IMAGE PROCESSING BASED CONTROL SYSTEM FOR PRECISE POSITION CONTROL OF PCB SCREEEN PRINTER

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ABSTRACT

In this paper, a precise position control system of PCB screen printer incorporating the image processing technique is introduced. The positions of two fiducial marks drilled on the PCB are used as the sensing points for the image processing to recognize the position errors in directions of $X-Y-\theta$ coordinates. The precise alignment device is composed of $X-Y-\theta$ tables and the tables are controlled by stepping motors which are driven by 80c196kc microprocessor based controller. To decrease the noise effect in the image screen of the fiducial marks, we use two CCD cameras with ultraviolet ray type of light source. Since the effect of the illumination change is considerably decreased by using the ultraviolet light source, we can remove the filtering preprocessing procedure in the image processing. The centers of the fiducial marks are obtained by a least square error method. The sum for square of the errors between the circle equation with center position (x_0, y_0) of radius r and the coordinate values of the boundary pixels on the images captured from the fiducial marks is chosen as the criterion function. The exactness of the least square method is compared to the simple method based on the concept of the average values for the abscissa and ordinate of the center for the fiducial marks. By applying the developed precise position control system for a practical PCB screen printing system, we can prove the effectiveness such that it realizes the precision about 2.5μm in the position control of $X-Y-\theta$ tables and the high speed processing time about 1sec.

1. INTRODUCTION

Recently, the needs for printer circuit board (PCB) with fitting capacity of high precision and high density are increasing in several industrial fields according to super miniaturization and large scale integration of electronic devices. Generally, screen type of printing machine is used in the fields of PCB production. The screen printing machine fixes the PCBs transferred by conveyor system with $X-Y$ stopper and clamp and prints the PCBs with impressed (intaglio) silk screen according to the circuit pattern. A PCB is producted through at least 3 times repeated printing procedure. In the case of the general PCB, the position precision of the circuits on the PCB should be satisfied about 0.2mm but in the case of high precision PCB, it needs below 20μm. As the factors decreasing the position precision of the circuit lines on PCB, there are the accumulation of the printing errors caused by flexibility of the silk screen, the size variation of the PCB cut from the original plate and the variation of the fixing position in the clamping system etc.[1],[2]

To realize a precise position control of $X-Y-\theta$ tables by using the image processing method to detect the position error, most of all we must pay attention to the noise caused by the variation of the light illumination and the gray value change according to the position of the captured image screen. So, we need not only more reliable hardwares for CCD camera, light source and its image frame grabber card, but also, real time algorithms assuring the detection of the precise position such as center detection with high speed image processing, and position tracking with high resolution etc. should be developed. Since in the case of the realization of the motor control with micrometer precision, even the difference of a pixel in the captured image influences deeply to the precise position control of the $X-Y-\theta$ tables, the calculation algorithm for the centers of the fiducial marks should be developed as measurable as more precisely in spite of illumination change of light source around the printing system and drilling size variations of fiducial marks on PCB.[1]

In this paper, to increase the position precision in screen printer, we use the image processing technique, detect the positions of two fiducial marks drilled on the PCB and adjust in real time the position error of the PCBs by precision position controls of $X-Y-\theta$ tables. The two fiducial marks are used as the sensing points for the image processing to recognize the position errors in directions of $X-Y-\theta$ coordinates. The precise alignment device is composed of $X-Y-\theta$ tables and the tables are controlled by stepping motors which are driven by 80c196kc microprocessor based controller. The controller accepts the control signal from personal computer based main controller and it drives the actuating motors for operation of $X-Y-\theta$ tables corresponding to the amounts of the errors of the fiducial mark positions which are calculated by the image processing procedure. We use two CCD cameras with ultraviolet ray type of light source to capture more precisely the images of the two fiducial marks made by drilling holes at appropriate position on PCB. The centers of the fiducial marks are obtained by a least square error method. The sum for square of the errors between the circle equation with center position (x_0, y_0) of radius r and the coordinate values of the boundary pixels on the images captured from the fiducial points is chosen as the criterion function.

The exactness of the least square method is compared to the simple method based on the concept of the average values for the abscissa and ordinate of the center for the fiducial marks.[1] By applying the developed precise position control system for a practical PCB screen printing system, we can prove the effectiveness such that it realizes the precision about 2.5μm in the position control of $X-Y-\theta$ tables and the high speed processing time about 1sec.

2. Composition of screen printer

The printing system is composed of alignment part, printing part, output part and carrier part. The alignment part aligns the PCBs at exact position to be printed, and the printing part prints the circuit pattern on the aligned PCB. The carrier part transfers precisely the aligned PCBs in the alignment part to the printing part and from printing part to output part, by using a vacuum type of clamp. The output part transfers the printed PCBs to the outside.

Fig. 1 shows the configuration of the alignment part $X-Y-\theta$ table. The X and Y tables are located on the θ table, and limit sensors are attached at both side of each table to protect motors. 3 stepping motors are used for drives of $X-Y-\theta$ tables. The precision of X and Y axes is about 2.5μm and the precision of θ. axis is about 0.573mdeg. The alignment table is positioned on $X-Y-\theta$ table and it is moved together with PCBs during adjusting working.

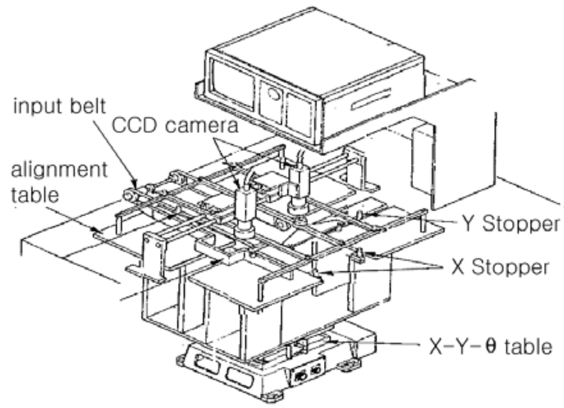


Fig. 1 Composition of PCB alignment part

The image processing system is composed of CCD camera capturing the image of circle type of fiducial mark, frame grabber board and light source. The size of the captured image is 640(H)x480(V) pixels. The fiducial marks are circular types which are regarded as the target points for the image processing. So, in the case that we use a halogen light source, since a diffused reflection is generated, we can not distinguish exactly the target points. In the paper, to capture the image of the fiducial marks exactly in spite of variation of around light illumination, we use a ultraviolet ray light source. So, we can abbreviate the preprocessing procedure such as the filtering.[1],[5],[6]

To drive the $X-Y-\theta$ table according to the command signal of the alignment result in the image processing system, we make Intel 80c196kc microprocessor based motor drive. The printing, carrier and output parts are driven by PLC controller. Fig. 2 shows the schematic block diagram of the microprocessor based motor drive. The microprocessor receives the moving distance and direction of each axis calculated by the image processing system through RS232C communication and using HSO (high speed output) function. It transfers the pulse number and direction corresponding to the moving distance of the stepping motors. Also, using the input port, it receives the signal from limit sensors set up at the both sides of each motor axis, and transfers the operating command to PLC controller to proceed the total printing process. We can monitor the data of the overall printing procedure at PC.

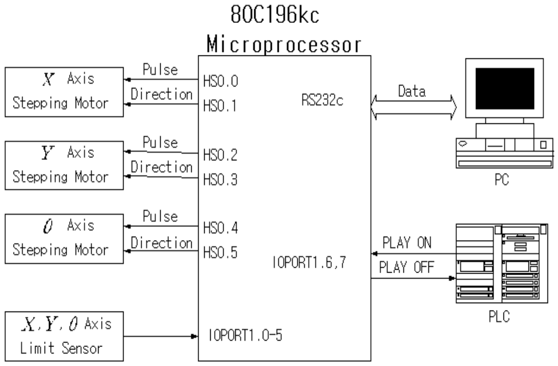
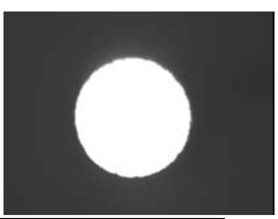


Fig. 2 Schematic diagram of the developed drive module

3. Algorithm for precise position control of PCB screen printer

The two fiducial marks are used as the sensing points for the image processing to recognize the position errors in directions of $X - Y - \theta$ coordinates. We use two CCD cameras with ultraviolet ray type of light source to capture more precisely the images of the two fiducial marks made by drilling holes at appropriate position on PCB.

Fig. 3 and 4 show respectively the gray scale image of the fiducial mark captured from the CCD camera and its binary image.



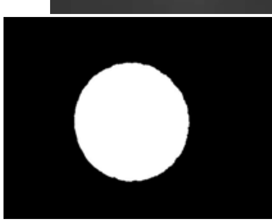
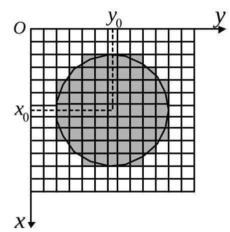


Fig. 3 Grayscale image
Fig. 4 Binary image

3.1. Algorithm for determining the center of fiducial mark

Since in the case of the realization of the motor control with micrometer precision as stated in the previous section, even the difference of a pixel in the captured image influences deeply to the precise position control of the $X - Y - \theta$ tables, the calculation algorithm for the centers of the fiducial marks should be developed as measurable as more precisely in spite of illumination change of light source around the printing system and drilling size variations of fiducial marks on PCB. To get the precise center of the fiducial marks, we use the well known least square error method.[4]



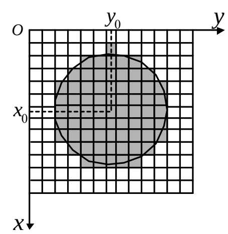


Fig. 5 Image without noise
Fig. 6 Image with noise

The circle equation with center position (x_0, y_0) of radius r can be expressed as:

$$(x - x_0)^2 + (y - y_0)^2 = r^2 \qquad (1)$$

The sum E for square of the errors between the circle equation with center position (x_0, y_0) of radius r and the coordinate values of the boundary pixels on the images captured from the fiducial points is chosen as the criterion function of the following:

$$E = \sum_{i=1}^{n} [(x - x_0)^2 + (y - y_0)^2 - r^2]^2 \qquad (2)$$

where, n is the number of boundary pixels and (x_i, y_i) is the coordinates of boundary pixels.

Let z be given by: $z = x_0^2 + y_0^2 - r^2$

Substituting z into equation (2), we obtain:

$$E = \sum_{i=1}^{n} (x_i^2 - 2x_i x_0 + y_i^2 - 2y_i y_0 + z)^2 \qquad (3)$$

To find the parameters x_0, y_0 and z which minimize the error function E, the partial derivative for each parameter is set to 0. We obtain the following equations:

$$\frac{\delta E}{\delta x_0} = 2\sum_{i=1}^{n}(x_i^2 - 2x_i x_0 + y_i^2 - 2y_i y_0 + z)(-2x_i) = 0$$

$$\frac{\delta E}{\delta y_0} = 2\sum_{i=1}^{n}(x_i^2 - 2x_i x_0 + y_i^2 - 2y_i y_0 + z)(-2y_i) = 0$$

$$\frac{\delta E}{\delta z} = 2\sum_{i=1}^{n}(x_i^2 - 2x_i x_0 + y_i^2 - 2y_i y_0 + z) = 0$$

Rearranging above equations, we can obtain:

$$\begin{bmatrix} 4\sum_{i=1}^{n} x_i^2 & 4\sum_{i=1}^{n} x_i y_i & -2\sum_{i=1}^{n} x_i \\ 4\sum_{i=1}^{n} x_i y_i & 4\sum_{i=1}^{n} y_i^2 & -2\sum_{i=1}^{n} y_i \\ -2\sum_{i=1}^{n} x_i & -2\sum_{i=1}^{n} y_i & n \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z \end{bmatrix} = \begin{bmatrix} 2\sum_{i=1}^{n} x_i^3 + 2\sum_{i=1}^{n} x_i y_i^2 \\ 2\sum_{i=1}^{n} y_i^3 + 2\sum_{i=1}^{n} x_i^2 y_i \\ -\sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} y_i^2 \end{bmatrix}$$

which yields the values x_0, y_0 and z.

3.2. Calculation of position errors

Generally, the general coordinate of the $X-Y-\theta$ table and the local coordinates in screen of each CCD camera are not parellel. When the table translates in the X direction, a fiducial mark which has ordinate equaling 0 in local coordinate going to a new position and its ordinate equal Δy_1. That is generated a unreliable result of alignment. To calculate the difference between the general coordinate and the local coordinate, we assume as follows :

① The positions of two cameras are fixed in the generalized coordinate.
② The distance of the two fiducial marks on the PCB is constant.
③ The position of the $X-Y-\theta$ table is fixed on the each initial position specified by the controlling the motors using the limits sensors.
④ Each table has two limit sensors to protect over moving range for two motors.

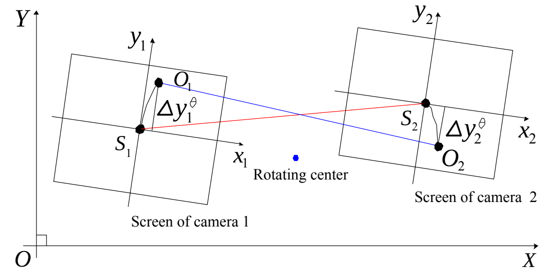


Fig. 7 Principle of calibration

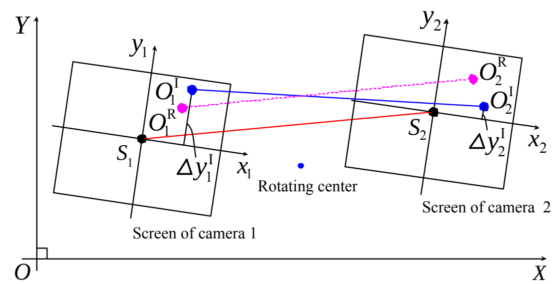


Fig. 8 Principle calculating position errors

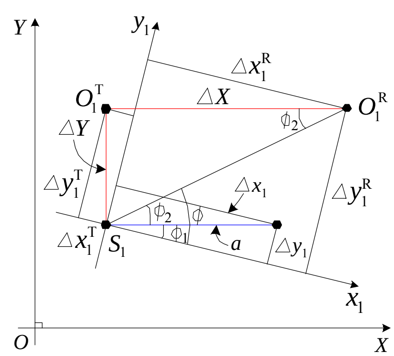


Fig. 9 Principle calculating errors on X, Y coordinate

Figs. 7-9 describe the concepts calibrating the coordinate position errors of $X-Y-\theta$ table after detecting the fiducial marks captured by CCD camera.

The nomenclatures used in Figs. 7-9 are as follows:

k : the number of camera, $(k=1,2)$.

XOY : generalized coordinate of the $X-Y-\theta$ table.

S_k : model centers in screen of camera k.

$x_k S_k y_k$: the local coordinates in screen of camera k.

O_k^I : the centers of two fiducial marks at initial positions in screen of camera k.

O_k^R : positions of O_k^I after rotating the θ

table an angle θ.

O_k^T : positions of O_k^R after translating the table a distance ΔX.

Δy_k^I : ordinates of O_k^I in local coordinates $x_k S_k y_k$.

Δx_k^R, Δy_k^R : abscissas and ordinates of O_k^R in local coordinates $x_k S_k y_k$.

The procedure of calibration can be stated as follows:

Step 1: We adjust two cameras by hand until the center of two fiducial marks to coincide with two model centers S_1 and S_2. We call this position as a standard position.

Step 2: From standard position we rotate the θ table as number as A pulses and obtain Δy_1^θ, Δy_2^θ (Fig. 8).

Step 3 : Similarly to step 2, we translate the X table A pulses and obtain Δx_1, Δy_1 (Fig. 10).

In Fig. 10, the distance a is calculated as:

$$a = \sqrt{(\Delta x_1)^2 + (\Delta y_1)^2}\ .$$

When PCB is loaded to the $X-Y-\theta$ table, two cameras will capture the images of two fiducial marks on the PCB. We obtain O_k^I. The purpose is adjusting the $X-Y-\theta$ table so that O_k^I are moving to the model centers S_k respectively.

The number of pulses needed for rotation of the θ table is calculated as

$$N = A\frac{\Delta y_1^I + \Delta y_2^I}{\Delta y_1^\theta + \Delta y_2^\theta} \qquad \text{(pulses)}$$

The number of pulses needed for translation of the X table in the X direction is given by

$$P = A\frac{\Delta X}{a} \qquad \text{(pulses)}$$

where $\Delta X = (\cos\Phi_2)\sqrt{(\Delta x_1^R)^2 + (\Delta y_1^R)^2}$

$$\Phi_2 = \Phi - \Phi_1$$

with $\tan\Phi_1 = \dfrac{\Delta y_1}{\Delta x_1}$, $\tan\Phi = \dfrac{\Delta y_1^R}{\Delta x_1^R}$.

The number of pulses needed for translation of the Y table in the Y direction is calculated as

$$Q = A\frac{\Delta Y}{a} \qquad \text{(pulses)}$$

where $\Delta Y = \sqrt{(\Delta x_1^T)^2 + (\Delta y_1^T)^2}$.

Fig. 11 shows the schematic diagram of the adjusting errors considering in screen of camera 1. At first the θ table rotates an angle θ to move O_1^I to O_1^R. After the X table translates in the X direction as a distance ΔX to move O_1^R to O_1^T. Next the Y table translates in the Y direction as a distance ΔY to move O_1^T to the model center S_1.

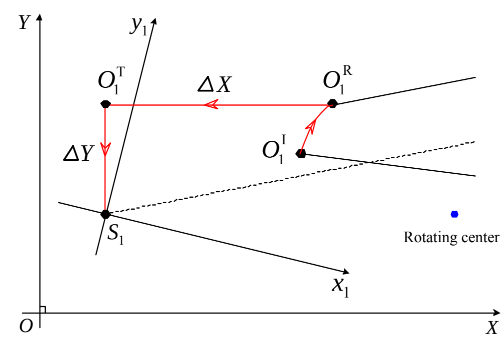


Fig. 10 Schematic diagram of the adjusting errors

Fig. 11 describes the block diagram of the algorithm for the control of the automatic printing system incorporating the developed image processing system.

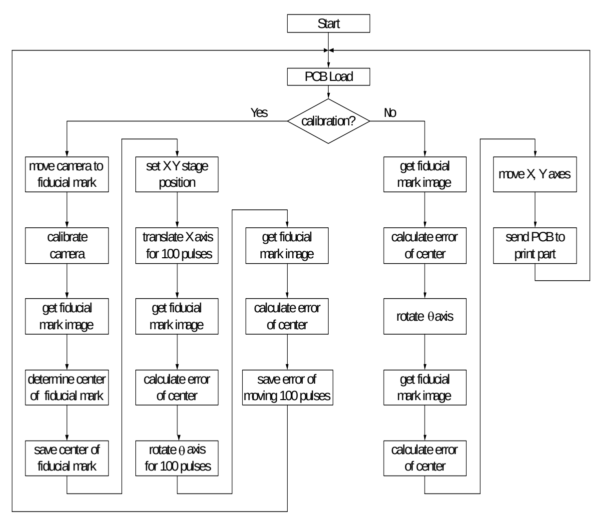
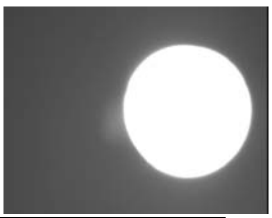


Fig. 11 Block diagram of algorithm for initializing and automatic print stage

4. Experimental results

To prove the effectiveness of least square error method we used 20 different images to calculate the coordinates of the center, radius and total error of fiducial marks using both simple and least square error methods. In all case, the total error by using least square error method is always smaller than the total error by using simple method. So the obtained center position is more precise. For illustration we consider two images with different positions of fiducial marks in a screen as shown in Fig. 3 and Fig. 12 and determine the centers of fiducial marks in the figures using the simple and least square error methods. The comparison results are given in table 1 (in local coordinate).

Fig. 14 and Fig. 15 show the histograms of Fig. 3 and Fig. 12 respectively.



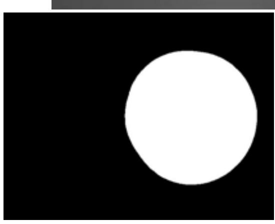


Fig. 12 Grayscale image
Fig. 13 Binary image

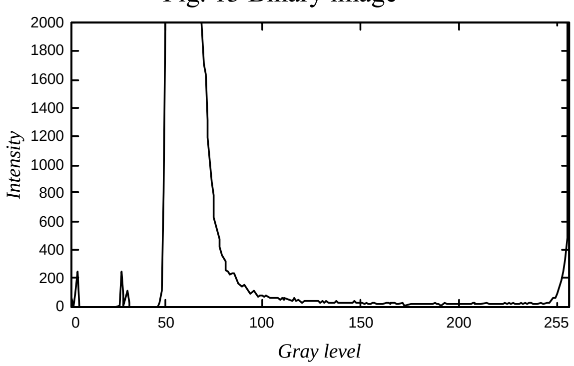


Fig. 14 Histogram of the image in Fig. 3

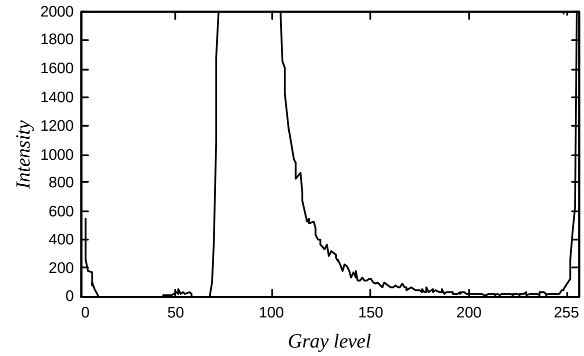


Fig. 15 Histogram of the image in Fig. 12

Table 1. The comparison results for the simple and least square error methods.

Image / Method		Fig. 3	Fig.12
Simple	x_0	-10.5000	-3.5000
	y_0	-13.5000	124.0000
	r	137.5000	156.0000
	Toatal error	102.8999	143.8860
Least square error	x_0	-10.0956	-1.7541
	y_0	-14.2565	124.3453
	r	138.4048	155.2275
	Toatal error	11.5180	8.0854

The comparison results show that the least square error method is better than the simple method. So we can use this method to determine the center of fiducial mark.

Photo. 1 shows the PCB screen printing part with position control system and the alignment part for the control of $X-Y-\theta$ table. Photo. 2 shows the monitoring screen for the practical printing operation.

Photo. 1 Developed PCB alignment part

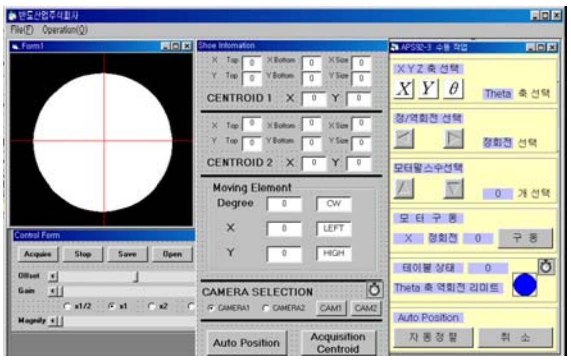


Photo. 2 Monitoring screen correcting PCB alignment error

5. Conclusion

In the paper, the development for a precise position control system incorporating the image processing technique is introduced. The positions of two fiducial marks drilled on the PCB are used as the sensing points for the image processing to recognize the position errors in directions of $X-Y-\theta$ coordinates. The centers of the fiducial marks are obtained by a least square error method. The exactness of the least squared method is compared to the simple method based on the concept of the average values for the abscissa and ordinate of the center for the fiducial marks. By applying the developed precise position control system for a practical PCB screen printing system, we can prove the effectiveness such that it realizes the precision about 2.5μm in the position control of $X-Y-\theta$ tables and the processing time about 1sec.

Acknowledgement

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