Path Planning Method of Garbage Cleaning Robot Based on Mobile Communication Network

Xinyan Tan and Xiaoying Lv(✉)

Dalian University of Science and Technology, Dalian 116052, China
lvxy1986@126.com

Abstract. Aiming at many problems brought by the complex running environment, controller performance and obstacles of garbage cleaning robot, this paper puts forward a path planning method of garbage cleaning robot based on mobile communication network. Jud that initial signal rate of the mobile communication network, constructing a motion model of the clean robot, and planning the robot grasping trajectory according to the model; According to the straight path planning and turning path planning, the planning method is studied. The experimental results show that the navigation deviation of the proposed method is small, which can avoid obstacles and effectively plan the path of the garbage cleaning robot.

Keywords: Mobile Communication Network · Garbage Cleaning Robot · Path Planning · Initial Rate · Motion Model

1 Introduction

With the acceleration of urbanization, the amount of urban garbage is increasing, which poses a serious threat to the environment and public health. The traditional garbage cleaning method needs a lot of manpower, material resources and time cost, which is inefficient and has the problem of incomplete cleaning [1]. In this context, robots are widely used in industrial development to replace manual cleaning operations. With the development of society, people's lifestyles have undergone many changes, and modern scientific and technological means have been improved year by year [2]. At present, people have more and more strict requirements for the autonomy of garbage cleaning robots, and whether the path planning can be effectively completed has become one of the main identification conditions for robot autonomy detection, so the path planning of garbage cleaning robots has become the main research field of robotics [3, 4]. The garbage cleaning robot based on mobile communication network can realize remote control and data transmission through the Internet, and has the advantages of autonomous navigation and rapid cleaning. Path planning is the basis of robot's autonomous movement, so the rationality and efficiency of path planning method are directly related to the actual operation effect of garbage cleaning robot.

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At present, reference [5] proposes a vision-based detection method for underwater garbage cleaning robot YOLOv4, and selects YOLOv4 algorithm as the basic neural network framework for target detection. In order to further improve the detection accuracy, YOLOv4 is converted into a four-scale detection method; In order to improve the detection speed, the new model is trimmed. Through the improved detection method, the robot can collect garbage on its own. The detection speed is as high as 66.67 frames per second, and the average accuracy is 95.099%. The experimental results show that the improved YOLOv4 has good detection speed and accuracy. Reference [6] puts forward a beach garbage collection robot based on wireless communication, which effectively uses the Internet of Things to keep the continuous connection between the central server and the garbage disposal and collection network, relies on the system to produce accurate results, and greatly reduces the cost, thus providing a feasible solution to minimize the manpower and cost in the garbage collection process. There is always a trade-off between the accuracy, efficiency and cost of garbage collection.

However, the above methods have some defects, such as high planning complexity and easy to be disturbed by the environment, and the intelligent algorithm needs a large number of sample data to support it. Therefore, how to establish an efficient and reliable path planning method has become the research focus of the practical application of garbage cleaning robots. Combining the characteristics of mobile communication network and garbage cleaning robot, this paper proposes a path planning method based on mobile communication network. This method evaluates the initial rate of mobile communication network signal, establishes the motion model of garbage cleaning robot, and plans the grabbing trajectory based on this model. Through the methods of linear path planning and curve path planning, the research is carried out. The experimental results show that the proposed method has a small deviation in the navigation process, can effectively avoid obstacles, and successfully plan the path of the garbage cleaning robot. The path planning method of garbage cleaning robot has the characteristics of high efficiency, intelligence, accuracy, reliability and expansibility, and can better meet the needs of users.

2 Path Planning of Garbage Cleaning Robot Under Mobile Communication Network

2.1 Mobile Communication Network Signal Initial Rate Determination

In the path planning of garbage cleaning robot, the initial speed of mobile internet communication network signal is judged [7]. In the robot multi-sensor information transmission, because the motion postures of the active and passive terminals change in real time, the sensor information can start to change before reaching the optimal predicted transmission rate, and the slow start mechanism will not quickly judge the correct network bandwidth in a short mobile communication period. In order to increase the end-to-end data throughput, all wired source nodes must choose the best expected rate for information transmission after the correct network connection is established, and must make full use of all available wireless broadband and select an appropriate transmission window to establish wireless connection, but at the same time, the transmission rate determined on the transmission window cannot exceed the transmission speed used in the whole transmission link [8, 9]. At the same time, it should also prevent the speed of the sender from changing too fast to cause congestion, which will greatly reduce the performance of the whole garbage cleaning robot network system.

The process of determining the initial signal rate of the mobile communication network is as follows: firstly, the starting frequency of the source node of the mobile communication network must meet the restriction requirements, that is, the forwarding frequency determined by the starting window does not exceed the data processing frequency of the mobile communication network, so as to prevent the occurrence of bottleneck link congestion. Through the data information transmission of the source node layer, the forwarding end timely adjusts and dynamically adjusts the forwarding frequency of data packets so as to approach the effective width of the wireless network. The initial rate of the mobile communication signal is determined as shown in Formula (1):

$$P_U = R_T(n_1 + n_2 + n_3 + n_4) \tag{1}$$

In formula (1), P_U represents the communication signal transmission rate; R_T represents the number of transmissions; n_1, n_2, n_3 and n_4 respectively represent the four processes of transmitting communication signals, receiving communication signals, sending data, and inputting to the source node. Through the above formula, the available wireless bandwidth can be estimated, connected to the transport layer and fed back to the source node, and the source node sets the corresponding initial rate according to the received feedback signal.

2.2 Constructing the Motion Model of Cleaning Robot

According to the initial signal rate of the mobile communication network, the state quantity of the robot at t moment is obtained, and the pose transformation of the cleaning robot is solved, as shown below:

$$M_t = F(A_t, B_B) + \lambda \times P_U \tag{2}$$

In formula (2), A_t represents the state of the cleaning robot at t, B_B represents the control quantity, $F(\cdot)$ represents the state transfer function, and λ represents the noise generated by the cleaning robot during the movement.

Using the way of mobile communication network, the trajectory of garbage cleaning robot is optimized to make it continuous. The path of the road section can be expressed as:

$$P(o) = \sum_{i=1}^{n} \frac{L_i}{t_i} \times M_t \tag{3}$$

In formula (3), $P(o)$ represents the polynomial programming result of the o-th path; L_i represents the curve of i short path, and t_i represents the time required for the i road section. In this section, you can get the starting point and ending point of locating the search node:

$$\begin{cases} q_1(t_1) = F_1 \times P(o) \\ q_2(t_2) = F_2 \times P(o) \end{cases} \tag{4}$$

In formula (4), $q_1(t_1)$ represents the road section at the starting point q_1 at t_1 time; F_1 indicates the distance traveled at this time; $q_2(t_2)$ represents the end point q_2 section of t_2 time; F_2 represents the distance traveled during this period. Combining the whole path, can get:

$$Q(t) = \begin{cases} q_1(t) = \sum_{i=1}^{n} \left(\frac{F_1}{t_1}\right)^2, t_1 \leq t \leq t_2 \\ q_2(t) = \sum_{i=1}^{n} \left(\frac{F_2}{t_2}\right)^2, t_2 \leq t \leq t_3 \\ \cdots \\ q_n(t) = \sum_{i=1}^{n} \left(\frac{F_n}{t_{n-1}}\right)^2, t_{n-1} \leq t \leq t_n \end{cases} \tag{5}$$

In formula (5), $Q(t)$ represents the function value represented by each endpoint in the piecewise function; t_1, t_2, t_{n-1} and t_n represent the time at each endpoint. Under this preset optimization problem, the time coefficient is obtained according to a certain proportion:

$$t_n = \left(\frac{F_{\max}(t)}{K_{FGH}}\right)^{\frac{1}{n}} \times Q(t) \tag{6}$$

In formula (6), t_n represents the time required for preset optimization under the n segment in a certain proportion; $F_{\max}(t)$ represents the maximum function value under piecewise function in different time periods; K_{FGH} represents the expected value. Combined with the above formula, the search node of garbage cleaning robot can be located, so as to find the planning path.

In the process of finding the path planning results, the extended nodes are used to explore the next step, so as to reduce the complexity of the mobile communication network and the number of iterations, thus reducing the running time of the method and improving the efficiency. At this time, it is necessary to locate the search nodes of mobile communication network equipment, and the actual cost of each node is:

$$R_{EU} = \sqrt{\frac{(E_x - U_x)^2}{\left(E_y + U_y\right)^2}} \times t_n \tag{7}$$

In formula (7), R_{EU} represents the actual cost of searching nodes for each mobile communication network device; E_x and E_y represent the vertical and horizontal coordinates of the starting point, and U_x and U_y represent the vertical and horizontal coordinates of the ending point. Combined with this cost function, the heuristic functions of intermediate nodes and target nodes can be redefined and the pheromone of mobile communication network can be initialized. In the mobile communication network, pheromone

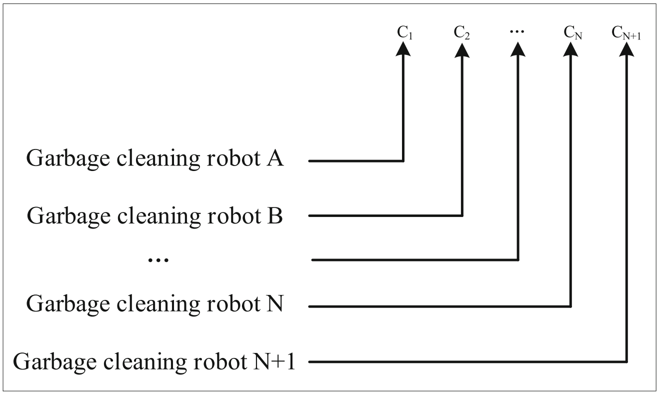

Fig. 1. Structure diagram of path information of garbage cleaning robot during driving

is generally used as the path information of the garbage cleaning robot during driving, and its structure is shown in Fig. 1.

In the path information structure of the garbage cleaning robot in the driving process as shown in Fig. 1, the kinematic constraints of the garbage cleaning robot of the mobile communication network equipment can be determined:

$$C_{N+1}(V_m, V_n) \geq 0 \tag{8}$$

In formula (8), $C_{N+1}(V_m, V_n)$ represents the constrained pose of the target area. Calculate the path planning evaluation function of the robot from this:

$$\Psi(\psi) = \sqrt{\frac{t(\psi)}{\zeta(\psi) + \mu(\psi)}} \times C_{N+1}(V_m, V_n) \tag{9}$$

In formula (9), $\Psi(\psi)$ represents the planning and evaluation function of the garbage cleaning robot within this path; $t(\psi)$ represents the time parameter; $\zeta(\psi)$ represents the minimum cost function; $\mu(\psi)$ represents the path search function. By combining the above formula, a motion model of the garbage cleaning robot can be established.

The posture transformation of the cleaning robot is related to the state quantity and the control quantity, so the motion model of the cleaning robot is constructed based on the linear state transition relation, which is expressed by the equation expression as follows:

$$\begin{bmatrix} a_l \\ b_l \\ c_l \\ d_l \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \Delta t & 0 & 0 \\ 0 & 1 & 0 & 0 & \Delta t & 0 \\ 0 & 0 & 1 & 0 & 0 & \Delta t \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \times [M_t] + W \tag{10}$$

In formula (10), $X_t = (a_l, b_l, c_l, d_l)$ represents the attitude motion model of the garbage cleaning robot, and W represents the noise predicted by the model when the garbage cleaning robot is working.

Based on the mathematical model of the cleaning robot, the pose relationship of the robot components is obtained, and the dynamic analysis of the garbage cleaning robot is realized.

2.3 Trajectory Planning of Garbage Cleaning Robot

Because the garbage cleaning robot needs to plan the trajectory path on the basis of robot dynamics when it grabs foreign objects at work, the garbage cleaning robot can efficiently grab foreign objects [10, 11].

During the operation of the manipulator of the garbage cleaning robot, the position and posture of the end effector of the manipulator is set to K_i, and the manipulator of the cleaning robot will move smoothly from K_i to the position of the foreign object target point in the rectangular coordinate space, and its target position and posture is defined as K_{i+1}, so as to realize the planning of the trajectory target. Wherein the coordinate space is shown in Fig. 2.

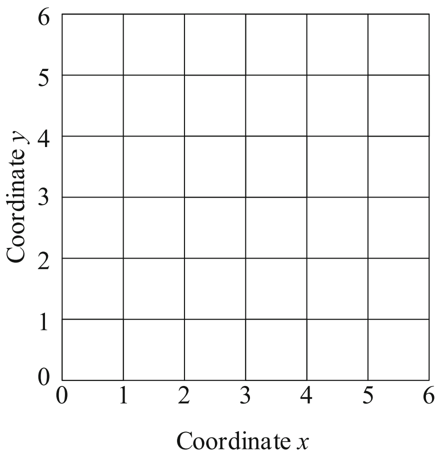

Fig. 2. Coordinate space structure diagram

According to the rectangular coordinate space structure and the kinematics analysis of the garbage cleaning robot [12], the current pose and target pose of the manipulator are defined respectively:

$$\begin{cases} T_i^0 = T_B^0 + K_i + T_B^{-1} \\ T_{i+1}^0 = T_{B+1}^0 + K_{i+1} + T_{B+1}^{-1} \end{cases} \tag{11}$$

In formula (11), T_B^0 represents the linkage system, T_{B+1}^0 represents the tool coordinate system, K_{i+1} represents the homogeneous transformation of the target pose, T_B^{-1} represents the end linkage transformation of the manipulator, and T_{B+1}^{-1} represents the homogeneous transformation of the current pose.

According to formula (11), the manipulator of cleaning robot will undergo driving transformation when it moves from K_i to K_{i+1}, that is $D(\lambda)$, which is expressed as:

$$D(\lambda) = T \times (K_i + K_{i+1}) \times \left(T_i^0 \times T_{i+1}^0\right) \times \chi \tag{12}$$

In formula (12), χ represents the time function, and T represents the total time of the robot's trajectory movement. Therefore, the formula for calculating the grasping trajectory planning of the garbage cleaning robot is:

$$D(\lambda) = L(\lambda) \times \left(T_i^0 \times T_{i+1}^0\right) \tag{13}$$

In the rectangular coordinate space, the position, speed and acceleration of the end effector of the garbage cleaning robot will be uniformly used as a time function. After kinematics analysis, the parameter values of the end effector of the robot manipulator in the current posture state will be solved, and then the parameter values of the end effector in the target posture state will be solved by inverse kinematics. Finally, the values of the two positions will be interpolated, from which the expected trajectory of the end effector of the garbage cleaning robot manipulator will be planned, and the grasping path planning of the robot manipulator will be realized.

2.4 Realize Path Planning

Based on the mobile communication network, the improved S-shaped trajectory planning method ensures the shortest planned path distance, and when the robot encounters obstacles, the software system can quickly plan the path to effectively avoid obstacles [13, 14], in which the path planning is divided into straight-line path planning and turning path planning. The details are as follows:

2.4.1 Linear Path Planning

Step 1: When the trajectory of the garbage cleaning robot from the origin to the garbage target point is a straight line, the planning value of the garbage cleaning robot's grasping trajectory is introduced, and the robot's origin O and destination G are expressed by vector equation. The formula is as follows:

$$\begin{cases} O = X_1 \times m + Y_1 \times n + Z_1 \times D(\lambda) \\ G = X_2 \times m + Y_2 \times n + Z_2 \times D(\lambda) \end{cases} \tag{14}$$

In formula (14), X, Y and Z respectively represent the coordinates of the origin and destination of the disinfection robot; m and n represent vector coefficients respectively.

Step 2: Calculate the position vector of the garbage cleaning robot at any time according to the running speed and total time of the intelligent robot by using the linear distance between the origin and the destination of the garbage cleaning robot based on the mobile communication network. The formula is as follows:

$$\begin{cases} X = \left(\dfrac{X_2 - X_1}{q}\right) \times v_X t + X_1 \\ Y = \left(\dfrac{Y_2 - Y_1}{q}\right) \times v_Y t + Y_1 \\ Z = \left(\dfrac{Z_2 - Z_1}{q}\right) \times v_Z t + Z_1 \end{cases} \tag{15}$$

In formula (15), q represents the linear distance between the origin and the destination of the intelligent robot; v represents the velocity vector of robot motion; t represents the running time of the robot in this linear distance.

Step 3: In the path navigation software system of the garbage cleaning robot, according to the position vector of the intelligent robot and the obtained garbage target point, draw the motion trajectory of the garbage cleaning robot, and then calculate the change process of the robot direction to complete the linear path navigation planning of the garbage cleaning robot based on the mobile communication network.

2.4.2 Turning Path Planning

Step 1: The garbage cleaning robot automatically navigates the planned turning path based on the mobile communication network. Firstly, the three-dimensional coordinate system of the garbage cleaning robot is converted into a two-dimensional coordinate system, and any three points that are not on the same straight line are selected to determine a turning plane, and then the plane is divided vertically [15]. The central angle of the path is determined by calculating the radian of the turning path. The coordinate system of turning path is shown in Fig. 3.

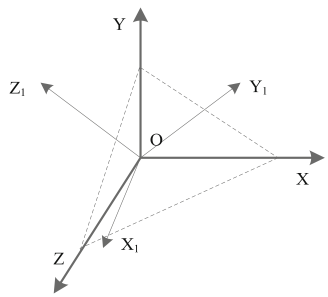

Fig. 3. Turning path coordinate system

Step 2: Introduce a transformation matrix to represent the transformation between the turning path coordinate system and the basic coordinate system. When the garbage cleaning robot based on mobile communication network moves, it will produce the basic conditions of relative coordinate system, so the transformation matrix can be obtained by rotating the coordinate axis, which is expressed by the following formula.

$$Z_{HJZ} = \begin{bmatrix} \cos\alpha & -\cos\alpha\sin\alpha & \sin\alpha\cos\alpha & X \\ \sin\alpha & \cos\alpha\cos\beta & -\sin\beta\cos\alpha & Y \\ 0 & \sin\beta & \cos\beta & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{16}$$

In formula (16), Z_{HJZ} represents the transformation matrix; α represents the angle between the basic coordinate system and the X axis; β represents the angle between the basic coordinate system and the Y axis.

Step 3: There is a certain correspondence between the basic coordinate system and the turning path coordinate system in any time period, and the central angle $\Delta\gamma$ and the total step P corresponding to the trajectory period are calculated according to the following formula. Where M is the moving length of the basic coordinate axis and R is the length of the turning path.

$$\begin{cases} Q = (X, Y, Z) \times M(X \times \alpha) \times M(Y \times \beta) \\ \Delta\gamma = \frac{v \times t}{R} \\ P = \frac{\gamma_1 + \gamma_2}{1 + \Delta\gamma} \end{cases} \tag{17}$$

Step 4: Calculate the position coordinates of the i trajectory point in the turning path of the garbage cleaning robot based on the mobile communication network according to the central angle and the total step calculated by the formula (17).

Step 5: Based on the automatic path navigation software program of the garbage cleaning robot in the mobile communication network, combined with the main controller in the hardware platform, the pose angle of the end effector of the garbage cleaning robot in the position coordinates of all trajectory points can be calculated, and then the path planning of the garbage cleaning robot can be completed. The formula is as follows:

$$G_H = Q \times P + \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} \tag{18}$$

In formula (18), G_H represents the trajectory of turning position. To sum up, the path planning method of garbage cleaning robot based on mobile communication network is completed.

3 Experimental Analysis

In order to verify the effect and effectiveness of the path planning method of garbage cleaning robot based on mobile communication network, experiments are carried out. Taking a garbage dump cleaning robot as an example, the path planning of this kind of robot is implemented by using this method, and the practical application performance of this method is tested by the planning results. Two robots with the same size and specifications were selected from the garbage cleaning robots in the garbage dump, named Robot A and Robot B respectively, and a virtual map was established, which was expressed in the form of a network. Then, according to the real-time transmitted garbage stacking information and robot position information, the path of the robot is planned by using the mobile communication network. Specifically, the goal of mobile communication network is to make robots clean up garbage as efficiently as possible, and at the same time avoid colliding with obstacles. In the process of mobile communication network, the fitness of candidate paths is determined by the length of paths and the collision situation on paths. The simulation experiment is carried out in Matlab2017 software environment, and the key parameters in the experiment are shown in Table 1.

Table 1. Setting of key experimental parameters

Serial number	Parameter name	Parameter value
1	Total number of grids in grid model/unit	900
2	Target point coordinates of robot a	(29.5,29.5)
3	Target point coordinates of robot b	(0.5,29.5)
4	Number of particles/piece	30
5	Maximum weighting coefficient	0.9
6	Minimum weighting coefficient	0.6
7	Weight coefficient ω1	1
8	Weight coefficient ω2	3
9	Normal number	0.5

Under the setting of the above experimental parameters, the robot path is planned by using this method. Navigation deviation is used as an index to evaluate the accuracy of path planning of each method. The larger the navigation deviation value, the lower the navigation accuracy of the method; The smaller the navigation deviation value, the higher the navigation accuracy of the method. The navigation deviation value consists of horizontal deviation and vertical deviation, and the calculation formula is as follows:

$$\begin{cases} H_1 = |C - c| \\ H_2 = |D - d| \end{cases} \tag{19}$$

In Formula (19), H_1 and H_2 respectively represent the lateral deviation value and the longitudinal deviation value; C and D respectively represent the horizontal and vertical values of the disinfection target point; c and d represent the horizontal and vertical coordinates of the robot terminal respectively.

Plot the navigation deviation test results of the proposed method, the method of reference [5] and the method of reference [6], and the results are shown in Fig. 4.

From the analysis results in Fig. 4, it can be known that the proposed method has high navigation accuracy and stability in the path planning of garbage cleaning robots, and its navigation deviation is smaller than that of the methods in Reference [5] and Reference [6]. The maximum navigation deviation values of the proposed method, Reference [5]

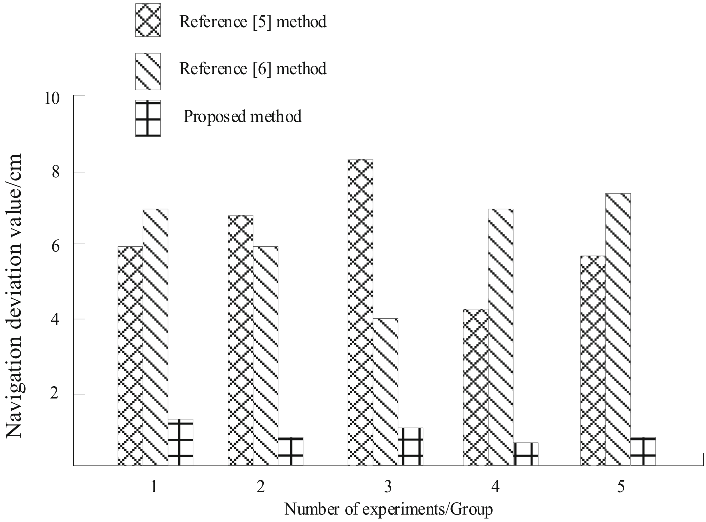

Fig. 4. Navigation deviation values of different methods

and Reference [6] are 1.2 cm, 8.2 cm and 7.8 cm respectively. With the increase of the number of experiments, the navigation deviation value of the proposed method presents a relatively stable trend. This shows that the proposed method can maintain consistent navigation performance in different scenarios and will not be greatly affected by environmental changes. However, the navigation deviation values of reference [5] method and reference [6] method fluctuate greatly and lack consistency. Therefore, for the path planning task of garbage cleaning robot, the proposed method shows a high level of navigation accuracy and stable performance. This will effectively improve the efficiency and accuracy of the garbage cleaning robot and help people better meet the needs of garbage cleaning.

Using the proposed method, the test robot can intelligently plan the obstacle avoidance path, and the result is shown in Fig. 5.

According to the results of Fig. 5, it can be confirmed that the proposed method has successfully designed and measured the intelligent obstacle avoidance path planning of the garbage cleaning robot. In the final planned cooperative path of robot, the robot can effectively avoid obstacles without changing the original optimal path. This means that the proposed method can simultaneously consider the requirements of avoiding obstacles and keeping the shortest path in the path planning of garbage cleaning robots. Through intelligent algorithm and technology, the robot can perceive and analyze obstacles in the environment in real time, and make intelligent planning according to their positions and attributes, thus realizing an efficient and safe garbage cleaning path. This intelligent planning method, which can avoid obstacles, is of great significance to the practical application of garbage cleaning robots. It not only improves the working efficiency of the robot, reduces the risk of collision and damage, but also can better adapt to the needs of garbage cleaning in different environments. To sum up, the method proposed in this paper successfully realizes the intelligent path planning of garbage cleaning robot, which

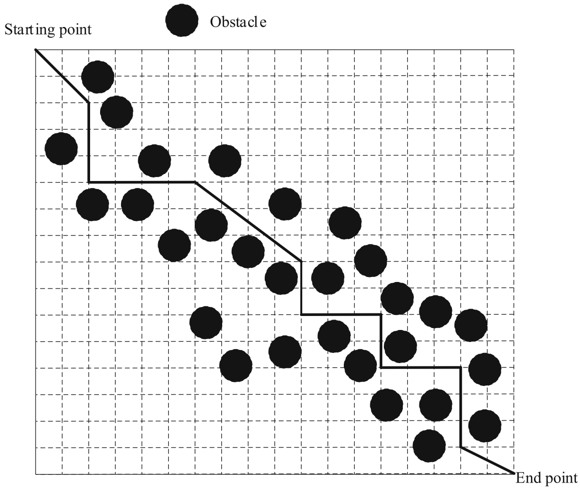

Fig. 5. Result diagram of intelligent path planning of garbage cleaning robot

can effectively avoid obstacles and maintain the optimal path, and bring higher benefits and reliability to the practical application of garbage cleaning robot.

4 Conclusion

The article proposes a path planning method for garbage cleaning robots based on mobile communication networks, and the following conclusions are obtained through research:

(1) The navigation deviation values of the proposed method are all smaller than those of the reference method, indicating high and stable navigation accuracy.
(2) The method proposed in this article can effectively plan the path of the garbage cleaning robot by avoiding obstacles in the final planned robot collaborative path.

The garbage cleaning robot studied in this paper can improve the efficiency of garbage cleaning, ensure the personal safety of operators, and achieve the basic Functional requirement of the robot. However, due to limited time, and currently only tested on the artificial layer, it has not yet been translated into actual industrial value, so further research on the garbage cleaning robot is needed. Future research work can be carried out in the following aspects:

(1) Add waterproof devices. Because the robot did not consider cleaning garbage on the water surface, water splashes may occur during the specific operation process. Therefore, it is necessary to improve the waterproof performance of the robot.
(2) Water surface path planning. Design more complex path planning schemes, calculate the most suitable route, and carry out garbage cleaning.
(3) Collect and treat according to the type of garbage. At present, the designed robot can recognize a small number of garbage types. In the future, the garbage types that can be identified by the target recognition algorithm should be added, and Waste

sorting devices should be added, so as to collect according to the types of garbage and protect the ecological environment.

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2. Research on the Prediction method and system of base station network traffic based on Smart City-2021 Basic Scientific Research Project of Education Department of Liaoning Province (Youth Project).

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