficiency of Frontier-Based Exploration Strategies."* talks about different ways to address this problem. A reachability map is created, and it is also stored with cost of reaching destination frontier. This strategy avoids looking at the cells which have been deemed as unreachable. Only the cells which give information are taken into consideration. Repetitive rechecking makes the robot explore an unknown region before reaching or detecting its frontier. Once this region is explored, the adjacent detected frontiers are ignored. This reduces the computation time significantly.

IV. Analysis of Results

The Frontier based exploration algorithm was tested with multiple Gazebo worlds. The Algorithms was able to map the environment to a considerable extent. There were times when the Algorithm created structures in the Map that did not exist. There was sometimes a mismatch with the relative size of the different objects present in the environment.
As the complexity of the Map increased, the time required to create the Map also increased. One of the drawbacks of the Algorithms was that: If the frontiers were far apart in the map, the robot had to spend a lot of time moving inside the known map.

One of the other problem that was found while mapping was that: some time robot navigated into wall, blocking itself from any frontiers. In this situation, the mapping stops without exploring all the frontiers.
But Overall, Maps created by the algorithm were fairly identical to the original map of the environment. The exploration process stopped when there were no frontiers to explore.

V. Discussion

By working on this project, I learnt to work with Gazebo Simulator, Rviz, Turltebot. I learnt to build Gazebo worlds using Gazebo Editor. I learnt the concept of frontier based exploration.
If I were to redesign the Algorithm, I would find way to decrease the amount time that is required by the robot to map the world. I would like to improve the process of selecting the next frontier to move to, so that robot does not waste lot of time moving inside the known world.

VI. Partnership

I worked on Occupancy Grid Mapping part of the project. I worked on dividing the grid cells into occupied cells, unoccupied cells, frontier cells and unexplored cells. I worked on finding biggest frontier cluster and calculating the centroid of that cluster to which the robot should next.
My partner worked on the Navigation of the robot. She worked on the A* Search Algorithm which is used in the Navigation.

VII. Conclusion

Frontier based Exploration answered the two questions relating to Mapping an Environment:

- Where to move next to continue mapping
- Exhaustive Mapping: Mapping is only stopped until there are no other frontiers to be explored.

Frontier based Exploration produced maps resembling the original map. There were deficiencies in algorithms. The Algorithms took a lot of time when the maps were more complex. This problem should be solved by improving the frontier cluster selection step.

There are various variations being made to the traditional frontier based exploration algorithm to improve the accuracy of the map being built. The two main aspects of this approach can further be analyzed individually or in combination, especially to address complex maps. A more sophisticated strategy can be implemented to detect the nearest frontier. Re visiting the same frontier or frontiers at an insignificant distance can be avoided. The ability of the robot to perform obstacle avoidance will allow it to improve its efficiency in a dynamic world making it more real-world ready. Incorporation of this approach and making changes to other parts of the frontier based exploration can contribute to making it one of the most sophisticated exploration approaches. Despite the issues that still must be addressed, we concluded that frontier based exploration, although a simple strategy is an efficient one.

VIII. Acknowledgements

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