IMAGE BASED AUTOMATIC DEFECT INSPECTION OF SUBSTRATE, DIE ATTACH AND WIRE BOND IN IC PACKAGE PROCESS

[1]YUNG-KUAN CHAN, [2]CHENG-SIANG JHANG, [3]YI-CHEN LIN

[1,2,3]National Chung Hsing University
E-mail: [1]ykchan@nchu.edu.tw, [2]g105029056@mail.nchu.edu.tw, [3]yc0@nchu.edu.tw

Abstract - There are many inspection stations in the IC packaging process to ensure that the quality in the manufacturing process is consistent and stable. In the past, the large amount of manpower was required to use a microscope to check for quality defects. We propose an inspection method for IC packaging processes to collect the images of the three visual inspection stations behind the welding line site, analyzes the differences in the characteristics of good and bad products, and uses these feature values to distinguish them. We hope to reduce labor costs, production cycle time, and misuse of defective products through automated inspections.

The inspection method is divided into three stages. In the first stage, we focus on incoming substrate defects. The image divided into the foreground and background by Otsu threshold selection method. The connected-component labeling method calculates the area of the image and distinguish defective products. In the second stage, we focus on the defects of die bonding, using the area of the marker to find the corners of the substrate lead, and the horizontal projection pixel accumulation method cuts out the upper and lower metal lead images, then cut out the IC by its proportion. Finally, use Canny edge detection, Hough line conversion method to find the edge of the IC and calculate the angle of the line to determine whether the IC chip is skewed, drained, or offset. In the last stage, we focus on the defects of wire bond. Use the connected-component method to determine whether the wire breaks or leaks, and use the ratio to find the solder joint on the IC to determine whether there is a connection error.

In this study, the image identification is segment into the three parts of defect recognition procedure respectively for calculating the recognition accuracy. From the experimental results, the recognition accuracy of abnormal substrate can reach 100% in first part of procedure, and the recognition accuracy of abnormal die bonding can reach 97% in the second part of procedure, and the recognition accuracy of abnormal wire bonding can reach 100% in the third part of procedure.

Index Terms - AOI, Image Process, Die Bonding Inspection.

I. INTRODUCTION

The integrated circuit (IC) is almost one of the essential components of electronic information products, and it will have great challenges in process capability and quality requirements as the size requirement is reduced. In this study, we discuss the quality inspection in the IC package Process. This IC is currently widely used in proximity sensors combined with ambient light sensors, and its has used "Double mold All-in-one (DMA)" package process.

The IC packaging process is to cut the processed Wafer into chips, then use plastic, ceramic, metal and other materials covered, so that it can protect the chips to avoid pollution, the solid support and the heat dissipation. Also it can easy to assemble applications and achieves the electrical connection between the chip and the electronic system.

The Die Attach (DA) and Wire Bond (WB) are part of the overall IC packaging process, and it requires high precision and quality. Artificial vision were used for quality inspection in the past, and each of the ICs on the substrate was inspected one by one under a microscope for quality defects. Work fatigue resulting in misjudgments or omissions that make inspections less reliable, coupled with expensive labor costs and time consuming. Therefore, the industry's prevailing automated optical inspection (AOI). In addition to reducing labor costs, the manufacturing quality can be maintained at a high level.

This study aims at the quality inspection after the Die Attach process, finds a suitable computer vision algorithm and implements it. The input image obtained from the charge coupled device (CCD) is processed through image preprocessing, image segmentation, feature extraction, and recognition. Classify according to the characteristics of quality defects, and finally achieve the purpose of automated quality testing to reduce labor costs.

II. CRITERIA FOR QUALITY DEFECTS

We focus DA and WB processes. The quality defects can be divided into three major categories: substrate loading, DA loading, and WB bonding. There is a small amount of defective substrates from the supplier, as shown in Fig. 1(b). The lack of a black insulating layer in the good substrate causes the entire metal lead is gray and its surrounding lines are bare. Fig. 1(a) shows good substrate's image are nine metal lead with different shapes and sizes. The left half of the Fig. 1(a) and 1(b) clearly shows that the good metal lead is rectangular, and the defective metal lead is not rectangular. After DA process, good substrate with

LED and IC chip shows Fig. 1(c), where some possibility of defective as shown on Fig. 1(d) to (g). Fig. 1(h) wire bonding good, but fail process may make wire lost, broken, offset, shorted as shown Fig 1(j) to (j).

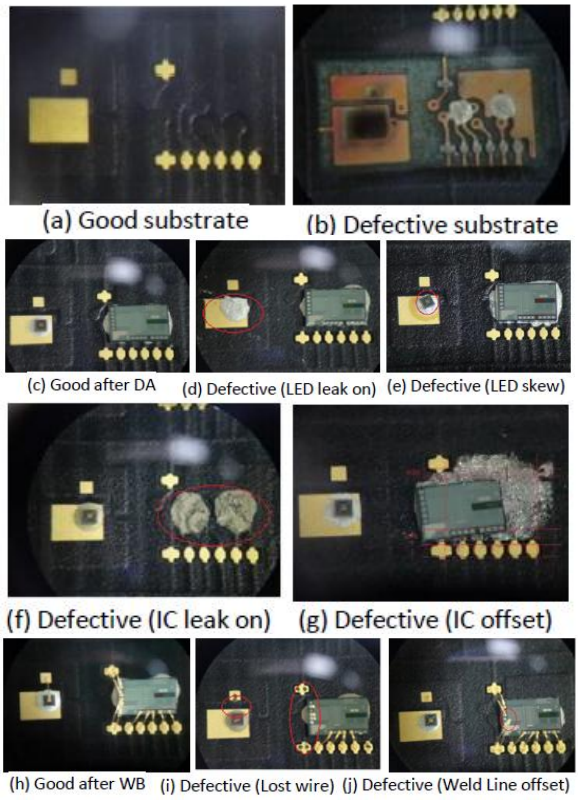


Figure 1: Some possibility of defective

III. THE PROPOSED METHOD

This section describes the method of how to identify the defective products for the input image of the IC packaged DMA in front of the bonding wire station. It is divided into three stages, the first stage is the image processing method for the identification of the defective substrate; the second stage is the image processing method for the identification of the Die Attach; the third stage is the image processing method for the identification of the Wire Bonding. Each image includes the entire product whose components are IC chip, LED chip, gold wire, substrate metal lead, and may also include the edge of the adjacent product such as the substrate metal lead.

A. Substrate identification stage

Calculate the area of the virtual rectangle and the real area, and then use the ratio of the two areas to judge whether the metal lead is rectangular or not to identify good and defective substrates. First, the color map is converted to obtain grayscale images of the six channels R, G, B, H, S, and L [1], as shown in Fig. 2. The white metal lead in the image of the S and L channel's images after the geometric averaging is particularly noticeable, while the other places are relatively dark, as shown in Fig. 3(a), which will help Subsequent image segmentation.

In order to distinguish the target object from the background image, the threshold selection algorithm proposed by Otsu [2] is used to automatically find the threshold value with the largest variation among groups, and the pixel value greater than the threshold value is given white, Conversely, if the pixel value less than the threshold value is given black, the processed image of the SL grayscale image will become a binary image, as shown in Fig. 3(b).

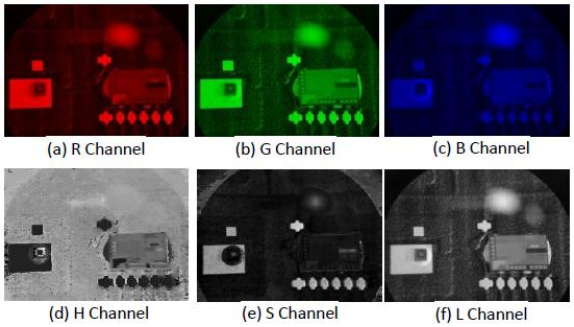


Figure 2: R, G, B, H, S, L channel diagram

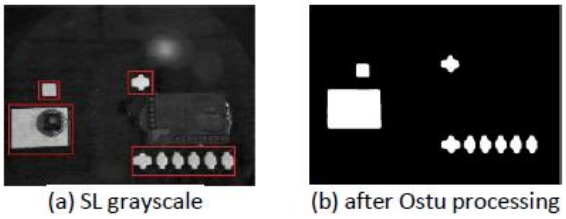


Figure 3: Ostu processing

Observing the different substrate images of good substrates, we found that the shape of the bottom lead of the LED is rectangular. Therefore, the $area_{actual}$ is calculated by (1) in advance by finding top(Y_t), bottom(Y_b), leftmost(X_l) and rightmost(X_r) coordinates, and find the actual area $area_{actual}$. Divide the two areas to get the area ratio, which is mathematically defined as (2). The closer the proportion is to 1, the more the rectangle is represented. Otherwise, it is not rectangular. If the proportion is judged to be less than the threshold 0.8, the image is the defective substrate.

$$area_{vitual} = (X_r - X_l) \times (Y_b - Y_t) \quad (1)$$

$$area_{proportion} = area_{actual} / area_{vitual} \quad (2)$$

B. The identified stage of Die Attach

The requirements for quality specifications at this stage, in addition to IC and LED chips must not be leaked or be damage, the position requirements for the Die Attach also need to be specified within a certain range, meaning that the IC and LED offset and

rotation angle need to be within the specification. Since the quality characteristics of the PCB substrate factory are all within strict standards, this study assumes that all substrates are identical, in other word, the position, size, and color of the metal lead on different substrates are the same. This stage is divided into two parts: the first part is to identify the defects of the LED, and the second part is to identify the defects of the IC.

Because some of the images are skewed due to the angle of the shooting, in order not to affect the correctness of the follow-up judgment skew of the LED and the skew of the IC, the judgment of the skew of the image is first performed. First, the image is binarized by Ostu to find the left bottom and right bottom corners large metal lead of the left half of the image, and then the pixel values of the surrounding pixels of each pixel are compared one by one for the entire image. The pixels whose surrounding pixel values meet the conditions, as shown in Fig. 4, represent a rectangular corner. Then use the lower left and lower right two points to calculate the angle of the straight line. Mathematical definition is shown in (3). When the skew angle is greater than the specification of 3 degrees, the image is judged to be too skewed to corrected [8]. Mathematical definitions such as (4) to (5). The correcting image is shown in Fig. 5.

0/1	1	1
0	1	1
0	0	0

(a) the condition that meets the lower left point

1	1	0/1
1	1	0
0	0	0

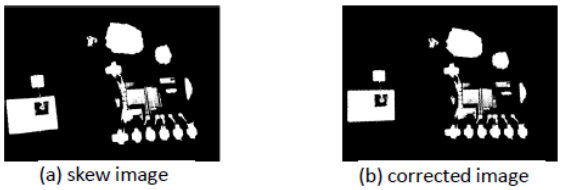
(b) the condition that meets the lower right point

Figure 4: The conditions for corner searching

$$\theta = \left|\operatorname{atan}\left(\frac{x_{downright}-x_{downleft}}{y_{downright}-y_{downleft}}\right)/\pi \times 180\right| \quad (3)$$

$$x' = x\cos\theta - y\sin\theta \quad (4)$$

$$y' = x\sin\theta + y\cos\theta \quad (5)$$



(a) skew image (b) corrected image

Figure 5: The skew image angle correction

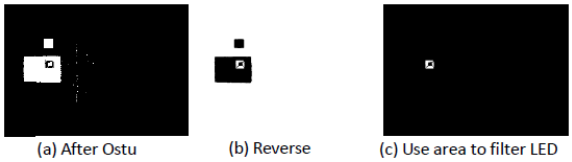
The defective identification of LED. First, using gamma equalization to make the LED and the metal lead more obvious difference between the light and dark, and then use Otsu to cut out the LED to determine whether there is omission, finally, do Canny [4] and Hough transform [5] [6] to check whether it is skewed gamma equalization. In order to highlight the darker areas of the LED image, the pixels of the input image are normalized to between 0 and 255 using the gamma equalization method [7], which value is taken as the power of 1.0882. Equations (6) to (8), where $P(x_i, y_i)$ is the value of each pixel in the original image, $P_{gamma}(x_i, y_i)$ is the normalized output value, P is the set of all pixels in the original image, and $Max(P)$ is the maximum value of the input image, $Min(P)$ is the minimum value of the input image.

$$P_{gamma}(x_i, y_i) = \left(\frac{P(x_i, y_i) - Min(P)}{Max(P) - Min(P)}\right)^{1.0882} \times 255 \quad (6)$$

$$Max(P) = \max(P(x_i, y_i)) \quad (7)$$

$$Min(P) = \min(P(x_i, y_i)) \quad (8)$$

For the previous step, the Otsu method is used to generate the black and white image and do the impurity removal. Because the LED is the object to be selected, the black and white image will be reversed, meaning that black to white or white to black. The LED and the background are all white, through the area of the way to filter, the foreground of the largest block is turned to black, so that the image with the remaining LEDs as the foreground, the steps shown in Fig. 6.



(a) After Ostu (b) Reverse (c) Use area to filter LED

Figure 6: The cutting step diagram of LED

For the LED image cut from the previous step, use Canny to find out the border of the LED, and draw the boundary line with the Hough conversion method. Since Hough transform will get many straight lines, we need to set the threshold value of the number of curve intersections in the polar coordinate system ρθ parameter plane. Here, we set the threshold value to be 0.1 times the maximum value in the polar coordinate system. Filter small lines that are not linear at the edge of the IC. After connecting the selected line segments, it is judged whether the angle is within the range of -3°~+3°, if not, it is skewed, as shown in Fig 7.

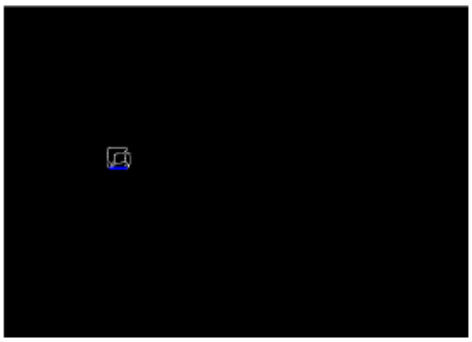


Figure 7: The LED image after Canny and Hough transform

The identification of IC is divided into five steps. The

first step is to find the corner position of the metal lead under the LED area on the substrate. The second step uses the corner coordinate of the previous step and the relative distance to divide the metal lead of the IC area. The third step cuts out the middle part of the metal lead under the IC area. The fourth step, the width of the middle part of the metal lead is taken as the unit length ratio 1, and the IC is segmented by the ratio of the upper and lower metal lead specification distances. The fifth step draws the edge of the IC line and judges whether the angle of the value line is within ±3°, thereby knowing whether the IC is skewed or not.

Segment the upper and lower metal leads of the IC area. Use the method of substrate identification stage(Section II.A.) to obtain the length and width of the metal lead under the LED in the left half of the image and use this as the unit side length. Add the 0.05 and 0.7 times lead length (subtract upper side from lower side) of the X-coordinate at the bottom of the metal lead. The right-most point Y coordinates are added 1.03 times and 3.14 times the width of the lead (subtract the left side from right side), and the metal lead below the IC is cut out by the boundary of the expected edge. Similarly, the uppermost point X coordinates plus 0.38 times and 1 times the length of the metal lead, the rightmost point Y coordinates plus 0.9 times and 1.52 times the width of the metal lead to find the IC region of the upper metal lead, as shown in Fig. 8.

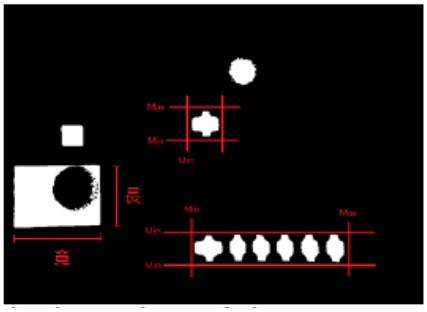


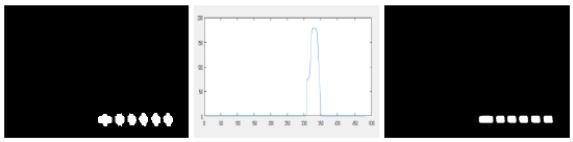
Figure 8: The boundary of the IC area metal lead

Segment the middle part of the metal lead. In order to segment the IC area, this study assumes that if the supplier's substrate is good, the position and size of its metal lead are consistent and fixed, so the middle part of the metal lead below the IC area is measured in advance. The width of the pixel in the middle of the lead is equal to 1 unit.

The goal of this section is to cut the middle part of the metal lead below the IC in the lower metal lead image $I_{metallead}$ by using horizontal projection method. First, a new histogram H_x will be defined whose X-axis is the top-to-bottom pixel of the image, and then do a left to right pixel scan for each column of pixels to find the white pixel. If there is, then do the accumulation, the mathematical definition is as in (9), x is a pixel with a length of image, y is a pixel with a wide of image, and finally a histogram is obtained.

$$H_x = \sum_{y=1}^{y} I_{metallead}(x, y) \quad (9)$$

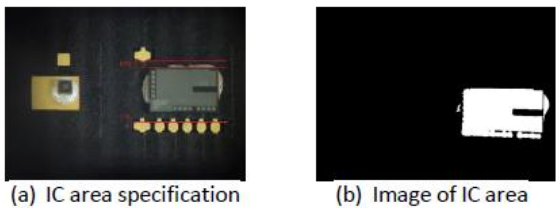
Since the upper and lower areas of the metal lead are smaller, the graphs accumulated at the pixel point after the projection are relatively low, and the middle part of the lead is larger. It can be seen that the intersection between the middle and upper and lower ends is just the largest difference in the accumulated pixels, so comparing the difference in the number of accumulated pixels in the X-axis position and finding the largest difference can cut out the middle part of the lower metal lead. As shown in Fig. 9.



(a) Lower metal lead image (b) The histogram after horizontal projection method (c) The middle part of the lower metal lead image

Figure 9: The step of Horizontal projection method

Segment IC area. Use the image of the previous step to calculate the width W of the middle part of the metal lead, then from the upper lead about 0.85 times the width, and from the lower lead about 1.48 times the width to define two hypothetical parallel line, as shown in Fig. 10(a). If the offset of the IC is within the range of these two horizontal lines, it can be determined that there is no offset in the IC.



(a) IC area specification (b) Image of IC area

Figure 10: IC area Spec. and image of IC area

Since the IC chip is green, geometrical averaging of the green channel and Lightness channel is performed, making the IC area more bright. Then use Otsu algorithm to take the threshold for this enhanced grayscale image and use this threshold to convert to the black and white image. After removing the noise, take the right half of the image. Then use the two horizontal lines defined above to set the IC area, as shown in Fig. 10(b).

Identify skew IC. In order to know that the skew of the IC meets the quality specification within ±3°, the angle between the bottom edge of the IC and the lead must be calculated. First, the contour boundary of the IC is obtained by the Canny edge detection method,

and the obtained boundary line is extracted through the Hough transform, then calculate its straight angle. If the angle is less than ±3°, count the line once. If the number of line segments that meet the rotation angle specification is consistent with the number of straight lines obtained by Hough transform, judge the IC image is not skewed, as shown in Fig. 11.

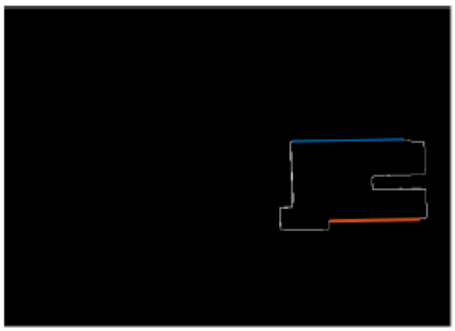


Figure 11: A straight line image through Hough transform

C. Identified stage after Wire Bond

The last stage is mainly to identify the image after the welding line and whether the welding line is flawed, and to screen for missed welding and welding line breakage. First, the image of the IC area is used to determine whether the LED and the IC are connected with the metal lead by using the Connected Component Labeling Algorithm. Then use the geometric average of the H-channel and R-channel and use the ratio of the relative positions of the solder joints to determine the offset of the solder joints.

Because it is necessary to determine whether the welding line is connected, the IC, metal lead, welding line and LED must be cut together. In view of the darker color of the IC area, the brightness of the IC is brightened by using the geometric average of the R (red) channel and the inverted H (hue) channel. The other brightness is already very high. After using Ostu's method, the four places mentioned above will become the foreground.

Since the bonding wire is connected to the LED and the IC and the metal lead, it is possible to judge whether or not there is a connection by treating the same object. From the image of the previous step, the foreground object is marked with the label by the connected component labeling method [3], the total area of each label is calculated, and the impurity is first filtered out by using the area size. If the figure is connected correctly, there will only be two labels for the entire image, namely the object on the left half where the LED is connected to the metal lead and the object on the right half where the IC is connected to the metal lead. Therefore, the use of the number of tags can be screened to know whether the metal line is disconnected or missed.

In order to analyze whether the weld line is connected to the IC's welding point for offset, the welding line and the welding point must be segment first. Since the gray value of the welding line portion of the image is close to the middle gray value of 0 to 255, the threshold value 127 is given by the two-part gamma equalization method. When the value of the pixel is less than 127, the luminance will be suppressed, and if not, the luminance will be increased. The mathematical definition is as shown in (10). Max in the formula is the maximum pixel value in the image. After processing, the difference between the brightness of the metal lead and the welding line and the other background parts is increased. Using Ostu method, the Fig. 12 can be obtained.

$$I_{(x,y)} = \begin{cases} ((I_{(x,y)} - 127)/(Max - 127))^{\frac{1}{\gamma}} \times 128 + 127, & if I_{(x,y)} \geq 127 \\ ((I_{(x,y)} - 0)/(128 - 0))^{\gamma} \times 128, & otherwise \end{cases} \quad (10)$$

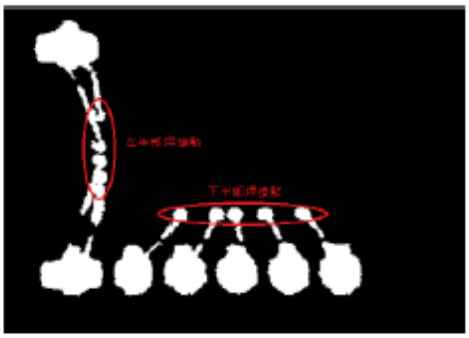
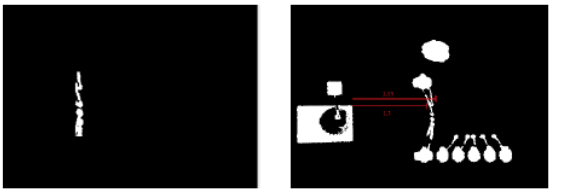


Figure 12: Binary image of metal lead and welding line

The image of the previous step is cut out of the IC area by the second-stage method, so that the image will only have the solder joint and part of the welding line. In order to remove part of the weld line for analysis of the weld point, the vertical projection method is used to find the intersection between the middle area of the upper metal lead and the area of the upper metal lead. Use this junction to remove part of the weld line.

Similar to the horizontal projection method, a new histogram H_y is first defined and its X-axis is the left-to-right pixel of the image, and then the top to bottom white pixel scan for each row of pixels to find the white pixel. If there is, then do the accumulation, mathematical definition as (11). x is a pixel with a length of image, y is a pixel with a wide of image, and finally a histogram is obtained. For the right half of the histogram to find out the most significant difference between before and after the pixel, and record the y-axis position. Finally, deleting the left half of the y-axis image will remove some of the weld lines, leaving the welds as shown in Fig. 13(a).

$$H_y = \sum_{x=1}^{x} I_{metallead}(x, y) \quad (11)$$



(a) Binary image of welding point and remaining weld line (b) Use relative proportions of large metal on right of image to find the solder joints

Figure 13: Welding point and relative proportions

In order to determine the precise position of the solder joint to determine whether it is offset, the large metal lead under the LED in the image has small variability and consistency, and it is found that the upper right corner extends a certain proportion to the right can find the first solder joint. Therefore, firstly calculate the width of the large metal lead from left to right, consider the upper right corner as the reference point and use this reference point to extend the relative width of the lead 1.55 times to find the relative position of the first welding point, as shown in Fig. 13(b). Then find the second welding point from the relative position of the first welding point, and so on. Lastly, determine the area size at these positions. If the position is larger than 60 pixels, the welding point is considered to be in the correct position.

D. Genetic algorithm search for optimal parameters

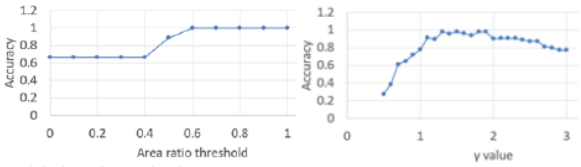
The gamma equalization and two-part gamma equalization gamma parameter values for the best accuracy in the third stage of this study. First, each value was set to 8 bits, and this study has two parameter values, so each Genes have 16 bits. Because there are 8 bits representing a value is 0 to 255 from binary to decimal. Also, It is not desirable that the gamma value is too large or too small to cause the image to be too dark or too bright. Therefore, the value is normalized to 0.5 to 3, the mathematical definition is as in (12), and the value is converted to a decimal value.

$$\frac{3-0.5}{255} \times value + 0.5 \quad (12)$$

IV. RESULTS

This study is divided into three stages, so the data is also categorized into three categories to calculate the accuracy. The first stage substrates are 24 good products and 20 defective products respectively. In the second phase, there were 24 good Die Attach products, and there were 77 defective Die Attach products, which further subdivided into LED leakage and skew, and the IC leaked, skewed, and shifted. In the final stage, there were 5 good Wire Bond products, and there were 79 defect Weld Bond products including weld line leakages, disconnections, and solder joint offset. In total, there were 44 in the first phase, 101 in the second phase, and 84 in the third phase. The image size of each image is 480×640.

In the first stage, the threshold value of the area ratio is determined using the for loop. When the value is greater than 0.6, the accuracy rate reaches 100%, as shown in Fig. 14(a). The second stage also uses the for loop to determine the γ value, as shown in Fig. 14(b). It is found that when the γ values are 1.3, 1.8, and 1.9, the accuracy reaches the maximum of 97.959%. Therefore, choose the middle γ parameter value 1.8 as a fixed value for the experiment. In the third stage, there are two γ parameter values to be determined. Therefore, the genetic algorithm is used to search for the best value. Finally, the best accuracy of 100% is obtained when the γ of two-part gamma equalization is 1.3529 and the γ of gamma equalization is 1.0882.



(a) The relationship between accuracy and the area ratio (b) The relationship between accuracy and second stage γ parameter

Figure 14: The relationship between accuracy and the area ratio and γ parameter

The three-stage Precision, Recall, F-measure and Accuracy are shown in Table 1, and are compared with the manual identification. The accuracy of the three stages have improved.

Stage	Result Precision	Result Recall	Result F-measure	Result Accuracy	Manual Accuracy
First	100%	100%	100%	100%	95%
Second	96%	100%	97.959%	99.009%	92%
Third	100%	100%	100%	100%	95%

Table 1: Experimental results and manual

CONCLUSIONS

We found that the accuracy of the film in the second stage is less than 100%. The reason is the IC skew angle that the method identified is too small to fall within the general specification, and this causes the IC skew product to recognize a good product. There is a foreign object in the classification of defective products. Based on irregular features, it is difficult to identify them by using methods. For example, there may be a large piece of silver glue sticking on the IC, or there may be black tape and a pile of silver glue is scattered throughout the image.

In the discussion of experimental problems and difficulties, it has been found that the channels of the image are easily affected by bright light, and some images are affected by these noises in the process of

identification due to the reflection of light. Some images are due to bad shooting angles that affect the effectiveness of subsequent processing. To address the above issues, we must take the time to do preprocessing. Therefore, we hope to improve the standards and quality of image and help increase the processing speed in the future.

REFERENCES

[1] R. C. Gonzalez, R. E. Woods, Digital Image Processing, 3ed., Prentice Hall Press, pp. 731-735, 2008

[2] N. Otsu, "A threshold selection method from gray-level histograms," IEEE Trans. Systems, Man, and Cybernetics, vol. 9, no. 1, pp. 62-66. Jan. 1979.

[3] P. Bhattacharya, "Connected component labeling for binary images on a reconfigurable mesh architecture," Journal of Systems Architecture, vol. 42, no. 4, pp.309-313, Nov. 1996.

[4] J. Canny, "A computational approach to edge detection," IEEE Trans. Pattern Analysis and Machine Intelligence, vol. PAMI-8, no. 6, pp. 679-698, Nov. 1986.

[5] P. V. C. Hough, "Method and means for recognizing complex patterns," US Patent 3069654, Dec. 1962.

[6] T. Asano, N. Katoh, "Variants for Hough Transform for Line Detection," Computational Geometry, vol. 6, no. 4, pp. 231-252, July 1996.

[7] C. Poynton, Digital Video and HDTV: Algorithms and Interfaces, Morgan Kaufmann. pp. 260-630, 2003.

[8] C. B. Owen, F. Makedon, "High quality alias free image rotation", Conference Record of The Thirtieth Asilomar Conference on Signals, Systems and Computers, pp. 115-119, Nov. 1996.

★★★