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# Path planning for autonomous robots – a comprehensive analysis by a greedy algorithm

**Bih-Yaw Shih[1], Hsiang Chang[1] and Chen-Yuan Chen[1,2,3]**

**Abstract**

The so-called problem of path planning refers to the computation of an optimal path for the movement of a robot from the origin to the destination without colliding with any obstacles. In this study, three main steps are used to solve the problem of path planning. First, we calculate the minimum distance of the path from the origin to the destination with no obstacles in the environment. Then, we consider the case where the robot comes across an obstacle along the aforementioned path. In this case, we set a turning point that is close to the collision point and is within an obstacle-free area. In the third step, we set a new path that crosses this turning point. We use these three steps in a loop until an obstacle-free path is found.

Further, we select six types of obstacles for a simulation utilizing the proposed algorithm. This algorithm requires little time and only a relatively small number of rounds to calculate the path. In particular, in a simple environment, it is quite efficient. We also compare the proposed algorithm with the hierarchical evolutionary algorithms. The comparison results reveal that the proposed algorithm requires close to just half the number of rounds required by the hierarchical evolutionary algorithms. Furthermore, the amount of memory needed to store the path tree is just one-twentieth that required in the case of hierarchical evolutionary algorithms. Hence, the proposed algorithm requires fewer system resources and has a lower computation time than do the hierarchical evolutionary algorithms.

**Keywords**

Artificial intelligence, graph theory, greedy algorithm, intelligent robot, path planning

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## 1. Introduction

Robotic path planning is a promising research topic in the field of robotics (Shih et al., 2010, 2011). Robots use maps to move from one point to another. Thus far, a number of algorithms have been used for creating maps used by robots for the purpose of navigation. These algorithms use information obtained from various sensors, cameras, etc., to create the maps (Ge and Lewis, 2006). In this study, we use a path planning method to determine an optimal obstacle-free path that a robot can follow to reach its destination from a certain point. We have focused on a path planning method that considers both static and dynamic conditions. Assuming that there are various stationary obstacles in the considered area under the static conditions, we first use an algorithm to compute the entire path from the origin to the destination of the robot. Then, the robot is moved along this computed path. The use of robotic controllers ensures that the robot does not collide with any obstacles.

However, this problem of path planning is difficult to solve under dynamic conditions. Under such

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conditions, the positions of obstacles change with the passage of time (Shukla et al., 2009). Therefore, the movement of robots needs to be planned on the basis of time units; this implies that all the computations in this case must be completed within a certain time frame. Moreover, every computation must learn and efficiently use the past computations. Here, the planner uses a robot controller to realize robot motion. Most evolutionary methods are faced with considerable time complexity in the process of obtaining optimal effective results. In other words, we must find an optimal path planning method to ensure that the robots reach their destination. However, robots are slower than computers at solving problems when many computations need to be performed within a limited time. The evolutionary algorithm needs a considerable amount of memory to store the information of every generation because the algorithm requires a significant number of specimens and generations for achieving the best solution. Robots do not have so much memory; hence, we use an external function to compute the optimal path in order to reduce the computational burden on the robots.

In this study, we continue to use the previous proposition (Shih et al., 2011b) by a graph to perform mathematical calculations in a plane. Further, we use a linear planning method to reduce the time complexity of the computation and the amount of information that needs to be stored for the computation. We also use two other methods in this study. One of them provides a function to help the robots' arithmetic logic unit (ALU) to compute the path within a relatively small time. The other uses an evolutionary algorithm to find the optimal path. Both methods will be discussed in the following sections.

## 2. Maps and path planning

For path planning, we mainly use topologies and maps. A topology is created by using points and tracks; robots move along these tracks from the origin to the destination. These tracks are mapped mainly by users or computed by computers from a map. However, moving along these tracks is not the same as moving in a real environment; moreover, it takes more time for robots to move along these tracks while avoiding obstacles by using sensors and retracing steps along an incorrect track in order to move along the correct track to reach the destination. When the local site has no points or tracks, robots are required to move along the nearest track in order to correctly follow the determined path. Consequently, nowadays, maps are mainly used for robot navigation. Maps are quite similar to a real environment, and robots can be used for drawing unknown obstacles with laser rangefinders (Tungadi and Kleeman, 2011). An evolutionary algorithm is often used to execute path planning for a map. In the following sections, we will describe the structure of a map and a path planning method that uses an evolutionary algorithm.

### 2.1. Maps

Maps commonly use an $M \times N$ matrix for storing information. Each cell in this matrix has a value of 1 or 0 depending on the obstacles. Any cell Cij in the matrix can be expressed as follows (1):

$$CIJ = \begin{cases} 0 \text{ if there is no obstacle at location } (i, j) \\ \text{of the map} \\ 1 \text{ if there exists an obstacle at location } (i, j) \\ \text{of the map} \end{cases} \quad (1)$$

These cells only store values of 0 or 1; hence, we use one bit to store the value of a variable. The use of bitmaps can facilitate the storage of relatively large maps. Considering that the number of locations that have obstacles is small, we can record only the coordinates of obstacles.We can also use a three dimensional obstacle, for instance, a ladder for the humanoid robots to move on (Xia et al., 2011).

### 2.2. Evolutionary algorithm for path planning

A basic evolutionary algorithm is used for computing certain turning points in the path planning method. The path distances are regarded as fitness values, and all the turning points on a path are collected and considered as one individual. Further, two individuals may get altered to produce a new generation or mutation. An advanced evolutionary algorithm may increase or decrease the number of turning points and makes the path relatively smooth and short (Kala et al., 2010). However, this algorithm requires a significant amount of memory to store the individual turning points as well as a considerable amount of time and a large number of generations to compute the optimal path. Therefore, this algorithm requires the use of considerably advanced hardware.

## 3. Path planning method

First, assuming that there are no obstacles in the environment, we set the minimum distance path from the origin to the destination. When the path crosses the obstacles, we set a new path for the robot. A simple greedy algorithm is used for this purpose, as this algorithm requires relatively few resources and consumes less time.

### 3.1 Set the minimum distance path between two points

The minimum distance path between any two points is a straight line; hence, we set the minimum distance path between the origin and the destination. This straight line can be expressed as follows (2):

$$aX + Y = c \tag{2}$$

By using a simultaneous equation for the two points (x,y), we can obtain the value of the variables a and c. As the minimum distance path from the source to the destination is a straight line, robots are given a simple path to follow and all we need to check for is whether there are any obstacles on this path.

### 3.2 Does the path have any obstacles?

The straight line function mentioned earlier can be expressed as follows (3):

$$aX + bY + c = 0 \tag{3}$$

While substituting a point (x,y) into function (3), we select a point that is located on the path in order to ensure that the point satisfies function (3). Hence, the storage of a map in the memory is discrete and not continuous, as shown in Figure 1.

If the robots collide with obstacles along the path, the answer will be in the range of $-1$ to 1.

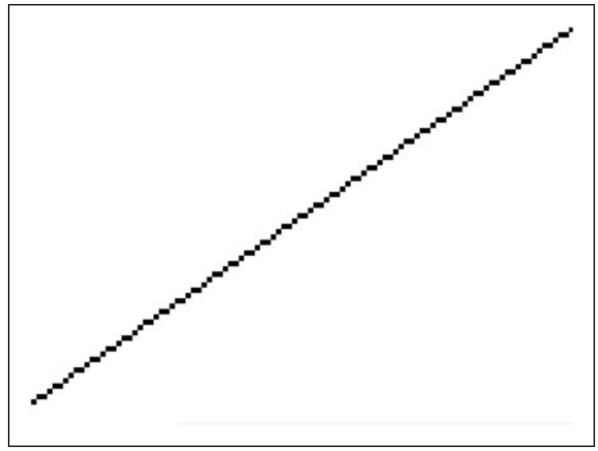

**Figure 1.** Representation of discrete memory storage.

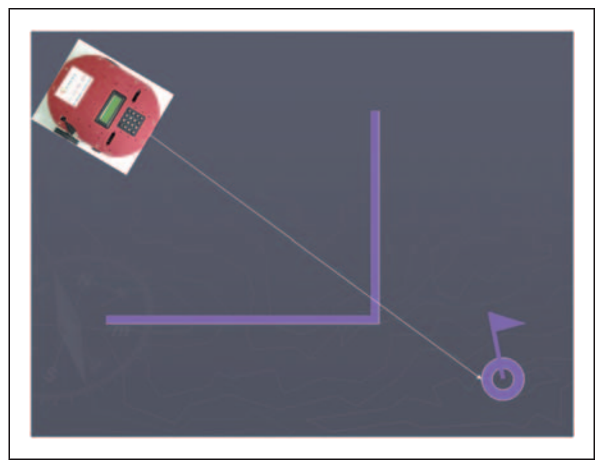

**Figure 2.** Basic path without any obstacles.

### 3.3 Set a turning point for a new path

When the determined path has obstacles, we need to compute a turning point for a new path. For obtaining the turning point, we usually search the space near the obstacle. First, we find the straight line function that crosses this obstacle and a straight line function of a perpendicular path. If the former straight line function is expressed as (4)

$$aX + bY + c = 0 \tag{4}$$

the straight line function perpendicular to this function is as expressed in (5).

$$bX - aY + k = 0 \tag{5}$$

By substituting the values of (x,y) for X and Y, respectively, we obtain the value of k and define the straight line function. We use this straight line function to search for an empty position near the obstacle. Once we find a new movable point, we set it as the turning point; we can then calculate the new path from the origin and next turning point.

### 3.4 Total flow path

Figures 2, 3, and 4 show the abovementioned three steps.

First, we do not consider the obstacles in the environment and set the minimum path from the origin to the destination, as shown in Figure 2.

Then, we set the turning point near the collision point where the path crosses an obstacle, as shown in Figure 3.

We use step 1 given below to calculate the two paths shown in Figure 4 [where path 1 is that from the original location to the turning point, and path 2 is that from the turning point to the destination]. Then, we use

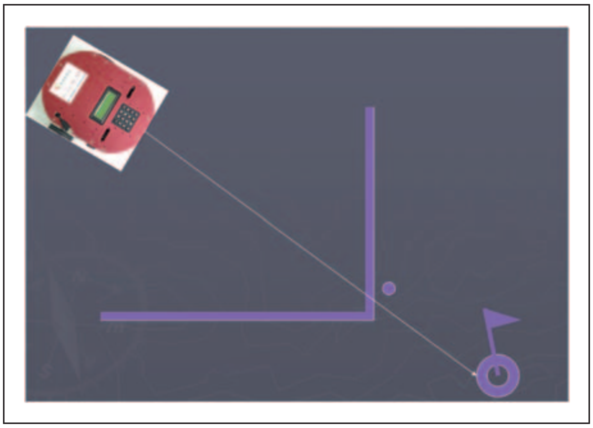

**Figure 3.** Turning point set near an obstacle.

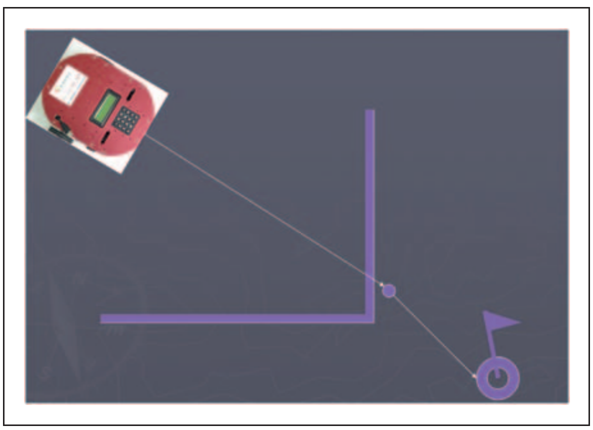

**Figure 4.** New path from the turning point.

these two paths and the turning point as the new path, as shown in Figure 4.

The evolutionary algorithm used in this study is as follows:

1. Calculate the minimum path from the origin to the destination
2. Check whether there are any obstacles on this path.
   2.1. If there are no obstacles, go to 5.
3. If there is an obstacle
   3.1. Search for an empty position near the obstacle.
   3.2. Set it up as a turning point.
   3.3. Delete the current path.
   3.4. Calculate the new path.
4. Go to 2.
5. Follow this path to the destination.

This process is illustrated in Figure 5.

We use the abovementioned three main steps in a loop and obtain the optimal obstacle-free path, as shown in Figure 5. The obtained path is expected to be as shown in Figure 6.

## 4. Greedy algorithm for path planning

The proposed path planning method does not fit the spirit of a greedy algorithm. The required algorithm needs to allow backward movement in order to delete a path, but the greedy algorithm allows only forward movement. Therefore, we need to modify the greedy algorithm suitably before using it in the study.

### 4.1 Modified algorithm

First, a path needs to be changed into a path array; then, we need to check for obstacles along the path. When the coordinates of the path array are the same as an obstacle's coordinates, we set a turning point in the nearby empty space at a certain distance. Because the robot will collide with an obstacle if the coordinates of the current location of the robot are the same as those of the obstacle, we set a collision detection range. When the robot collides with obstacles, it will move to the turning point. Hence, the modified algorithm can be defined as follows:

1. Calculate the path array from the origin to the destination.
2. Check the coordinates in the path array.
   2.1. If there is no coordinate, go to 6.
3. Calculate the coordinate in the range of the coordinate array.
4. If there are obstacles within the collision detection range
   4.1. Set a turning point in the empty space at a certain distance.
   4.2. Modify coordinates the path array after this point.
5. Go to 2.
6. End.

### 4.2. Simulation

The dimensions of the map are 200 cells $\times$ 200 cells; the origin of the map is at (0,0) and the destination at (200,199). The collision detection distance is 3 cells, and the distance of the movable empty position is 20 cells. These two distances can be changed by users depending on the environment required. We select six types of obstacles in order to simulate this algorithm and describe the processing of the method.

We use a flipped L-shaped obstacle and the path shown in Figure 7. The robot begins to move in the direction toward the destination. At location (126, 144), an obstacle is detected in the collision detection range; hence, the robot attempts to find an empty place within 20 cells of the obstacle. The robot selects the

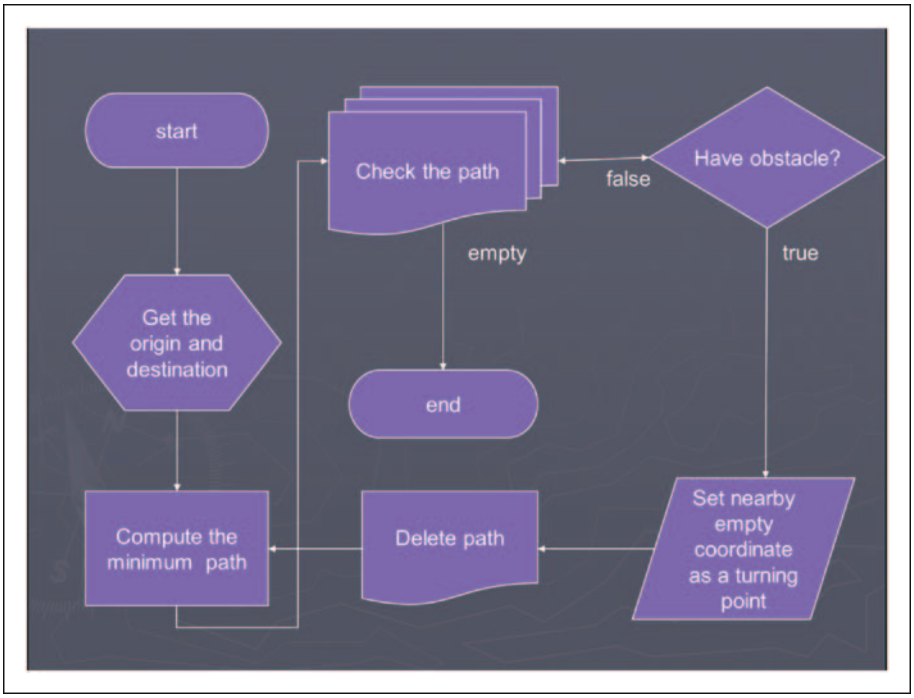


**Figure 5.** Schematic representation of evolutionary algorithm.

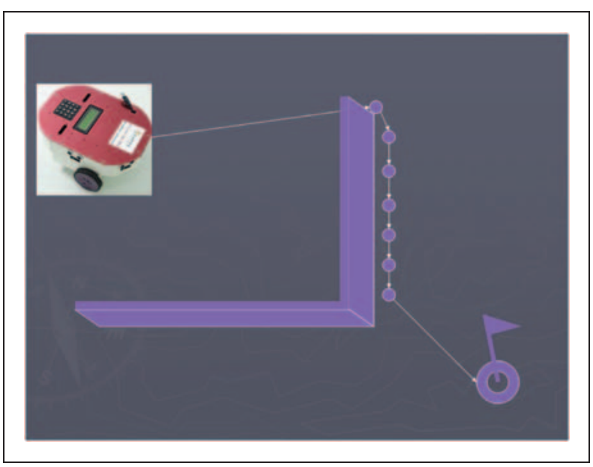

**Figure 6.** Expected path obtained using the evolutionary algorithm.

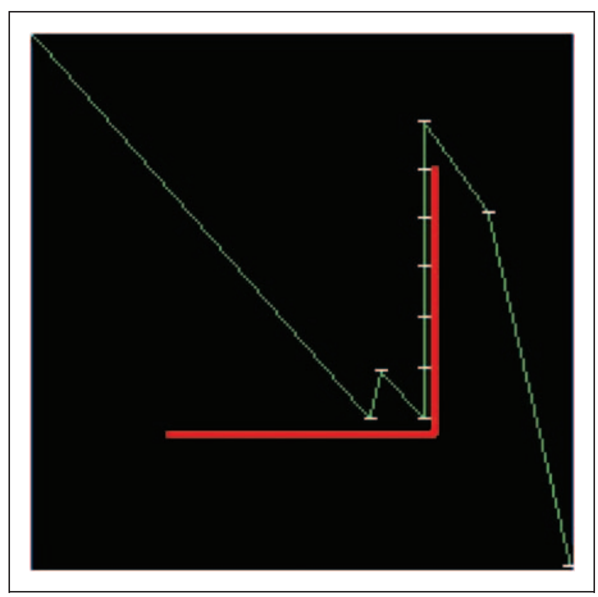

**Figure 7.** Execution of the proposed algorithm with a flipped L-shaped obstacle.

location (130, 126) because it is relatively close to the destination. If there are no obstacles around it within 3 cells of this new location, the robot continues to move toward the destination. At location (146, 144), another obstacle is detected in the collision detection range. This time, the nearby location (146, 125) is selected. The robot then moves forward from location (146, 125), and an obstacle is detected at location (146, 33). Then, the robot selects the location (170, 67) in order to bypass this obstacle and continues to move toward the destination. A total of 6.85 s is required to compute the optimal obstacle-free path in 11 rounds, and the path array is [(0, 0), (126, 144), (130, 126), (146, 144), (146, 125), (146, 106), (146, 87), (146, 69), (146, 51), (146, 33), (170, 67), (200, 199)].

Next, we consider a vertical line obstacle and the path shown in Figure 8. The robot begins to move toward the destination. At location (96, 115), an

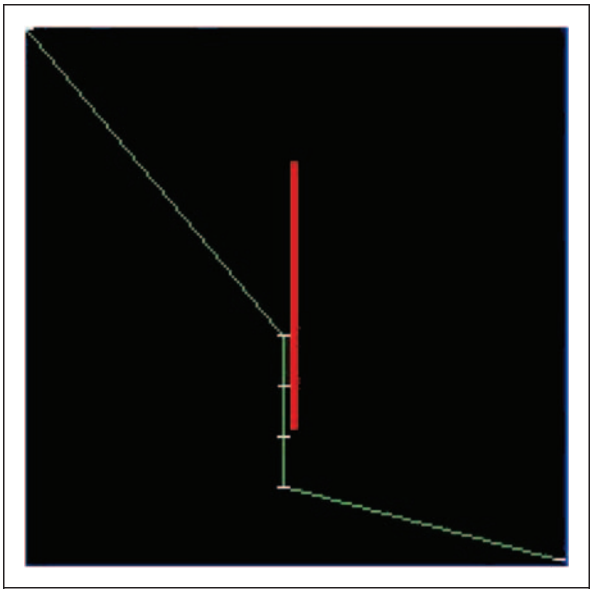

**Figure 8.** Execution of the proposed algorithm with a vertical line obstacle.

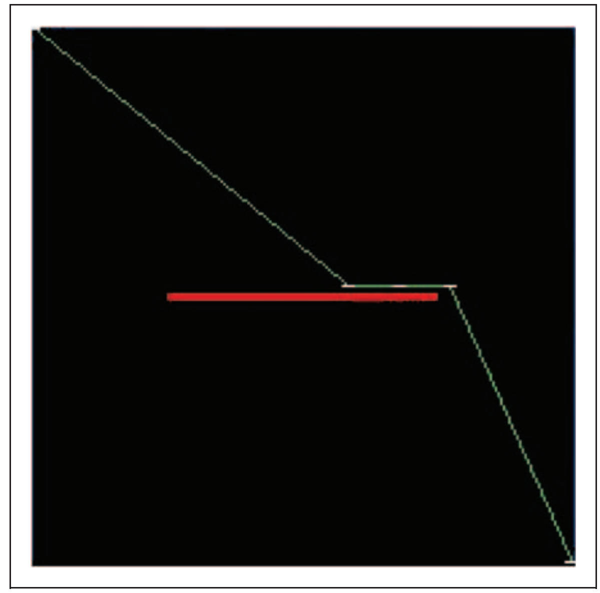

**Figure 9.** Execution of the proposed algorithm with a horizontal obstacle.

obstacle is detected in the collision detection range; hence, the robot attempts to find an empty place within 20 cells of the obstacle. The robot selects location (96, 134) because it is relatively close to the destination. When the robot moves forward from this location, another obstacle is detected at the location (96, 153). However, there are no other obstacles within 3 cells of this location. Hence, the robot then continues to move toward the destination. A total of 3.31 s is required to compute the optimal path in 5 rounds, and the path array is [(0, 0), (96, 115), (96, 134), (96, 153), (96, 172), (200, 199)].

Further, we consider a horizontal obstacle and the path shown in Figure 9. The robot begins to move toward the destination. At location (117, 96), an obstacle is detected in the collision detection range; hence, an empty place is selected within 20 cells of this obstacle. The robot selects the location (136, 96) because this location is relatively close to the destination. When the robot moves forward from location (136, 96), another obstacle is found at location (155, 96). However, there are no other obstacles within 3 cells of this obstacle. Hence, the robot continues to move toward the destination. A total of 3.13 s is required to compute the optimal path in 4 rounds, and the path array is [(0, 0), (117, 96), (136, 96), (155, 96), (200, 199)].

Next, we use a cross-shaped obstacle and the path shown in Figure 10. The robot begins to move toward the destination. At location (76, 95), an obstacle is detected in the collision detection range; hence, the robot attempts to find an empty place within 20 cells of this obstacle. The robot selects the location (78, 76) because it is relatively close to the destination. As there are no other obstacles within 3 cells of this location, the robot continues to move toward the destination. At location (96, 95), another obstacle is detected in the collision detection range. This time, the robot selects the location (96, 75) and moves from this location to location (96, 75). An obstacle is detected at location (96, 37). Hence, the robot selects the location (121, 67) to bypass the obstacle and then identifies the empty place (157, 96) that it can use to bypass the obstacle again. Finally, the robot moves in the direction toward the destination. A total of 5.24 s is required for computing the path in nine rounds, and the path array is [(0, 0), (76, 95), (78, 76), (96, 95), (96, 75), (96, 56), (96, 37), (121, 67), (157, 96), (200, 199)].

We then consider a T-shaped obstacle and the path shown in Figure 11. First, the robot selects the location (47, 66) to bypass the obstacle and moves toward the destination. At location (96, 128), an obstacle is detected in the collision detection range; hence, the robot attempts to find an empty place within 20 cells of this obstacle. Then, the robot selects location (96, 147) because it is relatively close to the destination. When the robot moves forward from location (96, 147), it detects an obstacle at location (96, 166). However, as there are no other obstacles within 3 cells of this obstacle, the robot continues to move toward the destination. A total of 2.72 s is required to compute the optimal path in five rounds, and the path array is [(0, 0), (47, 66), (96, 128), (96, 147), (96, 166), (200, 199)].

Finally, we consider an inverted T-shaped obstacle and the path shown in Figure 12, but the distance of the movable empty position is changed to 30 cells.

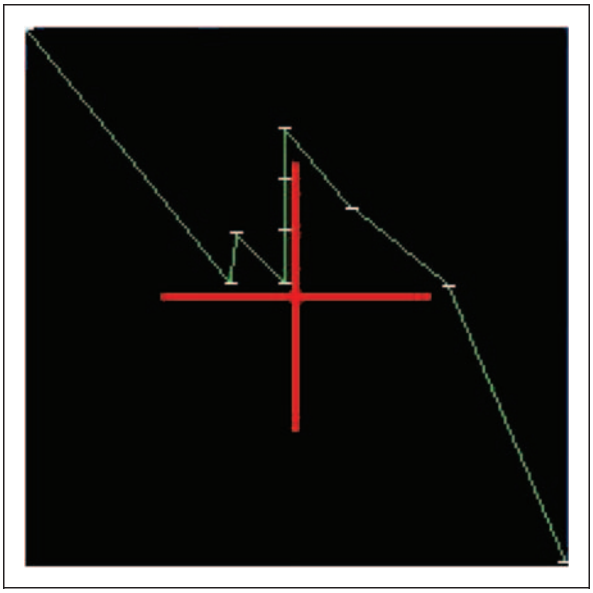

**Figure 10.** Execution of the proposed algorithm with a cross-shaped obstacle.

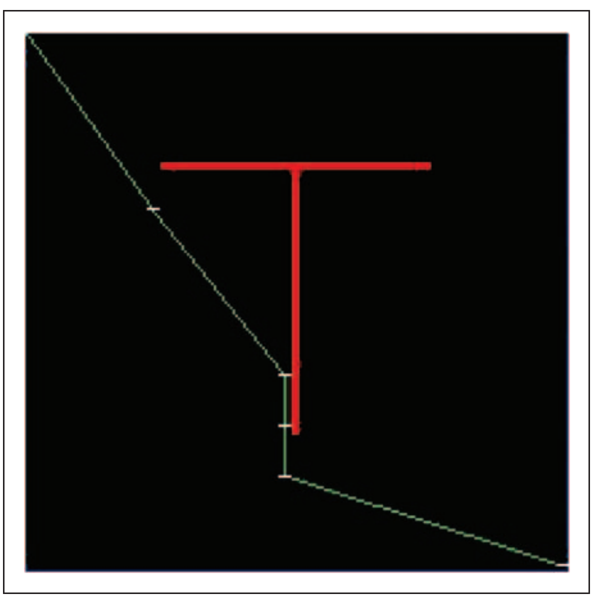

**Figure 11.** Execution of the proposed algorithm with a T-shaped obstacle.

The robot begins to move in the direction toward the destination. At location (96, 125), an obstacle is detected in the collision detection range; hence, the robot attempts to find an empty place within 30 cells of this obstacle. Then, the robot selects location (96, 94) because it is relatively close to the destination. When the robot moves forward from this location, it finds another obstacle at location (96, 36). The robot selects location (132, 77) to bypass the obstacle and continues to move toward the destination. A total of 4.37 s is

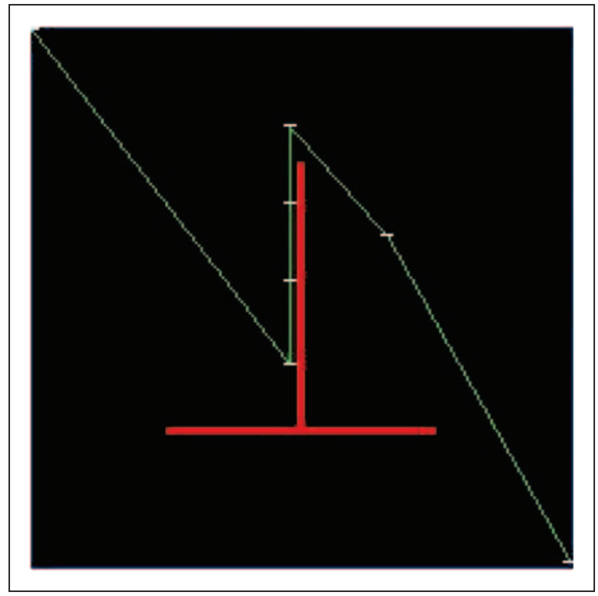

**Figure 12.** Execution of the proposed algorithm with an inverted T-shaped obstacle.

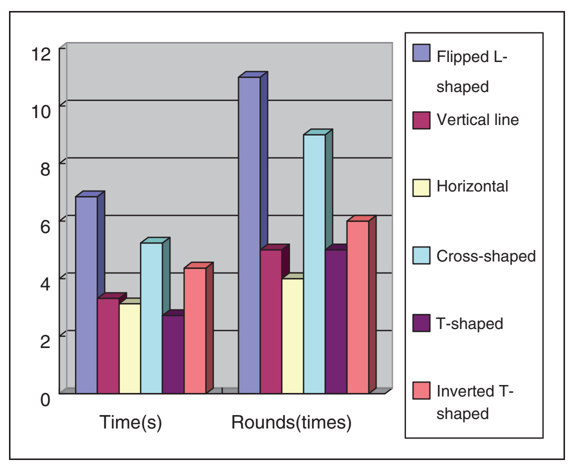


**Figure 13.** Comparison of path planning time and the number of rounds required by the proposed algorithm for different obstacles.

required to compute the optimal path in six rounds, and the path array is [(0, 0), (96, 125), (96, 94), (96, 65), (96, 36), (132, 77), (200, 199)].

Next, we compare the path planning time and the number of rounds required by the proposed algorithm for tackling different obstacles; this comparison is illustrated in Figure 13.

The proposed algorithm requires less time for path planning in a simple environment than in a complex environment. The total number of turning points required is equal to the number of rounds plus one. Hence, a better path is found in a simple environment than in a complex environment. Therefore, it can be

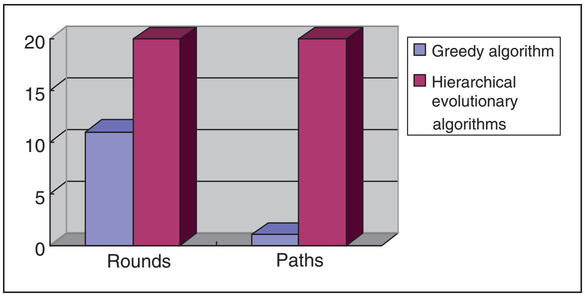


**Figure 14.** Comparison of greedy algorithm and hierarchical evolutionary algorithms.

concluded that the use of the proposed modified greedy algorithm is preferable in the case of a simple environment.

### *4.3 Comparison with hierarchical evolutionary algorithms*

Compared to the hierarchical evolutionary algorithms, the proposed algorithm uses 100 individuals to execute 100 generations in a 1000 cell $\times$ 1000 cell map (Kala et al., 2010). Because the dimensions of the map used in this study are 200 cells $\times$ 200 cells, we divided the individuals and the generations by 5 and then compared the number of rounds and the requirement for the storage of paths, as shown in Figure 14.

The greedy algorithm requires fewer rounds and a lower amount of memory for the storage of paths than the hierarchical evolutionary algorithms; this is a significant difference between them. Hence, we need to consider the computation time and storage size when solving the path planning problem of robots.

## 5. Conclusions

In reality, soft computing and artificial intelligence have been successfully applied to the natural physics and practical engineering, even in management (Hsiao et al., 2005; Chen et al., 2005, 2006, 2007, 2009, 2010, 2011, 2012; Chen, 2006, 2009, 2010, 2011, 2012; Hsieh et al., 2006; Tsai et al., 2008; Yang et al., 2008; Yeh et al., 2008, 2012; Almutairi and Zribi, 2009; Amini and Vahdani, 2009; Lin et al., 2009, 2011, 2012; Guclu and Metin, 2009; Lin and Chao, 2009; Omurlu et al., 2009; Tu et al., 2009; Tusset et al., 2009; Zhao et al., 2009; Lin and Chen, 2010, 2011, 2012; Chen and Chen, 2010; Chen and Saif, 2010; Lee et al., 2010, 2011; Li et al., 2010; Solihin et al., 2010; Chiang et al., 2010; Chiang and Wang, 2011; Cheng et al., 2011; Chu et al., 2011; Chiou et al., 2011; Chen and Huang, 2011; Kuo et al., 2011; Kuo and Chen, 2011, 2012; Liu et al., 2011, 2012; Jayaswal et al., 2011; Marichal et al., 2011; Metin and Guclu, 2011; Soundarrajan and Sumathi, 2011; Shen et al., 2011; Tang et al., 2011; Tsai and Chen, 2011; Yu et al., 2011; Lee and Chen, 2012; Su et al., 2012; Tseng and Chen, 2012; Tseng et al., 2012 Hsu et al 2011; Chen et al 2007; Liu et al., 2010; Shih et al., 2011). Moreover, many people use an evolutionary algorithm to carry out the path planning process for creating a map. Although this algorithm finds an optimal path, it requires a considerable amount of memory and significant computation time. If the robot is not required to follow the most optimal path, a greedy algorithm may be used, for example considering the authors' preliminary report (Shih et al., 2011b) instead of an evolutionary algorithm. A greedy algorithm requires less storage and computation time than an evolutionary algorithm, but the path obtained by the greedy algorithm is not the most optimal path. Hence, the use of a greedy algorithm in the case of a complex environment may not be suitable, but this algorithm can be used effectively in a simple environment.

The greedy algorithm used in this study is a basic one. The path obtained by the used planning algorithm was not good, and hence it had to be modified in order to be optimal. When we solved the path planning problem, the path distance was not the only consideration. We still need to consider other factors such as the use of hardware. Some people believe that robots will be quite advanced in the future, and hence the time complexity and data size need not be considered. However, when robots become more advanced, they will be used in micro machines such as PDAs, e-Readers, and mp4 devices. Therefore, the time complexity and data size of the computation will remain an important consideration even in the future.

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