A binocular machine vision system for ball grid array package inspection

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Abstract
Purpose – In this paper, an optical inspection method of the ball grid array package(BGA) is proposed using a binocular machine vision system.
Design/methodology/approach – The height of each solder ball is calculated based on spatial geometrical size and location obtained from the two CCD cameras capturing range images of a LED illuminated BGA chip at certain orientation.
Findings – The structure of this system is simple and the accuracy is 0.02 mm, The experimental results have proved the validity of this system for BGA failure detection.
Practical implications – The developed machine vision system can provide some of the critical factors for BGA quality evaluation, such as the height of solder ball, diameter, pitch and coplanarity.
Originality/value – Compared with other systems, the structure of this system is simple and accurate, which meets the demand of off-line and on-line inspection. The limitation of this system is that the margin of field of view (FOV) is fuzzy. Further study could be focused on this problem.

Keywords Image processing, Inspection, Printed circuits

Paper type Technical paper

1. Introduction

Aiming at higher performance and lower cost, the trend towards miniaturization continues in electronic products (Schneider and Schick, 1997). Ball grid array (BGA) packages are widely used in portable electronic products because of its advantages, such as, more input/output ports, smaller size, wider lead pitch, better electric characteristics (Rooks and Benhabib, 1995). Referring to Figure 1, solder balls are arranged regularly on the chip's mounting surface. In order to increase the functionality and reliability of integrated circuits, it is essential to control the quality before it is being soldered to printed circuit boards. There are two kinds inspection of BGA package. One is inspection of BGA chip itself and the other is inspection of solder joints. This study is focused on the anterior part, including the height of solder ball, diameter, pitch and coplanarity, etc. 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 effective techniques have been proposed for BGA chip inspection. The techniques can be characterized based on the radiations employed, such as line-structured laser sensor (Kim and Rhee, 1999), X-ray laminography (Moore and Vanderstraeten, 2002), acoustic microscopy (Santangelo and Kessler, 1989). A comparison of these methods is shown in Table I.

This paper has proposed a new optical method for BGA leads coplanarity measurement based on a binocular machine vision system. With LED ring lights illuminating the BGA chip, two CCD cameras capture range images of BGA chip from certain orientation. The height of each solder ball can be obtained based on spatial geometrical size and location obtained from these range images. The inspection process is developed to evaluate quantitative factors for assessing products quality. First, original images are segmented by the Otsu threshold (Otsu, 1979). Then the geometrical shape features can be gotten through seed-fill algorithm (Foley *et al.*, 1990). Finally, defects of BGA chip can be detected and classified by using these features.

The system does not require complex equipment to generate the radiation, e.g. X-ray, acoustic wave, and its structure is simpler than others. A desired inspection speed has to be maintained to meet manufacturing assembly demands.

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Figure 1 Ball grid array chip

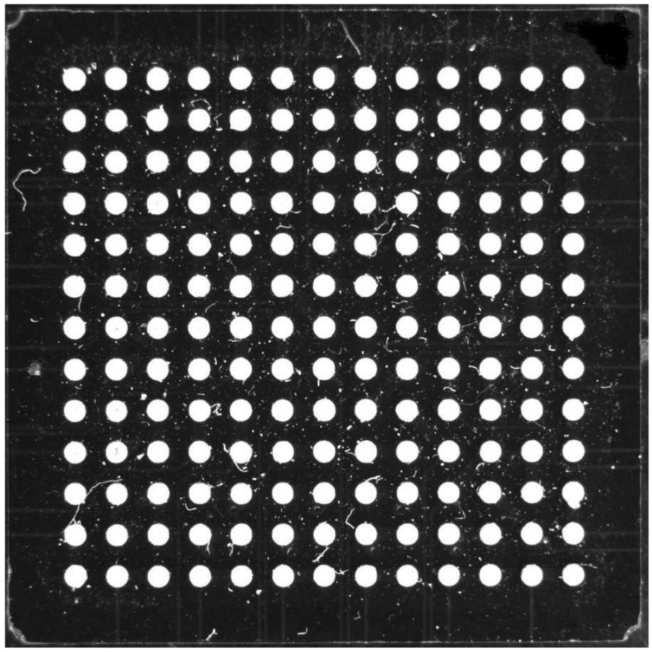


Table I Comparison of different methods

Radiations employed methods	Advantages	Disadvantages
Line-structured laser scanning	A sophisticated method Reliable	Low speed Needs of a stepping motor to move the worktable with BGA chips
X-ray radiography	Non-destructive More powerful in detecting much finer package details and defects Capable of inspecting the BGA joints under substrates	More expensive Requiring experienced workmen to operate and maintain

2. Measurement principle

2.1 Overview of system

The binocular machine vision system consists of two parts, the optical imaging unit and image processing unit. The size of experimental plastic BGA chip is 23.0*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. In the optical imaging unit, the size of chip is magnified by the optical microscope and forms an image on CCD camera fixed on the top. The annular blue LED light under the microscope provides illumination for the top CCD. The features of the BGA chip such as lead pitch, diameter, and centroid can be acquired by analyzing images captured by this CCD camera. The height information can be obtained by processing the image captured from the side CCD that is fixed at a specific angle. The opposite LED light provides illumination for the side CCD camera. All optical apparatus is encapsulated in a box made of diffuse-reflection material for avoiding noise disturbance.

2.2 Principle for measuring height

It is essential to get the height of each solder ball for assessing its coplanarity. Figure 2 illustrates the rule for determination of angle with which the side CCD camera is fixed. Here, the parameter D is the diameter of the ball, h is the height of the ball, and p is the pitch. The parameter y is defined as the horizontal distance from the center of BGA chip to the side CCD camera. The deduction and conclusion used in this paper are obtained assuming the following conditions. First, we assume each pin is an ideal ball, without considering the deformation. Secondly, the distortion of lens camera has been corrected (Li and Lavest, 1996) and the system has been calibrated (Bacakoglu and Kamel, 1997). Finally, the ratio of BGA chip's size to the distance y is so small (≈ 0.05) that the beams from the chip to the side CCD camera can be considered parallel to each other. The principle for fixing the side CCD camera is that its position is kept as low as possible and each joining edge of solder ball with the substrate can be captured by the side CCD camera. As shown in Figure 2, point A is the limit position for the side CCD camera. θ is defined as

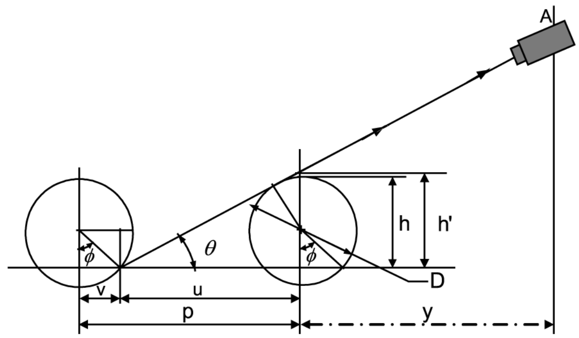
$$\theta = 2\arctan\left[\frac{(p-v)-\sqrt{p(p-2v)}}{D-h}\right] \tag{1}$$

where v is defined as

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

where h is the standard height of ball, P is the pitch of the chip, D is the standard diameter of the ball and θ is the angle with which the side CCD camera is fixed.

Figure 2 The rule of determination θ



According to the specification of the chip, $D = 0.75\,\mathrm{mm}$, $p = 1.50\,\mathrm{mm}$, $h = 0.60\,\mathrm{mm}$, $\theta = 28.5°$. In our experiment, we considered $\theta = 32°$.

Figure 3 illustrates the principle for calculating the height of balls. From Figure 3 the following expressions can be obtained,

$$\varphi_{ij} = \pi - \phi_{ij} + \theta \tag{3}$$

$$\sin(\varphi_{ij}/2) = \frac{l_{ij}}{D_{ij}} \tag{4}$$

$$h_{ij} = \frac{D_{ij}}{2}(1 + \cos\phi_{ij}) \tag{5}$$

thus, the height of balls is defined as

$$h_{ij} = \frac{D_{ij}}{2}\left[1 - \cos\left(\theta - 2 \times \arcsin\frac{l_{ij}}{D_{ij}}\right)\right] \tag{6}$$

where l is the width of the image projection captured by the side CCD. θ can be obtained through the system calibration. The diameter D can be obtained by processing the image captured by the side CCD camera.

3. Image processing

3.1 BGA locating algorithm

Figure 4 shows the algorithmic flow used to evaluate the quantitative factors such as position, diameter, pitch and coplanarity. As shown in Figure 1, the bright circular objects are solder balls. The histogram of image has a deep and sharp valley between two peaks representing the objects and background. Now, the input image can be segmented into objects and background by Otsu threshold (Otsu, 1979). 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. Because the image is corrupted by noises, we have adopted the developed Otsu method (Liu and Li, 1991).

Each ball is identified and located exactly through the seed-fill algorithm. 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 starts with a seed and checks its neighboring points to fill in the polygon. Based on this algorithm, the process can calculate the geometrical shape characteristics of each ball, including each ball's area A, Diameter D, perimeter P, roundness C, and coordinates of centroid (Xc_{ij}, Yc_{ij}).

Due to the occurrence of noise, first we have to judge whether the object is a ball or not. The judgment condition is not only the size of objects, but also the geometric distribution of the balls. 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 (Ruo and Shih, 2003). The result of image processing is shown in Figure 5.

3.2 BGA checking algorithm

Every ball has been recognized and their characteristics are obtained through threshold segmentation, ball location and noise elimination. Specifications of BGA, such as ball's position, diameter, pitch and coplanarity, have to meet the industrial standards. Here, referring to the Motorola PBGA standard, defects of BGA can be detected and classified according to the features.

Balls are arranged regularly in a two-dimensional array pattern on the chip's surface and will be interconnected on a printed circuit board. So it is necessary to check whether every ball is located in the correct position or not. Offset

Figure 3 The principle of measuring height

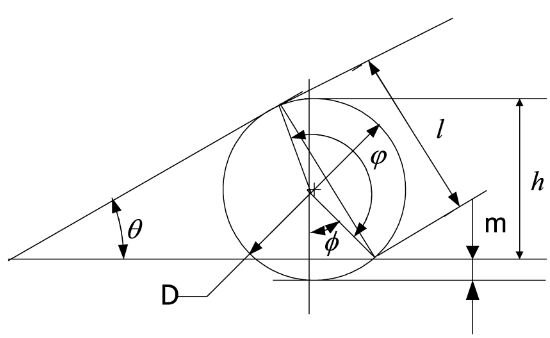


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Figure 4 Flow chart of BGA inspection processing

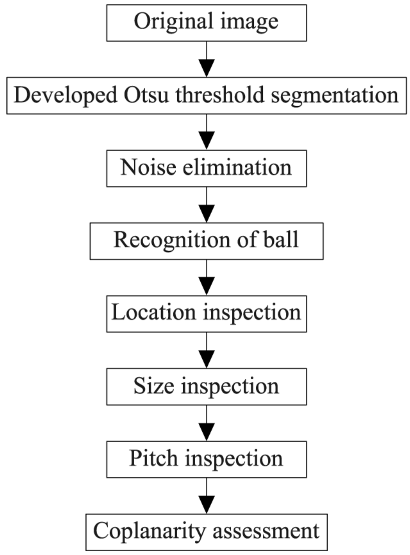
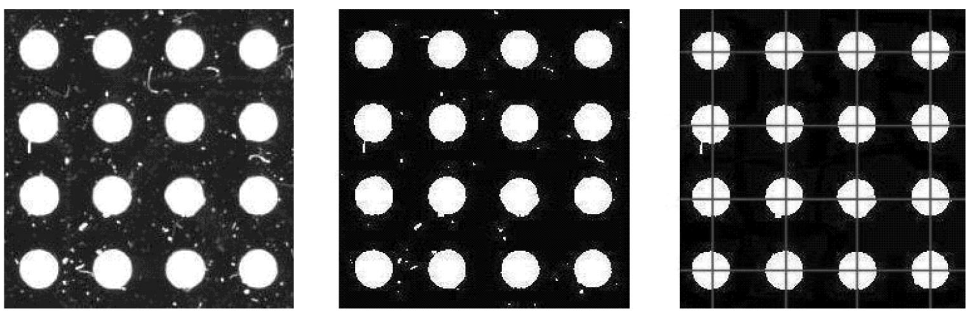


Figure 5 Result of image processing



(a) original image **(b)** image segmentation **(c)** noise elimination

can be detected by comparing the coordinates of centroid (Xc_{ij}, Yc_{ij}) of every ball with its standard coordinates. It also can detect the absence of a ball. As shown in Figure 6(a), each dot describes the actual position of every ball and circle represents its theoretical position. To detect oversized or undersized balls, we check if each ball's diameter is between a lower limit (0.6 mm) and an upper limit (0.90 mm). As shown in Figure 6(b), the three lines respectively represent maximum, nominal and minimum values of diameter. For pitch inspection, we have to calculate the distance between centroids of adjacent balls along the same grid line, as shown in Figure 6(c) and (d). The shape of the ball can be detected by its roundness C.

4. Coplanarity assessment

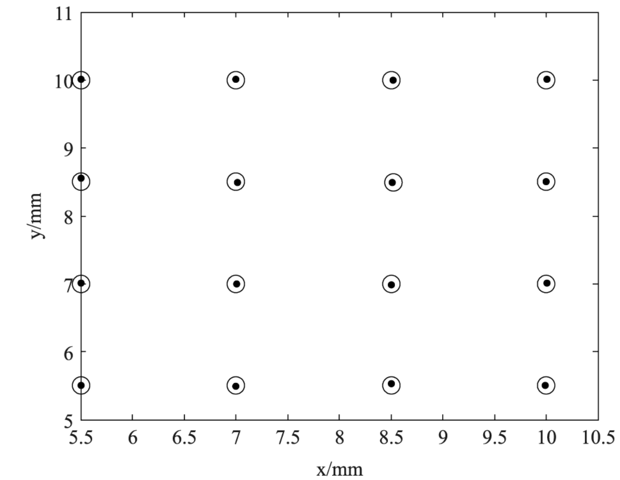
The BGA chip is directly mounted on printed circuit boards. So the high coplanarity of solder balls is the key to ensure the production reliability. Poor coplanarity would cause weak contact with circuit boards and incur open or insufficient solder joint. Coplanarity is defined in the JEDEC standard 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 7(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 the equation (6), the height of each ball is calculated, as shown in Figure 7(b). Based on these data and referring to literature (Kim and Rhee, 1999), the coplanarity of the chip is found to be 0.039 mm. The JEDEC standard for maximum allowable non-coplanarity is currently 0.15 mm. On the other hand, the BGA chip which is inspected also has to meet the condition that the height of each ball must be higher than 0.50 mm and lower than 0.70 mm. According to Figure 7(c), the height of each ball and coplanarity both satisfy the specifications.

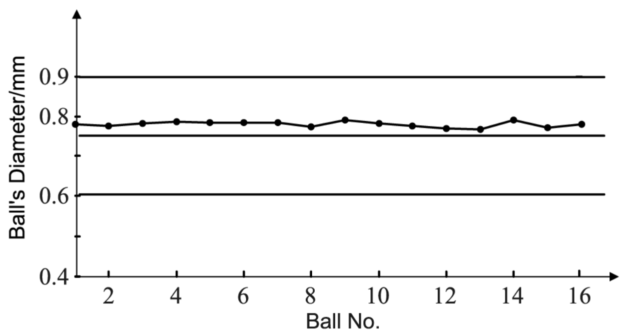
5. Conclusion

In this paper, we proposed an optical method for BGA coplanarity inspection. This machine vision system could provide enough geometrical information of the BGA chip through the processing of the 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.

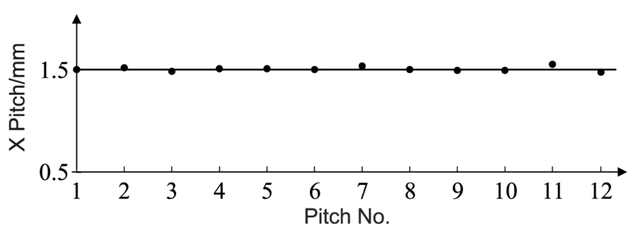
Figure 6 Ball inspection



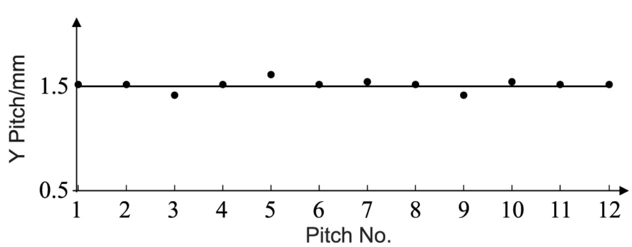
(a) Location inspection



(b) Size inspection



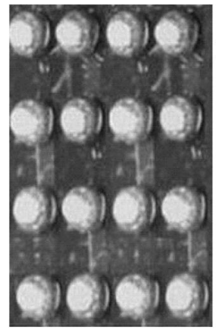
(c) Pitch inspection in the X direction



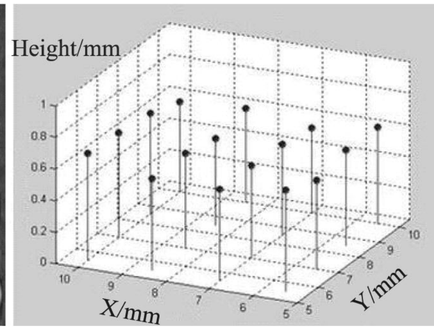
(d) Pitch inspection in the Y direction

Compared with other systems, the structure of this system is simple and accurate, which meets the demand of off-line and on-line inspection. The limitation of this system is that the margin of FOV is fuzzy. Further study could be focused on this problem.

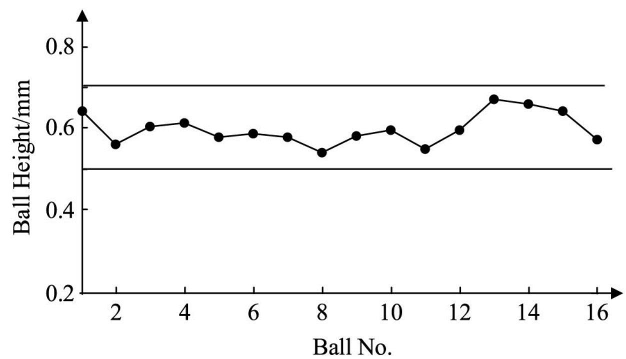
Figure 7 Coplanarity inspection



(a) Image captured by the side CCD camera



(b) 3-D sketch for balls



(c) Height inspection

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