A Survey on Frontier based Strategies for Multi Robot Exploration

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ABSTRACT :Nowadays robots become terribly powerful components in industry due to its capability to perform many alternative tasks and operations exactly in short time with high accuracy; growing complexity of multi operations in manufacturing leading to use of multi robot system to do the tasks quicker than a single robot. Multi- Robot system is used in the applications where the time is crucial and lot of coordination activities is to be done in short time and it is difficult to achieve by human beings with high accuracy. Examples of such systems include assembly operations in an automotive industry, surveillance, ordinance disposal, firefighting, relief operations after disaster and agricultural applications. Hence the paper focuses on exploration task of multi robot system; the multi robot systems are capable of searching best path and optimizing itself to achieve minimum time to explore such environment. Exploration task involves localization, path planning, map building and map merging techniques. Many strategies will be used to cover the areas within a minimal time, the paper present different strategies used in such exploration by multi robots.

Keywords: Multi robot system, Localization, Exploration, Path planning, Navigation.

1. INTRODUCTION

The fundamental and challenging task in mobile robot system is the exploration of an unknown environment. There are many strategies to explore the areas within the minimal time. Some of the global situations that involve exploration algorithms are oceanic exploration, homeland security, surveillance, planetary exploration, rescue operations etc. During exploration, robot should take a move to get information about unknown areas and for representation of unknown area. The most commonly used solution proposed by Yamauchi [1] is Frontier based exploration. The frontier is nothing but the boundary between the unexplored and explored region. During exploration robot moves to the frontier and creates a map based on the information gathered and extends the same procedure to new frontiers.

The exploration terminates, when all the frontiers in the area are explored. The most common challenges during the exploration process are map-building, navigation, localization, inter- robot communication etc. Multi robot exploration has many advantages over single robot exploration.

- Potentially takes a shorter amount of time.
- Avoids having single point of error.

1.1 Frontier-Based Exploration

The frontier is nothing but the boundary between the unexplored and explored region. During exploration robot moves to the frontier and creates a map based on the information gathered through sensor and extends the same procedure to new frontiers. The robot incrementally gains the knowledge of the surroundings. It is different for different environment and also depending on single or multi robot navigation adopted; in multi robot navigation map merging techniques and nodes sharing are used to arrive at optimal solutions.Before stepping to the frontier based exploration details used for a multi robot environment it essential to understand some of the concepts and techniques involved in the field autonomous coverage with suitable case study in this paper forklifts transferring material to common goal point is considered as mobile robots and Navigation, Map building, Localization and Path planning are discussed below.

1.1.1 Navigation

In mobile robots, navigation is the most significant block, where the robot senses the surrounding environment and plans the path to reach the goal by avoiding obstacles. Once the frontier is detected, robot starts moving towards the goal employing one of the best path planning algorithms. In a dynamic environment with multi robot operation for example autonomous forklifts used in industrial material handling for common location point, it is necessary to avoid collisions with other systems moving which can be done only when distance and speeds of other are clearly defined by the sensor information obtained. These behaviours allow the forklifts used to steer around these dynamic obstacles and return to follow its path to the destination as long as the world has not changed too drastically otherwise change the path to reach the goal.To successfully perform navigation robot has to do map building, localization and path planning operations efficiently which are explained in detail.

1.1.2 Map Building: In multi robot system, each robot may be equipped with different types of sensors namely laser sensor, sonar sensors, infrared sensors and vision cameras.Map of the environment is created from sensor information and it is essential to understand various types of information which are coming from different sensors through different robot and fusion of information to provide necessary data for map building, to enable each robot to build their own map and interact with each other for mutual sharing of information about target location and other necessary data. Each robot maintains the knowledge of the environment in its own global map. Whenever the robot recognizes the new frontier, it creates the local map of the current surrounding environment using sensor information. The robot updates local map information in its own global map and broadcast the same to all other robots. Every other robot in the team updates received information in their global map. It is essential to use ROS or other standard Operating systems to consider all the errors and implement Frontier-based exploration.

1.1.3 Localization: Localization is nothing but the problem of estimating orientation and location of the robot in a given map. Based on type of information available, Localization can be further categorized into Local and Global localization. If the initial pose of the robot is known before the exploration, it becomes a local localization problem. The initial position and orientation of the robot is not known then it is referred to as global localization. Localization is one of the important parameter to achieve effective navigation, hence it has grabbed the attention of researchers and as a result, vital advances have been done to reduce errors in GPS errors, sensor noise and illumination dependency.

1.1.4 Path Planning: Based on the pose and knowledge of the environment, Robot should perform path planning task to travel from current position towards goal.

1.2 Traditional Coverage Approaches

Early coverage approaches available for autonomous mobile are Heuristic approach and random approach. They are simple but failed to deliver a provable guarantee of whole coverage. To achieve complete coverage cellular decomposition technique is used.

1.3. Coverage Strategies

Frontier based coverage is one of popular among the various available strategies. Frontier is nothing but the edge between the explored region and unexplored region. Various frontier based methods are discussed in section II.

2. EXISTING FRONTIER BASED APPROACHES

2.1 Nearest Based Allocation

This method is introduced for single robot by Yamauchi[1] in 1997, later it was extended to multiple robots in1998. Nearest Based allocation is most popular and commonly used frontier exploration strategy. In this method, each robot senses the surrounding environment and broadcasts that information with the other; all other robots with same frontiers list construct a similar representation of the environment. This process continuous until no frontiers is left. The decision of each robot about next target is independent and no communication is required for coordination among the robots. This approach is robust, distributed and asynchronous, but takes more time for exploration

2.2 Greedy Based Allocation

Greedy based [2] approach tries to allocate the nearest unassigned frontiers for robot and optimizes the total cost of exploration. This approach requires the coordination among the robots but it might result in multiple robots moving towards the same region.

2.3 Rank Based Allocation

Based on the position and distance of each robot towards frontier, robots are allotted for exploration in Rank based allocation [7], where each robot calculates rank and the robots are assigned with a frontier which is in best pose towards them.

2.4 Goal seeking algorithm

This algorithm aims at reaching the goal with minimum number of moves. The robot finds the route to reach the goal in an environment, where only the goal region location information is available.

After reaching the goal, the mobile robot changes its mode to exploration to detect the goal. Initially the probability (Pox) of 0.5 is set to all the cells. The free cells are denoted with 0.5 Pox and occupied cells Pox as 1. Basic Goal Seeking (BGS) algorithm and Modified Goal Seeking (MGS) algorithm are used to en route the robot towards goal region,

Goal seeking index and cost function metrics are used by BGS algorithm to select the best frontier cell. The cost function to every frontier cell is determined by considering probability of occupancy. The frontier cell with minimum cost path is selected. Goal seeking index is determined in such a way that robot takes a minimum number of moves to reach the goal region. It is computed by considering the cost between the frontier cell and the goal region.

MGS algorithm is the variant of BGS algorithm, where frontier cells selection is done efficiently. MGS algorithm considers a Trap Situation, where no frontier cells are found nearby. To make the robot to move out from trap situation, BGS algorithm proposes four different strategies.

2.5 Circle partitioning based exploration

In circle partitioning method, the unknown is divided into subareas equal to number of available robots. This method is proposed to share the workload and to reduce the exploration time. Two steps are involved in this method: area partitioning and subarea coverage. To partition the area, circle partition method is used, where centre of the circle is considered as centre of circle. To achieve good coverage, robots will move towards frontier cells using EA* algorithm, creates the map of surrounding and continues with same procedure until no frontier cells are left.

2.6 Multi robot exploration using pruning frontiers

The problem with multi robot exploration is assignment of sub regions to robots and distribution of robots in the environment. The proposed algorithm uses K means clustering [22] algorithm to segment the area into sub regions and Hungarian method to assign robots to every single sub regions for exploration. An improvement to exploration strategy is suggested by pruning the frontier cells that reduce the computation time.

2.7 MinPos: Frontier allocation algorithm for exploration

This algorithm provides an efficient and decentralized way for maintaining the well balanced spatial distribution of robots. Every single robot calculates its relative rank, which depends on the distance of robot to frontiers. The robots are allocated with frontier having least rank, where the rank is computed using wave front propagation algorithm (WPA). This algorithm is implemented in four steps: (i) frontier identification and clustering, where every single robot will keep frontier cell list. (ii) Distance to frontiers is calculated using wave front propagation algorithm (iii) frontiers are assigned to robots based on position rather than on distance. (iv) Robots navigate towards the assigned frontiers using WPA.

2.8 Exploration using Fast frontier detection

Frontier based exploration algorithm uses the whole map information for exploration, which will increase the memory size requirement and exploration time. Fast frontier detection involves two algorithms: Wave Front Detector (WFD) technique which is based on breadth first search (BFS) method and Fast Frontier Detector (FFD) technique, which does not need the whole map information for exploration.

The Wave Front Detector algorithm processes the area which is already been scanned by the robot and hence scanning of whole region is not required again. BFS algorithm scans only the known cells by queuing them in the data structure. Since this algorithm scans only the known region, the exploration time can be reduced significantly. The Fast Frontier Detector processes only the laser range finder data which are collected in real time and eliminates the search in known and unknown environment.

In addition to the above discussed exploration algorithms, there are different exploration approaches for multi-robot systems, which are being discussed briefly in Table 1 taking time to explore the environment, energy consumption during exploration and coverage as key parameters. The performance of the exploration process also depends on the type of the robots used and the type of coordination architecture among the multiple robots .In centralized [10] architecture, one robot acts a master, which communicates with other robots in the team to share the global data. Here the master collects the information about the environment from other robots and generates a global map. The performance of centralized architecture is good for a smaller number of robots and runs faster compared to decentralized architecture. But it becomes inefficient for a large number of robots due to loss of data, higher communication overhead and produces highly vulnerable the system if the master malfunctions.

Decentralized architecture [11] is characterized by the absence of a master robot; all robots in the team are completely independent in decision making and perform well for larger number of robots. Each robot in the team creates the map individually, shares the map and completes the map building when they meet each other.

Table 1: Work carried out by other researchers

Author	Exploration Strategies	Performance Parameters	Technique	Year
B. Yamauchi [17]	Each robot in the team broadcasts the information obtained during exploration to another team member; all the other members build a similar representation of the world with the same list of frontiers.	Time, Energy	Nearest unvisited frontier cell	1998
W. Burgard, M. Moors, D. Fox, R. Simmons, and S. Thrun[18]	Prevent Robots from selecting the same target location. Hence the robots will not explore the area which is already been explored by some other robot.	Reducing redundant coverage, Consider both cost and utility	Nearest unvisited frontier cell	2000
Vazquez And Malcolm[8]	Based on the local information, robots will explore the area with limited communication range	Calculate Time to explore the environment	Decentralized	2004
ShengandZlot [9]	Robots are selected for exploration based on the bid value. Bids value is assigned by travel cost and information gain	Calculate Total distance travelled	Centralized	2006
Rooker and Brik[10]	Robots maintain communication with each other and master robot. Master robot collects the position of entire robots and build future map	Calculate Time take to explore the environment	Centralized	2007
Doniec [11]	Robots have to collaborate to locate on the environment. Robots coordination constraints have distributed constraint satisfaction Problems	Calculate Exploration time and number of exchanged messages	Decentralized	2009
Metin Ozkan, Ahmet Yazici, Muzaffer Kapanoglu, Osman Parlaktuna[15]	Task completion time is minimized by Genetic algorithm for multi-robot sensor based coverage.	Minimize traverse distance, Exploration time minimized	Back Tracking Spiral Algorithm (BSA)	2009
Roy and Dudek[12]	Robots meet at rendezvous point for exchange the information	Calculate percentage of environment explored per time step	Hybrid	2010
Yiheng Wang and Alei Liang[16]	By use of Particle Swarm Optimization Map exploration Through Frontier based Multi-Robot	Minimization of walking Time	Grid based technique	2011
Pal[13]	Other Robots follow the leader robot instruction maintain connectivity	Use of LFIP path length and Energy consumption	Centralized	2012
Pal[14]	Searching and visiting of interested location in environment	A Energy consumption, Path length, and exploration time	Hybrid	2012
A. Bautin, O. Simonin, and F. Charpillet[19]	Each robot calculates its relative rank among the other robots in term of travel distance to each frontier. Accordingly, robots are allocated to the frontier for which it has the lowest rank	Reducing redundant Coverage	Relative ranking based approach	2012

3. CONCLUSION

The most frequently used technique for space exploration problem is frontier based region exploration. This algorithm processes the whole map data and if the region is large, the robot will take more time for exploration. Recently many techniques are proposed to make the exploration of area faster. BGS and MGS algorithms perform best, if only a goal region is known and not the goal. Better work load sharing and faster area exploration can be achieved using circle partitioning algorithm and pruning algorithm. MinPos algorithm is decentralized and computationally efficient which maintains well balanced spatial distribution of robots. Fast frontier detection based technique process only the data from the laser range finder which are perceived in real time and no need to process the whole representation of the environment. Many authors proposed different approaches to improve the exploration efficiency and reduce exploration time. Many authors proposed exploration approaches for multi robot system which are discussed in Table 1. Centralized approach works well for small team size and runs faster compared to decentralized approach, but it becomes inefficient for large team size due to higher communication overhead. In Decentralized approach, all robots in the team are completely independent in decision making and perform well for larger number of robots. Based on the application requirement, one should decide whether to use centralized or decentralized architecture for Multi robot exploration.

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