Dynamic Path Planning Algorithm in Mobile Robot Navigation

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Abstract—**Mobile Robot Navigation is an advanced technique where static, dynamic, known and unknown environment is involved. In this research, Genetic Algorithm (GA) is used to assist mobile robot to move, identify the obstacles in the environment, learn the environment and reach the desired goal in an unknown and unrecognized environment. This study is focused on exploring the algorithm that avoids acute obstacles in the environment. In the event of mobile robot encountering any dynamic obstacles when travelling from the starting position to the desired goal according to the optimum collision free path determined by the controller, the controller is capable of re-planning the new optimum collision free path. MATLAB simulation is developed to verify and validate the algorithm before they are real time implemented on Team AmigoBot™ robot. The results obtained from both simulation and actual application confirmed the flexibility and robustness of the controllers designed in path planning.**

Keywords-Genetic Algorithm (GA); Genetic Controller; Genetic Algorithm (GA) based Dynamic Path Planning Algorithm (DPPA); Team AmigoBot™ robot and MATLAB.

I. INTRODUCTION

The evolution of robotics research in the last fifty years has been dominated by human needs that evolve from industrial robotics to field and service robotics [1]. Current research in robotics aims to build an autonomous and intelligent robot which can plan its motion in a static, dynamic and uncertain environment. Mobile robots have been widely used in exploration and navigation to guide the mobile robot moving from the starting position to the desired goal where static, dynamic and unknown environment is involved. The environment is distinguished by variable terrain and obstacles that may block the movement of the robot in reaching the desired destination [2]. Mobile robot relies on sensors to get information about their surroundings [3].

Some of these basic behaviors are Goal Seeking, Obstacle Avoidance and Wall Following. Numerous researches have been carried out by adapting Artificial Intelligence techniques to improve the performance of the mobile robot navigation in terms of the accuracy in avoiding obstacles, shortest path travelled and total time consumed. The Artificial Intelligence techniques includes Fuzzy Logic (FL) [4-5,6-12], Artificial Neural Network (ANN) [13-18], Genetic Algorithm (GA) [19-26], and/or the combination of a few of them [27-40]. Each method has its own strength over others in certain aspects.

In the last decade, genetic algorithms have been widely used as alternative method to generate the optimum path by taking advantage of its strong optimization ability. Although the existing algorithms [19-21] have rapid search and high search quality, there are six problems associated with the existing methods. Firstly, the initial population contains many infeasible paths, which have negative influence on the performance of the genetic algorithm. Secondly, there are not sufficient heuristic knowledge based genetic operators. Thirdly, after each generation, offsprings may contain infeasible path. Furthermore, Qing Li *et al.* [19-21] merely guide the mobile robot from the starting position to the desired goal and do not take into consideration the circumstances when mobile robot is trapped inside acute 'U' or 'V' shaped obstacles. In the cases when mobile robot encounters acute 'U' or 'V' shaped obstacles, mobile robot will be trapped and unable to come out from the trapped environment. Fifthly, during the process of guiding the mobile robot travelling from the starting position to the goal position, mobile robot might encounter with some dynamic obstacles. The existing algorithms do not take into consideration about these circumstances. Lastly, there is no reported real time implementation to prove the applicability of the algorithm in the actual mobile robot.

In order to generate a feasible collision free path from the starting position to the goal position when the mobile robot is trapped in an acute 'U' or 'V' shaped obstacle or the mobile robot encountering dynamic obstacles, Genetic Algorithm (GA) based Dynamic Path Planning Algorithm (DPPA) is proposed. In this paper, fourteen different subalgorithms are developed in this GA based DPPA to solve the above mentioned problems using MATLAB and its Genetic Algorithm and Direct Search Toolbox™ 2 [41]. In addition, this newly developed GA based DPPA is goal oriented and thus reduces unnecessary search time. The effectiveness of this algorithm is demonstrated by simulation studies. The algorithm is further verified and validated through the application of the algorithm in actual Team AmigoBot™ [42] robot. The performances of GA based DPPA in both simulation and real time implementation are investigated and evaluated on various aspects including the ability to (i) generate feasible path, (ii) avoid acute obstacles, (iii) avoid any dynamic obstacles, and (iv) find a shortest path from starting position to the goal position.

II. PROPOSED METHODOLOFY

In this paper, the research objective is to assist the mobile robot to find an optimal collision free path that enable the mobile robot to travel to the desired goal without colliding with the obstacles in the environment. In the cases where dynamic random obstacle(s) is/are positioned in the environment, mobile robot is capable of avoiding the dynamic obstacle(s). The flowchart of the proposed Genetic Algorithm (GA) based Dynamic Path Planning Algorithm (DPPA) is shown in Figure 1.

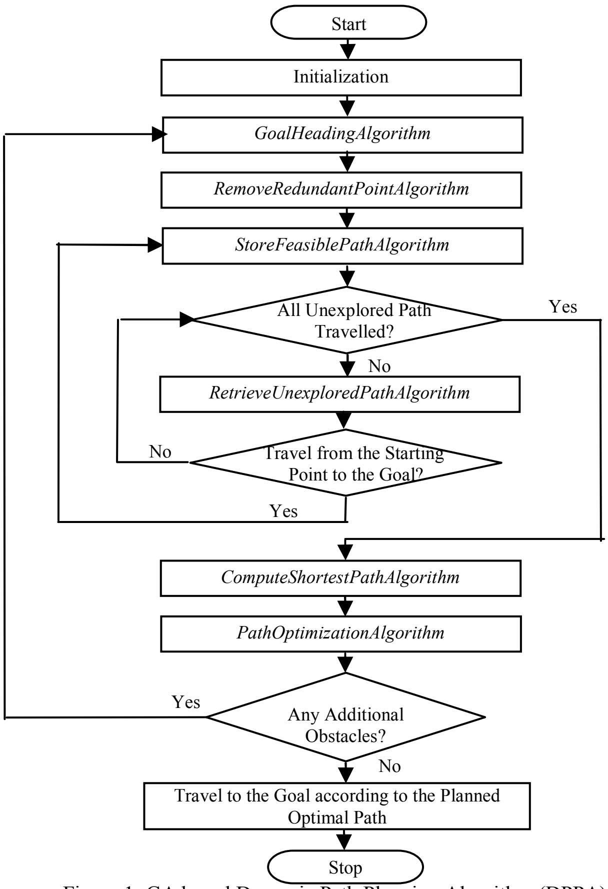


Figure 1: GA based Dynamic Path Planning Algorithm (DPPA)

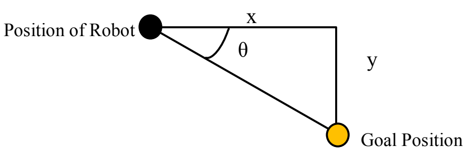


Figure 2: The Rotational Angle of the Mobile Robot, θ

Details of how GA based DPPA works are described in the following steps:

Step 1: ***Initialization***

GA based DPPA starts with the initialization of the parameters.

Step 2: ***GoalHeadingAlgorithm***

In GA based DPPA, Mobile robot is required to seek for the direction of the goal in order to move towards it. The rotational angle of the robot towards the goal is controlled by the angle 'theta' which is shown in Figure 2 and defined as below:

$$\theta = \tan^{-1}\frac{y}{x} \qquad \textbf{(1)}$$

where y = y_coordinate of goal position and
x = x_coordinate of goal position
both with reference to the robot's base position.

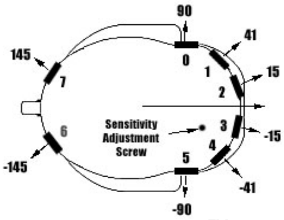


Figure 3: Top View of Team AmigoBot^{TM} robot [42]

SensorAlgorithm simulates a set of simulated sensors, *S*, that are used in MATLAB simulation environment. The set of simulated sensors, *S*, is as follows:

$$S = (s1, s2, s3, s4, s5, s6, s7, s8) \qquad \textbf{(2)}$$

where *s1*- *s8* are 8 sensor readings indicating the configurations of the nearest obstacles to the mobile robot from the current position.

In real time implementation, array *S* is used to store the sonar sensors' readings obtained from the environment. The turning angles of Team AmigoBot^{TM} robot ranging from -90^o to 90^o are shown in Figure 3. Positive angle is to the left and negative angle is to the right.

Step 3: ***RemoveRedundantPointAlgorithm***

After new collision free path is found, unnecessary neighbouring coordinate(s) is/are screened out to remover redundant points lying along the path through *RemoveRedundantPointAlgorithm*.

Step 4: ***StoreFeasiblePathAlgorithm***

The collision free path from the starting position to the desired goal is stored by activating the *StoreFeasiblePathAlgorithm*.

Step 5: ***RetrieveUnexploredPathAlgorithm***

Activate *RetrieveUnexploredPathAlgorithm* to explore all the unexplored paths. If the retrieved path is a feasible path from the starting position to the goal, Step 4 is repeated. In other words, *StoreFeasiblePathAlgorithm* is activated to save the feasible path.

Step 6: ***ComputeShortestPathAlgorithm***

Follow by activating *ComputeShortestPath Algorithm* to find the shortest feasible path saved in the *StoreFeasiblePathAlgorithm* in Step 4.

Step 7: ***PathOptimizationAlgorithm***

When the shortest collision free path without redundant point is found, *PathOptimization Algorithm* is utilized to find the optimum path from the shortest obstacle free path obtained in Step 6. Figure 4 shows the path optimization of three nodes.

Step 8: ***DetectObstacleAlgorithm***

DetectObstacleAlgorithm is called to identify if there is/are any dynamic obstacle(s) while guiding the mobile robot to travel from the starting position to the desired goal according to the optimized collision free path.

Step 9: No Dynamic Random Obstacle

If no dynamic random obstacle is detected during the process of guiding the mobile to the desired goal, the mobile robot will travel from the starting position to the desired goal according to the optimized collision free path determined by *PathOptimizationAlgorithm*.

Step 10: Encounter Dynamic Random Obstacle

In the cases where dynamic random obstacle(s) is/are positioned in the environment, the current position is taken as the new starting position. The original goal remains as the new desired goal of the mobile robot and Steps 2–10 are repeated. *GoalHeadingAlgorithm* is activated to search for new obstacle free path from the new starting position to the desired goal.

III. RESULTS AND DISCUSSIONS

A. MATLAB Simulation

The main objective of the MATLAB simulation is to validate and check the feasibility of GA based DPPA before real time implementations are carried out on the actual mobile robot, Team AmigoBot^{TM} robot. Simulation test, named Test-1, is established according to the specifications in Table 1 in the simulated environment. The simulated mobile robot is positioned in the starting position (grid 1) and is expected to find a shortest collision free path from the starting position to the desired goal (grid 100). *SensorAlgorithm* is used to assist the mobile robot to determine if there is/are any obstacle(s) while navigating towards the goal. After identifying the shortest collision free path, unnecessary paths are removed to create or obtain an optimum collision free path. During the process of guiding the mobile robot, mobile robot might come across and detected dynamic obstacles and the proposed GA based DPPA will take care of such eventualities. The Test-1a and Test-1b are carried out to find the optimum collision free path (a) without and (b) with dynamic obstacles respectively. The final path of Test-1a is shown in Figure 7. The final path of Test-1b is shown in Figure 10.

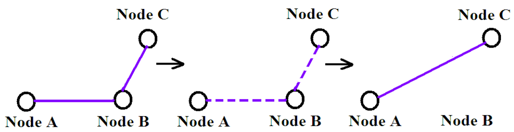
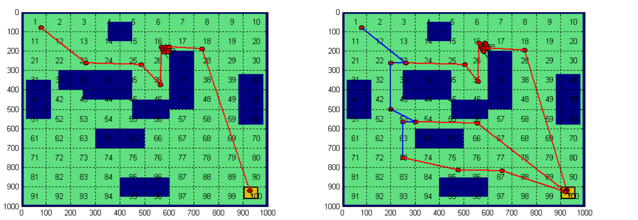


Figure 4: Optimization of the Path Travel from Node 1 to Node 3

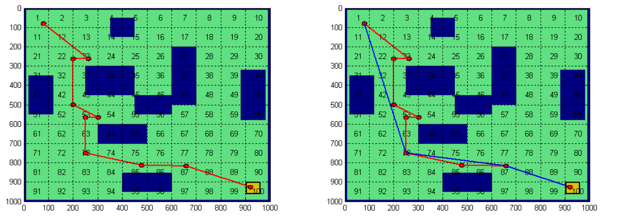
Table 1: Input Parameters for Test-1

Environment size	1000 x 1000, shown as 10 x 10 grid
Starting position	(80, 80)
Goal position	(930, 930)
Obstacles	Obstacles defined by user
Dynamic Obstacles after Path Optimization	Test-1a: No. Test-1b: Yes.



(a) (b)

Figure 5: Results of Test-1 (a) Initial Collision Free Path from the Starting Position to the Desired Goal; (b) Other Collision Free Paths from the Starting Position to the Desired Goal



(a) (b)

Figure 6: Results of Test-1 (a) Shortest Collision Free Path from the Starting Position to the Desired Goal; (b) Optimized the Shortest Collision Free Path

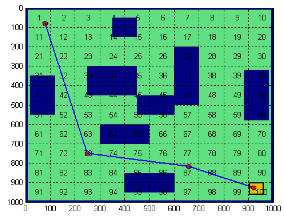


Figure 7: Mobile Robot Travels from the Starting Position to the Desired Goal in the Optimum Collision Free Path WITHOUT Dynamic Obstacles (Test-1a)

Figure 5 shows all the feasible paths navigating the mobile robot to the desired goal. A minimum clearance distance was provided between mobile robot and obstacles to avoid the mobile robot from colliding with the obstacles. Virtual walls were created so that the same grids and positions would not be traversed, travelled or analyzed again. Moreover, mobile robot was able to move away from 'U-shaped' type obstacles and it did not traverse in between two obstacles. Mobile robot escaping from the acute obstacle can be seen in Figure 5(a). A shortest collision free path among all the feasible paths as seen in Figure 5 will be taken as the feasible path for further consideration.

Figure 6(a) shows the shortest feasible path navigating towards the goal. Optimization has taken place to achieve the optimum path in goal seeking mobile robot navigation. Unnecessary pathways were removed in order to come out with an optimum collision free path as shown in Figure 6(b).

Referring to Figure 7, it shows the result obtained by Test-1a, in which the mobile robot reaches the goal position when there are no dynamic obstacles. Before guiding the mobile robot moving from the starting position to the desired goal in the optimum collision free path generated by GA based DPPA, the *DetectObstacleAlgorithm* is activated to identify if there is any dynamic obstacles in between any of the two continuous points of the optimum collision free path from the starting position to the goal position. If mobile robot does not detect any dynamic obstacle, the mobile robot will travel according to the optimum collision free path as in Figure 7 and no path searching was required.

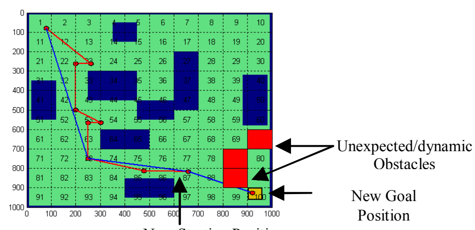
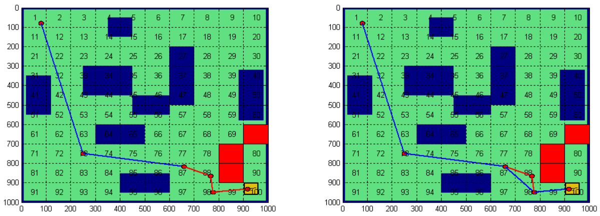


Figure 8: Dynamic Obstacles are in the Simulated Environment of Test-1



(a) (b)

Figure 9: Results of Test-1b (a) Collision Free Path from the Starting Position to the Desired Goal when Dynamic Obstacle(s) are encountered; (b) Optimized the Collision Free Path

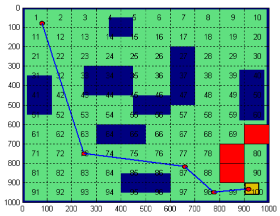


Figure 10: Mobile Robot Travels from the Starting Position to the Desired Goal in the Optimum Collision Free Path WITH Dynamic Obstacles (Test-1b)

Figure 8 depicts the simulated environment of Test-1 with dynamic obstacles present before the mobile robot is allowed to travel according to the optimum collision free path generated by GA based DPPA. In Figure 9, the complete process of guiding the mobile robot moving from the new starting position to the desired goal is shown. Optimization is carried out to achieve the near optimum path planning in goal seeking mobile robot navigation. Figure 10 shows the result obtained by Test-1b. When mobile robot encountered any dynamic obstacles, GA based DPPA is capable of coming out with an optimum collision free path from the starting position to goal position without colliding with any of the obstacles in the environment.

Referring to Figure 8, mobile robot does not detect any dynamic obstacle in the optimum collision free path before grid 87. Mobile robot travels according to the optimum collision free path determined earlier and no path searching is required before grid 87. When *DetectObstacleAlgorithm* is activated to identify if there is any dynamic obstacles in between grid 87 and grid 100, dynamic obstacles are detected. New starting position is located in grid 87 and the goal position is located in grid 100. *GoalHeadingAlgorithm* is activated to re-plan the new path to guide the mobile robot travelling from the current position to the desired goal without colliding with any of the obstacles in the environment.

From Test-1, all the additional features of GA based DPPA were successfully implemented in the simulation where GA based DPPA is capable of (i) generating the feasible path, (ii) resolving the circumstances where mobile robot is trapped in the acute 'U' or 'V' shaped obstacle, (ii) finding an optimum and shortest collision free path with a given starting position and goal position, and (iv) avoiding dynamic obstacle(s) when travelling from the starting position to the goal position in the optimum collision free path. In short, MATLAB simulation has verified and has validated the effectiveness of GA based DPPA.

B. *Real Time Implemention*

Team AmigoBot™ robot is used in real time implementation to validate the feasibility and the applicability of the algorithm that was proven working in the simulation. In real time implementation, the dimensions of the environment are in millimeters (mm), and the coordinate specification are in (x,y). The actual working environment for real time implementation of GA based DPPA is a 2750mm x 2750mm area. A representation environment is also created using MATLAB to illustrate the real time path taken by the mobile robot. The real time implementation, named Test-2, can be summarized as in Table 2. Two tests have been carried out and the comparison of shortest optimum path obtained in real time implementation and MATLAB simulation is presented below. In Test-2, other than looking into the travelling activity of the mobile robot from starting position to the goal position, we have looked into the circumstances where dynamic obstacles(s) is/are (a) not included and (b) included during the process of guiding the mobile robot travelling from the starting position to the desired goal in the optimum collision free path.

The sensors on the Team AmigoBot™ robot are used to assist the mobile robot to determine if there is/are any obstacle(s) while navigating towards the goal. Investigation discovered that DPPA is strongly relies on the encoder readings and sensor readings. Sensor readings referred in the ideal simulation environment are based on mathematical calculations which are 100% accurate and consistent. In real time implementation, sensor readings are found fluctuating. This can be resolved by increasing the grace period after each action is taken place. Additional checking can be taken to ensure sensor readings are steady and not fluctuating before recorded as current state.

When the sonar sensors of the mobile robot detected dynamic obstacles blocking the travelling path, *GoalHeadingAlgorithm* is activated to re-plan the new optimum collision free path. The current position was set to become new starting position and the original goal position was set to become new goal position. Results are summarized in Figure 12 and Figure 13. In conclusion, real time implementation has confirmed the practicality and robustness of Genetic Algorithm (GA) based Dynamic Path Planning Algorithm (DPPA).

Consolidate the research findings and results obtained from the MATLAB simulation and real time implementation with Team AmigoBot™ robot, we can conclude that the proposed Dynamic Path Planning Algorithm (DPPA) confirmed the flexibility and robustness of the controllers designed in path planning. The limitation in the existing algorithm [19-21] are resolved.

IV. CONCLUSIONS

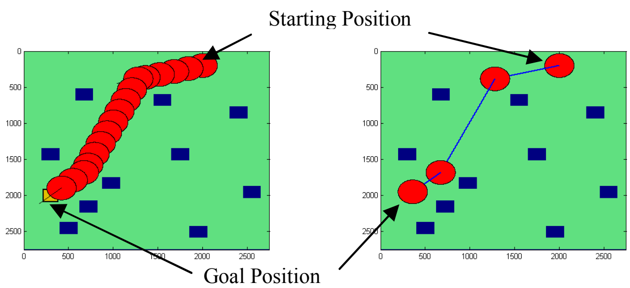
In this research, the optimal path for the autonomous mobile robot to move from the starting point towards the goal without hitting any obstacles in an unrecognized environment is investigated. Mobile robot is capable of escaping from complicated obstacles such as acute 'U' shaped obstacles, or obstacles that trap the mobile robot from further moving. Allocate feasible path cum goal seeking strategy is proposed to come out with the feasible path from the starting position to the desired goal. Optimization strategy proposed in this research assists the mobile robot to remove the unnecessary path ways to reduce the total traveled distance. Path remembering strategy proposed in this paper assists the mobile robot to come out from acute obstacles. Virtual walls are created to avoid the same position to be traversed over and over again. In the event of mobile robot encountering any dynamic obstacle according to the optimum collision free path determined by Genetic Algorithm (GA) based Dynamic Path Planning Algorithm (DPPA), GA based DPPA is capable of re-planning the new optimum collision free path to guide the mobile robot. Real time implementation of GA based DPPA was investigated in detail. The results obtained from real time implementation are compared with the MATLAB simulation study to verify the practicality and robustness of the proposed algorithm. This investigated GA based DPPA is flexible to enable the mobile robot to reach goal position from any arbitrary starting position. The effectiveness of the following features for the newly proposed GA based DPPA have been verified, validated and proven with MATLAB simulation and real time implementation using Team AmigoBot™ robot: (i) generate feasible path, (ii) avoid acute obstacles, (iii) avoid any dynamic obstacles, and (iv) find a shortest path from starting position to the goal position.

Table 2: Input Parameters for Test-2

Environment size	2750 x 2750
Starting position	(2000, 200)
Goal position	(270, 2200)
Obstacles	10.
Dynamic Obstacles after Path Optimization	Test-2a: No. Test-2b: Yes.

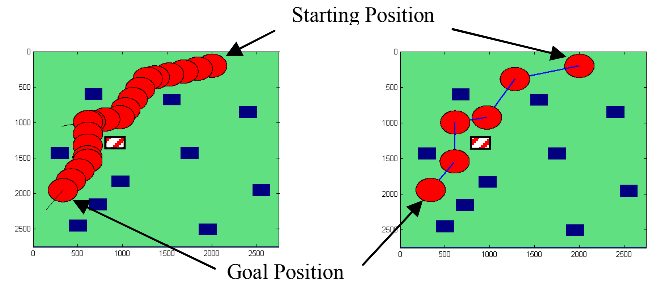
(a) **(b)**

Figure 11: Actual Environment (2750mm x 2750mm) of Randomly Located Obstacles where Team AmigoBot™ Robot is Located at (a) Starting Position; (b) Goal Position



(a) **(b)**

Figure 12: Result of Test-2a in (a) Real-Time Implementation Representation Environment; (b) MATLAB Simulation Environment



(a) **(b)**

Additional Obstacles added for Returning Path

Figure 13: Result of Test-2b in (a) Real-Time Implementation Representation Environment; (b) MATLAB Simulation Environment

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