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Research on Improving the Inspection Efficiency of Substation Based on Big Data Analysis

Zhenzhen Zhou, Yunhai Song, Haohui Su, Jianing Shang, Zhengyang Luo, Qi Wang

China Southern Power Grid EHV Transmission Company Maintenance Test Center, Guangzhou, China

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ABSTRACT

With the continuous improvement of scientific and technological level, big data analysis technology has been vigorously promoted in substations. Though the big data technology can be real-time insight into the status of substation operation and inspection, how to improve the efficiency of substation inspection is still a hot topic at present. Based on this, this article through the perspective of path planning are studied, in particular, through simulation experiment to determine transformer substation inspection robot path planning algorithm system before and after the end of the work, inspection path planning system in substations by way of test results, from the results, the substation inspection robot can better avoid obstacles and complete the final inspection work along the optimal inspection path.

***Index Terms*—**Big data technology; path planning; path planning; substation.

I. INTRODUCTION

To complete the inspection work, the substation inspection robot needs to find an optimal path, so as to improve the inspection efficiency of the substation [1]. To achieve this purpose, this article design of substation inspection robot path planning system is mainly divided into two parts: System front end. Obtain the shortest distance between any two stops by a related algorithm, and store the required distance in the working solution set for the next step. It is worth noting that each element in the working solution set corresponds to a set of two stops the shortest distance, each element of the solution set corresponds to a set of the shortest distance between the two docking stations. At the back end of the system, the final order of the shortest stopping points of the patrol line is obtained by combining the solution set of the front-end work of the system with relevant algorithms. Because there may be obstacles between any two docking points, the operating idea of different algorithms is not the same to get the shortest distance, so it is necessary to carry out simulation tests on the selected alternative algorithms to select the algorithm with the best performance. Then through the way of test verification, optimal path is found out, from the root to improve the substation inspection efficiency.

II. PRE-SELECTION OF FRONT-END WORKING ALGORITHM OF PATH PLANNING SYSTEM OF SUBSTATION INSPECTION ROBOT

A. Bellman–Ford Algorithm

In the 1950s, Charlie Behrman and Lester Ford Jr. proposed Bellman–Ford algorithm as a solution to the shortest path problem [2,3]. Although the algorithm runs inefficiently, it has a remarkable effect in solving the path problem. Specifically, Bellman–Ford algorithm mainly relaxes when seeking the shortest path, with each relaxation followed by an update representing each edge. If the algorithm continues to update after N−1 relaxation operation, it indicates that the required result cannot be calculated and the operation ends otherwise [4,5]. In addition, besides solving the shortest path problem, it also plays a significant role in solving the problems of directed graph and undirected graph, difference constraint system, the existence of positive and negative wall safety, etc.

Corresponding author:
Zhenzhen Zhou

E-mail: zz93v3@yeah.net

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B. Floyd Algorithm

Floyd algorithm was proposed by Professor Robert Freud et al. [6,7]. It can solve the shortest distance problem with negative whole graph, the shortest distance problem between any two points, and the shortest distance problem of mixed graph [8,9]. Its main idea is to solve the shortest distance problem between any two points.

C. Dijkstra Algorithm

In the 1950s, Dijkstra proposed the Dijkstra algorithm to solve the problem of the path from one point to the other points in the graph [10,11]. The core idea of the algorithm is to choose a point in the graph as the starting point of the path and then spread out circle by circle until the end of the path stops [12,13]. In addition, Dijkstra algorithm will search in all directions around the starting point. When there are more points in the figure, the search area of Dijkstra algorithm will be larger and the search time will be longer, so the efficiency of the algorithm will be inhibited.

III. PRE-SELECTION OF BACK-END WORKING ALGORITHM FOR PATH PLANNING SYSTEM OF SUBSTATION INSPECTION ROBOT

A. Genetic Algorithm

Genetic algorithm (GA) is an algorithm based on the principle of survival of the fittest in nature, which is mainly used to search for optimal problems [14]. The key steps of the algorithm are as follows: (1) coding operation, (2) construction of initial population, (3) construction of fitness function, (4) selection operator selection, and (5) crossover operation. Among them, there are two main methods of variation operation, time basic variation and contravariant variation, respectively.

B. Ant Colony Algorithm

In 1992, Dorigo proposed the concept of ant colony optimization (ACO) [15]. At present, ACO is mainly used in the solution of path planning problem, business travel problem, and optimization problem.

C. Simulated Annealing Algorithm

In 1953, Metropolis et al. proposed the simulated annealing (SA) [16]. Then, in the 1980s, S. Kirkpatrick and others used the idea of annealing to solve the problems they encountered, and formed the SA algorithm. Simulated annealing algorithm mainly uses iteration to find the optimal solution randomly. In the iterative cycle of the SA algorithm, there will be a probabilistic jump, which is from the local optimal solution to the global optimal solution. At present, SA algorithm has been applied to solve production scheduling problems, path planning problems, machine learning problems, and optimization problems, but when solving path planning problems, some parameters are difficult to set, so it can not be carried out effectively.

IV. SIMULATION EXPERIMENT

The algorithm required by the two parts of the path planning system of the substation inspection robot was analyzed in the above paper. It is necessary to carry out targeted simulation on alternative algorithms in order to understand the running effect and performance of each algorithm. The simulation test is divided into two parts. The first part of the test content is: in the same environment, taking 5 groups of different numbers (22, 39, 70, 143, 277) of stop points as examples, using Floyd algorithm, Bellman-ford algorithm and Dijkstra algorithm for these five different. The number of stop groups performs the calculation of the shortest distance between any two stops and puts the resulting distance into the working solution set. The second part of the test content is to use GA, ACO, and SA algorithms, respectively, to combine the solution set of the same number of docking point groups to get the final path planning results. The indexes investigated in the simulation tests are the final length of the path and the effect of path planning obtained by Floyd algorithm, Bellman–Ford algorithm, and Dijkstra algorithm. Genetic algorithm, ACO, and SA algorithm combine the same solution set algorithm running time. In order to test the performance of the algorithm, the simulation test is conducted. There are five different stop groups. In order to avoid the contingency and randomness of test results, the simulation test tests the same number of stop groups for three times, respectively.

A. Simulation Experiment on the Front End of the Path Planning System

In the case of random docking points set in this paper, Floyd algorithm, Bellman–Ford algorithm, and Dijkstra algorithm solve the same number of docking groups for three times and gets the same result. Therefore, this paper lists only the test results of the three algorithms in one simulation test in Table I. The performance of Floyd algorithm, Bellman–Ford algorithm, and Dijkstra algorithm is judged by the length of the final route planning distance and the effect of the path planning.

By analyzing the data in Table I, it can be seen that the data of Bellman–Ford algorithm are all the smallest in the item of path minimum value indicating that Bellman–Ford algorithm has the best performance in the item of path minimum value. Although the goal of path planning of substation inspection robot is to find the shortest path, other factors should be considered comprehensively. By combining the four data in the table, it can be seen that Dijkstra algorithm is slightly larger than Bellman–Ford algorithm only in the path minimum value item, and the other three data are all the minimum. Flyod algorithm and Bellman–Ford algorithm have the same performance, but there is a big gap between Dijkstra algorithm and Flyod algorithm. For the 277 docking points with the largest number of docking points, the minimum path value of Dijkstra algorithm is 1272.49, the minimum value of path obtained by Bellman–Ford algorithm is 1230.68, and the minimum value of path obtained by Floyd algorithm is 3723.08, which shows that the performance of Dijkstra algorithm and Bellman–Ford algorithm is almost the same in this index. However, in the test of path maximum and path average, Floyd algorithm and Bellman–Ford algorithm have a large gap compared with Dijkstra algorithm. This indicates that the Dijkstra algorithm has the best comprehensive performance in a complex environment. It can also be seen from the path standard deviation that Dijkstra algorithm has the best smoothness. Therefore, this paper chooses Dijkstra algorithm for the front-end work of the path planning system.

B. Simulation Experiments on the Back End of the Path Planning System

The second part of the simulation test is to test the paths of GA, ACO, and SA algorithms. The solution set obtained from the front-end work of the planning system is combined to determine the speed of the final result. The second part of the simulation test combined all the 45 groups of solution sets obtained from the first part of the test to get the final path planning route. The running time of the three algorithms is shown in Table II.

TABLE I. TEST RESULTS OF THE FRONT-END ALGORITHM OF THE PATH SYSTEM

Number of Tests	The Algorithm Name	Path Minimum	Path Maximum	Path Mean	Path Standard Deviation
22	Bellman–ford	339.05	946.01	436.29	156.59
	Floyd	339.07	628.28	360.36	58.30
	Dijkstra	339.05	428.05	342.56	13.31
39	Bellman–ford	486.30	1946.02	724.08	372.52
	Floyd	494.81	1574.11	744.44	273.42
	Dijkstra	486.30	764.53	504.89	47.34
70	Bellman–ford	682.25	3573.31	1334.23	898.07
	Floyd	699.45	3191.95	1088.14	555.00
	Dijkstra	696.94	1414.45	752.39	146.96
143	Bellman–ford	928.21	7350.59	2460.38	2025.22
	Floyd	1437.10	7067.60	3161.39	1382.80
	Dijkstra	989.28	2512.74	1076.33	267.89
277	Bellman–ford	1230.68	7032.90	3716.64	3170.60
	Floyd	3723.08	7572.35	6124.59	1839.64
	Dijkstra	1272.49	3799.57	1430.06	454.38

TABLE II. RUNNING TIME OF BACK-END ALGORITHM OF PATH PLANNING SYSTEM

Number of Tests	The Algorithm Name	Running Time of the Algorithm (s)		
		Group 1	Group 2	Group 3
22	GA	0.076747	0.076801	0.076783
	ACO	0.098321	0.097892	0.098361
	SA	0.096972	0.097044	0.096995
39	GA	0.106920	0.106785	0.106892
	ACO	0.331062	0.331066	0.330969
	SA	0.117420	0.117367	0.117990
70	GA	0.307087	0.307117	0.307260
	ACO	0.820925	0.821130	0.821956
	SA	0.318206	0.317838	0.318065
143	GA	0.717301	0.717266	0.717496
	ACO	1.328917	1.291990	1.329980
	SA	0.7990780	0.798882	0.798942
277	GA	1.103678	1.099848	1.101402
	ACO	1.528954	1.59947	1.529978
	SA	1.219324	1.220013	1.219247

GA, genetic algorithm; ACO, ant colony optimization; SA, simulated annealing.

By analyzing the data in Table II, it can be seen that in the three groups of tests with five different number of docking points, when the number of docking points is the same, the running time of the genetic algorithm is the shortest. Therefore, it can be concluded that among the alternative algorithms for the back-end work of the path planning system, the GA is the fastest to complete the solution set of front-end work of the combined system. In the case of 277 docking points, the convergence curves of GA, SA, and ACO algorithms in one group of tests are shown in Fig. 1.

As can be seen from Fig. 1, the GA begins to converge at about 30 generations and completes the convergence at about 100 generations. Although the SA algorithm began to converge earlier, it did not converge until about 400 generations. The ACO also failed to converge in 1000 generations. The convergence graph once again proves that the performance of GA is optimal, so this paper chooses GA for the back-end work of path planning system.

V. ALGORITHM OPTIMIZATION

Through the above simulation experiments, it can be seen that the path planning performance of Dijkstra algorithm is the best. When designing the substation inspection robot path planning system, the parameters to be considered in this paper are not only the path distance and the path planning effect, but also the running time of the algorithm. If the running time of the algorithm is too long, it does not meet the requirements of the inspection work. According to the above analysis, although Dijkstra algorithm has superior performance in path planning, the central idea of Dijkstra algorithm is to spread out from the starting point circle by circle, and the algorithm stops running when the diffusion reaches the end point. In addition, the algorithm searches in all directions around the starting point. Therefore, there will be some problems in the actual use of Dijkstra

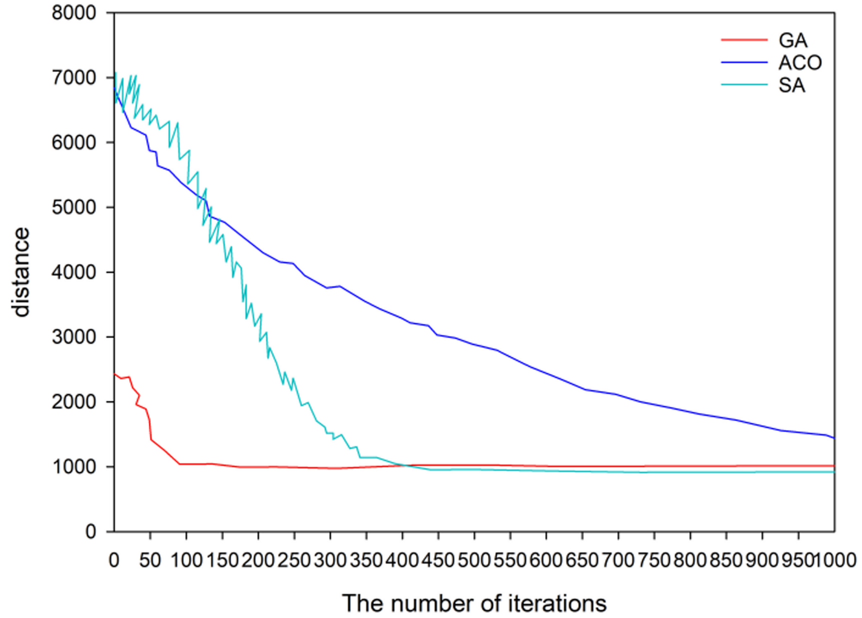

Fig. 1. Convergence of the back-end algorithm of the path planning system at 277 docking points.

algorithm. The main problem is that Dijkstra algorithm is not suitable for the situation that the graph contains a large number of points. There are a large number of points in the figure, which will make the search content of Dijkstra algorithm to increase, the running time to be longer, and the storage space occupied by the algorithm to be larger after the algorithm is run. In view of the existing problems of Dijkstra algorithm, the Dijkstra algorithm will be improved here to make it more suitable for the path planning system of substation inspection robot. Therefore, this paper uses the method of limiting the search area of Dijkstra algorithm to improve Dijkstra algorithm. It can be realized in three steps. First, the starting point and the end point that need to be planned are all included in the same quadrant. Second, the starting point and the endpoint that need to be planned are, respectively, included in the two adjacent quadrants. Third, the starting point and finishing point that need to be planned are respectively included in the two diagonal quadrants. Through optimization, the improved Dijkstra algorithm can be selected according to the different positions of starting and ending coordinates, can better adapt to the different planning conditions, can accurately limit algorithm search area according to different planning conditions, will not affect planning and performance of the algorithm, and can guarantee the results of the algorithm for optimal results.

VI. PATROL PATH PLANNING TEST

A. Workflow of Path Planning System

The working flow of the path planning system studied and designed in this paper can be summarized into seven steps. First, obtain the environment map of the path planning required. Second, input the data of map transformation, positioning information, and the information of starting and ending points of patrol inspection into the path planning program. Thirdly, the improved Dijkstra algorithm is used to solve the shortest distance between any two docking points. Fourth, check whether all the stops have been traversed. If not, return to step 3. Otherwise, proceed to the next step. Fifth, the combination of genetic algorithm is used to improve the solution set obtained by Dijkstra algorithm, and the combination with the shortest path distance is obtained as the global shortest path. Sixth, judge whether the global shortest path obtained by the genetic algorithm is less than the preset maximum. If it is greater than the preset maximum, the output path does not exist. Otherwise, execute the next step. Seventh, the IPC parses the path planning route into motor control commands and sends them to the underlying controller when the robot is running, and the underlying controller sends the commands received to the motor controller to control the robot to run according to the path planning route. The details are shown in Fig. 2.

Through the study of the algorithm part above, this paper determines that the algorithm used in the front-end work of the path planning system of the substation inspection robot is the improved Dijkstra algorithm. The algorithm used for back-end work is GA. The path planning system designed in this paper only contains global path planning in the traditional sense. Since substations rarely contain dynamic obstacles, the system does not conduct in-depth research on local path planning. In this paper, a robot dynamic window approach (DWA) is used for local path planning when the substation inspection robot is executing the inspection route. All the algorithms involved in the path planning experiment were run under the ROS robot operating system, and the various sensor data acquisition programs carried by the robot were run under the Ubuntu 16.04 operating system. The main purpose of the performance test of the path planning system of the substation inspection robot is to test the operation effect of the path planning system designed in this paper in different path planning environments and to judge whether the designed path planning system can meet the requirements of different substation inspection route planning. In order to comprehensively test the performance of the robot path planning system for station inspection, the test content is mainly divided into four parts: map acquisition, robot positioning, path planning, and execution of inspection routes. The support column in the environment will serve as the stop point during the inspection, and the feasible area in the environment is the underground parking lot road.

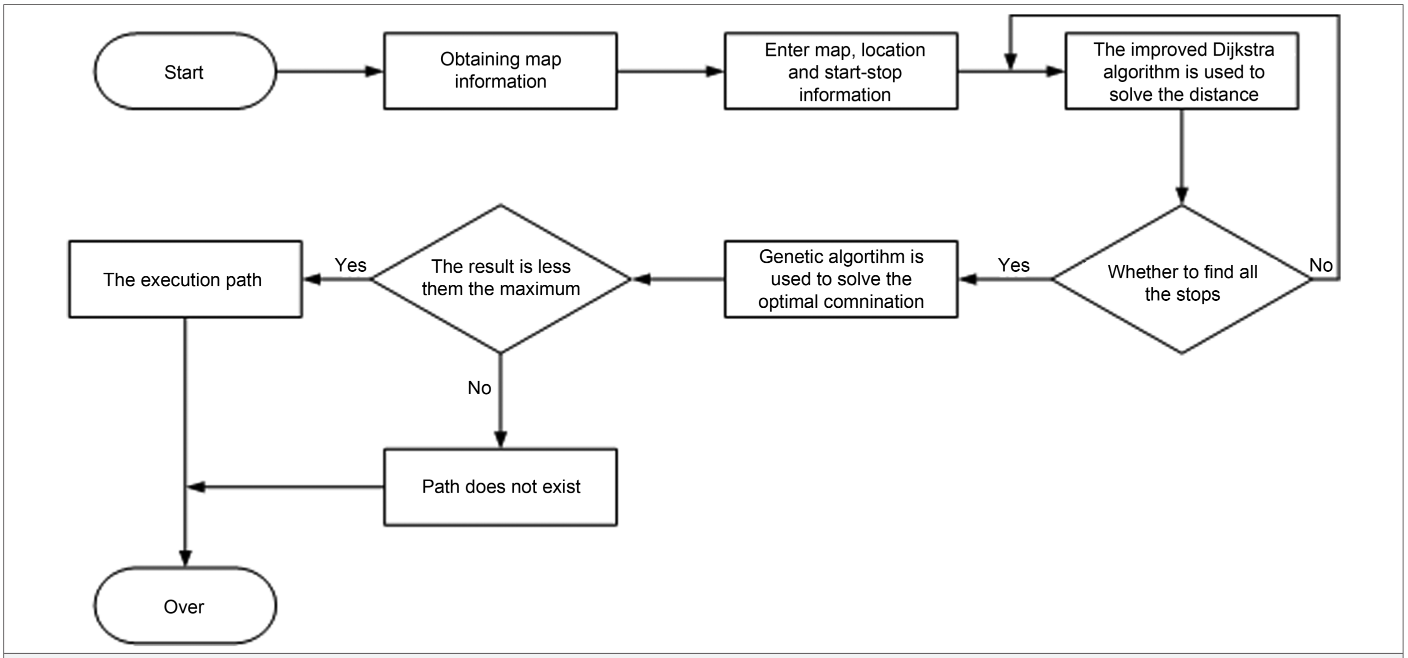

Fig. 2. Workflow of the path planning system.

When the path planning system of the substation inspection robot designed in this paper works, it needs to access the database to obtain the substation environment map of path planning. Because the test in this paper is carried out in the simulated substation environment, there is no prior map that can be directly accessed and obtained by the path planning system. The starting point and end point of the test environment patrol in the path planning set in this paper are all located in the lower right corner of the environment. There are 14 stopping points in the test environment, and the obstacle area is divided into 4 blocks, namely, 2 L-shaped obstacle areas, 1 Z-shaped obstacle area, and 1 rectangular obstacle area. The map of the path planning test environment obtained by the path planning system from the self-built map database is shown in Fig. 3. Because the number of stops in the test environment is large, it is specified here that the stops are numbered horizontally starting from the top left corner of the test environment.

As can be seen from Fig. 3, the map clearly reflects the number and distribution location of docking points in the test environment and also clearly reflects the number, location, and shape of obstacle areas. It provides accurate information for the work of the path planning system. After obtaining the environment map, the path planning system needs to obtain the position of the robot in the map so as to carry out the corresponding path planning. The robot was parked at the starting point of the inspection and the positioning information of the robot was displayed in the map using the adaptive Monte Carlo positioning technology. The positioning effect of the robot at the starting point of the inspection is shown in Fig. 4. From Fig. 4, it can be seen that the robot has accurate positioning and correct posture.

Although the simulation tests of alternative algorithms have been carried out in the previous paper, the performance of each algorithm in actual use cannot be truly explained. In addition, the designed path planning system works together with the two algorithms to get the final path planning results. Therefore, in the actual test, this paper selects one algorithm from the two groups of alternative algorithms respectively to carry out path planning for the test environment. The path planning results of different combinations for the test environment are shown in Table III.

It can be seen from the data in Table III that the shortest path distance obtained by the three algorithms for front-end operation is the same due to the small number of stops in the environment. For the same front-end working algorithm, the system running time of the GA combination is the shortest. For the same back-end working algorithm, the system combined with the improved Dijkstra algorithm has a shorter running time. In addition, the performance of the

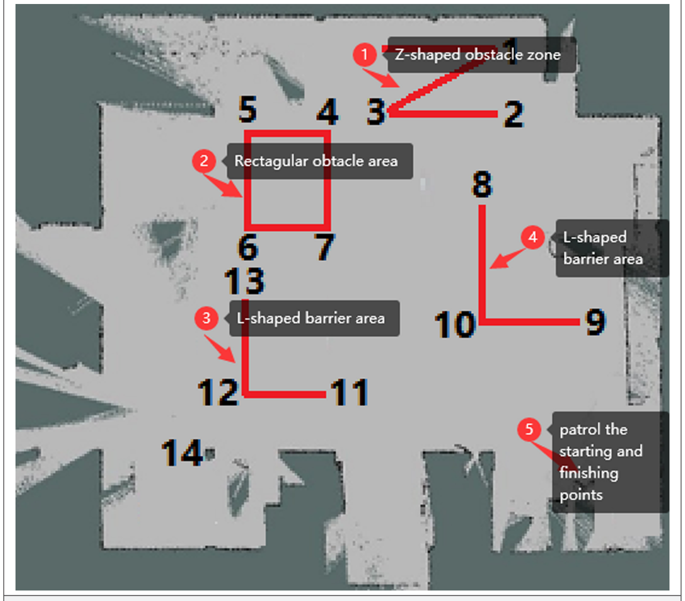

Fig. 3. Path planning environment map acquisition.

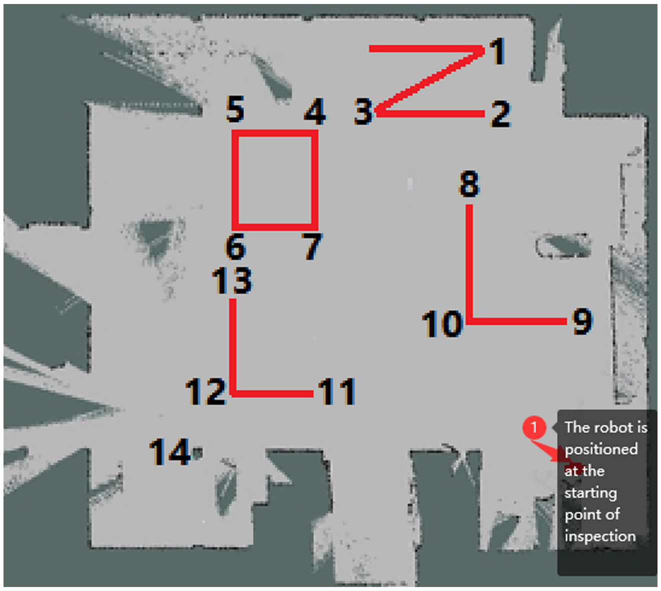

Fig. 4. Positioning diagram of a robot at the starting point of inspection.

improved Dijkstra algorithm is the same as that of the simulation test. This paper combines the improved Dijkstra method and GA to write the program substation inspection robot path planning. Combined with Fig. 3 for map information and Fig. 4 for robot positioning information, together with the inspection starting point and end point information input transformer substation inspection robot path planning process, it is concluded that the theory of path planning line as shown in Fig. 5.

The path planning program makes the path planning for the test environment, obtains the shortest inspection route, and defines the

TABLE III. TEST RESULTS OF COMBINATION OF DIFFERENT ALGORITHMS

Algorithm Combined	Shortest Path Length (m)	System Uptime
Floyd + GA	185.2	1.940
Floyd + ACO	185.2	1.968
Floyd + SA	185.2	1.956
Bellman–ford + GA	185.2	5.772
Bellman–ford + ACO	185.2	5.783
Bellman–ford + SA	185.2	5.779
Dijkstra + GA	185.2	3.657
Dijkstra + ACO	185.2	3.673
Dijkstra + SA	185.2	3.657
Improved Dijkstra + GA	185.2	3.515
Improved Dijkstra + ACO	185.2	3.534
Improved Dijkstra + SA	185.2	3.528

GA, genetic algorithm; ACO, ant colony optimization; SA, simulated annealing.

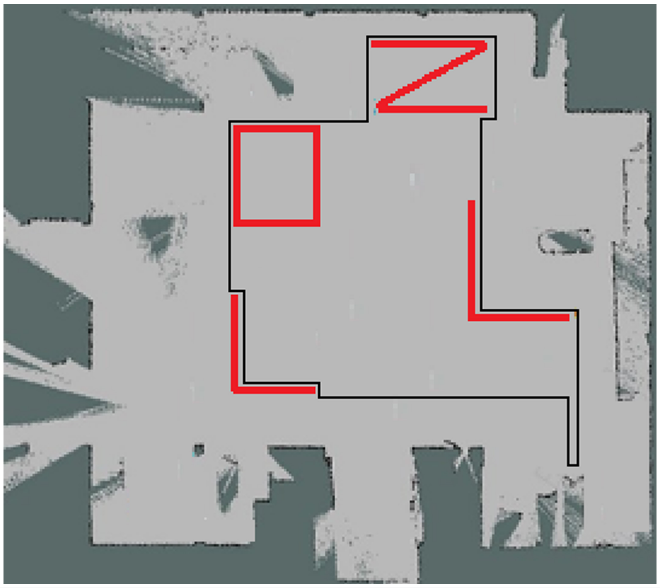

Fig. 5. Theoretical path planning route.

sequence of robot inspection stopping points. After the planning result is obtained by the path planning program, the IPC parses the obtained path planning route into commands that can be received by the motor controller, which are sent to the underlying controller when the robot is inspecting the route to control the robot to walk according to the path planning result. The actual running route of the substation inspection robot according to the route planning in the test environment is shown in Fig. 6.

As can be seen from Fig. 6, the line bends when the robot walks between two stops. There are two reasons for this: on the one hand, because the performance of the robot itself is unstable, after a long time of operation, the robot will have a problem of deviation from straight-line driving. At the same time, when the industrial computer

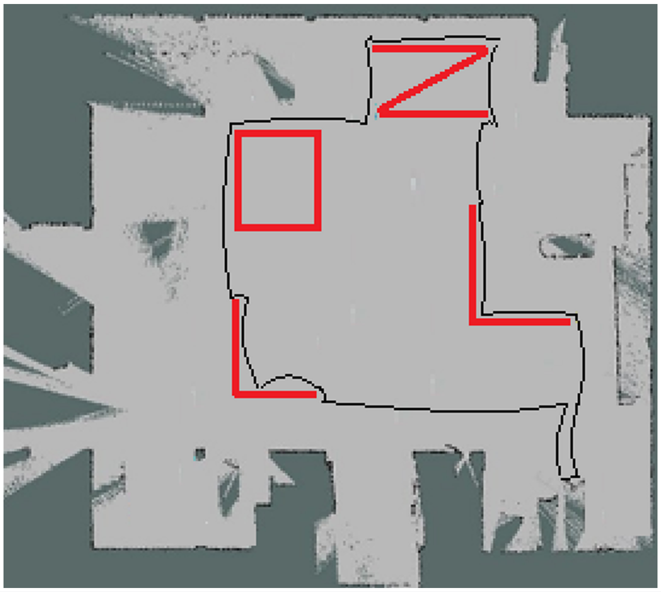

Fig. 6. Actual driving routes.

analyzes the path planning results, there will be some errors in the algorithm, and the accumulation of these errors will also cause the robot to deviate from the straight line. On the other hand, the DWA algorithm corrects the running direction of the robot after the robot deviates straight, so that the robot returns to the correct driving route. The combination of these two causes produces this bending in the actual path of the robot. Although the actual driving route of the robot has a lot of bending compared with the theoretical route, the overall effect meets the requirements of path planning. The robot inspected each stop point in strict accordance with the inspection route in order, and there was no missed inspection, wrong stop point, and no collision with obstacles in the inspection process.

VII. CONCLUSION

In general, this paper first preselects the working algorithms of the front and back end of the substation inspection robot path planning system and then determines the working algorithms of the front and back end through simulation experiments, which are Dijkstra algorithm and GA, respectively. Second, the shortcomings of the front-end algorithm are identified in the simulation experiment, and Dijkstra algorithm is improved and optimized to make up for this deficiency. Finally, the path planning system performance test is carried out, including experimental environment acquisition, robot positioning, theoretical, and practical path planning. Among them, through the acquisition of the experimental environment, it is found that the map clearly reflects the number and distribution location of stops in the experimental environment and also clearly reflects the number, location, and shape of obstacle areas. Through the positioning experiment, it is found that the robot designed in this paper has accurate positioning and correct posture. Through theoretical and practical path planning experiments, it can be known that the robot does not have collision problems during the experiment and provides the shortest inspection path. However, in the actual path experiment, the robot will have bending problems when walking between two stops. But on the whole, the robot can inspect each stopping point in strict accordance with the inspection line in order, and there is no missed detection, wrong stopping point, and no collision with obstacles in the inspection process, which has a good inspection effect and can be promoted in practice. Therefore, in future in-depth research, the author will focus on the optimization of robot performance, so as to better meet the actual inspection needs and be accepted by the broad field.

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Zhenzhen Zhou received a master's degree from the Beijing University of Aeronautics and Astronautics in 2010. He is a senior engineer. He is working in China Southern Power Grid EHV Transmission Company Maintenance Test Center. He is interested in intelligent identification and artificial intelligence.

Yunhai Song has received a master's degree from the South China University of Technology. He is a senior engineer. He is working in China Southern Power Grid EHV Transmission Company Maintenance Test Center. He is interested in intelligent identification and artificial intelligence.

Haohui Su has received a bachelor's degree from Chongqing University. He is an engineer. He is working in China Southern Power Grid EHV Transmission Company Maintenance Test Center. He is interested in robotics and artificial intelligence in 2014.

Jianing Shang has received a master's degree from the South China University of Technology in 2011. He is a senior engineer. He is working in China Southern Power Grid EHV Transmission Company Maintenance Test Center. He is interested in online monitoring and artificial intelligence.

Zhengyang Luo graduated from the South China University of Technology in 2012. He is working in China Southern Power Grid EHV Transmission Company Maintenance Test Center. He is interested in online monitoring and artificial intelligence.

Qi Wang has received a doctor's degree from the South China University of Technology. He is a senior engineer in 2009. He is working in China Southern Power Grid EHV Transmission Company Maintenance Test Center. He is interested in direct current technology.