Research of the Machine Vision Based PCB Defect Inspection System

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***Abstract*—Machine vision-based PCB defect inspection system is designed to meet high speed and high precision requirement in PCB manufacture industry field, which is the combination of software and hardware. This paper firstly introduced the whole system structure and the principle of vision detection, while described the relevant key technologies used during the PCB defect inspection, finally implemented one set of test system with the key technologies mentioned. The experimental results show that the defect of PCB can be effectively inspected, located and recognized with the key technologies.**

Keywords-machine vision; defect detection; double sigmoid image enhancement algorithm; image alignment

I. INTRODUCTION

China has become a country that produces large amount of PCBs. Statistics show that there are about 2800 PCB enterprises around the world and more than 1200 of which are in china mainland. The dimension of China's PCB industry had been expanded gradually since 2000 and surpassed the U.S at the first time in 2003. In 2006, China had replaced Japan as the world's largest PCB manufacturing factory[1].

In the PCB manufacturing process, it is an important process to detect bare board defects. The process mainly check whether the boards after etching has the problems such as: 1).line problems: short circuit, broken circuit or too wide or too narrow distance between lines etc. 2).defects: depression, superfluous copper etc.3).hole defects: hole deviation ,hole missing and so on.

Currently, there are several commonly used bare board defect detection methods [2,3,4]:artificial visual detection, touch detection(needle-bed test, flying probe test, functional test),non-touch detection. Automatic optical inspection (AOI) is one of the important non-touch detection methods. The system detects and recognizes the existed defects non-destructively, swiftly and precisely. Compared with the touch detection methods, AOI method has small investment and can be converted flexibly, updates quickly, detects swiftly with no touch of the detected object and also no damages. While compared with the traditional manual visual detection methods, it has many advantages such as broader detection range, higher detection precision, and lower wrong detection rate etc. Therefore, by using the machine vision technology to control PCB product quality, the PCB product can be detected real-timely and it is also beneficial to improve the product quality and lower the production costs.

After nearly ten years of growing, the AOI technology has gradually been going into mature, however, the technology is mainly mastered by foreign companies. Currently, the main AOI equipment manufacturing factories include: DiagnoSYS in Britain, Teradyne in U.S ,OMRON in Japan ,OptRotech in Israel, MVT in Ireland and other companies. The products of these companies are so expensive[5] that it is difficult for many PCB manufacturers to bear. At present, many small or medium enterprises had to use outdated electrical test methods or manual vision test methods. Although the big PCB manufacturers have the ability to buy the expensive detection device, but the operating interface of the imported AOI detecting equipment usually do not meet the Chinese operating habits, thus the function of the system can not be fully applied.

Domestic research of automated optical inspection (AOI) dated from the middle 1990s. At present, there are few research institutions working in this field. Influenced by many other factors, the research of AOI system still remains at a relatively primary level [5].

Therefore, it is necessary to develop relatively cheaper AOI detection equipment that can test comprehensively and have full independent intelligence property. After a few years' study, our team developed a cost-effective set of AOI testing system that can fit the detection needs of domestic small and medium PCB enterprises.

II. SYSTEM ARCHITECTURE

There are a few steps to detect defect of bare PCB for AOI system. First of all, the AOI system should collects PCB images through CCD camera. Then it has to denoise and enhance and binarize the image. After special image recognition and analysis process, the images should be compared with the templates, thus the common defects such as short circuit, open circuit ,burrs, defects and voids and other defects can be found out precisely. Finally the recognition results will be acquired and reported

The hardware structure is shown in figure1. Under the control of the computer, the PCB delivering components automatically move the given PCBs to the testing room.

When finishing the detection, the PCBs are divided into qualified and non-qualified one. Image acquisition and moving control subsystem receives the central computer's

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control commands, acquires the PCB images real-timely and preprocesses them. The result data will be sent to the central computer.

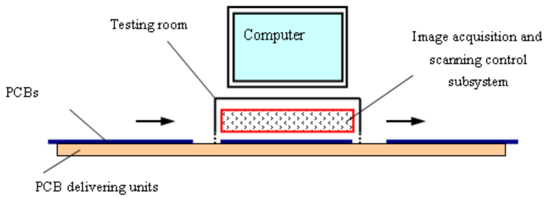

Figure 1. the hardware structure of AOI-based PCB defect inspection system

Central computer is the core of the system. On the one hand, it controls the action of the delivering units and the image acquisition units. On the other hand, it needs to receive image data, processes the data, finds out the defect and outputs the detection report.

III. THE KEY TECHNOLOGIES OF THE SYSTEM

A. *Image Acquisition*

As to the PCB bare board testing, the camera used in image acquisition are generally black and white CCD cameras. In order to reduce the hardware costs, the area cameras are preferable. There are three kinds of camera data transmitting modes: USB, Camera Link, Gigabit Ethernet ports. Light sources includes: point light source, surface light source, ring light source, coaxial light source etc. The light source installation includes two kinds: top light source and bottom light source.

In the AOI system, the quality of acquiring images is one of the key technologies, which depends on the camera devices and the environment. When the camera devices are determined, it is crucial to provide proper illumination approaches to ensure image quality. When extracting images, the luminary intensity and the stability of the auxiliary light source have great impacts on the image quality. Too weak or too strong light will cause the extreme deterioration of the image quality [6]. Furthermore the PCB has high light reflection, it acts like a mirror, which will cause shadows of the object images when the images come into being by the top light source, which impacts the image quality greatly, and even terminate the follow-up processing works. In order to acquire high quality to-be-test images, reasonable design and adaptive control of the luminary intensity are key technologies of controlling imaging qualities.

LED light source is used as the light source for its low power, long life, and flicker-free property. Circuit boards of different base material have different transmittances and reflective properties. Light sources with the same illumination have different impacts on the bright and contract of the images as to the different contrast of the background (base board) and the target object (wire or pad). So the luminary of LED light source should be able to be adjusted automatically according to different PCB base material. The LED adaptive light source module is a closed-loop control circuit, which is shown in the following figure 2.

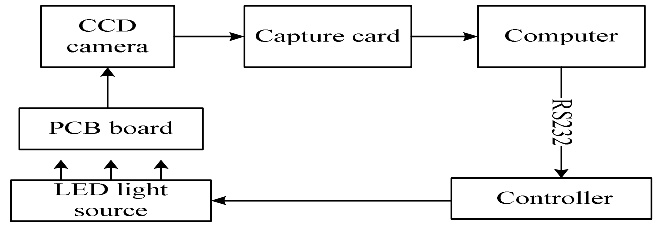

Figure 2. Light source adjusting module

B. *Image Processing*

Image segmentation is usually the key step in the image processing and analyzing. However, no common-used image segmentation algorithm is available. It is needed to study one most reasonable segmentation algorithm according to the practical image characters and the actual needs comprehensively.

There are many areas with ague edge in the gray PCB images acquired by the CCD camera. So before image segmentation, the image enhancement is necessary. The main aim of the image enhancement is to enhance edges and refrain noises effectively at the same time, especially the noise near the edges. The PCB image resolution is usually greater than 600dpi, which mean that the 10 mil width wire of PCB just occupies more than 6 pixels in the image. From the edging locating point of view, the wire edge is phase step type. According to the above characters of the PCB images, double Sigmoid image enhancement algorithm should be adopted, which can sharpen the PCB objective image and refrain the noise effectively.

The PCB images are enhanced using Sigmoid operator. Suppose the gray PCB image is expressed as f(x, y), the enhanced image is h(x, y). With double Sigmoid algorithm, we can get the following formula:

$$h(x,y) = f(x,y) - \beta \times \zeta^2[f(x,y)]_\theta \quad \textit{subject to} \quad \max_\theta\{|\zeta^2[f(x,y)]_\theta|\} \qquad (1)$$

The constraint condition shows that it is needed to choose the $\zeta^2[f(x,y)]_\theta$ .With the maximum absolute value related with θ, β is the enhancement coefficient. The enhancing effects is preferable if the value of β is bigger. However, if β is too big, the ripple interference will be appeared. $\zeta^2[f(x,y)]_\theta$ is the repeated operation of transforming $\zeta[f(x,y)]_\theta$, which is the convolution of f(x, y) and $s(\rho)$ on the ρ-axis. Consider the circle area with the central point (x, y), the radius of the circle is σ, ρ is the radial axis runs through the center of the circle. The angle between the x-axis and ρ is θ, then

$$\zeta[f(x,y)]_\theta = \int_{-\sigma}^{\sigma} f(x+\rho\cos\theta, y+\rho\sin\theta) s(\rho) d\rho \qquad (2)$$

In the formula, $s(\rho) = \dfrac{1-e^{-\rho/a}}{1+e^{-\rho/a}}$, a is the scale factor.

We implement the double Sigmoid algorithm for the PCB image. Figure 3(b) is the enhanced result of figure3 [a]. The enhanced image shows that the dense wires area become very clear, and the image edges are obvious, which will make the defect area highlighted.

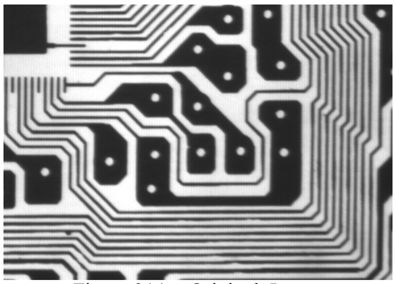

Figure 3(a). Original Image

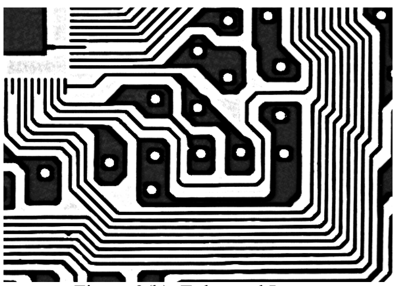

Figure 3(b). Enhanced Image

After enhancing the images, there are two distinct peaks in the PCB gray histogram: one is for base material, the other is for the target object. The twin peak segmentation is the simplest segmentation method. The system use the more stable and classical OTSU [7] algorithm. OTSU algorithm divides the image into two parts of background and object. The segmentation threshold is T. The ratio of target pixel number to the total image pixel number is X0, the average gray value is Y0, and the ratio of the background pixel number to the image pixel number is X1. The average gray value is Y1; The total average gray value is Y, then Y=X0*Y0+X1*Y1. Traverse T values, when the $G=X0*(Y0-Y)^2+X1*(Y1-Y)^2$ achieve the maximum value, the T is the most reasonable threshold. When the OTSU is used directly, the computation is very large. The equivalent formula $G = X0*X1*(Y0-Y1)^2$ is used instead in practice. The threshold chosen through OSTU is relatively idea. Desirable segmentation effects can be achieved for various PCBs.

C. *Image Alignment*

The AOI system use cameras ,scanners etc to scan PCBs, and then compare the standard board with the to-be-test circuit board to find out defects[8].In this regard, many scholars study on AOI-based PCB defect recognition and a lot of algorithms are proposed[9,10,11,12,13]. To sum up, the methods can be concluded into three kinds: reference comparison method, non-reference check method and hybrid method. Reference comparison method compare the tested image with the reference image point by point, which is simple and easy to realize but it is not easy to detect the defects such as line wide fault and line space fault etc. Non-reference comparison method does not require any reference images, the pre-defined PCB designing rules are used to determine whether the PCB image has defects, which acts quite well in detecting line wide fault and line space fault but computes complicatedly and computes considerably, additionally, this method is easy to miss lines ,pads and other defects. Hybrid method is the combination of the two above methods, it overcomes the shortcomings of the two methods to some extent .However, and this method is not very mature.

Relatively speaking, the reference comparison method is easy to implement but the point to point reference comparison method has strict requirements for the light and location. If the image to be tested is not aligned to the reference image precisely, a large amount of false warnings will occur. We use the edge contour feature comparison method, which has strong adaptively to the uncertain conditions such as the acquired PCB images in two different times are not aligned precisely to each other or the local distortion exists in CCD camera etc.

Sample templates need to be collected when using edge contour comparison method. After processing the sample images, the lines and the pad edges are gotten through edge contour extraction algorithm, thus the edge contour character library are constructed. According to the positioning information provided by the sample character library, the samples and the PCB images are aligned in precise position. According to the character information and extraction method specified by the sample contour character library, the character parameter can be extracted from the PCB image to be tested and then the samples and the PCB image to be tested can be matched and calculated. The match level can be indicated by the reference coefficients. The match threshold condition is set so that when the relative coefficient does not meet the threshold condition, it is considered to be unmatched. The coordination of the position where the mismatch exists is computed and then recorded and reported.

The following figure 4 shows the sample template and the tested PCB

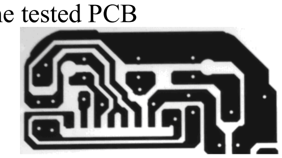

Figure 4(a). the Sample PCB

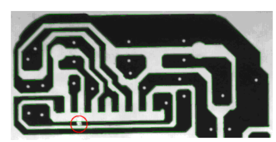

Figure 4(b). the Tested PCB

D. *Experiment*

According to the above key technologies, we implemented a set of AOI system.because the system is mainly for the medium PCB manufacturing enterprises to detect defects, the hardware type selection is mainly considering the high performance-price ratio device. VC++ developing language is chosen as the software. The maximum area of the testing PCB is 500×500mm. The inspecting speed is 5 PCBs per minute. The main interface of the software are shown in figure5:

Figure 5. The system software inferface

IV. CONCLUSION

The bare board detecting system based on AOI involves many aspects such as computer science, mechanical manufacturing, automation, electronic information optical, etc. It is a complex electromechanical optical intelligent device. In the process of implementing the system, we found out that careful plans are required in each steps such as image acquisition, image processing, image edge extraction and defect recognition. At present, the finished designed system can detect common PCB defects such as: short circuit, open circuit, depressions.

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