University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

New Algorithm For Multi-Robot Path Planning In Known Environment

Wessam Adel Dakhil — *Computer Centre*, *University of Thiqar*, *wessam1444@utq.edu.iq*

Ahmed Muqdad Alnasrallah — *Dep. Of Studies & Planning*, *University of Thiqar*, *ahmed@utq.edu.iq*

Hanan Ali Alrikabi — *Marshes Research Centre*, *University of Thiqar*, *hanan@utq.edu.iq*

https://doi.org/10.32792/utq/utj/vol15/1/5

Abstract

In this paper, solved a robot path planning problem in known environment using anew algorithm called the Fuzzy Probalistic Road Map Star PRM* algorithm. In this algorithm, we have modeled the workplace including obstacles As fuzzy. Here, we develop PRM algorithm, so that it can run in a fuzzy environment.We assign a weight for each obstacle (fuzzy number) which represents the obstaclemeasures, meaning that whenever this weight is larger, the obstacle becomes more impassable (or more dangerous). This algorithm has been designed for using by robot's movement in difficult areas (such as areas full with obstacles in which the robot requiresto crossover these obstacles to reach its goal). By compare the FPRM* withnormal PRM we found that modeling the environment as fuzzy helps to improve the path.

Key words: PRM, Path Planning, Multi-robot, known environment, Fuzzy set.

1. Introduction

Path planning is generating a path for a robot from an initial position (start) to a final position (goal) [1]. In most routing algorithms to achieve the goal in a way the robot turns around Obstacles. However, in some cases, robot is required to cross over the obstacle, (for example using rescue robots to assist the injured have to cross the barriers) [13], [14]. We decided to design an algorithm that contain minimal cost while maintaining robot performance (The robot to reach the goal cross over the obstacles that have less degree of difficulty).

Motion Planning has three large families: the potential fields, cell decomposition and sampling-based algorithm. Since cell decomposition relies heavily on the accuracy forming cells as well as potential functions trapped in a local minimum, and these methods are ineffective in high dimensions [3]. So, we will apply the idea of Probabilistic Roadmap algorithm (PRM)of sampling-based methods [2] to solve the problem of path planning. PRM can help with responding to multiple inquiries in an environment.This method is called multiple query.Another set of algorithms to solve problems exist in state Single Query where the goal is only to solve the problem in the shortest time possible and regardless of the details of previous queries. It is possible to use the second method in the case of the dynamic environment in which change over time. Including methods that fall in the category Single query can be noted to EST [4], RRT and RRT * [5]. PRM method the first time in [2] was introduced. This method works in two stages: in the first stage which is called pre-processing or learning phase,road map in Q is created. In the second phase (phase inquiry) positions specified by the user as the primary (start) and end (destination) positions are added to the built road map. And ultimately the best route between the two points on the map is determined and given to the robot.This method can be used to solve problems with high dimensions as well as, the probability is completed [6]. There are many variations of the basic PRM algorithm have been published to improve the performance of the PRM in general, or in specific cases, such as Visibility PRM [7], Fuzzy PRM [8], Lazy PRM [9], Probabilistic Roadmap of Trees (PRT) [10], Probabilistic Cell Decomposition [11], flexible PRM [12], etc. They all rely on the same underlying concepts, and aim at improving specific aspects of PRM. In Fuzzy PRM, obstacles divided into two categories: impassable obstacles (Dangerzones) and obstacles that are difficult to pass (Desirezones) (These concepts are stated fully in [8] and [12]).And tries to stay away from impassable obstaclesbut use the edge for the obstacles of the second category as a path. In this algorithm for connecting two nodes to each other check that the two nodes in what condition or case, for example if one node overlaps with the dangerzones and another with a desire zone, the two nodes not connected to each other. The fuzzy PRM in [8] is introduced to handle manipulation planning for a system consisting of a single redundant robot arm in which each edge of the roadmap is annotated with a probability. Only obstacles are considered in [8] and so a probability associated with an edge only depends on the length of the edge. This algorithm relies heavily on spots checking.

2.Proposed system features

This algorithm is designed for multi-robot. Starting and goal points of the robot can be the same or different. Robots move with their maximum speed or stop to prevent the collision. Like the previous issue, obstacles in the environment are static and have different sizes and dimensions. Measurements of Obstacles are determined by fuzzy number. Whenever this number is larger, obstacle becomes more impassable (dangerous). Other features of the system are determined as follows:

1. The path determined for the robots by central controller that is aware of the environment.

2. Organizing system takes the form of a centralized system.

University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

3. Before starting the robot movement, the path will be determined completely for them.

4. Robots haven't sensors and they travel only the path that specified for them.

5. Path planning is as offline.

*3- Fuzzy PRM * Algorithm*

This algorithm is considered from multiple query Algorithms, it is therefore very suitable for static environments, and, if necessary, can be easily implemented the idea on single query algorithms (for dynamic environments).This algorithm is designed primarily for environments filled with obstacles. In other words, when the robot to reach the target does not have choice except Crossing over obstacles, Strategy approach offers with a fuzzy set.As described PRM algorithm is a two-step algorithm that in the first step, it makes the map and in the second step, find a path. For a case that we have several queries this algorithm done quickly. In this paper, we have changed this algorithm based on the needs. Changes are in two basic parts, construction of the map and find the path.

1.3 Construction of the map

Like the first PRM algorithm we choose a certain number of nodes with uniform distribution. And each node by edge connected to a certain number of other nodes. Our algorithm difference in fuzzy model with classic PRM is that in the case of non-fuzzy the nodes and edges should not be in collision with the obstacles (fig. 2). But in the fuzzy model nodes can be over the obstacle and the edges can cut the obstacle (fig. 1). For this reason, is needless to local planner, and map can be quickly made. There are three important factors in making map, first, the number of nodes, second the number of neighbors of a node (edge) and third minimum distance between nodes. As the number of nodes and edges increases, the time of program increase and by reducing them the path become away from the optimum. There is no precise formula for calculating the three factors and these factors are calculated empirically.

University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

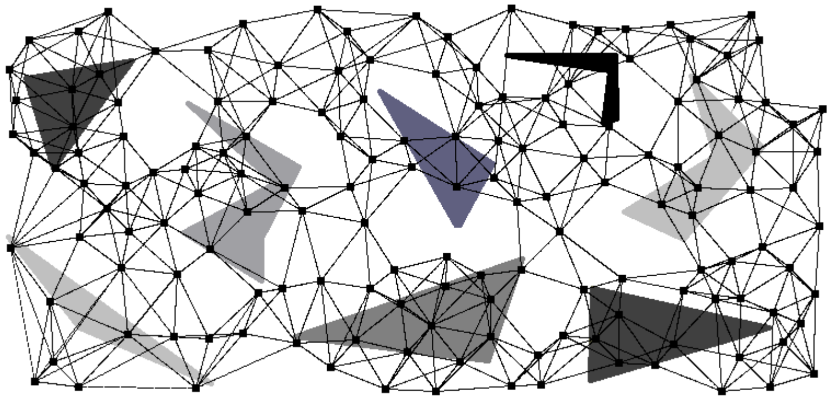


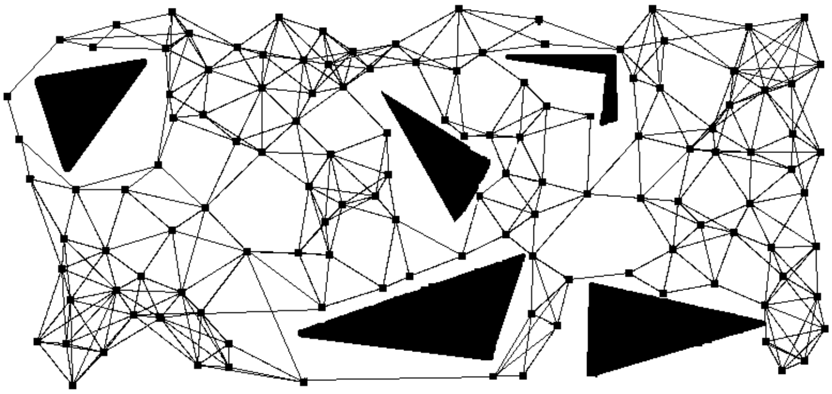
Fig.1: Map in case of fuzzy

Fig.2: Map in case of non- fuzzy

2.3 Find a path in fuzzy model

In the past works used the A* algorithm to find the path. In this algorithm, nodes of map divided into three groups: *expanded, in the case of expansion* and *not met*. *Expanded* nodes are intermediate nodes of the search tree A*. *In the case of expansion* nodes are the leaves of the search tree A*. Always cost path counted from the start node to tree leaves A *. Then with a function, the cost was expected to reach the goal. This function is usually direct distance of node to the target. Leave that had lowest cost path expands. The cost of the path includes expected cost in addition to the cost of getting from the starting point to the leave.

In the algorithm that used in this paper we change the A* algorithm depending on



need. In non-fuzzy model, the cost of passing through each edge is the edge length. But in fuzzy because there is probability to cross over the obstacle must calculate the cost of crossing it. So, in the first step for each obstacle a weighting between zero and one (According to the degree of the obstacle difficulty and the robot strength) is calculated by using the following cost formula:

$$Woi = p\left({}^{h}/_{Q}\right)$$

Where Woi represents the weight of each obstacle, p is a constant coefficient, h is the degree of obstacle difficulty and finally Q represents the amount of robot's strength to cross over an obstacle.

Then, in the second step calculate the cost of each edge to find the optimal path. Thecost of each edge is calculated using the following cost formula:

$$W_j = c(W_{qj} + kW_{oi})$$

Where W_j is the final weight of the edge jth, and W_{qj} is the Weight of the edge j without crossing over the obstacle (euclidean distance of both nodes), K is a constant number, W_{oi} is the obstacle ith if the edge is collided with the obstacle or that the end point of the edge is located in the obstacle ith, the weight of the obstacle is also considered in the equation. Otherwise W_{oi} will be zero.

Finding the optimal path in a greedy way

If r is a path from the starting point (s) to the target point (G) on the map obtained from the previous step, we call R = {r1, r2, r3, ...} the valid path set from points S to G if all paths between these two points are available on the map above (Formula 3 displays the way of calculating each path). Finally, the optimal route is the least cost route, the optimal route can be obtained using Formula 4.

$$r_i = \sum_{j=S}^{G} W_j$$

$$f(q) = \min(r)$$

3.3Robot collision avoidance in multi-robot system

In this case, several robots in several separate locations move toward separate goals. First, motion planning for the first robot is done. First robot is moving obstacle for the second robot. Then the second robot motion planning is done. The first and second robots are moving obstacles for the third robot. If there was a chance encounter (collision) when crossing the road, the robot pauses until the other robot passes. Then it passes.

4. Experiment results

To evaluate the performance of the Fuzzy PRM* method, two different environmentsare considered. The process of doing the tests is as follows: which is considered a constant (non-moving) environment, and two algorithms PRM and Fuzzy PRM* has been executed in 20 different timesby randomly selecting starting and target points, and they were compared for speed in reaching the goal once in the presence of one robot and once in several robots, then the results are recorded. The first test environment is a sample of structured environments. The purpose of this test examines the behavior of algorithms in regular environments. The purpose of the second experiment is to investigate the performance of algorithms in an unstructured and complex environment.

1.4 A comparison between Fuzzy PRM* and PRM algorithm for single-robot system

Samples of test and analysis of fuzzy PRM* and PRM algorithm of single robot system in both environments are shown from figure (3) to figure (6). Where Non-fuzzy modeling of the environment increases the cost of the route for two reasons. Firstly, the obstacles whose fuzzy number are low (e.g. 0.1, or 0.2) are considered a normal space in non-fuzzy model. Although passing over them harms the robot, its cost is considered zero. Secondly, obstacles whose fuzzy number is relatively high are considered impassable. In some cases, non-fuzzy algorithm increases the path length to not to let the robot cross this kind of obstacles.

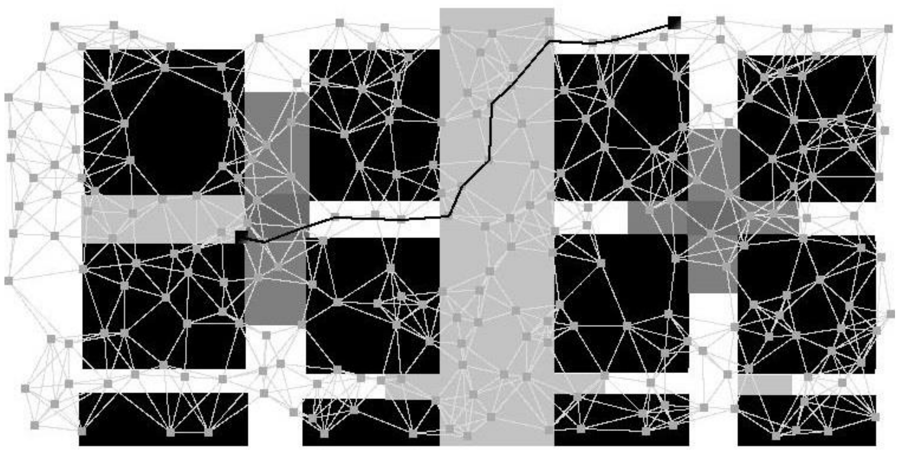


Fig.3: Fuzzy PRM* algorithm in the structured environment

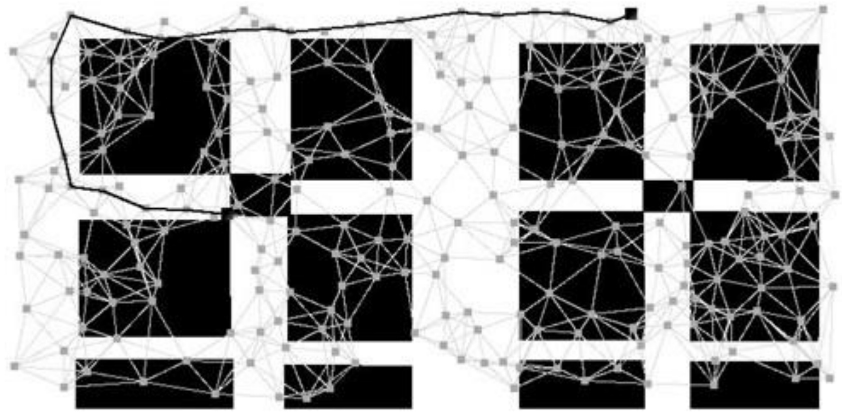


Fig.4: PRM algorithm in the structured environment

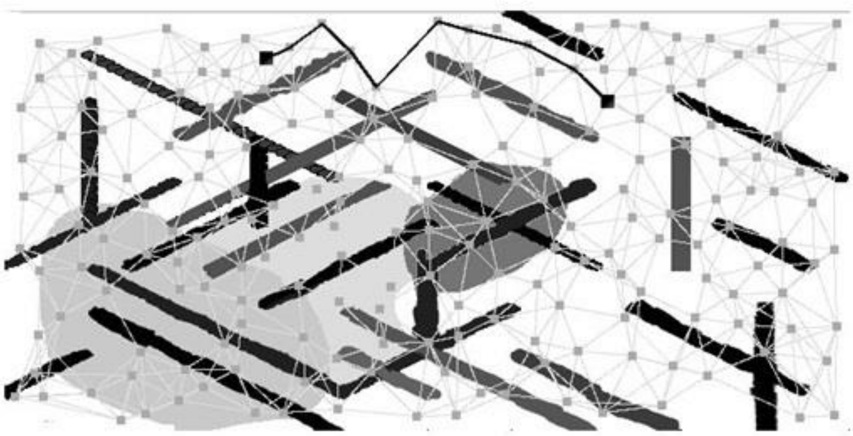


Fig.5: Fuzzy PRM* algorithm in the unstructured environment

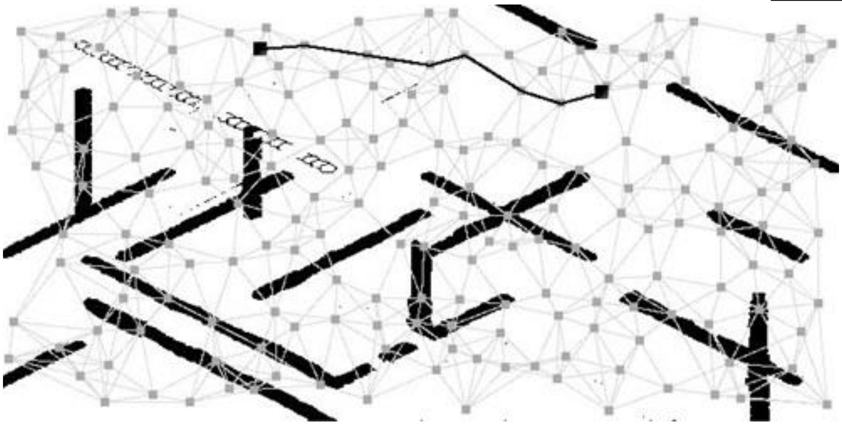


Fig.6: PRM algorithm in the unstructured environment

In Fuzzy model, the path length more than in non-fuzzy model fig. (5, 6). However, non-fuzzy model many times over obstacles passes and increases the cost of the route by damage to the robot. Here the question arises why we have taken a high threshold of the obstacle? Our reason. The environment in fig. (5) is modeling a city after the earthquake and access to all parts of the city is important. If the fuzzy threshold being lower and more spaces are considered as obstacle, a part of the city cannot be achieved. Tests were carried out in both environments and 20 tests in each of them. After selecting a starting point and a goal point randomly, every test which includes 2 sub-tests (one with fuzzy PRM* algorithm and the other with PRM algorithm) is done.

University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

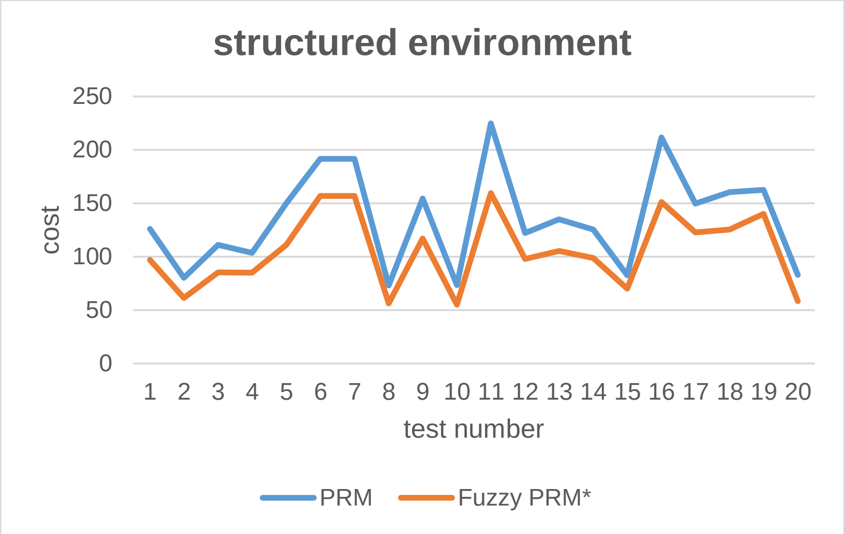


Fig.7: Histogram shows the costs of the path in PRM and FuzzyPRM* algorithms for single-robot system in the structured environment

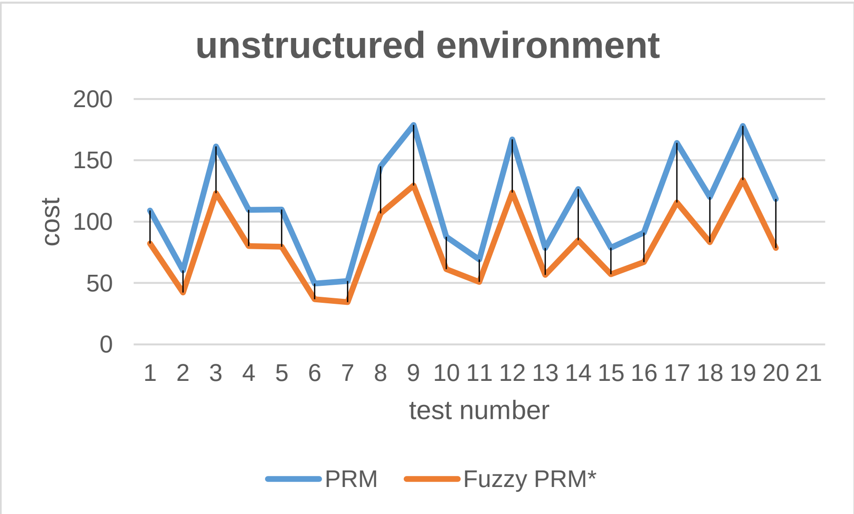


Fig.8: Histogram shows the costs of the path in PRM and FuzzyPRM* algorithms for single-robot system in the unstructured environment

As it can be seen, Fuzzy PRM* algorithm has made 28% and 39% improvement in costs of the paths in the both environments.

2.4 A comparison between Fuzzy PRM* and PRM algorithm for Multi-robot system

Fuzzy PRM* algorithm is an algorithm for multiple query. In this paper, The Fuzzy PRM* algorithm is used when the environment as well as the starting and the target points are known. That is why we do not need to search in the space environment. Thus, we also do not expect that the cost of the route from the starting point to the target point reduces because of the increased number of robots. Like the previous series, tests were carried out in both environments and 20 tests in each of them. Each test includes 2 sub-tests itself (one done with fuzzy PRM* algorithm and the other with PRM algorithm). We consider 5 distinct target points and 5 distinct start points.

We plan for the first robot. The first robot is a moving obstacle for the second robot. To prevent collisions, the second robot pauses in case of collision risk to let the first robot move. Then we plan the move for the third robot. This time, we consider the first and the second robots as moving obstacles.

University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

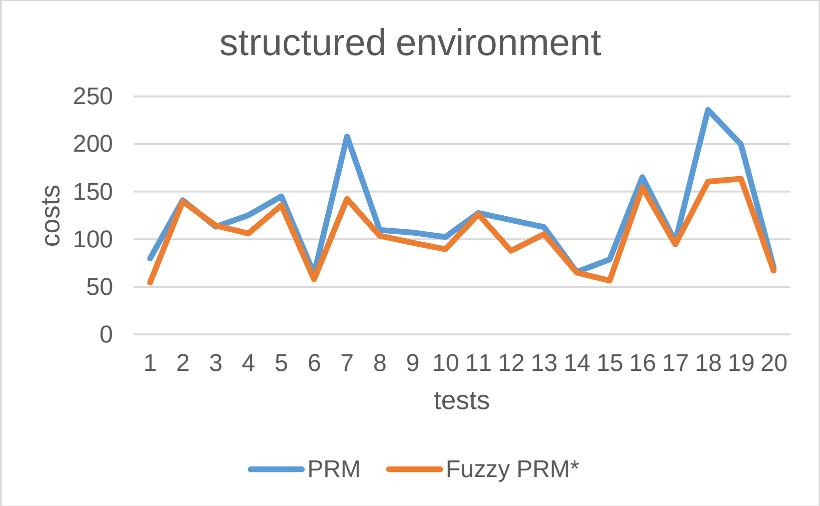


Fig.9: Histogram shows the costs of the path in PRM and FuzzyPRM* algorithms for Multi-robot system in the structured environment

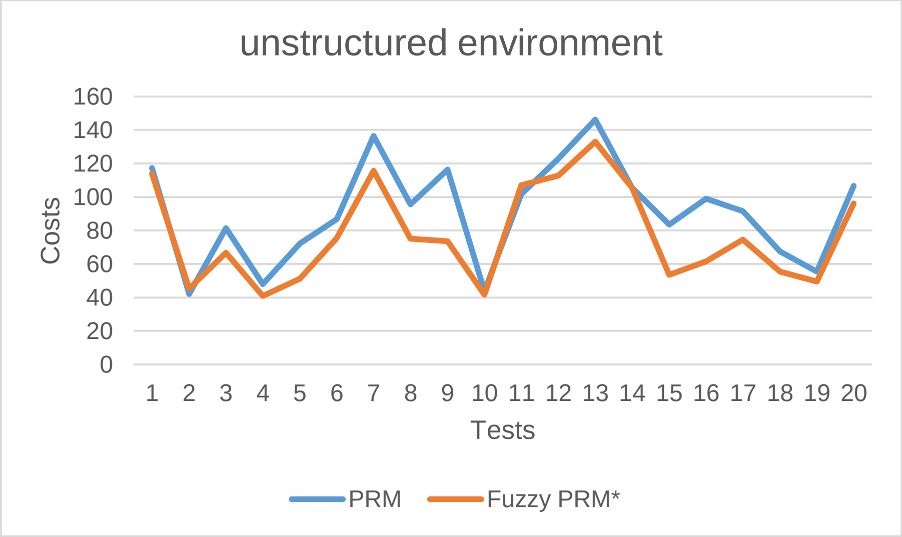


Fig.10: Histogram shows the costs of the path in PRM and FuzzyPRM* algorithms for Multi-robot system in the unstructured environment

University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

When the environment and goal location is known, it means that our knowledge is complete, and increasing the number of robots will not cause reaching the goal faster. The only difference between a single-robot and a multi-robot system in Fuzzy PRM * is that sometimes to avoid collision, robot is forced to stop or slow down the movement which increases the cost of time. Five robots participated in the test environment. Improvement due to fuzzy perspective is 23% and 30% in the both environments.

1.4 Time spent and memory consumed in the processor of Fuzzy PRM* algorithm

In this algorithm, motion planning is done as offline. The algorithm is applicable to several queries. It consists of two parts making map that has relatively high time cost and only can be run one time. Finding path by algorithm A* that in each query is done and has lower time cost. Simulations in this paper are done with MATLAB 2014, and on a computer with a single-core CPU Intel 1.2 GHz. Because of time consuming nature of the operation (I / O), when running do not perform any operations such as showing data or pictures of robots on the map. The data in the table below are the average of 20 tests each of which have been done in every condition. Connotation of time in the table refers to the time that CPU assigns to run the algorithm. This time is calculated with the help of two orders tic, toc in MATLAB. The number of objects made in PRM can be a symbol of memory consumption. These objects consist of map nodes, edges and search tree nodes in A*. In the table (1) below memory refers to the number of objects made. To build the map, 300 points were selected randomly, and each point is connected to the nearest neighbor with at least 6 edges. However, according to the conditions a point can have more than 6 neighbors. In the case of multi-robot, in the table, the query time is considered only for one robot, and the cost of time was neglected for the first four robots. The first four robots are moving obstacles to the robot 5th.

Table1: the average of time and memory in the search tree and roadmap

Memory in search tree	Time of query path	Memory of map construction	Time of map construction	No. of robots	Type of model	Environment
38	0.44	1365	9.08	1	FuzzyPRM*	Environment 1
43	0.48	1294	9.14	5	FuzzyPRM*	Environment 1
48	0.32	1281	11.75	1	PRM	Environment 1

36	0.31	1302	11.27	5	PRM	Environment 1
112	1.29	1293	8.67	1	FuzzyPRM*	Environment 2
132	1.43	1247	9.14	5	FuzzyPRM*	Environment 2
138	1.01	1278	11.76	1	PRM	Environment 2
125	1.16	1316	11.75	5	PRM	Environment 2

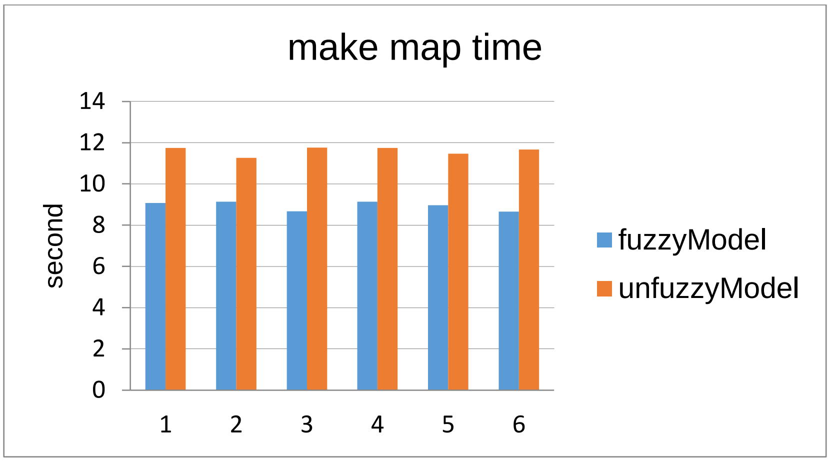


Figure 11: Chart of map construction time in fuzzy PRM* and PRM algorithm

In Fuzzy PRM*, due to time and memory consumption of the algorithm (Algorithm needs a lot of memory and time), these two factors are very important. As seen, in the fuzzy model the map construction is 33 % faster (Figure11). Because in fuzzy model edges pass over obstacles, and there is no need to check (local planer) whether the edge has collision with the obstacle. As we know, the map construction is random and not dependent on environment, so no significant difference in terms of time in the environment when making a map is observed. On the contrary, when making the search tree A* in non-fuzzy environment, the operation is done quickly. In the non-fuzzy, only the edge length is a sign of cost edge, and calculations are done quickly. But in fuzzy model we must calculate the cost of passing the obstacle which slows down the fuzzy model. As you can see, the fuzzy model is 38% slower than non-fuzzy model in making the search tree (figure 12).

University of Thi-Qar Journal

ISSN (print): 2706- 6908, ISSN (online): 2706-6894

Vol.15 No.1 Mar 2020

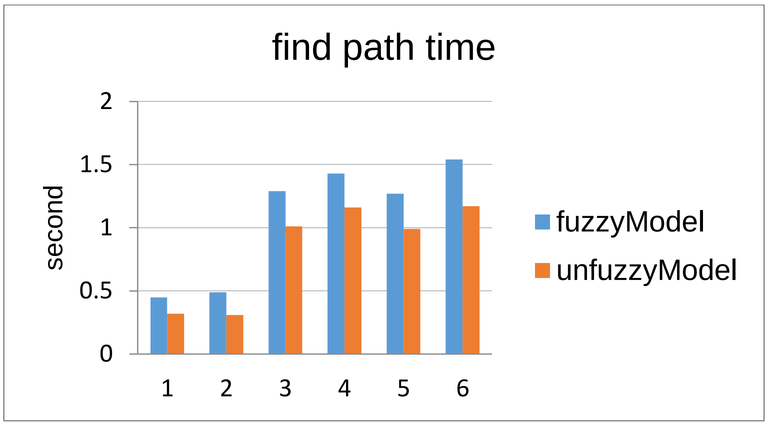


Figure12: Chart of find path time in fuzzy and non-fuzzy models of fuzzy PRM* algorithm

5 .Conclusion

In this paper, we introduced a new method for the PRM algorithm, called Fuzzy PRM* algorithm, which is designed to be used in obstructed areas (for places where the robot does not have a way to reach the goal except for crossing the obstacles). In this method, fuzzy obstacles are considered, and on that basis, the robot decides which obstacle to pass.The algorithm was tested in two environments. In both environments,experiments show that the Fuzzy PRM* algorithm, in comparison With the PRM method,improves path and reduces costs.

References

[1] J.H. Reif. Complexity of the mover's problem and generalizations. In Proc. IEEE Symp. On Foundations of Computer Science, pages 421–427, 1979.

[2] Kavraki, L.E., Svestka, P., Latombe, J-C., Overmars, M.H.; "Probabilistic roadmaps for path planning in high-dimensional configuration spaces", Robotics and Automation, Vol.12 Issue: 4, p.p. 566-580, 1996.

[3] Z.Yan, N. Jouandeau, AA. Cherif , A survey and analysis of multi-robot coordination, International Journal of Advanced Robotic Systems, 2013.

[4] E. Johnson, T. D. Murphey, Dynamic deling and Motion Planning for Marionettes: Rigid Bodies Articulated by Massless Strings, IEEE International Conference on Robotics and Automation, 2007.

[5] O.Adiyatov, H.Atakan, Rapidly-Exploring Random Tree Based Memory Efficient Motion Planning, Department of Robotics and echatronics Nazarbayev University Astana, 2013

[6] L. E. Kavraki, Random Networks in Configuration Space for Fast Path Planning. PHD Thesis, Stanford University. 1995.

[7] T. Simeon, J. Laumond, and C. Nissoux. Visibility based probabilistic roadmaps for motion planning. Advanced Robotics Journal, 14(6), 2000.

[8] C. Nielsen and L. Kavraki. A two level fuzzy PRM for manipulation planning. In Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, pages 1716–1721, 2000.

[9] R. Bohlin and L. Kavraki. Path planning using Lazy PRM. In Proc. IEEE Int. Conf. on Robotics and Automation, pages 521–528, 2000.

[10] E. Plaku, K. Bekris, B. Chen, A. Ladd, and L. Kavraki. Sampling-based roadmap of trees for parallel motion planning. IEEE Transactions on Robotics, 21(4):597–608, 2005.

[11] F. Lingelbach. Path planning using probabilistic cell decomposition. In Proc. IEEE Int. Conf. on Robotics and Automation, pages 467–472, 2004.

[12] Z. M. Ma1, Froduald, Towards a Robot Path Planner for Dangerzones and Desirezones, 2002.

[13]Q. ZENG, W. ZHOU, G. ZHENG, "Advance of Hazardous Operation Robot and its Application in Special Equipment Accident Rescue", chapter in Mechanical Engineering and Control Systems book, 2016.

[14] J. Zhao, J. Gao, F. Zhao, Y. Liu *"A Search-and-Rescue Robot System for Remotely Sensing the Underground Coal Mine Environment",Sensors (Basel). 2017.*