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Intelligent Hybrid Approach for Multi Robots-Multi Objectives Motion Planning Optimization

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Abstract: This paper proposes enhanced approach to find multi objective optimization and obstacle avoidance of motion planning problem for multi mobile robots that have to move smoothly, safely with a shorter time and minimum distance along curvature-constrained motion planning in completely known dynamic environments. The research includes two stages: the first stage is to find an multi objective optimal path and trajectory planning for each robot individually using the Enhanced GA with modified A*. The second stage consists of designing a fuzzy logic to control the movement of the robots with collision free. The global optimal trajectory is fed to fuzzy motion controller which has ability to regenerate the local trajectory of the robot based on the probability of having another dynamic robot in the area. A simulation of the strategy has been presented and the results show that the proposed approach is able to achieve multi objective optimization of motion planning for multi mobile robot in dynamic environment efficiently. Also, it has the ability to find a solution when the environment is complex and the number of obstacles is increasing. The performance of the above mentioned approach has been found to be satisfactory of dynamic obstacle avoidance.

Keywords: Multi-Robot Motion Planning, Multi objective optimization, obstacle avoidance, Genetic Algorithm, A*search algorithm, Fuzzy contrl, dynamic environment.

Introduction

Motion planning is a primary task in robot operation, where the objective is to determine collision-free paths for a robot that works in an environment that contains some moving obstacles. A moving obstacle may be a rigid object such as another mobile robot or an industrial manipulator [1,2]. In a persistently changing and partially unpredictable environment, robot motion planning must be on line. The planner receives continuous flow of information about occurring events and generates new commands while previous planned motions are being executed. Off–line robot motion planning is a one shot computation prior to the execution of any motion, and requires all pertinent data to be available in advance. With an automatic motion planner and appropriate sensing devices, robots can adapt quickly to unexpected changes in the environment and be tolerant to modeling errors of the workspace. Clearly, both robotic manipulators and mobile robots (as well their combination, i.e. mobile manipulators) need proper motion planning algorithms called motion Control, which means the strategy by which the platform approaches the desired location, and the implementation of this strategy [1,2].

The multi objective optimization for multi robot motion planning in dynamic environment is considering one of the most important and interesting problem, where, the each robot has to create their optimal path and trajectory of motion from start position to target position with obstacles avoidance in the environment. For the multi mobile robots motion planning different methods have been proposed and studied by researchers [3-10]. Actually, these researches solved the motion planning and obstacles avoidance problem with complicated mathematical computations and planned optimal path are in single objective.

This paper addresses one such problem of multi-robot motion planning taking into consideration multi objective optimization of path and trajectory in the environment with obstacles. The main contribution of this paper is to study the performance of multi objective optimization and obstacles avoidance for multi robot motion planning by using proposed approach in [11-13]. Finally, we have verified the proposed and approach confirmed its effectiveness by conducting simulations with various scenarios of environment. The rest of this paper is arranged as follows. First, the problem formulation is described. Second, the definition of motion planning and principle of kinematics model of mobile robot are presented. Then, the proposed approach to solve multi objective optimization of motion planning and obstacle avoidance problem is provided. After that, computer simulation is given and finally, in this paper, we conclude and point out some possible research topics as the future work.

Problem Formulation

In this study the multi robots motion planning is considered as an obstacles avoidance and optimization problem simultaneously. Which means the multi objective function for each robot is concerning of minimizing traveling distance, minimizing traveling time, minimizing total angles of all vectorial path segments (minimum curvature and then, minimizing energy consumption of robots), maintaining the clearance requirements,(the robot is safer and farthest from obstacles) and avoiding the static and dynamic obstacles in environment . Finally, the robots must stay inside the grid boundaries of environments.

The research includes two important stages of fining optimal solution. The first step refers to generate the multi objectives optimal path and trajectory for each robot from its start and goal positions without hitting any obstacle. The second step deals with maximizing of the distance between mobiles robots and obstacles. These two steps are put together to build a multi objective optimization in single solution, which here has been optimized by proposed approach.

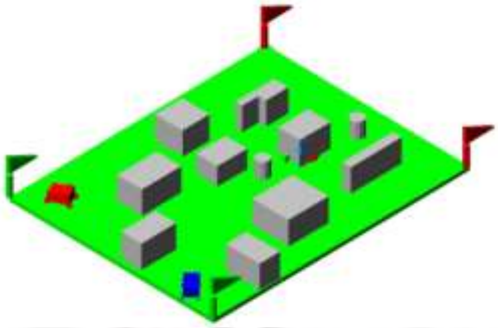


Fig.1: Problem description

As shown in Fig.1 it has assumed that the robot operates in 2D indoor environment and has the predefined map. The environment has static obstacles as well as dynamic obstacle (another robot). The Multi objective optimal path and trajectory generated by the proposed approach (GA+A*). In case there is new dynamic obstacle is coming near to the robot, the fuzzy motion controller will find the degree of the probability of the new obstacle. The probability relies on the weight of the distance between both of them (ground robot and the obstacle robot). Then, the controller will decide to accelerate the speed of our target robot when the probability of the distance gets higher. In addition, the controller for the obstacle object will decide to decrease its speed based also on this probability. In this way, we increase the safety navigation for both robot and they can reach the target position without collide each other.

Path and Trajectory Planning Problem

Path planning problem can be divided in two different ways: global path planning and local path planning. Hence, the global path planning depends on the a priori complete information about static (off-line Planning) [14, 15]. The advantage of global methods is in the fact that a complete path from the starting position to the target position can be obtained off-line. However, the disadvantages of global methods are not appropriate for dynamic obstacle avoidance, and their low speed due to the inherent complexity of robot motion planning. While local-path planning is based on the sensory information in dynamic environment (on-line Planning). Local-path planning methods have been focused on sensory information that comes from the robots external sensors. While, navigating the environment has been processed on-line in order to achieve mobile robot task successfully in complex environment without a priori information [15,16]. On other hand, trajectory planning is generating from a geometric path that takes the robot from the initial to its goal position and taking into consideration the time specified (an explicit function of time) and representing it in polynomial equations form such as cubic spline, quadratic, and quintic[17].

Fig. 2: Trajectory Generation

Mobile Robot Kinematics Model

The Kinematics model of mobile is shown in Fig. 3. The mobile robot has a differential drive system with two independent drive wheels which attached to its motors, and the third is castor wheel for stability. The motion of mobile robot has been assumed on horizontal plane with pure rolling and without slipping conditions. The non holonomic constraint can be written as [18, 19]:

$$\dot{x}\sin\theta - \dot{y}\cos\theta = 0 \qquad (1)$$

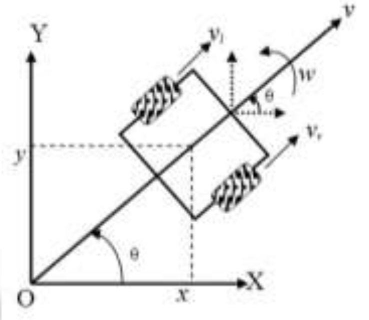


Fig. 3 : The Kinematics model of mobile

The Kinematics model of mobile can be represented by

$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\theta}\end{bmatrix} = \begin{bmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v\\ w\end{bmatrix} \qquad (2)$$

For the robot's movement, the linear velocity v and the angular velocity w are chosen and can be defined as

$$v = \frac{v_r - v_l}{l}, \quad w = \frac{v_r + v_l}{2} \qquad (3)$$

The linear velocities of left and right wheels are $v_l$and v_r of robot, respectively and can described by

$$v_r = rw_r \;, \; v_l = rw_l \qquad (4)$$

Where w_r and w_l are angular velocities of left and right wheels of robot respectively. Both wheels have same radius defined by r and distance between two wheels is l.

In this study the geometrical collision-free path assumed to be a sequence of points x, y and θ in three dimensions. The motion planner generates a geometrical path collisions free, but the motion controller needs the trajectory based time as the input. Hence, the trajectory generating is to impose a velocity profile to convert the path to a trajectory (Trajectory is a time-based profile of position and velocity from start to destination while paths are depend on non-time parameters). For the trajectory function parametric cubic spline function form has been used.

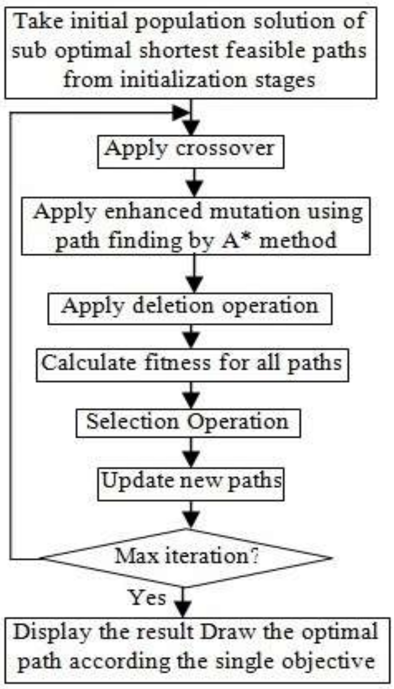
In addition to nonholnomic constraint, the boundary conditions including the position, velocity and acceleration constraints of robot, respectively. Velocity and acceleration constraints of mobile robot has to start its motion from initial position with certain acceleration to reach its maximum velocity and near the target position it has to decelerate for stopping at the goal position.

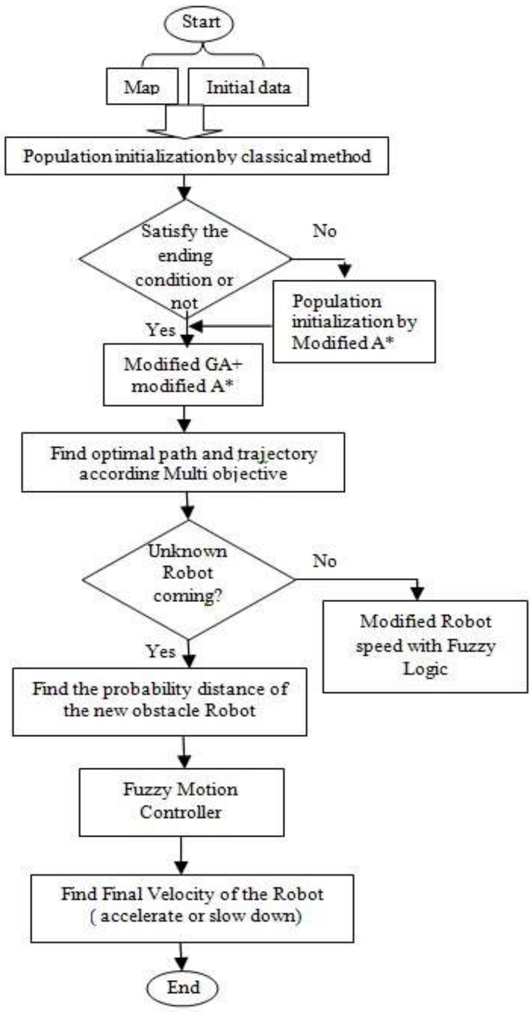
Velocity Planning

The mobile robot has to move among environment with existence of dynamic obstacles. We have to give the relative velocity of the robot and the moving obstacles (another robot) takes in mind that both will navigate without collision. Hence, for this purpose of research study the future trajectory for each robot is requiring. Then, the velocity planning for robots that are moving with uniform velocities can be done using the velocity robot concept. Also, the collision is avoided if and only if the robot velocity is chosen such that its velocity, relative to obstacles velocity, does not enter the corresponding collision cones [7]. In other word, the fuzzy motion controller will control the velocity of each robot based on the weight of the probability distance as it is described previously. The ground robot will move fast in case another robot comes to its path, whilst the obstacle robots controller will decrease the velocity giving enough time for the ground robot to move away to its target.

Proposed Approach

In this section, a description of proposed approach is presented and the general schema of the proposed approach can be defined in the following steps and flow charts in Fig. 4 and Fig. 5





Units Fig. 4: Enhanced GA with A* Fig. 5: The proposed approach

A. *Optimization by Enhanced GA with modified A**

The proposed approach based on performing modification of A* and GA is presented to enhance the searching ability of robot movement towards optimal solution state. In addition, the approach can find a multi objective optimal path and trajectory for mobile robot navigation as well as to use it in complex static environment. The classical method and modified A* search method in initialization stage for single objectives and multi objectives have been proposed to overcome GA drawbacks. Also, in order to avoid fall into a local minimum complex static environment we have proposed several genetic operators such as deletion operator and enhanced mutation operator by adding basic A* to improve the best path. The aim of this combination is to enhanced GA efficiency and path planning performance. Hence, several genetic operators are proposed based on domain-specific knowledge and characteristics of path planning to avoid falling into a local minimum in complex environment and to improve the optimal path partly such as deletion operator and enhanced mutation with basic A*. In addition, the proposed approach is received an initial population from a classical method or modified A*. For more details someone could see [11-13]. The general schema of the proposed approach to the problem can be defined in Fig. 4 and flowchart in Fig.5. First, some of definitions corresponding to the initialization stage are presented. Then, the environment model is described and some corresponding definitions are presented. We construct 2D static map (indoor area) with and without different numbers of obstacles. Also, a shortcut or decreased operator has been used to eliminate obstacles nodes from the map at the beginning of the algorithm. The next step is the initial population which is called generating and moving for sub optimal feasible paths. In this stage, the classical method and modified A* are used for generating a set of sub optimal feasible paths in a simple map and a complex map, respectively. Then, the paths obtained are used for establishing the initial population for the GA optimization. Here, the mobile robot moves in an indoor area and it can move in any of eight directions (forward, backward, right, left, right-up, right-down, left-up, and left-down). There are two methods in this step. Someone can use the classical method where the movement of the mobile robot is controlled by a transition rule function, which in turn depends on the Euclidean distance between two points and the roulette wheel method is used to select the next point and to avoid falling in a local minimum on the complex map. The robot moves through every feasible solution to find the optimal solution in favored tracks that have a relatively short distance between two points, where the location of the mobile robot and the quality of the solution are maintained such that the sub optimal solution can be obtained. When, the number of the obstacles is increasing, the classical method may face difficulties finding a solution or may not even find one. Also, the more via points are used, the more time consuming is the algorithm, as it depends mostly on the number of via points it will use on the path in the complex map. If the modified A* search algorithm is added in the initialization stage of GA proposed approach will find a solution in any case, even if there are many obstacles. The A* algorithm is the most effective free space searching algorithms in term of path length optimization (for a single objective). We propose a modified A* for searching for sub optimal feasible path regardless of length to establish the initial solution of GA in a complex map, by adding the probability function to the A* algorithm. We have modified the A* in order to avoid using the shortest path which could affect the path performance in terms of multi objective (length, security and smoothness) in the initial stage.

$$F(n) = Rand*(g(n)+h(n)). \qquad (5)$$

The last step is the modified GA optimization which uses the modified GA for optimizing the search for the sub optimal path that was generated in step above as initial population (chromosomes). Hence, the main stages in the modified GA are natural selection, standard crossover, proposed deletion operator , enhanced mutation with basic A* and sort operator to improve the algorithm’s efficiency in terms of path planning, because it is difficult to achieve convergence and generate optimized feasible paths only with operators in the standard GA. A chromosome represents the path and its length varies depending on the case at hand. This means that it consists of a set of genes (via-points) from the start position to the target position of the path. Since p(x0, y0) is always the starting point and p(xn,yn) is always the target point, the via-points of the path are p(x1,y1) and p(xi+1,yi+1), and all these points represent the genes of the chromosome as it is given as the following:

$$Path\ (P) = \{(x_0, y_0), (x_1, y_1), \ldots\ldots, (x_{i+1}, y_{i+1}), \ldots\ldots, (x_n, y_n)\} \qquad (6)$$

In each generation, all chromosomes will be evaluated by the fitness function F, which will be discussed later. Thus, a chromosome with minimum fitness has a considerably higher probability than others of selecting and reproducing by means of GA operators in the next generation. These steps are repeated until the maximum number of iterations is reached. We proposed enhanced mutation operator and deletion Operator. The enhanced mutation operator is enhanced by adding the traditional A* search method to mutation operator and is used to avoid falling into a local minimum, and to improve and decrease the distance of the partial path, between two random points included in the main path. Also, deletion operator is used to delete the repeated points (redundant) from path. For a specific point, the approach reversely checks if this is equal to others, and this is done for each point.

B. ***Fuzzy Motion Controller***

Fuzzy logic is a powerful problem-solving methodology with a myriad of applications in control and information processing. Fuzzy can provide a remarkably simple way to draw definite conclusions from vague information. In a sense, fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions for the issues. Fuzzy Logic has been gaining increasing acceptance during the past few years. There are over two thousand commercially available products using fuzzy logic, ranging from washing machines to high-speed trains. Nearly every application can potentially realize some of the benefits of fuzzy logic, such as performance, simplicity, lower cost, and productivity. In this work, in order to develop an approach to avoid collision for the wheeled mobile robot the fuzzy logic has been used. The fuzzy control has the ability to detect another robot in the environment based on the probability of existence robot in the grid cell.

It could reduce or increase the speed of the mobile robot depends on the case at hand. The forward speed values of the wheeled mobile robot are selected by fuzzy control. Then, these values help the robot to navigate safety without collision with another robot or obstacles. Actually, the time to collision, traveling time and safe distance between mobile robots are considering as criteria to estimate the danger that encountering mobile robots. The previous criterion is evaluated for every cell. Fig. 5 presents the flow chart of the proposed approach.

Application of Collision Avoidance

As it has been mentioned earlier, the mobile robot must detect obstacles in the environment and avoid collision with them [7]. In order to solve the obstacle avoidance issue, fuzzy control motion has been designed for the mobile robot. It depends on the probability of unknown robot which is the probability of existence a dynamic obstacle on the ground robot path. The fuzzy control has two inputs: velocity and probability of the dynamic robot (obstacle) and the output is the final speed for the mobile robot. In fuzzy reasoning, the most important fuzzy implication inference rule is the generalized modus ponens (GMP), which uses an IF-THEN rule that implicitly represents a fuzzy relation. The use of fuzzy rules is important when the causal link between domains is not known. Usually partial knowledge about the relation between these domains exists in the form of fuzzy rules. The fuzzy rules define the connection between input and output fuzzy (linguistic) variables. The rule consists of two parts: an antecedent and a consequence part. A typical rule, which describes this simple fact as:

IF ***velocity*** is ***A*** **AND** ***probability of unknown obstacle*** is ***B*** **THEN** ***Final velocity*** is ***C***

The membership functions for the proposed algorithms are shown in Fig 6, Fig 7, and Fig.8. According to Fig. 6, fuzzy membership functions for input velocity has 9 linguistic variables. These linguistic variables are (Z: Zero, VVL: very very low, VL: very low, Medium, H: High, VH: very high, VVH: very very high, Max: Maximum). The second input, the probability, has 3 linguistic variables (N: No, M: Medium, Y: Yes). For the output, there are 9 membership functions which have been used (Z: Zero, VVL: very very low, VL: very low, Medium, H: High, VH: very high, VVH: very very high, Max: Maximum).

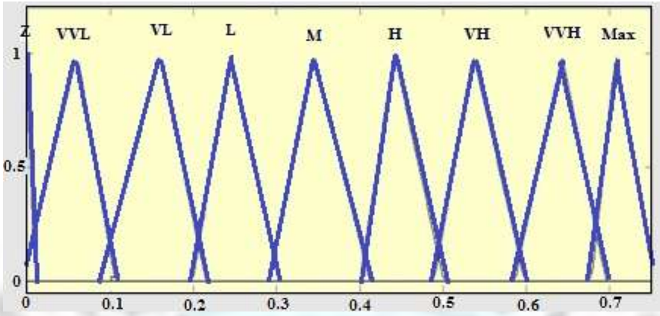


Fig 6. Membership functions for the input Velocity.

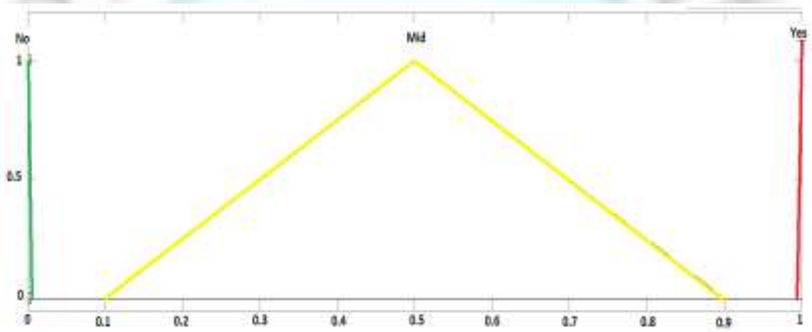


Fig.7 Membership functions for the input detect obstacle

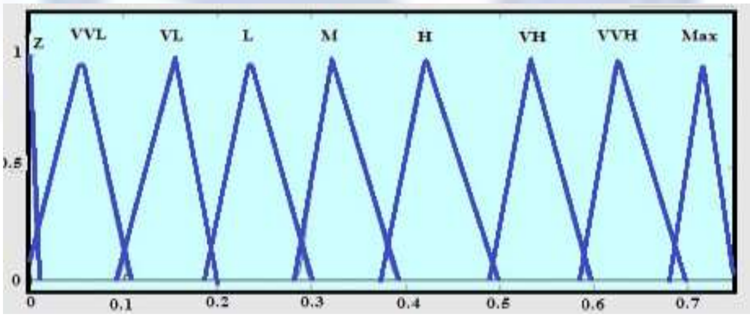


Fig.8 Membership functions for the output

These membership functions are the same for both mobile robot and the dynamic obstacle. The main difference between the two controllers is the Rule-Base for example:

In case of the mobile robot:

IF ***velocity*** is ***0.4*** **AND** ***probability of unknown obstacle*** is ***0.5*** **THEN** ***Final velocity*** is ***0.6***

In case of the dynamic obstacle:

IF ***velocity*** is ***0.4*** **AND** ***probability of unknown obstacle*** is ***0.5*** **THEN** ***Final velocity*** is ***0.3***

As it is shown in this example the rule-base for the mobile robot increases the velocity of the robot by 0.2m/s to be 0.6m/s, whilst for dynamic obstacle it decreases to 0.3m/s.

The most common defuzzification methods are including centroid and the weighted average methods. This step is an operation to produce a non-fuzzy control action. It transforms fuzzy sets into crisp value. Therefore, in this work, for the ultimate defuzzification the gravity method has been used as it is given by:

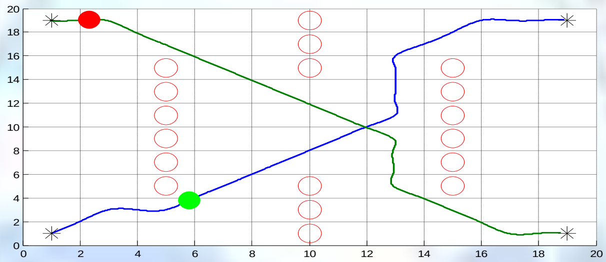
$$Z_a = \frac{\int \mu_c(z).zdz}{\int \mu_c(z)dz} \qquad (7)$$

where μc(z) is the degree of membership, z_a is the crisp value.

Simulation Results

In order to verify the effectiveness of the proposed hybrid approach presented above. We used it in simple and complicated 2D environments with different numbers of obstacles, each map has two robots, the robot mission is to generate optimal trajectory and move from start point to target point with obstacles avoidance. The MATLAB software (CPU is 2.61 GHz) is used for the simulation.

The optimal trajectories for the two robots for different maps are shown in Fig. 9a, Fig. 10a, Fig. 11a and Fig. 12a. For the mobile robot one, the velocities profile of the optimal trajectory are shown in Fig. 9b, 10b, 11b, 12b. It is shown in these figures the comparison between the fuzzy velocity and the profile velocity. It is clear that both of them are slightly the same, which means the mobile robot will accelerate its speed slightly as the maximum velocity of the robot is 0.75m/s. The effective of the fuzzy motion controller is appeared in case of the second robot as they are shown in Fig. 9c, Fig. 10c, Fig. 11c and Fig. 12c. It is clear obvious that the robot speed is decelerated because the probability of another robot is increased in these cases. The speeds were decreased from 0.75m/s to 0.34m/s for each case with different time depends on the map and the probability of the dynamic obstacles. The decelerate time intervals were [2000-3000] ms, [200-2500] ms, [1000-2000] ms and [1000-2000] ms, respectively. The multi mobile robots navigation for each robot is successfully traveled from the start point to the target position with collision free. The simulation results for these maps are shown in Fig. 9d, Fig. 10d, Fig. 11d and Fig.12d. The results are very good and validate the successful for the proposed approach to solve the multi objective optimization and avoid obstacles issues for multi mobile robots motion planning.



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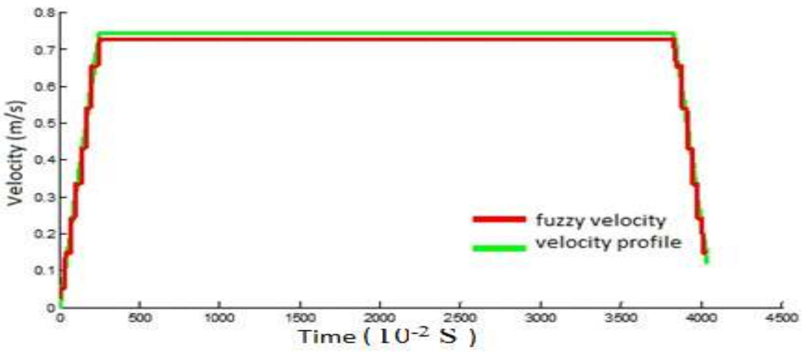

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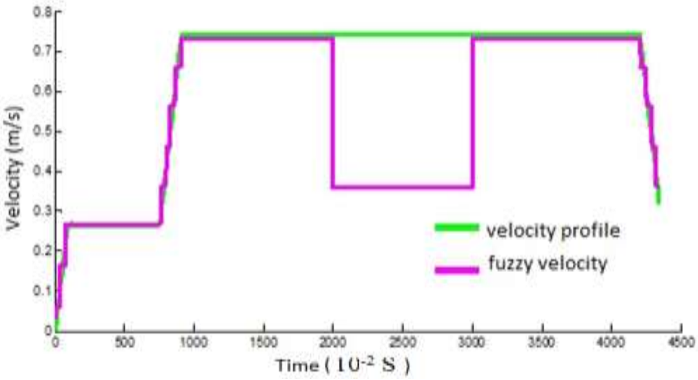

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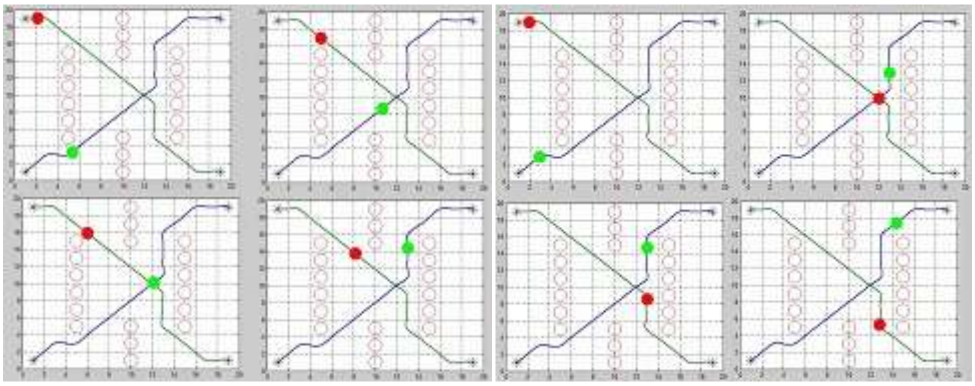


(d)

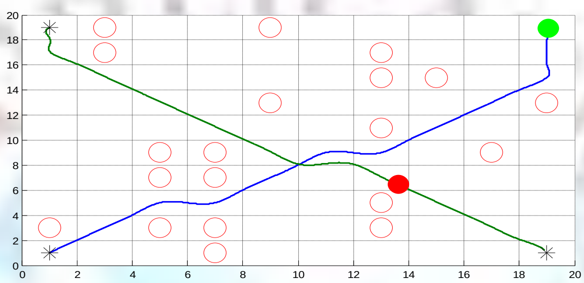
Fig. 9: up to down:

(a) Optimal trajectory for robots in map 1.

(b)Velocity Profile of the Optimal Trajectory generation for the mobile robot 1

, (c)Velocity Profile of the Optimal Trajectory generation for the mobile robot 2

(d)The simulation of Multi robot navigation.



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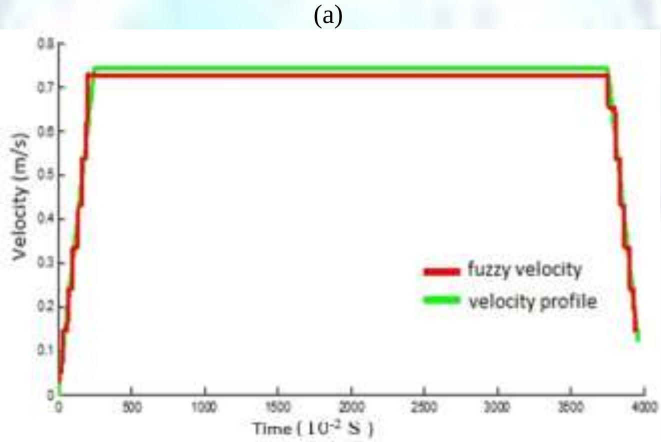

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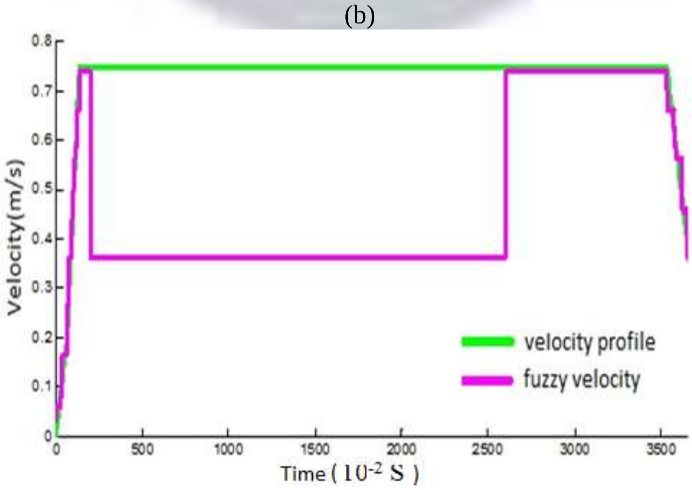

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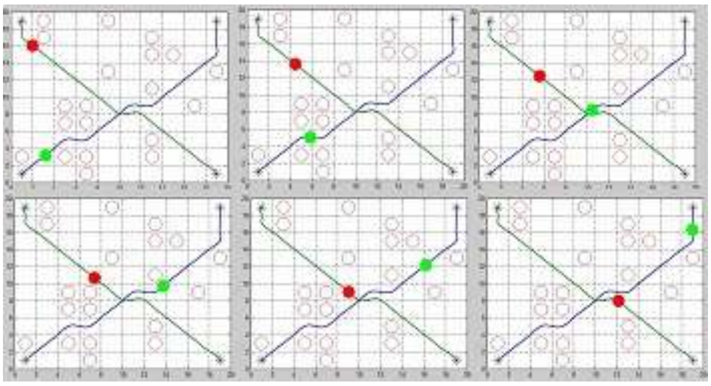
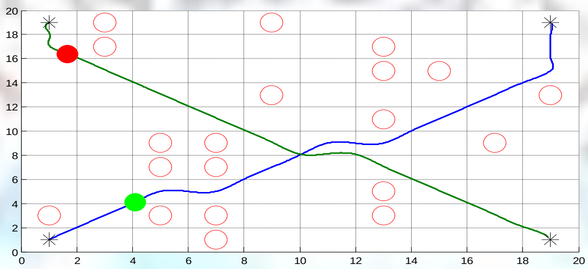


(d)

Fig. 10:
(a) Optimal trajectory for robots in map 2.
(b)Velocity Profile of the Optimal Trajectory generation for the mobile robot 1
,(c) Velocity Profile of the Optimal Trajectory generation for the mobile robot 2
(d) The simulation of Multi robot navigation.



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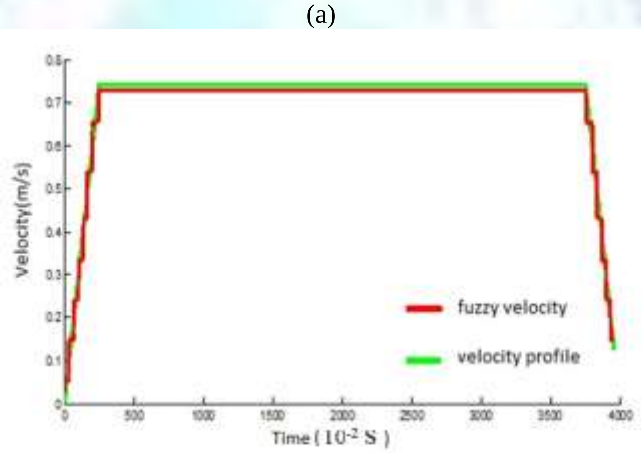

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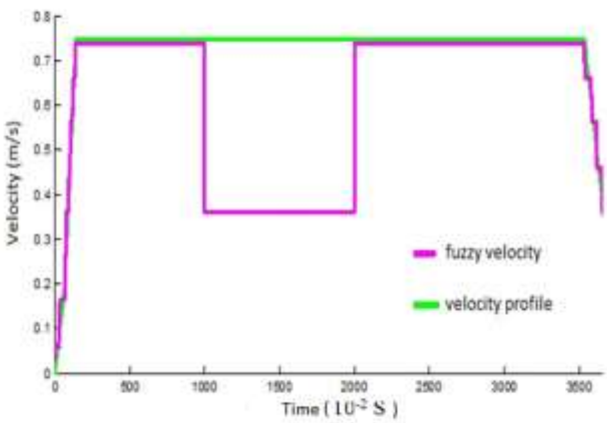

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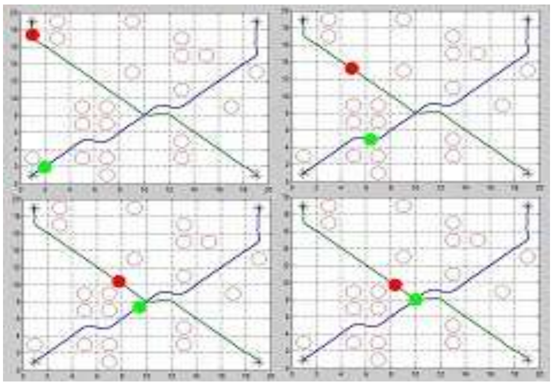
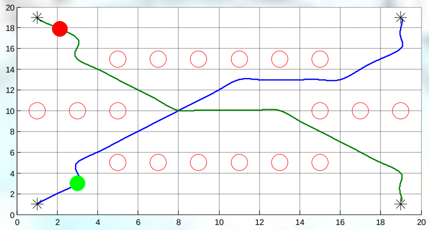


(d)

Fig. 11:
(a) Optimal trajectory for robots in map 2.
(b) Velocity Profile of the Optimal Trajectory generation for the mobile robot 1
, (c) Velocity Profile of the Optimal Trajectory generation for the mobile robot 2
(d) The simulation of Multi robot navigation.



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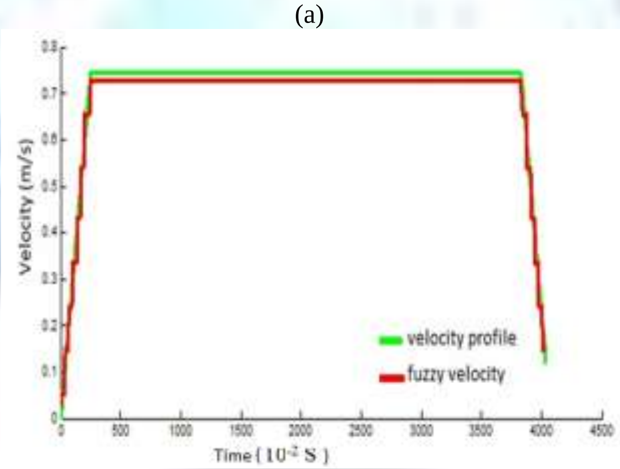

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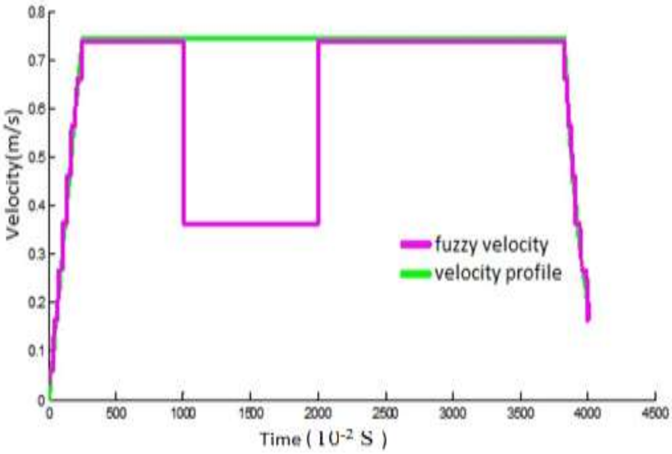

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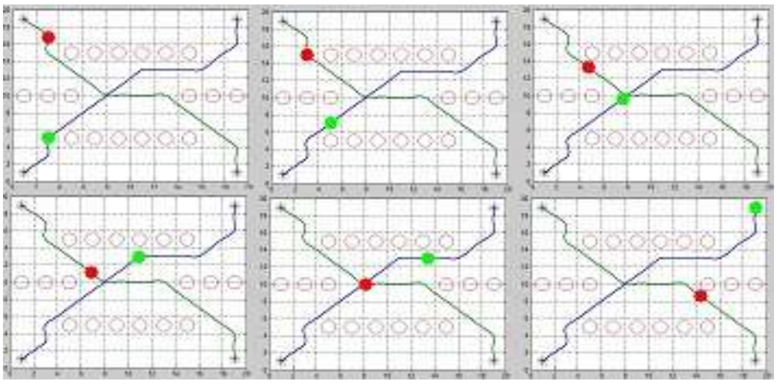

(d)

Fig. 12:
(a) Optimal trajectory for robots in map 3.
(b) Velocity Profile of the Optimal Trajectory generation for the mobile robot 1
(c) Velocity Profile of the Optimal Trajectory generation for the mobile robot 2
(d) The simulation of Multi robot navigation

Conclusion

We have introduced the concept for solving the multi objective optimization of motion planning and obstacles avoidance for multi robots in environment with obstacles using enhanced approach in [11-13]. In this research, the motion planning based on two stages. The first stage was to obtain an multi objective optimal trajectory for each robot individually by using the Enhanced GA. The second stage was to build a motion strategy in order to allow the robots move around without collision with each other by using Fuzzy motion controller. Each robot analyzes the motion for other robots, and then determines the best solution to avoid the collision. The analyzing depends on the probability of the robot to be close to another one. Finally, a simulation of this strategy and its evaluation was presented. The simulation results show that the proposed approach is effective and efficient in solving the motion planning problem in different environments. In fact, the proposed approach has a flexibility to deal with the problem in order to achieve an optimal solution for mobile robots navigation. The motion strategy proposed in this research produced good results to avoid collisions between the multi robots and they can reach their target position in a good time as well as avoid each other. In other words, the strategy minimizes the total motion time of the robots along their optimal trajectories.

For the future work, the extended of this proposed algorithm will be linked with heterogeneous aerial-ground robots. The aerial vision system will provides the robot with environment data and the proposed approach will define the trajectory and the path for the mobile robots in the real time.

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References

[1]. Laumond J.," Robot Motion Planning and Control", LAAS-CNRS, Toulouse August 1997.

[2]. Kortenkamp D., Bonasso R. P., & Murphy R., "Artificial Intelligent and mobile robots", the MIT press, pp.3-20, 1988.

[3]. M. L. Steven M., and A. H. Seth, "Optimal Motion Planning for Multiple Robots Having Independent Goals", IEEE, Transaction on Robotics and Automation, vol. 14, No. 6,1998.

[4]. A. K. Fedor, A. B. Alexander, "Multi-agent Optimal Path Planning for Mobile Robots in Environment with Obstacles", D. Bj_rner, M. Broy, A. Zamulin (Eds.): PSI'99, LNCS 1755, pp. 503-510, 2000.

[5]. H. Ashraf Huwedi, "Multi-Robots Cooperation Strategies in an Exploration Task", In the International Arab Conference of Information Technology (ACIT), Benghazi, Libya, 2010.

[6]. H. Ashraf Huwedi, "3D Mapping of an Unknown Environment by Cooperatively Mobile Robots", In the International Arab Conference of Information Technology (ACIT), Riyadh, Saudia Arabia, 2011.

[7]. A. Muhammad A.C. Mohamed , " Trajectory Planning of Mobile robot in Unstructured Environment for Multiple Objects", Mehran University Research Jounral of Engineering & Technology, [ISSN 0254-7821], vol. 31, No. 1, 2012.

[8]. [8] S. H. Ashraf and M. B. Salem, "Finding an Optimal Path Planning for Multiple Robots Using Genetic Algorithms", The 13th International Arab Conference on Information Technology ACIT', ISSN : 1812-0857, 2012.

[9]. [9] R. Suparna, B. Dhrubojyoti, G. M. Chiranjib, K. Amit, and R. Janarthanan, "Dynamic Obstacle Avoidance in Multi-Robot Motion Planning Using Prediction Principle in Real Environment ", Automation, Control and Intelligent Systems, 1(2) :16-23, 2013.

[10]. K. P. Fatemeh and E. Sadegian , " Path Planning of Mobile robots Via Fuzzy Logic in Unknown Dynamic Environments with Different Complexities", J. Basic Appl. Sci. Res., 3(2s) 528-535, 2013.

[11]. B. Kadhim Oleiwi, R. Al-Jarrah, H. Roth H., and B. Kazem," Multi objective optimization of Trajectory Planning of Non-Holonomic Mobile robot in Dynamic Environment using Enhanced GA by Fuzzy motion control and A*" . Submitted to The 8th International Conference on Neural Network and Artificial Intelligence.

[12]. B. Kadhim Oleiwi , H. Roth, and B. Kazem, "Modified Genetic Algorithm based on A* algorithm of Multi objective optimization for Path Planning", submitted to 6th International Conference on Computer and Automation Engineering (ICCAE 2014).

[13]. B. Kadhim Oleiwi, H. Roth, B. Kazem , A Hybrid Approach based on ACO and GA for Multi Objective Mobile Robot Path Planning, Applied Mechanics and Materials Vol. 527, pp. 203-212, 2014.

[14]. Brumitt B.L., Coulter R.C., & Stentz A.,"Dynamic Trajectory Planning for A Cross-Country Navigator" Robotics Institute, Carnegie Mellon University.

[15]. Tzafestas S. G., & Zavlangas P. "Industrial and Mobile Robot Collision– Free Motion Planning Using Fuzzy Logic Algorithms Industrial-Robotics- Theory-Modeling-Control", ISBN 3-86611-285-8, pp. 964, ARS/plV, Germany, December 2006.

[16]. Spong W. S., Seth H., & Vidyasagar M., "Robot Dynamics and Control", Second Edition, John Wiley & Sons, Inc. January 28, 2004.

[17]. E. Papadopoulos and J. Poulakakis, " Trajectrory Planning and Control for Mobile Manipulator Systems", Proceed. 8th, IEEE Mediterranean Conference on Control and Automation (MED'00), 2000.

[18]. A. D. Trajano, M. F. Armando and S. D. Max, "Parametric Trajectory Generation for Mobile Robots", ABCM Symposium Series in Mechatronics - Vol. 3 - pp.300-307, 2008.

[19]. R. Vivekananthan, L. Karunamoorthy, "A Time Optimal Path Planning for Trajectory Tracking Of Wheeled Mobile Robots", vol. 5, N° 2, 2011.