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Research on Complete Coverage Path Planning Algorithms based on A* Algorithms

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Abstract: The complete coverage path planning algorithm based on A* algorithms for the cleaning robot in known environment is proposed in this paper, which uses A* algorithm as heuristic in the U-turn search algorithm. The idea of this algorithm is the cleaning robot clean the cleaning area from the point of origin by using U-turn algorithm, then planning of the shortest path from cleaning robot to not clean area by using A* algorithm when the robot into the dead nodes, and then the cleaning robot for sweeping along this path to not cleaning area by using U-turn search algorithm until this environment area is all covered. The simulation results show that this algorithm proposed of this paper is high coverage rate and low repetition rate.

Keywords: Cleaning robot, A* algorithm, U-turn search algorithm, complete coverage path planning.

1. INTRODUCTION

The research on intelligent robot path planning [1] technology is becoming more and more attention researchers' attention with the rapid development of artificial intelligence technology [2] and the mobile robot [3]. The research of intelligent robot path planning is divided into two aspects: the one is point-to-point optimization path planning, the other is complete coverage optimization path planning. At present, the point-to-point optimization planning is more researched by the experts at home and abroad, while the study of the complete coverage path planning is relatively less. The complete coverage path planning [4] traversal the whole area of this environment that not including obstacle in as short time as possible and with repetition rate as low as possible. The complete coverage path planning has extensive application background, and it has important significance in cleaning robots, harvesting robots, seeding robot and search and rescue robot, and so on.

According to the different mobile strategy, the complete coverage path planning can be divided into random movement strategy [5] and non-random movement strategy [6]. The random movement strategy is cleaning robot rotates an angle randomly in meet obstacles, so cleaning robot working efficiency is not high by this way, and which can finish the complete coverage of this work area only work for a long time, and the location and environment modeling also need further exploration. The non-random movement strategy controls the motion path of cleaning robot by using a kind of performance evaluation function, and the performance evaluation function [7] is the key of cleaning efficiency. The complete coverage path planning methods can be divided into the path planning in known environment and the path planning in unknown environment by according to the different environmental information. In known environment, the cleaning robot modeling and generating graph based on the known environment information, and then using the method of graph traversal to path planning; In unknown environment, the cleaning robot using their own sensing system to explore and identify the environment, and which modeling and generating graph by according to the identified information of environment, and the using the corresponding method to plan path.

This paper is structured as follows. In Section 2 we describe the basic concepts in detail. The new algorithm of the complete coverage path planning based on A* algorithm is given in Section 3. Section 4 gives experimental results of our algorithm for complete coverage path planning. Finally, we give the conclusions.

2. PRIMARY CONCEPTS AND RELATED WORKS

2.1. Primary Concepts

The complete coverage path planning is the robot traversed the whole region except obstacles reasonably and efficiently. This paper will applied A* algorithm that is more popular heuristic search algorithm to U-turn algorithm of complete coverage path planning, and to improve the efficiency of the complete coverage path planning. The specific definitions are as follows.

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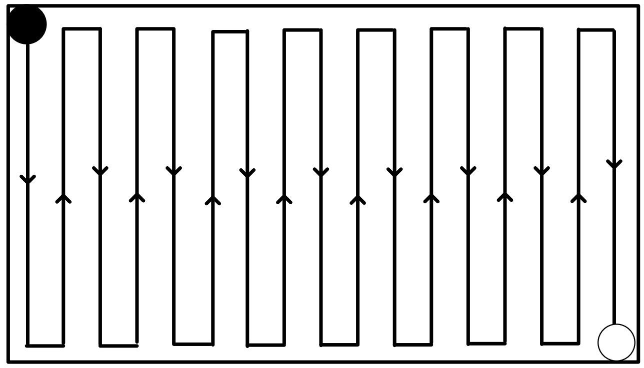

Fig. (1). The map of U-turn algorithm. It uses "●" to indicate the starting point of cleaning robot, and uses "○" to indicate the ending point position of cleaning robot. The back of the figure have the same representation.

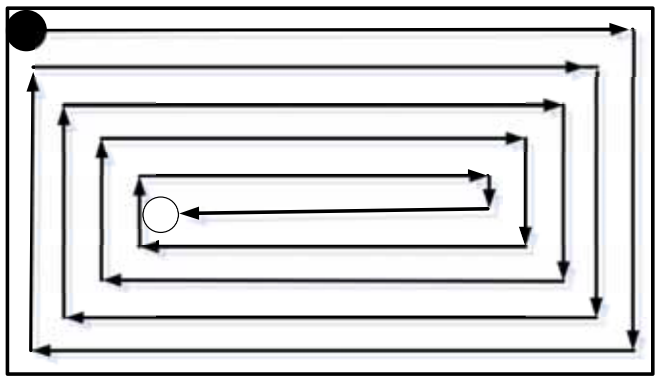

Fig. (2). The map of ISS.

2.1.1. Complete Coverage Path Planning

Definition 1 Complete coverage path planning: Given an environmental area Ψ, F is represented by the obstacle in this environment, the path L of the robot A traversal this environmental area Ψ around the obstacle is the complete coverage path planning.

In this environment area, the time of traversal and the repetition rate of traversal path are two important indexes of complete coverage path planning. The traversal time shorter and the repeat rate lower, and that the complete coverage path planning algorithm is more superior.

2.1.2. A Algorithm*

A* algorithm is one of the point-to-point shortest path planning algorithms as a heuristic search, and it is the more popular. We need to select evaluation function in the path planning based on A* algorithm, and evaluation function is used can save a lot of meaningless search and improve search efficiency in A* algorithm. It is important to the position of the valuation. And which using different valuations will have a different effect.

2.1.3. U-turn Search

The U-turn search mode of cleaning robot is to walk along a straight line starting from the edge point, and met after the border to the same direction rotating 180 degree, and then walk straight along the reverse direction. Hear the turning diameter and robot consistent L diameter. When encountering an obstacle, the robot adopts isolated method to avoid obstacle. So repeatedly until the entire area is covered, as shown in Fig. (**1**).

2.1.4. Internal Spiral Search (ISS)

The basic idea of the inner spiral algorithm is robot traverses this environment area in a certain direction. When the front of grid is not covered, the robot moves forward. If the front of grid covered already or there is obstacles, and then the robot turn right 90 degree, as show in Fig. (**2**).

The internal spiral algorithm comparison with the algorithm of this paper is cleaning robot rotate inward coverage according to clockwise. The robot moves forward when the front grid is not covered. If the front grid of robot with obstacles or have been covered, then it left or right rotation of 90 degree; If the left or right grid of cleaning robot with obstacles, then it along the original path back to the end of the left or right obstacle; If the grids of robot left and right are covered, it shows that the robot get into the dead state, at this time we use the A* algorithm to find the optimal path from this robot to not cleaning area in this paper.

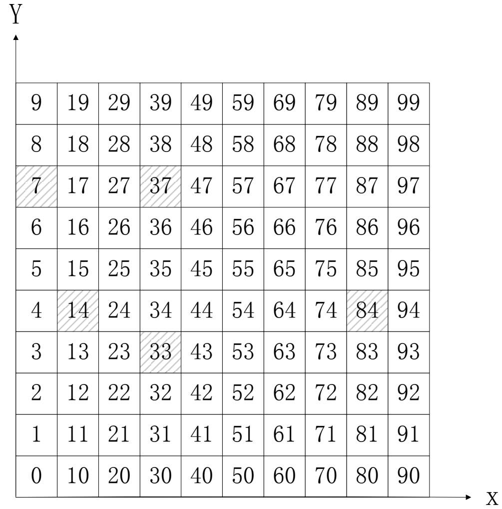

Fig. (3). Grid modeling graph.

2.2. Related Works

At present, the main complete coverage path planning methods are random covering method [8, 9], the template model method [10], Boustrophedon covering method [11], STC covering method [12] and ISC(internal spiral) [13] covering method etc. These methods have some disadvantages, such as random covering method cannot guarantee complete coverage of the environment because of the random steering of obstacle and limited battery power. At the same time, the intelligence of this algorithm is very low and repeated cleaning rate is very high. The template model method using different map and the template for complete coverage by according to the different environment, and the mismatch of the environment cannot achieve complete coverage. Boustrophedon overlay method will cause incomplete coverage because of the more obstacles. STC overlay method cannot cover a smaller area because of its grid standards. ISC (internal spiral)overlay method often leads to obstacles nearby areas cannot be completely covered. Taking into account the cleaning robot cleaning not cleaning area with the shortest path as far as possible, this paper use grid method modeling environmental information, and gives a new complete coverage path planning combined with the U-turn path planning algorithm(Boustrophedon overlay method [14], and apply A*algorithm [15] in this algorithm. And compared with this algorithm and the internal spiral method [16], and has carried on the simulation experiment by MATLAB.

3. THE COMPLETE COVERAGE PATH PLANNING ALGORITHMS BASED ON A* ALGORITHMS

In this paper, we use the grid method for modeling the environment information, and use *2* marker grids with obstacles, use *0* marker grids without obstacles. It applied A* algorithm to U-turn algorithm as new complete coverage path planning algorithm. It use U-turn way of complete coverage path planning search this area except obstacles in the grid model has been modeled, at the same time, use *1* marker girds with area covered. And then, it use A* algorithm to find a shortest path from the cleaning robot to this area on the uncovered area, and this cleaning robot for cleaning work on the uncovered area along this path by using U-turn path planning, until the whole area was covered so far.

3.1. Grid of the Environment

The grid method as a kind of modeling method is more research, and the whole area covered is divided into many small grids and mark each grid. This paper gives two kinds of marking represent the area not covered and obstacle area respectively. The establishment of environmental model with grid method put the actual room map transformation to a digital matrix, and realizes the discrete representation of the room area by mapping of the actual area and the grid area. In order to achieve the purpose of clean indoor sanitation, the objective of cleaning robot is to spend less time searching for a shortest path to clean all shadow grids. In this paper, the grid can be divided into two types, the shaded part is grid does not need cleaning and the blank part is the grid to be cleaned, and the cleaning robot finding path for cleaning work in this grid.

Definition 2 Grid in the environment: The grid in the environment is defined as $g(a, b)$, where a (a=1,2,…,n) is the line number of g's grid, b(b=1,2,…,n) is the column number of g's grid, the sampling information of this environment is a series of continuous grid set $G(g_1,g_2,\ldots,g_i)$, i=1,2,…,n is the serial number of the grid sampling.

The system uses the grid method to model the environment indoor into 10*10 environment map in this plane, and abstract the environment into a 2D grid, as shown in Fig. (**3**).

3.2. Basic Idea

The cleaning robot cleans this environment area according to the idea of U-turn algorithm. In the U-turn path planning algorithm, if the front grid of robot is the boundary and the left or right grid of it there are barriers, the robot along the original path back to the end of the left or right obstacle; if the grids of robot left and right are covered, it shows that the robot get into the dead state, at this time the robot needs to stop to wait for the next task of cleaning; at this time, if the grid of robot left and right is not covered, then this robot turn left or right 180 degree to clean in the opposite direction.

When robot reaches the dead state by using U-turn algorithm cleaning the environment information, and the grid of robot left and right is clean, at this time, take this cleaning robot as the starting point, take the not cleaning area as the target point, and it use A* algorithm to find an optimal path to this target point. In the same way, the method finds the optimal path from the current cleaning robot to the entire uncovered region. We choose the shortest path as the preferred path is clean by robot. And so on until all the uncovered area is cleaned.

3.3. Valuation Functions

In this paper, the valuations of each position can used to this valuation functions to represent, and the valuation functions is shown as follows.

$f(n) = g(n) + h(n)$ (1)

$f(n)$is a kind of evaluation of the total cost from this location to the target node in Eq. (1), that is calculated optimal path. $g(n)$ represents the actual path cost from the initial node to any n node, $h(n)$ represents the estimated cost of the optimal path form n node to the target node, that is calculate the estimated value by according to a method. From this evaluation function can be seen the heuristic information of search was embodied with $h(n)$. If the evaluation value is more and more close to the actual value and its shows that the evaluation function is better.

We set a goal node is the number g in *10*10* grid environment of this paper, the number of heuristic function from n node to the g node is defined as:

$$h(n) = |[n/10]-[m/10]|+|n\%10-m\%10| \quad (2)$$

In this formula, "[ ]"represents the integer operations, "%"represents the mod operation, "| |"represents the absolute value operation.

3. 4 U-TURN A* PATH PLANNING ALGORITHM

This paper presents a new complete coverage path planning algorithm as U-turn A* Path Planning (UAPP) algorithm. It is described as follows.

Step 1. It uses the grid method model to the clean environment of regional in the plane, and abstracts the environment information into a two-dimensional grid.

Step 2. It uses 2 to mark the grid with obstacles, and use 0 to mark the grid without obstacles.

Step 3. It uses U-turn algorithm to search the complete coverage path of this environment, and use 1 mark the grid cleaned.

Step 4. If the front grid of robot has been covered or there is an obstacle, and it turns left (or right) rotate 180 degree and then walk straight along the reverse direction.

Step 5. If the left or right grid of cleaning robot is covered and it execution rollback operation. If the left and right grid of cleaning robot are cleaned and go to step6; if the around grid of cleaning robot there is grid uncleansed and go to step3.

Step 6. It let the current cleaning robot as a starting point, and the area not cleaning as the target point, and then use A* algorithm to find out the optimal path of this area without cleaning, at this time, we choose a shortest path as the preferred cleaning path, and then cleaning robot reach the area without cleaning along this path, go to step 3; If there is area without cleaning indicates that the region has been completely covered, go to step 7.

Step 7. The algorithm finishes.

4. EXPERIMENTAL VERIFICATION

This paper has done the simulation experiment by using MATLAB software. In this environment, the grid size and the diameter of robot is similar in order to ensure the completeness of cleaning for robot.

4.1. The Example Analysis of Single Obstacle Environment

If there is a regular obstacle in this environment, the robot clean this environment by using U-turn algorithm will cause the uncovered area due to the existence of obstacles, and then the robot only along a straight line to this uncovered area and clean by UAPP algorithm, and the effect diagram obtained by it is as shown in Fig. (**4**). If we use the ISS in this environment, and the effect diagram obtained by it is as shown in Fig. (**5**). In this paper, it uses the same method to cleaning this environment from different starting points respectively. The thick black arrow lines of the effect diagram represent path cleaned robot. The fine black arrow lines of this effect diagram represent repeated cleaning area of this robot.

In Fig. (**4**), there are 95 clean grids. Using UAPP algorithm proposed in this paper to complete the whole environment area search needs 5 repeated visited nodes, as Fig. (**4**) Shows. And using ISS to complete coverage path planning need 7 repeated visited nodes, as Fig. (**5**) Shows. It is obvious that the UAPP algorithm is superior to ISS algorithm in the environment with regular obstacles.

If there is an irregular obstacles in this environment, the robot clean this environment by using U-turn algorithm will cause a number of the uncovered area due to the existence of irregular obstacles. Take this cleaning robot as the starting point, take the not cleaning areas as the target point, and it use A* algorithm to find a number of optimal paths to these target nodes uncovered region, and choose the shortest path as the preferred path as the preferred path is clean by robot from this paths, and then use the U-turn algorithm to clean

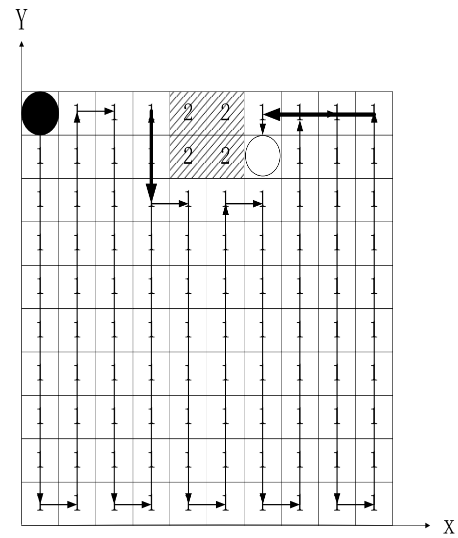

Fig. (4). The path of UAPP algorithm in the environment with regular obstacles.

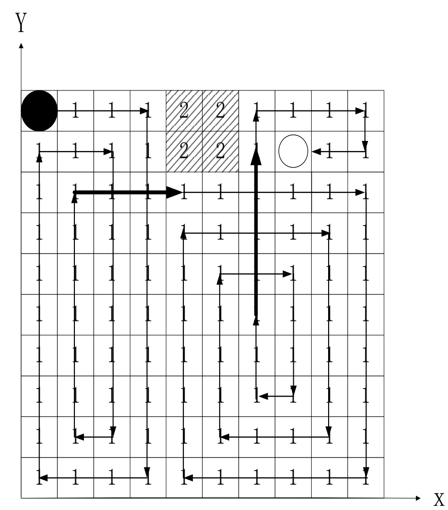

Fig. (5). The path of ISS in the environment with regular obstacles.

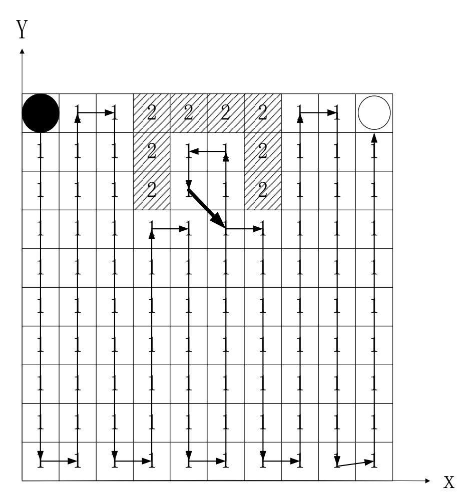

Fig. (6). The path of UAPP algorithm in the environment with irregular obstacles.

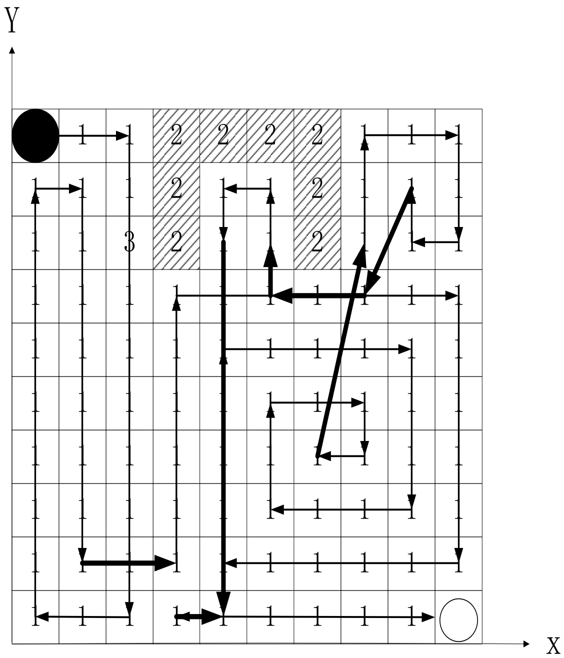

Fig. (7). The path of ISS in the environment with irregular obstacles.

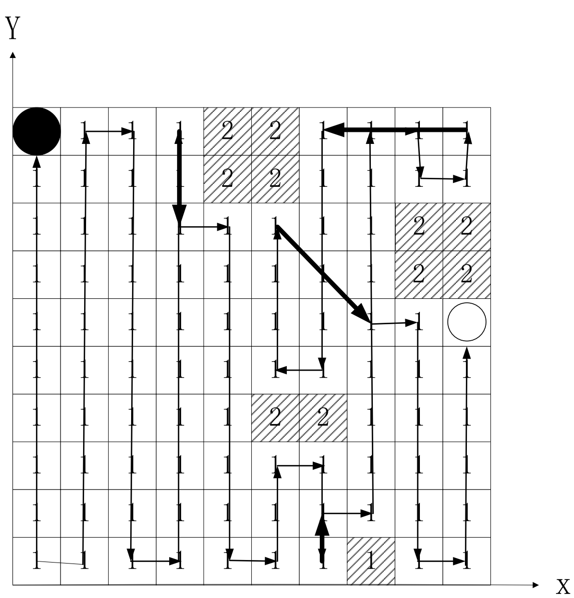

Fig. (8). The path of UAPP in the environment with multiple regular obstacles.

the uncovered area. The effect diagram using two methods are shown in Fig. (**6**) and Fig. (**7**).

In Fig. (**6**), there are 91 clean grids. Using UAPP algorithm proposed in this paper to complete the whole environment area search need 1 repeated visited nodes, as Fig. (**6**) shows. And use internal spiral method of complete coverage path planning need 20 repeated visited nodes as Fig. (**7**) Shows. It is obvious that the UAPP algorithm is superior to ISS algorithm in the environment with irregular obstacles.

4.2 The Example Analysis of Multi Obstacle Environment

If there is more than one regular obstacle in this environment, the effect diagram using the UAPP and ISS are shown in Fig. (**8**) and Fig. (**9**).

In Fig. (**8**), there are 89 clean grids. Using UAPP algorithm to complete the whole environment area search needs 8 repeated visited nodes, as Fig. (**8**) shows. Using ISS to

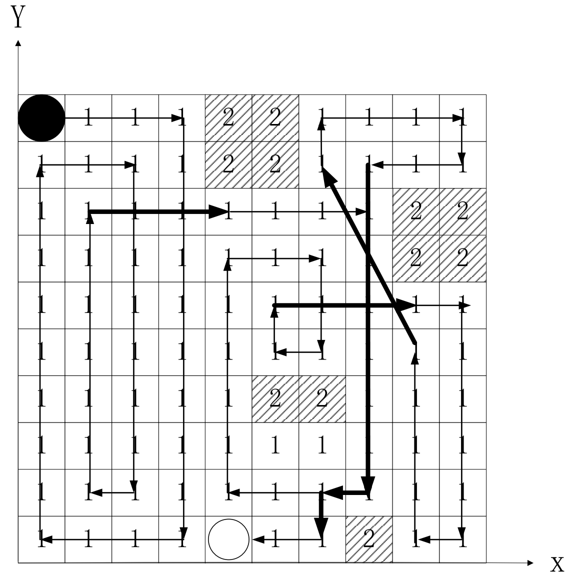

Fig. (9). The path of ISS in the environment with multiple regular obstacles.

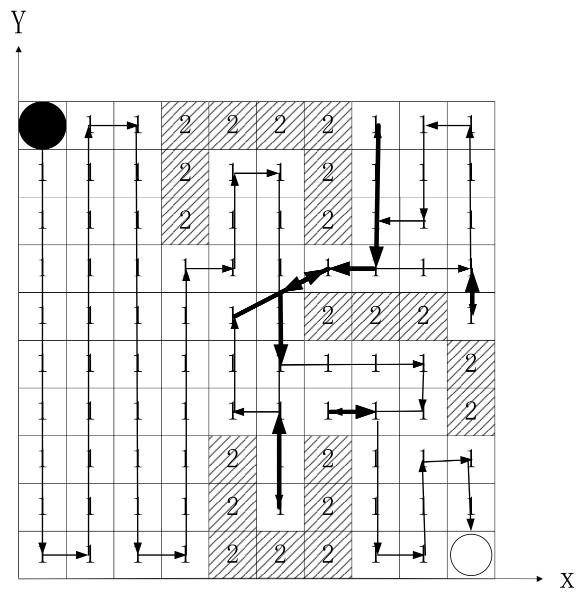

Fig. (10). the path of UAPP algorithm in the environment with multiple irregular obstacles.

complete coverage path planning needs 19 repeated visited nodes, as Fig. (**9**) shows. It is obvious that the UAPP algorithm is superior to ISS algorithm in the environment with multiple regular obstacles.

If there is more than one irregular obstacle in this environment, the effect diagrams using UAPP and ISS are shown in Fig. (**10**) and Fig. (**11**).

The Fig. (**10**) shows that UAPP algorithm can clean the larger environmental area at the first time, and can reach the full coverage of this environment in the best case. In the worst case, UAPP algorithm can reach the full coverage of this regional environmental, and which is compared with the ISS method can reach the full coverage of this environmental, and the repetition rate of this method proposed in this paper lower than the other methods and time of spend is shorter.

4.3. Repetition Rate Comparison

In this environmental area, UAPP and ISS algorithm respectively experiment in the regular obstacle environment and the irregular obstacle environment. The comparisons on repetition rate under different environment are shown in Table **1**.

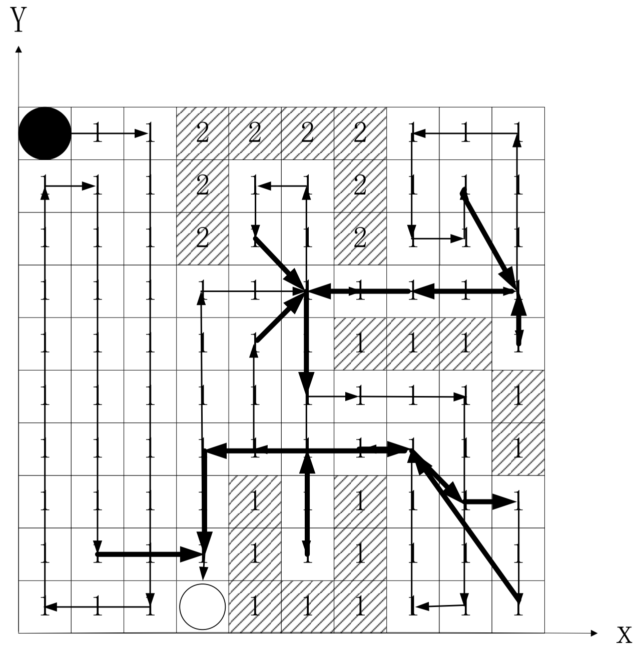

Fig. (11). the path of ISS in the environment with multiple irregular obstacles.

Table 1. Repetition rate comparison of ISS and UAPP under different environment.

	Regular Obstacles	Irregular Obstacles	Multiple Regular Obstacles	Multiple Irregular Obstacles
IIS	7%	20.4%	19.5%	26.1%
UAPP	5%	1.4%	8.85%	12.4%

It can be seen from Table **1**, the UAPP can achieve complete coverage of environmental area, and the repetitive coverage rate is low. Such as, the repetition rate of UAPP was slightly lower than ISS in a simple regular obstacles environment. In complex regular obstacles environment and irregular obstacles environment, the repetition rate of UAPP largely lower than ISS. So the UAPP has a very good application value.

CONCLUSION

This paper proposed a new complete coverage path planning algorithm that combination of the U-turn algorithm and A* algorithm. This algorithm can cleaning the uncovered area due to the existence of obstacles by using U-turn algorithm in this environment, and can achieve the complete coverage of this area. The experimental results show that this algorithm has no requirements for cleaning node compared with the internal spiral algorithm, and applicable in the environment existed arbitrary shape obstacles, and can achieve full coverage with low repetition rate.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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