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A multifunctional ship sorting and clearance robot implementation model

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Abstract: *In the process of transporting commodity by sea, the ship clearance of general cargo ship has always been a hassle for the crew. Under a tight schedule and heavy task chart, it is frequently essential to work day and night upside down for crew to accomplish the cleaning of the cabin and unloading work. Sometimes it may not even be possible to complete unloading and clearance in time, resulting in massive economic losses. In this paper, a multi-functional ship clearance and sorting robot model is proposed based on the actual environment of the cargo ship's hold, which can not only realize the sorting of goods, but also assist in the cleaning of the ship hold after unloading. We have combined a robotic arm, a relevant target recognition algorithm and an Automatic Guided Vehicle(AGV) chassis which equipped with a Simultaneous Localization and Mapping (SLAM) algorithm to realize this robot, Collaborate with each other through the Robot Operating System(ROS) system. Experimental trials show that our robot is more accurate in positioning in the cabin environment compared to other algorithms, and has the preliminary function of cleaning the cabins of general cargo ships as a potential intelligent future trend, it may be useful for ship clearance functions. This project can be applied to the above scenarios or other similar areas. This article also compared two classic SLAM algorithms: hector slam and gmapping, and ultimately concluded that hector slam is more suitable for the above environment.*

Keywords: *Ship clearance, Automatic sorting, Robot, Cargo, Automated guided vehicles(AGV)*

1. Introduction

According to the Review of Maritime Transport published by the United Nations Conference on Trade and Development in 2018, 53.57% of total global seaborne trade volume was transported by bulk carriers in 2017. Bulk cargo shipment is one of the major modes of transportation in the international trade[1].Due to factors such as time and weather, manual operations are limited, resulting in low efficiency and high accident rates in unloading operations. Therefore, automated loading and unloading technology is gradually receiving attention[2]. After the cargo ship berths, it usually takes 6-8 hours to unload, which includes gathering the cargo in the cargo hold into piles of cargo, which requires manual operation of forklifts and shovels for operation. Then, the grab bucket is used to grab and unload the cargo. The cargo ship has a large cabin and requires a lot of manpower. However, the introduction of artificial intelligence and robot technology can effectively solve this problem. Before entering the port, the robot can first pile up the cargo for convenient unloading. Cleaning the cargo hold of a general cargo ship is also a troublesome task for crew members. The cabin structure is complex and high, which is very dangerous for crew members. Our multi-functional robot can replace crew members in carrying out these dangerous tasks. By and large, the application of artificial intelligence and robot technology in the field of ship automatic sorting and cleaning can provide crew members with sufficient rest, ensure safety during sailing, and reduce the labor required for this essential task, allowing crew members to focus more on other tasks.

2. System Structure

In this paper, the hardware of our robot mainly consists of a controller module, radar module, power module, and visual recognition module. The appearance of the robot is shown in Figure 2 and 3, the system architecture framework of the robot is shown in Figure 1.

Our controller mainly uses NUC11PAHi7 with 32GB of running memory, providing powerful computing power for Simultaneous Locali-zation and Mapping (SLAM) and visual algorithms, it can control the speed of the robot in real time by receiving information from the IMU and gyroscope to control the motor speed. We use Wheeltec Radar sensor, the Radiant M10P, located in the middle of the front of our robot and connected to the central controller through a USB serial port. The robotic arm on the robot is a simple bus connection method, equipped with six servos, and connected to the central controller via Ardunio Mini and micro interface via USB. We installed the Ubuntu 18.04 system on NUC and built upon it with Robot Operating System.

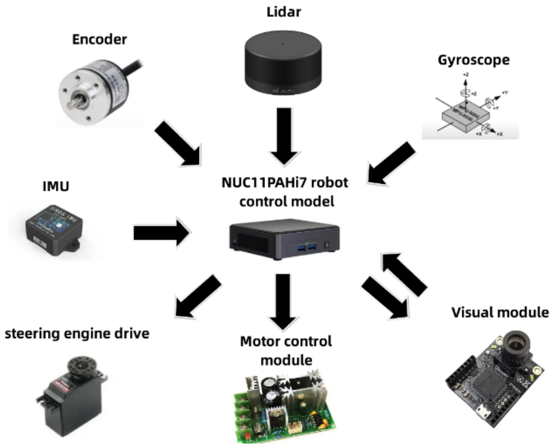

Figure 1: System structure of the robot

3. Robot mechanical structure

The mechanical structure design of robots has always been an prominence part of robotics engineering, and a outstanding robot physical construction can make the functions of robots more profundity. In this project, due to the sophisticated ship storage environment or other circumstances where our robot can be applied, we used an AGV chassis with omnidirectional Mecanum wheels and equipped it with a stepper motor and screw to simulate the elevator function to adapt to the height difference and equipped their platform with a self-designed six axis robotic arm. The six axis robotic arm is composed of multiple servos with six degrees of freedom, and the connecting components between the servos are 3D printed. We install an elevator consisting of a stepper motor and a sliding platform in the middle of the car, and carried with a robotic arm on it for convenient all-round movement. Its multifunctional robotic arm can complete cargo sorting. By replacing the end effector of the robotic arm, the robot can replace the water pipe for water spraying operations, thereby cleaning the walls.

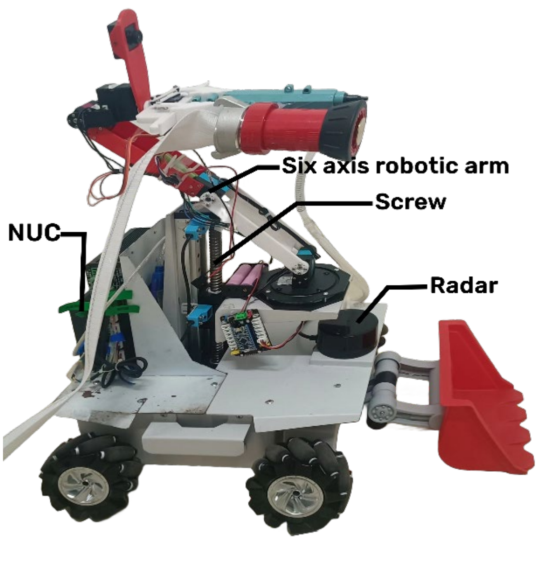

Figure 2: Side structure diagram of the robot

As shown in Figure 3, the bucket is installed directly in front of the robot and can be used during the clearance of general cargo ships. Through the bucket, scattered goods such as coal mines and grains can

ISSN 2616-5767 Vol.7, Issue 2: 56-62, DOI: 10.25236/AJETS.2024.070210

be gathered together. Meanwhile, during the cabin cleaning process, by replacing the end effector of the robotic arm, we can spray water onto the wall through a water pipe to help the crew clean the cabin.

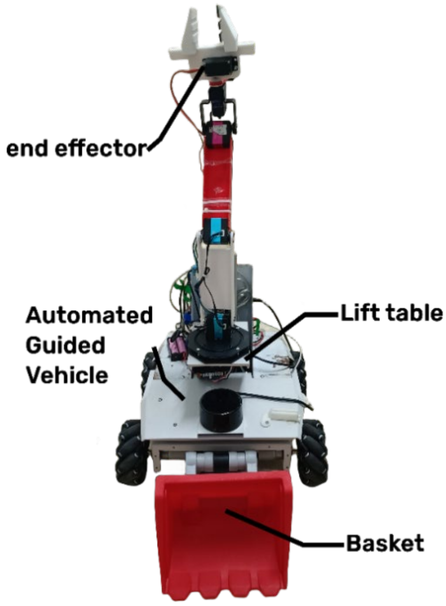

Figure 3: Front structure diagram of the robot

4. Slam Algorithm

The classic SLAM algorithms applicable to our robots include Gmapping, Cartographer, Hector, etc. Simultaneous Localization and Mapping (SLAM) is a fundamental technology in intelligent robot systems that enables the robot to autonomously navigate and map its environment[7]. SLAM allows for the positioning of robots in the map while creating the map[8],which is necessary For our autonomous robots.

4.1 Gmapping Algorithm

Gmapping algorithm is a Simultaneous Localization and Mapping method based on Rao-Blackwellized Particle Filters(RBPF).It has been used widely because of the efficacious use of odometer information and laser scan data[3-4][10].

When the robot odometer data u and observation information Z are known, The joint probability distribution $p(X_{1:t}, m|Z_{1:t}, u_{1:t})$ can be decomposed into two components: the robot's track X1:t and the surrounding environment m:

$$p(X_{1:t}, m|Z_{1:t}, u_{1:t}) = p(m|X_{1:t}, Z_{1:t}) \times p(X_{1:t}|Z_{1:t}, u_{1:t}) \tag{1}$$

The robot's track X1:t represents the robot's state at each time step from 1 to t. It includes the robot's position and orientation at each time step. The surrounding environment m re-presents the map or layout of the environment in which the robot is operating. It includes information about the location and characteristics of landmarks, obstacles, or any other relevant features in the environment.

RBPF is an algorithm of positioning first and constructing maps later. The Gmapping algorithm has been improved to address the shortcomings of the RBPF algorithm[5]. The Gmapping algorithm utilizes maximum likelihood estimation (MLE) to update the proposed distribution and narrow down its effective range using the observation data from the most recent frame. This approach helps reduce the number of particles required for the estimation process. Selective resampling is performed by applying a threshold. The threshold Neff, which can be determined using Formula (2), is used to determine whether the resampling step should be carried out. Resampling is a technique used to adjust the weight of particles and prevent degeneracy in particle filters.

$$N_{eff} = \frac{1}{\sum_{i-1}^{N}(w^i)^2} \tag{2}$$

In this formula, w is the normalized weight of particle i. When Neff is less than half of the total

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number of particles, resampling can reduce the sampling times and alleviate particle de-gradation to some extent[5].

In practical applications, robots using the gmapping algorithm usually need to first create maps in rviz, which is a three-dimensional visualization platform that displays multiple types of data, making it convenient for robot developers to visually see a large amount of data of the robot. However, in the scenarios where our robots are suitable, this function of creating maps first and then navigating is not very suitable. Figure 4 is the map created by the gmapping algorithm feature package.

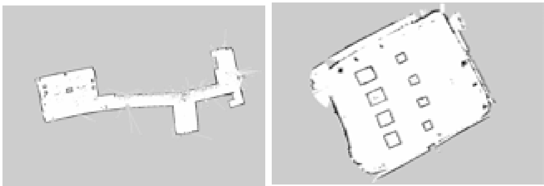

Figure 4: Gmapping map schematic diagram

4.2 Hector-slam

Hector SLAM is also a SLAM algorithm, which requires a higher scanning frequency for radar compared to gmapping. The laser data is acquired as the initial frame and used at time t to match it with the map from time t-1. This matching process maximizes the occupancy of the laser scan points, resulting in the estimation of the robot's pose. [6].

The real-time pose of a robot can be represented as:

$$X = (x + y + \theta)^T \tag{3}$$

The robot's pose (x, y, θ) represents its position coordinate and the angle between its motion direction and the X-axis in the world coordinate system.To estimate the pose, Hector SLAM formulates a least squares problem and solves it using the Gaussian Newton's method. The process can be summarized as follows:

$$X^* = argmin \sum_{i=1}^{n} [M(S_i(x)) - 1]^2 \tag{4}$$

In the equation, $M(S_i(x))$ represents the occupancy value of the laser point in the grid map. $S_i(x)$ represents the coordinate of the laser scan endpoint in the world coordinate system. The equation can be written as:

$$S_i(x) = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \times \begin{bmatrix} S_{ix} \\ S_{iy} \end{bmatrix} + \begin{bmatrix} x \\ y \end{bmatrix} \tag{5}$$

Although Hector uses Taylor expansion approximation to optimize the matching process of LiDAR data, so the pose change cannot be too large when collecting data twice, otherwise the residual error will be too large, causing the mapping to fail.

After experiments, Hector performed well in simulated environments with high accuracy.As shown in Figure 5.

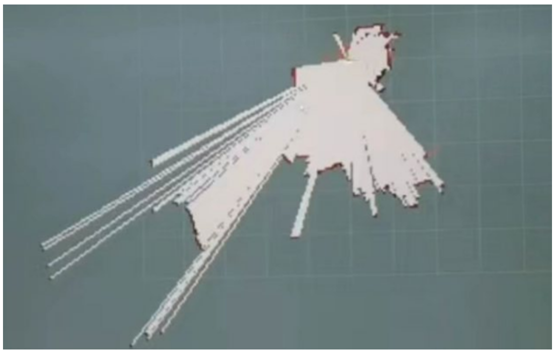

Figure 5: Hector map schematic diagram

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5. Experimental environment

A scene similar to the bottom of a general cargo ship has been found by us, we use it to test our algorithm, and in real navigation, ship sway is also an inevitable part. If we want to apply it in practice, future research must consider ship sway. We are testing the process of stacking soybeans and coal here.As shown in Figure 6.

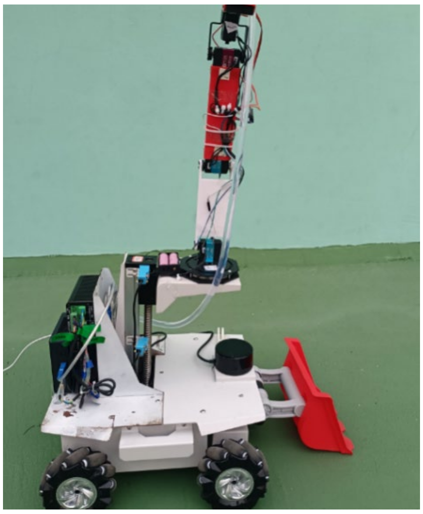

Figure 6 :Experimental environment

However, the actual structure of a bulk carrier cabin may be much more complex than this, so the simulation provided by this environment is relatively limited. If applied to a cabin, multiple factors must be considered. Figure 7 is a schematic diagram of the actual cabin, which also has a slope of 30-60 degrees. This poses a challenge to the collaboration, off-road pe rformance, and robustness of robots. We only simulated a relatively flat ground under the ship's hold, which may bring a new idea for ship clearance and cleaning.

Figure 7: Actual structure of the cabin

6. Path Planning

Because of the use of a single sensor in SLAM has certain limitations.[9] In the process of designing algorithms, we set coordinate points to sort and stack goods such as wheat, coal, etc.

The small piles that appear in actual scenarios are definitely more complex. The simulation environment in this experiment has limited capabilities, so there are only three piles of wheat and coal, which may be even larger in actual scenarios. As shown in Figure 8 & Figure 9.The general flowchart is as follows:

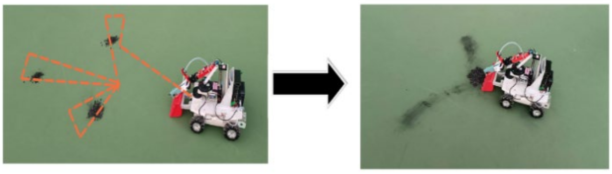

Figure 8: Schematic diagram of coal stacking path

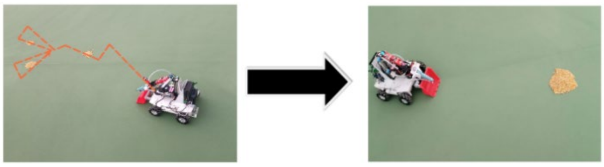

Figure 9: Schematic diagram of wheat stacking path

We move robots through radar positioning data by creating maps and writing predetermined coordinates. We write many functions in the program, including line_ Controller and yaw_ controller or some rotation functions, which includes coordinate system determination, allows us to easily move the robot. Figures 8 and 9 show the process of wheat and coal stacking.

7. Conclusion

In this paper, multifunctional sorting and clearance robot has been proposed and emphasized the use of the hector slam navigation algorithm in our Automated Guided Vehicle chassis. We compared it with the classic gmapping algorithm and found that hector slam performs better than the gmapping algorithm in the experimental environment. This may provide some automation ideas for ship clearance. Not only that, our automatic navigation chassis can also be applied to various other unknown environments. Traveling along a predetermined route and grabbing with a robotic arm, the front bucket can also achieve stacking function. The multi-functional and detachable end effector of the robotic arm can be replaced with a water gun for cleaning stains.

Acknowledgments

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