

Structure Design of Automatic Loading and Unloading Manipulator Based on Visual Positioning

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Abstract: The loading and unloading manipulator has an indispensable role in industrial production. The structure of the manipulator is divided into two parts: the manipulator body and the gripper. The special parts with position feedback and anti-collision function are designed according to the demand of the work. The key parts of the manipulator body and the gripper are checked to achieve the purpose of improving the efficiency; the use of image processing in the visual systems, workpiece position determination and camera calibration can improve the precision of loading and unloading. Experiments showed that the proposed method solves the problem of low accuracy for current manipulators, which can effectively improve the industrial production efficiency.

Keywords: Visual Positioning; Manipulator; Structural Design

1. Introduction

Machine vision refers to the application of computer vision technology to the field of manipulator technology. Creating a visual system for the manipulator, so that the manipulator can be more flexible to adapt to the current environment, such as visual autonomous guide manipulator and manipulator for industrial field visual recognition and positioning. Visual positioning of the loading and unloading manipulator is an important part of the production line (Abdelmohsen et al., 2016). Due to the continuous improvement of workers' treatment in recent years, many companies are facing great pressure to survive, many companies want to introduce automated equipment to replace the labor, which can improve work efficiency and reduce labor costs (Eraslan, Apatay, 2016). Automation equipment is easy to manage, and can still work well in some harsh working environment, which can improve the factory safety factor. So, the research of automatic loading and unloading manipulator based on visual positioning has important theoretical significance and practical value (Li et al., 2015; Huang et al., 2016).

To solve the problem of automatic loading of straw mill, Huang et al designed a new straw loading device to improve the accuracy and automation of the straw mill. The device uses the Canny operator to segment the straw image, and extracts the weak edge, passes the extracted information to the manipulator PC processing center, sends out the instruction to control the action of the manipulator, and uses the closed-loop control to complete the automatic control, which optimized start and stop time of the servo motor (Kirshenboim et al., 2016). The

results showed that compared with the manual loading, the use of automated control of the manipulator can improve the quality of straw crushing, and can reduce the damage caused by the material on the people, but the work efficiency is low. In order to solve the problem of high cost and poor anti-pollution ability of cylinder operating position servo system, Guo et al (Guo et al., 2017) analyzed the switching characteristics of high-speed valve and the flow characteristics and the thermodynamic characteristics of the cylinder, and established the system mathematical model; BP neural network controller is added in the traditional control loop, which can adjust PID and control parameters on-line based on the deviation between the actual output and the expected output of the system. Experiments showed that the PID control effect based on BP neural network is better than that of the traditional method under the same system parameters, which can realize the efficient control of the cylinder position servo system, but the control precision is poor.

2. Structure Design of Automatic Loading and Unloading Manipulator Based on Visual Positioning

Mechanical structure is an important part of the loading and unloading manipulator system, which can determine the stability, high efficiency and reliability of the system (Milne et al., 2016).. It includes hardware and software and other parts.

2.1. Hardware design of the automatic loading and unloading manipulator system

In the choice of system hardware, to protect the reliability of the system, the hardware of the mechanized system mainly includes: intelligent camera, lens, industrial computer, PLC, touch screen, gripper probe, etc.

The main consideration for the camera selection is: resolution, sensitivity, signal to noise ratio and video transmission signal standard. According to the type, size and other characteristics of the workpiece, the view field of the camera is 785mm*785mm. Combined with the above requirements, this paper selected the FZ-S2M smart camera, the specific parameters are shown in Table 1:

Table 1. FZ-S2M camera parameters

Model	FZ-S2M
Image components	1/1.8-inch CCD image components
Color/Black and White	Black and White
Effective Pixels	1600 (H) * 1200 (V)
Pixel size	4.4 (μm) * 4.4 (μm)
Vision and installation distance	Select the lens according to the installation distance
Working environment temperature	Operation: Less than 60°C; Store: -25°C to 65°C
Weight	77g

the choice of the lens is 3Z4S-LESV0814H, the main consideration is the size of the field of vision, focal length, object distance and the camera target surface size. The distance from the camera is determined by the distance from the surface of the workpiece, and the target face size is determined by the camera. The focal length of the camera is 8.07mm. The main parameters are shown in Table 2:

Table 1. Len parameters of 3Z4S-LESV0814H

Model	3Z4S-LESV0814H
Appearance size/mm	39*53
Focal length	8.07mm
Brightness	F1.4
Color filter size	M35.5P0.5

gripper probe sensor. To achieve the accurate grasp on the workpiece, the gripper probe is designed by using the angle information feedback of the relative position of the current position and the center of the workpiece. The hardware interface circuit is shown in Figure 1:

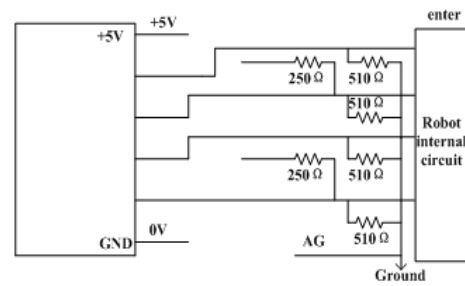


Figure 1. Hardware Interface Circuit of the Gripper Probe Sensor

2.2. Software control design of the automatic loading and unloading manipulator

The software part of the loading and unloading system is divided into information sensing layer, data processing layer, program control layer and execution layer. The system controller as the core of the entire structure can be completed with the real-time communication of peripheral devices, the control of the loading and unloading manipulator and the planning of the trajectory. The control flow of the system is shown in Figure 2:

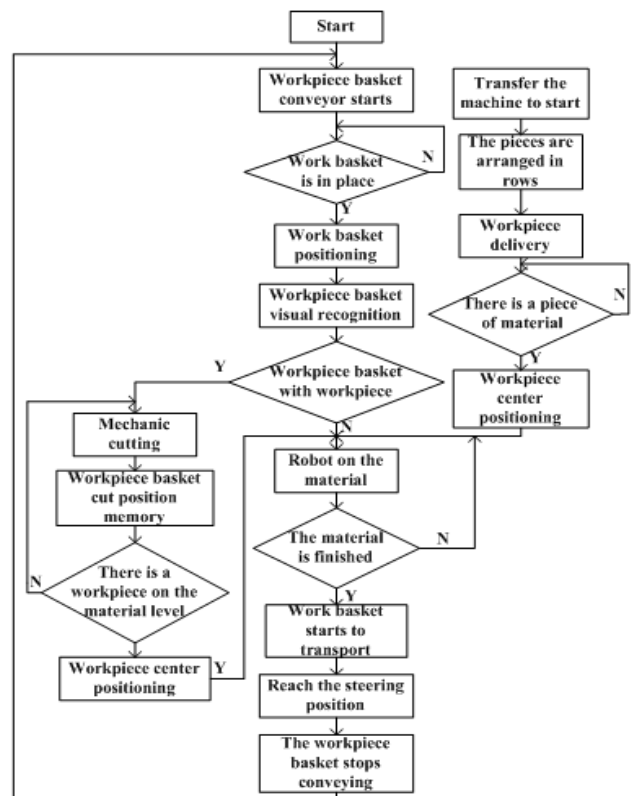


Figure 2. Working Flow Chart of the Loading and Unloading Manipulator System

The above figure 2 shows the use of the track wheel loading conveyor to the center positioning station to achieve the automatic positioning of the track wheel. The track wheel uses the pallet conveyor to transfer the tray to the box and use the visual sensor to determine whether the tray is empty, if empty, then the manipulator began to move the located track wheel to the workpiece box followed the planned path.

2.3. The main technical parameters of automatic loading and unloading manipulator

The main technical parameters of the loading and unloading manipulator are degrees of freedom, positioning accuracy, repeat positioning accuracy, working range, maximum working speed and carrying capacity. In the structure design of automatic loading and unloading manipulator, good system performance is built on excellent mechanical performance. To achieve the best mechanical performance, the effects of the technical parameters on the performance of the manipulator should be considered comprehensively.

The degree of freedom of loading and unloading manipulator. In the Cartesian coordinate system, the position can be described by three degrees of freedom that move relative to the origin along three axes, and the posture can be described by three degrees of freedom that revolve around a three-axis axis. In this case the shape of the workpiece is cylindrical, the cylinder should face up during the handling, the material only need to consider the location information without the workpiece posture problem, which only need 3 degrees of freedom.

The positioning accuracy of loading and unloading manipulator. Positioning accuracy and repeat positioning accuracy are two important technical parameters to measure the accuracy of manipulator. To a certain extent, the overall performance of the manipulator is represented by the loading and unloading manipulator system based on visual positioning. Positioning accuracy refers to the difference between the theoretical position required by the manipulator to obtain the instruction and the actual position it can reach. Repeat the positioning accuracy is the manipulator to repeat the positioning in the same instruction requirements. The intensity of each actual positioning error is a measure of the ability of the manipulator to repeat the same position.

The working range of loading and unloading manipulator. The effective movement of the manipulator in the X direction is 1600mm; the effective movement of the manipulator in the Y direction is 600mm; the effective movement of the manipulator in the Z direction is 300mm.

The allowable running speed and loading capacity of the loading and unloading manipulator. The loading capacity is the maximum loading capacity that the end of the manipulator can bear. It includes the weight of the manipulator and the weight of the workpiece. The size of the

force of the manipulator is not only related to the loading but also by the acceleration of the manipulator. Considering the working requirements of the loading and unloading manipulator, the terminal loading capacity is to be set to 50Kg.

2.4. Structure design of loading and unloading manipulator

The structure of the manipulator can be divided into two parts: the design of the manipulator body and the design of the end effector.

The design of the manipulator body. Cartesian manipulator controls the position of the end of the manipulator through three mutually perpendicular axes of motion (X axis, Y axis, Z axis). These manipulators have simple structure, good rigidity, low inertia, easy control, high reliability, short design cycle, low cost and high positioning accuracy, which are mainly for material handling and tight assembly and measurement, and meet the requirements of the subject on the manipulator body. The overall structure of the manipulator in Cartesian coordinates is shown in Figure 3:

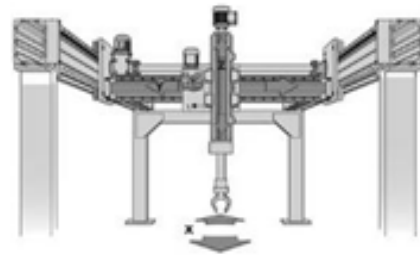


Figure 3. Overall Structure Design of Automatic Loading and Unloading Manipulator

the structure of the anti-collision gripper structure. As the weight of the workpiece is heavy, and the workpiece and the workpiece basket are all steel materials, which are not suitable for the use of adsorption but to crawl, so we designed the two-finger hook-type gripper. In actual work, due to various reasons, there have been claws and the workpiece collision, directly resulting in the manipulator damage. We designed an anti-collision mechanism on the basis of our existing experience, which reduced the collision probability to zero, and enhance the reliability of equipment.

2.5. Key structure components selection of the loading and unloading manipulator

The movement of the manipulator in the X direction is 1600 mm and the linear velocity on the slide is designed to be 600 mm/s. HGH-30CA is used as a supporting element; servo motor plus ball screw driver is used, which selected FSC series as the ball screw, screw nominal di-

iameter is 32mm, screw nut selection is the TYPE2 type in FSC series, screw nut model is FSC32-20K3, the lead is l=20mm, lead angle is 13.86 °. The components in the Y and Z directions are all the loads on the slide rail, and it is estimated that the load on the rail is about 2000N. The motor selection is the AC servo motor model of SGMJV-08A5R5A, the rated output power is 750W, the rated speed is 3000 r/min, and the maximum torque is 8.36N·m.

The movement of the manipulator in the Y direction is 600 mm, and the linear velocity on the slide is designed to be 600 mm/s. HGH-30CA is used as a supporting element; servo motor plus ball screw driver is used, which selected FSC series as the ball screw, screw nominal diameter is 20mm, screw nut selection is the TYPE1 type in FSC series, screw nut model is FSC 20-20K2, the lead is l=20mm, lead angle is 13.86 °. The components in the Z direction are all the load on the slide rail, and the load on the rail is estimated to be about 900N. Motor selection is AC servo motor model of SGMJV-04A2R8A, rated output power 400W, rated speed is 3000 r/min, the maximum torque is 4.46 N·m.

The movement of the manipulator in the Z direction is 300mm, and the linear velocity on the slide is designed to be 600mm/s. HGH-30CA is used as a supporting element; servo motor plus ball screw driver is used, which selected FSC series as the ball screw, screw nominal diameter is 20mm, screw nut selection is TYPE1 in FSC series, screw nut model is FSC 20- 20K2, the lead is l=20mm, lead angle is 13.86 °. The maximum mass of the workpiece is 40kg, and the load on the rail is estimated to be about 500N. Motor selection is AC servo motor model of SGMJV-04A2R8A, rated output power is 400W, rated speed is 3000 r/min, the maximum torque is 4.46 N·m.

2.6. Movement time check of the loading and unloading manipulator

The maximum movement in the X-axis direction is

$$N_{gen}(t) = \ln\left(\frac{T_f(t)}{T_f}\right) + \frac{r_f(dp \cdot n)^3 C_d(2h_1 + d)pd_1}{2T_f(t)m_f c_f}, \quad \text{the}$$

maximum movement of the manipulator table in the Y-axis direction is $s_1 = 600\text{mm}$, and the maximum speed is $v = 600\text{mm/s}$. Two directions of the servo motor acceleration and deceleration time are set to $t = 0.5\text{s}$, then the acceleration and deceleration of the motor is:

$$a = \frac{v}{t} = 1.2\text{m/s}^2 \quad (1)$$

Calculate the maximum time t_x moved in the X axis:

$$\frac{1}{2}at^2 + vt_2 + \frac{1}{2}at^2 = s_2 \quad (2)$$

Where, $a = 1.2\text{m/s}^2$, $t = 0.5\text{s}$, $v = 0.6\text{m/s}$, $s_2 = 1.6\text{m}$; then: $t_2 = 2.2\text{s}$. The maximum time for the X-direction

movement is: $t_x = 2t + t_2 = 3.2\text{s}$. Calculate the maximum time t_y in the Y direction:

$$\frac{1}{2}at^2 + vt_1 + \frac{1}{2}at^2 = s_1 \quad (3)$$

Where, $a = 1.2\text{m/s}^2$, $t = 0.5\text{s}$, $v = 0.6\text{m/s}$, $s_1 = 1.6\text{m}$; then: $t_1 = 0.5\text{s}$. The maximum time in the Y direction is: $t_y = 2t + t_1 = 1.5\text{s}$.

2.7. The working principle and camera calibration of the visual system

The visual system consists of three parts: image acquisition, image processing, display output or function execution (Wang et al., 2017).. Different hardware has different basic functions, according to each part of the visual system has different task, the hardware is divided into three parts:

Image processing equipment. It is composed of a camera for acquiring images and an image processing card for image processing. The camera works by converting the acquired image into an electrical image, then converting it into an electrical image according to the image pixel value in a certain order, and converting it into an electrical signal that can be converted, finally A/D conversion is performed on the obtained images. The image acquisition card then converts the electrical signal from the camera into the computer and converts it into computer-readable data by computer processing, then stores the data and performs some necessary post-processing.

followed by a certain order, in the entire loading and unloading system, the controlled equipment mainly includes the control system of the manipulator, the lathe control system, the camera and the image acquisition card. The control system also includes several motors, drivers, motors and auxiliary devices.

computer system: the system has two main functions. One is the control function, which can control the camera, the image acquisition card, and the image processing. The other is the image information processing function that the image acquisition card carries the data into the computer, and the computer system analyzes the relevant data processing to obtain the relative coordinates of the measured object points. To carry on the real-time processing to the digital image, it is required that the computer system memory is large, the operation is quick, the software function is comprehensive, in order to facilitate processing huge picture data information.

The working principle is shown in Figure 4:

First, the object image is acquired, then the visual positioning system performs a large number of processing operations on the image. Next, it analyzes the data needed for the workpiece acquisition in the image. Image processing in the visual positioning of the data processing is very important, the quality of the image and

the correctness of the results has a very large impact to the accuracy of the loading and unloading (Zhang et al., 2015). That is, to further obtain the relevant information

of the workpiece image, the visual system needs to separate the workpiece image from the original image.

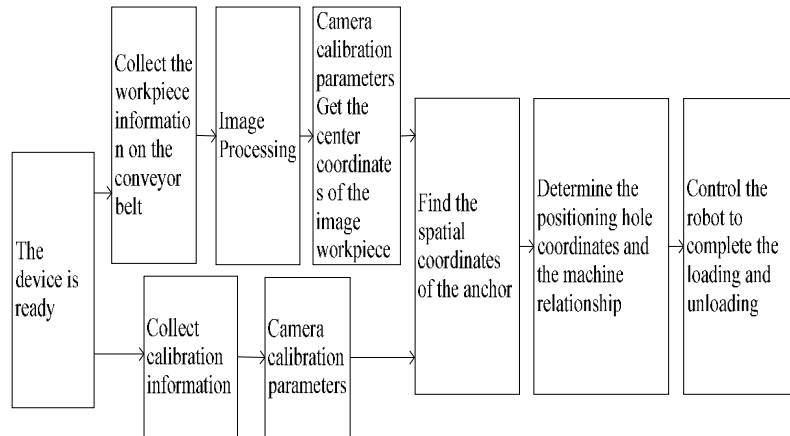


Figure 4. Work Flow Chart of Visual Positioning System

In this paper, the workpiece is shown as black charcoal, the conveyor belt is yellow, at the edge of the workpiece, the color change is obvious, and the gray scale is very different. So, it is easy to judge the workpiece from the boundary line. Matlab software is used to enhance the obtained images, and finally get the specific location of the workpiece.

In MATLAB, using imadjust (a) as the image enhancement function to enhance the image file. The function call format is: k1=imadjust (a) represents the enhanced image file information.

Through the Matlab image processing function, the center coordinates of the cylindrical workpiece can be well obtained. As shown in the following figure 5, five crosses have been marked in the image after the Matlab software processing:

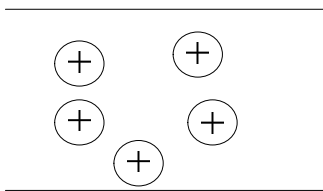


Figure5. Determination of the Center of the Workpiece

The cross in Figure 5 is the position of the center, through the Matlab software transformation, the size of the image and the coordinates at the center of the circle can be obtained.

The purpose of the camera calibration is to establish the imaging model, determine the position of the camera and the attribute parameters, to obtain the position relationship between the image point and its corresponding spatial geometric point. The camera imaging system typically transforms a 3D scene into a 2D grayscale image or a color image, which can be represented by a mapping from 3D space to 2D space. This paper used the calibration method proposed by Zhang (Zhang et al., 2017), which can be calibrated by taking a few images of the calibration plate from different angles. The advantage of this method is that the calculation is relatively direct, the accuracy is also high, and the internal parameters will not change when the calibration is completed. The use of working principle of visual positioning system, image processing, workpiece position determination and camera calibration to achieve visual positioning, can enhance the positioning accuracy of the workpiece and speed up the efficiency of the manipulator loading and unloading.

3. Experimental Results and Analysis

Control the manipulator, to simulate the effect of anti-collision gripper on collision detection under different positioning deviation, and compare with the gripper without anti-collision function, the experimental results are shown in Table 3:

Table 3. Comparison of anti-collision performance of different grippers

Form of gripper	Upper part of the workpiece	The middle of the workpiece	The lower part of the workpiece
Anti-collision	Calculate the position deviation for accurate	Let the probe close to the workpiece surface and	Calculate the center of the circle according to the distribution of the center of the circle.

gripper	crawling	automatic grasping stability	Try to secure the workpiece
Ordinary gripper	Wiping with the workpiece, and workpiece starts to tilt after grabbed	The grips collide directly with the workpiece, the workpiece or the fingers are damaged	Wiping with the workpiece, and crawling cannot be completed

Table 3 showed that after the use of a probe in the gripper, the probability of collision greatly reduced during the process of grabbing the workpiece which improved the reliability of the equipment. Especially when the positioning deviation is in the middle of the workpiece, it improved the positioning accuracy of the gripper and speeded up the work efficiency without improving the accuracy of the visual positioning.

The measured 25 sets of data were derived separately, Figure 6 shows the workpiece as the experimental object, take the workpiece center x coordinate data as the abscissa, y coordinate data as the vertical axis, a scatter plot of data markers was established, as shown in Figure 7:



Figure6. Loading and Unloading Workpiece

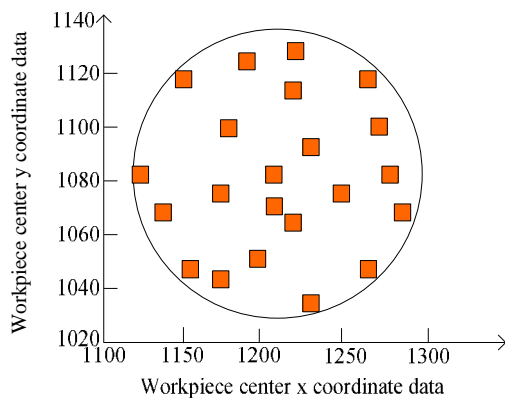


Figure7. Coordinate Distribution of the Workpiece Center

Figure 7 showed that the center of the workpiece is distributed in a finite neighborhood and the workpieces in each compartment of the workpiece basket are distributed in a limited neighborhood, which conformed to the camera calibration method mentioned in this paper, the correctness of the workpiece position can be detected to

be assessed which improved the accuracy of the manipulator.

The grip between the two fingers of the mechanical gripper is shown in Figure 8:

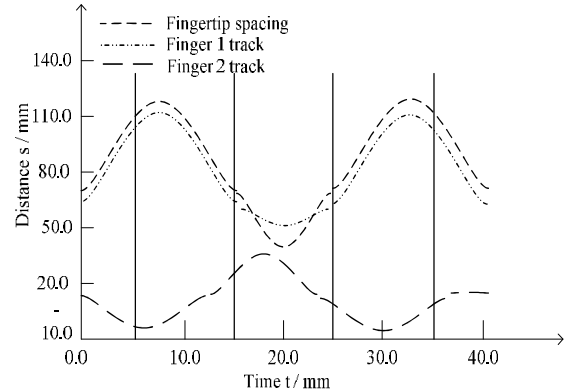


Figure 8. Gripping Range Between the two Fingers of the Manipulator

Figure 8 showed that in the process of opening and closing the cylinder telescopic movement was about 10mm, thus selecting the cylinder movement of 30mm. It drives the opening and closing of the gripper and make the actual effective clamping range of 70 to 115mm, which meet the size requirements in Figure 7, and also improve the processing efficiency.

In the structure of automatic loading and unloading manipulator, the image processing is the key factor to judge the accuracy of loading and unloading. In this paper, the workpiece image is processed by using the image enhancement method mentioned in Figure 6 to observe the effects of different methods on the workpiece image after adding noise. The experimental results are shown in figure 9:



(a)Workpiece image after the addition of Gaussian noise



(b) Image enhancement effect of the method proposed in Reference 5



(c) Image enhancement effect of the proposed method

Figure 9. Image Enhancement Effect of Different Metho

4. Conclusions

Visual positioning combines image processing, mechanical engineering, machine control and other theories and technologies, which is a very new research field with a rapid development. The application of visual positioning method and theory to solve the target positioning in the process of manipulator loading and unloading can effectively improve the positioning accuracy and efficiency. The application of visual positioning technology in flexible manufacturing system will increase and become more perfect. Although this experiment proves the proposed method has a certain feasibility, but in the face of future opportunities and challenges, further studies should be focus on the following areas:

The research on the visual system should be more specific;

The situation of force and the program control of the loading and unloading manipulator will be further studied;

In the face of more and more high standard of the work-piece, it is necessary to calculate the depth information of the workpiece.

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