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Automated Visual Inspection System for Electronic Devices Mounted on Printed Circuit Boards Using Light-Section Method

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ABSTRACT

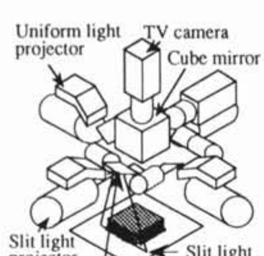
An automated system has been developed to visually inspect surface mount devices (SMDs) on printed circuit boards (PCBs). The location of an SMD is recognized from range data detected by the light section method. Since the PCB surface is treated as the base height in a recognition task, its accurate determination is extremely important, especially for reliable inspection of small SMDs such as 1005 chip components (1.0mm× 0.5mm) and the fine pitch leads of LSIs. However, the light section method is adversely affected by noise in the form of secondary reflection that results in partially incorrect range data. To determine the accurate base height from the waveform without the influence of noise, we adopted statistical techniques that approximate the PCB surface as a straight line. This paper describes the inspection algorithm and provides a brief explanation of the automated inspection system.

1. Introduction

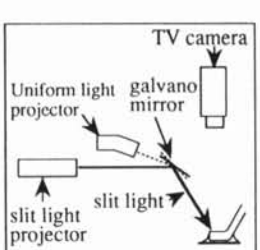
In the electronics industry, visual inspection has been indispensable for maintaining the quality of products. Some form of visual inspection is especially necessary after the soldering process. Recently, however, visual inspection by a human operator has become more difficult as increasingly smaller components are packed onto PCBs. In response to the problem presented by visual inspection, we developed an automated visual inspection system capable of detecting small chip components such as 1005 chips and LSI leads with a pitch of 0.5mm.

2. Light-section detection unit

The light-section detection unit (Fig. 1 (a)) consists of two optical units, each of which is used exclusively to detect horizontal or vertical light-section waveform. Each optical unit has one TV camera and two projection units, each containing a slit light projector, a uniform light projector and a galvano mirror (Fig. 1 (b)). Slit light is projected obliquely and detected by the TV camera arranged just above the PCB. Uniform light is projected from the same direction as slit light, and is detected by the same camera.



(a) Light-section detection unit



(b) Arrangement of projection unit

Fig.1 Light-section detection unit

Figure 2 shows the procedure for extracting the light-section waveforms. The slit light image is divided by the uniform light image in order to normalize the reflectivity. This normalization processing increases the accuracy with which the light-section waveform can be extracted by minimizing the influence of weakly reflected slit light in the calculation. The central tendency of the intensity data of the normalized image along the Y-direction (A-A in Fig. 2) is calculated in sub-pixel accuracy to determine the Y-coordinate of a light-section waveform at each X-coordinate[1]. The resulting light-section waveforms are shown in Fig. 3 and 4.

3. Inspection algorithm

The location of an electronic device is recognized from numerous light-section waveforms from the horizontal and vertical directions. First, PCB base height

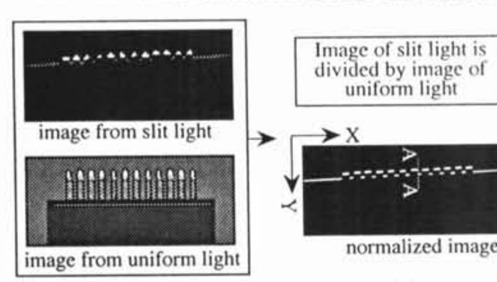


Fig. 2 Normalization of reflectivity

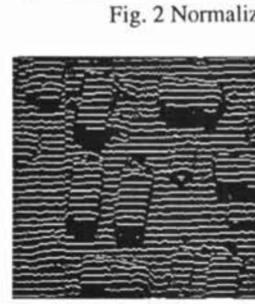


Fig. 3 Detected light-section waveforms for chip components

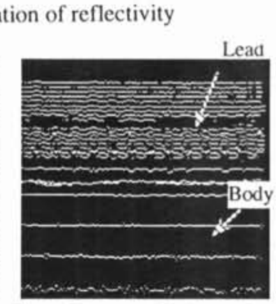


Fig. 4 Detected light-section waveforms for LSI leads

is calculated from each waveform and regarded as the reference height for subsequent processing. Assuming that the detected height of the component minus the calculated PCB height is nearly equal to the design thickness of the component, then the edges of the body can be found from each waveform. The position of the body is recognized from the detected edges of all the waveforms using the caliper method[2),3)]. Assuming that the top of the body exhibits a flat surface, the body can then be approximated to a rectangle in three-dimensional space. The lift of the body is calculated from the approximated rectangle. If the target device has leads, the location of the leads is calculated after incorrect range data caused by secondary reflection has been eliminated.

3.1 Calculation of PCB height

The board surface will appear slanted in the view field if the PCB is bent. It is therefore necessary to approximate the waveform corresponding to the PCB surface to a straight line. The range data is often influenced by noise caused by secondary reflection[4)] from the solder fillets (Fig. 5). It is thus very difficult to determine the PCB height accurately. To overcome this problem, we applied several statistical techniques as described below in the following 2 steps.

STEP1: Approximation to a straight line

The waveform is divided into n small regions (Fig.6). Each divided waveform is projected to the Y axis and the lowest peak is taken as the rough height of the PCB. Each point of the divided waveform is evaluated as to whether it lies within a fixed range from the rough height. If it does, the data associated with that point is extracted as data belonging to the PCB surface. The variance of the extracted surface data is calculated in each of the sub-regions and is regarded as the error variance, σ_i^2, of the region i. Assuming that the linear equation approximated for the surface of the PCB is of the form $Y = aX + b$, then a and b can be calculated by solving the following equations;

$$\frac{\partial \varepsilon}{\partial a} = 0,\ \frac{\partial \varepsilon}{\partial b} = 0, \text{ and} \tag{1}$$

$$\varepsilon(a,b) = \sum_{i=1}^{n} \frac{1}{\sigma_i^2} \sum_{j=1}^{m(i)} \left(Y_{i,j} - aX_{i,j} - b\right)^2, \tag{2}$$

where $\left(X_{i,j}, Y_{i,j}\right)$ is the jth waveform data in region i, σ_i^2 is the variance in region i, and $m(i)$ is the number of data in region i.

The equations differ from the ordinary least squares method in that the error function ε is divided by σ_i^2 for each region i. Therefore, even if a divided waveform contains noise, its variance will increase and the noise contribution to the approximation will decrease. In such cases, the PCB height calculation is not as greatly influenced by noise as the ordinary least squares method.

STEP 2: Evaluation of approximation

When secondary reflections occur at numerous points in the waveform, the approximated straight line may not be accurate. The accuracy of the approximation can be evaluated as follows; First, the variance σ'^2_i in each divided region i is calculated as the variance around the approximated line. After the variance σ'^2_i is calculated, the expected variances of parameters of the linear equation V_a and V_b, are estimated. To simplify the calculation of V_a and V_b, we assume that σ'^2_i is not greatly different from σ_i^2. The variance of the approximated line at position x, indicated as $V_y(x)$, can be calculated by the following expression.

$$V_y(x) = V_a\left(x - E_x\right)^2 + V_b \tag{3}$$

where

$$V_a = \left(\sum_{i=1}^{n} \sum_{j=1}^{m(i)} \frac{X_{i,j}^{\ 2}}{\sigma'^2_i} - \frac{\sum_{i=1}^{n} \sum_{j=1}^{m(i)} \left(\frac{X_{i,j}}{\sigma'^2_i} \right)^2}{\sum_{i=1}^{n} \sum_{j=1}^{m(i)} \frac{1}{\sigma'^2_i}} \right)^{-1}, \tag{4}$$

$$V_b = \left(\sum_{i=1}^{n} \sum_{j=1}^{m(i)} \frac{1}{\sigma'^2_i} \right)^{-1}, \tag{5}$$

$$E_x = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m(i)} \left(\frac{X_{i,j}}{\sigma'^2_i} \right)}{\sum_{i=1}^{n} \sum_{j=1}^{m(i)} \frac{1}{\sigma'^2_i}}, \text{ and} \tag{6}$$

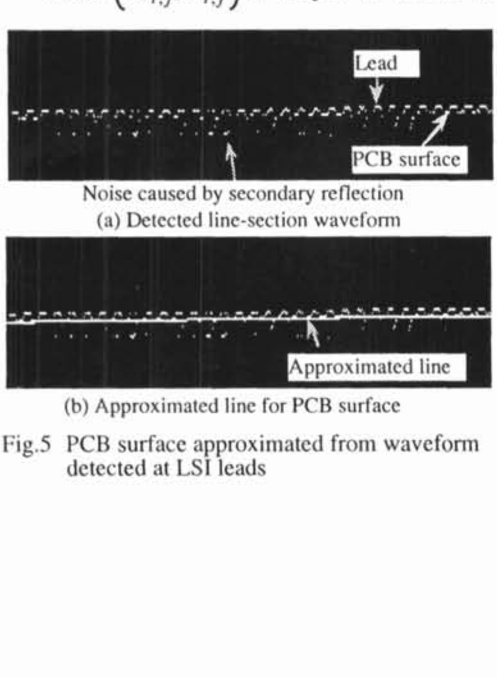


Fig.5 PCB surface approximated from waveform detected at LSI leads

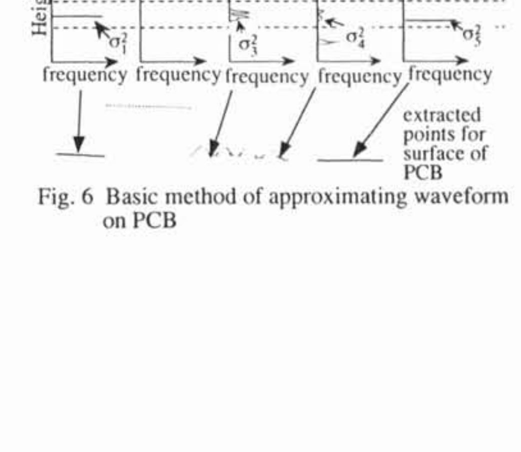


Fig. 6 Basic method of approximating waveform on PCB

$$\sigma'^2_i = \frac{\sum_{j=1}^{m(i)} \left(Y_{i,j} - aX_{i,j} - b \right)^2}{m(i)} \qquad (7)$$

The expected variance of the approximated line $V_y(x)$, attains a maximum value when horizontal position x is at the starting point or ending point of the waveform. The maximum value of $V_y(x)$ is calculated for each waveform and, if it is judged too large, the linear equation is evaluated as unreliable.

An approximated line that has been judged as unreliable is re-calculated using interpolation from other lines that have been judged reliable.

3.2 Calculation of body location

The location of the body of the component is calculated after the determination of the PCB height using both the horizontal and vertical waveforms. First, the body edges are found from each waveform. Since the surface height of the body from the PCB base height is almost the same as the design thickness of the component, threshold height for determining the edges of the body can be decided from the design thickness. Each waveform is scanned from both sides and the first point that exceeds the threshold height is detected as the rough position of body edge (P_e : Fig 7). The center P_c on both sides of the rough edge is calculated, and point P where the angle θ between P_e and P_c assumes the minimum value, is detected as the body edge. The procedure described above is applied to all the waveforms in the horizontal and vertical directions.

After body edges of all the waveforms are detected, edge lines of the body are determined. Usually the top of the body of a component is rectangular, so we applied the caliper method[2)3)] to determine the longitudinal edge lines efficiently. Using this method, the longitudinal edge lines are found as the two parallel lines that satisfy the following conditions (Fig. 8).

(a) All the edge points exists between the two parallel lines.

(b) The distance between the two parallel lines is the shortest distance.

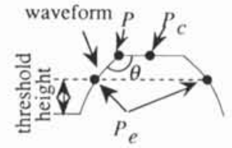


Fig. 7 Edge detection algorithm

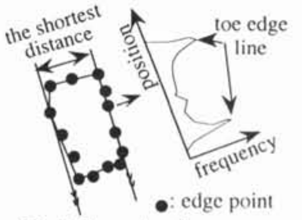


Fig.8 Toe edge line detection algorithm

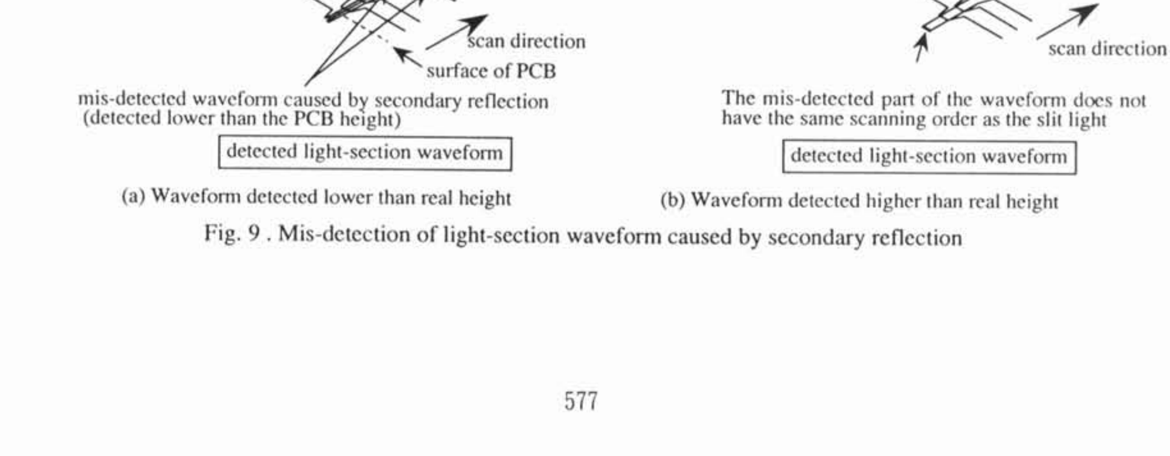
After the longitudinal edge lines are detected, the shorter edge lines are found using the condition that the longitudinal edge lines and the shorter edge lines intersect orthogonally. The rotation angle of the body is calculated from the detected longitudinal edge lines, then all the body edges are projected to an axis parallel to the longitudinal edge line. The first and last peaks of the projected profile are detected as the position of the short edge lines of the body.

Assuming that the top surface of the body exhibits a flat surface, the surface area of the top can be expressed in three-dimensional space as $Z=aX + bY + c$, where parameters a, b, and c, in the expression can be solved using the least squares method. If the target device is a chip, the location of the electrodes in three-dimensional space can be calculated from the approximated rectangle expressed by the longitudinal edge lines, shorter edge lines and the expression shown above, so misplacement and the lift of the electrodes can be calculated with high precision.

3.3 Calculation of lead location

After the location of the body is detected, the rough position of the lead heel is calculated, referring to the shape described by the design data for the component. Waveforms detected around the rough position of the lead heel are selected as representative of the target lead shape.

First, incorrect range data caused by secondary reflections are eliminated from the selected waveforms. Slit light is projected obliquely and is detected by the TV camera just above the PCB. In this configuration, secondary reflection can occur in two ways as follows (See Fig. 9).



(a) Waveform detected lower than real height (b) Waveform detected higher than real height

Fig. 9 . Mis-detection of light-section waveform caused by secondary reflection

(a) Slit light projected on a solder fillet is reflected to the leads and component body. In this case, range data calculated from the reflected part of the waveform are lower than the actual PCB base height.
(b) Slit light projected on a lead is reflected to a solder fillet. Range data calculated from the reflected part of the waveform is extremely high compared with correct range data.

Incorrect range data resulting from (a) is lower than the PCB height. Since any component on the PCB must be higher than the PCB base height, any data that is lower than the detected PCB height is recognized as noise and eliminated. In case (b), secondary reflection can be recognized from the relative position of the neighboring waveforms. If slit light is scanned as shown in Fig. 9, any neighboring waveforms must have the same order as the scanning slit light. If this condition is not satisfied, the waveform is judged to contains noise caused by secondary reflection.

After noise caused by secondary reflection has been eliminated, the location of the lead can be calculated from the previously selected waveforms that are least influenced by noise.

4. Automated Inspection System

Figures. 10 and 11 show the configuration of the system and the overview of the automated inspection system. Normalization of reflectivity and extraction of the light-section waveform are carried out using proprietary curcuit boards on a VME-bus. Using these boards, two light-section waveforms (one each for horizontal and vertical directions) can be detected every frame (16.67ms). All the other procedures of the inspection algorithm are carried out on a micro computer connected to the VME-bus.

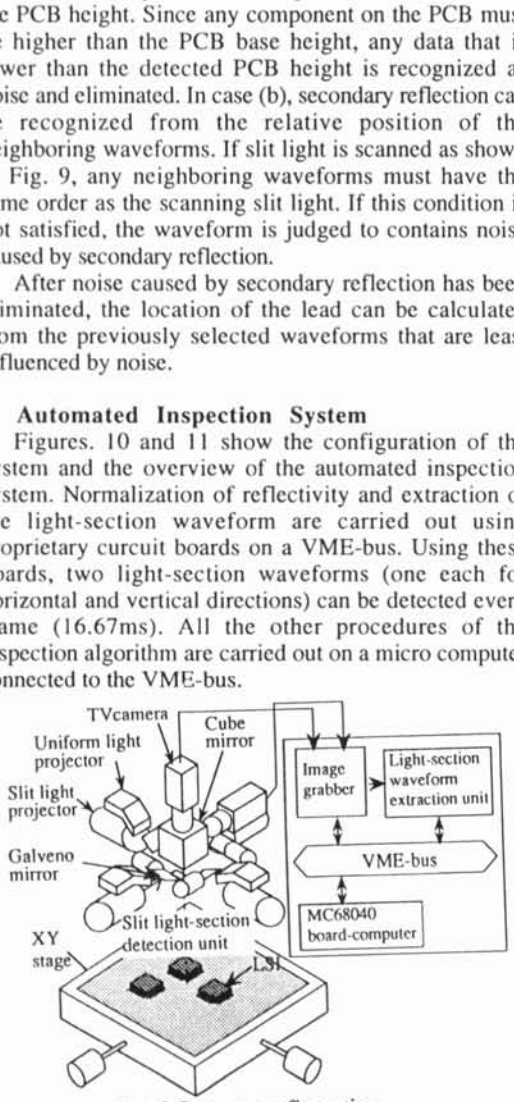


fig.10 System configuration

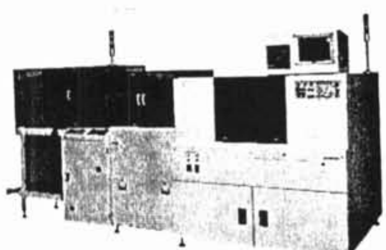


Fig.11 Overview of inspection system

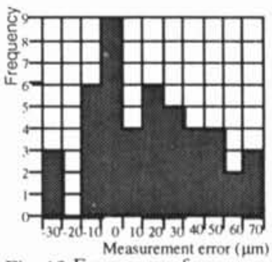


Fig. 12 Frequency of misdetection of height measurement of chip components (N=46)

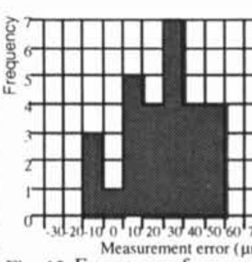


Fig. 13 Frequency of misdetection of height measurement of LSI leads(N=31)

Figures 12 and 13 show the experimental results of accuracy of the height measurement of chip components and LSI leads using the techniques described above. The repeatability of the height measurement (3σ) is 81μm for chip components and 62μm for LSI leads, while the pixel size in the Z direction is 100μm. The maximum error is 99μm for chip components and 95μm for LSI leads.

The developed system has been applied to an actual production line and performance of the system was evaluated. Samples consisting of 22,880 satisfactory points and 212 defective points were inspected. The system achieved a defect detection rate of 100% and a very low rate of false alarms (0.08%) while counteracting the influence of bending of the PCB and secondary reflection from solder fillets.

5. Conclusion

We developed an automated visual inspection system capable of accurately inspecting minute surface mount devices on printed circuit boards. To overcome problems such as bending of the PCB and incorrect range data caused by secondary reflection from solder fillets, a statistical method was developed for approximating the PCB surface. Performance of the inspection system was evaluated and it achieved a 100% defect detection rate with a very low false alarm rate. The system is now being used on an actual production line.

Acknowledgments

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