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DESIGN OF PCB ALIGNMENT USING VISION SERVO CONTROL SYSTEM

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Abstract. *The automation technology has been widely used to enhance the measurement accuracy and speed in industry. In this paper, we perform and develop the PCB unit positon alignment by using the CCD and XXY stage system. The research focuses on the development of the XXY stage control system and image process system. The motion controller is used to integrate the stepper motor driver to control XXY table, and the OpenCV software library is applied and implemented to pattern matching. Six pattern matching algorithms are tested and experimented to demonstrate the performances. After image correlation processing, the position deviations between input and pattern images can be calculated, and the error command is sent to the servo control loop for precision compensation of the mask alignment. The experimental results show that the alignment process can be achieved quickly and accurately by using our proposed system.*
Keywords: XXY stage, Charge-coupled device (CCD) camera, OpenCV library, Printed circuit board (PCB) unit, Vision servo control system, Pattern matching algorithm

1. **Introduction.** Due to the increasing complexity of manufacturing process, there is now an increasing requirement for automatic optical alignment in automation. This technology is widely developed [1-6] in the industry area, such as opto-mechatronic integration, microsystem control, wireless communication, nanometer technologies and biomedical electronics system. It is necessary to integrate the vision algorithm and control system in automatic alignment system.

Lee et al. [1] used the four CCD cameras, two alignment objects and a novel design three degree of freedom parallel stage. The lamination alignment algorithm is designed and implemented to accomplish the precision positioning. The system is developed using the visual servo system, and the alignment error is ± 1 pixel (about $\pm 7\mu$m). An adaptive threshold method [2] based on an evaluation index which represents the binary state of characteristic local patterns was used for position alignment in semiconductor application. They also presented four general methods: (a) pixel counting method [3], (b) cross-correlation method, (c) pattern matching method and (d) feature parameter method [4]. Chuang et al. [5] used the piezo motion stage to develop an automatic optical fiber alignment system. The multi-rate control scheme and visual feedback control are adopted to reduce the error due to the delay time between the motion control system and vision system. Kim et al. [6] used the XYθ table and two CCD cameras to perform the self-learning method for alignment in wafer processing. A cross mark was used for alignment in this research. Because of the clearly identified feature, it was commonly used in many visual alignment systems. Thus, the algorithm is not easily implemented and the performance needs to be further improved. In order to resolve this alignment problem, a vision servo scheme with multi-axis robot stage system is proposed to deal with this difficulty.

In this paper, the automatic alignment system using vision control scheme for PCB unit is presented. The mark information that is received from CCD vision system is compensated by image library tool. Six kinds of pattern matching algorithms are designed and implemented to demonstrate the feasiblility of our system. The square difference matching and normalized square difference matching methods can provide better matching results, and the mark coordinate can be obtained clearly. From this information, it can adjust the position movement after the position error is obtained from the feedback by controller. During this process, we have to tune the position several times in order to reduce the position error. By using this technique, it can enhance the accuracy of alignment and improve the rate of product.

The remainder of this paper is organized as follows. Section 2 describes the system architecture. In Section 3, vision servo system is described. The experimental results are shown in Section 4. Section 5 concludes this paper.

2. **System Architecture.** The system architecture of the vision servo control system is shown in Figure 1(a). The system consists of the CCD camera and lens, a dimmer, an illuminance, a motion controller, a XXY stage and a PC-based controller. In this system architecture, the motion controller is connected with the computer by USB interface, and the computer is connected with CCD camera by Ethernet cable. After the image is captured by CCD camera, the PC-based controller can calculate the correlation results and give the position command to motion controller to execute the alignment process. This research uses the XXY table which is designed by CHIUAN YAN TECHNOLOGY. It is different from the traditional XYθ table, and it uses the two X axes and one Y axis to replace to pile the motors on one another. It can significantly reduce the height and weight of the control stage. The proposed XXY control systems contain the motion controller, stepping motors and motor drivers. The multi-axis motion controller is used and it can connect to computer by USB 2.0, RS-485 protocol, and Ethernet interface manufactured by ARCUS. The micro stepping driver we used is the model of Extion EXD2020MB which can provide fifteen kinds of micro step resolution. The minimum resolution is divided into 128 microsteppings, and we adopt the 10 degrees of microstepping here. The computer controller gives the commons to motion controllers and microstepping motor drivers. Due to the reason of simplicity, the open-loop control architecture of stepping motor is applied to achieving the position alignment. The pulsed command signal is applied as driver signal, so the accurate position can be approached accurately.

We need to recognize the resolution relation between CCD camera and XXY table before the alignment process is carried out. When the ball screw moves in the linear motion mode, we can calculate the step of pitch. Given that a typical motor has 200 steps per revolution, the step angle of the steeper motor is 1.8 degree. The step angle becomes 0.18 degree here because the microstepping resolution is set to 10. The accuracy of the plane that can be calculated by the resolution of the stepper motor is 2000 pulses per cycle, and the corresponding pitch of ball screw is 2 mm. The resolution R_m can be expressed as:

$$R_m = \frac{P_c}{r} = \frac{2\text{ mm/rev}}{2000\text{ pulse/rev}} = 1\,\mu\text{m/pulse} \tag{1}$$

where P_c is the pitch of ball screw and r is the resolution of the stepper motor. The XXY table will move 1 μm in each axis when one pulse command is sent into steeper motor.

3. **Vision Servo System.**

3.1. **Control procedure.** The vision servo system mainly consists of the XXY stage control and image processing system. The program flowchart is shown in Figure 1(b). After the XXY table is connected and its position is back to original home point by computer, the PCB unit will be moved to the table by the developed "Go" subroutine.

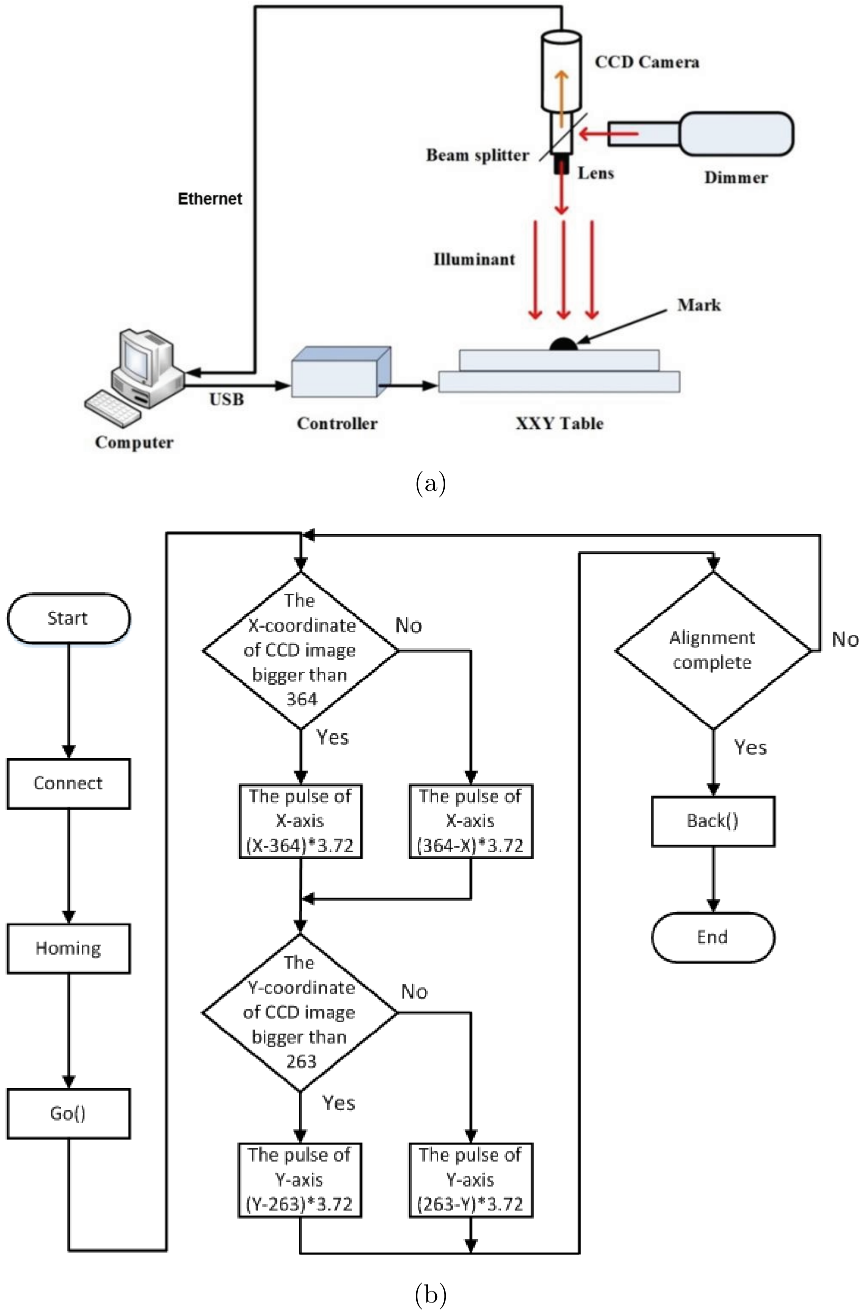


Figure 1. (a) The proposed system architecture, (b) software flowchart of visions servo control system

The mark image in the CCD camera will move 270 pixels when the input command of 1000 pulses is sent to the XXY table. The resolution relation between stage pitch and camera image can be calculated by a factor of 3.72 pulses per pixel. Then the pattern matching scheme can be applied and the coordinate is generated to move to the center of CCD camera image. After finishing the position alignment, the PCB will be moved back to static table by using the "Back" subroutine.

3.2. **Pattern matching algorithms.** The open source image process software OpenCV (open source computer vision) library is used for image processing here. Because it is the open source software, it can be used for free in the business and academic area and applied to human-computer interaction, object identification, motion tracking and facial recognition system. This tool can not only execute on the PC-based system but also mobile system. The pattern matching algorithm is employed for image processing, and it can find the region of interest (ROI) which we set in advance in the main image. If the correlation results are successful, the position and the size of pattern can be obtained in the main image. When the image pattern is disturbed by noise or the image is rotated, the pattern matching can still match the image object correctly. So it is the simplest and the quickest matching method. We need to set the source image $I(x,y)$ which is an w-by-h matrix, template image $T(x,y)$ whose size is an w-by-h matrix, and the results of the pattern matching are stored in matrix $R(x,y)$. Six methods of the pattern matching algorithm are applied and expressed as:

(a) Square Difference Matching Method: this method uses the squared difference, so a perfect match will be 0 and bad matches will be large.

$$R(x,y) = \sum_{j=0}^{w-1}\sum_{i=0}^{h-1}[T(i,j) - I(x+i,y+j)]^2 \tag{2}$$

(b) Normalized Square Difference Matching Method:

$$R(x,y) = \sum_{j=0}^{w-1}\sum_{i=0}^{h-1}[T(i,j) - I(x+i,y+j)]^2 \Bigg/ \sqrt{\left[\sum_{j=0}^{w-1}\sum_{i=0}^{h-1}T^2(i,j)\right]\left[\sum_{j=0}^{w-1}\sum_{i=0}^{h-1}I^2(x+i,y+j)\right]} \tag{3}$$

(c) Correlation Matching Method: this method multiplicatively matches the template against the image, so a perfect match will be large and bad matches will be small or 0.

$$R(x,y) = \sum_{j=0}^{w-1}\sum_{i=0}^{h-1}[T(i,j)I(x+i,y+j)] \tag{4}$$

(d) Normalized Correlation Matching Method:

$$R(x,y) = \sum_{j=0}^{w-1}\sum_{i=0}^{h-1}[T(i,j) \cdot I(x+i,y+j)] \Bigg/ \sqrt{\left[\sum_{j=0}^{w-1}\sum_{i=0}^{h-1}T^2(i,j)\right]\left[\sum_{j=0}^{w-1}\sum_{i=0}^{h-1}I^2(x+i,y+j)\right]} \tag{5}$$

(e) Correlation Coefficient Matching Method: this method matches a template relative to its mean against the image relative to its mean, so a perfect match will be 1 and a perfect mismatch will be -1; a value of 0 simply means that there is no correlation.

$$R(x,y) = \sum_{j=0}^{w-1}\sum_{i=0}^{h-1}[T'(i,j)I'(x+i,y+j)] \tag{6}$$

with

$$T'(i,j) = T(i,j) - \left\{(w \cdot h)\left[\sum_{l=0}^{w-1}\sum_{k=0}^{h-1}T(k,l)\right]\right\}^{-1},$$

$$I'(x+i,y+j) = I(x+i,y+j) - \left\{(wh)\left[\sum_{l=0}^{w-1}\sum_{k=0}^{h-1}I(x+k,y+l)\right]\right\}^{-1}$$

(f) Normalized Correlation Coefficient Matching Method:

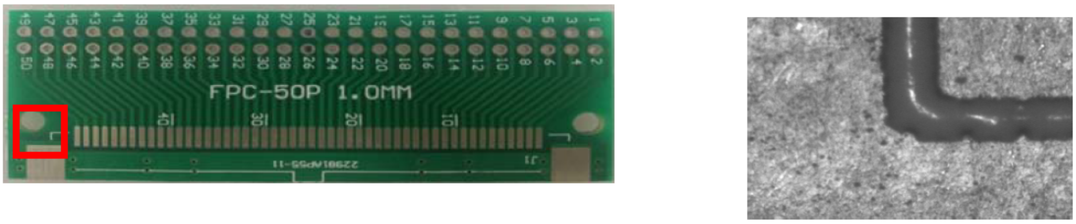
$$R(x,y) = \sum_{j=0}^{w-1}\sum_{i=0}^{h-1}[T'(i,j) \cdot I'(x+i,y+j)] \Bigg/ \sqrt{\left[\sum_{j=0}^{w-1}\sum_{i=0}^{h-1}T'^2(i,j)\right]\left[\sum_{j=0}^{w-1}\sum_{i=0}^{h-1}I'^2(x+i,y+j)\right]} \tag{7}$$

where $R(x, y)$ is the correlation result corresponding to image coordinate (x, y), $T(i, j)$ is the pixel value from the template at coordinate (i, j), and $I(x, y)$ is the pixel value from the image at coordinate (x, y).

4. **Experimental Results.** The prototype of the PCB alignment system based on vision servo control is developed shown in Figure 4. The two-axis robot manipulator can move the measured object to the XXY table from the fixed table. The PC controller will give the command to motion controllers and capture the image of CCD camera by USB.

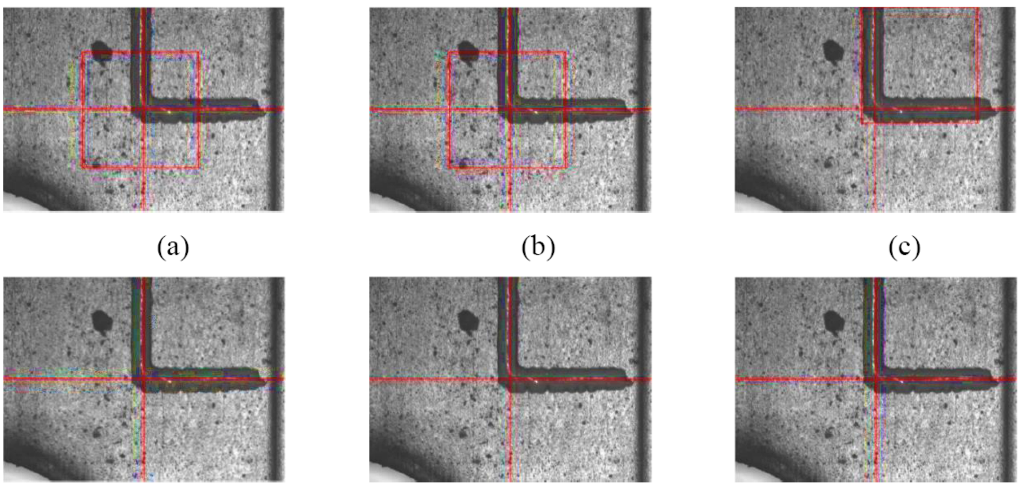
Before pattern matching process, the feature mask needs to be found initially on the PCB unit. The red rectangle mark is shown in Figure 2(a). The template image is captured and stored as the target pattern shown in Figure 2(b). The patterns of source image are shown by the area of the red rectangle mark in Figure 3. If we choose the square difference matching method and normalized square difference matching method for the pattern matching, the matching results are better and the mark coordinate (x, y) can be obtained clearly shown in Figure 3(a) and 3(b). On the other hand, the matching results cannot be obtained with the other schemes. The results are shown in Figure 3(c), 3(d), 3(e), and 3(f), respectively.

The control system is developed by using Microsoft Visual Studio C# tool. The graphical user interface of our vision system is designed and developed shown in Figure 5. In the first step, the computer connects to motion controllers, and the two-axis robot manipulator and XXY table are back to their origin points. After this initialization, the



(a) (b)

Figure 2. (a) Feature point of PCB unit, (b) pattern template image



(a) (b) (c)

(d) (e) (f)

Figure 3. The results of each pattern matching method: (a) square difference, (b) normalized square difference, (c) correlation, (d) normalized correlation, (e) correlation coefficient, and (f) normalized correlation coefficient methods

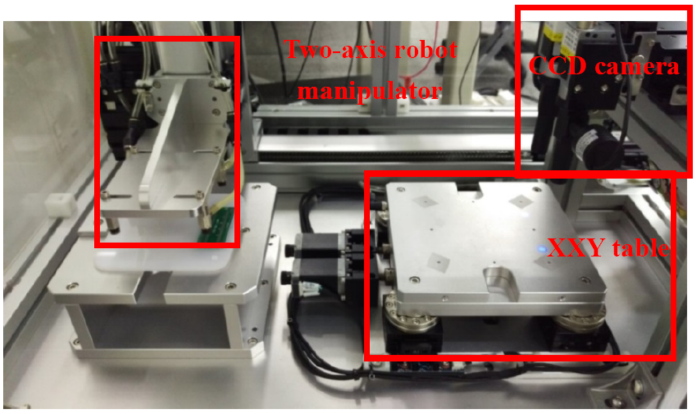


FIGURE 4. The physical architecture of PCB unit alignment system

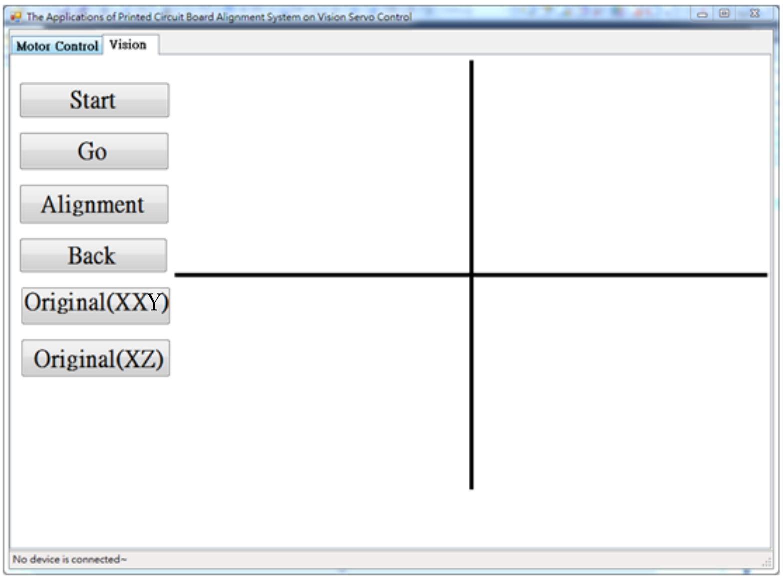
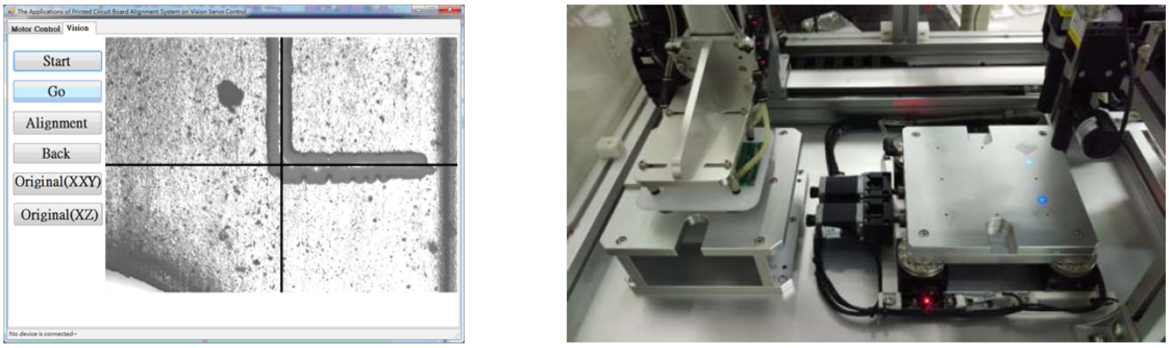


FIGURE 5. Graphical user interface of vision control system

(a) (b)

FIGURE 6. (a) Moving PCB unit to XXY table, (b) the image before alignment process

PCB unit can be moved and put onto the XXY platform by the X-Z robot manipulator shown in Figure 6(a). It is starting to capture the image by CCD camera shown in Figure 6(b). The system performs the pattern matching and calculates the difference of pixels between the mark image and the capture image. After computing the correlation value, the position error information is obtained and transformed into the pulse number by the



(a) (b)

Figure 7. (a) The image after alignment process, (b) moving PCB unit to the fixed table

relation of resolution. It generates the command to the motion controller to move fast to the desired center positon shown in Figure 7(a). Then, the PCB unit moves to another fixed table from XXY table by X-Z robot manipulator after completing the alignment shown in Figure 7(b).

5. **Conclusions.** In this research, we use the CCD camera to capture the image and develop the graphical user interface to accomplish the precision alignment process realized by XXY stage. The error of alignment can be reduced and enhanced efficiently by using our proposed system. In this experiment, we find that the square difference method and normalized square difference method are the better methods used in the PCB alignment. With use of the proposed matching methods, the better position accuracy of the PCB alignment can be achieved. It can be developed and implemented to be a useful precision alignment system for industry applications in the future.

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