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An inspection and classification method for chip solder joints using color grads and Boolean rules

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ABSTRACT

In order to improve the comprehensive performance of solder joints inspection in three aspects, i.e. high recognition rate, detailed classification of defect types and fast inspection speed, a new detection and classification algorithm of the chip solder joints based on color grads and Boolean rules is developed in this paper. Firstly, the region features, evaluation features and color grads' features are defined and extracted based on the special solder joint image, which is acquired by a particular image acquisition system composed of a 3-CCD color digital camera and a 3-color (red, green, and blue) hemispherical LED array illumination. Secondly, the models of solder joint types are built based on extracted features and statistical characteristics of solder joint types. Thirdly, the detection and classification method is designed and presented using Boolean rules, then eight common solder joint types, including the acceptable solder joint, pseudo, no solder, lacked solder, excess solder, shifted, tombstone, and miss component, can be classified and detected by the proposed algorithm. Fourthly, the proposed algorithm is optimized to improve the inspection speed based on a parallel computing method. Finally, to evaluate the performance of the proposed method, 79 pieces of PCBs with defects were inspected by the commercial AOI system developed by the authors which integrates the proposed algorithm. Experiment and result analysis illustrates that the proposed method is better than other methods in three aspects, it can detect and classify properly all the eight common types of solder joints, its detailed classification, and high correct rate, which is up to 97.7%, are more useful to the quality control in the manufacturing process, and its inspection speed is faster, thus helping us to improve the efficiency of the manufacturing process.

1. Introduction

With the development of electronic products continuously tending to be multifunctional, miniature, portable and reliable, surface mounted technology (SMT) has been widely used in the electronic manufacturing, and components assembled on printed circuit boards (PCB) become more and more miniature and the density is increasing [1–3]. Consequently, the potential defects of solder joints, which connect chips and other components to PCBs, are increasing dramatically. It will increase quality costs and deteriorate the product performance. Therefore, solder joints inspection is a critical process in the electronic manufacturing industry to reduce manufacturing cost, improve yield, and ensure product quality and reliability [4]. It is obviously out of date to depend on the manual vision to find out these defects. Fortunately, the automatic optical inspection (AOI) technique has been developed and applied to the SMT based production recently [5–8,12]. The AOI system, which includes image acquisition, image preprocessing, features extraction, solder joints detection and classification, results analysis and feedback, can inspect the solder joints' quality uniformly, repeatedly, and reliably [9,10].

However, the solder joint inspection by an AOI system has been proven to be a more challenging task than many other visual inspection problems [7]. Though all solder joints can be classified into several types and the same type of solder joints belong to the set of the same solder quality, the appearance and shapes are not identical with each other even among the same solder joints type due to their soldering conditions [1]. Furthermore, the surface of solder joints after reflow PCB is curved, tiny, and specular reflective, and this reflectivity on solder joints' surface makes it difficult to extract the shape information of a solder joint from its acquired image [1]. Besides that, the acquired images of solder joints are also susceptible to the stability of the illumination light and the environment light [10]. For those reasons, it is a challenging work to identify all solder joints' defects based on the AOI system efficiently and correctly.

To overcome the above mentioned problems, many different inspection methods with a certain degree of success have been

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developed recently. For example, Loh and Lu [6] developed a slant map surface shape estimation technique based on structured lighting for solder joints. By this technique, a solder joint can be determined to be a good one, bad one, bridged, or surplus solder, lacking solder. However, it is sometimes hard to give a clear definition of the difference between a convex and a concave solder joint. In order to cope with the variability for solder joint shapes, Ko and Cho [1] used a neural network with fuzzy rule-based classification to detect three types of solder joints, i.e. insufficient soldering, acceptable soldering and excess soldering with high success rate. Chiu and Perng [11] developed a new set of features to inspect solder joints. Its illumination requires only one layer of tiered light and its classification method only uses two features to discriminate three types of insufficient, acceptable and excessive solders. However, it cannot inspect other solder joint types with high recognition rate. Ong et al. [7] proposed an inspection method using images from both orthogonal and oblique viewing directions to the solder joint, in which an artificial neural network was used to extract features and the learning vector quantization architecture was used as the classifier. Then two defects of excess and insufficient are detected. A neural network-based AOI system for the diagnosis of five types of solder joints, i.e. poor solder, acceptable poor or excess solder, good solder, excess solder, was developed by Acciani et al. [9]. In this algorithm, GW-features (geometric features and wavelet features) were extracted and the diagnosis was handled as a pattern recognition problem with a neural network approach. And three supervised neural networks and two fuzzy rule-based modules used in a neurofuzzy method for evaluation of soldering global quality index were proposed in [2]. Furthermore, the technology was developed by the same authors to assess the quality of the soldered interconnections in 2011 by reproducing the modus operandi of the human experts during their assessment [13]. It can reduce some equipment cost and the influence of the human experts with a certain degree by shifting the assessment of a solder joint in that proposed method. Mar et al. [4] proposed two inspection modules for an automatic solder joint classification system and five different levels of solder quality with respect to the amount of solder paste were detected. However, its recognition rate is susceptive to the quality of the solder joint image.

Different components, such as chips, integrated circuits, transistors, have different kinds of solder joints in the PCB, and their solder joints have entirely different surface shapes. Designing different detection algorithms for different kinds of solder joints is an effective way to improve the inspection performances [3,10] in the AOI system. Focused on detecting the solder joint defects of the chip component, an effective detection algorithm is developed in the paper. Common solder joint types of the chip include acceptable solder joint, pseudo, no solder, lacked solder, excess solder, shifted, tombstone, miss component. More detailed and accurate classification of solder joint defects will give more information on the quality of the manufacturing process. However, those proposed methods mentioned above only focus on part types of the solder joint defects, such as poor solder, acceptable solder and excess solder, and few reports on detecting other common solder joint defects of the chip can be found in the literature. In addition, the high misjudgment rate of the AOI system is still a big problem puzzling in the field of SMT. Furthermore, few research results report on improving the inspection speed and meanwhile keeping both high recognition rate and detailed defects classification. In fact, besides the detailed defects classification and high correct rate, inspection speed cannot meet the fast manufacturing process and it is becoming a challenging problem in extensive application of AOI systems.

In order to improve the comprehensive performance of solder joints inspection in three aspects, i.e. high recognition rate, detailed defect classification and fast inspection speed, a new detection and classification algorithm of the chip solder joints based on color grads' models and Boolean rules is developed in this paper. Experiment and result analysis illustrates that the eight common solder joint types of the chip, including acceptable solder joint, pseudo, no solder, lacked solder, excess solder, shifted, tombstone and miss component, all can be classified properly and they are detected with high correct rate by the proposed algorithm. Furthermore, its inspection speed is faster obviously than other latest four compared methods.

This paper is organized as follows. The image acquired system and its image information are introduced in Section 2. The solder joint image analysis and features extraction method are illustrated in Section 3. And then the models of solder joint types are built in Section 4. The detection and classification algorithm is developed in Section 5. Next, the proposed algorithm is optimized in Section 6. Experimental results are presented and analyzed in Section 7. Finally, some conclusions are reported in Section 8.

2. Image acquired system and its image information

Acquiring and reconstructing the three-dimensional surface of the inspected solder joint by two or more cameras is expensive in hardware and time consuming in reconstructing computer. Fortunately, it is not the only way to obtain the surface information of solder joints. The surface shape of solder joints also can be described by its surface grads' information. In this paper, the solder joint image is obtained by a particular image acquisition system, which includes a 3-CCD color digital camera and a 3-color (red, green, and blue) hemispherical LED array illumination [5,6,10,14]. As shown in Fig. 1, the red, green and blue light irradiate to the flat, slow slant and rapid slant surface of the solder joint, which are reflected to the camera, respectively. As shown in Fig. 2, the color distributing of red, green and blue in the solder joint image indicates the slant grads and the three-dimensional shape information of the solder joint [15]. With such an image acquired system, the 3-D shape information of solder joints can be extracted by its 2-D color image.

3. The solder joint image analysis and features extraction

As mentioned above, the color solder joint image contains the shape information of the solder joint. In this section, the solder joint image is analyzed by region features, evaluation features and color grads' features, and then these features are extracted. With the help of these features, solder joint types can be formulated later.

3.1. Defining inspected regions

Considering the relationships between the color distribution of red, green and blue in the solder joint image and the three-dimensional shape information of the solder joint, several inspection regions are defined in the solder joint image based on analyzing and the statistical features of defect types of solder joints. As shown in Fig. 3, inspected region, polarity region, solder region, edge region, middle region, and up/down polarity region are set based on its color distribution and the solder land size, which are obviously different from the methods proposed in [3,15] due to designing more simple and critical regions.

As shown in Fig. 3. The regions are defined as follows:

Inspection region D_{Ir}: As shown in Fig. 3(b), its length is set between two edges of solder land, and its width is set based on one quarter of its solder land width. Its center is same as the mounted center of the chip, which can be obtained from mounted files.

Polarity region D_{Pr}: As shown in Fig. 3(c), there are two polarity regions at the ends of the chip, their lengths are set by polarities' size and their widths are same as the inspection region, their