Journal of Computers Vol. 29 No. 2, 2018, pp. 174-185
doi:10.3966/199115992018042902017

Research on Path Planning of Intelligent Plant Inspection Robot

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Received 24 July 2017; Revised 19 September 2017; Accepted 19 October 2017

Abstract. To enhance the accuracy of mobile robot inspecting in Intelligent Plant, a path planning method for mobile robots combining with indoor GPS positioning and fuzzy algorithm is presented. The method utilized the transmitter at the top of the robot to emit infrared signal, and the trilateration principle to calculate the robot's real time position. Meanwhile, the ultrasonic sensor on the base of mobile robot detected the environment and obtained the obstacle's location information, using fuzzy reasoning. Then the fuzzy rules were established and calculated to build the local path planning graph of robot's movement, and to achieve the robot's dynamic obstacle avoidance. The experimental results show that the proposed method can achieve centimeter-level positioning accuracy, and the robot can avoid the dynamic obstacles in the environment sensitively, so as to accomplish the path planning more effectively.

Keywords: fuzzy reasoning, indoor GPS, path planning

1 Introduction

Robots have been used not only in laboratories but also in life. A robot called "TWENDY-ONE" [1], which is a good example of a health care and rehabilitation robot. However, it may harm humans or damage household goods unless it can plan its own motion correctly. With the research of current path planning, there are many motion control methods, which have been developed by leveraging radio wave, magnetic field, acoustic signal, or other sensory information collected by mobile devices [2]. Yoshihiro Sakamoto proposed active-localization methods for mobile robots that increased the positioning accuracy in [3]. C. Chen proposed an indoor positioning system, which used a single pair of off-the-shelf WiFi devices in [4]. However, these methods require the robots focus primarily on ensure positioning accuracy and move along a predefined path which has been designed in advance. The path planning problem has been solved by different evolutionary methods including fuzzy logic [5]. Fatemeh Khosravi Purian used fuzzy logic in [6], and he proposed an optimal path which chose the nearest obstacle distances and angle deviation to the target as two criteria. T. Jin and B. J. Choi proposed a hierarchical path planning method based on behavior control in [7]. In these methods, the robot rotates an angle to avoid the obstacles appropriately when it obtains the distance values between nearby obstacles and itself through its sensors. However, the existing path planning strategy pays little attention to the position of robot, which lead to robot can't arrive at destination point accurately (if destination point is an object).

According to the above analysis, the issue now is many mobile robots are designed on the embedded system platform, so the algorithm should take cost, power, easy to move and other factors into account. And algorithm will take up most CPU time and RAM space when robot planning the path in a dynamic environment, and this will make robot responding slowly. Thus, the fuzzy algorithm is a better choice because it responded quickly, saved cost and RAM space.

This paper, based on smart factory environment, presents a novel path planning method that combined with indoor GPS positioning and fuzzy algorithm for mobile robots. The method used indoor GPS to locate the robot in real time so as to ensure that the robot can reach the target accurately. At the same

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time, Fuzzy reasoning algorithm is used to build local map so that robots can use the map to avoid obstacles dynamically in the environment.

The remainder sections are organized as follows. Section 2 describes the hardware platform of mobile robot, and Section 3 derives the position principle of indoor GPS. The path planning strategy is presented in Section 4. Simulation and experiment results are given in Section 5. Conclusions are provided in Section 6.

2 Intelligent Plant Robot Hardware Platform

This paper uses scout2 robot to do experimental research. The design system of scout2, which is widely used in the field of space robot research and development, is the "Distributed Computing Robot Architecture". This system is to increase the number of fault-tolerant systems and the multiple fault-tolerant corresponding mechanisms. When the local or remote terminal or the working layer accesses the system through the wireless network and operates, the upper layer functions of the robot, such as motion, perception, etc., can be manipulated by basic programing and modification. The underlying digital signal processor (DSP), which is under the control of the underlying program, controls the underlying data so that the external control can be separated from the internal calculations. The external computer only needs to be responsible for the calculation and analysis of the parts. This ensures that what the robot needs to do is as little as possible, but also reduces the weight of the robot itself. At the same time, the service life and working time of robot are extended with lower cost of R&D manufacturing. Because the upper layer data is controlled by external control, so the robot server driver and DEMO update and transformation can be done through the Internet remote operation and shared with other robots.

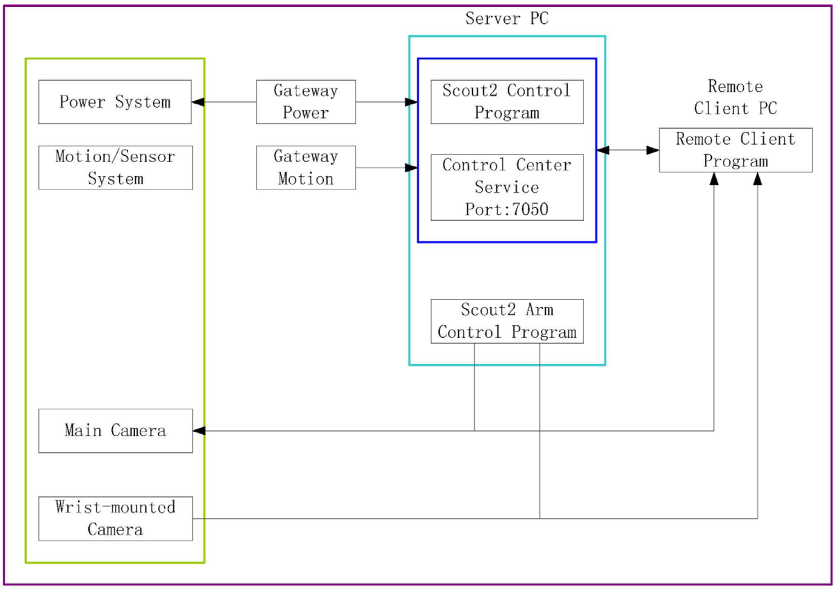


Fig. 1. Scout2 hardware platform

Intelligent plant robots need to have the ability to accept and deal with great amounts of information at the same time. Therefore, the study of intelligent plant robot system must collect and reorganize all aspects of data information so as to enable robots to understand the expression and presentation of this information and then do analysis work in face of dense, multi-level information. In its research process, the navigation function has always been the primary task of all researchers, which is to make the inspection robot separate itself from the human support and complete the necessary control of autonomous motion. The research of mobile navigation is to study how to make the inspection robot to acquit external information through the equipment such as ultrasonic sensors in the absent of human support. Thus robots can achieve the positioning, obstruction and planning and task- implementing function.

3 Indoor GPS Location

The indoor GPS location method is one of the absolute positioning types, and the setting is that the robot must determine its position and attitude without knowing the original position [8]. The general location methods are the following: passive or active identification positioning, probability positioning, beacon positioning, map matching positioning. After the robot is equipped with a sensing device to measure the surrounding environment in detail, the information collected will be reconstructed using a certain algorithm. The robot uses this method to determine the position and direction in the map. However, the disadvantage of this method is that the accuracy is not high, easily affected by the surrounding things. identification positioning is more common in the absolute positioning, but also be divided into artificial positioning and natural positioning. Artificial positioning refers to that under the artificial information setting, robots could make use of those information to identify where they are in the map. Beacon positioning would consume a lot of manpower and material resources in the equipment installation and post-maintenance needs. Although it would have a high cost, the use is very simple and convenient with high positioning accuracy. In summary, no matter what kind of positioning methods, it is of great need to know the surroundings of the robot. So from the consideration of positioning accuracy, this paper uses the beacon positioning method.

3.1 The Components of Indoor GPS System

Indoor GPS system mainly consists of the transmission controller, beacon, control software, launchers, receivers and other auxiliary equipment (Fig. 2).

(a) Launcher, receiver (b) Beacon (c) The transmission controller

Fig. 2. Indoor GPS system components

The transmitter is the basic element of the formation of the field. Relatively low weight and smaller size are the advantages of the transmitter. It can emit sectoral laser and gating pulses with fixed angles. The transmitter has the following characteristics: wide range of applications, simple and convenient maintenance, high measurement accuracy, strong adaptability in harsh environments.

The materials of the beacon are reflective patches which does not consume any energy but been set on the ceiling to reflective lasers. Each beacon has a unique identification number (ID) that identifies the robot's position and direction information which is stored in the robot in advance. By comparing the received signal with the stored data, robot could determine its location in the room. The beacon ID is encoded as shown in Fig. 3.

Beacon installation height is between 1.35~3.15m, equivalent to what the robot internal positioning sensor measured--1.1~2.9m. The higher the ceiling is the greater the distance between the beacons, otherwise the smaller. According to the indoor area of the intelligent plant laboratory, 18 beacons are installed on the ceiling. And the beacons located directly above the charging piles are used as reference beacons to establish the coordinate system. Fig. 4 shows a schematic diagram of the beacon installation.

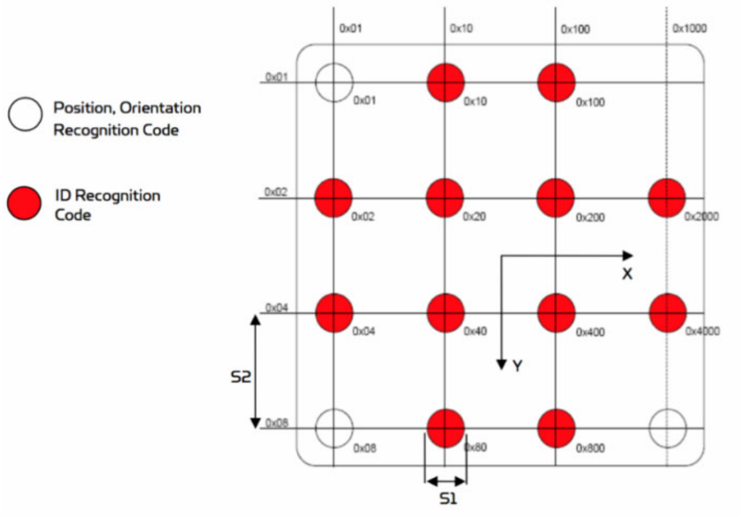


Fig. 3. Beacon ID

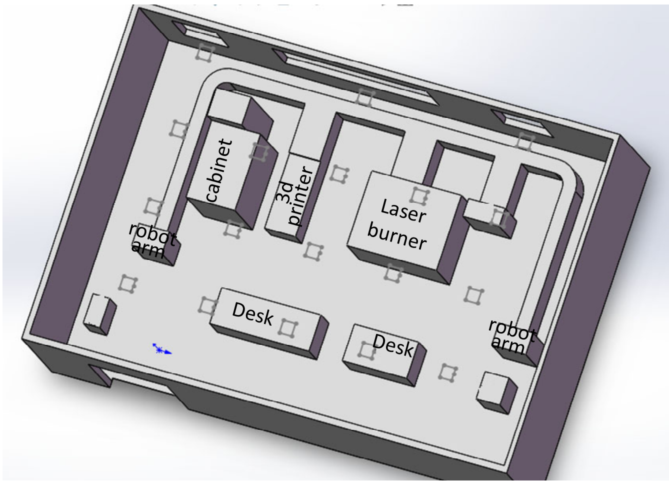


Fig. 4. Beacon installation

There are many types of indoor GPS receivers such as ball type, T-shaped type, cylindrical type, etc. [9]. Based on the purpose of real-time tracking and collecting measurement, this paper selects cylindrical receiving device, and use the base to fix it at the measuring point. Once the receiver receives the sectoral laser which is reflected back, the optical sensing device set in the receiver would sense the corresponding signal.

The transmission control system is generally composed of a signal receiving device and an amplifying device [10]. The receiving device uses the wireless transmission mode to transmit the collected optical signal to the control system. At the same amplifier amplify the optical signal. After the analog-to-digital conversion, the angle value is output. And then the central processor would transfer the final angle value through the software data analysis. At last, the control software would display the robot's parameters.

"Sentinel3 Localization / GPS Setup" is a kind of control system configured in the intelligent plant robot, which can be used to record the position information of each beacon, and display the coordinates of the robot, the coordinates of the GPS sensor and the robot relative height to the ceiling.

3.2 Indoor GPS Positioning Principle

When the robot operates, the infrared emitter sends infrared signals within the time break. Then the receiver receives the infrared signal reflected by the beacon. When the receiver receives the same infrared signal reflected by the one beacon, an image processing unit analyzes the infrared ray image which is reflected from different ID number-given beacon on the ceiling. It would calculate the distance respectively between reference point, beacon and receiver. And then through the three-dimensional distance measurement principle, the signal transmitter coordinates can be calculated too. Since the infrared rays are transmitted very fast in space, the controller will determine the coordinates of the two beacons according to the different IDs of the reflected beacons after the signals received by the two beacons received by the receiver. The location of the infrared transmitter, that is, the position of the target. When the target moves, by uninterrupted measurement, the target trajectory [11] would be drawn.

Fig. 5 shows the specific coordinates A (x1, y1, z1), B (x2, y2, z2) of the two beacons, and the coordinates of the infrared emitter are (x, y, z). Assume that L and M are the distances between the two beacons and the emitters, respectively, and the distance formula is as follows:

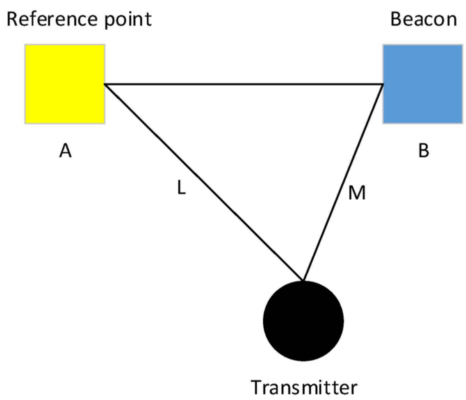


Fig. 5. Indoor GPS measurement principle

$$L=\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2} \quad (1)$$

$$M=\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2} \quad (2)$$

Where the value of z, z2 is constant for the height of the ceiling, the value of z is also determined, for the robot body infrared transmitter height.

The path planning position and direction data the robot used are the center of the robot, which is along the center of the wheel axis, relative to the global coordinates. When the robot direction is aligned with the X coordinate of the global coordinates, the direction is 0 degrees. And the direction is 90 degrees when the robot direction is aligned with the Y axis of the global coordinates. Here are the right hand coordinates. Fig.6 shows that the forward direction of the GPS sensor of the robot is opposite to that of the robot. And the distance between the center of the GPS sensor and the center of the robot is 0.126m. The positive direction of rotation of the GPS sensor is clockwise around the Z axis while the forward rotation of the robot rotates counterclockwise around the Z axis. So the direction and position of the robot GPS sensor and the robot are as follows:

$$\begin{cases}\theta_{\text{Robot}}=180-\theta_{GPS},\theta_{GPS}\in(0,180)\\ \theta_{\text{Robot}}=-180-\theta_{GPS},\theta_{GPS}\in(-180,0)\end{cases} \quad (3)$$

$$\begin{pmatrix}\mathrm{x}_{Robot}\\ y_{Robot}\end{pmatrix}=\begin{pmatrix}0.126*\cos(\theta_{Robot})+x_{GPS}\\ 0.126*\sin(\theta_{Robot})+y_{GPS}\end{pmatrix} \quad (4)$$

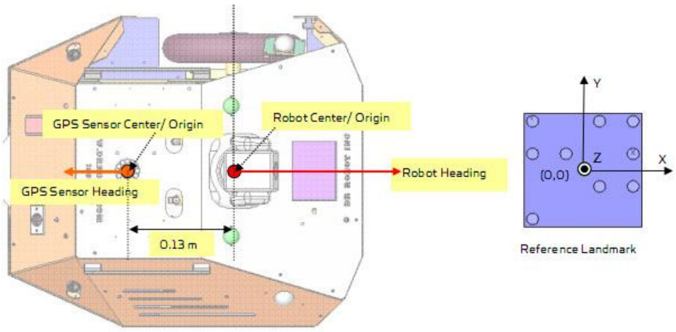


Fig. 6. Coordinates and Heading Direction

4 Navigation Inspection Robot Autonomy

4.1 Mobile Robot Path Planning Method

Path planning is a reasonable path planed by mobile robot before it conducts the task according to the various information in the environment, especially the obstacle location information, which could avoid all obstacles. In the environment, door switches, stairs, and all kinds of objects would be obstacles for robots.

For mobile robots, it would be a very important performance which could be applied to the reality if they could avoid all obstacles and reach the target position in the absence of complete access to environmental information. The practical robot should have the ability of the path planning in the existing environmental information conditions. The application of its perception of the environment is necessary to detect the environment, and constantly access to environmental information and dynamic planning and adjustment of the path to ensure that in accordance with the set Request to reach the designated location. Static planning needs to understand all the environmental information. The planning method is relatively simple. Because the dynamic information is limited, and it is not enough to formulate the corresponding path before work. Therefore, it is necessary to collect various environmental information in the continuous process and information discovery, and finally make a reasonable path according to the information and According to the information subsequently explored on the path to make dynamic adjustments.

According to the robot's understanding of some surrounding environment information, the general robot's global path planning often uses the method of view, free space, and raster. Robot local path planning often uses artificial potential field method, fuzzy logic algorithm and genetic algorithm.

4.1 Path Planning Algorithm Based on Fuzzy Logic

Based on the fuzzy logic path planning, the input is the distance data of the ultrasonic sensor, the current walking speed of the robot and the direction of the target, and the output is the left and right wheel's acceleration of the robot [12]. The robot system structure is shown in Fig. 7. The mobile robot is equipped with six ultrasonic sensors which are divided into three groups. And choose the smaller data as the input of the group.

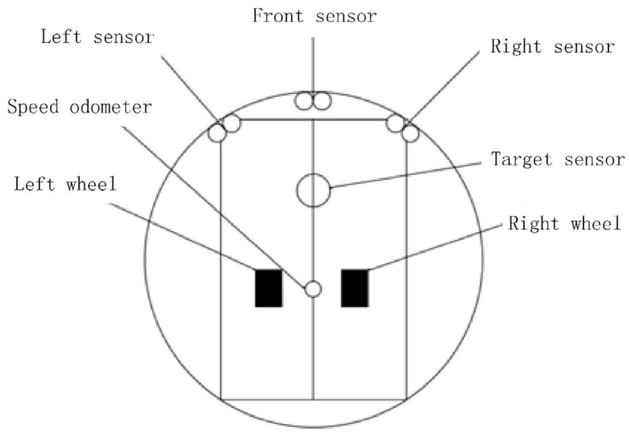


Fig. 7. Coordinates and heading direction

If the sensor detects an obstacle at the same time, then it is considered to be the same object; otherwise, it is considered multiple objects. Since the ultrasonic is angularly discrete and it is possible to hold two objects as the same object that very close to each other. The robots can't move from the middle of two obstacles when they are closely that it doesn't matter the walking of the robot. So it is reasonable to hold them as an obstacle. Fig. 8 shows the environment detection by the robot ultrasonic sensor.

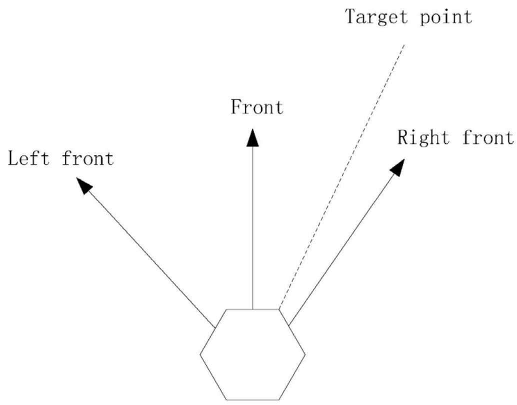
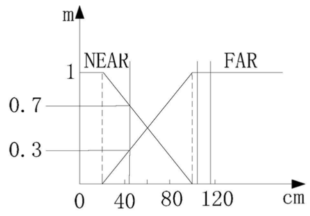


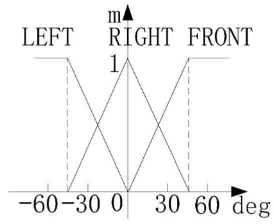
Fig. 8. Coordinates and heading direction

The linear function is adopted in order to reduce the workload and improve the speed of operation. The fuzzy language set of the direction of the obstacle is{Left front, Front, Right front}, the corresponding language variable is denoted as: {LD, FD, RD}; The fuzzy language set of the distance of the obstacle is {Near, Far}, The corresponding language variable is denoted as {N, F}; the fuzzy language set of robot's speed is {Fast, Slow}, the corresponding language variable is denoted as {F, S}; the fuzzy language set of target azimuth is: {Left, Front, Right}, the corresponding language variable is denoted as {L, C, R}; the fuzzy language set of the acceleration of output is: {Negative big, Negative small, Zero, Positive small, Positive big}, the corresponding language variable mark is denoted as: {NB, NS, Z, PS, PB}.

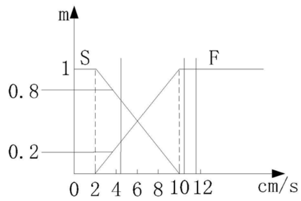
The shape of the membership function of each language variable is triangle and the fuzzy segmentation is symmetrical. Specifies that the θ is positive when the target is in the right front of robot and vice versa. The membership function is shown in Fig. 9.



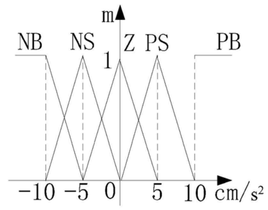
(a) The membership function of LD, FD, RD



(b) Membership function of target angle θ



© The membership function of the current velocity v



(d) Membership function of left and right wheel acceleration

Fig. 9. Fuzzy membership function

Fuzzy control system is based on the language of expert knowledge to express and a series of fuzzy conditions describe the fuzzy rules which constitute a fuzzy control rule base [13]. Fuzzy rules reflect the relationship between input and output according to Fuzzy Set theory. The whole system constitutes a multi-input and multi-output fuzzy system with five inputs and two outputs. When the ultrasonic sensor detects an obstacle that robot change the left and right wheel's acceleration to rotation. The fuzzy rules can be described as If (condition) then (result) according to the determined input / output set.

A series of criteria can be developed based on the trajectory of the robot and the target azimuth. Here is only one case to illustrate the rules established by the method. When the ultrasonic sensor detects the obstacle within the 0.4m of the robot and is close to it, the fuzzy rules are compiled into the table as shown in Table 1.

Table 1. Obstacle is close to the left front of the robot

Rule	Input					Output	
Number	LD	FD	RD	θ	v	a_l	a_r
1	F	F	F	L	S	PS	PB
2	F	F	F	L	F	NS	Z
3	F	F	F	C	S	PB	PB
4	F	F	F	C	F	Z	Z
5	F	F	F	R	S	PB	PS
6	F	F	F	R	F	Z	NS
7	N	F	F	L	S	Z	NS
8	N	F	F	L	F	NS	NB
9	N	F	F	C	S	PS	Z
10	N	F	F	C	F	Z	NS
11	N	F	F	R	S	PS	Z
12	N	F	F	R	F	Z	NS

Multiple conditions under the control rules can be established according to the above method. The development of fuzzy rules adopts the action mode based on the behavior of the controller and simplifies the complex behavior so that simplifies the determination of fuzzy rules and reduces the number of fuzzy rules. The fuzzy reasoning process is based on the relation and the reasoning rule in the fuzzy logic, and the fuzzy matrix is obtained according to the Mamdani fuzzy reasoning method.

Such as LD=40cm, FD=90cm, RD=110cm, the reasoning decision process in MATLAB simulation shown in Fig. 10.

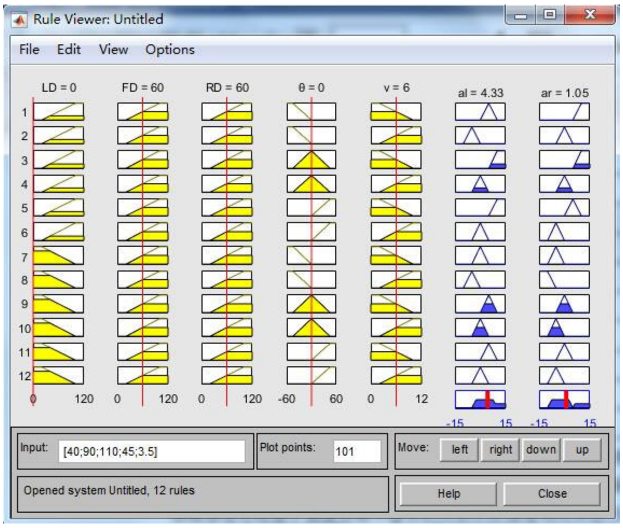


Fig. 10. Fuzzy reasoning simulation results

The result of fuzzy reasoning is a fuzzy set, and there is a certain value in the actual fuzzy control to drive the actuator. The effect of fuzzy reasoning is to convert the result of fuzzy reasoning into exact value. There are five kinds of methods used to solve the ambiguity in MATLAB2016. The center of gravity method is adopted in this paper, and it's the most reasonable and the most popular method. The mathematical expression is:

$$a_l = \frac{\int a_l \mu_L(a_l)d(a_l)}{\int \mu_L(a_l)d(a_l)}$$
$$a_r = \frac{\int a_r \mu_R(a_r)d(a_r)}{\int \mu_R(a_r)d(a_r)} \quad (5)$$

Using the center of gravity method to convert the fuzzy value into the exact value, and then the actual input send to DC motor to control robot's movement through the linear scale conversion.

5 Achievement of Intelligent Plant Robot's Inspection Task

The Path Control module in the path planning operation interface of scout2 wireless intelligent robot contains real-time data of the robot. It includes the target point coordinates, real-time coordinates of the robot, deflection angle, angle error, real-time distance, arrival time of robot and other parameters. The yellow dot represents the mobile robot, the white line above the circle represents the current direction of the robot and the blue dot represents the target point in Fig. 11. Click the GO button to start the path planning function and click the STOP button to stop the path planning function.

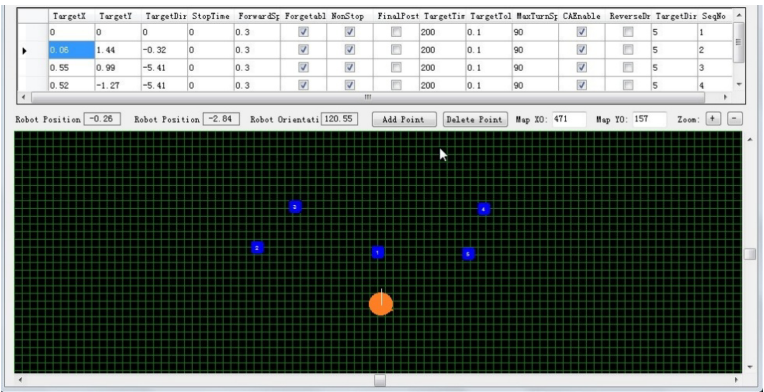


Fig. 11. Robot Path Planning Interface

The path planning diagram is designed in motion control interface of the scout2 wireless intelligent robot platform. Use the beacon above the charging station as the reference point, so the origin (0,0) of the global coordinates is below this flag. GPS sensor will be connected and will be able to read the robot's position data (X, Y and direction) after running the control program. Indoor experimental environment and path planning of intelligent plant is shown in Fig. 12.

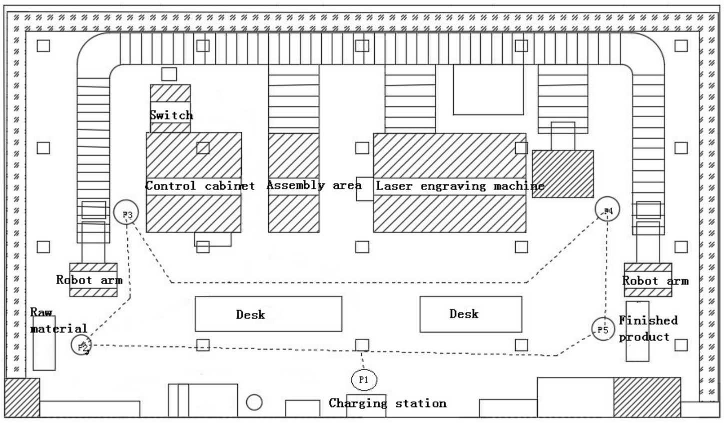


Fig. 12. Robot path planning interface robot path planning

Table 2. The planning tasks

Step	Position	Task
Step 1	P1~P2	Grab raw materials
Step 2	P2~P3	Put material
Step 3	P3~P4	Grab the finished product
Step 4	P4~P5	Put finished product
Step 5	P5~P2	Grab raw materials
⋮	⋮	⋮
Step n	P5~P1	Charge

The overall inspection plan. The path should be a loop in order to continue the inspection work until the battery is exhausted in the intelligent plant environment. First step 1 is the robot move from the charging station P1 to the raw material box P2, and use GPS navigation for the first step of the local path planning so that the robot can accurately reach the specified location.

Auto-recharging. In step 2 and subsequent stepn, when the robot discovers that the battery is low or receives a "Go charge" command during the patrol, it will recognize the nearest passing point on the patrol path and drive it there. After that, it will walk along the inspection path towards the end to charge.

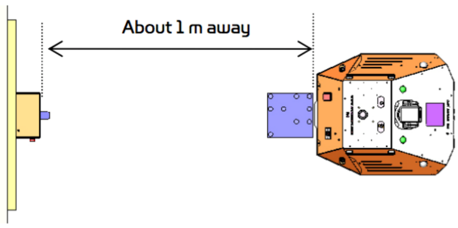


Fig. 13. The robot is connected to the charging pile

Automatic inspection process. Step 1~step 5 is inspection process of the robot. Firstly, robot arrived at raw material stacking area P2, and then use the arm to grab the raw material. Defined the value of multiple sets of steering gear to achieve the different movements of the robot, then walks to the processing area P3 and release the hand so that raw materials could fall into the processing area. The robot goes to the finished area P4 and sends the finished product to the finished box. Repeat the above inspection process. If the battery power is shortage during the process of inspection, then send a command to the controller and the robot will move to the charging pile itself.

Encountered in dynamic obstacles during inspection. If there is a person about 1 meter away from the path of inspection and if the pedestrian didn't find the moving robot then the robot immediately stopped the pedestrian said: "hello, please pay attention". After saying that, the robot use ultrasound sensors to avoid moving pedestrian.

Fig. 14. The intelligent plant laboratory environment

Start moving

Grab raw materials

Put material

Grab the finished product

Put finished product

Auto-recharging

Fig. 15. Actual inspection flow chart

6 Conclusion

A path planning method for mobile robots combining with indoor GPS positioning and fuzzy algorithm is presented in this paper to enhance the accuracy of mobile robot inspecting in Intelligent Plant. The method utilized the transmitter at the top of the robot to emit infrared signal, and the trilateration principle to calculate the robot's real time position. Meanwhile, the ultrasonic sensor on the base of mobile robot detected the environment and obtained the obstacle's location information, which would be obscured by using fuzzy reasoning. Then the fuzzy rules were established and calculated to build the local path planning graph of robot's movement, and to achieve the robot's dynamic obstacle avoidance. The experimental results show that the proposed method can achieve centimeter-level positioning accuracy, and the robot can avoid the dynamic obstacles in the environment sensitively, so as to accomplish the path planning more effectively.

Acknowledgements

This work is supported by Excellent Engineer Union Laboratory Construction Project of Beijing.

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