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A Machine Vision System for Ball Grid Array Package Inspection

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Abstract: An optical inspection method of the Ball Grid Array package (BGA) was proposed by using a machine vision system. The developed machine vision system could get main critical factors for BGA quality evaluation, such as the height of solder ball, diameter, pitch and coplanarity. The experiment has proved that this system is available for BGA failure detection.

Key words: ball gird array; machine vision system; coplanarity; image processing

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Introduction

BGA package has been widely used in portable electronic products because of its advantages, such as smaller size, wider lead pitch. In order to increase the functionality and reliability of integrated circuits, it is essential to control the quality of BGA package before soldered to PCBs. There are two kinds of BGA package inspection. One is inspection of BGA chip itself and the other is inspection of solder joints. This study is focused on the anterior one, including the height of solder ball, diameter, pitch and coplanarity. Among these characteristics, coplanarity is a crucial factor and the most difficult one to measured. Non-coplanarity of chips would cause poor contact with PCBs, which incurs open or insufficient solder joints.

Various techniques have been proposed for BGA chip inspection which can be characterized by radiations employed, such as line-structured laser sensor[1], X-ray laminography[2]. The problem of line-structured laser scanning is that it needs a stepping motor to move the worktable with BGA chip. X-ray radiography is a non-destructive technique used to detect the defects of BGA package. But it is more expensive and requires experienced workmen to operate and maintain it.

This paper has proposed a new optical method for BGA leads coplanarity measurement based on a machine vision system. It does not require complex implements to generate the radiation and its structure is simpler than others. It also has a desired inspection speed to meet manufacturing assembly demands.

1 Measurement Principle

1.1 Overview of the System

The machine vision system consists of two parts, the optical imaging unit and image processing unit. The size of experimental PBGA chip is 23.0 mm × 23.0 mm and the ball matrix is 13 × 13. The solder ball diameter is 0.75 mm and the pitch is 1.50 mm. The standard height of ball is 0.60 mm. In the optical imaging unit, the size of chip is magnified by the optical microscope and forms an image on the CCD camera fixed on the top. The annular blue LED light under the microscope provides illumination for the top CCD camera. The features of the BGA chip can be acquired by analyzing images captured by this CCD camera. The data of height can be obtained through processing the image captured by the side CCD which is fixed with a specific angle. The opposite LED light pro-

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vides illumination for the side CCD camera. All optical apparatuses are encapsulated in a box which is made of the diffuse-reflection material for avoiding noise disturbance.

1.2 Measuring Principle of Height

It is essential to get the height of each ball for assessing the coplanarity of solder balls. Figure 1 illustrates the rule of determination the angle θ with which the side CCD camera is fixed. The following deduction and conclusion are obtained on the following conditions. First, each pin is an ideal ball, not considering its deformation. Secondly, the distortion of lens has been corrected and the system has been calibrated. Finally, the ratio of BGA chip's size to the distance y is so small ($\approx$ 0.05) that the beams from the chip to the side CCD camera can be considered parallel each other. The principle of fixing the side CCD camera is that the position of the side CCD is as low as possible and each jointing edge of solder ball with the substrate can be captured by the side CCD camera. As shown in Fig. 1, the point A is the limit position for the side CCD camera. θ is defined as

$$\theta = 2\arctan\left[\frac{(p - v) - \sqrt{p(p - 2v)}}{D - h}\right] \quad (1)$$

where v is defined as

$$v = \sqrt{h(D - h)} \quad (2)$$

h: the standard height of ball,

p: the pitch of chip,

D: the standard diameter of ball,

y: the horizontal distance from the center of BGA chip to the side CCD camera.

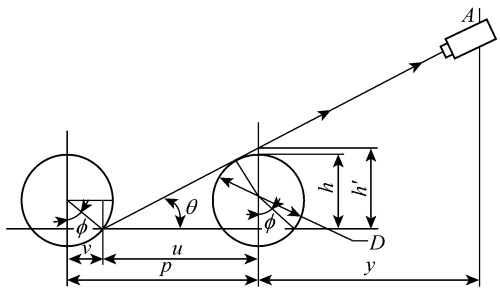

Fig. 1 The rule of determination θ

According to the specification of the chip, D = 0.75 mm, p = 1.50 mm, h = 0.60 mm, θ is equal to 28.5°. In the experiment, θ is set as 32.°

Figure 2 illustrates the principle of calculating the height of balls. From Fig. 2, obtain the following expressions:

$$\varphi = \pi - \phi + \theta \quad (3)$$

$$\sin\frac{\varphi}{2} = \frac{l}{D} \quad (4)$$

$$h = \frac{D}{2}(1 + \cos\phi) \quad (5)$$

Thus, the height of balls is defined as

$$h = \frac{D}{2}\left[1 - \cos\left(\theta - 2\arcsin\frac{l}{D}\right)\right] \quad (6)$$

where l: the width projection of image captured by side CCD. Here, θ can be obtained through the system calibration, in the experiment, θ = 32.° The diameter D can be obtained by processing the image captured by the side CCD camera.

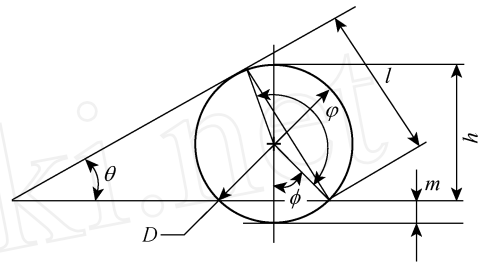

Fig. 2 The principle of measuring height

2 Image Processing

2.1 BGA Locating Algorithm

Figure 3 shows the algorithmic flow used to evaluate the quantitative factors such as position, diameter, pitch and coplanarity. The histogram of

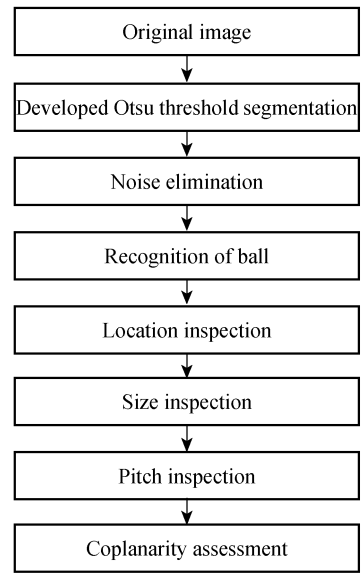

Fig. 3 Flowchart of BGA inspection processing

BGA package image has a deep and sharp valley between two peaks representing objects and background respectively. So the input image can be segmented into objects and background by Otsu threshold which is a nonparametric and unsupervised one of automatic threshold selection from a histogram of image[3]. Because the image is corrupted by noises, the process has adopted a developed Otsu method.

Each ball is found and located exactly through the seed-fill algorithm. This algorithm is a method to 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 each ball's centroid coordinates, diameter D, perimeter P, roundness C, area A.

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 information of balls distribution. A solder ball on the chip must have at least two neighbors within its four adjacents and they must lie on the intersection of grid lines[4].

2.2 BGA Checking Algorithm

Every ball has been recognized and factors of them has been obtained through threshold segmentation, ball location and noise elimination. Specification of BGA, such as ball's position, diameter, pitch and coplanarity, has to meet the industrial standard. Here, referring to the standard[5], defects of BGA can be detected and classified according to these features.

Balls are arranged regularly in two-dimentional array on the chip's surface and will be interconnected on a printed circuit board. So it is necessary to check whether each pin is located in correct position or not. Offset can be detected through comparing every ball's centroid coordinates with its standard position coordinates. It also can detect one ball is missing or not. To detect oversize or undersize balls, check whether each ball's diameter is between lower limit (0.6 mm) and upper limit (0.90 mm) or not. As shown in Fig. 4(a), the three lines represent maximum dimension, nominal dimension and minimum dimension of diameter, respectively. For pitch inspection, it needs to calculate the distance of centroid coordinates between adjacent balls along the grid line direction, as shown in Fig. 4(b), (c). The type of ball can be detected by roundness.

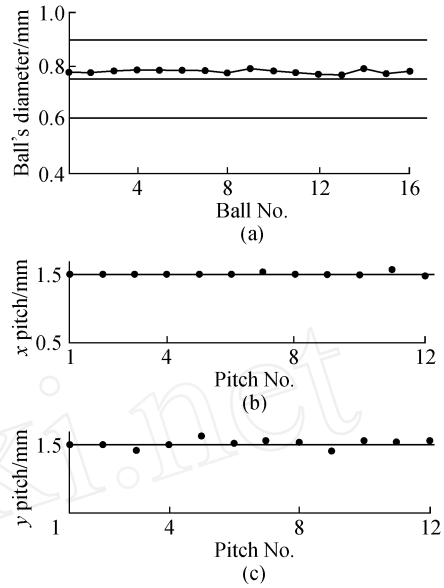

Fig. 4 Ball inspection: (a) size inspection, (b) pitch inspection in the x direction, (c) pitch inspection in the y direction

3 Coplanarity Assessment

The BGA chip is directly mounted on printed circuit boards, so the coplanarity of solder balls is the key to ensure the production reliability. Poor coplanarity would cause weak contact with circuit boards and incur open or insufficient solder joints. The coplanarity is defined in the JEDEC standard as the maximum distance from the highest ball to a seating plane formed by the three balls that the package would rest on if placed on a perfectly flat surface.

Figure 5(a) is the image captured by the side CCD camera. The parameter l and D, can be obtained from the image through image enhancement, threshold segmentation, ball location and noise elimination. According to Eq. (6), the height of each ball is calculated, as shown in Fig. 5(b). Based on these data, referring to Ref. [3], the coplanarity of the chip is 0.039 mm. The JEDEC standard for maximum allowable noncoplanarity is

currently 0.15 mm. On the other hand, the BGA chip which is inspected also has to meet the specifications as follows, the height of each ball must be higher than 0.50 mm and lower than 0.70 mm. According to Fig. 5(c), the height of each ball and copnalarity both satisfy the specifications

Fig. 5 Copnalarity inspection: (a) image captured by the side CCD camera, (b) 3-D sketch for balls, (c) height inspection

4 Conclusion

This paper proposed an optical method for BGA coplanarity inspection. This machine vision system could provide enough geometrical information of the BGA through processing images captured from different orientation. The characteristics of BGA chip which are used to assess the product quality can be obtained based on the above algorithmic flow.

Compared with other systems, the structure of this system is simple and the accuracy is 0.02 mm, which meets the demand of off-line and on-line inspection. The limit of this system is that margin of FOV (field of view) is fuzzy. Next study is focused on this problem.

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