An Automatic Optical Inspection Algorithm of Capacitor Based on Multi-angle Classification and Recognition

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Abstract. There are many plug-in components in PCB circuit production. The AOI of these components has always been a difficult problem because of the large deviation of manual installation position of these components. In this paper, an AOI algorithm based on multi-angle classification and recognition is proposed for the plug-in polar capacitors. The algorithm combines traditional image comparison method with feature recognition method, and uses AdaBoost classifier based on Haar-like feature to recognize and classify multi-angle polar capacitors. Experimental results show that the algorithm proposed in this paper can effectively detect three kinds of defects: capacitor missing, capacitor polarity error and capacitor size mismatch.

1. Introduction
In the manufacturing industry, automated optical inspection (AOI) is the key technique to improve the efficiency and quality[1]. Automatic Optical Inspection (AOI) has the advantages of high efficiency and high precision in the manufacture of Printed Circuit Board (PCB)[2].

At present, the AOI algorithms are mainly designed for small components assembled in Surface Mounted Technology (SMT), which are mostly placed by fast machines directly onto the solder pads. These algorithms improve the performance of AOI[3-5]. But there are several disadvantages. Firstly, it needs to program complex circuit board components and detection rules. Secondly, it has a high false alarm rate for the detection of plug-in components. Thirdly, it needs to detect components one by one, and the detection speed is very slow. Therefore, the traditional algorithm do not apply to plug-in components with through hole technology (THT). Large polar capacitors are mainly plug-in package. There are many kinds of capacitor components. The overall dimensions are not uniform. They are mainly installed manually. The polar capacitor is one of the most important detection contents in PCB manufacturing, and it is also the most difficult problem to solve. The polar capacitor AOI algorithm proposed in this paper mainly detects the defects such as missing parts, wrong parts and reverse insertion of plug-in polar capacitors on PCB.

There are three kinds of AOI methods: image comparison[4], key point comparison[5] and feature comparison[3]. Image comparison method mainly detects defects by pixel difference between standard image and test image. This kind of detection method is simple to use and fast in detection, but it requires high accuracy of image location and matching. Because of the variety of plug-in polar capacitors, non-uniform, high size, large position offset, simple image comparison method has high false detection rate and poor stability. The key point comparison method is used to detect errors by locating and analyzing the key points of components. This method has low requirements for alignment and good robustness to illumination variation and position offset. But the algorithm has a large amount of computation. Moreover, it is not convenient to use because it needs component library and key
point rule programming. The detection effect of key point comparison method is not ideal for manually installed plug-in polar capacitors. Feature comparison algorithm realizes AOI detection by feature extraction and comparison of components. The feature comparison algorithm is robust to illumination change and image quality, and has high detection accuracy. However, feature comparison algorithm has high requirements for component recognition and location, and its performance is also affected by component position offset and spatial distortion. This paper proposes a hybrid detection algorithm based on image comparison and feature comparison.

With the development of artificial intelligence, some target detection algorithms based on machine learning[6] and deep learning[7] are applied to AOI detection. However, the implementation complexity of these algorithms is high.

A plug-in capacitor AOI algorithm based on multi-angle AdaBoost classifier is proposed in this paper. Firstly, the suspicious ROI region of the error capacitor is obtained by pixel difference using image comparison algorithm. Then, the Haar-like texture features are extracted by AdaBoost classifier to recognize the multi-angle polar capacitor. Finally, the type of capacitor error is determined by hybrid decision.

2. Main Process of Automatic Optical Inspection

The main processing structure of the algorithm is shown in figure 1, which is divided into image acquisition, image pre-processing, suspicious ROI search, multi-angle capacitor recognition and defect diagnosis.

![Figure 1. Main processing structure block diagram](image)

The real-time image of circuit board is acquired by image acquisition. The normalized image to be tested is obtained by image pre-processing. The traditional AOI algorithm searches the whole picture components, and detects the components one by one, so the detection speed is slow. The algorithm proposed in this paper reduces the search area by locating the suspicious area, so as to effectively improve the detection speed and accuracy. Image comparison method is mainly used to locate the suspicious capacitor area. The difference image is obtained by analyzing the difference pixels between the normalized standard template and the image to be measured. The connected region satisfying the threshold condition is reserved as the suspicious region of capacitor defect. The recognition and diagnosis of capacitors only in suspicious ROI can improve the accuracy and efficiency of recognition.

3. Multi-angle Capacitor Recognition

3.1. Multi-angle Capacitor Recognition

Due to the inconsistency of manual installation, the position and angle of capacitors will be greatly offset, which will produce a large difference at the pixel level of the image. Plug-in polar capacitors have obvious texture structure, as shown in figure 2 (a). For polar capacitors with different angles, if uniform features are extracted, the accuracy and hit rate are not high. In this paper, a multi-angle capacitor classification and recognition algorithm is proposed. As shown in figure 2(b), the top view of polar capacitors is divided into 8 categories according to the angle: class A - 0°, class A' -180°, class B-45°, class B'-225°, class C-90°, class C'-270°, class D-135°, class D'-315°. In addition, if there is no capacitor target in the area, it is defined as class E. Where A and A', B and B', C and C', D and
D’ are complementary classes, corresponding to the opposite polarity of the component. Convention 
(M’)’ = M, M ∈ {A, A’, B, B’, C, C’, D, D’}.

Figure 2. Schematic diagram of multi-angle classification of polar capacitors

Haar-like features are extracted according to the above eight categories, and AdaBoost algorithm is 
used to train the classifier. The positive samples of the eight classifiers are shown in figure 3. 
Experimental results show that the proposed method greatly improves the recall and accuracy of 
capacitor target recognition.

Figure 3. The positive samples of the eight classifiers

3.2. Judgment and Classification of Plug-in polar Capacitor Defects

The classification result of capacitor in the suspicious ROI of the standard template image is M0, 
which is one of nine categories: A, A’, B, B’, C, C’, D, D’ and E. And the result in the test image is N1, 
which is also one of nine categories: A, A’, B, B’, C, C’, D, D’ and E. The classification results of 
corresponding regions constitute pairing (M0, N1), M0, N1 ∈ { A, A’, B, B’, C, C’, D, D’, E }. 
According to the classification pairing (M0, N1), defect judgment is made. Defects can be divided 
into these types of results: Correct, Error0 (capacitor missing), Error1 (capacitor polarity opposite), 
and Error2 (capacitor size mismatch).
If no capacitor is recognized in the suspicious ROI of the standard template and the test image, it is judged that the area is Correct. If there is a capacitor in the standard template, and no capacitor is detected in the corresponding area of the test image, it is judged as Error0. If the capacitor recognized by the standard template and the test image is complementary, it is judged as Error1. If the capacitor angle classification is the same, the judgment is made according to the capacitor size. The capacitor diameter of the standard template is \(d_0\), and the capacitor diameter of the test image is \(d_1\). Calculate the size difference rate \(D_r\) as follows:

\[
D_r = \frac{\text{abs}(d_0 - d_1)}{d_0}.
\]  

(1)

If the difference rate \(D_r\) is lower than the upper threshold \(H_u\) and greater than the lower threshold \(H_l\), it is determined as Correct. In other cases, it is judged as Error2.

The pseudo code of the detailed decision algorithm is as follows:

```python
function Defect-decision((M0, N1)) returns a defect result
    inputs: (M0, N1), the capacitor classification pairing
    output: Correct, Error0, Error1 or Error2
    local variables: T[9]=\{A, B, C, D, A', B', C', D', E\}, capacitor classification set
    if M0=N1=E, then return Correct;
    else if M0=T[i], i=0, 1, ..7, and N1=E, then return Error0;
    else if M0=E and N1=T[i], i=0, 1, ..7, then return Error2;
    else if M0=N1 and M0=T[i], i=0, 1, ..7, then return Error1;
    else if M0=N1 =T[i], i=0, 1, ..7
        calculate Dr
        if Hl<Dr<Hu then return Correct
        else return Error2
    else if M0= T[i] and N1= T[i+1], i=0, 1, ..7, ......................1
        calculate Dr
        if Hl<Dr<Hu then return Correct
        else return Error2
    else if M0= T[i] and N1= T[i-1], i=1, 2, ..8, ......................2
        calculate Dr
        if Hl<Dr<Hu then return Correct
        else return Error2
    else return Error2
```

Manual installation will cause deflection of the plug-in capacitor. Condition 1) and 2) are the case where the capacitor classification angle does not exceed 45 degrees. These are treated as the same angle classification, and the defect judgment is performed according to the size of the capacitor. According to the experimental results, this can effectively reduce the misjudgement caused by the deflection of the capacitor.

4. Experimental Results
The industrial camera parameters used in the experiment are as follows: 5 megapixel colour CCD area array industrial camera and matching lens. The PCB parameters used in the test are as follows: the PCB size is 150 mm x 120 mm, and there are three types of capacitors with diameters of 15 mm, 9.1 mm and 5.4 mm. There are 13 plug-in capacitors on the PCB.

4.1. Recognition Rate of Different Angle of Capacitors
The results of 8 kinds of angle recognition are shown in table 1. It can be seen that the rate of absolutely correct is about 65%. About 20% of the samples fall within the 45 degree angle, which is due to the irregularity of the plug-in capacitor and the nonstandard installation. However, there will be no polarity error within the adjacent 45 degree angle in the actual installation process. Therefore, condition 1) and 2) are added to the error detection algorithm.
Table 1. The results of 8 kinds of angle recognition

| Actual angle type | Experimental results of recognition |
|-------------------|-------------------------------------|
|                   | A  | B  | C  | D  | A' | B' | C' | D' | E  |
| A                 | 68.7 | 9.5 | 0.9 | 0.8 | 1.2 | 0.6 | 0.9 | 9.7 | 7.7 |
| B                 | 10.6 | 66.5 | 10.1 | 1.2 | 0.9 | 1.6 | 0.8 | 1.5 | 6.8 |
| C                 | 1.4 | 11.6 | 68.4 | 8.1 | 0.7 | 1.1 | 0.8 | 6.9 |
| D                 | 0.9 | 1   | 10.2 | 65.2 | 12.2 | 1.1 | 0.9 | 1.2 | 7.3 |
| A'                | 0.9 | 0.7 | 0.9 | 9.6 | 68.9 | 9.8 | 0.8 | 0.8 | 7.6 |
| B'                | 0.7 | 1.4 | 0.5 | 1.2 | 10.7 | 66.3 | 10.6 | 1.1 | 7.5 |
| C'                | 0.8 | 0.4 | 0.8 | 0.6 | 0.8 | 9.5 | 68.1 | 10.9 | 8.1 |
| D'                | 10.3 | 0.9 | 0.7 | 0.9 | 0.6 | 0.8 | 8.7 | 68.9 | 8.2 |

4.2. AOI Performance of Plug-in Polar Capacitor
The detection performance of three types of error is shown in table 2. The precision rate of the detection for capacitor missing is very high. The precision rate of the detection for capacitor polarity error exceeds 92%. The precision rate of the detection for capacitor size error is slightly low. In the actual production process, the first two errors are the main errors in the installation of plug-in capacitors.

Table 2. The results of 8 kinds of angle recognition

|                  | Recall rate | Precision rate |
|------------------|-------------|---------------|
| capacitor missing| 93.1%       | 96.7%         |
| capacitor polarity opposite | 87.3%       | 92.2%         |
| capacitor size mismatch | 83.3%       | 84.5%         |

5. Conclusion and Future Work
There are many kinds of plug-in components and their sizes are not uniform. In PCB production, this kind of components can only be installed manually. AOI detection of this kind of components has always been a difficulty in production. In this paper, an AOI algorithm for plug-in polar capacitor based on multi angle recognition is proposed. The algorithm combines traditional image comparison method with feature recognition method, and uses AdaBoost classifier based on Haar-like feature to recognize and classify multi-angle polar capacitors. Experimental results show that the algorithm proposed in this paper can effectively detect three kinds of defects: capacitor missing, capacitor polarity error and capacitor size mismatch. Further research is needed to improve the performance for small size capacitor and improve the detection rate of capacitor size mismatch. This algorithm can be extended to other plug-in components and applied to the AOI detection of PCB circuit board before and after wave soldering.

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