Modified Genetic Algorithm Based on A* Algorithm of Multi Objective Optimization for Path Planning

Bashra K. Oleiwi and Hubert Roth
Siegen University/Automatic Control Engineering, Siegen, Germany
Email: {bashra.kadhim, hubert.roth}@uni-siegen.de

Bahaa I. Kazem
Mechatronics Engineering,University of Baghdad, Iraq
Email: drbahaa@gmail.com

***Abstract*—A new hybrid approach algorithm based on modified Genetic Algorithm (GA) and modified the search algorithm (A*) and has been developed to solve the Multi objectives global path planning (MOPP) problem for mobile robot navigation in complex environment with static distributed obstacles. The aim of this combination is to improve 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*. The objective function for the proposed approach is to minimizing travelling distance, smoothness and security, without collision with any obstacle in the robot workspace. The simulation results show that the proposed approach is able to achieve multi objective optimization in complex static environment efficiently. Also, it has the ability to find a solution when the environment is complex and the number of obstacles is increasing.**

***Index Terms*—multi objectives optimization, path planning, mobile robot, static complex environment, GA, A*.**

I. Introduction

The most fundamental intelligent task for a mobile robot is the ability to plan an optimal path successfully from one location to another and reaches its goal with avoiding all obstacles. Moreover, the ”optimal” here means that the planning must satisfy some criterions such as length of the planning path is the shortest, and energy consumption of robot is the lowest etc. [1], [2]. The issue has attracted remarkable attention from many researchers and many interesting research results have been obtained such as traditional methods and intelligent algorithms. However, the most of these algorithms are used to solve single objective optimization that makes the length of planning path the shortest. Therefore, in many real-life situations, robot needs to keep a certain safe interspace from obstacles to avoid collisions for some factors like robot’s size. Besides, some path segments with small included angles needed to be considered when some types of robots are used, such as wheeled robot. If such path segments exist, the robot’s wheels will suffer from abrasions to a certain extent, and what is more serious is that the robot even can’t move ahead along the planned path [1], [2]. Therefore, mobile robot path planning can be regarded as a NP-Hard problem with multiple optimal objects, which is difficult to find the precise solution. In [3], [4] they present different methods applied in intelligent mobile robot navigation. They found that the heuristic approaches gave suitable and effective results for mobile robot navigation. Using the heuristic approach, the mobile robot can travels successfully from one location to another and reaches its goal with avoiding all obstacles. These approaches are also helpful for the solution of the local minima problem. A multi-objective mobile robot path planning is a wide research area, where many algorithms have been applied in [1], [2], [5]-[11].

The purpose of this study is to develop a new hybrid approach based on performing modification of A* and GA to increase the searching ability greatly of robot movement towards optimal solution state. In addition, the approach can find a multi objective optimal path for mobile robot navigation as well as to use it in complex static environment. However, when the environment is complex and the number of the obstacles is increasing, the basic GA may face some difficulties to find a solution or even it may not find one. The classical method and modified A* search method in initialization stage for single objectives and multi objectives have been proposed to overcome this 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 partly. The article is organized as follow: Section II describes the problem and then the proposed approach, flow charts and evaluation criteria are introduced in section III. Based on this

Manuscript received October 8, 2013; revised December 5, 2013.

doi: 10.12720/joace.2.4.357-362

formulation, section V presents simulation results. Finally, in section VI conclusions and future work are discussed.

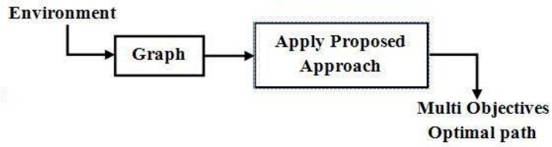
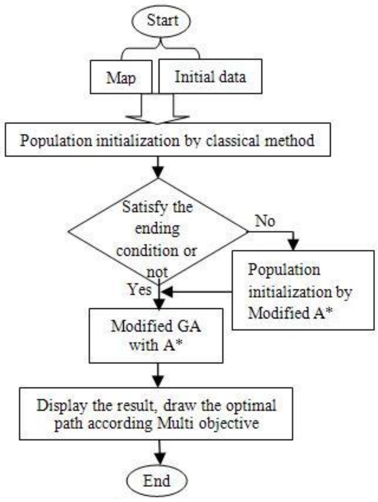
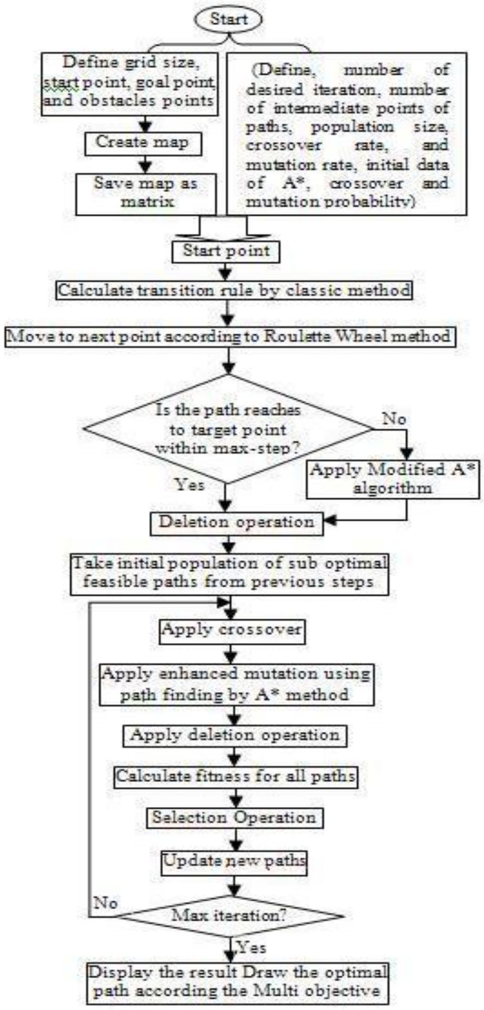


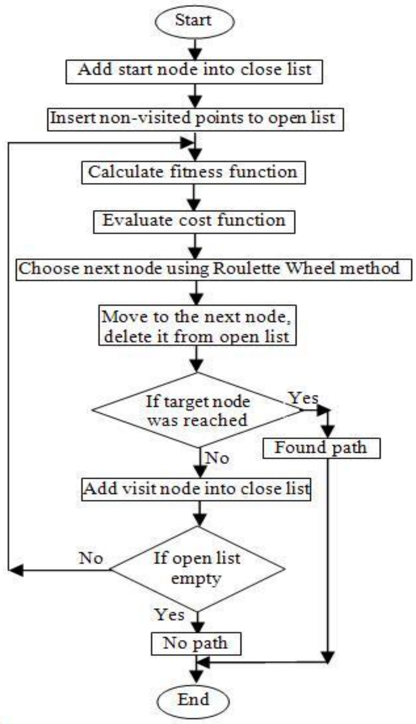
Figure 1. General schema of the methodology [12].



a. General Flowchart of proposed approach.



b. Flowchart of proposed approach with more details



c. Flowchart of modified A* search algorithm.

Figure 2. Proposed approach

II. Problem Description

Given a point mobile robot moves in 2D complex environment with stationary obstacles. These obstacles can be placed at any grid point in the map. The mobile robot's mission is to search offline the optimal path that travels from a start point to a goal point. The characteristics of path should be collision-free, minimum traveling distance, maintaining smooth path and Security (safe).

III. Proposed Approach

In this section, a description of proposed approach is presented and the general schema of the proposed approach to solve the MOPP problem can be defined in the following steps, Fig. 1 and flow charts in Fig. 2.

Step 1. Initialization

Some of definitions corresponding to the initialization stage are presented in Table I.

TABLE I. Proposed Approach Parameter Specifications

GA type	Modified GA
Population size	10
Chromosome length	Varies
Crossover type	One point crossover
Mutation type	Flip bits
Crossover rate, Pc	0.8
Mutation rate, Pm	0.35
Max. Iteration (i).	50

Step 2. Environment model

The environment model is described, and some corresponding definitions are presented. We construct a closed workspace (indoor area) without and with different numbers of obstacles. This area is described by a 2D static map (20 × 20); the starting point is S=(1, 1), and the target point is T=(19, 19) for a path. The positions of the obstacles are randomly chosen; in other words, the obstacles can be placed at any grid point in the map.

- *Shortcut or decreased operator*: This operator will eliminate obstacles nodes from map at the beginning of the algorithm.

Step 3. initial population: Generating and moving for sub optimal feasible paths.

In this stage, classical method and modified A* is used for generating a set of the sub optimal feasible paths in simple map and 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 the eight directions (forward, backward, right, left, right-up, right-down, left-up, and left-down).

A. Using Classical Method

The movement of the mobile robot is controlled by a transition rule function, which in turn depends on the Euclidean distance between two points (the next position j and the target position T) and roulette wheel method to select the next point and to avoid falling in local min in complex map. Hence, the distance value (D) between two points is:

$$D = \begin{cases} \sqrt{2} & \text{if the robot moved its diagonal direction} \\ 1 & \text{otherwise} \end{cases} \qquad (1)$$

The robot moves through every feasible solution to find the optimal solution in favored tracks that have a relatively less 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.

B. Using modified A* Algorithm

However, when the number of the obstacles is increasing, the classical method may face difficulties to find a solution or even they may not find one. Also, the more via points are used the more time consuming in the algorithm that depends mostly on the number of via points that they will use in the path in maze map. In the case of adding the modified A* search algorithm in initialization stage of GA, the proposed approach will find a solution in any case, even if there are many obstacles.

1) -Traditional A search algorithm*

A* algorithm is the standard search algorithm for the shortest path problem in a graph. The A* algorithm as shown in equation (2) below can be considered as the best first search algorithm that combines the advantages of uniform-cost and greedy searches using a fitness function [13].

$$F(n) =(g(n)+ h(n)) \qquad (2)$$

where *g(n)* denotes the accumulated cost from the start node to node *n* and *h(n)* is a heuristic estimation of the remaining cost to get from node n to the goal node [13] . In our study the accumulated cost and heuristic cost are the Euclidean distance between two nodes. The robot selects the next node depends on the minimum value of *F(n).*

2) -Modification of A algorithm*

The A* algorithm is the most effective free space searching algorithms in term of path length optimization (for single objective). We proposed modified A* for searching of sub optimal feasible path regardless of length to establish the initial solution of GA in maze map, by adding the probability function to A* method. We have modified the A* in order to avoid use the shortest path which it could affect the path performance in term of multi objective (length, security and smoothness) in initial stage.

$$F(n) =Rand*(g(n)+ h(n)) \qquad (3)$$

Step 4: Optimization by modified GA

This step uses the modified GA for optimizing the search of the sub optimal path that generated in step 3. Hence, the main stages in modified GA are natural selection, standard crossover, proposed deletion operator , enhanced mutation with basic A* and sort operator to improve the algorithm's efficiency according to characteristics of path planning, because it is difficult to achieve convergence and generate optimized feasible paths only by operators in standard GA.

The initial population of the potential solutions of the problem will be created by classical method or modified A* as the initial population, and it is called chromosomes. In the proposed approach, 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) of the path from the start position to the target position. Since, $p(x_0,y_0)$ =(1, 1) is always the starting point and $p(x_n,y_n)$ =(19, 19) is always the target point, the via-points of the path are $p(x_1,y_1)$ and $p(x_{i+1},y_{i+1})$, and all these points are represented the genes of the chromosome as shown in Fig. 3.

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

Figure 3. The chromosome structure.

In each generation, all chromosomes will be evaluated by fitness function F which will be discussed later. Thus, a chromosome with the minimum fitness has a considerably higher probability than others to select and reproduce by means of GA operators in the next generation. These steps are repeated until the maximum number of iterations is reached as shown in flowchart Fig. 2.

3) -GA operators

- *Selection*: Two parents randomly are selected based on their fitness by using the Roulette wheel selection method

- *Crossover operator:* During the crossover operation, two chromosomes that have an efficient fitness values are randomly selected as parents based on the selection method. Hence, each parent has its chromosome length. In this study, single point crossover is used. Crossover operation swaps the two parents around crossover points: This operation results feasible paths, because the nodes before crossover point in the first parent and the nodes after crossover point in the second parent and in opposite, are valid nodes, as shown in Fig. 4a.
- *Mutation operator:* The parental chromosome is chosen according to selection method. The parents start and target nodes are not mutated. The mutation operation is done by selecting an intermediate node in the parent according to mutation probability. These nodes are chosen randomly to replace the mutated node.
- *Enhanced mutation operator*: It is served as a key role to diversity the solution population, we proposed to enhance mutation operator by adding traditional A* search method to mutation. The enhanced mutation method is used to avoid fall into a local minimum, improve and decrease the distance of the partially path, between two randomly points (i and j) included in the main path, as shown in Fig. 4b
- *Deletion operator:* It proposed to eliminate the repeated genes (redundant) from an individual (path). For specific gene, the approach reversely check if this is equal to others and this is done for each gene, as shown in Fig. 4c.
- *Sort operation:* This operator sorts the chromosomes of population according to their fitness at each generation. The feasible chromosomes are organized in ascending order according to their fitness, and secondly, if a group of chromosomes has an equal fitness values, they are again sorted, in ascending order.

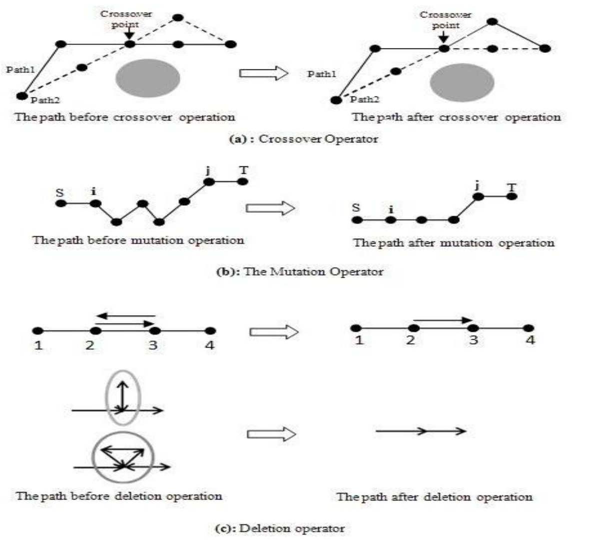


Figure 4. GA operators.

IV. -MULTI OBJECTIVE FITNESS FUNCTION

In recent years, the idea of Pareto-optimality is introduced to solve multi-objective optimization problem with the advantage that multiple tradeoff solutions can be obtained in a single run [14]. The total cost of fitness (or objective) function of feasible path P with n points is obtained by a linear combination of the weighted sum of multi objectives as follows [1], [2]:

$$\min F(P) = \min\{\omega_1 F_1(P) + \omega_2 F_2(P) + \omega_3 F_3(P)\} \tag{4}$$

$$\min F_1(P) = \sum_{i=0}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} \tag{5}$$

$$\min F_2(P) = \sum_{i=0}^{n-2} \theta_i + C_1 \times L. \tag{6}$$

$$\min F_3(P) = \frac{C_2}{\sum_{i=0}^{n} \min\_ \operatorname{dist}(p(x_i, y_i), OB^*} \tag{7}$$

where ω_1, ω_2 and ω_3 represent the weight of each objective to total cost $F(P)$. $F_1(P)$ 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, θi $(0 \le \theta \le \pi)$ is the angle between the two line segments, connecting the ith point, C_1 is a positive constant; L is the number of line segments in the path, $F_3(P)$ is the path clearance or path security, min_dist $(p(x_i,y_i),OB^*)$ is the shortest distance between the path point $p(x_i,y_i)$ and its proximate obstacle OB^*, C_2 is a positive constant.

By minimizing the overall fitness function regarding the assigned weights of each criterion, a suitable path is obtained. The weights of the shortest, smoothest and security fitness functions, ω_1, ω_2 and ω_3 respectively, are tuned through simulation and try and errors, with best found values ω_1=1, ω_2=0.05 and ω_3=1. Fig. 5 shows all components of the feasible path evaluation function

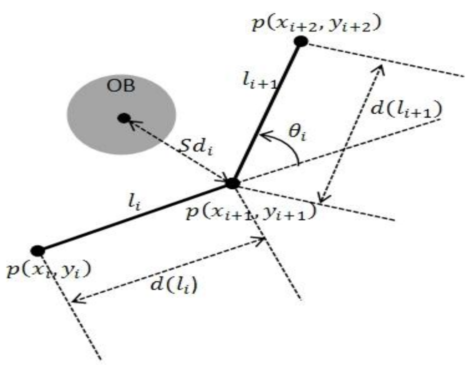
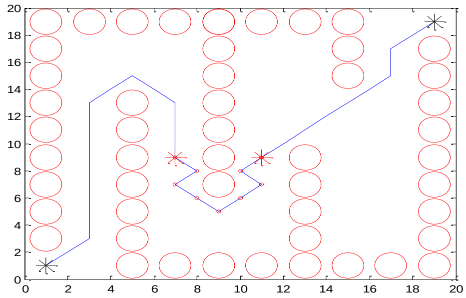


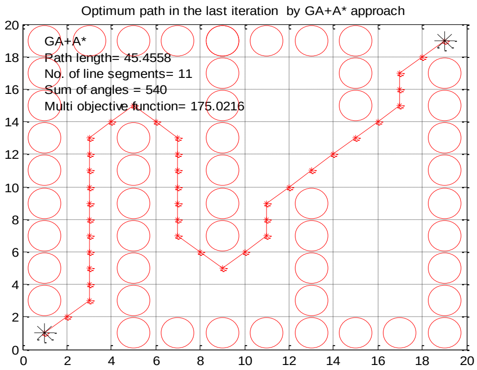
Figure 5. Path cost calculations.

V. SIMULATION RESULTS

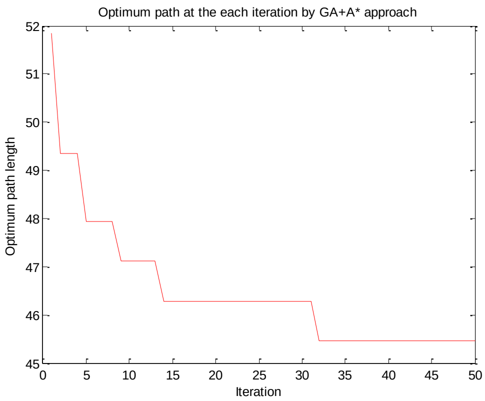
In order to verify the effectiveness of the proposed hybrid approach, we applied it in simple and complicated 2D static environments with different numbers of obstacles. The MATLAB software (CPU is 2.61 GHz) is used for the simulation. The Fig. 6, Fig. 7 and Table II show the execution of the program for various maps.



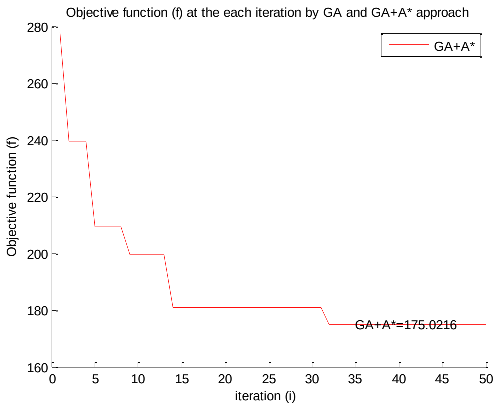
(a)



(b)



(c)



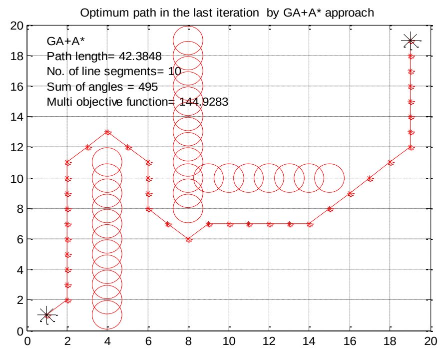
(d)

Figure 6. The final Pareto optimized paths (a and b) optimal path planning and (c) Relation between i values and optimal path length (d) Objective function F at the each i by proposed approach.

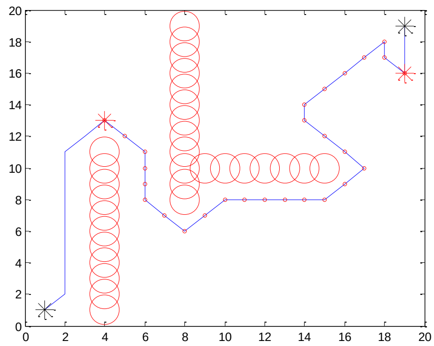
TABLE II. AVERAGE OF STATISTICS RESULTS FOR PROPOSED APPROACHES RUNNING OF 10 TRAILS OF MAP 1

Performance Index	Proposed Approach
Optimal path length	46.58
No. of Segments	12
Sum of angles	711
Multi objective value	190.5
Max. Iteration (i)	50
Running time	154 (Sec.)

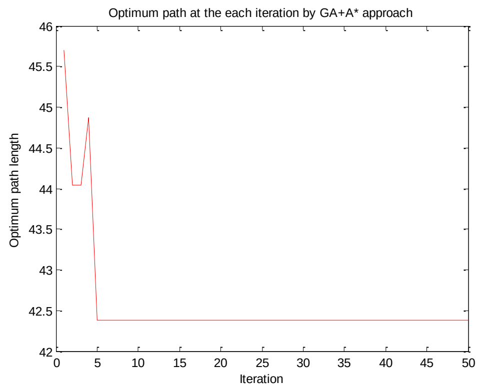
The proposed approach is tested to generate the optimal collision free path in term of length, smoothness and security in complex static environment as shown in Fig. 6 and Fig. 7. The results of multi objective optimal path for robot are shown in Fig 6a, b and Fig. 7a, b as well. It is clear that part of the path is improved after the modification. The simulation results show that the mobile robot travels successfully from one location to another and reaches its goal after avoiding all obstacles that are located in its way in all tested environment and indicate that the proposed approach is accurate and can find a set Pareto optimal solution efficiently in a single run.



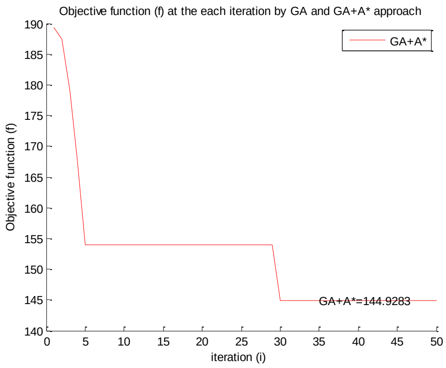
(a)



(b)



(c)



(d)

Figure 7. The final Pareto optimized paths (a and b) optimal path planning and (c) Relation between i values and optimal path Length (d) Objective function *F* at the each i by proposed approach

VI. CONCLUSION

The multi-objective optimization of mobile robot is adopted successfully using the proposed approach, and could find a set of Pareto optimal solution efficiently in a single run. Future research can investigate the performance of proposed approach for increasing the number of the Multi objective optimization of path planning in complex static and dynamic environment. Moreover, some specific genetic operators will design to fit the optimum path planning for mobile robot, which based on domain heuristic knowledge.

ACKNOWLEDGMENT

The authors gratefully acknowledge German academic exchange service (DAAD), University of Siegen and, Ministry of Higher Education and Scientific Research in Iraq for financial support.

REFERENCES

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

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

[3] 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.

[4] P. Raja and S. Pugazhenthi, " Optimal path planning of mobile robots: A review," *International Journal of Physical Sciences*, vol. 7, no. 9, pp. 1314–1320, 2012.

[5] O. Castillo, L. Trujillo, and P. Melin, "Multiple objective genetic algorithms for path-planning optimization in autonomous mobile robots," *Soft Computing- A Fusion of Foundation, Methodologies and Applications- Fuzzy-Neural Computation and Robotics*, vol. 11, no. 3, pp. 269-279, 2006.

[6] S. Nafiseh, "Mobile robot path planning by new structured multi-objective genetic algorithm," in *Proc. IEEE International Conf. of Soft Computing and Pattern Recognition*, 2011, pp. 79-83.

[7] Z. Wang, W. Zhang, J. Shi, and Y. Han, "UAV route planning using multiobjective ant colony system," in *Proc. IEEE Conf. on Cybernetics and Intelligent Systems*, 2008, pp 797-800.

[8] D. W. Gong, J. H. Zhang, and Z. Yong, "Multi-objective particle swarm optimization for robot path planning in environment with danger sources," *Journal of computers*, vol. 6, no. 8, pp. 1554-1561, 2011.

[9] K.-T. Hung, J.-S. Liu, and Y.-Z. Chang, "A comparative study of smooth path planning for a mobile robot by evolutionary multi-objective optimization," in *Proc. IEEE International Symposium on Computational Intelligence in Robotics and Automation*, 2007, pp. 254-259.

[10] M. Ellips and S. Davoud, "Multi-Objective PSO- and NPSO-based algorithms for robot path planning," *Advances in Electrical and Computer Engineering*, vol. 10, no. 4, pp. 69-76, 2010.

[11] F. Ahmed and F. Deb, "Multi-Objective path planning using spline representation," in *Proc. IEEE International Conf. on Robotics and Biomimetics*, 2011, pp. 1047–1052.

[12] N. B. Sariff and N. Buniyamin, "Comparative study of genetic algorithm and ant colony optimization algorithm performances for robot path planning in global static environments of different complexities," in *Proc. IEEE on International Symposium, Computational Intelligence in Robotics and Automation*, 2009.

[13] N. Sariff and N. Buniyamin, "An overview of autonomous mobile robot path planning algorithms," in *Proc. 4th Student Conf. on Research and Development*, 2006.

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

Bashra K. Chabor Alwaw, born in Baghdad, completed a Master degree in Mechatronics Engineering at University of Technology (UOT) Bagdad-Iraq. She is currently a PhD student at Control Engineering Department (RST), Siegen University, Germany. Her research interests are mobile robot, path planning, multi objective optimization and intelligent algorithm.
She worked as a lecturer in control and systems Engineering Department at UOT 2005

Hubert Roth, born in Oppenau, Germany, completed a Doctorate degree at Karlsruhe Technical University, Germany in 1983.
He employed at Dornier System GmbH in Friedrichshafen, Aerospace Systems Department 1983-1988. Currently he is the Chair in Control Engineering Department (RST) at Siegen University, Faculty of Electrical Engineering and Informatics since 2001.
Prof. Dr.-Ing. Roth is a vice Director of "Technical Committee on Computers and Telematics" of International Federation of Automatic Control (IFAC) since 2008 and vice Director of Centre for International Capacity Development (CICD) since 2009.

Bahaa I. Kazem is Prof at Mechatronics Engineering Dept, BSc, MSc and PhD at applied Mechanics University of Baghdad, Team Leader for the Solar-Iraq Research Group Consultant –The Higher Committee for Education Development in Iraq-PMs office, Government of Iraq. Visiting Professor- MIT Fulbright Visiting Scholar -MSU, the Main research orientations are: robotics, AI, ICT applications, path planning, flexible robot systems, vibration and control systems at manufacturing process.

