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A PCB Visual Target Positioning Algorithm based on Mark Points

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Abstract

In view of the problem of visual positioning of ceramic PCB pad contacts in industrial production, Mark point recognition is used as an auxiliary object for pad contact positioning. Ordinary template matching algorithms cannot accurately identify Mark points under the influence of the environment. An improved template matching positioning algorithm based on Mark points is proposed. The least square method is employed to accurately fit the edge information within the Mark point region image, followed by Hough line detection on the fitted line. The algorithm is enhanced by integrating template matching technology, and the matching degree of Mark points is verified using both the normalized correlation matching algorithm and the improved template matching algorithm. Results indicate that the average matching degree of Mark points using the improved template matching algorithm exceeds 0.96, which is 10% higher than that achieved by the normalized correlation matching algorithm, demonstrating the algorithm's robustness.

Keywords

CB; Pad Contacts; Mark Points; Straight Line Fitting; Improved Template Matching.

1. Introduction

As the automation level of industrial product inspection technology improves, PCB (Printed Circuit Boards) are occupying a core position in electronic devices. Among them, the detection of solder pad contacts is considered a key technology to ensure the reliability and performance of subsequent electronic devices. Mark point recognition serves as the foundation for accurately locating and detecting solder pad contacts on PCB.

Image processing and computer vision technologies have been currently integrated by researchers into the study of Mark point recognition. A visual positioning algorithm based on Mark points was proposed by Gang Peng et al. [1] to address the issue of Mark point recognition and localization, achieving the localization of adhesive targets on PCB. However, this algorithm is tailored specifically to Mark labels with geometric features on PCB and lacks universality. A machine vision-based algorithm for the localization of liquid crystal glass was proposed by Fei Zou et al. [2], achieving rapid and accurate positioning of cross-shaped Mark points on the glass. However, this algorithm only addresses simple issues such as image fogging and uneven lighting. A normalized template matching algorithm was introduced by Zhang Pingjun et al. [3] to achieve localization and coordinate extraction of Mark labels, enabling edge grinding machines to accurately locate mobile phone screens. [4] utilized the Canny edge detection algorithm from OpenCV to detect the edges of cross-shaped Mark labels, achieving localization. However, this method does not account for cases where Mark labels are not successfully matched, leading to limited applicability of the algorithm.

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Thus, building upon the aforementioned applications of Mark point identification and positioning, the project team is tasked with overseeing the visual inspection project of ceramic PCB solder pad contacts for a company. The team is delving into Mark point identification technology and suggesting an enhanced algorithm for Mark point identification based on these markers.

2. Image Preprocessing

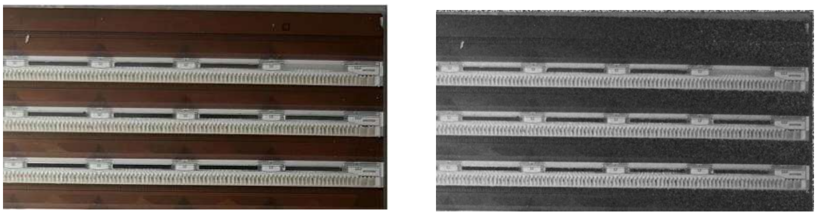
2.1 Image Grayscale Conversion

The images used in the experiments of this study were captured by a Hikvision MV-CU050 camera. These images contain a wealth of information about the surface of ceramic PCB. It is essential to extract pertinent information for Mark point recognition, emphasize the region of interest within the image, and streamline the data volume. Throughout the localization process, particular attention is paid to the contours and positional information of the Mark points. When processing images, the RGB components need to be handled separately. To mitigate processing complexity, this paper employs a judicious allocation method to merge the information from the three channels into a single channel, namely, grayscale images.

This paper adopts the weighted allocation as shown in Equation (1), F represents the grayscale image, R, G, and B represent the data of the red, green, and blue channels, respectively.

$$F = 0.229R + 0.587G + 0.114B \tag{1}$$

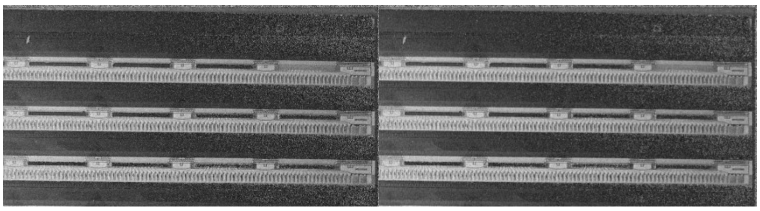
The original image of the ceramic PCB and the grayscale processed image are shown in Figure 1.



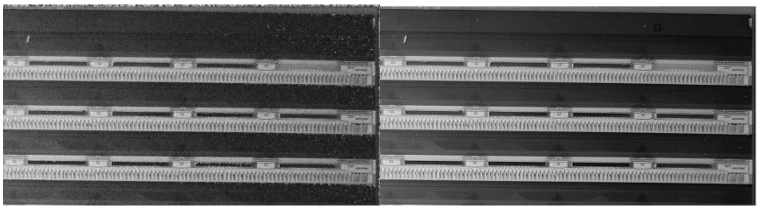
(a) The original color image (b) The grayscale processed image.

Fig. 1 Original image and grayscale comparison

2.2 Image Smoothing



(a) Noisy image (b) Mean filter image



(c) Median filter image (d) Combined algorithm processed image

Fig. 2 Comparison of different filtering algorithms

Due to variations in light intensity and the characteristics of the acquisition device, the original images of ceramic PCB may contain slight noise, which can affect the quality of subsequent image processing.

Common filtering techniques include median filtering, mean filtering [5, 6], etc. The edge features of the image are retained well during filtering by the median filter, yet it is characterized by a poor processing effect and extended processing time for large-area noise. The mean filter, on the other hand, computes the average value of pixels in the surrounding field of each pixel as the new pixel value, resulting in faster calculation speeds. However, it is noted for its limited efficacy in removing salt-and-pepper noise, and the preservation of edge information in the image is not achieved satisfactorily. The image smoothing in this paper is achieved through a combined algorithm using these two filtering methods. The ceramic PCB noisy image and the images after different filtering processes are shown in Fig. 2.

2.3 Edge Detection

To extract the edge features of Mark points in ceramic PCB images, the Canny operator is utilized for edge detection [7, 8]. During the detection process, the first step involves applying Gaussian filtering to the image. To refine the edges, the true local maxima are obtained by calculating the magnitude and direction of the gradient. By employing the eight-neighborhood method, the edges are further refined. Ultimately, dual thresholds are established, whereby points with grayscale values exceeding the higher threshold are designated a value of 1, while points with grayscale values below the lower threshold are assigned a value of 0, effectively retaining the true edge points. As shown in Fig. 3, the image processed by the Canny operator retains edge details without loss, exhibiting significant refinement.

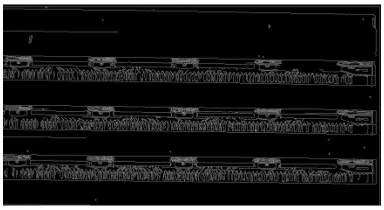


Fig. 3 Image after edge extraction using the Canny operator

3. Ceramic PCB Bare Board Mark Point Positioning Algorithm

3.1 Normalized Correlation Matching Algorithm

In the actual production of ceramic PCBs, different models of Mark points typically exhibit diverse shapes, commonly including rectangles, circles, and crosses. Due to their simplicity and ease of localization, circular and rectangular Mark points are often preferred for testing purposes. Subsequent to image preprocessing, smoothing, and edge detection, the regions containing the Mark points of interest are preserved for further analysis.

In traditional template matching visual recognition and positioning algorithms, the central idea involves both the target image and the template image being converted into grayscale images. [9, 10]. The template is then slid across the target image from left to right and from top to bottom, with each pixel in the image being compared to the template to compute the best matching result. As shown in Fig. 4, where the template image is denoted as T and the target image as J.

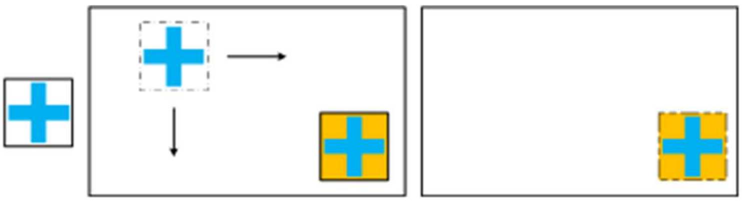


Fig. 4 Template Matching Schematic Diagram

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After the image processing is completed, the regions containing Mark points are retained. Since the overall area of the ceramic PCB exceeds the field of view of the industrial camera, each Mark point region in the image is sequentially identified in this paper. The Mark region map is depicted in Fig. 5, while the specific implementation steps of the traditional template matching algorithm are delineated in the flowchart presented in Fig. 6.

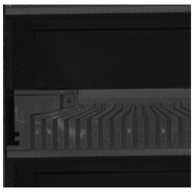

Fig. 5 Mark Region Map

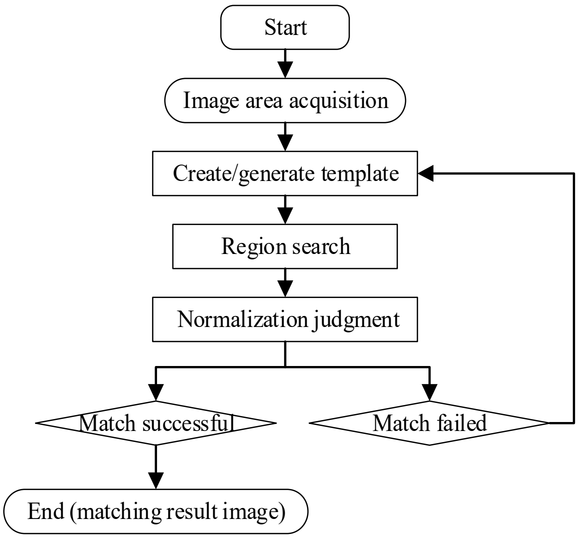

Fig. 6 Flowchart of Traditional Template Matching

In the target image, the image of the Mark point is selected as the template, and the similarity between the template and the target image is compared.Ultimately, the existence of the target point in the target image is determined. Utilizing the cv2.matchTemplate() function from the OpenCV [11] library, the similarity between each position in the target image and the template image is compared to attain the optimal match within the region. Employing the normalized correlation matching method [12], the calculation formula is shown as Equation (2): T represents the template image, and J represents the detection image.

$$R(x,y)=\frac{\sum_{x',y'}\left(T(x',y')J(x+x',y+y')\right)^2}{\sqrt{\sum_{x',y'}T(x',y')^2\sum_{x',y'}J(x+x',y+y')^2}} \quad (2)$$

The output range of the normalized correlation matching method is between 0 and 1. A higher computed value indicates a higher degree of matching. If the computed value is less than 0.8, it indicates a failed match; conversely, a match is successful. When the calculated value is 1, it indicates the highest matching degree, signifying that the content matches exactly with the template. Upon successful matching, After a successful match, the result is highlighted in the target image using a rectangular box.

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3.2 Improved Template Matching Algorithm for Mark Point Detection

In this study, Canny edge detection is employed to enhance the edge information in the Mark region images. Due to environmental lighting effects, the edge information of Mark points may be blurred, as illustrated in Fig.7. The least squares method is utilized for line fitting [13], complemented by the Hough transform to transform image pixel space into parameter space for processing. Feature points are detected in parameter space for Hough line detection. Furthermore, by integrating the squared difference template matching method, the template of the hollow cross is matched to accurately localize the specific Mark point positions leveraging the geometric properties of the template.

Fig. 7 Mark Edge Information Image

The formulas for the least squares method are given by equations (3) and (4):

$$S_l = \sum_{i=1}^{n}(y_i - (mx_i + b))^2 \quad (3)$$

$$\frac{\partial S}{\partial m} = 0, \frac{\partial S}{\partial b} = 0 \quad (4)$$

Here, $(x_{i,}y_i)$ represents the two-dimensional data points, m and b represent the slope and intercept of the best-fitting line, S_l represents the minimization of the sum of squared residuals. The fundamental idea is to solve this system of equations to obtain the optimal values of m and b.

The mathematical expression for the Hough transform is given by equation (5):

$$\rho = xcos\theta + ysin\theta \quad (5)$$

Here, ρ represents the polar radius, θ represents the polar angle, x and y represents the Cartesian coordinates in the image space. The fundamental idea is that two points in the image space can form a line [14]. When mapped to the Hough space, two intersecting curves will be generated. Similarly, multiple points will result in intersecting curves in Hough space. By determining the curves intersecting at these points in Hough space and finding the corresponding points in the image space, the line can be determined. The detection result is shown in Fig. 8.

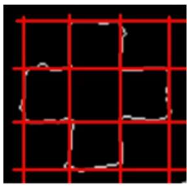

Fig. 8 Hough Line Detection Image

The mathematical expression for template matching is given by equation (6):

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$$S_{SSD}(x,y) = \sum_{i=1}^{I}\sum_{j=1}^{J}[(x+i,y+j) - T(i,j)]^2 \tag{6}$$

Here, the template size is (i,j), (x,y) represents the coordinates of the search area in the target image. When S_{SSD} equals zero, it indicates the best matching effect. When T equals J, it indicates that the template image coincides with the target image, signifying successful template matching.

The improved mathematical expression in this paper is given by equation (7):

$$S(x,y) = \sum_{i=1}^{I}\sum_{j=1}^{J} W(i,j)(J(x+i,y+j) - (mx+b+T(i,j)))^2 \tag{7}$$

Here, $W(i,j)$ represents the weight matrix, and $S(x,y)$ represents the objective function of least squares line fitting and template matching. By determining the minimum value of the objective function, this position corresponds to the optimal matching position of the template in the image, i.e., the precise location of the Mark point. As shown in Fig. 9.

Fig. 9 Detection Image of Improved Algorithm

The presence of lines in the Mark region is detected through the Hough transform. By combining this with template matching, the template of the hollow cross is further matched to accurately locate the specific Mark point positions. Detection accuracy is enhanced by leveraging the geometric properties of the template. The final results are delineated with green-colored filled boxes in the target detection image.

4. Experiment Results Comparison

The experimental software algorithm in this study is based on the Python language, facilitated by the visualization of code debugging in the PyCharm software terminal. The code is executed in an environment with Python 3.6.4 and OpenCV 3.4.1.15, ultimately completing the experimental validation. The recognition results of ceramic PCB images obtained through the normalized correlation matching method are displayed in Fig. 10. Meanwhile, the Mark point recognition results of the improved template matching algorithm are depicted in Fig. 11.

Fig .10 Normalized Mark Matching Image

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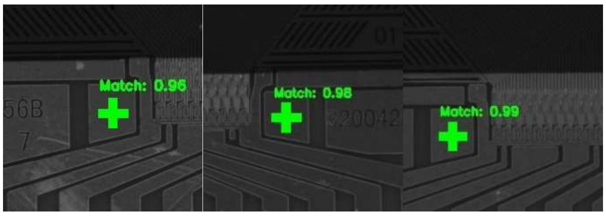

Fig. 11 Improved Mark Matching Detection Image

Through multiple matching detection images, it can be observed that the average matching degree for the normalized correlation matching method is approximately 0.876, while for the improved method, it is around 0.976. The Hough line detection can adapt to initial detection under various circumstances, but its results may be affected by noise or other interferences. Combining template matching with Hough line detection enables precise matching within this region, facilitating more accurate confirmation of the Mark point's position and reducing errors, thereby enhancing detection accuracy. The robustness of the entire Mark point detection system can be improved through the integration of line detection and template matching.

5. Summary

In this paper, an improved template matching algorithm based on Mark point improvement is proposed for the identification and positioning of PCB solder joints. Compared to the normalized correlation matching method, this algorithm achieves a recognition matching degree of over 0.96 for Mark points, which is an average improvement of 10% over the normalized correlation matching method. The algorithm exhibits high robustness, meeting the requirements of solder joint positioning, and possesses significant practical value.

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