A path planning algorithm research for seeing eyes robot based on visibility graph algorithm

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Abstract

This paper presents a new indoor path planning algorithm for seeing eyes robot using the RFID system. Through combination of UHF radio frequency identification system and low radio frequency identification system to realize accurate positioning for robot. New algorithm combines the idea of visibility graph algorithm with A* search algorithm, which not only improves the efficiency of searching but also guarantees the feasibility of path planning at the same time. The simulation verify the effectiveness and feasibility of the method.

Keywords: path planning, seeing eyes robot, visibility graph algorithm

1 Introduction

Path planning is an important element of seeing eyes robot system, which can fall into two types: First, global path planning, information on the surrounding environment is completely known for path planning; Second, local path planning, information on the surrounding environment is completely unknown or part unknown for path planning. In this paper, we objective is to build an indoor robotic guide for the visually impaired, so the best choice for us is global path planning. Global path planning involves two basic problems are environment modelling and search strategy. For environment modelling the typically method is visibility graph, which need less modelling time and Smaller storage space. When accurate localization information is obtain hardly, this algorithm can made robot to achieve the target point. Visibility graph use similar polygon instead of obstacles which in surrounding environment to make a map, and then utilize straight lines that not intersection with obstacles polygon in map to connect initial point, target point and obstacles polygon vertex. These lines are "lines-of-visibility" and the endpoint of lines-of-visibility are "points-of-visibility". The visibility graph is consist of lines-of-visibility. Once the map is generated, the robot computes and follows the optimal path to destination autonomously with search strategy. But visibility graph algorithm lack of flexibility and have highly complexity. When initial point and target point changed, the robot need to reconfiguration the map [1]. In our strategy, the new algorithm combines the idea of visibility graph algorithm positioning with A*, which not only improves the efficiency of searching but also guarantees the feasibility of path planning at the same time. It is used heuristic means to enhance the environment adaptability and improve the real-time of visibility graph algorithm. The simulation verify the effectiveness and feasibility of the new algorithm.

2 Environment model

2.1 HARDWARE

In this paper, we use a independent design seeing eyes robot for the application object, which consist of four layers yakeli board. The robot has three wheels, one universal wheel in front and two driving wheel in the back, 8 ultrasonic sonars in the front, two infrared sensor on the both sides, a Siemens PLC, a voice module, a radio frequency identification module, and is equipped with two stepping motors that control by PLC. Figure 1 shows the integral structure of seeing eyes robot.

FIGURE 1 Integral structure of robot

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2.1 ENVIRONMENT MODEL CREATION

We use a radio frequency identification (RFID) module to obtain rang data of the surroundings. The RFID module consist of a radio frequency identification reader and several RFID tags. The radio frequency identification reader mounted on top of the robot. These RFID tags can be attached to obstacles in the environment and stored the information of the obstacles such as global coordinates, feature points and so on. They do not require any external power source or direct line of sight to be detected by the RFID reader. They are activated by the spherical electromagnetic field generated by the RFID reader with a radius of approximately 1.5 meters. Each tag is programmatically assigned a unique ID.

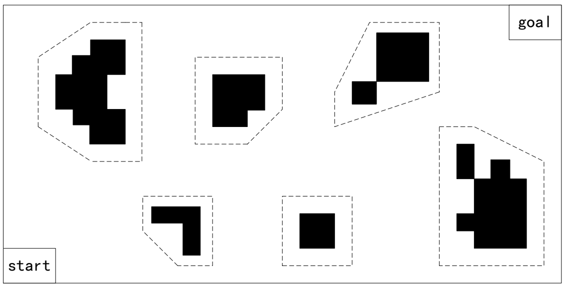


FIGURE 2 Mapping of environment model

As it can be seen in Figure 2, we use similar polygon instead of obstacles in the environment. Because of seeing eyes robot simplified to a point of 2D coordinates, obstacles polygon should be enlarge the object regions by $\omega/2 + a$, where ω is the robot width and a is the positional uncertainty of the robot (currently, 15cm) [2]. We only consider the obstacle polygon which is convex polygon and edge number less than seven. Those complex obstacles, such as concave polygon or roundness and so on, should be expansion to the convex polygon which accord with the requirements. Once the feature points of the obstacle polygon are known, we can record the information of the obstacle. During this process, we can record the information of the obstacles in environment to make a map. We should storage all points-of-visibility which in addition to itself of each feature point for path planning.

3 Indoor of robot localization

Because of the superiority to obtain the information of environment, the RFID system is very suitable for robot localization. But this system gained accurate localization information hardly, that it is easy by environmental influences [3]. In our method, we combine the uhf RFID module with low-frequency module, which reduce uncertainty of localization information due to effect of environment. We will introduces this method for the following aspects. First, the uhf RFID tags were attached to obstacles in the environment and stored the information of obstacles and the global coordinates of label. Second, the uhf RFID reader which mounted on the robot get the environment information, such as feature points of obstacles global coordinates of labels and received signal strength indicator (RSSI), by read the RFID tags in environment [4]. Because of the environmental influences is largely for RSSI, median strategy used to reduce this influences. By this strategy, the RFID reader collect n values of RSSI for a tag, and then these values be accorded to order of from big to small. The intermediate value is considered as the measurement result. Once the measurement result were obtained, we can make the RSSI value into distance value:

$$d = 10^{(ABS(RSSI)-A)/(10*n)}, \quad (1)$$

where A is the RSSI value when the distance from the reader to the tag one meter (currently, –45.8), and n is the attenuation coefficient of signal which because of the environmental influences (currently, 3). At a time, the reader receive many information of the tags in the environment. We choose three tags as nodes for localization which distance from the robot more recently, that the relative distance between tag and the robot is closer, the influence to robot localization is greater. Because of the complexity of environment, the estimated of distance between tag and the robot is greater than the actual one [5]. As can be seen in Figure 3, if three nodes' coordinates are $p_1(x_1, y_1)$, $p_2(x_2, y_2)$, $p_3(x_3, y_3)$, the estimated of distance values between tags and the robot are r_1, r_2, r_3, we used p_1, p_2, p_3 as the center of circle and used r_1, r_2, r_3 as the radius to painting circle.

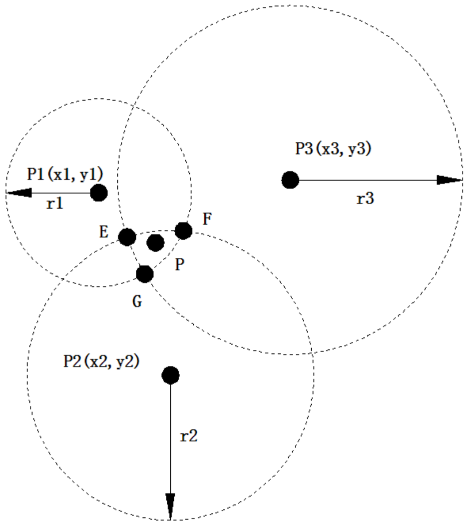


FIGURE 3 Location method

We were use triangle centroid localization algorithm to get the global coordinates of the robot in environment. In this method, the robot location is in two phases: First, we should calculation the three feature points coordinates which are the points of intersection of three circles and must in the overlap area of the three circles at the same time. And then, the position of robot is the centre of mass of tri-angular, which the three vertices of the triangular are the three feature points. To sum up, we can find out the global coordinates of point $E(x_e, y_e)$ using the Equation (2). In a similar way, we can obtain the global coordinates of point $F(x_f, y_f)$ and point $G(x_g, y_g)$. As indicated above, we can get the global coordinates of the point $P\left((x_e + x_f + x_g)/3, (y_e + y_f + y_g)/3\right)$, which is the position of seeing eyes robot:

$$\begin{cases} \sqrt{(x_e - x_1)^2 + (y_e - y_1)^2 \leq r_1} \\ \sqrt{(x_e - x_2)^2 + (y_e - y_2)^2 = r_2}. \\ \sqrt{(x_e - x_3)^2 + (y_e - y_3)^2 = r_3} \end{cases} \quad (2)$$

In the similar way, we can obtain the global coordinates of the point $P_1\left((x_{e+1} + x_{f+1} + x_{g+1})/3, (y_{e+1} + y_{f+1} + y_{g+1})/3\right)$ in other time. If the direction of the robot is θ. We can get this value as follows:

$$\theta = arctan\frac{(y_{e+1}+y_{f+1}+y_{g+1})/3-(y_e+y_f+y_g)/3}{(x_{e+1}+x_{f+1}+x_{g+1})/3-(x_e+x_f+x_g)/3}. \quad (3)$$

Then, we can layout low-frequency RFID tags in the environment which as a signpost. The low-frequency RFID reader were installed in the bottom of the robot for read the global coordinates which stored in the low-frequency RFID tags as the current coordinates of the robot, that reduce the location error which produced by the above localization algorithm and the robot move. Figure 4 show the layout of the low-frequency RFID tags in each intersection, that the read rang of the low-frequency RFID tags is small (currently, 10cm). In this manner, each tag apart to 20cm, and like this the robot can read the tags whether direction it passed through the intersection. If the robot read only to a tag, we used the global coordinates of this tag as the current coordinates of the robot. If the robot read two tags at the same time, we used the midpoint of the two tags as the current coordinates of the robot, for example, the robot read tag 1 and tag 2, the coordinates of the robot are $\left((x_1 + x_2)/2, (y_1 + y_2)/2\right)$. And if the robot read three tags, we used the center of mass of tri-angular, which the three vertices of the triangular are the three tags, as the current coordinates of the robot. For example, the robot read tag 2, tag 3 and tag 5, the coordinates of the robot are $\left((x_2 + x_3 + x_5)/3, (y_2 + y_3 + y_5)/3,\right)$. The location error of the robot were control within 10cm by this strategy.

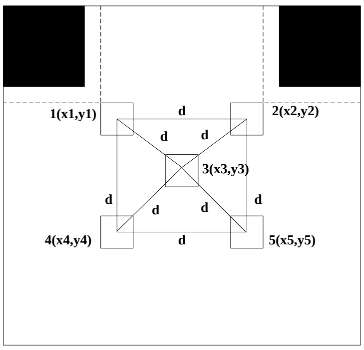


FIGURE 4 Mapping of low frequency tags

4 Description of the algorithm

4.1 THE RELATIVE POSITION OF LINE SEGMENT AND OBSTACLES

In the path planning process, we need to determine whether the desire line in conflict with obstacles in the environment [6]. In our strategy, as can be seen in Figure 5, if the desire line is the line segment SG which the starting point is S and the end point is G, we need to judgment whether S in conflict with the obstacle $ABCDE$. First, we should to work out the distances which between point S and the each feature of the obstacle are d_1, d_2, d_3, d_4, d_5 Second, we will make this distances to sorting by length and choose two feature points which distance from the S recently. Then, we need to judgment whether the line SG in conflict with the obstacle boundary line which the endpoint contain the two feature points. As shown in Figure 5, we need to judge whether the line SG in conflict with the lines AE, AB and ED. Obviously, if they are conflict that the line SG is in conflict with the obstacle; and if they are not intersect that the results is on the contrary. Therefore, the problem that whether the line SG in conflict with the obstacle is transformed into judge whether the line in conflict with the lines AE, AB and ED. As shown in Equation (4), the lines SG, AE, AB and ED were depicted as linear equation:

$$Ax + By + C = 0. \quad (4)$$

We can get the distance between points x, y and a line as follows:

$$d = (Ax + By + C)/\sqrt{A^2 + B^2}. \quad (5)$$

We can find it easily, in the coordinate system which as shown in Figure 5, that if the point is located in the top of the line, the value of d is less than zero, and if the point is located in the below of the line, the value of is greater than zero. Using the above relationship, if d_a is the distance between point A and line SG and d_e is the distance between point E and line SG, when $d_a * d_e < 0$ that the line SG is in conflict with the line AE; when $d_a * d_e = 0$ that the line SG is in conflict with the line AE and the node is the obstacles feature points, because of the line SG and AE only intersection one point and the obstacles were enlarged, so that the line AE not to interfere in the line SG; when $d_a * d_e > 0$ that the line SG is not in conflict with the line AE. In the similar way, we can judge whether the line SG in conflict with the line AB and line ED. Then we can judge whether the line SG in conflict with the obstacle.

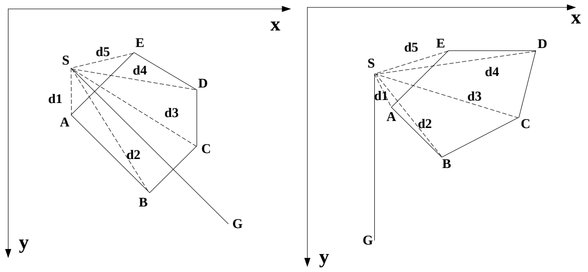


FIGURE 5 Verdict for relative of line SG and obstacle

4.2 VERDICT FOR POINTS-OF-VISIBILITY

In path planning process, when the change of the starting point and goal point, we need to search out new points-of-visibility for it. Therefore, we proposes a judgment method to judge whether a feature point of obstacles is the points of visibility for any point in space. We can find it easily that when obstacles polygon edge number less than seven, the number of the feature points of obstacle which can be the points of visibility for any point in space are no more than four, and the four points that distance from the point in space recently. Obviously, when without taking into consideration other obstacles in the environment, if the distance between the point in space and the feature point is shortest, and this feature point must be the points of visibility for the point in space [7]. In our strategy, the verdict for points of visibility in two phases: First, we only considerate one obstacle, if one feature point of the four points are not the points of visibility for the point in space, that the line of the feature point attach to the space point must be in conflict with the obstacle boundary line which the endpoints contain the nearest feature points. Therefore, we get the relative position which the line of the feature point attach to the space point and the obstacle boundary line which the endpoints contain the nearest feature points by the above method, and choose the feature points which are the points of visibility for the space point. Second, we need to judge whether the lines of this feature points attach to the space point in conflict with other obstacles in environment. If they are intersect, the feature point is not the points of visibility for the space point, and if they are not intersect that the results is on the contrary.

For example, as can be seen in Figure 6, the four points are point E, point F, point D and point A. Then, we need to judge whether the lines MF, MD and MA in conflict with the lines EF and ED. We can find that point E, point F and point D are the points of visibility for point M. And then, we should to judge whether the lines MF, MD and ME in conflict with other obstacles in the environment. Finally, we find that the points of E and D are the points of visibility for point M.

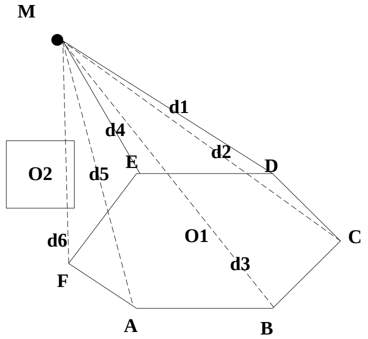


FIGURE 6 Verdict for points-of-visibility

4.3 THE ALGORITHM OF PATH PLANNING

A^* is a typical heuristic search algorithm in artificial intelligence, which uses a valuation function to estimate the weights of each node of the best, and work out the shortest path in the state-space [8]. In this paper, we should collect environment information by radio frequency identification module and voice module, and then combined with A^* algorithm for proposed a path planning algorithm. The algorithm processes as the following:

1) Create a two-dimensional environment model.

2) By UHF radio frequency identification module combined with low-frequency radio frequency identification module, the robot gets the current coordinates as starting point of S, and then obtain the information of the target point G by voice input functionality of voice module.

3) Search the feature points which can be the points of visibility for point S in the environment model.

4) Starting point of S joined the open list (open list is like a shopping list, and the path may through the point of it contain or may not be), as the current point. This article begins to search by formula 6 which as the valuation function.

$$f = g + h, \tag{6}$$

where the value of g is the actual value which is the travelled distance of from the starting point along the path to the current point. The value of h is the estimated value which is the euclidian distance of the current point to the target point. If the current point coordinates are (x_d, y_d) and target point coordinates are (x_m, y_m), you have:

$$h = \sqrt{(x_m - x_d)^2 + (y_m + y_d)^2}, \tag{7}$$

5) The current point was switched to the closed list (closed list saved all points that do not need to check again), and removed from the list of open. Then, we need to judge whether the feature points of obstacles which are the points of visibility for current point in the closed list. If in, we should skip over this point. Instead judge whether the feature points of obstacles which are the points of visibility for current point in the open list. If does not in, we are to the current point as its parent node for calculation

out its value of g, h and f and this feature point will joined in to the open list. If in, we should check new path whether more excellent by g value (g value is smaller, the path is better). If more excellent that we should change the parent node of the point to current point and update its value of g, h and f.

6) Judge whether the open list is empty, and if the open list is empty that the path does not exist, the algorithm ends.

7) Take the point which in the open list and the value of f is minimum as current point. And judge whether current point is the points of visibility for target point, if it is, we are to the current point as the parent node of target point for calculation out its value of g, h and f, and the target point joined in to the open list, the path is finding, end of the algorithm; otherwise go to step 5.

8) Save the path. Along every point of the parent point from the target point move until it is back to the starting point, and save the experienced points into the form of an array, reverse the order of the array, and then the array is the path.

4.4 PERFORMANCE ANALYSIS OF ALGORITHM

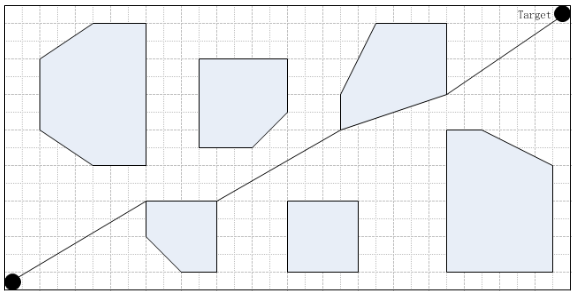
In this paper, we focus on the advantages and disadvantages of visibility graph algorithm, that proposed a path planning algorithm for the seeing eyes robot. This algorithm provides the method for judge the relative relationship of arbitrary points and the feature points of obstacles. The method ensure that path planning without need to refactor visual map when the starting point or target point is changed. Real time the path planning algorithm based on visibility graph are poor [9]. Such as the typical path planning algorithm of Dijkstra [10] based on visibility graph, it calculates the shortest path to each node to all other nodes, the main characteristics are use the starting point for the centre to the outer layers expand, until the expansion until the target point. Because of traverse a lot of nodes, its efficiency is very low. The new algorithm combines the idea of visibility graph algorithm with $A*$ search algorithm, and use of heuristic search approach greatly reduces the number of search nodes, that not only improves the efficiency of searching but also guarantees the feasibility of path planning at the same time.

5 Experimental debugging

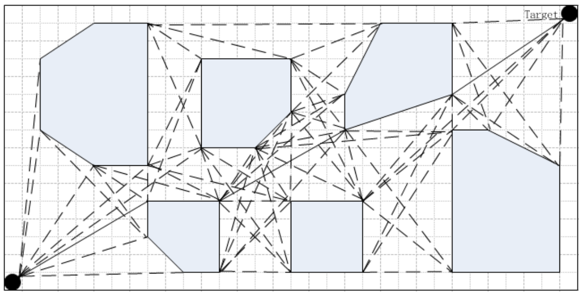
In the same of environment, we conducted simulation contrast test for the new algorithm and Dijkstra algorithm in MATLAB. We get the same path, but the new algorithm search time obvious is less than Dijkstra algorithm and the efficiency superior than the latter. And that the new algorithm can immediately again planning out effective path without need to refactor visual map when the starting point or target point is changed, but Dijkstra algorithm can't. As shown in Table 1 for the survey results of many experiments, Figure 7 are the find path of this article algorithm and Dijkstra algorithm, thus it can be seen that the new algorithm is better than Dijkstra algorithm.

TABLE 1 The time of search path

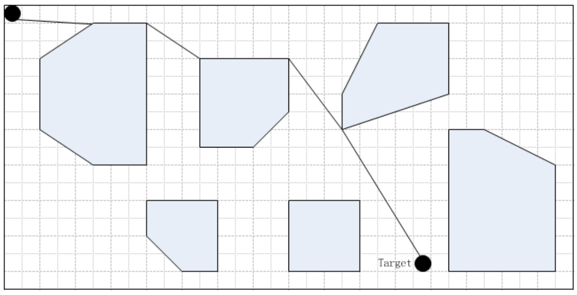
	minimum	maximum	average
New algorithm	0.4560s	0.8650s	0.6605s
Dijkstra algorithm	1.3550s	1.9460s	1.6505s



a) The path were found by the new algorithm



b) The path were found by Dijkstra algorithm



c) The path were found when the starting point or target point is changed

FIGURE 7 search path

Using the programming to the new algorithm to do the experiment, test sites and seeing eyes robot such as shown in Figure 8. In the process of moving, the robot getted the target point information by voice module, the system of robot will immediately planned an optimal or sub-optimal path which from the current position of the robot to the target point, and moving along the path until it reach the target point. Through the experiments that generate the executable path, meet the run-time requirements of robot, verify the viability and effectiveness of the algorithm.

FIGURE 8 Indoor environment experiment of robot

6 Conclusion

This article combines advantages of RFID module and voice module which on the data acquisition, first the robot gets the orientation of itself by UHF radio frequency identification module combined with low-frequency radio frequency identification module; then create the obstacles map by the idea of obstacles expansion and visibility graph; and then obtained the information of target point by voice module; finally use the search algorithm of $A*$ to search out the path which connection the starting point and target point. Experiments have shown that, the new algorithm which not only improves the efficiency of searching but also guarantees the feasibility of path planning at the same time.

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