Autonomous 3D map generation of indoor environments

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***Abstract*— The 3D map of a region are important for better planning and navigation in the closed environment. In order to reduce human efforts of manual exploration in the given area research is going on in the field to design self exploration algorithms for robot navigation for 3D map generation of closed room. The most commonly used algorithm is Frontier based exploration. Modifications to this algorithm are made to improve the performance of self exploration as well as quality of map generated.**

I. INTRODUCTION

In recent years, various unmanned mobile robots have been used in many production plants. Usual unmanned mobile robots move on the path on the floor, e. g., the magnetic guideline, thus the transportation points are fixed.Smart factories need robots that are flexible with environment. To achieve this the robust perceiving of the environment is needed. For the perception, appropriate sensors are needed, whereas for the interpretation,a representation model has to be found on which further processing can be based. For many navigation and localization algorithms [5], the processing of any interaction is based on an appropriate map representation. Building its own map representation is essential for an autonomous behavior of a robot. An autonomous indoor carrying robot requires a kind of map as knowledge of the work space in order to efficiently execute the navigation task. An environmental map composed of position information such as obstacles is required.At present, SLAM (Simultaneous Localization and Mapping) [1] is widely used as an environmental map generation method. Conventional map generation method is, however, based on premise that a human operates a robot. Such mapping which requires human experts is a burdensome task. Also the operator needs to have knowledge of SLAM and expertise in the domain. Autonomous robots must possess the ability to explore their environments, build representations of those environments, and then use those representations to navigate effectively in those environments.

We propose the project for autonomous 3D map generation my mobile robot in an unknown environment. The goal is to design an algorithm for autonomous exploration of the environment while creating 3D map without getting into any obstacle. Section II gives reachable as well as stretched goals for the project while section III explains about the methodology to achieve goals. [3]

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II. GOALS

To achieve the task of autonomous mapping of indoor environment, intermediate goals were set in the following way:

- Manual 3D map generation in simulation using RTAB Map and Octomap for Turtlebot Model
- navigation and obstacle avoidance of Turtlebot in simulation
- Coming up with an algorithm for autonomous exploration in an unknown environment
- Implementation of autonomous map generation in simulation

III. LITERATURE REVIEW

Many researches have been made exploration strategies for robot in unknown environment. These strategies seem to be performing well, but they have some assumptions made that needs to be satisfied by environment. Most of these stategies for map building are based on manual exploration of the region [7] [8]. Matrick [9] has developed an algorithm which explores the area by following simple topological planner that follows the walls and avoids the obstacles. Another algorithm requires the walls to be intersecting at right angles only while there must be no obstacle beween the robots point of view and the wall [6].Yamauchi for the first time described the frontier based algorithm in 1997 [10]. This algorithm is based on the idea to get maximum information possible by visiting the boundary of known and unknown regions. This keeps expanding the boundary on known region till the complete area is explored. This algorithm when used with good mapping strategies and obstacle avoidance gives satisfactory results for self exploration of the environment. The algorithm identifies the the frontier points, known points at the boundary of known and unknown region, selects the most suitable way-point from the available frontier points for further exploration. Based on the method of selection of this next way point and mapping techniques various versions of frontier based exploration are developed [11]- [15]. The prominent ones are Wavefront Frontier Detector (WFD) and Fast Frontier Detection [17].

Along with navigation way-point selection the mapping technique plays a important role in 3D map creation. Currently Simultaneous Localization and Mapping (SLAM) technique is most commonly used for mapping [19] [20].Ros generated application RTAB- MAP (Real-Time Appearance-Based Mapping) [22] gives a very satisfactory results 3D point cloud [2] [3]. For obstacle avoidance ros navigation planner creates trajectory to given point and moves base without hitting the obstacles in the path [21].

IV. Methodology

This section discusses about the way of map generation and exploration in order:

A. Setting up simulation environment

The simulation environment[Fig 1] chosen depicts an outside world scene scene with objects like dumpster, book shelf etc. We have chosen the environment in such a way that it poses significant challenges in designing exploration algorithm.

Fig. 1. Environmnet

B. Manual map generation

The manual map is being generated using Real Time Appearance Based Mapping (RTAB) [3], a RGB-D SLAM approach based on a global loop closure detector with real-time constraints. This ROS package can be used to generate a 3D point clouds of the environment and/or to create a 2D occupancy grid map for navigation.RTAB Map, a graph-based SLAM approach is driven by practical requirements such as online processing, robust and low-drift odometry, robust localization, practical map generation and exploitation and multi-session mapping.

Fig. 2 shows the map manually created using RTAB-Map. The turtlebot robot in the simulation environment were given velocities as input manually. Using visual odometry, map gets appended at each significant robot motion. The map becomes effective because of loop closure technique [22] and it also creates 2D occupancy grid to help in path planning and navigation.

C. Navigation and Obstacle avoidance

The Navigation stack should be robust for mobile robots to move from place to place reliably. The job of navigation stack is to produce a safe path for the robot to execute,by processing data from odometry, sensors and environment map. The onboarded kinect sensor data is used to create fake laser-scan data which inturn is used to create occupancy grids. Occupancy grids consists of three representations for free cells, occupied cells and cells with obstacles. Path planner uses the occupancy grid to create a collision free path. Motion planning is done for the path generated using an action server using move base in ROS.

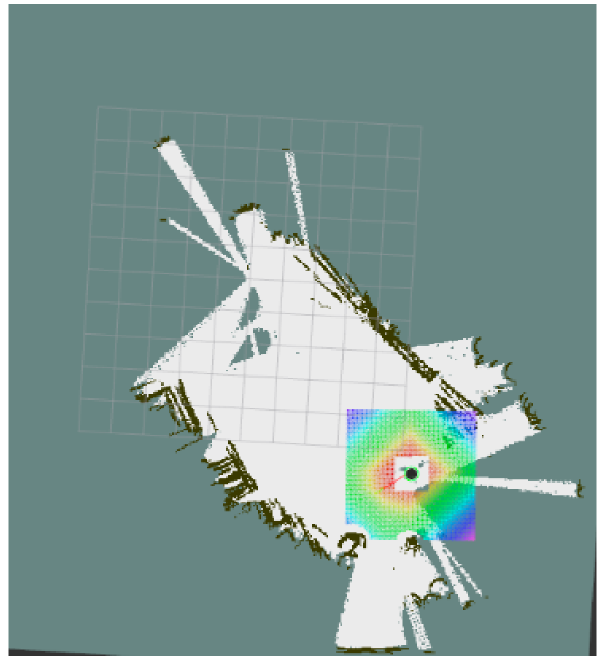

Fig. 2. Occupancy grid for the environment

D. Frontier based exploration

Exploration of an unknown environment is a crucial problem of Autonomous mobile robots which involves exploring unknown environment, creating a map of it and localizing it in the environment. Conventionally, human maps the environment in advance and that map is used by the robot for further navigation and updating of the map. In the autonomous exploration approach, the robot has to start mapping the unknown environment from starting. The central question is given the current knowledge about the world, where should we move to get the much new information as possible. This can be solved by the concept of Frontier based exploration. Frontiers are the regions on the boundary between unexplored and explored space. To explore the unknown environment the robot must move towards the frontiers and explore the new frontiers of the unknown environment. By repeating this process the known map expands by pushing the boundary between the known and the unknown. When there are no new frontiers left left to explore the exploration is considered complete. There are many techniques based on frontiers such as Wavefront Frontier Detector, Fast Frontier Detector which reduces the time complexity of the original frontier based exploration technique. The algorithm of frontier based exploration [18] is based on two Breadth-First Searches. It scans the entire grid at every iteration/cycle and detects the frontier points.

1) Evidence grid: - These are Cartesian grids containing cells, and each cell stores the probability that the corresponding region in space is occupied. Initially all of the cells are set to the prior probability of occupancy, which is the rough estimate of the overall probability that any given location will be occupied. Each time the kinect sensor reading is obtained the evidence grid is updated. Any open cell adjacent to an unknown cell is labeled as frontier edge cell. Adjacent frontier cells are grouped into frontier regions. Any frontier region bigger than a certain minimum size is considered as frontier.

2) Frontier Detection: - Frontier edge segments is a boundary between the open space and the unknown space is labelled as frontier edge cell/segment. Adjacent frontier edge segments are known as Frontier Regions. After the evidence grid is constructed each cell is classified by comparing its occupancy probability to the initial (prior) probability assigned to all the cells.

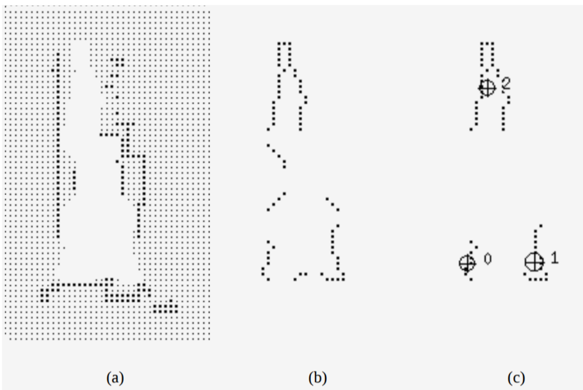

Fig. 3. (a)Evidence grid, (b) Frontier edge segments, (c) Frontier regions

- open : occupancy probability $<$prior probability
- unknown : occupancy probability = prior probability
- occupied : occupancy probability $>$prior probability

The figure is taken from the [10] (Fig. 5)a shows an evidence grid and (Fig. 5)b shows the frontier edge segments detected in the grid. (Fig. 5) shows the regions that are larger than the minimum frontier size. The centroid of each region is marked by crosshairs. Frontier 0 and Frontier 1 corresponds to open doorways, while forntier 2 is the unexplored hallway.

Navigating to Frontiers - Once all the frontiers at a given point are detected within a particular evidence grid, the robot decides to navigate to the nearest accessible, unvisited frontier. That frontier grid cell is given as a goal position and robots position as start position to the movebase node of ROS Navigation stack which further passes to navfn function then this function is responsible to plan a path. This function uses Dijsktra algorithm to plan a path. This node also has the reactive obstacle avoidance intelligence. The planned path is obstacle free and smooth curves are generated. When robot reaches to its destination, that location is added to the list of previously visited frontiers. The robot performs a 360 degree rotation and uses the kinect sensor values to add the new information to the evidence grid. And then further updates its goal to the nearest accessible unvisited frontier. If the robot is unable to make progress toward its destination then after a certain amount of time, the robot will determine that the destination is unaccessible and then its location is added to the list of inaccessible frontiers. The robot will then rotate 360 again and collect the sensor data to create a new list of frontiers. And repeat the cycle of selecting new goal and reaching the goal frontier to search the unknown map further.

V. Experiments and Results

The Robot is successfully able to generate the 3D map and 2D occupancy grid. It efficiently identifies the frontier cells and clusters them into groups. The centroid of the cluster which is closest to the robot is selected as next way point. The successful demonstration of robot motion planning and exploration can be seen in Figure Frontier exploratoin

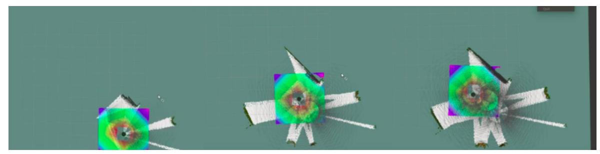

Fig. 4. Exploration Map at (a)time=10 secs (b) time=30 secs (c)time=60 secs

However when the environment is cluttered with many obstacles, as in our map, the self exploration takes a lot of time to explore complete region. The main reason for this is it keeps revisiting visited nodes to reach out to new frontiers. Sometimes the algorithm might get stuck between few positions of clustering. This can be seen as a infinite loop created due to cluttered environment when robot is not able to enter new region. At such instances we can manually move robot out of the cluttered environment and start the exploration again. The final mapping of the area after 1 hour of self exploration is seen the figure below.

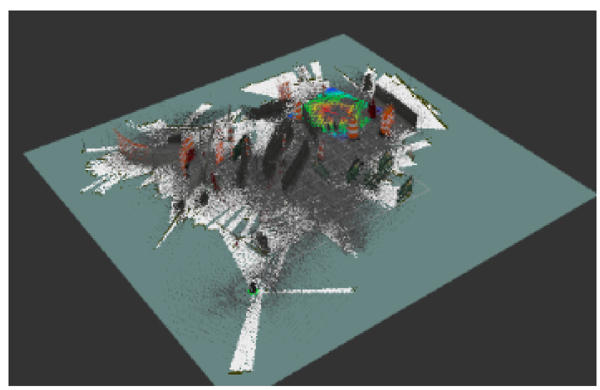

Fig. 5. Final map generated after self exploration

VI. Future Work

1) Improving the consistency in map generation.
2) Implementation on actual hardware
3) Performance comparison and identification of metrics to evaluate efficiency of frontier based algorithm
4) Improvements to algorithm for faster and better exploration

VII. Conclusion

Useing RTAB mapping gives satisfactory 3D mapping for the turtle bot. Frontier based exploration is great method towards autonomous mapping by robot in an unknown region. It identifies the frontiers at each step, cluster them into groups, find the centroid of frontiers and select closest centroid as next way point. Gradually it covers complete region. However, it's combination with other algorithms such as BFS shall give better results.

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