Automation and Machine Learning (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/autml.2024.050112
ISSN 2516-5003 Vol. 5 Num. 1

Analysis of Key Techniques of PCB Defect Detection Based on Machine Vision

Shengfang Li[1,a], Hao Zhou[1,b]

[1]Xihua University, Chengdu, Sichuan, 611730, China
[a]mszcy153@126.com, [b]my15010923357@163.com

Keywords: Machine Vision, Printed Circuit Board, Key Technology, Defect Detection, Basic Principle

Abstract: Under the background of the vigorous development of the electronics industry, printed circuit boards, as one of the important components of the electronics industry, provide more support for the production and research and development of many electronic devices. Electrical interconnection of electronic devices requires printed circuit boards as the carrier, its appearance directly reduces the workload of connecting conductive lines, simplifies the wiring work, and its quality can directly affect the performance of electronic products, which makes the defect detection of printed circuit boards is crucial. The application of machine vision not only improves the efficiency and quality of inspection, but also brings new opportunities and challenges to related industries. In view of this, in order to study the key technology of PCB defect detection based on machine vision, this paper based on the generation of PCB defects, analyzed the working principle and calibration principle of the relevant system, and finally proposed the nine-point calibration method, and expounded the image processing method, hoping to provide reference for relevant people.

1. Introduction

China is currently a printed circuit board (PCB) production country, with the upgrading of electronic products, the PCB also put forward smaller volume, higher device density, more precise integration and other requirements, PCB detection difficulty is also step by step. Currently: Artificial visual inspection, contact detection and non-contact detection methods are widely used in practice. Among them, automatic optical inspection (AOI) based on machine vision is one of the important methods in non-contact detection, which is developed on the basis of artificial intelligence. This kind of detection efficiency is high, without any damage to the PCB board, and compared with manual visual inspection, its detection range is wider, in-depth research on this technology, the detection of various industries in China are of great benefit, and can improve the quality of PCB defects detection, which is of great value to the relevant fields of the country.

2. PCB Defects Occur

To find the cause of PCB defects, we need to first analyze the PCB production process, etc. The

entire PCB production process can be summarized as: internal processing, pressing, drilling, copper plating, external processing, and character printing, surface protection. The above steps may have defects, want to find defects, you need to test each process. However, there is usually a gap between theory and practice, in the actual production process, repeated testing may lead to human and economic losses, from the cost of consideration, and the inspection is usually focused on the PCB production step. In theory, PCB defects are divided into potential defects and intrinsic defects, potential defects are a kind of quality assurance in the process of product not yet put into use, although such defects have not yet appeared, but with the product put into use, the defects are also exposed, all the hidden dangers mainly exist in the future, such as burrs, hole size changes, etc. Although such defects can be predicted before use, they cannot be specifically determined to which time node; Intrinsic defects refer to the defects existing in the PCB itself, such as wire missing, short circuit, etc. For the use of different detection methods, the defects are ultimately divided into dimensional defects and non-dimensional defects. The basic method of dimensional defect detection uses standard comparison templates to detect and allow errors within a certain range. For non-dimensional defect detection, correct data should be deduced based on color recognition and relevant calculation rules to finally evaluate the conformity of the product [1].

3. Basic Working Principle and Design Scheme of the System

PCB inspection system based on machine vision needs to obtain the image through CCD, and beautify the noise of the image twice, enhance the image quality, and further identify the PCB image, analyze the relevant elements in the image, refer to the PCB template, and finally can accurately find the related defects of PCB in the shortest time, such as burrs, short circuits, etc. After the defects are detected, they need to be further archived and analyzed. The entire hardware system is shown in Figure 1. With the computer as the control host, the PCB waiting for detection is transmitted to the waiting room. At this time, the area array CCD industrial camera scans and takes photos of the PCB, and the obtained image is further transmitted to the computer and stored for detection. After all the tests are completed, the PCB will be divided into qualified and unqualified two outputs respectively. The whole system is controlled by computer, which specifically controls PCB related image data, analyzes and processes it, and finally finds defects and prints out the detection report. In addition, it is necessary to control the real-time action of the PCB transmission mechanism, control the pressure plate and scanning action of the image acquisition unit. In actual work, the cost of inspection should also be considered, so the AOI system needs to be analyzed and upgraded constantly [2].

The overall design scheme of PCB defect detection system includes image acquisition system, image processing system and peripheral transmission mechanism. The overall design scheme is shown in Figure 2. Image acquisition system is divided into light source, lens and other different systems, image processing system needs to be based on computer system, in the way of software programming for detection. In the workflow of the overall scheme, it is necessary to first transmit the PCB circuit board to be inspected, and finally complete the detection within the specified time, and take photos under the pre-adjusted light source. In the whole testing process, the camera and lens can be selected through reasonable data, and the communication Settings can be carried out, and all the data can be analyzed and processed, and finally the relevant product quality data can be obtained [3].

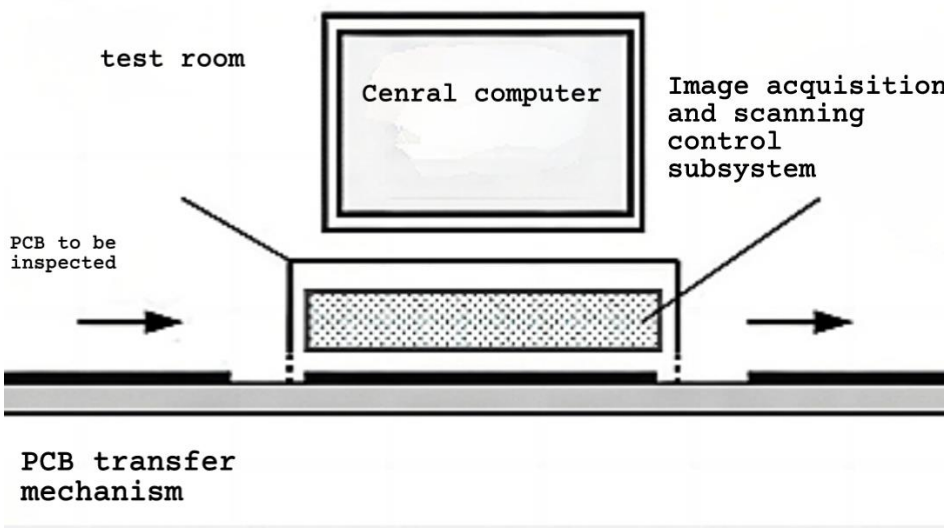

Figure 1: Working diagram of AOI system

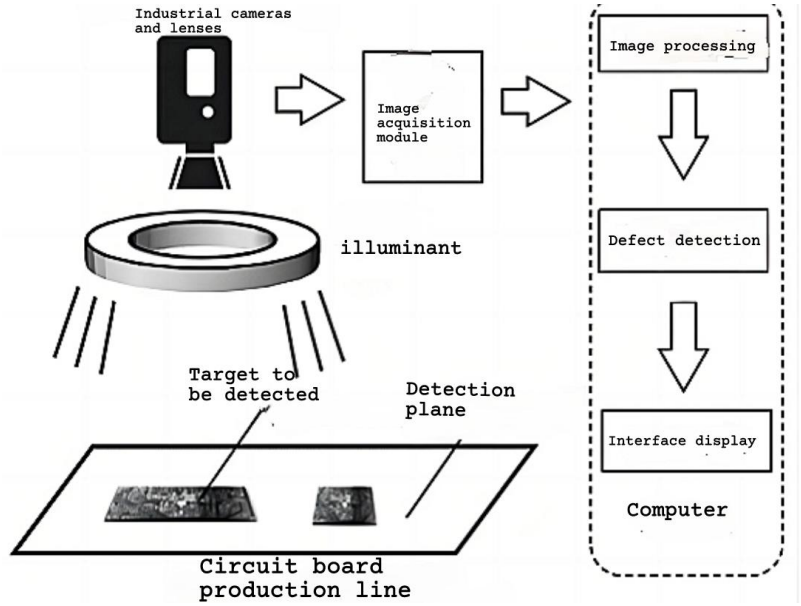

Figure 2: Overall design scheme

4. Principle of Image Acquisition

Pixels determine the quality of image acquisition, which is different from the real world objects, suppose there is a 2 million pixel camera, its resolution is 1600×1200, its actual field of view is 100mm, the wide side is 75mm, each pixel is 100mm/1600 = 0.0625mm. The final image can be composed of 1600×1200 small cells of 0.0625mm×0.0625mm, which are pixel points with an accuracy of 0.0625mm. On the contrary, in the process of image acquisition, if the length of the image line is 400 pixels, the corresponding line segment length for the object in the real world is 400×0.0625mm = 25mm, so in order to get the real detection data, the image under machine vision needs to be converted, and finally the data closer to the actual data.

5. Calibration Principle

The coordinates are selected in order to get the real physical size, and different coordinate

systems can be converted into the same coordinate system through calibration, and the obtained information can be processed finally. There are four coordinate systems in the vision system, namely, world coordinate system, camera coordinate system, image coordinate system and pixel coordinate system. When the PCB is tested, the relevant price needs to be divided by the agreed three-dimensional coordinate in a more timely manner, and the world coordinate system and the camera coordinate system are 3D coordinate systems. Pixel coordinates and image coordinates are both 2D coordinates. The north target is usually the imaging center and the center of the coordinate system, which is in the same horizontal plane with the measured target. The right side is the X-axis, and the Y-axis is 90 degrees with it. The image coordinate system is represented by (x,y). The working principle of pixel coordinates is also called the perspective principle, and the point in the upper left corner of the image is the reference point, which becomes the origin of the coordinates, which separates the pixel coordinates and the image coordinates, and uses (u, v) to represent the pixel coordinate system. The U-axis is parallel to the measured target horizontally to the right, and the V-axis is perpendicular to the measured target downward. At this time, the optical center of the lens is the origin of the camera coordinate system, and the world coordinate system takes the spatial position of the actual measured object as the reference. Suppose that a point F is found in the world coordinate, the position described by the world coordinate system of this point is F (Xs, Ys, Zs), and its coordinate in the camera coordinate system is Fj (Xj, Yj, Zj). Detection needs to be carried out by imaging. In the coordinate system f (x,y) in the image coordinate system, the coordinate of this point in the pixel coordinate system is f (u,v). Known image coordinate x,y data, unit mm, reactive distance. The coordinates in the pixel coordinate system are u and v, which represent the number of columns and rows of the array where point f is located respectively [4]. The coordinate space relationship shown in Figure 3 can be obtained. The coordinate f(x,y) of the image coordinate system is converted into the pixel coordinate f(u,v) according to the principle of pixel, and the conversion relationship between the image coordinate system and pixel coordinate system is shown in Figure 4. It can be seen that Δx and Δy are pixel dimensions, and Δx represents the number of units mm of each column. Delta y is how many units of mm per action. We know that u = x / Δx+u0 and v = y / Δy+v0.

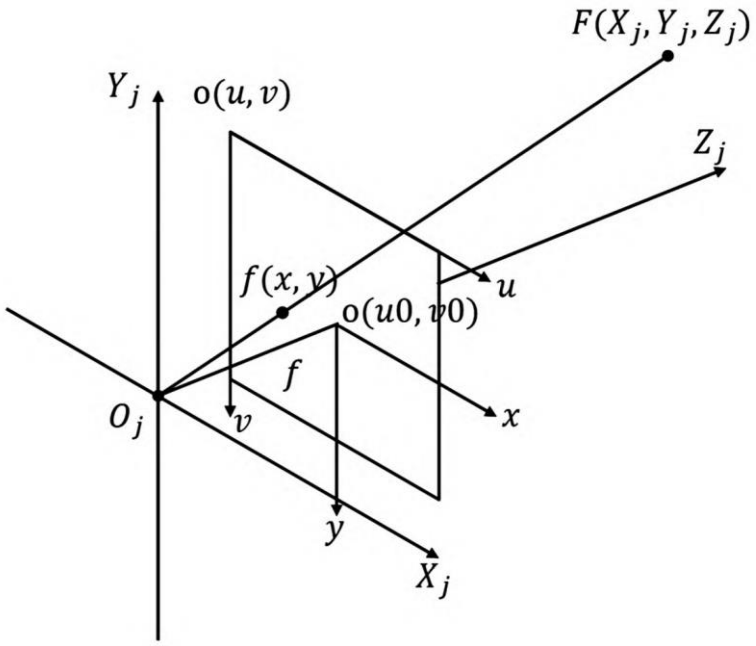

Figure 3: Spatial relationship diagram of each coordinate system

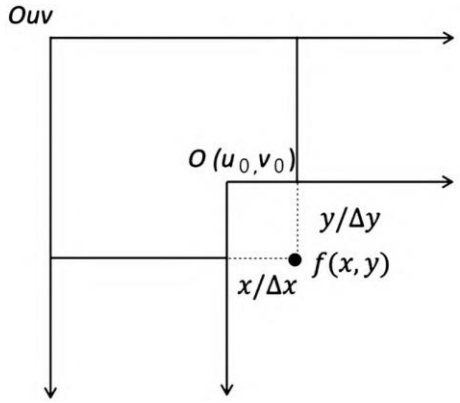

Figure 4: Transformation relationship between image coordinate system and pixel coordinate system

6. Nine-point Calibration Method (N-point calibration)

N-point calibration, also known as feature point calibration, is the most common calibration method in the process of machine vision image acquisition. N-point calibration requires N points, and N needs to be greater than or equal to 3 by analyzing the coordinate matrix. In the actual detection, the nine-point calibration method is the most common, and there are also six-point calibration, but the accuracy of six-point calibration is less than nine-point calibration. In the process of PCB defect detection, the camera can move in 2D space, move to the same plane, and the camera coordinate world coordinates are simplified and integrated, the entire process needs to complete the conversion of pixel coordinates and camera coordinates, so as to complete the expression and detection. The method of nine-point calibration is as follows.

The basic principle is affine transformation principle, the transformation between coordinate systems in three-dimensional space needs to go through translation, and get another space vector, and the transformation formula of matrix can be derived through formula calculation. Assuming that the 6 unknowns of the rotation matrix to be verified are a0, b0, c0, a1, b1, c1, invert the camera coordinates of any point. And randomly take 2 pixel coordinates (u1, v1) (u2, v2) (u3, v3) and 3 camera coordinates (X1, Y1) (X2, Y2) (X3, Y3) in this coordinate system, and substitute them into matrix (5) to obtain the matrix as shown in Figure 5:

$$\begin{bmatrix} X_1 \\ Y_1 \\ 1 \end{bmatrix} = \begin{bmatrix} a_0 & b_0 & c_0 \\ a_1 & b_1 & c_1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ v_1 \\ 1 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} X_2 \\ Y_2 \\ 1 \end{bmatrix} = \begin{bmatrix} a_0 & b_0 & c_0 \\ a_1 & b_1 & c_1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_2 \\ v_2 \\ 1 \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} X_3 \\ Y_3 \\ 1 \end{bmatrix} = \begin{bmatrix} a_0 & b_0 & c_0 \\ a_1 & b_1 & c_1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_3 \\ v_3 \\ 1 \end{bmatrix} \quad (8)$$

Figure 5: Matrix

Through calculation, the values of a0, b0, co, a1, b1 and c1 can be obtained, thus obtaining the affine matrix, which also explains that in the calculation of coordinates, the number of N must be greater than 3, so the data above 3 can be calibrated to obtain the affine matrix. Using nine-point calibration can reduce the final error of detection as much as possible and improve the quality of detection. Nine-point calibration data acquisition needs to be carried out in the sensitive area of the fixed plate, combined with the actual adjustment of the camera position and parameters, and finally completed with the assistance of the appropriate light source. After the 9 points are calibrated, the system will accurately calculate the number, and manually control the mechanical axis, so that it aligns with the feature points 1 ~9, different feature points correspond to different coordinate points, and finally get the relevant data of X axis and Y axis, and fill the above position parameters into the world coordinate system, and complete the 1-9 punctuation mark calibration. This completes the mapping between pixel coordinates and world coordinates. Finally, the affine matrix is calculated by analyzing the data of 9 feature points. When the PCB board is detected, the most realistic data of the object can be obtained, and the final marking is completed.

7. Image Processing Methods

The image obtained in the process of PCB defect detection has certain problems, under the influence of many factors, the severity of the problem is different, lighting, shooting equipment, etc., will affect the quality of the picture. The main purpose of image processing is to denoise and protect image details.

7.1 Digital Processing of Color Images

Suppose that different pixels in the image are all points in the coordinate system, then the coordinate value of the pixel represents the color of the pixel. The pixel is composed of three direction vectors R, G, and B in three-dimensional space, that is, any color can be composed of three colors R, G, and B. R is red, G is green, B is blue, and each color represents a different threshold. The composition of the three direction vectors R, G and B is different, and the color saturation is also different. The color of the whole process changes with different direction vectors. In the process of image processing, the channel coefficient can be adjusted more flexibly with the change of color, thus changing the color expression of the image [5].

7.2 Image Segmentation

Image segmentation is mainly convenient to extract the key information of the image, and it is necessary to partition the image by combining different features. This processing method needs to be established on the basis of pixel similarity and different continuity, and the convolutional network is used for algorithm analysis and model construction. In the whole way, with the same number as the same feature attribute, the image can also be classified according to different attributes, such as gray scale, color, geometric shape, etc. At the same time, in different image areas, data and images can be extracted and analyzed in areas of interest. Image segmentation can be used for focused processing of specific targets, image separation of fuzzy targets, and rapid capture of some key image information. Currently, image segmentation has been widely used in PCB defect detection systems. Image acquisition and image processing can be carried out on the circuit board, and the detection results can also be fed back to the software interface to provide a basis for the staff to analyze the fault of the PCB, and finally find out whether the PCB has defects.

7.3 Median Filtering

Median filtering is a more commonly used image processing method, which can effectively remove the nonlinear noise of the image. When there is a speckle change in the image, the window with an odd number of points 9 is generally selected and the image is translated. In the process of translation, the relevant data will be replaced by the "median" data, and the translation window will be the sampling window, and the collected data will be sorted in ascending or descending order to get the median data. In this process, inappropriate data will be filtered out by the median filter to eliminate isolated points. Since the median filter needs to constantly replace data, the image processing time will be longer in this way [6].

8. Conclusions

To sum up, machine vision is mainly composed of hardware and software, hardware is mainly composed of industrial cameras, industrial lenses and light sources, lenses and light sources to achieve object imaging, the chip inside the camera converts images into light signals for transmission. PCB defect detection based on machine vision can be embedded in the entire system through image calibration to improve the accuracy of data. At the same time, when detecting defects, it is necessary to accurately analyze the data of suitable images to complete the product quality inspection on the production line. The quality inspection system based on machine vision has a more accurate, reliable and efficient detection ability, and the size and error of the product are also grasped more accurately. At present, the machine vision inspection is becoming more and more intelligent, which is very beneficial for PCB defect detection, can create more possibilities for detection, and can lay a solid foundation for the quality improvement of PCB defect detection.

References

[1] Xu Liqing. Design of Parts Surface defect detection System based on Machine vision. Shihezi Science and Technology, 2024, (02): 43-45.

[2] Yang Jiang, Sun Fucai, Zhao Peijiang, et al. Research on Key technologies of PCB defect Detection based on Machine vision. Journal of Heilongjiang Institute of Technology (General Edition), 2024, 24 (02): 110-115. (in Chinese)

[3] Wu Shaofeng, Baiyun Jiao. Key technology of Surface defect Detection based on Machine vision. Agricultural Technology and Equipment, 2023,(10): 66-69.

[4] Cao Heng. Application of Machine vision technology in PCB automatic inspection. Journal of Integrated Circuit Applications, 2022, 39 (12): 258-259.

[5] Li Sen, Wan Gang, Wei Ziyuan, et al. Application of 5G+AI machine vision technology in PCB industry. Information and Communication Technology, 2021, 15 (06): 56-60. (in Chinese)

[6] Wang Yuping, Guo Fenglin. Research on Key technologies of PCB Board defect detection system based on machine vision. Chinese Science and Technology Bulletin, 2017, 33 (01): 101-105.