Simulation of Multi-robot Cooperative Scheduling System Based on ROS

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Abstract. Aiming at improving the management and scheduling efficiency of multi-robot in warehouse environment, a simulation method based on ROS system using 3D model and virtual activities to realize multi-robot collaborative scheduling was proposed and a multi-robot cooperating and scheduling system based on ROS was established, which includes building multi-robot simulation model, designing warehouse simulation environment, building multi-robot architecture and communication, task allocation and scheduling based on the minimum cost method. The system has the functions of map building, automatic navigation and obstacle avoidance, as well as the optimal scheduling of multi-objective points. The simulation results showed that the multi-robot collaborative scheduling system can reduce the workload of managers and improve the work efficiency of multi-robot.

1. Introduction

With the rapid development of e-commerce, warehousing logistics is facing new challenges. Multi-robot and intelligent management system are introduced into the traditional warehouse environment as a means to improve system efficiency and productivity. It is of great significance to improve the overall production efficiency of the system to realize efficient storage by using multi-robot. Therefore, the research of multi-robot cooperation and scheduling technology is very important. However, due to the limitations and constraints of many objective conditions and avoiding unnecessary consumption, more research should be completed by means of simulation experiments in advance. A scheme model of multi-robot cooperation mechanism under all environmental factors was proposed, which verified the model has good cooperation efficiency under fuzzy-based genetic algorithm scheduling [1]. An improved PSO algorithm was proposed to solve the order scheduling problem in multi-robot intelligent warehouse system, which proved the scheme can effectively improve the efficiency of intelligent warehousing [2]. There are some problems about limited bandwidth, delay and jitter in TCP connection of ROS nodes. A new ROS node pound was proposed, which can improve the wireless communication performance by reducing the delay and jitter in data exchange, and greatly improve the communication efficiency of multi-robot [3]. A method of building a control system of cooperative robot based on CAN communication on PC and ROS was proposed, which strengthened the characteristics of multi-robot system, such as modularization, high portability, clear frame and low delay [4].

Multi-robot collaborative scheduling system is a collection of many complex modules, which needs to consider the sensor, mechanical structure, electronic hardware and operation software. This work focuses on the design of automation and intelligence to improve the working efficiency of multi-robot in the warehouse system. In addition, the corresponding simulation experiment and verification are carried out.
2. Analysis of robot driving model

The driving gear system of the mobile robot can be divided into three categories: differential wheel, steering wheel and mecanum wheel. Due to the advantages of simple structure, flexible motion and low cost, differential wheel has been widely used in the storage robot drive. The dynamic analysis of the two-wheel differential drive system is shown in Figure 1.

![Figure 1. the structure and motion analysis of two-wheel differential drive system](image)

Let the linear velocity of the left differential wheel be \( v_1 \), the linear velocity of the right differential wheel be \( v_2 \), the distance between the centrum of the two differential wheels is \( D \), the linear velocity and angular velocity of the whole robot are \( v \) and \( \omega \). We can get it:

\[
    v = (v_1 + v_2)/2
\]

\[
    \omega = (v_1 - v_2)/D
\]

Let the total number of pulses of the encoder with one cycle of the wheel is \( s_e \). The unit time \( \Delta t \) increment of encoder of left and right differential wheels is \( c_{e1} \) and \( c_{e2} \), the angle between the robot coordinate system and the world coordinate system is \( \theta \), the radius of the differential wheel is \( r \). According to the calculation in reference [5], at time \( t \), cumulative odometer in \( x \) and \( y \) directions in world coordinate system \( X_w, Y_w \) and encoder cumulative angle \( \beta \) are as follows:

\[
    X_w = \int_0^t \Delta X_w \, dt = \int_0^t (c_{e1} - c_{e2}) \cdot 2\pi r \cdot s_e^{-1} \cdot \cos(\theta) \, dt
\]

\[
    Y_w = \int_0^t \Delta Y_w \, dt = \int_0^t (c_{e1} - c_{e2}) \cdot 2\pi r \cdot s_e^{-1} \cdot \sin(\theta) \, dt
\]

\[
    \beta = \int_0^t \Delta \beta \, dt = \int_0^t (c_{e1} - c_{e2}) \cdot 2\pi r \cdot s_e^{-1} \cdot D^{-1} \, dt
\]

The odometer can be represented by three-dimensional vector \((X_w, Y_w, \beta)\) as formulas 3-5.

3. Multi-robot cooperative scheduling in storage environment based on ROS

3.1. Analysis and establishment of warehouse environment model

The traditional method of map building relies on sensors such as encoder and lidar. The simultaneous localization and mapping (SLAM) technology is used to construct and save the map, which requires manual control to let the robot traverse the whole environment. If the environment is very large and there are many internal details, it is hard to traverse the whole environment with a single robot and it is easy to make mistakes. Therefore, using the method of multi-robot autonomous cooperation to build maps can greatly reduce the workload of managers and improve the accuracy of map building.
For the establishment of large scene complex map, this section proposes a method of multi-robot collaborative map building based on ROS system. There are two parts in the map building of multi-robot autonomous cooperation, one is to make the multi-robot establish local map separately; the other is to merge the local map established by multi-robot.

Firstly, robot 0 is placed in dispatch zone and robot 1 is placed in placement zone, and the initialization coordinates of each robot are recorded. By starting the “gmapping” function package and the “explore” function package, the robot can explore the environment and construct the local map by itself. The mapping constructed by the mapping algorithm is used to complete the automatic exploration service for unknown environment. Exploration services start immediately after node initialization.

Then, the local maps of multi-robot are merged. The “multi_map_merge” function package provides merging algorithm for local map created by robot 0 and robot1. To run multi-robot under multiple ROS hosts, it is necessary to run reliable communication between robots and provide maps of local topics for robots in the same host. This requires initial positions for each robot, which are within the overall size of the map. At the same time, the image feature matching technology is used to improve the accuracy of map mosaic. The geometric transformation between maps will be calculated according to the initial position, and the transformation between grids will be determined by heuristic algorithm.

The effect of environmental map established cooperatively by multi-robot is shown in Figure 2.

3.2. positioning and path planning of multi-robot base on ROS
For the function of multi-robot cooperation and navigation positioning, this section designs and uses three function packages of ROS, named as “nav_start”, “amcl” and “move_base”. The function analysis of each function package is as follows.

The “nav_start” package is the initialization start function package of multi-robot. Its function is to initialize and start all hardware drivers, sensor drivers and communication serial ports of multi-robot configuration, and release corresponding messages and coordinate transformation relations.

The “amcl” package is a multi-robot autonomous positioning function package. It is a probabilistic positioning system for two-dimensional mobile robots. It implements an adaptive Monte-Carlo localization method. The particle filter is used to track the position and attitude of the robot according to the known map.
The “move_base” package is a multi-robot autonomous navigation and path planning function package. Its function is to give a target point and try to generate a series of control instructions that can make the robot reach the target point. In detail, the global costmap and local costmap are obtained by processing the map and sensor data when the environment map and the robot's position in the map are known call the global path planner to get a global path, and call the local path planner to make the robot move along the path roughly and avoid obstacles dynamically. In the whole process of moving, it has to deal with some abnormal conditions, namely “recovery behaviors”. Its functions mainly include path planning and obstacle avoidance.

The communication and path planning structure of multi-robot is shown in Figure 3.

3.3. task allocation scheduling method based on the minimum cost method

The basis of task allocation and scheduling is based on the total generation value estimation method based on A* algorithm. A* algorithm is one of heuristic search algorithms. It is based on the graph plane, looking for the path of multiple nodes, and finding the lowest cost path through the cost estimation function \( f^*(x) = g^*(x) + h^*(x) \) \[6\].

Suppose there are two robots in the callable state, robot 1 is closer to the target point than robot 0. However, considering the obstacles (wall, flame column, shelves, people, etc.), it may cost more to call robot 1 than robot 0. The A* algorithm is used to plan the path of the two robots to reach the target point. At this time, it is difficult to determine which robot is more time-saving and consumption reducing.

The minimum cost scheduling is to calculate the cost of the path planned by A* algorithm as the basis for calling the robot. The cost of robot 0 is that \( \text{cost}_0 = 11.7 \), while the cost of robot 1 is that \( \text{cost}_1 = 23.1 \). Because of \( \text{cost}_0 < \text{cost}_1 \), the system will call robot 0. The method uses A* algorithm as a medium, considering the obstacles such as walls, shelves and people, which is more reasonable.

For the robot in the callable state, the generation value from the current position to the target point can be calculated. After unified calculation by the central controller, the task is assigned to the robot with the minimum generation value to complete the scheduling. On the basis of this A* algorithm, the total length of the path planned by A* algorithm and the maximum length of a single robot completing the task are considered as the cost function. The generation value of all possible path planning methods is calculated, and the path planning method with the minimum generation value is selected for multi-robot task allocation and scheduling.

4. Simulation experiment and verification

For the simulation platform environment, the hardware environment is portable PC, the processor is core i5 2.20 GHz. The running software environment is Ubuntu 18.0.0 version, 64 bit, ROS's melody version and upper computer software is QT creator (4.9.2) and database is MySQL (5.7.17).
Considering the time when three robots transport 12 goods to the corresponding 12 placement points, the minimum cost scheduling method based on A * algorithm is used to schedule the experiment. The path planning and collaborative scheduling process of multi-robot base on the minimun cost scheduling are shown in the figure 4.

![Figure 4. path planning and collaborative scheduling process base on the minimum cost scheduling](image)

As the result, the task completion time of this scheduling method is 253.1 s, and the total cost of multi-robot is 336.8. In addition, the task completion time of the fixed scheduling method is 314.7 s, and the total cost of multi-robot is 381.5. The experimental results show that the minimum cost scheduling method of the multi-robot is reasonable. It is better than fixed scheduling in terms of scheduling optimization.

Because a single experiment under a single condition is very accidental, based on the map environment and 3 robots in this paper, we consider the case that the goods transported are 6, 12, 18, 24 and 30 respectively, and conduct 10 independent repeated experiments in each group to calculate the average value. The average number of iterations and the average process time were counted, and the comparison chart was drawn in the figure 5.

![Figure 5. comparison of the minimum cost scheduling and fixed scheduling](image)

**Figure 5. comparison of total cost and completion time**

**a.** comparison of total cost  
**b.** comparison of completion time
It can be seen from Figure 5 that the performance of the minimum cost scheduling is better than fixed scheduling in terms of total cost and completion time. With the increase of the number of tasks, the scheduling conditions become more complex, and the total cost and completion time of the scheduling increases, and the rate of increasing the total cost and completion time of the minimum cost scheduling is smaller than that of fixed scheduling.

5. Conclusion
In this paper, a simulation method of multi-robot collaborative scheduling based on ROS system using 3D model and virtual activities was proposed. A multi-robot cooperative scheduling system based on ROS was established and the simulation experiment and verification were performed accordingly.

1) Multi-robot collaborative scheduling based on warehouse environment includes multi-robot autonomous collaborative map building, multi-robot positioning and navigation using ROS function package, reasonable task allocation and scheduling based on the minimum cost.

2) According to the simulation experiment, the results show that the multi-robot collaborative scheduling system designed in this paper can meet the expected functional requirements. At the same time, it has the advantages of reducing the workload of management personnel and improving the operation efficiency of the warehouse system.

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