Precise Positioning of the Tray Grabbing System Based on Machine Vision

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Abstract. To achieve the exact grabbing operation of the forming tray in the gantry space during the process of forming the cigarette filters, we propose a system using machine vision for precise positioning of the centre of the tray. In this system, multiple stacks of the trays do not require extra time for accurate manual stacking, these trays can be put into the gantry space directly from the factory stacking state, which improves the applicability and accuracy of the system. Combined with PLC as the control centre of the control system, equipped with motion module and three-axis servo-driven motion control mechanism, this system can realize the positioning movement of the target position with high precision and simple control.

1. Introduction
In the process of the cigarette filters production, the external needs to be wrapped with a narrow paper strip which is shown in Figure 1. At present, the paper splicing machine that continues to provide narrow paper strip uses the technology of single stack of tray. This technique requires the trays must be stacked orderly on the trolley before entering the tray replacing station. Nowadays, the production volume of the cigarette filters is huge, which means, the stack of trays should be replaced on time to meet the production frequency on the moulding equipment. Moreover, it cannot guarantee the consistency of the tray positioning with the trolley positioning, so that it is easy to bring instability for the work of replacing paper tray.

To reduce the frequent replacement of tray stacks and save labour time, a four-stack tray mechanism has been devised. Four stacks of paper tray on one chassis is purchased from the manufacturer and fed by the AGV car into the replacing station at one time, as is shown on the left in Figure 2, this is the ideal situation which the paper trays are close to each other. This improvement can reduce the frequency of tray stacking replacement to a certain extent. Compared with the replacement...
of single stacker, it can save nearly 3 times time. However, in practice, the tray stack which delivered by the AGV car is not always the same as the ideal case. Once encountered this situation shown in the right of Figure 2, the position of the four stack tray deviates from the ideal condition, which may easily result in the failure of grabbing, and the tray cannot be replaced timely, even cause the interruption of filter production process. It also affects the entire moulding process, reduces the production efficiency and so on. To increase the success rate of paper tray grabbing in the gantry space, we design a positioning and grabbing system based on machine vision, which effectively solves the problem that caused by the unfixed position of the paper tray.

2. System Overview
Considering the actual demand, the whole system includes displacement system, vision acquisition and target positioning system, positioning and grabbing control system. The displacement system includes the X-axis displacement mechanism, the Y-axis displacement mechanism and the Z-axis displacement mechanism of the manipulator. The displacement mechanisms of the shafts are composed of a pulley, a belt, a servo motor and the like. The vision acquisition and target positioning system and the positioning and grabbing control system include a DSP (Digital Signal Processing) processor [1-2], an FPGA (Field-Programmable Gate Array) module [3-4], a SDRAM (Synchronous Dynamic Random Access Memory) storage module, a FLASH storage module and a camera module. The positioning and grabbing control system includes a display system, a PLC (Programmable Logic Controller) control system and a motion control system. The detection control diagram is shown in Figure 3.

![Figure 3. The overall system diagram](image)

3. System structure
3.1. Displacement system design
Figure 4 shows part of the mechanical structure. The displacement system includes X-axis, Y-axis and Z-axis displacement mechanisms. To meet the requirements of the displacement, the X-axis displacement mechanism includes a coupling shaft, a coupling, a main pulley, a pulley, a belt, a slide rail, a moving platform, and a servomotor. Where both ends of the coupling shaft are provided with a coupling and a main pulley, a servo motor is arranged at the end of the coupling shaft, and the main pulley on the coupling shaft is driven by a servo motor to rotate. Then, the main pulley is driven by the belt to rotate from the pulley, and the moving platform is driven by the belt to move on the sliding rail. The Y-axis displacement mechanism comprises a screw rod, a main pulley, a pulley, a belt, a slide rail, a moving platform and a servomotor. Similarly, the servomotor is connected with the main pulley which is connected with the pulley by a belt. The pulley is connected with the screw rod, the screw rod is movably connected with the moving platform, the moving platform is arranged on the Y axis slide
rail, and the Y axis slide rail is arranged on the X axis moving platform; the Z axis displacement mechanism comprises a screw rod, a main pulley. The adjusting wheel is composed of a pulley, a belt, a moving platform and a servo motor, wherein the main pulley is connected with a servo motor, connected from the pulley through a belt and an adjusting wheel, from the pulley is connected with a screw, screw and mobile platforms are active connected.

![Figure 4. Part of the mechanical structure](image)

3.2. Vision Positioning System
As is shown in Figure 5, the visual positioning system includes a DSP processor, an FPGA module, an SDRAM storage module, and a FLASH storage module. Among them, the input of the DSP processor and the output of the FPGA are connected by EMIF (External Memory Interface). By this interface, it can transmit a large number of image data through DSP to FPGA quickly and easily. DSP is connected with its FLASH memory module and SDRAM memory module, FLASH module is the memory area of the DSP program, SDRAM provides a buffer for receiving FPGA image data. FPGA module is connected with the camera OV5640, FPGA provides SCCB signal and field sync signals and line synchronization signals. OV5640 returns RGB data for FPGA to storage and use, and FPGA external memory chip, which can do some image pre-processing operations to ensure that the DSP only makes the main algorithm after the data transmitted into the DSP, which makes it unique on complex algorithms and enhances the overall processing speed of the system. Machine vision positioning is an important part in this system where the positioning accuracy would have a direct impact on the manipulator grabbing accuracy.

3.3. Tray grabbing system
Cardboard capture control system includes a display system, PLC control system, motion control drive system [5]. Among them, the input of the PLC control system is connected with the data output of the display system and the DSP processor, the output of the system is connected with the motion control drive system, which is connected with the X-axis servo motor, the Y-axis servo motor and the Z-axis servo motor in the displacement system. Display system is composed of a touch screen which is connected by the Ethernet and PLC, which can provide a good human machine interface, so that it is easy to observe running status of the whole system. The PLC is Mitsubishi FX5U controller, which is used to receive and process data, and at the same time send signals to the relevant implementing agencies. Motion control drive system consists of a 4-axis positioning module, driver and associated motor to control the movement of the manipulator.
4. Software Design

4.1. Circle Center detection

In some cases, the centre position of the four trays is not the same as the ideal situation. Considering the stability of the entire system, it is necessary to determine the position of the tray before proceeding with the grabbing operation. The centre detection algorithm [6] is designed as follows:

First of all, build a world coordinate system for the entire stack of four trays, the standard four-stack ideal tray coordinate points are \( O \left( x_i, y_i \right) \), where the area inside the dotted square frame is where the actual areas where camera captures, the four regions are divided into regions \( A_1 \), regions \( A_2 \), regions \( A_3 \), regions \( A_4 \). Under ideal conditions, the circle centre coincides with the centre of the capturing region.

Move the manipulator to the centre of the collection area where is the centre of the ideal tray before grabbing the first tray, then, capture the actual tray image, take the collected RGB image into grey to reduce the complexity of the processor's operation. After that, calculate the threshold value of the grey image in this frame by Otsu algorithm. According to this threshold, the grey image is converted into binary image.

Expansion operation is for some cases where the actual position deviation is large, which can fill the non-white area inside the plastic ring inside the tray. Although it may expand the area of the detection area to a certain extent, the position of the centre will not be changed accordingly. Subsequently, calibrate the area of the image [7], mark the connected area in the image, and establish the circumscribed rectangle according to the connected area, as is shown in the third image of Figure 6.

![Figure 6. Detection process](image)

From the position information of the rectangular box, calculate the maximum and minimum coordinates of the X-axis of the rectangular box, the maximum and the minimum coordinate of the Y-axis, and the coordinates \( O_i \left( x_i', y_i' \right) \) of the center in the region \( A_i \) are defined as follows:
\begin{align}
    x_i' &= \frac{X_{i_{\max}} + X_{i_{\min}}}{2} \\
y_i' &= \frac{Y_{i_{\max}} + Y_{i_{\min}}}{2}
\end{align}

(1) (2)

The black dots in the third image and the white dots in the fourth image in Figure 6 represent the calibration points of the center detected by the algorithm. The offset between the actual tray coordinate and the ideal disk coordinate is \( \Delta x_i = x_i' - x_i, \Delta y_i = y_i' - y_i \). Transmit the offset \( (\Delta x_i, \Delta y_i) \) to the PLC through RS485 communication and the subsequent operation will be completed by the PLC and the manipulator.

According to the same principle, the second tray in the second region, the third tray in the third region, and also the fourth tray in the fourth region, the circle centers can be obtained.

Figure 7 is the detecting results of different stacks of paper tray, the centre of the tray has some position offset with the detecting centre. Experiments show that the detection algorithm can accurately locate the position of the circle centre in many cases and the image morphological processing based on the expansion operation has good robustness, as is shown in the second row of Figure 7.

4.2. Overall control method flow
The entire system control process can be summarized as follows:

1) First, PLC controls the displacement system move the paper tray to corresponding ideal location, after that, the manipulator drops at first time, down to the camera's shooting focus.

2) The image acquisition system in the visual positioning system starts to work. Using the circle centre algorithm to calculate the offset between the actual centre coordinates and the coordinates of the ideal position, then, send the offset to the PLC control system.

3) The PLC controls servo motor according to the offset, and the servo motor drives the main body of the manipulator to move along the X axis and the Y axis to reach the centre coordinates of the tray which will be picked up.

4) Repeat 2) - 3) operation process, conduct the second positioning operation, so that the detection accuracy is higher. Then the manipulator starts its second drop, down to the inner circle of the tray, open the jaws, grab the tray.

5. Conclusions
In this paper, we design a positioning and grabbing system based on machine vision, it uses DSP and FPGA to build an image acquisition and processing system, so that the efficiency of image processing...
has been greatly improved compared with those only use single processor. Achieve the centre of the tray positioning coordinates by image processing and calculate the offset with the current coordinates, then, send the results into the PLC. PLC controls manipulator to reach the centre of the tray according to the offset to grab it, so that the tray replacing process can be completed accurately and efficiently, and the production efficiency can be improved greatly.

References
[1] Yanjun L 2013 Design and implementation of embedded DSP image processing system. *Foreign Electronic Measurement Technology*. 32 11-14.
[2] Chuang W, Ying H, Xiaoxi Z and Shuo L 2017 Design and implementation of multi-core real-time image processing module. *Aeronautical Computing Technique*. 47 123-125.
[3] Sun, Rong Chun, and Y. Piao 2013 Platform of Image acquisition and processing based on DSP and FPGA. *Applied Mechanics & Materials*. 457-458 932-937.
[4] Zhiheng Z, Huan S, Yong M and Yifu Z 2017 Design on image sorting system based on DSP and FPGA. *Computer Measurement & Control*. 25 123-126.
[5] Yuanlian C and Hua Z 2017 Design of the worktable motion control system based on MITSUBISHIFX5U series PLC. *Mechanical & Electrical Engineering Technology*. 46 18-22.
[6] Shengxi J, Dejun X and Yifan K 2013 The application research of Hough transform algorithm on circle center vision positioning. *Science Technology and Engineering*. 13 4089-4093.
[7] Xiaoguang W, Diqiong W and Hui S 2004 An algorithm and implementation for obtaining minimum exterior rectangle of image region. *Computer Engineering*. 30 124-125.