Design and Test of a Multifunctional Mobile Manipulator Control System on an Experimental Platform

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Abstract: Mobile manipulators (MMs) performing the tasks of autonomous navigation, object grasp and transportation are widely used in industrial production and other domains. This paper presents a control system with multiple functions and good extendibility for a commonly configured MM, which controls the multi-degrees of freedom (DOF) movement of the MM while navigating, positioning, pose estimating and object grasp. This system has shown desirable control performance on an experimental platform.

1. Introduction
Mobile manipulator (MM) is a hybrid robot consisting of an articulated arm mounted on a mobile platform [1], which shows good application future in industrial production, logistics distribution and domestic service. The MM controller must be designed to realize the functions in specific application scenario. In this paper a comprehensive MM control system has been designed for a multifunctional MM platform to realize the functions of navigation, positioning, pose estimating and object grasp. A test on the experimental platform has shown desirable control performance of the control system.

2. Basic structure of the platform
The control system is based on an existing MM platform [2] as shown in figure 1.

![Figure 1. The MM platform](image-url)

The mobile chassis uses the omni-directional AGV (Automated Guided Vehicle) with Mecanum wheels. The hand of the manipulator is consisted of a 6-DOF manipulator and a two-finger gripper. The front of the mobile chassis is equipped with a Hokuyo UST-10LX laser scanner, which can collect range information between 0.06-10 m. An inertial measurement unit (IMU) in the centre of the vehicle can obtain accurate position and pose information of the MM. An Intel Realsense D435 depth camera is
equipped at the end of the manipulator, which can collect colour image data and depth image data of the scene.

In order to meet the needs of indoor object transportation, a complete control system should be built on the basis of each MM component to achieve indoor navigation and positioning, object pose estimation and object grasp.

3. MM control modes

Some typical control modes are used to control mobile chassis and manipulator respectively. Tracking control is used by MM chassis in certain application scenarios based on logistics sorting. The markers such as magnetic strips and control points are needed. In some application scenarios based on product assembly, the arm of the MM uses preset motion to complete the specified functions. However, there are some drawbacks to the existing approach.

(1) Lack of function integration. The MM application scenario is too simple and the functions of control systems are unitary designed, which have been hindering the full play of the structural advantages of MM. And poor integration of control systems in indoor autonomous navigation, route planning, and object grasp has resulted in weak autonomy and less functional perfection in MM control.

(2) Weak expansibility and portability. Most robot control systems for commercial service use self-developed control architecture with little expansibility for hardware interfaces. And the transportability between different hardware platforms is poor.

(3) Lack of vision-based control. Vision control has been widely researched on the manipulator platform. However, on the MM platform, the recognition ability of vision control part of most platforms is poor, and some platforms use monocular and binocular cameras to build vision control system [3], which leads to insufficient range accuracy and limitation on environment perception [4].

Existing MM control systems have limitations in application promotion, and are difficult to adapt to autonomy and comprehensive indoor object transportation. Therefore, further study in MM control system can improve its capability in the field of production and living.

4. Control system

With regards to the shortcomings of existing MM control systems, study in both hardware and software has done, and a control system with better capability and extensibility has been designed.

4.1 Hardware structure

The MM is equipped with an on-board control host computer. AGV, manipulator and other peripherals can be controlled by the mainframe integratedly. The control mainframe, which installed the Ubuntu 16.04 operating system, can run the main control program of the MM.

The MM control system has constructed a WLAN control network, which can realize wireless control of several MMs and improve the system control convenience and the expansibility of multi-device control. When MMs are connected to the WLAN control network respectively, a master control computer can be used to log in and control each MM by means of wireless connection, the hardware of control system connection is shown in figure 2.

Figure 2. Hardware connection diagram

Figure 3. Control system architecture
4.2 Software control architecture

Robot operating system (ROS) [5] is selected as the basic software system of the MM. The control system, combined with the characteristics of ROS, has taken the central node (Master) of ROS as its core and built a bridge between the raw data from sensors and various functional modules through ‘topic, service’ and other communication ways in ROS. Different algorithms can be chosen by each function module to realize its functions. The control program uses the algorithm planning results to realize the control of AGV and manipulator. The control system architecture is shown in figure 3.

The control system architecture has the following advantages:

1. Convenience for distributed robot system setup. This software architecture is based on ROS system and supports distributed design. The point-to-point robot nodes connection can be realized through TCP/IP protocol communication.

2. Weak corelation between control system and hardware. The software architecture does not rely on specific robot hardware. Users can access various hardware to the control system by converting hardware-related data to standard messages in ROS.

3. Rich in algorithm components. Each function module is able to support different algorithm. It is easy and fast to call algorithm set. The algorithm set supports follow-up expansion.

When designing the control system function module, The AGV control, manipulator control and vision-based control are mainly needed to achieve.

4.2.1 AGV control. The AGV is used to realize omnidirectional motion [6]. Through the kinematic analysis of the mobile platform, the Mecanum wheel omnidirectional movement of the vehicle can be realized in a specific layout mode by controlling the rotation speed of different wheels.

The system constructs the AGV control unit in ROS system. The work mode is shown in figure 4.

4.2.2 Manipulator control. The control of the manipulator is mainly divided into trajectory planning and instruction execution. Trajectory planning uses the important ROS component Moveit!, which ensures the control system to realize the functions of kinematics solution, collision detection, and plans trajectory according to the target state of the manipulator target object.

In the process of instruction execution, the control system will control the manipulator in various ways through the control unit of the manipulator. The work mode is shown in figure 5.
consistent with the planned trajectory, realizes the control process of the manipulator’s multi-DOF motion according to the specified target states.

### 4.2.3 Vision based control

The MM platform realizes object grasp function through vision-based control [7]. The vision control unit is constituted by hand-eye system and matching algorithm, which can do the hand-eye calibration [8] between the depth camera and the end-link of the manipulator. Through the coordinate transformation relationship of the manipulator, the target position in the camera coordinate system is transformed into the position in the manipulator coordinate, in order to guide the manipulator to grasp the target object. The specific work mode is shown in figure 6.

![Figure 6. Vision based control workflow](image1)

![Figure 7. Navigation testing workflow](image2)

### 5. Verification of control function

#### 5.1 Navigation and positioning control test

In the test of navigation and positioning, the ability of the MM to reach the designation is mainly tested. The workflow of the navigation test is shown in figure 7.

First, the MM builds a map of an unknown environment. After the map built and loaded, the user sets the destination manually. The control system uses the Movebase in ROS to plan the local and global path [9] to ensure the MM gradually move to specified work area.

In the process of testing, the navigation algorithm plans the path in sections to make the robot to move to the target continuously. The moving process control system receives the real time current position data of the platform, measures the deviation between the current position and the destination position, and constantly updates the path planning to ensure the distance between the platform and the wall or the corner always to be kept within the preset safety distance.

#### 5.2 Pose estimation and grasp control test

In the experiment, the object pose was obtained and the manipulator was guided to complete the grasp by vision control. The object to be recognized was a coke can. A depth camera of the control system was used to collect RGB image and point cloud data, and the LineMod algorithm was used in the pose estimation algorithm to recognize the position and pose of the target object [10], after the target model training process had been completed in advance. The target object appeared in the field of the vision centre. The depth camera collected the depth image and RGB image within the vision field. As shown in figure 8, the algorithm recognized the target and marked the credibility (0.905354).
Figure 8. Pose estimation results

Figure 9. Process of object grasp

With the help of the recognition results, the manipulator grasped the coke can and put it into the storage box of the vehicle according to the preset process, which verifies the recognition and grab control process. The step-by-step object grasp process is shown by the photographs in figure 9.

6. Conclusion
The control system of MM presented in this paper has the following characteristics:

(1) The control system is rich in functions, which has realized the control integration of navigation and positioning, trajectory planning, object grasp and other functions of the MM, and constructs a control architecture with integrated functions.

(2) In the vision-based control process, the depth camera is used to build the hand-eye system, which can collect RGB images, infrared images and point cloud data. This control system has improved the target identify ability of MM.

(3) Based on ROS architecture, a control system with extensible function modules and algorithm is constructed, which has high degree of data standardization and portability.

(4) The distributed wireless control network can support the wireless remote control of MM and realize the expanded control of multiple MMs.

The control system could effectively complete navigation and positioning, trajectory planning, position and pose estimation, object grasp, giving full play to the functional characteristics of the MM designed, and has a good application prospect in the fields of scientific research and industry application.

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References
[1] Liu R.H., Yuan H., Yang Y.C. (2017) Research Status and Development Trend of Mobile Manipulators. Tool Engineering, 05: 3-8.
[2] Ling, C., Xing, X.Y., Liu, L.W., et al. (2020) Design and Research of the Multifunctional Mobile Manipulator Based on ROS. In: AUTEEE 2020. Shenyang. pp. 86-90.
[3] Davison, A. J., Reid, I. D., Molton, N. D., & Stasse, O. (2007) Monoslam: real-time single camera slam. IEEE Transactions on Pattern Analysis and Machine Intelligence, 29(6), 1052-1067.
[4] Ling, C., Wei H.X., Li Z.Y. (2019) Environment Exploration and Obstacle Avoidance of 6-DOF Robot Arm Based on Robot Operating System. Mechanical engineering and automation, 3: 175-176,180.

[5] Guimaraes, R. L., Oliveira, A. S. D., Fabro, J. A., Becker, T., & Brenner, V. A. (2016) ROS Navigation: Concepts and Tutorial. Robot Operating System (ROS). Springer International Publishing.

[6] Liu Z., Wu H.T. (2011) The Motion Analysis and Simulation of Omni-Directional Moving Mechanism with Four Mecanum Wheels. Machine Design and Manufacturing Engineering, 40(5): 43-46.

[7] Xu D., Tan M., Li Y. (2011) Visual Measurement and control for robots. National Defense industry press.

[8] Tsai, R. Y., & Lenz, R. K. (1989) A new technique for fully autonomous and efficient 3d robotics hand/eye calibration. IEEE Transactions on Robotics & Automation, 5(3), 345-358.

[9] Chen S.Q., Dong L.F. (2010) Applied Analysis of Dijkstra Algorithm and A-star Algorithm in the Intelligent Guiding. Journal of Chongqing University of science and technology (Nature science edition), 12(6): 159-161.

[10] Liu H.L., Xiao P., Qiu M.W. (2018) Object Recognition and Position Estimation Based on RGB-D Image. Machinery, 07: 62-65, 74.