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Design and development of automatic visual inspection system for PCB manufacturing

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ABSTRACT

Inspection of solder joints has been a critical process in the electronic manufacturing industry to reduce manufacturing cost, improve yield, and ensure product quality and reliability. This paper proposes two inspection modules for an automatic solder joint classification system. The "front-end" inspection system includes illumination normalisation, localisation and segmentation. The "back-end" inspection involves the classification of solder joints using the Log-Gabor filter and classifier fusion. Five different levels of solder quality with respect to the amount of solder paste have been defined. The Log-Gabor filter has been demonstrated to achieve high recognition rates and is resistant to misalignment. This proposed system does not need any special illumination system, and the images are acquired by an ordinary digital camera. This system could contribute to the development of automated non-contact, non-destructive and low cost solder joint quality inspection systems.

1. Introduction

Assembly of Printed Circuit Boards (PCBs) using Surface Mount Technology (SMT) has been widely used in the electronic industry recently [1]. As a result, the electronic components rely on the solder joint to provide the electrical connection to the PCBs; therefore, the quality of the solder joint can be critical to the quality of the electronic components [2]. Automatic Optical Inspection (AOI) of solder joints has been a critical issue for quality control in PCB assembly as AOI has the enormous potential of completely automating human visual inspection procedures [3,4].

Automated solder joint inspection requires the extraction of information from the solder joint surface [5]. However, the specularity of the solder joint surface causes difficulties in the automated extraction of relevant information. Specular reflections of the solder joint surface may appear or disappear with small changes in viewing direction. A specular surface is often illuminated at a distance by a point light source, which prevents ideal smooth shading that matches its shape for the effective classification of solder joints. Furthermore, the shape of the solder joints tend to vary greatly with soldering conditions including the amount of solder paste and heating level applied during the soldering process. As a consequence, the variety of the solder joint shapes is also a barrier to the development of an automatic solder joint inspection system. Furthermore, the variety of components on the board and the sophisticated layout of the board introduce more complexity for solder joint inspection, which makes the development of automated pattern recognition systems for this purpose a non-trivial task. The aim of these inspection procedures is to detect and locate any potential solder joint defects, which will impede or break down the functions of the final PCB products. Common solder joint defects which are of concern include: no solder, opens, shorts, and bridges [6].

In this study, a computer vision system is proposed for the automatic detection, localisation, segmentation and classification of solder joints on PCBs under different illumination conditions. This paper introduces a new technique for solder joint defect classification using the Log-Gabor filter and classifier fusion which has been demonstrated to achieve a high recognition rate and is resistant to misalignment. Further testing demonstrates the advantage of the Log-Gabor filter over both Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT).

The outline of this paper is as follows. Section 2 will provide an overview of existing inspection techniques in the field. Section 3 will present the research methodology, the segmentation of the solder joint inspection system and experimental results on PCB images. The classification of solder joint defects and experimental results will be described in Section 4. In Section 5, the performance of the classifier fusion is evaluated. Lastly, the paper is concluded in Section 6.

2. Literature review

In commercial PCB assembly processes, solder joint inspection has one essential problem for quality control in the PCBs.

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For accurate visual inspection, it is necessary to obtain the system that is resistant to variation of light and requires robust algorithms for classification. Moreover, classification criteria for solder joints are usually based on human experience and can be changed according to the products. To overcome these limitations, complex image acquisition systems that need special illumination systems and several kinds of inspection algorithms are developed.

2.1. Illumination design

The imaging of solder joints is a difficult task in automated visual inspection technology due to the specularity of the solder joint surface. Reflections of the specular solder joint may appear or disappear even with small changes in viewing direction [5]. Moreover, specular surfaces rarely exhibit smooth shading that matches its shape, which makes it complex to recognise a specular surface from visual information. The different shapes of solder joints are also an obstacle to develop an automatic solder joint inspection system. The shape of the solder joints tends to vary with soldering conditions. Even those classified into the same type of solder joints are slightly different in shape when carefully examined. To overcome this problem, several researchers have tackled it by using a dedicated illumination system, which can maintain sufficient illumination levels to reveal the darker regions of the solder joint image.

Bartlet et al. [7] used four overhead fluorescent lamps and one fluorescent ring lamp to effectively inspect solder joints and avoid shadows in the captured image. Capson and Eng [8] used a tiered-colour illumination method to generate colour contours onto the solder joints. This illumination system consisted of red and blue circular fluorescent lamps with different heights. By examining the contour shape measured by geometric descriptors, solder joint defects could be determined. The lighting arrangement allowed direct correlation between the solder joint profile and colour planes. The colours of the lights also aided in segmentation of the solder joints from the PCBs.

Kim et al. [5,9] improved the previous system by using three colour circular lamps (Red, Green, Blue) with different illumination angles. Three different types of image were sequentially captured as three layers of lights were turned on one after another and obtained 2D and 3D features of the images. An attractive approach for an illumination system was developed by using only one layer of tiered light and two features [10]. Insufficient, acceptable and excess solder joints were classified by two straight lines on the 2D feature plane. The number of circular illuminations can be reduced to one when the incident angle was optimised. This method significantly saved time for image scanning and computation compared to previous illumination systems. However, the processing of colour images required very high over-heads in terms of computation and complex processing.

Meanwhile, a hemispherical lighting system with a structured LED array was developed with a CCD camera to take grey-level images sequentially [1]. The structured LED array was placed on the lighting system to project light from different positions onto the solder joint surface. A slant map was used to extract information from the images based on the slant angles which represented the solder joint shape and were directly relative to the quality of the solder joint. This system achieved a 7.69% overall false alarm ratio.

Ong et al. [11] combined orthogonal and oblique grey-level images with the use of two viewing direction configurations, namely, the orthogonal view and oblique view. For orthogonal images, a camera was set up perpendicular to the plan of the PCBs. A viewing direction inclined approximately 40° to the vertical plan was used for oblique images. However, it was important to maintain high accuracy of the relative geometrical position of the cameras for a multiple camera setup. Belbachir [12] used a simple method to capture images by using one CCD camera. The acquisition system was covered by a black screen and the PCB was illuminated by fluorescent lamps. This setting helped to control the illumination condition by avoiding an external light source.

2.2. Classifier design

In order to complete the inspection system, classifiers have been developed using different approaches to select features extracted from an image. A pattern recognition system classifies solder joints based upon statistics obtained from a "training set" of each solder joint's class. The Bayesian and maximum likelihood classifier are a traditional statistical approach for classification [7]. In this approach it is necessary to have knowledge on the probability distribution of each class and this requires a large number of experiments. Bartlett et al. [7] used a minimum classifier to classify each solder joint into one of the two good types and seven defected types depending on five different features.

Rule based classification systems have been widely used in machine learning applications because of their easy to understand ability and interpretability. In some cases, this method needs counter measures against the appearance of unexpected members of a class. Capson and Eng [8] proposed a tree classifier by using geometric descriptors, which measure the shape of the contours and the colour level intensities of the solder joint images. For board 'A', 93.5% of solder joints were correctly identified and for board 'B', a 76% success rate was achieved. The false alarm rates were 3.0% and 4.3%, respectively. Another rule based classification system was also employed by using fuzzy set theory [2,13]. This can be especially useful when objects are not clearly members of one class or another. In addition, fuzzy techniques specify to what degree the object belongs to each class, which is useful information in solder joint recognition.

In recent years, Artificial Neural Network (ANN) approaches have been applied to AOI systems due to their learning capability and nonlinear classification performance. ANNs can be divided into the unsupervised ANNs and the supervised ANNs. Multilayer neural networks are one of the supervised neural networks and have been applied to solder joint inspection. Kim et al. [5] proposed the neural network with two following modules: a processing module and training module. The first module was designed to implement the calculation of the correlations in functional terms and the second module was designed to learn about solder joint classification as a human inspector. The advantage of a multilayered neural network is the ability to learn human experiences. However, the complexity of solder joint shapes causes the neural network's convergence rate to degrade.

The other neural network approach is an unsupervised neural network such as a Learning Vector Quantisation (LVQ) neural network [14]. The LVQ method is good for pattern classification because of their fast learning nature, reliability and convenience of use. One disadvantage for LVQ is that it cannot sometimes produce a correct decision for complex classification problems. Kim and Cho [14] applied an adaptive learning mechanism to correct the LVQ classifier. The adaptive learning mechanism can select the optimal number of prototypes set to achieve performance within an acceptable error rate. Again, Ong et al. [11] proposed a new approach using a dual viewing angle imaging method with an ANN and learning vector quantisation architecture. From the experimental results, this system had an improved recognition rate and resistance to noise. However, high accuracy on the relative geometrical position of the camera was required.