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Defect Detection of SMT Electronic Modules

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Abstract: To automatically detect SMT (surface mount technology) electronic modules, algorithms are investigated for geometry and shape features, module matching and detection in PCB (printed-circuit board) components. First, geometry and shape features of SMT electronic modules are presented. Then matching technology and process for SMT electronic modules are studied through optimization searching algorithms, such as similarity based detection and pyramid algorithms. Based on the analysis of major defects, algorithms for detecting major defects in SMT electronic modules are investigated. Finally, the crucial factors affecting inspection precision and speed, i.e., components contour, searching range and minimum similarity, are analyzed. The experimental results show the detection time for Circuit Boards without defect is 0.82s, and for those with one component absent 0.89s, yet for multiple components absent 10.68s. Therefore, it can satisfy the requirements of high reliability, stability, precision, inspection speed and anti-interference for defect detection in SMT electronic module of Circuit Boards.

Keywords: SMT, electronic module, defect detection, matching technology, shape features.

1. Introduction

Rapid development of modern science and technology has posed higher requirements on performance and quality for electronic products. For Circuit Boards in SMT electronic modules, defect detection is an indispensible link in manufacturing SMT products [1–3]. With miniaturization of electronic components, increasingly higher integration of electronic modules and greater complexity of the circuits to be tested, high-powered magnifier can no longer satisfy the requirements set by modern testing technology, for visual inspection is largely dependent on human experience which can hardly guarantee test results consistency and reliability, leading to poor comparability. The complex testing and analysis process together with long-term operation imposes great work intensity and eyestrain on detecting personnel, highly increasing manufacturing costs. Furthermore, as it is unable to detect, forecast and modify the defects of SMT electronic modules in due time in production, visual inspection cannot realize real-time control in production process or quality forecast in batch production [4,5].

As for the electronic components in SMT electronic modules, since they are of little difference in geometry size, rich in color combination, highly integrated, of many batches and varieties, the main cause of testing errors are detecting personnels mental and visual fatigue from day after days duplicate work [6–8]. The rapid development in computer image processing and pattern recognition technology, together with decreased cost of computer visual hardware equipment, makes the method applied into many other research fields, which greatly enhances efficiencies of electronic product quality monitoring and detecting, fault trend predicting and maintenance decision [9,10].

On image processing and algorithm research, S. Ren using first-order transformation of OHM multi-wavelet, carrier image is decomposed into four components of lowest resolution sub-image to obtain embedding areas [11]. As there has been rapid development in Automatic Optical Inspection (AOI) recently, which can analyze, monitor and test SMT electronic modules qualitatively and quantitatively, AOI has become research focus for Electronics Industry both home and abroad, and many achievements have been made in both theoretical studies and practical applications[12]. High pixel charge-coupled device (CCD) is employed to improve precision of image defect detection; however, owing to limited field of vision, it can only shoot PCB local images in image acquisition process. This

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study proposed to adopt a seamless mosaic before defect detection, and rapid area matching method within double Mark points and Mark circle for accurate alignment to acquire the complete image of PCB assembly. Then common defects in SMT electronic modules were detected, such as welding defects (open circuit, short circuit, bridge connection, insufficient or superabundant soldering tin etc.) and component defects (polarization reversal, component depletion, and displacement, improper component etc.).

2. Image features of SMT electronic modules

2.1. Image features of SMT electronic modules

An image was first disposed through binary processing to extract its edge and contour information of related regions, and then analyzed for geometric features [13]. These geometric features, such as center of gravity (centroid), length, width, area, distance and direction, are very simple and intuitionistic, and therefore very effective for image analysis. Since there is more than one pixel point in the binarization images of an electronic module, which is usually of uniform density, the center of gravity coincides with its centroid. Therefore, its center of gravity can be calculated by formula (1),

$$\overline{x}=\frac{1}{mn}\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}x_{ij};\overline{y}=\frac{1}{mn}\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}y_{ij} \qquad (1)$$

where, x_{ij} and y_{ij} represent the position coordinates of the point in the module corresponding to the pixel point; m and n, the number of rows and columns respectively, indicate image size.

Boundary rectangle is the simplest method to determine an objects basic shape. When an objects boundary is known, to get the length and width of its minimum boundary rectangle, we only need to calculate the length in principal axis and the width in vertical direction, both of which reflect an objects shape features. Area is another very important and intuitionistic geometric feature to judge an object, and it can be used to detect sodering tin defects. The image is first binarized (1 standing for an object and 0 for its background), and then the number of pixel points on the boundary and in its interior is counted to detect the defects. Area can be calculated by formula (2),

$$A=\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}f(x_i,y_j) \qquad (2)$$

Where, $f(x_i,y_j)$ is the pixel value of pixel point (x_i,y_j) after binarization.

The distance between two points $P(x_1,y_1)$ and$Q(x_2,y_2)$ in an image can be represented by Euclidean distance $d_e(P,Q)$ or Block Distance $d_c(P,Q)$.

$$d_e(P,Q)=\sqrt{(x_1-x_2)^2+(y_1-y_2)^2} \qquad (3)$$

$$d_c(P,Q)=|(x_1-x_2|+|y_1-y_2| \qquad (4)$$

Direction is used to analyze whether there exists angle shift of components in an image. As there is not only one way to represent direction feature, the values vary with initial references.

2.2. Shape features

Shape features are also very important characteristics to describe an image, and therefore a basic issue in Computer Vision and Pattern Recognition. According to contents of shape features, shape feature representation can be grouped into boundary-based and region- based methods; according to realization modes, into EDGR (Encoded Directional Graph Representation) and Contour Simplified Representation, the former of which mainly includes Chain Yards, and the latter mainly includes approximate polygon and rotational function methods. Such representation methods should be selected in such a way as to guarantee the invariability of position, rotation and size for shape features relative to geometric shapes. Fourier Descriptor and shape invariant moment are usually employed to describe the shape features of boundary and region, which can be acquired by topological descriptors, shape descriptors and the shape features of its similar polygons. Topological descriptors are generally represented by Euler Number (i.e., difference between the numbers of connected components and holes in a region); shape descriptors are generally represented by major axis (i.e., the line connecting two furthest points on boundary), minor axis (perpendicular to major axis), circularity, eccentricity (the ratio of a regions incircle radius to that its circumcircle radius)and its solidness (which is to describe shapes concavity and convexity, i.e., the ratio of a regions polygonal area to its concave-convex area).

3. Matching of SMT electronic modules

3.1. Matching strategy and technology for SMT electronic modules

Usually large-range searching is needed to find the subimage that can match the template among the images to be matched, and point-point comparison and calculation is needed during the searching process, thus image matching takes a lot of time. This paper attempts to adopt optimizing searching methods such as similarity inspection and pyramid algorithms to speed up image matching.

Pyramid algorithms is an optimization matching method based on shape template, and it is a coarse-to- fine method which utilizes pyramid-like data structure to first match coarse images (i.e., low-resolution images) with a template for rough matching points and then gradually search for accurate matching points of original images (i.e., highest-resolution images). Its matching steps are as follows: (1) Average gray values of the pixel points within the 2×2 region for two original images to be matched to get the images of lower resolution. (2) Average gray values of the pixel points within the 2×2 region of the lower resolution images again to get the images of much lower resolution. Thus processed, a series of images that are pyramid-like can be obtained. Suppose there is altogether $L + 1$ levels, the $k = 0$ level is its original image. (3) Start matching searching from some lower- resolution images that are to be matched. As there is smaller number of pixel points in lower-resolution images, rough matching process is much faster. (4) Search and match the images that are higher-resolution than those in step (3), restricting search range to the neighborhood of one or several rough matching points. In this way, matching searching is conducted until $k = 0$ level (i.e., the original image) to identify the matching point between images.

Therefore, for first level images (i.e., of lowest resolution), all the pixel points are searched and matched; yet for the images from the second level to the highest resolution level, matching searching is conducted only around rough matching points of its last lower level. As a result, the overall number of searching steps for pyramid algorithms is about $(1/4)^L$ that of the common traversal searching.

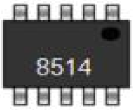
3.2. Matching process for SMT electronic modules

To satisfy the requirements of SMT electronic modules for actual online inspection, the process of offline template authoring and online template matching call is usually adopted. Template authoring can be realized through human-computer interaction and acquired by existing CAD design data. Parameters such as searching range, minimum similarity degree etc. can be set up through correlation functions to acquire the matching results of position, angle, similarity degree, scaling etc..

4. Defects and inspection of SMT electronic modules

4.1. Defect analysis of SMT electronic modules

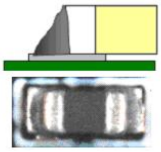
When assembling and manufacturing PCBs (printed circuit board), in the process of automatic chip mounting and welding, different defects are distributed as follows: (1) welding defects account for 75%, such as open circuit for lack of weld, short circuit from welder IC bridge connection (shown in Fig.1), welder deficiency or overabundance (Fig.2); (2) component defects account for $8\% - 10\%$, such as reverse polar (Fig.3), components absence (Fig.4), components position shift or angle revolving (shown in Fig.4) and improper components etc.; (3) other defects, such as unqualified electrical parameters, account for less than 10%.



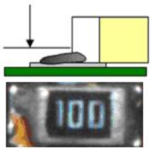
(a) Normal

(b) Bridge connection

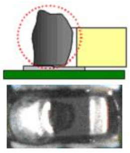
Figure 1 Defects of IC bridge connection.



(a) Normal

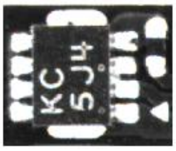


(b) Deficiency

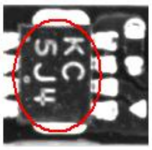


(c) Over-abundance

Figure 2 Defects in solder.



(a) Standard image

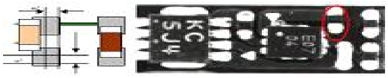


(b) IC reverse polar

Figure 3 Defects of reverse polar in components.

(a) Standard image

(b) Components absence



(c) Components position shift

(d) Components angle revolving

Figure 4 Defects of components absence, position shift and angel revolving.

4.2. Defect detection algorithms for SMT electronic modules

In view of fixed components standard specification, template matching is usually adopted to detect the surface mounting defects, such as components reverse polar, absence, inaccurate position and improper components, in which image of a standard component is served as template, and inspection can be realized through calling templates of concerned components when matching. And data concerning testing objects position in image, rotation angle relative to template, and similarity degree etc. can be acquired by shape matching and component matching, then compared with corresponding data from standard template to judge whether the object tested is qualified according to derivation degree. We need not only to judge components surface mounting quality according to matching results, but to identify the types of defects, such as deficiency, shift and rotation etc.. Its basic idea in inspection is as follows: first, judge whether there exists component deficiency, then make further judgments whether a components shift and rotation are beyond threshold values set by technical requirements, and if there is any defect detected, alarm and output report.

As more than 75% defects ofSMTelectronic modules are welding ones, which have no uniform characteristics for solder joints various morphology, template matching is ineffective in inspection, and this study attempts to use patch analysis to detect welder defects. Patch analysis is a method for the analysis and treatment of closed target shapes, and it is to transform simple gray data into shape information through analyzing connected domain (patch) of pixel points to acquire the number, position, shape and direction of the patches in an image, as well as topological structure between patches. Under normal conditions, there is no metal composition (i.e. solder) between IC pins, presenting poorer opacity. But when illuminated after welding, pins demonstrate better opacity for solder metal composition, and after being binarized, pins and solder present white for higher brightness because of better reflection, yet region between pins presents black for lower brightness because of worse reflection. If there emerges short circuit (i.e. bridge connection) between pins, the solder leading to short circuit between pins presents white for better opacity, and therefore short circuit is rather easy to be detected. When analyzing patches of IC pins, IC pin images shot by camera are first binarized, then divided into patch and pixel set of local background with threshold segmentation technology, and then binarized images patches are processed by shrinkage filter through median filter to eliminate smaller patches effects, and finally the patches divided from images are analyzed and judged to acquire inspection results, shown in Fig.5. IC pins can be judged defective when patches simultaneously satisfy the following two judgment criteria: (1) $S' > S$where S' represents total area of patches for detecting board, S that for standard board; (2) $L' < L$where L' is the number of connected domains in patch images of detecting board, L that of standard board.

Binarization treatment Median filter

Figure 5 Image processing in patch analysis.

5. Defect detection experiments on SMT electronic modules and result analysis

5.1. Defect detection experiments on SMT electronic modules

The experiments were conducted with IBM PC Computer of 2.93G main frequency and 2G internal storage, and the detection results are illustrated in Fig.6 to Fig.8, in which Fig.6 demonstrates a non- defective board, detection time being 0.82s; Fig.7 demonstrates a resistor (marked with “3”) absence in the detecting board, with detection time being 0.89s; yet for the detecting board illustrated in Fig.8, there exist defects of one resistor (marked with “1”) absence, one resistor (marked with “2”) shifting for 25 pixel points and angle revolving about 23.3°, one IC chip (marked with “5”) reversal (i.e., an angle revolving of 180°), with 10.68s detection time.

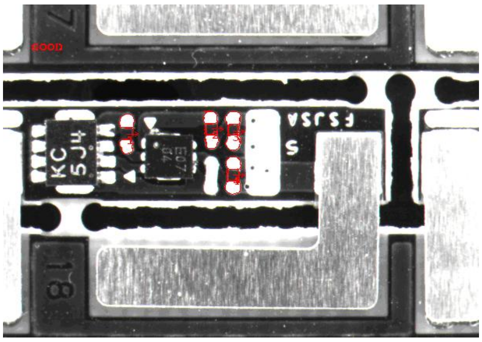


Figure 6 Normal (No defects).

5.2. Result analysis of SMT electronic module defect detection

The results of defect detection experiments on SMT electronic modules show that better inspection effects have been achieved, and when different threshold values are set up for different parameters, inspection precision and speed are mainly determined by components contour, searching range and minimum similarity degree. As a components contour is its appearance, the clearer its edge contour, the faster it is matched, and clearer contour can help separate a component from its background and increase the number of feature points, both of which can help guarantee matching success. In view of the characteristics of SMT electronic modules, specific illumination mode can help acquire the images that present components contour more accurately and clearly, so this high-quality image acquisition is of vital importance for SMT electronic module inspection. The inspection experiments also show that algorithm designs of software have little effect on increasing inspection precision and speed, yet hardware factors such as light source, camera and image acquisition card are of vital importance to the performances of the whole inspection system. The matching search range of a template in inspecting images should be determined by the possible range that components might be in. If searching range is set too large, there will be larger amount of calculation, which consequently affects inspection speed; if search range setting is too small, components may not be found in inspection and not detected. Therefore, in actual inspection, searching range should be set slightly larger than the upper limit of technical requirements, that is, to choose slightly larger offset and rotation angle. Too large minimum similarity

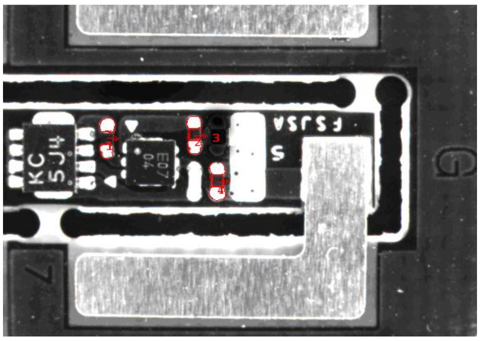


Figure 7 Components absent).

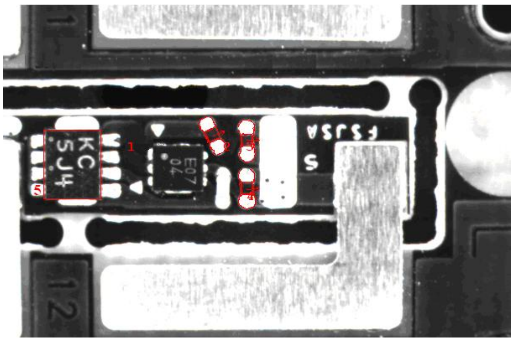


Figure 8 Components absent, shifting, revolving and reverse.

degree can lead to misjudgment, as illustrated in Fig.8, a module of five resistors being inspected through template matching, when minimum similarity degree was set as 0.8, all the five resistors could be detected; when minimum similarity degree of one component is set as 0.9, this component could not be detected. Therefore, minimum similarity degree should be set according to position relation among components of the same type in the inspection through module template matching.

6. Conclusion

To satisfy the requirements of higher precision and speed in board inspection for SMT electronic modules, this study proposed some inspection methods (template matching based on components characteristic images and modules, pyramid algorithms and patch analysis), studied the recognition and measurement algorithms of representative images for various defects in SMT electronic modules, as well as 2D-based solder defect detection, and finally analyzed the three factors that affects inspection precision and efficiency, i.e., components contour, searching range and minimum similarity degree. The experimental results show that the detection time for Circuit Boards with no defect is $0.82s$, and for those with one component absent $0.89s$, yet for multiple components absent $10.68s$. Therefore it can be concluded that the proposed methods can satisfy the requirements of high stability, reliability, precision, anti-interference and inspection speed in defect detection for SMT electronic module of Circuit Boards.

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References

[1] Q. X. Wang, D. Li and W. J. Zhang, Unsupervised defect detection for gold surface of flexible printed boar, Opt. Precision Eng. **18** (2010) 981-987.

[2] L. M. Wu, S. L. Cui and L.P. Wang, Novel automatic inspection method for repetitive patterned wafer, Opt. Precision Eng. **16** (2008) 925-930.

[3] Y. H. Li, Q. X. Li and D. S. Wang, Design and study on a novel micro-detecting device for superfinish surface scratch, Opt. Precision Eng. **13** (2005) 65-68.

[4] X. B. Li, L. Bao and S.G. Wang, Study on Image Mosaic Registration of Electronic Component through Surface Mounting Technology, Advanced Materials Research. **345** (2012) 113-118.

[5] H. Y. Zhao and W.B. Yu, Application of computer vision in detecting system of engines surface defects, Opt. Precision Eng. **8** (2000) 283-286.

[6] T. S. Newman. A survey of automated visual inspection, Computer Vision and Image Understanding. **61** (1995) 231-262.

[7] D. Q. Zhou, X. P. Cheng and G. J. Li, Research on the Acquisition of Object Image in PCB Visual Inspection System, Journal of Electronic Measurement and Instrument. **15** (2001) 10-13.

[8] S. J. Liu and X. P. Cheng, Research on the Approach of Real Time Visual Inspection of PCB De fective Image, Computer Engineering and Applications. **16** (2002) 71-74.

[9] S. L. Lu and X. M. Zhang, Analysis and optimal design of illuminator for leadfess tin solder joint inspection, Opt. Precision Eng. **16** (2008) 1377-1383.

[10] J. X. Huang, D. Li and F. Ye, Detection of surface defection of solder on flexible printed circuit, Opt. Precision Eng. **18** (2010) 2443-2453.

[11] S. Ren, T. Zhang and D. J. Mu, Study of Reversible Information Hiding Scheme Based on GHM and ASA, Applied Mathematics Information Sciences. **2** (2012) 253-260.

[12] J. M. Zhang, R. M. Liu and M. J. Wang, The development of an automatic post-sawing inspection system using computer vision techniques, Computers in Industry. **40** (1999) 51-60.

[13] D. J. He, Digital Image Processing, First Edition, Publishing House of Electronics Industry, Beijing, 2003.

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