Multi Robot Area Exploration Using Circle Partitioning Method
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Abstract
Exploration of an unknown area is an important topic in multi robot system. Due to its various applications it gains the concern of various researchers. In this paper an approach that is based on circle partitioning method for workload sharing is proposed. Unknown area is partitioned into sub regions equal to the number of available robots, each robot is assigned to different sub region and then the team of mobile robots starts exploration. The aim is to decrease the exploration time. A popular concept for the exploration problem i.e. based on the notion of frontiers has been used. The proposed algorithm has been tested in a set of environments with different level of complexity depending on number of obstacles. This can be used in real world for search and rescue operations where time is a major constraint.

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Keywords— Area exploration, Dispersion, Frontier, Circle partitioning method

1. INTRODUCTION

Due to the various advantages over humans, robots are used for performing complex tasks like inspection of hazardous areas, reconnaissance and surveillance, planetary exploration [1], search and rescue [2], environment monitoring and planetary operations and cleaning [3]. In order to provide efficient multirobot exploration proper coordination and cooperation is needed. Many approaches like line of sight and leader-follower [4], Frontier and utility, market principal, graph theoretic has been proposed for multi robot area exploration.

By using the multi robotics system it is relatively easy to achieve speed, accuracy, reliability and fault tolerance. In multi robotics system many issues arise that affect the overall performance of the system like coordination, cooperation, redundancy coverage, collision avoidance, communication among the robots. In this paper an approach is proposed for multi robot area exploration of an unknown environment i.e. based on the circle partitioning method.

The rest of the paper is organized as following: Section II describes the related work. Section III describes the problem formulation. Section IV presents methodology for Area exploration. Section V presents the simulation result using java applets. To conclude the paper, Section VI outlines the research conclusions and future work.

2. RELATED WORK

Yamauchi, B. (1997) [5] proposed simplest exploration method i.e. based on the concept of frontiers, boundary between open space and unexplored space. The approach considers only a single robot. In 1998 B. Yamauchi (1998) [6] extends pre-
-vious approach to multirobot area exploration.

In [7] an approach based on the bidding for choosing the frontiers have been proposed. In [8] a new, totally distributed bidding algorithm is developed, which maximizes the net gain - a weighted combination of the information gain, the travelling distance and the nearness measure. It overcomes the problem of information inconsistency caused by communication delay. In [9] a behaviour-based architecture is designed to guide the robots in a decentralized fashion in order to explore the environment and maintain local short-range communication in a mobile ad-hoc network. In [10] an approach to minimize the overall exploration time and making it possible to localize fire sources in an efficient way was proposed. In [11] a frontier-based algorithm i.e. based on a new bidding function is proposed a special parameter to decrease the overlap between the robots is introduced in addition to the utility and cost parameters. In [12] distributed frontier-based map exploration algorithm using Particle Swarm Optimization model for robot coordination is proposed.

In [13] a coordination algorithm that requires the k-mean algorithm to divide the unknown space into as many regions as available robots was proposed. In [14], Voronoi-based partitioning algorithm was used to divide the unknown space. In [15] a spatially distributed algorithm is proposed that allow a team of agents to compute a convex and equitable partition of a convex environment.

In [16] an approach based on the genetic algorithm for path-planning was proposed algorithm for local obstacle avoidance (local feasible path) of a mobile robot in a given search space. The algorithm tries to find a valid as well as an optimal path. In [17] an approach based on parallel differential evolution algorithms was provided for the co-operative multi-robot path planning problem. In [18] an approach using Genetic, ANN and A* algorithms was proposed that finds the nearly most optimal path of the robot. In [19] an approach based on MNHS for Robot Path Planning was proposed to make the problem robust against the uncertainties that might arise like the sudden discovery that the path being followed does not lead to the goal. In [20] algorithm for optimal path planning that chooses the shortest route with minimum energy consumption was proposed. In [21] focused wave front expansion algorithm based on wave expansion approach for path planning of robots was proposed that focuses on expansion of some waves instead trying to expand the entire waves. This avoids full wave expansion.

K-means uses an iterative computation technique to calculate the centroids at different stages thus involving computational complexity as well as requiring lot of time whereas the circle partitioning method mentioned in the paper reduces the computational time to a great extent thus making this method more favorable in situations where time is an important factor.

3. PROBLEM FORMULATION

This section describes the nature of the problem and assumption that has been made. Our goal is to explore the environment with the team of mobile robots. Stationary obstacles of different shape and size are placed in the environment. It is assumed that each robot has the localization and mapping capability means each robot is able to localize itself. Environment is a finite workspace and shape and size of the workspace is predetermined. The environment is modelled as a 2D occupancy grid. During the exploration each cell will have one of the following states:

- Unknown: Occupancy of cell is not known yet
- Free: Cell is not occupied by any obstacle
- Occupied: Cell is occupied by an obstacle

The main task is having the cells of the map being traversed by the robots at least once. Robot is taken in square form its dimension is set as size of grid cell. Robot uses its sensing range to find out the status of the cell.

4. METHODOLOGY

Our proposed approach basically deals with the environment partitioning to complete the exploration as early as possible. First area is divided into logical subareas using circle partitioning method then robots are assigned to these logical subareas and they start the exploration within their logical subareas. To explore the area robots need to move towards the frontier cells. EA* algorithm is used for path planning [22].

4.1 Environment partitioning

Environment to be explored is partitioned, so as to divide the whole area in the logical subareas. Because of division higher degree of dispersion is achieved among robots. An approach for environment partitioning is used i.e. based on the
method of circle division. Taking centre of the area as centre of the circle we form a circle that covers the whole area and then divide this circle into number of parts as available robots. With the help of circle division the area is divided in approximately equal parts. Robots are assigned to each subarea randomly.

4.2 Subarea Coverage

To provide efficient subarea coverage robots should keep moving to frontier cells and recording terrain of the neighbour cells until no frontier cells left in the same subarea. The cell currently occupied by the robot is marked as free cell, which means it has been covered. Within the surrounding unexplored cells, the cells occupied by obstacles are marked as wall cell and cells that are not occupied by obstacles are marked as frontier cells. In order to explore the complete subarea robot move towards frontier cells based on EA* Algorithm [22]. The exploration state is ended when there is no frontier cell left in the local subarea.

5. EXPERIMENT RESULTS

The algorithm is tested using Java. Input of the map is given in the form of image. The proposed algorithm has been tested with a set of environments shown in Fig.1 with different level of complexity depending on number of obstacles. Experiment was conducted with equal velocities for all robots.

![Fig. I. Simulation Environments (a) Map-1 with less obstacles (b) Map-2 with complex environment with more obstacles](image)

The parameters used in experiment are shown in table 1.

| Parameters                  | Value                      |
|-----------------------------|----------------------------|
| Map Size                    | 100*100                    |
| Robot Sensor Range          | 8 cell units               |
| Team Size                   | 4 robot                    |
| Robots initial Location     | Randomly selected          |

We have compared results of our algorithm with k-means algorithm. Fig II (a)-(b) and shows the map coverage using circle partitioning and k-mean for map-1 respectively.
Fig III (a)-(b) and shows the map coverage using circle partitioning and k-mean for map-2 respectively.

![Fig III. (a) Map Coverage by circle portioning for Map-1. (b) Map coverage by k-mean for Map-2](https://via.placeholder.com/150)

| Maps   | Circle Partitioning | K Mean |
|--------|----------------------|--------|
| Map-1  | 6 min                | 8 min  |
| Map-2  | 9 min                | 10 min |

From the results, it is observed that exploration using circle partitioning requires less time as compared to k-means algorithm.

6. Conclusions

We have presented a novel approach for multirobot area exploration; our main concern is to explore the environment as early as possible. An approach i.e. based on the circle partitioning method for environment partitioning is presented in order to maximize the robot dispersion in the team of mobile robot. The proposed algorithm have been tested with a set of environments with different level of complexity depending on number of obstacles, simulation and experimental results of the proposed exploration method illustrate that using circle partitioning method team of mobile robots required short period of time to complete the exploration. This is mainly due to the reason circle partitioning method does not required to calculate the distance of all point from the centroids.

The work can be extended for the real world environment. We shall deal with different shapes of environment and consider the limited communication range.

REFERENCES

[1] D. Apostolopoulos et al., “Robotic antarctic meteorite search: outcomes,” in Proc. IEEE Int. Conf. Robot. Autom. (ICRA), pp. 4174-4179, 2001.

[2] J. L. Baxter, E. K. Burke, J. M. Garibaldi and M. Norman, “Multi-Robot Search and Rescue: A Potential Field Based Approach”, IEEE International Conference on Robotics and Automation, Volume 2, Issue, pp 1217-1222, 2002.

[3] Rtdf I. Wagner and A. Bruckstein, “Cooperative cleaners: a study in ant robotics,” Tech. Rep. 9512, CIS Report, Technion, IIT Haifa, June1995.

[4] Yintao Wang, “A leader-follower formation control strategy for AUVs based on line-of-sight guidance”, Mechatrons And Automation, ICMA 2009, pp. 4863-4867.

[5] B. Yamauchi, “A frontier-based approach for autonomous exploration,” International Symposium on Computational Intelligence in Robotics and Automation, pp. 146-151, 1997.

[6] B. Yamauchi, “Frontier-based exploration using multiple robots,” Second International Conference on Autonomous Agents, pp. 47-53, 1998.

[7] R. Simmons, D. Apfelbaum, W. Burgard, D. Fox, M. Moors and S. Thrun, and H. Younes, “Coordination for multi-robot exploration and mapping”, in Proceedings of the AAAI National Conference on Artificial Intelligence (AAAI),”2000.

[8] Weihua Shenga, Qingyan Yangb, Jindong Tanc and Ning Xid “Distributed multi-robot coordination in area exploration,” Journal of Robotics and Autonomous Systems, Vol.54, Issue 12, 2006R, pp. 945-955

[9] J. Vazquez and C. Malcolm, “Distributed multirobot exploration maintaining a mobile network,” International Conference on Intelligent Systems, Vol.3, pp. 113 - 118, 2004.

[10] Marjovi, A., Nunes, J.G., Marques, L.,de Almeida, A.,” Multi-Robot Exploration and Fire Searching,” Intelligent Robots and Systems, pp. 1929 – 1934,2009.
[11] Al-Khawaldah, S. Livatino and D. Lee, “Frontier based exploration with two Cooperative Mobile Robots,” International Journal of Circuit, Systems and Signal Processing, Vol. 4, Issue 2, 2010.

[12] Yiheng Wang, Alei Liang and Haibing Guan,” Frontier-based Multi-Robot Map Exploration Using Particle Swarm Optimization,” IEEE Symposium on Swarm Intelligence (SIS), pp. 1 – 6, 2011.

[13] Agusti Solanas and Miguel Angel Garcia,” Coordinated Multi-Robot Exploration Through Unsupervised Clustering of Unknown Space,” International Conference on Intelligent Robots and Systems, Vol.1, pp. 717 - 721, 2004.

[14] Ling Wu, Miguel Angel Garcia, Domenec Puig and Albert Sole,” Voronoi-Based Space Partitioning for Coordinated Multi-Robot Exploration”, Journal of Physical Agents, Vol.1, No. 1, Sept. 2007. ISSN 1888-0258, pp.37-44.

[15] Marco Pavone, Alessandro Arsie, Emilio Frazzoli, Francesco Bullo,” Distributed Algorithms for Environment Partitioning in Mobile Robotic Networks”, IEEE Transactions On Automatic Control, Vol. 56, Issue 8.pp. 1834 – 1848, 2011.

[16] K.H. Sedighi, K. Ashenayi, T.W. Manikas, R.L. Wainwright and H. Tai, “Autonomous Local Path Planning for a Mobile Robot Using a Genetic Algorithm,” International Conference on Robotics and Automation, Vol.2, pp. 1338 - 1345, 2004.

[17] Jayasree chakraborty, Amit Konar, L.C Jain and Uday K. Chakraborty, “A Distributed Cooperative Multi-Robot Path Planning Using Differential Evolution,” Journal of Intelligent & Fuzzy Systems ,pp. 718 – 725, 2008.

[18] Kala Rahul:”Mobile Robot Navigation Control in Moving Obstacle Environment using Genetic Algorithm, Artificial Neural Networks and A* Algorithm,” IEEE World Congress on Computer Science and Information Engineering, pp. 705–713, 2009.

[19] Kala Rahul, Shukla Anupam, Tiwari Rita”Fusion of probabilistic A* algorithm and fuzzy inference system for robotic path planning,” Artificial Intelligence Review Vol.33, pp. 275–306, 2010.

[20] Anshika Pal, Ritu Tiwari, and Anupam Shukla,” Multi Robot Exploration using a Modified A* Algorithm,” Third International Conference on Intelligent Information and Database Systems, Vol. 1, pp. 506–516, 2011.

[21] Anshika Pal, Ritu Tiwari, and Anupam Shukla,” A Focused Wave Front Algorithm for Mobile Robot Path Planning,” International Conference on Hybrid Artificial Intelligent Systems, Vol. 1, pp. 190–197, 2011.

[22] Anshika Pal, Ritu Tiwari, and Anupam Shukla,” Multi Robot Exploration using a Modified A* Algorithm,” Third International Conference on Intelligent Information and Database Systems, Vol. 1, pp. 506–516, 2011.