

A Machine Vision System of Ball Grid Array Inspection on RT-Linux OS

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Abstract

In this paper, a machine vision system of the ball grid array (BGA) inspection is proposed. The binocular vision system can provide enough geometrical information by optical approach for monitoring the quality of solder balls. It has proposed a new optical method for BGA leads coplanarity measurement whose feasibility was verified in theory. This study is focused on algorithms for evaluating the critical characteristics, including the height of solder ball, the size of solder ball, coplanarity and pitch, which are used to detect defects of solder balls. These algorithms are implemented on RT-Linux operation system. It provides a reference for the development of higher-speed and real-time inspection method.

Index Terms — real-time image processing, solder ball, coplanarity, geometrical relationship

1. Introduction

In order to increase the functionality and reliability of integrated circuits (IC), advanced package technologies are demanded. Due to the advantages of more I/O ports, smaller size, better electric characteristics, Ball Grid Array (BGA) package technology has been developing very fast recently. Solder balls, the electrical connection leads, are arranged regularly on the chip's mounting surface and will be interconnected on a printed circuit board, as shown in Fig.1. Some factors such as the coplanarity of BGA leads and lead pitch are crucial performance data to ensure the quality of products.

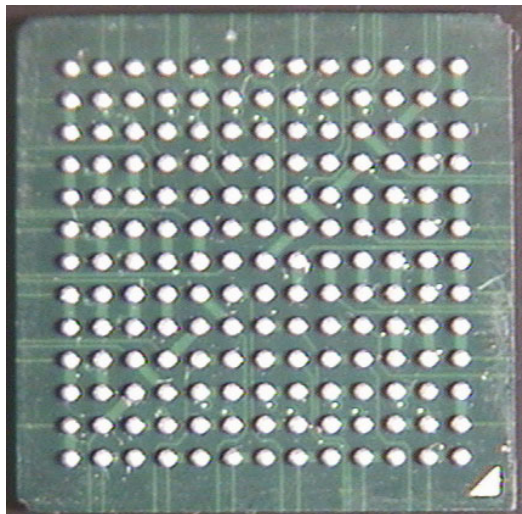


Fig.1 Ball Grid Array chip

Low failure rate, accuracy, and flexibility are requested for BGA inspection systems for ensuring the reliability of circuits. It also has a desired inspection rate and low cost to meet manufacturing line demands [1]. There are two kinds inspection of BGA package. One is inspection of BGA chip itself. The other is inspection of solder joints [2]. This system is focused on the anterior one. The critical characteristics of

BGA chips include the height of solder ball, the size of solder ball, pitch and coplanarity. Defects such as oversize, undersize, offset, deformation can be detected by above features, as shown in Fig.2.

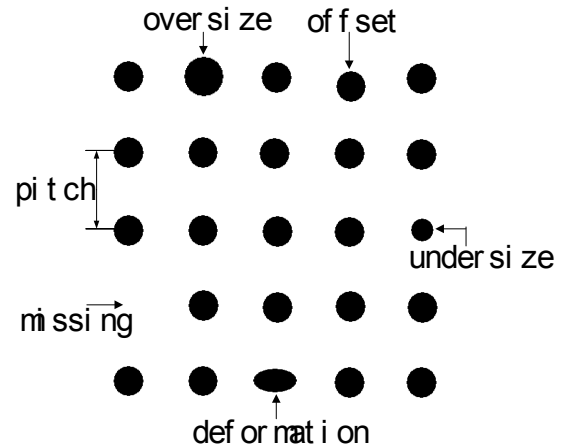


Fig.2 defects diagram

Some techniques have been proposed for BGA chip inspection already. The main techniques can be characterized by radiations employed, such as line-structured laser sensor [3], X-ray laminography [4], acoustic microscopy [5]. When the line-structured laser is projected onto the BGA chip, the contour of the object illuminated by the laser line is imaged onto the sensor. One problem of this method is that it has to control the moving of BGA chip quite accurately. The second one is its low speed. Scanning acoustic microscopy uses acoustic impedance to produce high-resolution images of the product interior structure based on the acoustic penetrativity of materials [6]. However acoustic microscopy is not suitable for all BGA packages because of air gaps existing in the chip and some materials, which can highly attenuate the acoustic wave. X-ray radiography is another non-destructive technique used to detect the defects of BGA package. X-ray radiography is a more powerful technique for detecting much finer package details and defects compared with two others. But it is more expensive and requires experienced workmen to operate and maintain the systems. Because acoustic wave and X-ray are penetrating radiations, they can be used to inspect the BGA joints under substrates.

In fact, most defects of BGA package chips can also be detected by optical approaches. The focus of this research is to develop an automatic optical inspection system. In this paper, a new optical method for BGA leads coplanarity measurement is put forward and an inspection process is proposed based on two images captured from different angle. First, original images are segmented by the developed Otsu threshold. Then the geometrical shape features can be gotten through seed-fill algorithm. Finally, defects of BGA chip can be detected and classified by utilizing these features.

This system has some advantages. It is much cheaper than other methods. Its speed is higher for it can inspect several chips at the same time. In addition, it does not need to move the BGA chips and doesn't require complex implements to generate the radiation, e.g. X-ray, acoustic wave. Thus the structure of system is simpler than others.

2. Overview of the system

This machine vision system is to detect the BGA chip's

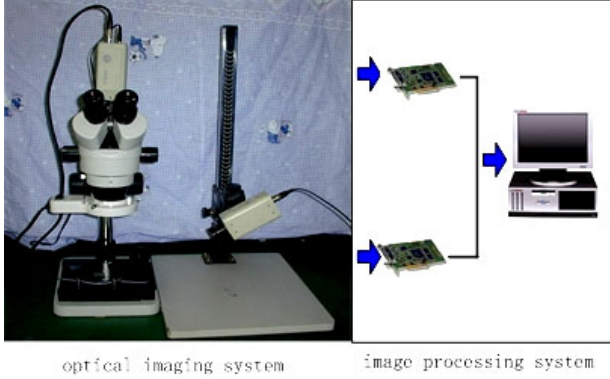


Fig.3 Sketch of measuring system

defects by optical approach automatically. The body size of PBGA chip checked is 23.0*23.0mm and the ball matrix is 13*13, a full array chip. The solder ball diameter is 0.76mm and the ball pitch is 1.5mm. Fig.3 illustrates the sketch of measuring system. It has two modules: optical imaging and image processing. In the optical imaging module, the annular red LED perpendicular to the top CCD is the system lighting. The size of chip is magnified by the microscope and forms an image on CCD camera fixed on the top. The features of the BGA chip such as lead pitch, diameter, and centroid can be acquired by analyzing the image captured by the top CCD. The data of height can be obtained through processing the image captured by the side CCD which is fixed with a specific angle. All optical apparatuses are encapsulated in a box which is made of the diffuse-reflection material.

In the literatures, a number of techniques have been proposed for real-time inspection [7][8][9][10]. In order to achieve the high inspection speed, the inspection program is developed in environments with real-time operation system. At present, famous real-time systems such as VxWorks, QNX and pSOS are typically expensive. Especially, because of its proprietary, it is unable to interact in open environments. Real-Time Linux (RT-Linux) follows General Public License (GPL) and opens source code. In addition, it supports many kinds of hardware platforms, such as Inter x86, PowerPC and Alpha [11]. These features are very beneficial to scientific research. Linux, like most general-purpose operating systems, is designed to optimize average performance. It becomes a universal solution in many situations. For real-time programming, precise timing and predictable performance are more important than average performance. RT-Linux developers have implemented a real-time kernel underneath the operating system and mask Linux itself to run as another task [12]. It provides more excellent guaranteed performance. For existing automatic optical inspection (AOI) systems, image grabbing and image processing are distributed in different hardware modules. The development of computer

technology and microelectronic technique makes it possible that grabbing and processing are implemented in one module. Furthermore, the inspection function can be integrated in an embedded system in the future. It is meaningful to develop the system under Linux OS.

3. Measuring principle of height

In order to assess the coplanarity of solder balls, the height of each ball is essential data. Ones have proposed line-structured laser scanning measurement method for BGA lead coplanarity [13]. The fatal disadvantage of this method is to need a motor to drive the worktable with the BGA chip. The control has to be precise and the vibration of motor brings measuring errors. Here the optical measurement method is introduced for BGA lead coplanarity.

As shown in Fig.4, the data of height can be obtained through processing the image captured by the side CCD that is fixed with a specific angle θ . Fig.4 illustrates the rule of determination angle θ . The following deduction and conclusion are obtained on ideal assumptions. First, each pin is an ideal ball, not considering the deformation. Secondly, the distortion of lens camera has been corrected. Thirdly, the system has been calibrated precisely. The calibration method is proposed by Mengxiang Li [14] and Bacakoglu, H. [15]. Finally, the ratio of the size of BGA chip to the vertical distance from CCD camera to the BGA Chip is so small ($\approx 1/20$) that the beams can be considered parallel with each other. All parameters are remarked on the figure. θ is defined as

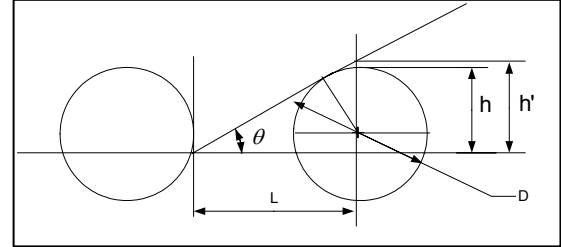


Fig.4 the rule of determination θ

$$\tan \theta = \frac{\frac{D}{2 \cos \theta} - \frac{D}{2} + h}{L}$$

and therefore,

$$\tan \theta / 2 = \frac{L - \sqrt{L^2 - h * (D - h)}}{D - h}$$

According to the specification of the chip, $D=0.76\text{mm}$, $L=1.12\text{mm}$, $h \approx 0.5 \sim 0.6\text{mm}$. Here h is assumed to be equal to 0.5mm . Thus,

$$\theta = 25.8^\circ$$

In the experiment, the angle θ is set as 30°

Fig. 5 illustrates the principle of measuring the height of balls. The parameter h is the height of balls. θ is the angle mentioned above. The parameter D is the diameter of balls and l is the width projection of image captured by the side

CCD. From Fig.5, obtain the following expressions and the height can be calculated,

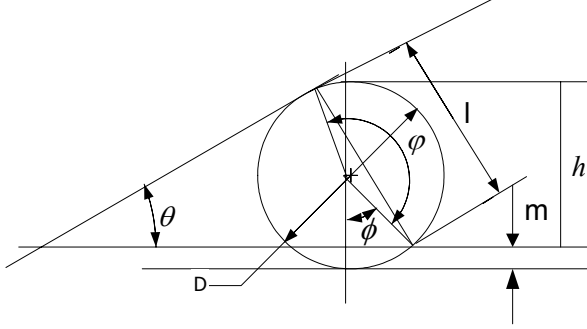


Fig.5 the principle of measuring height
 $\varphi = \pi - \phi + \theta$ (1)

$$\sin \varphi / 2 = \frac{l}{D} \quad (2)$$

$$h = \frac{D}{2} * (1 + \cos \phi) \quad (3)$$

Here, θ can be obtained through the system calibration, in the experiment, $\theta = 30^\circ$. The diameter D can be obtained by the method which is mentioned later. The parameter l can also be obtained by processing the image captured by the side CCD and camera calibration. So the angle φ can be calculated from equation (2). Thus, the height of balls is defined as

$$h = \frac{D}{2} [1 - \cos(\theta - \varphi)]$$

4. The algorithm of image processing

Let $\{G_{ij} : 0 \leq i \leq X, 0 \leq j \leq Y\}$ denote the gray level image of the BGA chip, as shown in Fig.1. As shown, the bright circular objects are solder balls. The quantitative factors, such as the height of balls, lead pitches, the size of balls, have to satisfy strict design rules. In this section, algorithms for detecting defects are proposed.

4.1. Threshold segmentation algorithm

As shown in Fig.1, the brightness of objects and background show a striking contrast. Moreover, the brightness of each ball and background are quite similar respectively. Namely, the histogram has a deep and sharp valley between two peaks representing objects and background. So the input image can be segmented into objects and background by Otsu threshold [16]. The Otsu method is a nonparametric and unsupervised method of automatic threshold selection from a histogram of image. It uses discriminant analysis to divide foreground and background by maximizing the discriminant measure variable. The procedure is simple because it only utilizes the zeroth- and the first-order cumulative moments of the gray level histogram, but it is a quite good threshold method.

Let L denote the gray levels of the input image and set threshold at level k . Divide all pixels of the image into two classes c_0 and c_1 , which denote pixels with levels $[1, \dots, k]$

and $[k+1, \dots, L]$. Then discriminant criterion $\eta(k)$ is defined as

$$\eta(k) = \frac{\sigma_B^2(k)}{\sigma_T^2}$$

σ_B^2 is the between-class variance and σ_T^2 is the total variance of levels. The optimal threshold of the image depends on maximizing σ_B^2 . That is to say, the maximum value for the discriminant criterion can be discovered using only the σ_B^2 term.

$$\sigma_B^2(k) = \frac{[\mu_T w(k) - \mu(k)]^2}{w(k)[1 - w(k)]}$$

μ_T is the total mean level of the original image, $w(k)$ and $\mu(k)$ are zeroth cumulative moment and first cumulative moment of class c_0 respectively.

Because the image is corrupted by noises, the process adopts a developed Otsu method which utilizes the gray-level

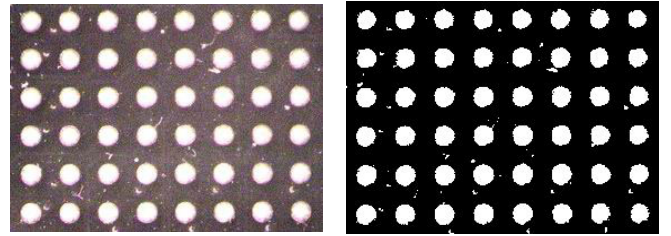


Fig.6 (a) the original image (b) result of segmentation information of each pixel and its spatial correlation with the neighborhood [17]. The result of threshold segmentation is shown as Fig. 6.

4.2. BGA locating algorithm

In order to check each ball, its position has to be located in the above binary image accurately. Each ball is found and located exactly through the seed-fill algorithm [18]. This algorithm is a method that can find and fill all other pixels interior to the region by a known interior pixel called the seed. The method is to start with a seed and check its neighboring points to fill in the polygon. Based on the algorithm, the process can calculate the geometrical shape characteristics of each ball, including area A , perimeter C , zeroth- and first-order moments, centroid's position (x_{cij}, y_{cij}) , circular degree, boundary, Fig.7 is the result of edge detection.

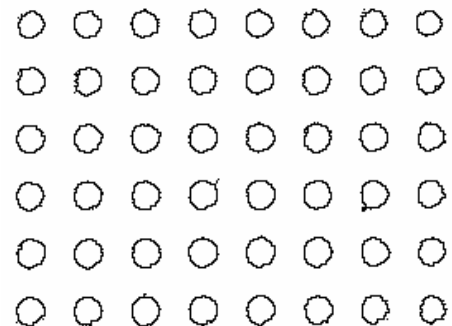


Fig.7 the result of edge detection

4.3. BGA checking algorithm

The program flowchart for BGA inspection is shown as Fig.8. First, segment the original image by the threshold obtained by developed Otsu threshold algorithm. Then the geometrical shape characteristics can be gotten through seed-fill algorithm. Finally, defects of BGA chip can be detected and classified by utilizing these features.

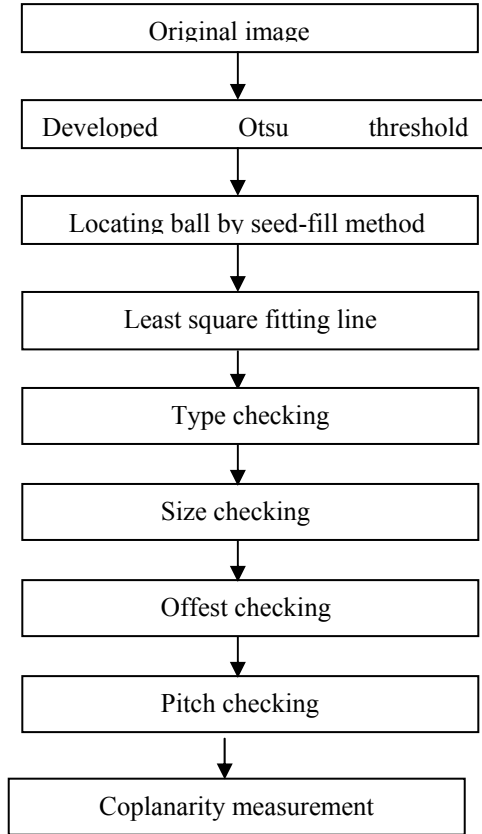


Figure.8 Flow chart of BGA inspection processing

Because of noise occurring, whether the object is ball or not has to be judged first. The judgment condition is not only the size of objects, but also the geometric distribution information of balls. A solder ball on the chip must have at least two neighbors and they must lie on the grid lines. After that, failure analysis begins. The size of balls can be detected by the area A of objects. The ball type is decided by the object's roundness λ . For the area A and perimeter C is defined as

$$C = 2\pi r$$

$$A = \pi r^2$$

The roundness λ can be obtained as

$$\lambda = \frac{C^2}{4\pi A}$$

If the object is an ideal circle, the roundness is equal to 1. The shape of ball being good or not can be determined by λ . In order to ensure the reliability of interconnection, the precise position localization of every ball is vital. Then, the centroid's coordinates are fitted into a straight line through least square method and the tolerance limit is controlled under an

appropriate level. Based on these grid lines, the offset, missing, and pitch can be inspected. To detect the offset of balls, the centroid of each ball is compared with the cross of vertical and horizontal lines. To detect the pitch, it only needs to calculate the distance of centroid coordinates between adjacent balls along the grid line direction. Fig.9 is a diagram which illustrates items of BGA inspection.

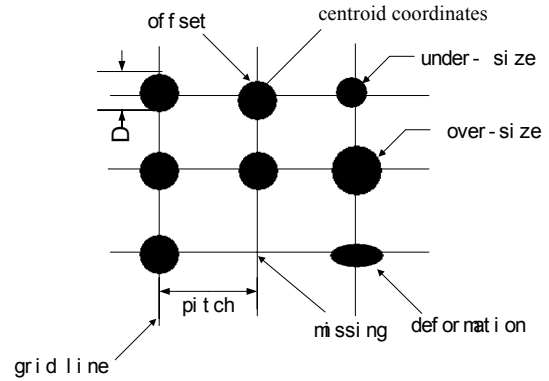


Fig.9 illustrating inspection item

The BGA chip is directly mounted on the printed circuit board, so the high coplanarity of solder balls is the key to ensure the production reliability [19]. According to the measuring principle proposed above, the precise data of each ball's height can be calculated. Then the coplanarity of the chip can be evaluated by the proposed methods [20]. Fig.10 is captured by the side CCD.

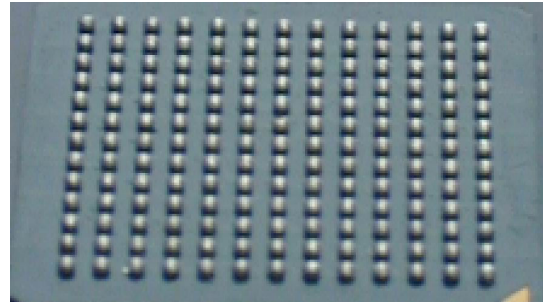


Fig.10 the image captured by side CCD

5. Results and conclusions

From the above processing flow, the characteristics of BGA chip which are used to assess the product quality can be obtained by image processing. As for the proposed optical method for measuring the height, It has been proved in theory.

The paper proposed an optical method for SMT-based BGA chips three-dimensional measurement. The experimental binocular vision system can provide enough geometrical information to inspect the BGA package. All algorithms were implemented on Linux system. The whole system proved to be applicable by theoretical and experimental results. The accuracy and reliability will be verified later.

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