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Mapping and Autonomous Obstacle Avoidance of Mobile Robot Based on ROS Platform

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With the progress of science and technology and the continuous development of robot technology, the performance and intelligence of robots are also constantly improving. It has been widely used in many fields such as life service, military, industrial production and so on. Among them, autonomous mobile is an important embodiment of intelligence. Therefore, it is necessary to solve the problem of robot real-time positioning and map building (SLAM). SLAM is the abbreviation of Simultaneous localization and mapping, which means "synchronous localization and mapping". It is mainly used to solve the problem of localization and mapping when robots move in unknown environments. This paper designs and implements a positioning and navigation system for mobile robots based on lidar in the environment of robot operating system (ROS). The system is based on the gamping algorithm of particle filter, so that robots can perform self-positioning and map building in strange environments. By studying the Rao-Blackwelized particle filter algorithm and enlarging the bandwidth of Kalman filter to increase its estimation accuracy, the filter was optimized. In the process of robot implementation of map construction and autonomous obstacle avoidance, the robot can conduct self-positioning and map building in unfamiliar environments by using the algorithm provided by the open source Gampping function package in the robot operating system (ROS).The navigation function package allows the robot to navigate independently and avoid obstacles with known maps of the environment. Finally, the simulation tool gazebo of the robot operating system (ROS) is used to build the simulation environment required for the experiment and simulate the real environment of the robot. Finally, the robot is equipped with lidar sensors to carry out experimental simulation, so that it can achieve the functions of self-positioning, map building, self-navigation and obstacle avoidance.

Keywords: Particle filter, Mobile robot, Mapping, Path planning

1 Introduction

1.1 Research background

At present, many intelligent manufacturing industries and robot research institutions at home and abroad are using ROS to design and develop products. FANUC of Japan, Yaskawa electric, ABB of Switzerland and KUKA, which have a monopoly position in the industrial robot market, all have products based on ROS. Many technology companies and vehicle production and research companies also use ROS as an important tool to develop smart cars and UAVs. ROS can be applied to ground mobile vehicles, unmanned aerial vehicles, artificial intelligence robots, etc. it provides a rich program library and auxiliary tools for the combination of software and hardware, such as functional function library, visualization tools, communication components, interfaces, software management and other standard operating system services. At the same time, ROS can provide interactive services for the model, status and clicking of intelligent devices. It can also provide planning services for intelligent device path planning, collision detection, voice and image processing [1].

ROS is an open-source operating system specially used in the field of robots. Its main purpose is to provide code reuse support for robot developers, save developers a lot of programming time, and enable them to focus on in-depth research in a certain field. With the continuous deepening of robot technology and robot operating system, simulation technology is gradually known to people. It simulates the real environment of robot operation through the simulation platform, provides safe and reliable basis for robot related physical experiments, and greatly shortens the development and experiment cycle of robots. It has the advantages of safety, reliability, efficiency and flexibility [2].

The current robot application fields are mainly focused on automatic driving, safety inspection, intelligent shopping guide, intelligent distribution, rehabilitation and medical care. If completing its work in a complex environment, the robot needs to solve the problems such as mapping, self-positioning, and perception of the surrounding environment, behaviour prediction and decision-making control. See Figure 1 for the relationship between various parts.

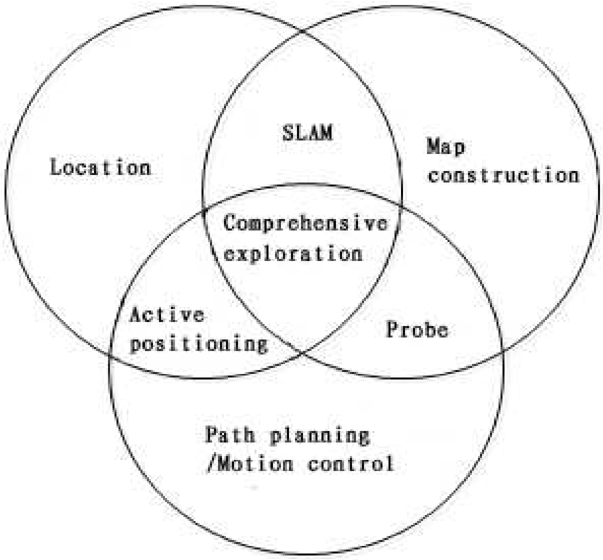

Fig. 1 *Relationship between mobile robot and mobile technology*

How does the robot move in an unknown environment? How does the sensor sense the changes of the external environment and then transmit information to the robot controller so that the robot can complete the work? This mainly depends on the robot's ability of self-positioning, map construction and self-navigation.

1.2 Research Status

It has always been a human dream to make robots walk freely in the real environment like people, and it is also the most important topic in the field of robot research. The key to solve this problem lies in how to realize autonomous positioning and autonomous path planning of robots. In real life, GPS signal is often unstable and positioning error and other shortcomings, especially for indoor environment, GPS signal can not be used, the traditional positioning method is no longer suitable. At the same time, Simultaneous localization and mapping technology has solved the localization and map building problem of robots in unknown environments [3]. Slam was first proposed at the conference on Robotics and automation in the mid-1980s. The path planning of mobile robots is mainly based on the research of relevant algorithms based on the different needs of robots for different tasks, so that the robots can reach the final goal with the optimal path. As early as the 1990s, the Western European and American countries have been able to produce relatively excellent autonomous mobile robots. After the European and American countries, Japan has also launched a humanoid robot named "ASIMO", which shows superior performance in walking, jumping and playing football. Slam technology is an important means for mobile robots to become autonomous and intelligent. Therefore, it has always occupied an important position in the field of robot research in the past ten years. [4]

SLAM technology is receiving increasing attention in China. SLAM based on image optimization is a new method developed in recent years, which is mainly based on vision sensors. This is an online total solution. It adds loop detection on the visual front end and optimization back end to identify previously arrived scenes when building the map. It can solve the error accumulated in the process of motion well, the problem of large amount of calculation. Typical examples are orb-slam, lsdslam, SVO, and rtab-map.

2 Symbol Description

Tab. 1 *Symbol description*

Symbol	Explain
$x_t^{[k]}$	**Robot path estimation**
$p(x_{1:t}^{(i)}\|z_{1:t}, u_{1:t})$	**Robot trajectory**
$P\square m^{(i)}\|x_{1:t}^{i}, z_{1:t})$	**Map information**
$x_t^{(i)}$	**Robot posture**
$w_t^{(i)}$	**Weight**
w_{fast}	**Short term average**
w_{slow}	**Long term average**

In order to better understand the full text, the formula is briefly explained. The following is the relevant description of the main variables in this paper, as shown in Table 1 below.

3 Overview of Particle Filter Algorithm

3.1 Rao Blackwell Particle Filter Algorithm

Rao blackwelled particle filter is one of slam estimation methods. This method uses a limited number of sampling particles to represent the distribution of probability density. The area where the robot is located indicates that there are particles with high probability or the density of particles in this area is very high. In this project, the most important research is to use a group of random sample particles with weights to represent its probability distribution. In areas with high probability, the density of particles is high, whereas in areas with low probability, the density of particles is low. This method can be used to approximate the probability distribution of the robot location [5]. Slam method based on Rao Blackwell particle filter can accurately make out the distribution of posterior probability.

In the SLAM algorithm based on Rao Blackwell particle filter, the map features are represented by independent EKF, where the EKF filter corresponds to feature points. It is assumed that N particles are used to estimate the path of the robot, and each particle corresponds to Q independent EKF to estimate Q feature points. The relationship is shown in Figure 2 below.

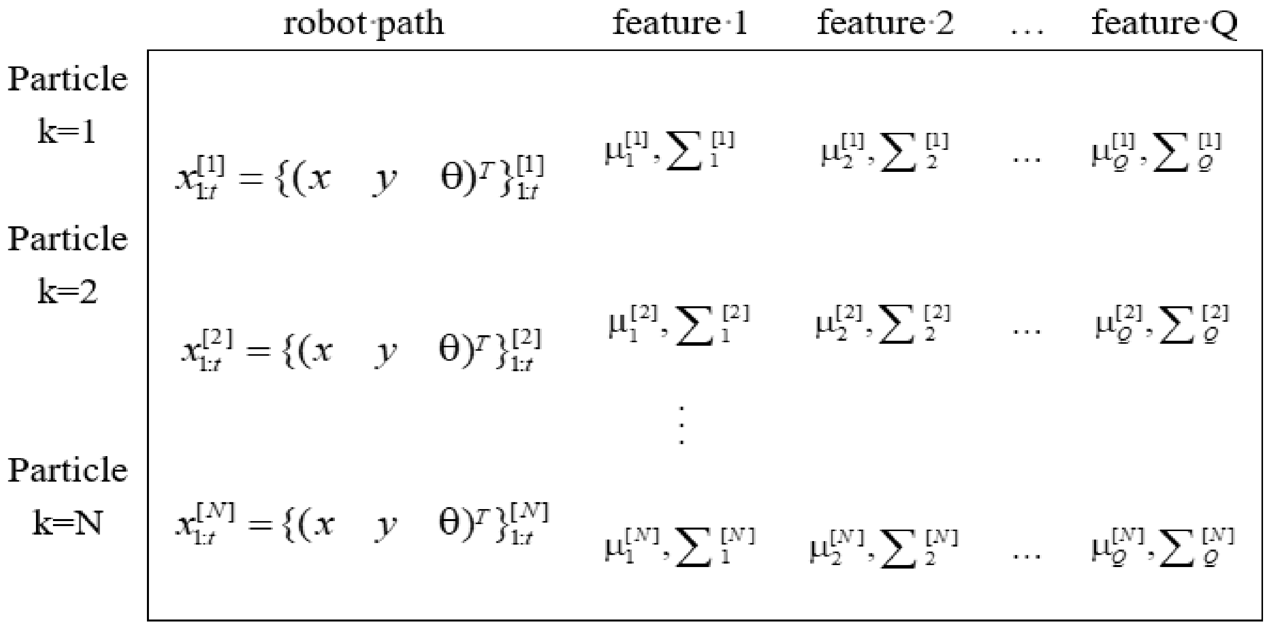

Fig. 2 *Robot path represented by N particles and corresponding characteristic landmark points of particles*

In RBPF's method of solving slam, SLAM problem can be divided into two parts: The first part is the non Gaussian posterior part of positioning by using particle filter, and the second part is the conditional Gaussian part of global map updates by using Kalman filter [5], whose formula is expressed as:

$$p(x_{1:k}, m|z_{1:k}, u_{1:k-1}) = p(m|x_{1:k}, z_{1:k})p(x_{1:k}, |z_{1:k}, u_{1:k-1}) \quad (1)$$

3.2 Principle and Optimization of Kalman Filter

Kalman filter is to provide an effective recursive method to estimate the situation of the system by means of equations. Particle filter is used to track the position and posture of the robot in the known map for positioning [7]. A standard Kalman filter algorithm has problems such as slow convergence speed, poor estimation accuracy and large amount of calculations under its uncertain or erroneous noise statistics. According to the relevant theory, through the relevant theory, people can know that when the motion state of the robot is load, the estimation accuracy can be increased by increasing the bandwidth of the Kalman filter.

Prediction update:

Prediction state quantity:

$$x(t/t-1) = Ax(t-1) + bu(t) \quad (2)$$

Prediction error covariance matrix:

$$P(t|t-1) = AP(t-1)\,A^T + Q \quad (3)$$

Measurement update:

The most estimated state quantity:

$$x(t) = x(t|t-1) + K(t)[z(t) - Hx(t|t-1)] \quad (4)$$

Calculate the error gain;

$$K(t) = P(t|t-1)H^T/[R + HR(t|t-1)H^T] \quad (5)$$

Error covariance matrix:

$$P(t) = [1 - K(t)H]P(t\,|\,t-1) \quad (6)$$

Let the speed of the robot at time be, then the system state equation is:

$$x_k = x_{k-1} + w_{k-1} + 0.5 \quad (7)$$

Measure The equation is:

$$z_k = x_k + v_k \quad (8)$$

Combined with the prediction and measurement update process of the Kalman filter algorithm, it can be obtained:

$$A = [1], B = [1], u=0.5, Q = E(\mathrm{ww}^T), H = [1], R = E(vv^T) \quad (9)$$

Based on the above analysis, the comparison curve of the observed value of the mobile robot speed, the real value, and the filtered value can be obtained (Figure 3).

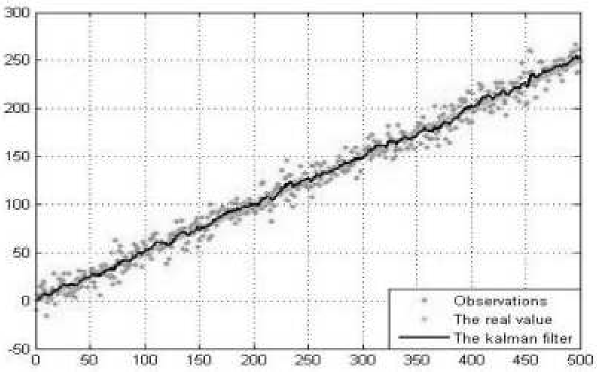

Fig. 3 *Alignment diagram of robot speed observations, true values, and filter values*

4 Gmapping Mapping and AMCL Adaptive Positioning

4.1 Gmapping drawing-make

Gmapping is mainly based on the RBEF particle filtering method [8], in which RBEF particle filtering divides the SLAM problem into two parts, one is robot positioning, and the other is map construction with known robot posture. The formula is as follows:

$$\{p(x_{1:t}, m|u_{1:t}, z_{1:t}) = p(x_{1:t}|z_{1:t}, u_{1:t}) * p(m|x_{1:t}, |z_{1:t})\} \quad (10)$$

The algorithm mainly has the following four steps in conducting the robot trajectory estimation:

4.1.1 Sampling

In the proposed distribution,by sampling the pose of the robot at the next moment $x_t^{(i)}$. By comparing lidar with odometer,we can know that the information obtained by lidar scanning is more accurate than the information obtained by the odometer. The interval of the largest observed likelihood domain function is found by scan-matcher. [6]

$$x'^{(i)}_t = x^{(i)}_{t-1} \oplus u_{t-1} \quad (11)$$

$$\hat{x}_t^{(i)} = argmax_x\, P\,(x|m_{t-1}^{(i)}, z_t, x_t^{i(t)}) \quad (12)$$

When samples were performed countless times near the $\hat{x}_t^{(i)}$ maximum region, $\oplus$ is the pose calculation operator that generates the new poses $x_t^{(i)} \sim N(u_t^{(i)}, \Sigma_t^{(i)})$.

4.1.2 Importance weight calculation

For weights $w_t^{(i)}$, means the degree of similarity of the target distribution at the i th particle at time t and also indicates the trust in particles, the updated formula:

$$w_t^{(i)} = w_{t-1}^{(i)} \cdot \sum_{j=1}^{k} P(z_t \Big| m_{t-1}^{(i)}, \mathrm{x}_j) \cdot P(x_j \Big| x_{t-1}^{(i)}, \mathrm{u}_{t-1}) \quad (13)$$

4.1.3 Adaptive resampling

Gmapping adopting adaptive resampling can solve the problem of particle diversity loss during frequent resampling, when N_{eff} less than the corresponding threshold value T, the resampling was performed.

4.1.4 Map estimation

According to the calculated robot trajectory $p(x_{1:t}^{(i)}|z_{1:t}, u_{1:t})$ to estimate the map $P(m^{(i)}|x_{1:t}^{i}, z_{1:t})$.

4.2 AMCL Repositioning

AMCL localization mainly consists of Augmented_MCL and KLD Sam-pling MCL algorithm. It based on the result that odometer information obtained u_t with the last moment m the position of particles x_{t-1}^{m} to make estimates, and then you can get the current moment m the position of particles x_t^{m}. Taking advantage of rangefinder beam model or likelihood domain model from the observed information z_t and the current moment of the particles m the position of $x_t^{[m]}$ with the map m, calculates the current particles m weight of $w_t^{(i)}$. According to the corresponding weights, important samples are performed to realize the positioning of the robot.

The robot may have global positioning failure during movement. In order to cope with such problems, AMCL is combined with Augmented_MCL algorithm. Augmented_MCL uses the exponential smoothing method thought to measure the probability by tracking the sensor $p(z_1|z_{1:t-1}, u_{1:t}, m)$ short-term mean w_{slow} and long-term mean w_{fast} to determine under what circumstances to increase the particles, in order to strengthen the robustness of the localization. [8]

AMCL combines the data of IMU with odometer through EKF, which can better maintain the convergence state of the particle, thus reducing the occurrence of inaccurate particle estimation of the robot when turning or slipping during the movement.

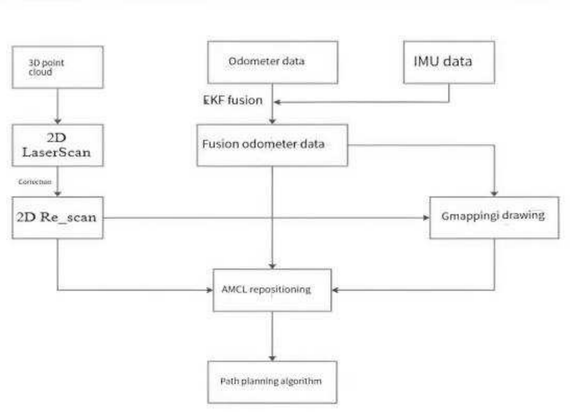

Fig. 4 *AMCL self-localization*

Figure 4 shows that the collected point cloud information, odometer data and IMU data are built based on Gmapping, and the AMCL repositioning can fulfill self-positioning, thus providing a basis for path planning.

5 Robot Self-navigation and Obstacle Avoidance

5.1 Navigation Framework

All functions are based on toolkit in the ROS system that is a software package called move base [10]. The software package can use the information of measuring the distance in laser with the odometer to achieve accurate positioning and navigation functions. Its system composition is shown in Figures 5.

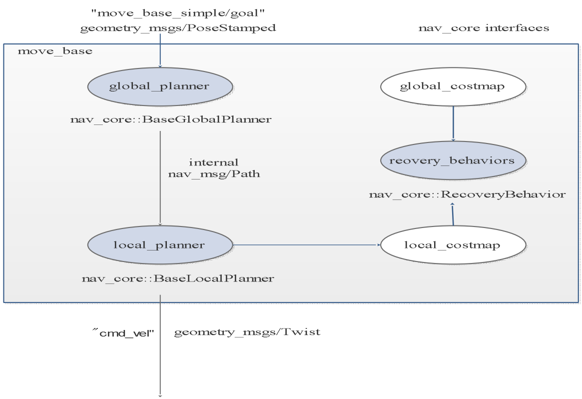

Fig. 5 *Move_base framework diagram*

From Figure 5, move base simple / gaol is where the user publishes a ROS message that contains the destination point to which the planning robot navigates. The amcl is based on the particle filtering algorithm to get the position of the robot while mapping. To realize the self-positioning of the robot, the relevant parameters need to be optimized and the configuration can not be used when there is no map. The coordinated change between the sensor and the robot is made by sensor transform, for example, in the use of the coordinates of the encoder and the center of the robot, so as to obtain the encoder information. The odometer releases mileage information through odometry. At the same time, it can get the prediction information of the robot trajectory and help the robot better plan the route.

The sensor sensor module is to check whether there are obstacles during the movement of the robot, and take the value through the grid map. When the grid value is 254, the obstacle coincides with the center of the robot, and the robot and the obstacle will inevitably collide, which is then called the fatal obstacle. When the grid value is 253, the position of the obstacle is located inside the inner circle of the robot outline, the robot and the obstacle will inevitably collide. When the grid value of 0~252 indicates that the robot may not collide with the obstacle [9]; When the grid value is 0, the robot can move normally, and the grid value of 255 means that the robot has not obtained the information about the map at this time, the robot will continue to move to the target point and build the map.

Global planner's global path planning is based on Dijkstra algorithm by default. The simulation study sets A * navigation algorithm; Local planner's local planning is DWA navigation algorithm based on dynamic window; Dynamic window (DWA) method is commonly used in path planning robot with dynamic obstacle environment [13]. Map data is acquired via map serve nodes during navigation. The actions performed by the robot when encountering a navigation failure need to be configured through the recovery behaviors node. The parameter configuration in path planning is implemented by setting the global costmap global costmap and local cost local cosmap files. [12,14]

5.2 Navigation Function Fulfillment

ROS is a meta operating system applied in the field of robot research and development [15]. The move base in the robot operating system (ROS) performs the function of the robot navigation. The overall framework diagram is shown in Fig. 6.

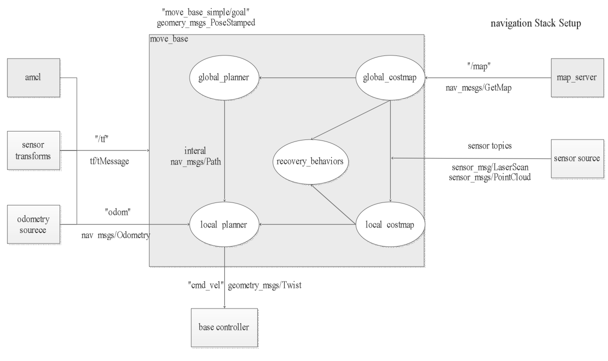

Fig. 6 *The move base based on navigation framework*

According to Fig. 6, the map information is obtained by map server. According to the map information and target point information, global planner plans to move in time-saving route. In the process of movement, the position information of the robot is received by converted tf coordinates and the external information is obtained through the sensor. The local planner replans the path according to the obtained information, and finally output the "cmd_vel" message to control the speed of the robot so as to perform the function of self-navigation and obstacle avoidance of the robot.

5.2.1 Global Map

Real-time positioning and mapping is the function of SLAM map. For SLAM, the problem is that the robot moves at a point in the unknown area. By getting information about the target point, using external sensors to get information. When robot move to the designated place, it will use the location estimation and map information to build the map. In order to draw SLAM map, the robot must be equipped with sensors to obtain external information.

5.2.2 Self-positioning

The robot should clearly know its position in the whole process of navigation. In SLAM, by adopting amcl positioning, an adaptive Monte Carlo positioning method, which tracks the posture of the robot by using a particle filter through the obtained map information. It is a probabilistic positioning system for 2D mobile robots.

5.2.3 Path Planning

Global path planning (global planner), analyzing the given target point information and global map information, gives the overall path planning, and generally the Dijkstra or A algorithm is used for global path planning. In this paper, a more efficient A * algorithm is used to calculate the global optimal path to obtain the global route. For the local_planner, the robot may encounter obstacles in actual movement, which may make the robot fail to execute the given globally optimal route in the navigation process. Robots generally adopt Dynamic Window Approaches (DWA) to avoid obstacles, and choose the current optimal path and the global optimal path consistent with the execution.

5.2.4 Movement Control

By writing the node subscription to the "cmd_vel" topic, we can convert the speed command into the motor command, and then sent the geometry_msgs / twist type message which is based on the base coordinate system of the robot to realize the transmission of the motion command and control the robot movement.

The main functions of the motion control system of the mobile robot are as follows: (1) The wheel motor is driven by the motion command sent by the robot controller to make the mobile robot move according to the command; (2) Odometer information can be calculated from the pulse signal generated by the encoder and provided to the robot controller [17].

5.2.5 Environmental perception

The detection of uneven road surface and obstacles during the driving process of mobile robots is an important research direction in the field of environmental perception technology [19]. Robot is very dependent on environmental information. In the process of SLAM map and navigation, environmental information is indispensable, and environmental information perception is acquired through all kinds of sensors. Encoder can get motor speed information, then generating odometer information for robot positioning. At the same time, it can use laser radar to get the external environment information in depth, which provides necessary information for robot mapping and navigation.

In the process of autonomous exploration, the machine needs to perceive the local environment to obtain a series of target points, and then guide the robot to traverse the environment. An effective exploration strategy is to generate complete or nearly complete maps within a reasonable time [15].

6 Results and Discussion

6.1 Simulated Mapping

The robot simulation map software is mainly gazebo, which is a 3D dynamic simulator based on ROS system [16]. Users can edit the floor plan of the house through the building editor function in gazebo, so as to generate 3D buildings in gazebo. In addition, you can build different simulation scenarios by inserting the built-in model or user-defined model in gazebo. Therefore, gazebo simulation software is used to build obstacles to simulate the indoor environment, and the robot is equipped with various required sensors. The robot is used to explore the simulated environment, build an environment map, and analyze the results in detail [21]. The following figure is the construction effect of simulation experiment map using gazebo, as shown in Figure 7.

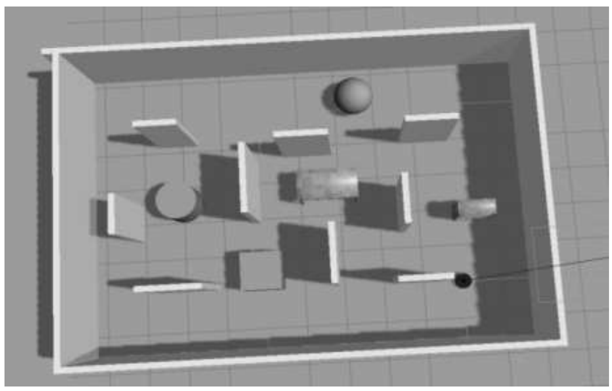

Fig. 7 *The gazebo Simulation environmental map*

As shown from Figure 7, the overall experimental environmental map is an area closed by walls. In the closed area, there are established robot models, multiple boxes and columns, etc. The boxes and columns act as obstacles, which lays the foundation for the experiment of robot autonomous obstacle avoidance. In this way, the position of obstacles can be set at any time according to the experimental situation, and ideal experimental results can be obtained. It can be particularly important in practical applications, so gazebo simulation can complete the simulation of complex environments in real scenes, greatly improving work efficiency.

6.2 Autonomous Robot Positioning and Mapping

The robot initialization and the gazebo simulation environment were initiated by the $ roslaunch mbot_gazebo mbot_laser_nav_gazebo.launch command, and the launch file was initiated by the $ roslaunch mbot_navigation exploring_slam_demo launch to obtain the initialization state of the robot at the rviz interface.

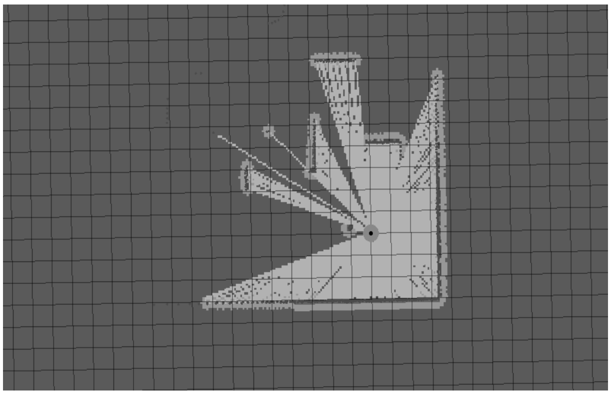

Fig. 8 *Initial diagram of the rviz robot environment*

From Figure 8, when the rviz interface is started, the lidar will detect and create the environment which the robot is in. The blue edge represents the obstacle, and the blue boundary will be avoided when the robot moves, and the black area indicates the unfamiliar area of the robot.

The simulation process based on SLAM navigation mainly starts the move_base node. The amcl algorithm is used to realize the self-positioning of the robot. By compiling the code to start the initialization in the rviz interface. By clicking 2-D Nav Goal in rviz to determine the target point information. According to the global planning, the robot will get a practical plan by combining the target point information and environmental map information, the experimental results are as follows: Fig. 9, Fig. 10, Fig. 11 and Fig. 12.

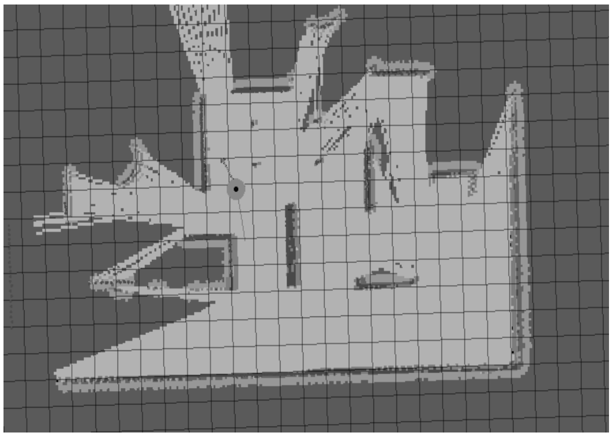

Fig. 9 *The Robot moves autonomously*

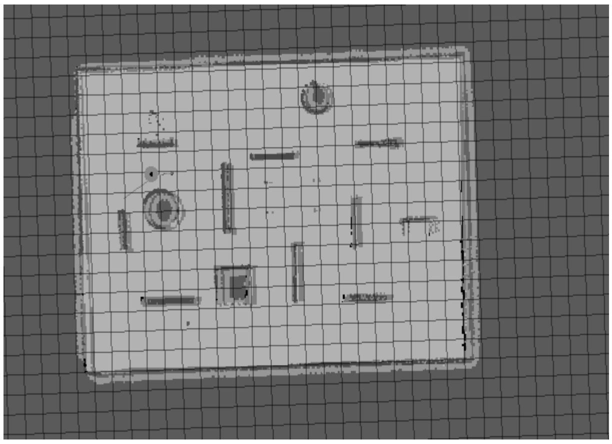

Fig. 10 *Global Path Planning*

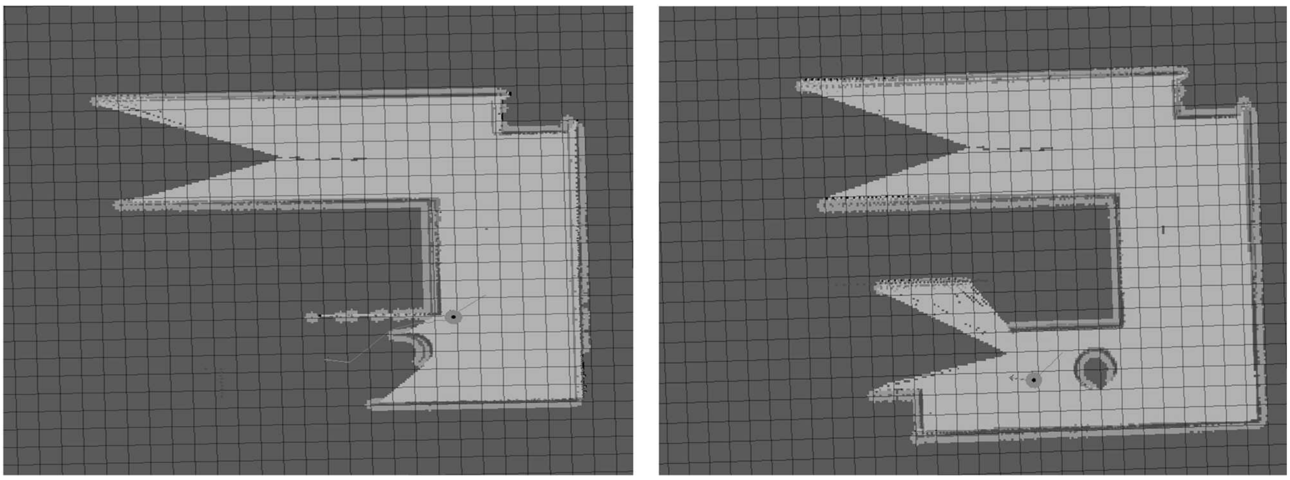

Fig. 11 *Replanning of obstacle avoidance*

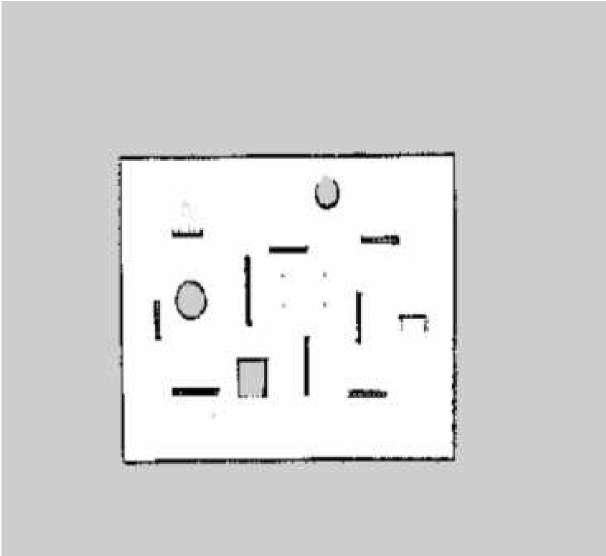

Fig. 12 *Grid plot of the map construction*

6.3 Analysis of Experimental Results

In an unknown working environment, mobile robots should have the ability to sense the environment to avoid obstacles and realize automatic navigation [22]. Through the virtual platform simulation experiment using the robot operating system (ROS), the robot's ability to perceive the environment has been greatly improved when it is equipped with a laser sensor. The external environment of the robot during its movement is restored with high clarity. In the autonomous positioning experiment, it can achieve self positioning and composition by collecting coordinate point information and writing Python programs, so that it does not need to send coordinate point information many times manually, for the local planning of path planning, DWA (dynamic window approvals) navigation algorithm based on dynamic windows is used to avoid obstacles, and the current optimal path and the global optimal path are selected for execution. Through the experimental results, we can see that the obstacle avoidance effect is good, and when encountering obstacles, we can avoid obstacles well and re plan a path that conforms to the global optimum.

7 Conclusion

In this paper, we study the Rao-Blackwelized particle filter algorithm and increase the estimation accuracy by expanding the bandwidth of the Kalman filter. The simulation tool Gazebo of the robot operating system (ROS) is used to build the simulation environment needed for the experiment, simulate the real environment of the robot, and assemble the robot with lidar sensors to carry out the experimental simulation. According to the experimental simulation results, we can see that the robot senses the external environment through the lidar sensor in this simulation environment and completes self-positioning. In the process of moving, it plans its path through the move base function package. If it encounters obstacles, it can re-plan its route by avoiding obstacles through local planning. It can be seen from Figure 12 that the drawing effect is good.

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