System development and structure analysis of intelligent material handling robot

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Abstract. This paper analyzes the current popular machine vision modules and various manipulator in the market. It independently realizes the reading of two-dimensional code information, the recognition of material color and shape, and the intelligent grasping system of grasping. By screening the existing commercial motors and the whole positioning system composed of orthogonal encoder and all-directions wheel, it realizes the positioning and moving system that can plan the path autonomously. It realizes self-reading information, identifying, grabbing and stacking materials through the combination of the above systems. This paper uses MATLAB software to calculate and adjust the positioning speed and position, and carries out the overall design and three-dimensional modeling of the robot for the above modules, and it performs static load analysis on the main components of the robot through the Solidworks Simulation module, and performs simulation experiments. After summarizing the function integration of the robot, the author puts forward the application of scenario hypothesis, proposes the application promotion scope for this scenario hypothesis, and conducts the simulation experiment. The results show that the robot is simple in design, easy to implement and conduct mass production, and it is practical and reliable, and has good positioning, grabbing and recognition effects. It can be widely promoted in the field of automation.

1. Introduction

1.1. Introduction

After the advent of the robot, the development of industry has been injected with fresh blood. In recent years, both the proposal of "made in China 2025" and the arrival of "5G era" are closely related to the development of intelligent robots. The application of high-end science and technology in the robot industry has been paid more and more attention. Under the background of the current national "prospering the nation with science and education", the development of high-end intelligent robots is the trend of the times.

As shown in figure 1, with the increasing investment in intelligent robot in various countries, the exposure degree of intelligent robot is getting higher and higher. Whether it is the artificial intelligent robot displayed by GOOGLE or the express delivery sorting robot used by Jingdong to fight "double 11", it represents that the development of intelligent robot is gradually heading for the peak [1] [2].
2. Module selection and analysis

2.1. Central processing unit selection

Intelligent handling robots have a wealth of modules and high requirements for real-time computing power, which makes the main control chip we used need to have more pin interfaces and CPU with higher performance.

There are many kinds of main control chips on the market, such as ARM, FPGA, etc. Among them, we need a chip with short development cycle, simple language, and open source program. According to these, we chose a core processor with excellent real-time performance, high frequency and moderate price among all kinds of chips: ARM.

According to this chip, we have chosen the CPU, as shown in Figure 2. Because of our data processing requirements, the Cortex-m4 can better meet our requirements.

![Figure 2. Performance comparison of various models of CPU](image)

After the CPU selection is completed, we use a processor of ST Company with a market share of up to 90%: STM32. It meets our requirements and has an AD/DA module interface and an encoder interface. The CPU core chip of RS232 and other communication interfaces is STM32F407ZGT6 chip. Robot vision module selection
OPENMV uses Python as its programming language, its development cycle is short, and the cost-effective features are in line with our requirements for visual modules. Its rich hardware resources such as UART, I2C, etc. are more suitable for our integration of various modules.

In summary, we use OPENMV as the core of our machine vision system, which can complete the color recognition and two-dimensional code recognition as shown in Figure 3 efficiently.

![Figure 3. OPENMV color recognition example](image)

2.2. Module grab selection
As a handling robot, its capturing module should have large torque, convenient control, low price and other characteristics. Through the comparative analysis of similar products in the market, we choose the gear type manipulator controlled by the steering gear.

In summary, we have adopted the manipulator shown in Figure 4, which is combined with the OPENMV described above to shorten the recognition and capture time of the robot, and to improve the efficiency of industrial production handling.

![Figure 4. Steering machine controlled gear type manipulator](image)

2.3. Mobile module selection
The robot's mobile module consists of two parts: the motor and the wheel. Among them, for the selection of the motor, the author considers two points: Controllable speed, Cost-effective.

2.4. Whole field positioning system
For the handling robot, positioning is the core of its handling accuracy, and is also the top priority of its development and application. Nowadays, the market has developed a lot of positioning systems, such as laser sensors, tracking sensors, gyroscopes, etc. The robots studied by the author are applicable to each factory, so the planning of the path needs to avoid the interference of the reference objects, that is, the relative positioning is used [8].

Due to the influence of the factory environment, the common signal guiding and positioning on the market and the positioning of the magnetic compass may not be accurate. Therefore, the author uses the mileage positioning module [9].

In view of the above characteristics, the author finally adopts OPS-9 omni-directional plane positioning system as our positioning module as shown in Figure 5. The positioning module uses MEMS inertial navigation technology and magneto resistive displacement measurement technology, and uses extended Kalman filtering algorithm for precise positioning. As shown in Figure 6, the positioning
module can achieve accurate calculation of coordinates by the combination of a quadrature encoder and a gyroscope [10].

3. The combination of the module design
The combination of modules is the most important link in the realization of intelligent handling robot. The author combines the OPENMV machine vision module with the manipulator to form an identification and capturing system. Through the combination of Mecanum wheel and dc geared motor with Hall encoder, the mobile system is formed. The combination of the above two systems and whole field positioning module forms the integrated system of the whole robot. Its modular design allows each module to be replaced or added according to the actual usage scenario without affecting the overall design of the robot.

3.1. Identification capturing system
Manipulator and OPENMV combined to form a grasping system, the total control is OPENMV built-in STM32F427 chip. Combining the two together makes the program run faster and more efficiently.

3.2. Mobile system design
For the robot's mobile system, the author combines the Mecanum wheel with the dc geared motor with Hall encoder. Through a series of program control, the author realizes a gradual change of speed of the moving process, so as to ensure the smooth movement of materials.

As shown in Figure 7, the author conducts simulation analysis of incremental PID curve through MATLAB, and makes the robot's acceleration process smoother by adjusting the robot's speed.

As shown in figure 8, the relation between input e (t) and output u (t) is:

\[ u(t) = kp(e(t)) + 1/TI \int e(t) dt + TD \frac{de(t)}{dt} \]

Its transfer function is:

\[ G(s) = \frac{U(s)}{E(s)} = kp(1 + 1/(TI*s) + TD*s) \]

Where, KP is the proportionality coefficient, TI is the integral time constant, and TD is the differential time constant.
3.3. Total system design

The author integrated the PCB board used by the robot for the actual required module and the driver board. It is equipped with a driver board such as L6470 and STM32F407 chip, which makes wiring and arrangement of robots easier. Meanwhile, the communication function is integrated into the main chip, which shortens the programming cycle.

4. Structural Composition and Finite Element Analysis of Intelligent Handling Robot

4.1. Finite element analysis of intelligent handling robot

A robot has many stressed parts. The author analyzes its stress and displacement through Solidworks Simulation, and defines the material properties of the sliding rail and the bending pieces (see table 1).

In Solidworks Simulation, the software itself is gridded and an example analysis is conducted, and the result of the example is obtained, as shown in figure 9 and 10. As can be seen from the results, the sliding track analysis results are (see table 2): The maximum strain is 0.00162173mm and the maximum stress is 546760pa, which meets the allowable strength in practical application. The analysis results of bending pieces are as follows (see table 3): The maximum strain is 0.0152395mm and the maximum stress is 17672pa, which meets the allowable strength in practical application.

| Sliding rail and bending pieces material properties |
|----------------------------------|
| **Attribute**                  | **Value**             |
| Elasticity modulus/N/m²        | 1.9299×10^11         |
| Poisson’s ratio                | 0.27                  |
| Density/kg/m³                  | 8000                  |
| Tension strength/N/m²          | 619 999 997.3        |
| Yield force/N/m²               | 234 421 748           |
| Thermal expansion coefficient/K | 1.7×10^-5             |
| Thermal conductivity/W/ (m·K)  | 16.1                  |
| Specific heat capacity/J/(kg·K)| 500                   |

| Sliding rail static load analysis results |
|------------------------------------------|
| **Model**                  | **Maximum stress/pa** | **Maximum strain/mm** |
| Sliding rail                | 546760                | 0.00162173            |

| Static load analysis results of bending pieces |
|-----------------------------------------------|
| **Model**                  | **Maximum stress/pa** | **Maximum strain/mm** |
| Bending pieces              | 17672                 | 0.0152395             |
5. Application scenario hypothesis

5.1. Simulation test exemplar
In the specific use, the working steps of the robot are divided into the following steps (see Figure 9).

![Robot Work Flow Chart](image)

Figure 9. Robot Work Flow Chart

5.2. Robot picture of real products
As shown in Figures 10, after repeated experiments and calculation, it can be concluded that the operating error of the actual robot is 0-18mm, which meets the common requirements of robot precision in the market. Meanwhile, the average completion time of the above processes is 4 minutes and 32 seconds, which also meets the working speed of the robot. At the same time, the volume of robot space is less than 210mm*297mm*297mm, meeting the requirements of the factory.

![Robot picture of real products](image)

Figure 10. Robot picture of real products
6. Conclusion
With the approach of Industry 4.0, the intelligent robot as its foundation has been vigorously developed, which also makes China change from a manufacturing great power to a manufacturing strong power. This paper studies the design and implementation of an intelligent handling robot. Through the combination of various modules, it realizes efficient, fast and intelligent robot operation.

Through the comparison and selection of each module, this paper analyzes the system requirements, completes the design of the robot for the overall structure of the robot, finite element analysis, and simultaneously makes the physical production and a large number of experiments. The experiment results show that the operating speed and load strength of the intelligent handling robot meet the expected requirements, the structure is simple and reliable, and the cost performance is high, which is suitable for popularization.

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References
[1] Wang Jiegao. Research and development and application of Eston robot core technology [J]. Robotics and applications, 2012, 4: 1 - 5.
[2] Liu Jinchang, Wang Wei, Ou Hejian. Opportunities and challenges brought by "blowout" in the market -- thoughts and suggestions on the development of industrial robots in China [J]. Robotics and applications, 2014, 1: 14 - 1.
[3] Wang Hongpeng, Yang Yun, Liu Jingtai. Research status and development trend of high-speed mobile robot [J]. Automation & instrumentation, 2011, 12: 1 - 4.
[4] Han Xiaoming. Design and control of anti-terrorist explosive disposal robot and manipulator [D]. Shanghai: Shanghai Jiaotong University, December - 25, 2005.
[5] Hu Weihua. Research on obstacle avoidance and navigation of indoor mobile robot based on RFID and WSN [D]. Hubei: Wuhan University of Science and Technology, 2009, 70 - 73.
[6] R. M. Robin. Introduction to AI robotics [M], BEIJING: Publishing House of Electronics Industry, 2004, 45 - 56.
[7] Hu Jincao. Research on indoor autonomous mobile robot positioning method [J]. Mechanical and electrical product development and innovation, 2006, 5:28 – 30.
[8] H. M. Rat, L.R. Petzold. A new look at proper orthogonal decomposition [J] . SIAM Journal on Numerical Analysis, 2003, 41 (5): 1893.
[9] I. Kolmanovsky, N. H. Mcclamroch. Developments in nonholonomic control problems[J],IEEE Control System Magazine, 1995, 15 (6): 20 - 36.
[10] B. Barshan, H. F. Durrant-Whyte. Orientation estimate for mobile robots using gyroscopic Information [C]. International Conference on Intelligent Robots and Systems (IROS'94). Munich, Germany. September 1994, 3: 1867 - 1874.