Design of Vision Based Punching Machine having Serial Communication

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Abstract: Automatic FPC punching instrument for the improvement of working condition and cost saving is introduced in this paper. FPC(flexible printed circuit) is used to detect the contact position of K/B and button like a cellular phone. Depending on the quality of the printed ink and position of reference punching point to the FPC, the resistance and current are varied to the malfunctioning values. The size of reference punching point is 2mm and the above. Because the punching operation is done manually, the accuracy of the punching degree is varied with operator's condition. Recently, The punching accuracy has deteriorated severely to the 2mm punching reference hall so that assembly of the K/B has hardly done. To improve this manual punching operation to the FPC, automatic FPC punching system is introduced. Precise mechanical parts like a 5-step stepping motor and ball screw mechanism are designed and tested and low cost PC camera is used for the sake of cost down instead of using high quality vision systems for the FA. 3D Mechanical design tool(Pro/E) is used to manage the exact tolerance circumstances and avoid design failures. Simulation is performed to make the complete vision based punching machine before assembly, and this procedure led to the manufacturing cost saving. As the image processing algorithms, dilation, erosion, and threshold calculation is applied to obtain an exact center position from the FPC print marks. These image processing algorithms made the original images having various noises have clean binary pixels which is easy to calculate the center position of print marks. Moment and Least square method are used to calculate the center position of objects. In this development circumstance, Moment method was superior to the Least square one at the calculation of speed and against noise. Main control panel is programmed by Visual C++ and graphical Active X for the whole management of vision based automatic punching machine. Operating modes like manual, calibration, and automatic mode are added to the main control panel for the compensation of bad FPC print conditions and mechanical tolerance occurring in the case of punch and die reassembly. Test algorithms and programs showed good results to the designed automatic punching system and led to the increase of productivity and huge cost down to law material like FPC by avoiding bad quality.

Keywords: FPC(flexible printed circuit), Image Processing, ROI(Region of Interest), Active X, Binary Image

1. INTRODUCTION

Most of the computer K/B is assembled with FPC(flexible printed circuit) which functions like a contact switch. When user presses the K/B, contact point located below the key top moves toward film style on-off switch and this leads to the serial communication by PS/2. The main role of FPC is to transfer the K/B switch location data to the main instrument. The fabrication of FPC is not easy because the location of reference punching mark requires the 100um tolerance. Currently, the punching operation of the FPC reference punching mark is done manually and led to the bad quality of punched FPC. To solve this inexact operation, we developed a control system which can calculate the position of FPC reference mark and compensate for the error position between the punching point and the FPC reference mark point by vision module[1]-[4].

Automatic vision punching system is comprised of mainly three parts which are vision system, x-y translation module, and punching mechanical parts. Vision system acts like a sensor detecting the FPC reference punching mark. The x-y translation module has a role of moving the error position to the punching one for the exactness. And punching mechanical parts is to operate pressing works.

Precise vision system and x-y translation module are designed for the exactness of punching tolerance and interface between the computer and microprocessor. And main control panel is programmed for the RS232C communication and display of the reference FPC mark. The target thickness of FPC as work piece is 0.025 – 0.8mm, and driving module and position calibrating system is designed to meet the precise punching operation. The web camera (USB 1.0, 15frames/sec) was used for the sake of the cost down and camera driver was developed by Visual C++[5][6]. Device driver of web camera maker was used to program for obtaining the data of the image saving and pixel position and control lever was designed for the purpose of the white balance and brightness. RS232C(9,600bps) communication was used to transfer the position data of image to the step motor drive(SPL42T2-05, 0.72deg/step). Step motor driver was controlled by the AVR microprocessor communicated with the PC(Pentium 4, 2GHz). Acceleration control method was applied to the step motor driver for the adequate working speed and moving characteristics. Also, safety design was performed to stand the load of work piece.

2. IMAGE PROCESSING ALGORITHM

Analogue camera is mainly used in FA vision system because of its excellent durability and high speed. Moreover, frame grabber (mage processing board) which converts image file to the binary one has a sufficient DLL and active X program except high price. In this study, low price digital web camera was used for the cost saving and image processing algorithm was studied using Visual C++. Image processing algorithms are as below.

2.1 Erosion Calculation

Erosion is a morphological transformation that combines two sets using vector subtraction of the set elements[7][8]. Suppose that object and structuring element B are represented as two-dimensional Euclidean space. Then the erosion of A by B is defined as the set of all points c for which c+b∈A for every b∈B, That is,

$$A \ominus B = \{c \mid c + B \in A \ \ for\ every\ b \in B\}$$

or

$$A \ominus B = \{c \mid c = a - b \ \ for\ every\ b \in B\} \qquad (1)$$

Where a={a_1, a_2, …, a_n}, b={b_1, b_2, …, b_n}, and the operation symbol $\ominus$ denotes Minkowski subtraction.

2. 2 Dilation Calculation

Dilation is a morphological transformation that combines two sets using vector addition of set elements. Suppose that object A and structuring element B are represented as two sets in two-dimensional Euclidean space. Then the dilation of A by B is defined as the set of all points c for which c = a + b

$$A \oplus B = \{c \mid c = a + b \ \ for\ some\ a \in A\ and\ b \in B\}$$

or

$$A \oplus B = \bigcup_{x \in B} A + x \qquad (2)$$

Where a={a_1, a_2, …, a_n}, b={b_1, b_2, …, b_n}, and the operation symbol $\oplus$ denotes Minkowski addition

3. ALGORITHEM CALCULATING THE CENTER OF CIRCLE

3.1 Moment Method

Moment method calculates the center of the vertical and horizontal image of the labeled arbitrary ROI(region of interest).

$$\bar{x} = \frac{\sum_i^N x_i}{N}, \quad \bar{y} = \frac{\sum_i^N y_i}{N} \qquad (3)$$

Here, x_i is x-coordinate of the pixel, y_i is y-coordinate, N is the total number of pixel.

3.1 Least Square Method

We suppose a circle equation to obtain radius r and center of circle(x_0, y_0) by the first order differential equation

$$(x_i - x_o)^2 + (y_i - y_o)^2 = r^2 \quad , \qquad i = 1, \cdots, n \qquad (4)$$

Where n denotes the number of pixel making the boundary, (x_i, y_i) is the (x, y) coordinates of the boundary pixel. Error equation is as below.

$$\begin{aligned} E &= \sum_{i=1}^{n}\left[(x_i - x_o)^2 + (y_i - y_o)^2 - r^2\right]^2 \\ &= \sum_{i=1}^{n}\left(x_i^2 - 2x_i x_o + x_o^2 + y_i^2 - 2y_i y_o + y_o^2 - r^2\right)^2 \\ &= \sum_{i=1}^{n}\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + x_o^2 + y_o^2 - r^2\right)^2 \\ &= \sum_{i=1}^{n}\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right)^2 \end{aligned} \qquad (5)$$

Where $z = x_o^2 + y_o^2 - r^2$

By applying the partial differential calculation to obtain (x_0, y_0), we can get Eq. (6) and from this the radius r and center (x_0, y_0) of the circle can be extracted.

$$\begin{aligned} \frac{\partial E}{\partial x_o} &= \sum_{i=1}^{n} 2\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right)\left(-2x_i\right) = 0 \\ &= 2\sum_{i=1}^{n}\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right)\left(-2x_i\right) = 0 \\ \frac{\partial E}{\partial y_o} &= \sum_{i=1}^{n} 2\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right)\left(-2y_i\right) = 0 \\ &= 2\sum_{i=1}^{n}\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right)\left(-2y_i\right) = 0 \\ \frac{\partial E}{\partial z} &= \sum_{i=1}^{n} 2\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right) = 0 \\ &= 2\sum_{i=1}^{n}\left(x_i^2 - 2x_i x_o + y_i^2 - 2y_i y_o + z\right) = 0 \end{aligned} \qquad (6)$$

Eq. (7) can be obtained by expanding above equation

$$\begin{aligned} x_o\sum_{i=1}^{n} 2x_i^2 + y_o\sum_{i=1}^{n} 2x_i y_i - z\sum_{i=1}^{n} x_i &= \sum_{i=1}^{n} x_i^3 + \sum_{i=1}^{n} x_i y_i^2 \\ x_o\sum_{i=1}^{n} 2x_i y_i + y_o\sum_{i=1}^{n} 2y_i^2 - z\sum_{i=1}^{n} y_i &= \sum_{i=1}^{n} x_i^2 y_i + \sum_{i=1}^{n} y_i^3 \\ x_o\sum_{i=1}^{n} 2x_i + y_o\sum_{i=1}^{n} 2y_i - z &= \sum_{i=1}^{n} x_i^2 + \sum_{i=1}^{n} y_i^2 \end{aligned} \qquad (7)$$

We can get finally the radius r and center (x_0, y_0) of the circle by applying the crammer's rule to Eq. (7)

4. COMPOSITION OF AUTOMATIC VISION PUNCHING MACHINE

4.1 3D Design (Pro/E) S/W

3D design program (Pro/E) was used for the comprehensive design of vision punching system. Fig. 1 shows the 3D view of the punching machine and Fig. 2 is the actual photo of the developed system. As you can see from the picture, light material like a wood was used to decrease the total weight of the machine. Additional plates for piling up FPCs beside the main body of punching were installed for the convenience of the working condition. Also, Aluminum was used for the improvement of the strength with the wood. The most optimal pneumatic system was designed to make a hole to the FPC ranged from 0.025 to 0.8mm.

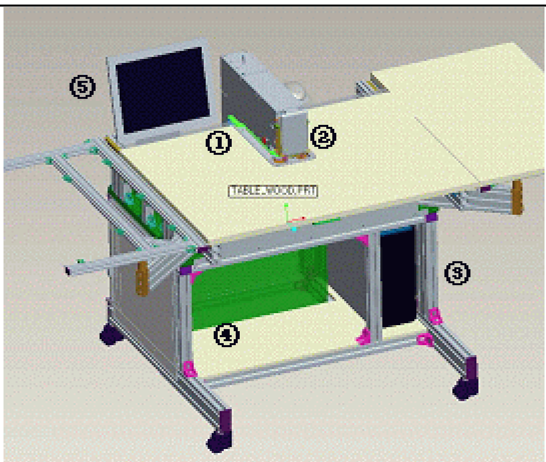


Fig. 1 3D model of vision punching machine (①punch & die ②camera ③computer ④controller ⑤ LCD monitor)

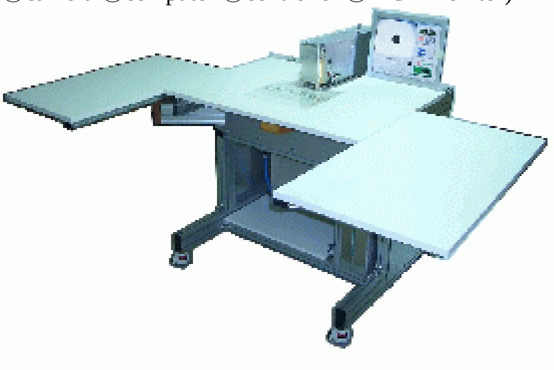


Fig. 2 Actual photo of vision punching machine

4.2 System Block Diagram and Working Order

Table 1 explains the specification of parts used in the study. Fig. 3 is the block diagram explaining the control flow of vision punching system. Error compensation is done by the programmed algorithm flashed in microprocessor which manages the camera image data and x-y translation moving system. Punching operation is done when error compensation is completed.

Table 1. Specification of vision punching system.

	Part Name	Specification
1	PC	-Pentium 2, 2Ghz, Win XP
2	Web Camera	-USB PC type -1/3” CMOS sensor -640 * 480 -VGA : 15f/sec
3	Microprocessor	-ATmega128 -Clock Speed : 16Mhz
4	Light	-LED(5V): white
5	Translation Moving Slider	-SPL42 -Max. Speed: 24mm/s -Max. Load: 6kg -Resolution: 0.004mm -Lead: 2mm

Punching operator have to select the hall size(2mm, 3.5mm, 4mm) and FPC material and specification(transparent, opaque, stripped pattern). Image saving is done applying the foot switch after punching pressure is controlled by manually to the 3bar. From the saved image, the reference punching mark is calculated in the ROI(region of interest) to detect whether this mark is located inside the ROI or not. This leads to the improvement of working speed and worker’s intensity. Image data is transformed to the binary one which is easy to compile to the computer and calculate the center of object image. Detected reference mark is calculated to the x-y error values compared to the origin of the ROI and these data is transferred to the microprocessor by the RS232C communication. Transferred data is calculated to the number of pulses which operate the each stepping motor drives and rapid position control is done by the interrupt for exact punching operation.

4.3 X-Y Translation Moving System

The target of x-y translation moving system is comprised of mainly two items. First is the high speed and second is the good resolution. Target speed is 20mm/sec and resolution is 0.004mm and these conditions can meet the working tack time 1.5sec. In this experiment, working load is 6kgf and speed of operating pulse is 5kHz and minimized the accelerating time.

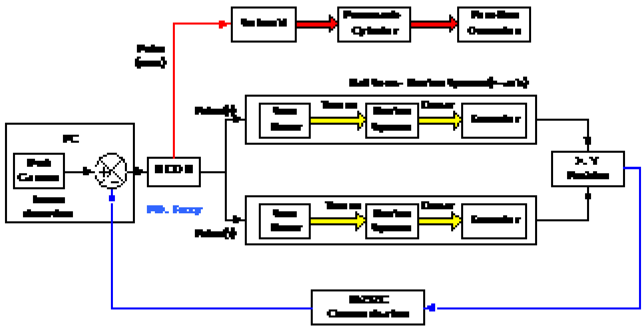


Fig. 3 Block diagram of vision punching system

4.4 Vision System

Fig. 4 shows the FPC of POS K/B. The size of reference punching mark is 2mm and 3.5mm and printed tightly each other. The camera and lighting system is designed to capture the punching image. And the type of camera is low cost web camera and lighting system was fabricated to set the focus on the center of reference hall. Back lighting system was adapted to the Transparent FPC to avoid of the disturbances from the external light like a solar beam. Down side lighting system was used to the Opaque FPC.

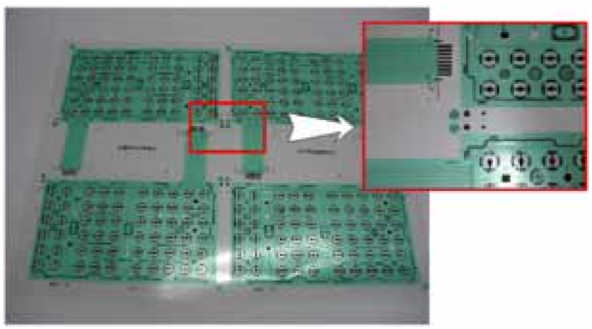


Fig. 4 Photo of FPC(flexible printed circuit, 60Key)

4.5 Punching Mechanism

The material of FPC is flexible film and high force is not needed to punch this type of films, but static electricity is occurred on the film when it is punched by puncher and die which material is steel. When separator film with 0.025mm thickness is attached to the FPC film, punching condition becomes more severe. In this case, additional punching stripper is needed to strip the punched film of reference mark.

Fig. 5 explains the designed punching mechanism. The up-down movement is done by the pneumatic cylinder related to the lever(10: 1) to punching operation. Pneumatic regulator and speed controller was designed to control the punch speed and pressure. The diameter of pneumatic cylinder was designed to resist 50kgf load and finally 500kgf punching load can be applied by the lever mechanism.

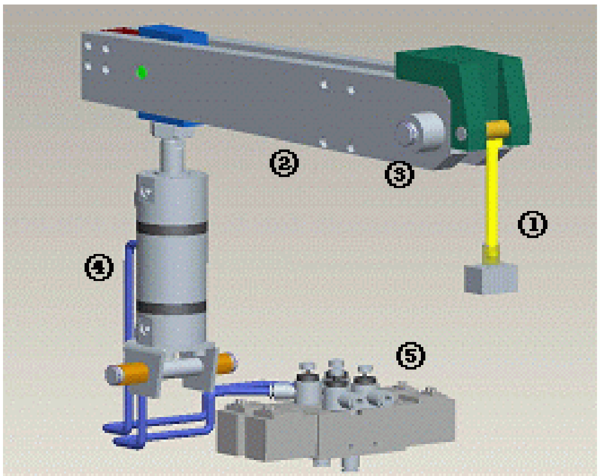


Fig. 5 3D view of punching mechanism(①punching parts ②lever ③lever pin ④pneumatic cylinder ⑤solenoid valve & speed controllers)

5. OPERATING PROGRAM AND EXPERIMENT RESULT

5.1 Operating Program

Image processing algorithm was programmed by the Visual C++ and MFC DLL function was used to save the image. Graphical display was organized to be as simple as it is for the real time calculation and communication between the computer and microprocessor.

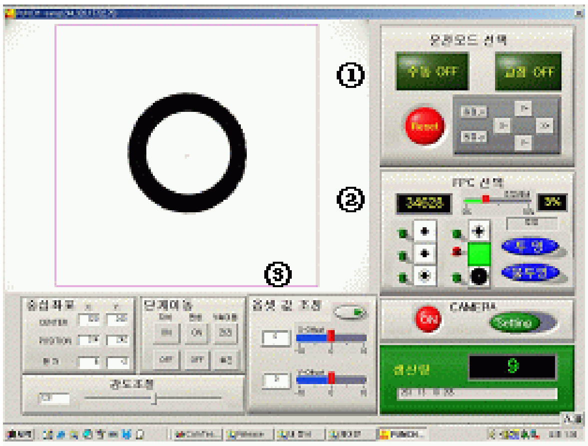
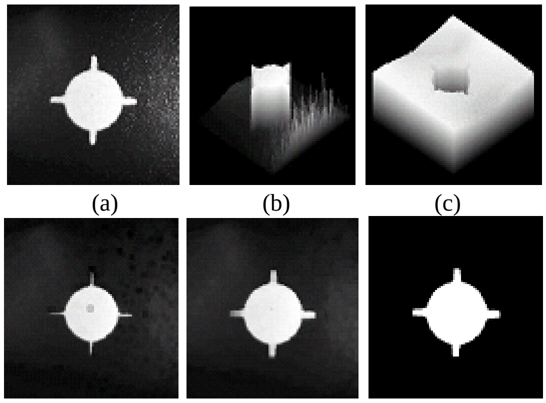


Fig. 6 Main control panel of punching machine (①operating mode selection panel, ②FPC selection panel, ③offset value setting panel)

Fig. 6 shows the main control panel which controls and displays the whole working operation. The focal length of the camera lens is 8mm and we can get more enlarged image than the previous 6mm lens and working distance of the camera is 13mm. Inspecting image size is 640×480 and ROI size is 460×460 to track the center of reference hole mark. Operation mode has two types, one is manual mode and the other is automatic mode. This is distinguished by the calculated circle area with 2mm diameter. The calculated circle area is compared with already saved reference hole to judge the error tolerance is above the ±3% or not. This is for the exact punching position calculation and working operation when the FPC has a blurred hole mark or inserted ink spot, the center position of the reference hole mark is changed and this leads to the bad punching quality.

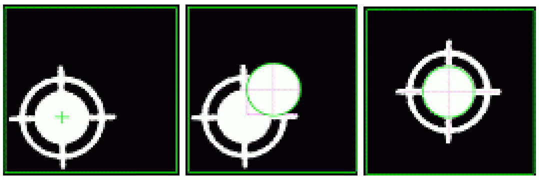
5.2 Experiment Result

Fig. 7 shows the 3D graphical image of detected reference hole mark receiving external light like a solar beam (b, c). Fig. 7(d, e) is the image processed ones by the erosion and dilation calculation. Multiplication calculation and threshold value is given to obtain the clean and stable image like a Fig. 7(f).



(a) (b) (c)
(d) (e) (f)

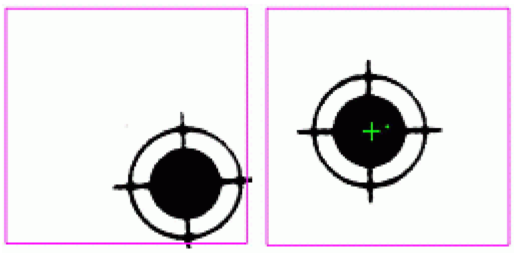
Fig. 7 Image processing procedure for removing the noise of captured image. (a)original image (b)3D view of original image (c)inverse 3D view of original image (d)by erosion calculation (e)by dilation calculation (f)by multiplication and threshold



(a) (b) (c)

Fig. 8 Image of punched FPC. (a)calculated center position by moment method (b)by manual mode (c)by automatic mode

Fig. 8(a) displays a focused cross mark which is centered at the image in the automatic mode. Moment and least square methods were used to calculate the center of the circle, moment method was more stable to the disturbances than the least square method. The test results punched in the manual mode is shown in Fig. 8(b).

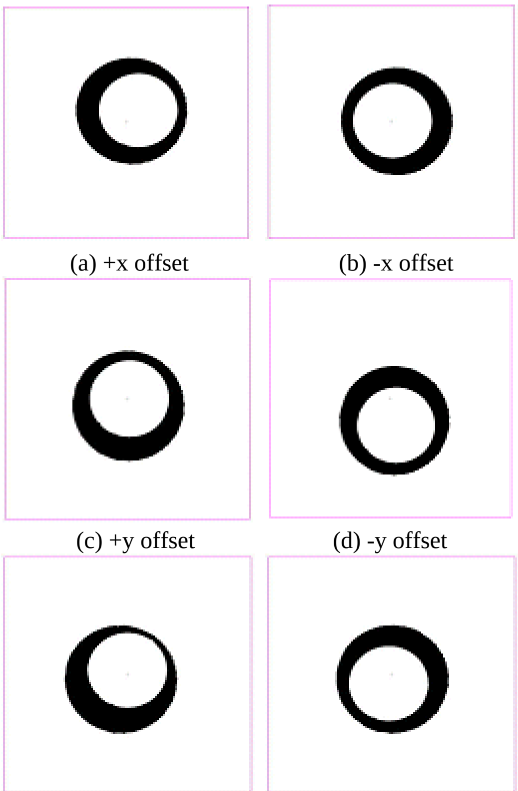


(a) (b)

Fig. 9 Image with center position(b) and not(a)

Fig. 9 explains the conditions to capture the center of circle in the automatic mode. ROI boundary was formed to compensate the image distortion. When the reference hole is lies on the ROI boundary, the calculation of circle center is not executed to prevent the bad quality of punching.

Fig. 10 shows punched test results as the offset values are changed from +x to –x, +y to –y, and +xy to –xy. And the test results matched well to the ordered offset values.



(a) +x offset (b) -x offset

(c) +y offset (d) -y offset

(e) +xy offset (f) -xy offset

Fig. 10 Image of punched FPC having offset values. -without calibration of punching mechanism

6. CONCLUSION

We have several conclusions as the developed automatic punching machine is operated in the factory field.

1. Punched quality to the FPC became excellent using developed automatic punching machine compared to the manually operated punching and productivity has increased to the 30% ratio.
2. Cost down to the raw material was realized by removing the occurrence of badly punched FPC by the developed machine.
3. Cycle time of the punching machine is 1.3 sec and we met the targeted cycle time : 1. 5sec
4. RS232C communication between the AVR microprocessor and designed image software was well adapted to the developed machine.

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