Design and application of automated mechanical arm and intelligent transport vehicle

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Abstract. At present, the constant development of industrialization has ushered in a wide use of vehicle-mounted mechanical arms in all walks of life. Yet there are still some deficiencies, such as large load, low intensity, poor efficiency, etc. In such case, an arm-type automated transport system is designed to improve its dynamic performance. The multi-degree-of-freedom mechanical arm is used as the mechanical structure to realize loading and unloading and the single-chip microcomputer is used as the main controller. Loading and unloading can be realized through smooth and flexible movements and the motion control of mechanical arm and automated transport vehicle is achieved through Raspberry Pi. The traditional mechanical arms are optimized in their structure and precision to increase their precision and enable them to meet different system requirements with applicability, economy, robustness and scalability.

Keywords. Mechanical arm; automated transport vehicle; structural optimization; motion control

1. Introduction

Industrial robots have been widely used in current industrial production. As a supplement to traditional modes, they not only free humans from heavy work, but also promote scale and automatic development of production lines. In particular, mechanical arms can protect humans from any injuries in situations such as transporting explosive ordnance or dangerous operations. Integrating mechanical and electrical technologies, industrial robots are important standard of a nation's scientific and technological level. As one of the most widely used industrial robots, the mechanical arm is an intelligent industrial robot that mimics the motions of a human arm and grasps things according to specific commands. Compared to traditional single mechanical arms, the automated mechanical arm has unparalleled advantages in its maneuverability, robustness and extensibility [1]. The system structure of mechanical-arm transport vehicle has defined the relationship and function distribution between humans and the system in the whole system, which improves the logical topology structure and information flow relationship between humans and the system.

The mechanical-arm transport vehicle in this paper is a specific realization of automated transport vehicle. This system adopts mobile power as its power source for transportation. This intelligent and automated system scans and identifies the objects and paths through sensors, and achieves intelligent vehicles’ transport control, full load design and recycle design through Raspberry Pi [2].
As the mechanical arm needs to work on the transport vehicle, it should be characterized by lightweight, stable and accurate motions, low battery consumption and so on while ensuring precise grasping. The automated control system includes a drive system, direction control device and several power assisting manipulators to complete the transporting work, greatly improving the efficiency and flexibility, as shown in Figure 1.

![Figure 1. schematic diagram of the principle of automatic processing system](image)

2. Design and optimization of mechanical structure

2.1. An Overview of overall system structure

The automated transport vehicle consists of two parts: mechanical arm and intelligent transport vehicle. The mechanical arm is separate from the vehicle structure. The vehicle identifies different paths through built-in cameras and realize full load design with the help of pressure sensor. It also supports identification and detection to strengthen the coordination between the manipulator and the vehicle [3]. The manipulator identifies, grasps and puts away the goods, and the intelligent transport vehicle delivers the goods to dedicated location according to the planned path.

This system design has the following features:

1. the sensor mounted on the transport vehicle is used to identify and grasp objects and increase the system’s reliability;
2. the sensor design enables the vehicle to support precise location space;
3. the intelligent tracking function follows planned path or optimal path;
4. the mechanical arm is used with intelligent vehicle to load and unload the goods;
5. the main control system based on Raspberry Pi supports programming, which can increase the system’s flexibility.

2.2. The hardware system

The hardware design of the control system should meet the function requirements of the mechanical arm and support long-time and stable operation with relatively low power consumption. In order to make the automated transport vehicle work continuously, batteries are used as the power source of the mechanical arm. The battery features stable voltage, low fluctuation, small size, and easiness to be mounted on the intelligent vehicle. The control system hardware is composed by an input part, a main controller and sensors. As the Raspberry Pi features rapid processing speed, low power consumption and excellent computing capacity, high-performance micro-controller is adopted as the main controller. The controller can also detect and analyse signals sent from the sensors to know the status of the mechanical arm.

According to the analysis results, the main controller’s output control signal uses closed-loop control. The main controller based on Raspberry Pi contains a 1.2 GHz 4-core 64-bit CPU, 1 GB RAM, a 10/100 Ethernet port and 4 USB ports. The Micro-SD card is used as the hard disk, and mobile hard disk can also be connected, which significantly improves the system’s flexibility and compatibility [4]. The installation and analysis of the above system and software can provide good system environment and development foundation for communication, object tracking and so on, as shown in Figure 2.
2.3. The software system
Software system. The software design should consider how to deal with the input signal and feedback signal. After powered on, the single-chip microcomputer initiates its internal storage and firstly deploys its function modules. Then it checks whether there are input signals or sensor signals. If there are relevant signals, it conducts corresponding handling procedures [5]. Some processing procedures follow the pattern of interrupting service routines and other procedures follow the pattern of inquiring service routines, as shown in Figure 3 and Figure 4.

![Figure 2. Raspberry Pi 3 Model B+](image)

**Figure 2.** Raspberry Pi 3 Model B+

**Figure 3.** Mechanical Arm Motion Control

**Figure 4.** Transport Vehicle Motion Control

3. Design and analysis of control system

3.1. Structural design of mechanical arm
The mechanical arm consists of a base, a large arm, a front arm and a holder. Its altitude and position is controlled by four servos (No.1, No.2, No.3 and No.4 from the bottom to the top). No.1 servo rotates to cause the rotation of the whole arm; the rotation of No.2, No.3, and No.4 servos controls the tilt of the holder so as to adjust the mechanical arm’s azimuthal angle and the holder’s grasping. During the whole process, the coordination of the mechanical arm and intelligent vehicle is achieved through information integration of the sensor and automated control of several main control panels.

In order to improve the system reliability, low-density and strong-intensity aluminum alloy materials are used to reduce its weight and maximum the load capability. The mechanical arm has four degrees of freedom.

(1) A standard steering gear I (the degree of freedom is 1) is mounted between the bracket and the base. With a rotation angle of $(0, 180 ^\circ)$, it is used for horizontal rotation.
(2) A standard steering gear II (the degree of freedom is 2) is mounted between two arms. With a rotation angle of (0, 180 °), it is used for the extension of the front arm. When the standard steering gear (2) rotates to 160 °, the front arm extends forward to 170 ° and the lower arm also extends.

(3) A standard steering gear III (the degree of freedom is 3) is mounted between the front arm and the holder. With a rotation angle of (0, 180 °), it is used for the front arm’s upward and downward movements.

(4) A standard steering gear IV (the degree of freedom is 4) is mounted at the rear side of the holder and its aperture angle is 0 to 180 °, as shown in Figure 5.

![Figure 5. The original structure of the arm](image1)

The mechanical arm with four degrees of freedom can be regarded as an open movement chain composed by four rotation junctions where relative rotation drives the connecting junction rotation. According to the test results of the firstly designed arm structure, its control performance and work space can fulfill the design requirements. But further precision experiment results show that the mechanical arm features low positioning precision and the servo becomes too hot during the steering process [6]. Therefore, it is supposed that the servo has insufficient output power and the mechanical arm lacks enough stiffness. Hence, the mechanical arm’s structure is optimized and a prototype is made, which is under test in the lab as shown in Figure 6.

![Figure 6. The optimized structure of the arm](image2)
3.2. Structure and functions of intelligent vehicle
The intelligent vehicle maintains good performance during its operation based on the following methods. The front wheels are controlled by standard steering gears, which enables the vehicle’s compliance steering. Regarding path identification, the vehicle needs to support accurate identification, stable operation and real-time capability. The system provides power through gear drive to avoid directional deviation caused by differential rotational speed of the rear wheels, increasing the vehicle’s stability. Figure 7 shows the actual intelligent tracking vehicle.

![Figure 7. The intelligent vehicle and mechanical arm](image)

3.3. Stability and precision analysis
The main control purpose is to enable the mechanical arm to grasp things like human arms. The movement path is analyzed and decided by setting several points in the work space. But the path acquired in this way is a broken line that stops at key points. In order to solve this problem, we optimize the path through linear interpolation to realize more smooth movement of the mechanical arm. The movement path acquired in this way is closer to actual path. The stability problem mainly exists in the detection of mechanical arm status. If the sensors make errors due to external environmental factors, the main controller will also make wrong decisions. The precision error is mainly caused by the arm deformation after loaded with goods of different weight and shape, and the reduction or increase of clearance between mechanical joints. However, the mechanical error is fixed for the same servos [7]. Hence, the fixed error can be transformed into kinematical equation and be corrected in the control.

4. Conclusion
Based on current vehicle-mounted mechanical arms, the paper proposes an automated transport system based on mechanical arm and intelligent transport vehicle. It integrates the mechanical arm, intelligent transport vehicle, multiple sensor information, and Raspberry Pi and completes the design of an automated transport system. According to the experiment results, the design is reasonable and feasible. The automated loading and unloading system based on mechanical arm and intelligent transport vehicle features high efficiency, flexibility and extensibility, so it has practical significance for automated production. Compared with traditional equipment, this transport vehicle features the following advantages:

1. After structural optimization, the mechanical arm has higher intensity and stiffness, which increases the motion accuracy and the load capacity.
2. The studies on vehicle-mounted mechanical arm is beneficial for industrial development and provide reference for dynamic loading and multiple mechanical arms coordination.
3. The path control algorithm is optimized through interpolation to realize compliance movement.
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