Application of Different Sensors in Obstacle Avoidance of Delivery Robots

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Abstract. People's living conditions are constantly rising as the global economy and society evolve at a rapid pace, and improving production efficiency has become a crucial concern. This paper proposes a combination of multiple obstacle avoidance schemes and algorithms to achieve dynamic obstacle avoidance for delivery robots. By analysing three different obstacle avoidance schemes including visual obstacle avoidance scheme, ultrasonic obstacle avoidance scheme and laser obstacle avoidance scheme, three robot usage scenarios including hotels, restaurants and hospitals, and three vital algorithms including Dijkstra’s algorithm, ORCA algorithm and PID algorithm. Then by analyzing the advantages and disadvantages of each scheme and algorithm and the characteristics of different usage scenarios, this paper obtains a robot obstacle avoidance and algorithm usage plan in a specific scenario.

Keywords: Delivery robot, obstacle avoidance, algorithm.

1. Introduction

From ancient times to the present, delivery has mainly been the responsibility of humans, people need to spend a lot of time and money to achieve the delivery of goods. However, with the rapid development of the world’s economy and society, people's living standards are constantly improving, and human needs have also become diverse and personalized. How to improve the efficiency of production and daily life has become an important issue. The drawbacks of human delivery are highlighted in this situation. For example, goods delivered by humans may raise privacy, security, and efficiency concerns. The existence and use of delivery robots solve this problem, providing effective and safe delivery services. The most important point is that applying delivery robots can reduce costs and promote the development of technology.

Delivery robots have multiple application scenarios. In restaurants and supermarkets, delivery robots can deliver food. And in the hotels, it can also deliver the groceries. In the hospitals, it can deliver packages and medicine. During the COVID-19 pandemic, the government's regulations on contactless services have further promoted researchers' attention to delivery robots. For example, Uber Eats released its delivery robot in various cities in the United States.

Furthermore, the delivery robots can also receive human interaction, which means the delivery robots can interact with people without any professional assistance. For instance, man machine interface (MMI) is widely used in industry, and can be simply divided into two types: "input" and "output". Input refers to the operation of machinery or equipment by humans, and output refers to notifications sent by machinery or equipment, such as faults, warnings, and operating instructions.

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2. Obstacle avoidance scheme for delivery robots

2.1. Visual obstacle avoidance scheme

Robots usually install cameras, which can capture image data. Then robots can analyze feature points from the images, they can match feature points and their internal or networked databases, which is the process of identifying. After the identification, the robot will then locate feature objects by adjusting the camera's pose. After that, the robot will establish a three-dimensional grid map based on the obtained positioning information. The robot will indicate the occupied part, unoccupied part and unknown part on the map to determine how to navigate itself. The whole process needs robots to complete for a very short period.

This scheme mainly uses the cameras on the delivery robots, which means this can save cost and optimize the internal structure layout of robots, and it can also improve the heat dissipation effect of the robot. What's more, many robots can share a networked database, which improves the efficiency of robot usage.

However, this visual obstacle avoidance scheme can cause the robot to reject to reach the edges, because the robot can only determine four directions and sometimes choose the wrong arc for the edge as interesting [1]. Furthermore, if there is a network malfunction, the robots cannot be used normally, which means the normal use of the robot depends heavily on the network.

2.2. Ultrasonic obstacle avoidance scheme

This scheme mainly uses the ultrasonic sensor to receive obstacle avoidance. The vibrating plate of the sensor vibrates at the frequency of ultrasonic waves and launches it forward. When encountering the obstacles, the sound waves will be reflected back to the receiver, which converts the vibration into an electrical signal. The robot then processes the electrical signal to measure the distance between the robot and the obstacle.

The advantage of ultrasonic ranging is that it can measure the distance precisely and it is less affected by external factors. Moreover, the ultrasonic can receive real-time obstacle avoidance, which can effectively avoid the collision of the delivery robots [2].

However, the maximum effective distance measuring range of the ultrasound is limited at a certain power, which means the sensor needs to emit high power when the robot is moving rapidly. This undoubtedly leads to a larger battery capacity to support the robots' endurance. So the robots equipped the ultrasonic sensors should be used in low-velocity circumstances.

2.3. Laser obstacle avoidance scheme

This scheme is similar to ultrasonic obstacle avoidance, which means there is a three-dimensional time of flight (3D TOF) sensor or a 3D structured light sensor inside the robot. The advantage of the 3D TOF sensors is that they can help robots in building 2D models and play a role in navigation and obstacle avoidance. On the other hand, 3D structured light sensor can send out the invisible line laser, and then the graphic sensor receives the deformed pattern projected onto the surface of the obstacle by the line array. The robot will then calculate the heading direction or velocity command based only on the local sensor information and develop an obstacle avoidance plan [3].

This kind of scheme has two main advantages. First, Lidar sensors have a long lifespan, which means their critical components can be used normally for a long time. Moreover, its cost of the maintain is very low. Second, the LiDAR sensors have a strong anti-interference ability, because they measure distance by emitting light, which is not likely affected by the external environment, and it is also not affected by other forms of waves.

However, the laser obstacle avoidance scheme has several limitations. LiDAR sensors are not suitable for use in low visibility environments, such as foggy or snowy weather, as this can cause the light to refract when passing through the air, and the robot will lose the ability to measure the distance. Plus, LiDAR is likely to cause irreversible damage to the human eye when directly exposed to it. In

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China, there have been reported vehicle LiDAR being directly exposed and causing serious eye damage due to the excessive power and precise angle.

3. Environment for delivery robots

3.1. Hotels

The hotel environment is relatively easy for delivery robots to predict. First, because its lobby is generally commodious so that delivery robots can easily make a decision. Secondly, its corridor is wide, delivery robots can easily pass through. However, most hotels have multiple floors, robots should use lifts to realize movement between multiple floors, robots need to be equipped with special sensors to interact with lifts and move in such a narrow space inside the lift.

3.2. Restaurants

The restaurant environment is hard for delivery robots to deal with. On the one hand, the crowd density in restaurants is high, so delivery robots need to quickly judge and respond to the behavior of each person they are passing by. On the other hand, delivery robots in the restaurant also need to pay attention to their speed when delivering food to prevent food from spilling. This requires robots to have more sensitive sensors and set a relatively appropriate speed that can ensure the delivery robots safely and punctually deliver food to the target dining table.

3.3. Hospitals

The hospital environment has higher requirements for delivery robots. Robots should not have excessive acceleration when transporting drugs. Moreover, there is radiation which is generated by complex medical equipment. This requires delivery robots have the ability to defend strongly from magnetic and radiation. Plus, hospitals also have many floors, which also requires the linkage between the robot's sensors and the lift.

4. Obstacle avoidance algorithms

The following three algorithms are very commonly used yet very crucial in the field of robot obstacle avoidance.

4.1. Dijkstra's algorithm

Dijkstra's algorithm was found in 1956 by Nederland computer scientist Edsger wybe Dijkstra. The principle can be described as follows. The first step is confirming the starting node and the target node, and order any other node is the unvisited node, the distance from the starting node to the unvisited node is infinity. The distance from the starting node to itself is zero. The second step is finding the node near the starting node, if the distance from the near node to the starting node is shorter than the infinity, update the distance and record the back node as the starting node, tab the shortest distance node and the node will switch into the visited node. The third step is finding the node near the visited node, if the distance from the near node to the starting node through the visited node is shorter than the infinity, update the distance and find the shortest distance between these near nodes, tab it as the visited node and record the back node. Loop the third step until the visited node is the target node. The final step is from the target node to the back node, repeat it until the back node is the starting node, and sum the distance, which is the shortest distance.

Dijkstra's algorithm is a simple but powerful method. The algorithm can let robots be located on a well-defined and well-mapped environment, which can also swiftly calculate the heuristic [4]. Therefore, this kind of algorithm is popularly used in the field of path-planning, navigation and obstacle avoidance of robots. Moreover, the algorithm ensures the robots find the shortest route from the starting node to the target node so that it can effectively save time. Plus, the calculation cost of the algorithm is very low because it is based on basic mathematical calculations.

The algorithm cannot be used when the distance from one kind of node to another node is below zero. Plus, this algorithm takes a long time to process complex scenes, which has high-performance requirements for robots, therefore it cannot be used in complex environments.

4.2. ORCA algorithm

Optimal Reciprocal Collision Avoidance (ORCA) algorithm is also a commonly used algorithm for robots in obstacle avoidance. ORCA develops from Velocity obstacle (VO) algorithm and the Reciprocal Velocity Obstacle (RVO) algorithm. However, the ORCA algorithm considers the direction and extent of the velocity, and primarily uses linear programming, whereas the other two kinds of algorithms only consider the direction of the velocity and mainly use non-linear programming, which brings difficulties in data processing. ORCA introduces preferred velocity and limited velocity. When there is no collision risk, the robot will choose the preferred speed to move. However, when the robot handles obstacle avoidance, it will approach the preferred velocity to zero, which means deceleration. If the preference velocity is zero, a deadlock situation may occur when the robot density is high, where multiple robots are squeezed into a small area. But if the preferred velocity is set more than zero, robots will slowly avoid the obstacle.

ORCA algorithm has many advantages in this field. First, The ORCA algorithm is effective when multiple robots occur or when other agents' positions and velocities are noisy, which can minimize the impact of obstacle avoidance on efficiency for multiple robots [5]. Second, robots applied ORCA algorithm generally use linear programming to process data, robots can find the optimal velocity within a velocity range.

However, there are some disadvantages of the ORCA algorithm. First, the solution of the ORCA algorithm is very complex, which means solving obstacle avoidance problems requires robots a large amount of computing resources. This will become the bottleneck of the robots. What's more, the ORCA algorithm cannot utilize the principle of symmetry, which means that the robots need to comprehensively scan and analyze obstacles, so the computing speed and efficiency of robots will also decrease.

4.3. PID algorithm

Proportion Integral Differential (PID) algorithm consists of three parts: proportional unit, integral unit and derivative unit. The final form of the PID algorithm is as follows:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

This is the main formula of the PID algorithm, it demonstrates the impact of three different computational approaches on output and the effect of errors on output [6].

PID algorithm superimposes the output into the input using three different calculation methods and controls the whole system. The difference between the PID algorithm and other algorithms is that it actively controls the various parameters of the robot through data rather than reacting to the environment. Plus, this algorithm can precisely control the linear velocity and angular velocity of the delivery robots, which means the delivery robots can use this algorithm to avoid obstacles and achieve real-time responses to dynamic environments.

On the one hand, if appropriate parameters are selected for the PID, it will provide a stable response to the robot and there will be no data oscillation, and this will greatly increase the stability of the robot usage. On the other hand, PID is a cyclic algorithm, so it has three units of data correction system, which ensures high precision of the data.

However, the PID algorithm also has limitations. First, the parameters of the PID algorithm often need to be adjusted to achieve the balance, it is a difficult and complex work, so this requires a huge amount of human resources. Second, the parameters of the PID algorithm require active input, so the PID algorithm cannot achieve high-precision control and cannot adapt to complex control systems.

5. Optimization and suggestions for obstacle avoidance scheme of delivery robots

In the hotel environment, due to the limited number of robots and the indoor environment, the obstacles encountered by the robots may be human. Therefore, for safety and cost considerations, hotels can use visual obstacle avoidance systems and apply Dijkstra's algorithms, which ensure high precision of the robot and do not encounter performance bottlenecks.

In the restaurant environment, it is a vital part for autonomous control of the robots to do the obstacle characterization, because the restaurant is a complex environment with high human density and multiple robots and obstacles [7]. So in the selection of robots, restaurants should tend to use robots equipped with ultrasonic obstacle avoidance systems and ORCA algorithms which can deal with multiple robot navigation.

In the hospital environment, because the radiation and waves emitted by medical equipment in hospitals can affect the normal usage of robots, and in the hospitals, the robots need high precision requirements, hospitals should tend to use robots equipped with laser obstacle avoidance systems and PID or Dijkstra algorithms, which can ensure the safe and stable use of robots. Plus, to ensure the safe transportation of medical items, hospitals can apply circuit design robots, which involve the interconnected electronic components system that can communicate and cooperate between robots to achieve the objectives of the robot [8].

6. The future of the delivery robots

Nowadays, delivery robots can improve the speed, efficiency, and reliability of package delivery, therefore, delivery robots become more and more popular [8]. Relying on the combination of software and hardware of the robot industry, the delivery robot industry is currently developing rapidly, more and more practitioners are involved in it. However, the development of the delivery robot is still insufficient and imperfect, which means many issues such as "How to make robot behavior close to humans?" or "How to make robots replace humans to do more refined work?". In the future, delivery robots should be combined with artificial intelligence (AI) and large data models to achieve human-machine collaboration, enabling delivery robots to deeply integrate with human society in both daily life and the working scene. Only by doing so can delivery robots truly become an indispensable part of the society.

7. Conclusion

The delivery robots have diverse usage scenarios, so people should combine different obstacle avoidance schemes and algorithms in different usage scenarios: In the hotel environment, the robots should be equipped with cameras and should use the Dijkstra's algorithm. In the restaurant environment, the robots should be equipped with ultrasonic sensors and should use the ORCA algorithm. In the hospital algorithm, the robots should be equipped with laser sensors and should use the PID or Dijkstra's algorithm. Furthermore, for different and more complex usage scenarios, people can flexibly choose and combine solutions based on the characteristics, advantages and disadvantages of different obstacle avoidance schemes and algorithms. In addition, when considering the selection of delivery robots, the focus should be more on which usage scenarios have usage restrictions rather than which scenarios can be used.

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