Mobile Robot Motion Planning and Multi Objective Optimization Using Improved Approach

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***Abstract*—In this paper, we have considered optimal motion planning problem of mobile robot. The two hybrid approaches are proposed based on Modified Genetic Algorithm (MGA) and Ant Colony Algorithm (MACO). A sub optimal collision free path is established by proposing the classical search and Modified A* search method (MA*) in initialization stage. The globally optimal path will be finding by optimizing the sub optimal path and then converting it to optimal trajectory. The enhancements for the two approaches are proposed in initialization stage, enhanced operators, and in reducing the energy consumption for mobile robot by using Cubic Spline interpolation curve fitting for optimal planned path. Moreover, four objective optimization functions are proposed for minimizing traveling length, time, smoothness, and security of feasible path and trajectory. By comparing the both approaches, the simulation results demonstrate that the MGA has more accurate and better performance govern the robot's movements successfully from start to target point after avoiding all obstacles in all tested environment.**

***Index Terms*—multi objective optimization, motion planning, mobile robot, genetic algorithm, A* search algorithm, ant colony algorithm**

I. Introduction

Usages of mobile robots have been increased dramatically in the last years in many types of application. By end of 2012 more than 3 millions mobile robots in service compared to the industrial robots which are around 1.5 millions [1]. Mobile robots are increasingly used in automated industrial environments. The mobile robot applications have been improved the quality of traditionally human tasks, and have completely automated some tasks that are required for humans to carry out them [2].

Many applications of mobile robot assume repeated the movement or traversal between predefined specific points and follow the pre-planned path. For example, in industry applications, the mobile robot could be utilized to transport the materials between two positions. The ammunition transportation is quite used in military applications. In addition, a mobile robot can be applied for surveillance what means visiting certain checkpoints on a specific area [2]. In all these applications, the automated environments demand from intelligent robots, the optimal motion planning, in order to the mobile robots carry out their tasks successfully, so optimal motion planning is a prerequisite. That is how we started the research based on multi objectives optimization and improved approach.

As a result of the importance of optimization for mobile robot motion planning problem, this research focuses on finding better performance of the genetic algorithm (GA) and ant colony algorithm (ACO). In this paper, we extend our study in [3], [4] by proposing some improvement of ACO in [5] to become MACO, and make a comparison between them to verify their performance. Finally, the simulation results have shown that as long as proposed approaches can plan a feasible and optimal path, but the MGA has faster efficiency and better performance than MACO to solve the proposed problem. Both approaches have tested in different environments and compared in the simulation results section.

The article is organized as follow: Section II describes the state of the art. The proposed problem and the proposed approach are introduced in Section III and IV, respectively. The multi objective optimization function is addressed in Section V. Based on this formulation, Section VI presents the evaluation criteria and simulation results. Finally, in Section VII conclusions and future work are discussed.

II. State of the Art

The motion planning and optimization for mobile robot are important problems in navigation, and have become an active research area in the last years [6]. The aim of path planning is to find a collision-free path between start and target points with satisfying some optimization criteria such as traveling length, time, etc. While the

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trajectory planning is the movement schedule of a mobile robot along the planned path. Because of the traditional methods for motion planning have been their weakness; therefore, finding a better and efficient algorithm is a still an open research study in this area [6], [7]. The different algorithms that have been used for mobile robot navigation are presented in [7]. They have found that the heuristic approaches are giving suitable and effective results of the mobile robot navigation as compared to the traditional methods. By applying the heuristic approach, the mobile robot can navigate safely among the obstacles without hitting them and reach the predefined target point [7]. The GA and ACO are becoming well-known and important technique in combinatorial optimization problems. The objective of both algorithms is to search for an optimal path in a motion planning of mobile robot field or an optimal solution for different applications [7]. With regarding to this, many researchers have used the GA and ACO algorithms to find optimal solution for mobile robot motion planning problem. Accordingly, the modified GA is used for optimizing a single objective in [8], [9] and for multi objective in [10], [11]. Moreover to that, the modified GA has been combined with ACO as hybrid model in [10] for multi objective. GA and improved ACO for optimizing the single objective proposed in [11]. Several researches showed that there are many improvements provided for the ACO and GA for solving proposed problem, and some researchers are still investigating this problem to explore further or more improvements of the algorithm. However, most of these researches solved the mobile robot motion planning problem and the planned optimal path was in term of single objective. Despite that few researchers have been studied the multi objective problem, but they ignored some important criteria such as minimum travelling time for the trajectory generating, safety factor, and security as a multi object optimization. In this work, we proposed the hybrid approaches as comparison study to verify their performance and we have taken in the consideration the four objectives of the optimal planned path and convert it to trajectory as well as reducing the energy consumption of mobile robot robots by using Cubic Spline interpolation curve fitting.

III. Problem Description

The proposed problem is to find an optimal motion planning of the mobile robot according to multi objective optimization, it means that the mobile robot should find a optimal path and trajectory between the start and target point and avoid the collision risk with the static obstacles in the environment. As shown on the left side of Fig. 1, despite that path **A** is the shortest, but it has the lowest security performance. On the other side, path **C** has the high smoothness performance with minimum angles of all line segments; but, it is the longest path. Although the path **B** presents the best security performance, however its length and smoothness performance are not the best [10], [11]. Path D presents a minimum-time smooth trajectory and minimum energy consumption; nevertheless, it has the lowest security performance. Thus, optimal trajectory generating of mobile robot in term of the multi objective represents the dotted black path, as shown on the right of Fig. 1. It introduces a trade off among these criteria by taking the advantage of multiple solutions that can be obtained in a single run to get the optimal solution.

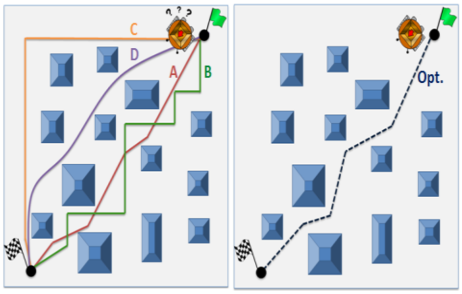


Figure 1. Problem description

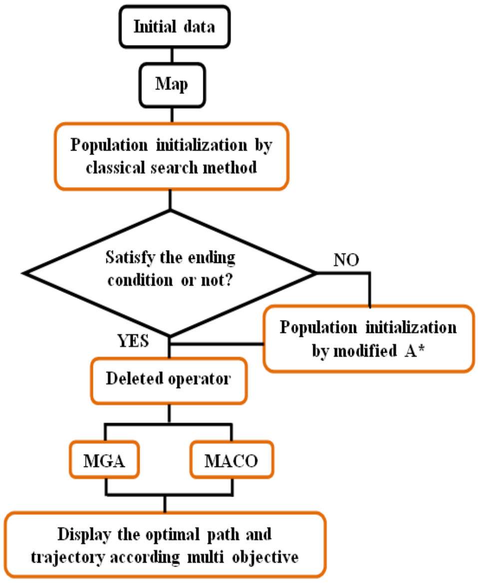


Figure 2. General flowcharts of proposed approaches

IV. Proposed Approaches

This section the proposed approaches are presented which are defined in details in [3], [4] based on MGA and MACO approaches. The flowcharts of proposed approaches are introduced in Fig. 2, Fig. 3 and Fig. 4. In initialization stage, the 2 D static environment model is described, and some corresponding parameters are presented.

By proposing the classic search and modification of A* to find sub optimal path as initial solution, and to improve the searching performance in initialization stage of the proposed approach to find the optimal motion planning for mobile robot.

By applying the proposed approaches, The sub optimal path will be optimized to find the globally optimal path and converted it to optimal trajectory in term of multi objectives for mobile robot navigation in complex static environment. To reduce the energy consumption of mobile robot robots the Cubic Spline interpolation curve fitting is used.

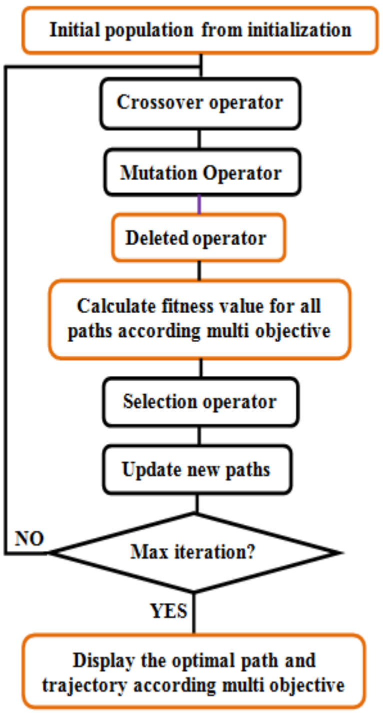


Figure 3. MGA approach flowchart

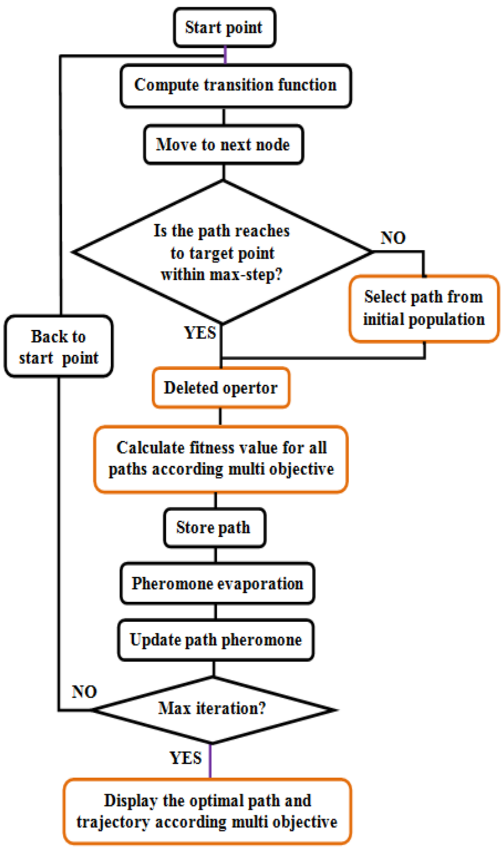


Figure 4. MACO approach flowchart

Moreover, the basic GA operators and enhanced mutation operator with A* are used in MGA which is defined in [3], [4], in addition the deleted operator in both proposed approaches is proposed. As it can be seen in Fig. 2, Fig. 3 and Fig. 4, the improvement of both proposed approaches are presented in blocks marked in orange color in all flowcharts.

V. Multi Objective Function

The Pareto-optimality idea is introduced to solve multi-objective optimization problem with the advantage that multiple solutions can be obtained in a single run as compromising of or tradeoff multi criteria of specific problem [12]. The total cost of fitness function of feasible collision free path P with set of n points is obtained by a linear combination of the weighted sum of multi objectives as shown below [4], [10], [11]:

The Path structure: $P = \{p_1, p_2, \ldots\ldots, p_n\}$

$$F(P) = \min\{w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4\}. \quad (1)$$

$$f_1(P) = \sum_{i=1}^{n-1} |p_i p_{i+1}| \quad (2)$$

$$f_2(P) = \sum_{i=1}^{n-2} \theta\left(p_i' p_{i+1'} p_{i+1} p_{i+2}\right) + C_1 S \quad (3)$$

$$f_3(P) = \frac{C_2}{\sum_{i=1}^{n-1} Sd\left(p_i, Ob\right)} \quad (4)$$

$$f_4(P) = \sum_{i=1}^{n-1} \int_0^{l_i} \frac{dl}{v(t)} \quad (5)$$

where w_1, w_2, w_3 and w_4 represent the weight of each objective: length, smoothness, security and time in the total cost F(P), respectively. The weights are tuned through simulation by trail and errors to find the best values of the weights evaluation function. By minimizing the overall fitness function in regard to the assigned weights of each criterion, a suitable optimal path and trajectory in term of multi objective can be obtained. Where, $f_1(P)$ is the total length of path and criteria of path shortness is defined as the Euclidean distance between two point, $f_2(P)$ is the path smoothness, where $\theta\left(p_i' p_{i+1}, p_{i+1} p_{i+2}\right)$ is the angle between the vectorial path segments $p_i' p_{i+1}$ and $p_{i+1} p_{i+2}$, $(0 \leq \theta \leq \pi)$. C_1 is a positive constant, S is the number of line segments in the path, $f_3(P)$ is the path clearance or path security, where $Sd(p_i, Ob)$ is the shortest distance between the path point p_i and its proximate obstacle Ob. C_2 is a positive constant to make the numerical value of $f_3(P)$ in the same magnitude with the three objective values. $f_4(P)$ represents the total consumed time for robot motion, from start to target point.

VI. Simulation Results

This section presents the simulation results of mobile robot motion planning and optimization according to multi objectives using the proposed approaches.

Before applying the proposed approaches to plan the optimal path and trajectory, the environment model is presented which contains free and occupied places, so the different shapes of obstacles are surrounding by one circle or more. The free places are representing out of circles as shown in Fig. 5.

The proposed approaches are tested in different simple and complex environment to generate the multi objective optimal collision free path and trajectory. The comparison results of their performance index are shown in Table I. As it can be seen, the performance index of MGA is better than MACO in term of multi objective function: travelled time, length, safety and smoothness. In addition, the computational time of MGA is faster.

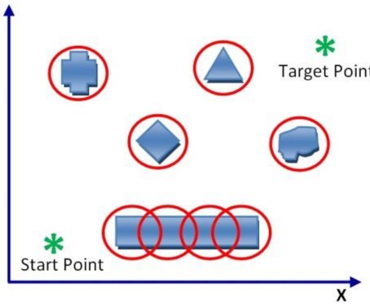
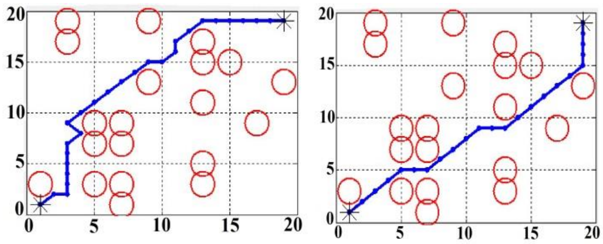


Figure 5. Environment representation [13]

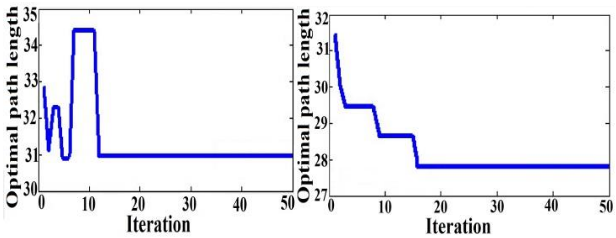
TABLE I. PERFORMANCE INDEX OF PROPOSED APPROACHES

Performance Index	Proposed Approaches Performance	
	MACO	***MGA***
Travelling length	30.9706	27.799
No. of line segments	11	6
Sum of angles	585	225
Travelling time (s)	50.8	40.13
Multi objective value	200.8899	169.9632
Processing time (s)	4379.5564	803.5815
Population size	10	10
Iteration	50	50



(a) Using MACO (b) Using MGA

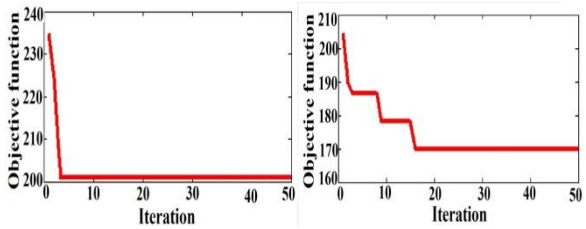
Figure 6. Optimal path planning of mobile robot



(a) Using MACO (b) Using MGA

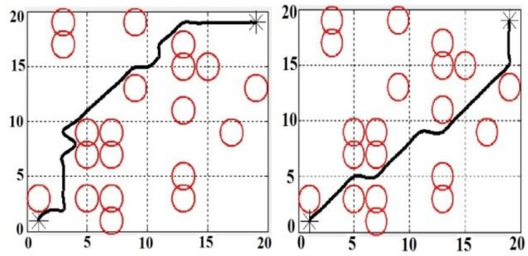
Figure 7. Optimal path length versus iteration

The optimal path planning in term of multi objective, optimal path length, multi objective function and the optimal trajectory for mobile robots of both approaches are shown in Fig. 6, Fig. 7, Fig. 8, and Fig. 9 respectively.



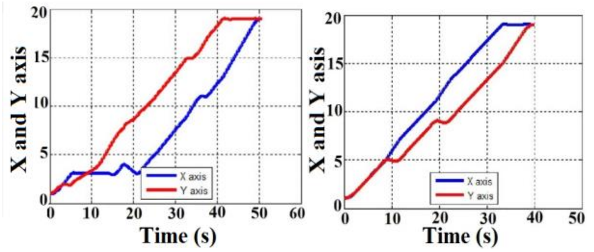
(a) Using MACO (b) Using MGA

Figure 8. Multi objective value of the path versus iteration



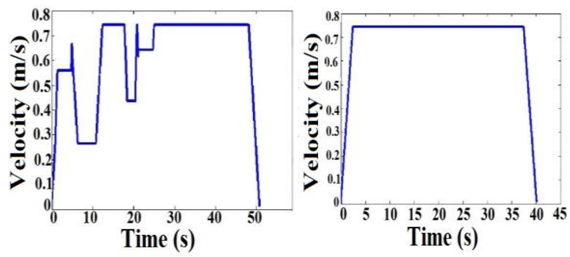
(a) Using MACO (b) Using MGA

Figure 9. Trajectory generating with cubic Spline interpolation



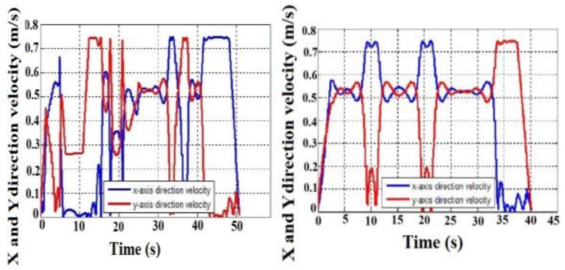
(a) Using MACO (b) Using MGA

Figure 10. X, Y axes are blue and red, respectively for the trajectory generating



(a) Using MACO (b) Using MGA

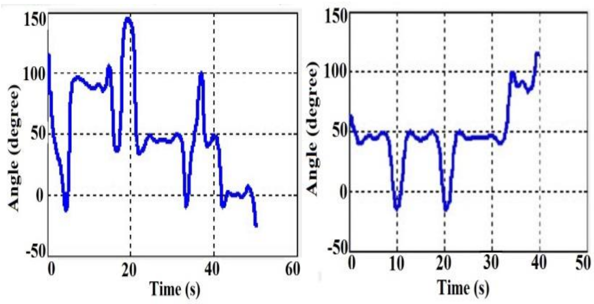
Figure 11. The final velocity profile for trajectory generating



(a) Using MACO (b) Using MGA

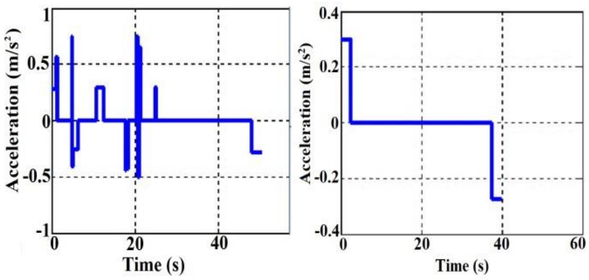
Figure 12. X, Y axes direction velocity for trajectory generating

Both approaches are generated and used the trajectory with Cubic Spline interpolation curve fitting of optimal planned path for reducing the energy consumption of mobile robot. The x and y axes, the velocities profile, x and y direction velocities profile, angle and the acceleration of the optimal trajectory are shown in Fig. 10, Fig. 11, Fig. 12, Fig. 13, and Fig. 14, respectively.



(a) Using MACO (b) Using MGA

Figure 13. The angle behavior for trajectory generating



(a) Using MACO (b) Using MGA

Figure 14. The acceleration behavior for trajectory generating

Accordingly, as it can be seen, the mobile robot navigates from start point and reaches its goal point successfully with avoiding all static obstacles in its way in all tested environment and indicate that the proposed approach MGA is accurate than MACO and can find a set of Pareto optimal solution efficiently in a single run.

VII. Simulation Results

In this paper, we have introduced the concept for finding the multi objective optimization for mobile robot motion planning in static environment. In this paper, we extend our study in [3], [4] by proposing some improvement in initialization stage and deleted operator of ACO in [5] to become MACO, and comparing between them to verify their performance. Two hybrid approaches are proposed based on MGA and MACO. The potential solutions of the problem will be established by classical method and MA* as the initial population. MACO and MGA approaches have been used for optimizing and finding the global motion planning. The enhancements for two models are proposed in initial generation, enhanced operators, and reducing the energy consumption of mobile robot by Cubic Spline interpolation curve fitting of optimal path. Moreover, four objective functions to minimize traveling length, time, smoothness, and security of feasible path and trajectory. Finally, the performance of both approaches was evaluated. Accordingly the MGA is effective and efficient in solving the motion planning problem in different environments as compared it with MACO performance. In fact, the MGA has a flexibility to deal with the problem in order to achieve an optimal solution for mobile robots motion planning and minimize the total motion time of the robots along its optimal trajectories. The following suggestions of the further study of the current work will be extend:

- To compare MGA with other proposed approaches.
- To take into account additional costs, such as avoiding moving obstacles in multiple mobile robots environments.

References

[1] Executive Summary World Robotics. (2012). Industrial Robots, International Federation of Robotics–IFR, 2013. [Online]. Available: http://www.worldrobotics.org/

[2] R. Siegwart and I. R. Nourbakhsh, *Introduction to Autonomous Mobile Robots*, MIT Press Cambridge, 2004.

[3] B. K. Oleiwi, H. Roth, and B. I Kazem, "Multi objective optimization of path and trajectory planning for non holonomic mobile robot using enhanced genetic algorithm," *Neural Networks and Artificial Intelligence Communications in Computer and Information Science*, vol. 440, pp. 50-62, 2014.

[4] B. K. Oleiwi, H. Roth, and B. I. Kazem, "Modified genetic algorithm based on A* algorithm of multi objective optimization for path planning," *Journal of Automation and Control Engineering*, vol. 2, no. 4, 2014.

[5] K. Han and R. W. McLaren, "Collision free path planning algorithms for robot navigation problem," Master thesis, The Graduate School, University of Missouri-Columbia, 2007.

[6] Z. Juanping, F. Xiuhui, and J. Ying, "An improved ant colony optimization algorithm for mobile robot path planning," in *Proc. IEEE, 3rd International Workshop on Intelligent Systems and Applications*, 2011, pp. 1-4.

[7] P. K. Mohanty and D. R Parhi, "Controlling the motion of an autonomous mobile robot using various techniques: A review," *Journal of Advance Mechanical Engineering*, vol. 1, pp. 24-39, 2013.

[8] N. A. Shiltgh and L. D. Jalal, "Path planning of intelligent mobile robot using modified genetic algorithm," *International Journal of Soft Computing and Engineering*, vol. 3, no. 2, pp. 31-36, 2013.

[9] M. J. Mohamed, "Genetic algorithm using sub-path codes for mobile robot path planning," *Iraqi Journal of Computers, Communication and Control*, vol. 12, no. 1, pp. 104-117, 2012

[10] H. Jun and Z. Qingbao, "Multi-objective mobile robot path planning based on improved genetic algorithm," in *Proc. IEEE International Conference on Intelligent Computation Technology and Automation*, 2010, pp. 752-756.

[11] S. Geetha, C. G. Muthu, and V. Jayalakshmi, "Multi objective mobile robot path planning based on hybrid algorithm," in *Proc. IEEE 3rd International Conference on Electronics Computer Technology*, 2011, vol. 6, pp. 251-255.

[12] C. M. Fonseca and P. J. Fleming, "An overview of evolutionary algorithms in multi-objective optimization," *Evolutionary Computing*, vol. 3, no. 1, pp. 1-16, 1995.

[13] W. M. Abbas, "Path planning of mobile robots using genetic algorithms and modified artificial potential field," Master thesis, University of Technology, Iraq, 2013.

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