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Visual Inspection Scheme for Use in Optical Solder Joint Inspection System

Y.K. Ryu* and H.S. Cho**
*Department of Automation and Design Engineering. Korea Advanced Institute of Science and Technology
207-43 Cheongryangridong, Dongdaemoongu,Seoul, Korea, Tel: +02-958-3461 / Fax:+02-968-1638
**Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology
373-1 Kusongdong, Yusonggu, Taejon, Korea, Tel: +42-869-3213 / Fax:+42-869-3210,
e-mail address: hscho@lca.kaist.ac.kr

ABSTRACT

An optical solder joint inspection system(OSJIS) has been developed for the automatic visual inspection of soldered parts on the printed circuit boards. Its advantages over existing techniques include the detection of 3-D shape of specular objects with high reliable and high speed. In this paper, we will propose a solder joint inspection scheme for a prototype of the OSJIS. The inspection scheme is composed of two steps: feature extraction and classification. In the feature extraction step, by scanning a laser beam over the area of solder joints the system obtains two orientation curves representing the quality of soldering condition, and then nine features are extracted from the curves. In the classification step, a neural network classifies the solder joint according to the application requirements by using the features. Experiments were performed for SOP(small outline package)s and QFP(quad flat package)s in insufficient, normal and excess soldering condition. Based upon observation of the experimental results, the proposed inspection scheme shows excellent consistency with visual inspection and a good accuracy of classification performance of 94.2%.

1. INTRODUCTION

Surface inspection of machined parts, printed circuit boards, solder joint surfaces, and plastic sheets are a few examples of industrial tasks that are desirable to have automated because they are laborious for human to perform. In recent years, considerable efforts have been directed toward the development of automated inspection systems.

Several methods for the automation of the visual inspection of solder joint[1-4] defects have been reported, an optical cutting method[5], a method using thermal conductivity[6], and a method using colored illumination [7,8]. However, all of these methods have some limitations. In case of the optical cutting method, specular reflection[9,11] causes a loss of the optical cutting line. When thermal conductivity is used, the heat emission pattern is unstable due to the difference of the soldering condition. In case of the colored illumination, the tired illumination generates color highlighted contours on the soldered joint surface. The shape of the contour was used to inspect the solder joint. This method, however, can only produce the feature of 3-dimensional shape and cannot recover the entire shape of object. To overcome these problems, Ryu and Cho[12-14] proposed an optical solder joint inspection system(OSJIS). The system obtained the shape of solder joint surface by scanning the focused laser beam over the area of solder joint and observing the direction of the reflected beam.

In this paper, we will propose a solder joint inspection scheme. The proposed inspection scheme was performed by two procedures; the teaching procedure and the inspection procedure. In the teaching procedure, the windows which represent the inspection area of solder joints are determined. And, in the inspection procedure, the system obtains the surface orientation curves by scanning the laser beam along two scanning lines: the longitudinal and the lateral scanning line. Then, feature values are extracted from the orientation curves. The quality of solder joints is strongly related to the shape of solder flow, and the features are effective in capturing this shape information. Moreover, the shape of solder joint tends to greatly vary according to soldering conditions, type of electric components, size of joints, and amount of paste cream, etc. Therefore, even if solder joints belong to the same acceptable class of quality, their shapes are different from each other to some extent. This makes it difficult to classify solder joint shapes into distinct groups. Due to this complexity, careful attention is required to define features by which various shapes of solder joint surface are discriminated. Also, classification criteria is difficult to determine, since it can be obtained from a large number of experiments that test the discriminating power of each feature. Therefore, statistical pattern recognition such as minimum distance classification and bayes decision rule does not guaranteed an accurate classification. To overcome such a complex classification task, we have employed an artificial neural network.

This paper presents a solder joint inspection method using an efficient shape extraction technique, and an artificial neural network to classify the defects of solder joint are discussed. We then describe our implementation of the OSJIS to the solder joint inspection.

2. THE OPTICAL SOLDER JOINT INSPECTION SYSTEM

Ryu and Cho[12-14] proposed an OSJIS which detects the surface orientations of specular objects. The sensing system is composed of a GSU(galvanometer scanning unit)[15] which steers the laser beam's incident position, a mirror unit(parabolic mirror and conic mirror) which gathers the reflected beam to its center and a sensing unit whose outer surface is covered by photo diode arrays. A schematic diagram of this system is shown in Fig. 1. In the figure, the ray depicted by solid line represents a ray trace of the reflected light whose intensity is maximum. The sensing unit is positioned at the center of the mirror unit and detects the intensity of reflected light. If the laser is projected on the curved surface of an object by a GSU, the reflected rays from each different surface normal vectors are incident to the different position of the sensing unit. In other words, the direction of the reflected ray can be detected by the sensing unit and, accordingly, the vector normal to the surface of an object can be estimated.

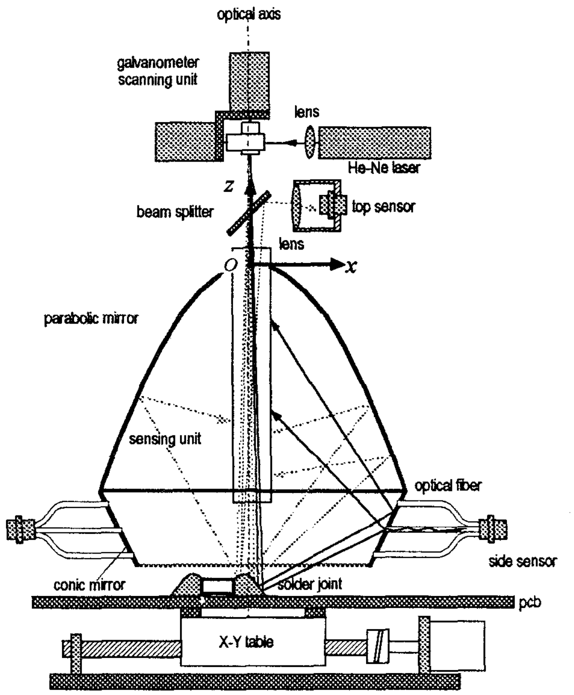


Fig. 1 Schematic diagram of the optical sensing system

Applying these optical properties to the system has the following advantages: First, the sensing range was extended so that the system is able to detect the surface normal vectors of steep specular surface such as excess or insufficient solder joint. Second, smaller number of optical sensors can be placed on surface of the sensing unit so that they are able to effectively detect the direction of the reflected ray. Third, the system is able to obtain the reliable surface orientation because the specular component of reflected light is concentrated on the optical axis. Fourth, the proposed system is not only capable of recovering the 3-dimensional shape, but also able to extract the features of the solder joint shape. When the beam from the GSU is reflected straight back to the sensor unit by passing or outside the conic mirror, the proposed system cannot detect the reflected ray. To distinguish the beam leaving the light source from the beam reflected back to the source, a beam splitter and a top sensor are placed on top of the parabolic mirror. In case when the rays are reflected on the conic mirror, small components of reflected light are detected by the side sensor of optical fiber positioned on the conic mirror. Therefore, by monitoring the optical signal detected on the side sensor, the reflected ray on the conic mirror is distinguished from that on the parabolic mirror.

3. SOLDER JOINT SHAPE RECOGNITION

Fig. 2(a) illustrates the shape of a typical surface-mount solder joint. The flow of solder around the perimeter of the lead relates to the quality of the joint.

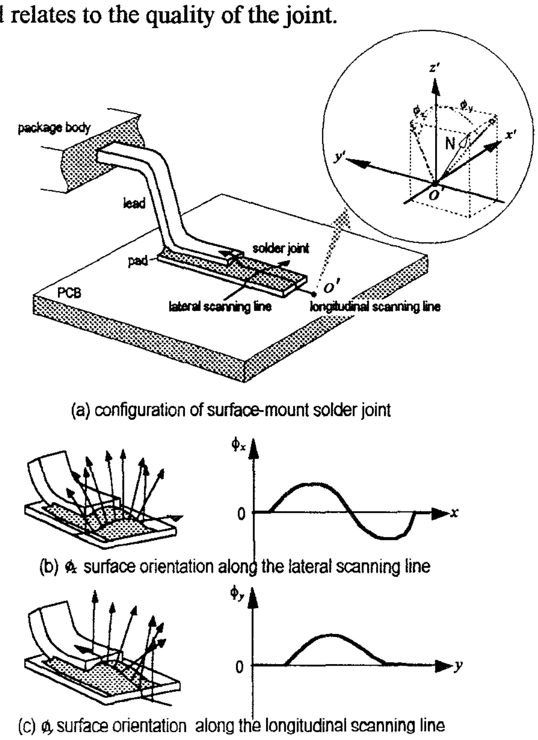


Fig. 2 Surface-mount solder joint and surface orientation curves

To describe the orientation of a surface normal vector, we employ a local coordinates $x'y'z'$ whose origin o' is positioned at the end of a pad. Let x' axis perpendicular to the direction of lead. When the laser beam is traversed along the lateral scanning line, the zenith angle of a surface normal vector projected in $x'z'$ plane is denoted by

ϕ_x. In the case of the longitudinal scanning line, the zenith angle of a surface normal vector projected in $y'z'$ plane is denoted by ϕ_y. As an example, the trends of the surface normal vector orientations ϕ_x and ϕ_y are shown in Fig. 2(b) and 2(c).

3.1 Visual Detection of Soldering Defects

If by using the laser beam the galvanometer scans points by points the laser beam along the lateral scanning or the longitudinal scanning line as shown in Fig. 2, the surface orientations of solder joint along the two different scanning lines are shown in Fig. 3.

In case of a normal solder joint, the solder is uniformly distributed from the lead edge to pad and formed as a concave fillet. Deviation from this profile can result in inferior joints which may ultimately fail. From the figures we see that the surface orientation curves of solder joint represent the quality of soldering condition. Therefore, in the proposed inspection scheme, solder joints are classified by the features extracted from the surface orientation curves measured along two scanning lines.

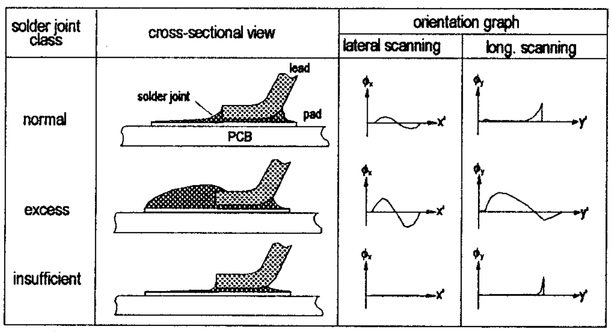


Fig. 3 Relationship between the surface orientation and the cross section of a solder joint

3.2 Classification Features

Selection of features is critical to the success of any classification algorithm. In this study, nine features were chosen from the orientation curves of solder joint surface for each class. The classification scheme identifies two types of acceptable solder joints(QFP, SOP) and three different classes of joints(normal, insufficient, excess). Fig. 4 shows a typical example of the surface orientation curves of solder joint fillets. Fig. 4(a) represents the detected zenith angle during the lateral scanning while Fig. 4(b) represents the detected zenith angle during the longitudinal scanning. To extract the trend of the surface orientations, the curve of Fig. 4(b) is fitted as a line. Defining,

$\tilde{F}$: feature vectors($= [f_1, f_2, \cdots, f_9]$)

$\phi_{x,i}$: zenith angle of solder joint surface at i_{th} position along the lateral scanning line

$\phi_{y,j}$: zenith angle of solder joint surface at j_{th} position along the longitudinal scanning line

$\phi_y^{\max}$: maximum value among the ϕ_y

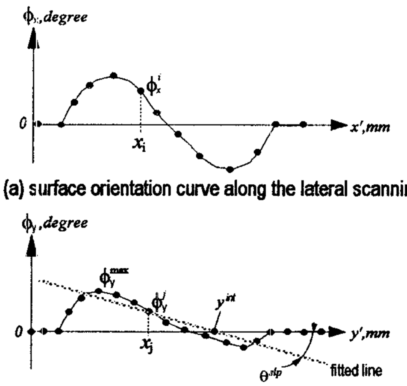
N_x : number of ϕ_x data on the lateral scanning

N_y : number of ϕ_y data on the longitudinal scanning

y^{int} : y *axis-intercept* point of the fitted line

θ^{slp} : slope of the fitted line,

and using these variables, the following nine features can be obtained.



(a) surface orientation curve along the lateral scanning line

(b) surface orientation curve along the longitudinal scanning line

Fig. 4 Typical example of surface orientation curves

In the lateral scanning line, one feature value was estimated as an

absolute area of ϕ_x : $f_1 = \sum_{i=1}^{N_x} |\phi_{x,i} \times x|$.

In the case of the longitudinal scanning line, eight features are chosen as

the area of ϕ_y: $f_2 = \sum_{j=1}^{N_y} (\phi_{y,j} \times y)$

the absolute area of ϕ_y: $f_3 = \sum_{j=1}^{N_y} |\phi_{y,j} \times y|$

the absolute area divided by $\phi_y^{\max}$: $f_4 = f_3 / \phi_y^{\max}$

the number of crossing the 0 degrees of ϕ_y is denoted by f_5

the centroid of ϕ_y : $f_6 = f_2 \Big/ \sum_{j=0}^{N_y} \phi_{y,j}$

the moment of ϕ_y : $f_7 = \sum_{j=0}^{N_y} \phi_{y,j} \times y^2 \Big/ \sum_{j=0}^{N_y} \phi_{y,j}$

the y *axis-intercept* point of the fitted line : $f_8 = y^{int}$

the slope of the fitted line : $f_9 = \theta^{slp}$.

By using these nine features, defects were identified based on the characteristics of the orientation curves.

4. INSPECTION BASED ON NEURAL-NETWORK

Fig. 5 shows the training and classification procedures for the quality of solder joints from the obtained features by using neural networks. Before the actual classification is conducted, training is performed to determine the parameters necessary to construct the appropriate neural network classifier. The training data are obtained from the experiments conducted for various soldering conditions. They include the feature values mentioned in the previous, and the solder joint condition. The feature values($f_1, f_{2,} \cdots f_9$) and the integer value indicating the solder joint condition(insufficient:0, normal:1, excess:2) are taken the input and output parameters of the neural network classifier, respectively, as shown in Fig. 5. In the beginning of the training, the classified results may be largely different from the results of human inspector, because construction of the appropriciate neural network classifier is not completed. To reduce these differences, the set of network parameters is corrected according to the training algorithm. The classified results are recalculated from the recorrected network parameters and are compared with the results of human inspector.

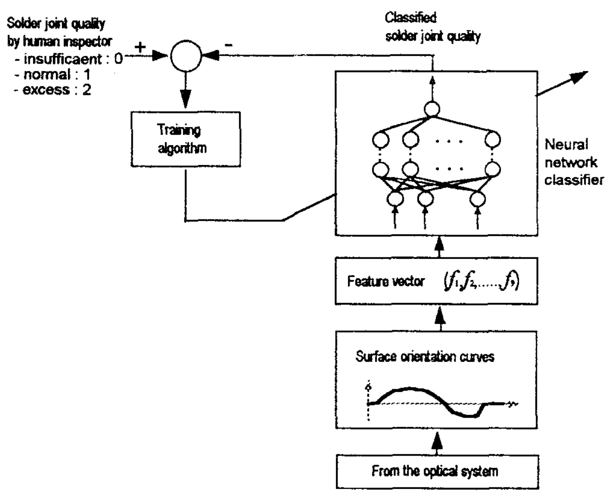


Fig. 5 Training and classification procedures for the quality of solder joints

In this study, a semi-linear feedfoward network [16,17] is implemented to learn the mapping characteristics and then to classify the solder joint quality from the estimated features. The network consists of a large number of nodes arrayed in layers. A node denotes own processing element, and a line between the nodes represents the connecting link that amplifies or attenuates the outputs through a weighting factor. Except for the input layer nodes, the input to each node is the sum of the weighted outputs of the nodes in the proceeding layer. Each node is activated according to the respective input, the activation function and the bias of the node, resulting in the node output.

5. EXPERIMENTAL RESULTS

The proposed system was demonstrated with the results obtained from inspection of two commercially manufactured PCB's. There were 360 inspection points per PCB. A photograph of the implemented system is shown in Fig. 6.

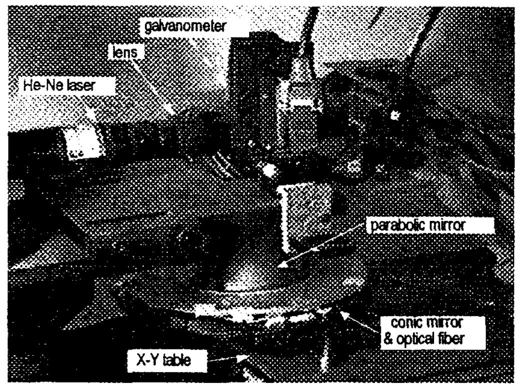
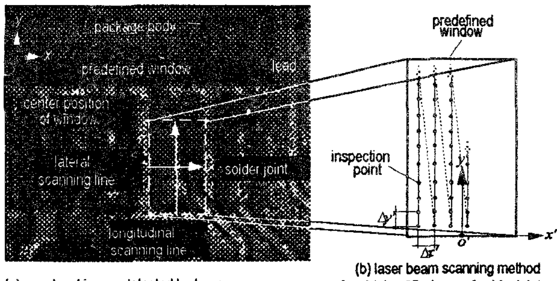


Fig. 6 A photograph of the implemented system

5.1 Laser Beam Scanning

The solder joint inspection was performed by two procedures; the teaching procedure and the inspection procedure. In the teaching procedure, gray level image of the scanning area was used to determine windows which represent the inspection area of solder joints. The gray level image was obtained by scanning the laser beam over the maximum scanning area($8.0 \times 8.0 mm^2$) and observing the signal of the top sensor placed on the top of the parabolic mirror. By using this image, the position and the size of windows were determined such that individual solder joints are positioned within predefined windows for inspection. An example of the gray level image and predefined window were shown in Fig. 7(a). In the inspection procedure, the proposed system detects the orientation curves ϕ_x, ϕ_y by scanning the laser beam along the lateral and the longitudinal scanning lines. As shown in Fig. 7, the position of lateral and longitudinal scanning lines were determined by the center position of the predefined window.

In case that the system measures the surface profile of solder joint, the GSU scans the area of the predefined window in a raster scan manner as shown in Fig. 7(b). Here, the scanning point first moves by distance of $\Delta y'$ in the positive y' direction, then by distance of $\Delta x'$ in the positive x' direction and moves continuously in the same manner.

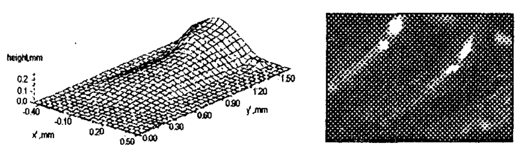


(a) gray level image detected by top sensor (b) laser beam scanning method for obtaing 3D shape of solder joint

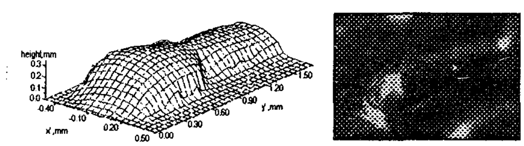
Fig. 7 Grey level image detected by the top sensor and laser beam scanning method

5.2 Experiments

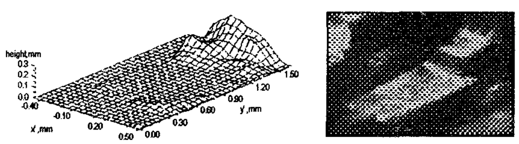
To obtain the three dimensional shapes of solder joint, a series of experiments was performed on the three classes such as normal, excess and insufficient soldering conditions. The normal joints were wave soldered with flaws produced by manual modification of normal joint. Fig. 8 shows the three dimensional shapes of SOP recovered from the detected orientation data and the photographs of the corresponding actual fillet shape.



(a) normal solder joint



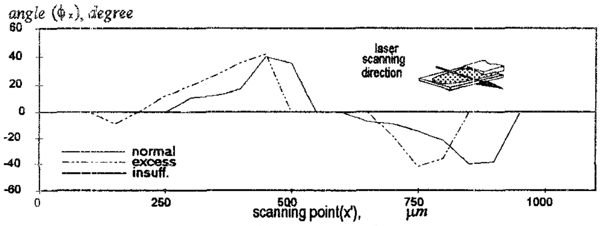
(b) excess solder joint



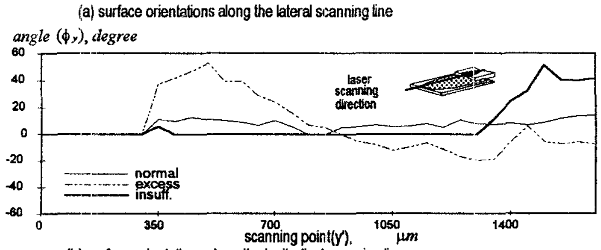
(c) insufficient solder joint

Fig. 8 Recovered three dimensional shape of the SOP solder joints

The window size was $1.6 \times 1.0mm^2$ and scanning interval ($\Delta x', \Delta y'$) was $50\mu m$. The recovered shape well resembles the actual shape. To inspect the solder joints automatically, a X-Y table was used in the sensing system. Fig. 9 show example of the estimated orientation curves ϕ_x and ϕ_y of SOP along the lateral and longitudinal scanning lines. The figures show that the defective solder joints such as the insufficient and the excess have the different form of orientation curve compared with the normal case.



(a) surface orientations along the lateral scanning line



(b) surface orientations along the logitudinal scanning line

Fig. 9 Variation of surface orientations of SOP

Since the two types of SMD, namely QFP and SOP, are different from each other in mapping characteristics from the feature vectors, the neural network classifier were individually designed. In training the classifier, the learning and the momentum gains[17] were chosen to be 0.9 and 0.7, respectively. Their selection was based on the speed of convergence and the oscillation phenomena of the classification error[17]. The number of iterative training runs was set to be 10000. More detail information for the learning procedure and the architecture of the neural network mentioned in reference 18.

Table 1 shows the classification results of all the data sets when 100 sets were used for training and 720 sets were tested for the neural network architectures of 9-4-8-1 nodes for the QFP and 9-6-6-1 nodes for the SOP.

Table 1 Inspection Results

board number	part type	solder joint class	number of joints	classification result	
				CC(CC%)	GB(GB%) / BG(BG%)
Board 1	QFP	normal	83	69(83.1%)	14(16.9%)
		excess	57	54(94.7%)	3(2.5%)
		insufficient	60	60(100.%)	
	SOP	normal	77	75(97.4.%)	2(2.6%)
		excess	38	36(94.7%)	3(3.6%)
		insufficient	45	44(97.8%)	
Board 2	QFP	normal	80	75(93.8%)	5(6.3%)
		excess	60	50(83.3%)	9(7.5%)
		insufficient	60	60(100.%)	
	SOP	normal	75	70(93.3%)	5(6.7%)
		excess	40	39(97.5%)	1(0.0%)
		insufficient	45	45(100.%)	

To measure the performance of the statistical techniques using the nine features and the three classes, the following three quantities are calculated:

CC - the number of joints correctly classified

GB - the number of acceptable joints(normal case) classified as unacceptable(insufficient and excess case).

BG - the number of unacceptable joints classified as acceptable.

The percentage of the correct classification shows about 94.2%, only 5.8% of the joints were incorrectly classified. This error rate is not sufficient to apply in industrial application. This error rate was due to the followings. The computer is supplied with a map of the circuit board layout, and joints on the board are automatically positioned over the sensing device by means of an x-y servo controlled table. Then, the system scans laser beam along the scanning lines and obtains the orientation curves. The two scanning lines were predetermined in the teaching procedure. If the position error of the x-y table was occurred during the inspection procedure, the orientation curves provided the incorrect information for shape of solder joint. That is, to guarantee the precision scanning, the study on the algorithm which adjusts the position of the scanning lines with respect to the position error of the x-y table was required.

6. CONCLUSIONS

In this paper, we have introduced a solder joint inspection scheme of the OSJIS that extracts feature values from orientation curves and classifies many solder joints into three different quality classes by using a neural network classifier. Inspection was performed for SOPs and QFPs in insufficient, normal and excess conditions. The following conclusions can be drawn from the experimental results:

First, the proposed system shows reasonable accuracy of classification for solder joint defects. In this study, the percentage of the correct classification was about 94%.

Secondly, to classify the solder joint, we proposed nine features extracted from the surface orientation curves.

Thirdly, The classification results of this scanning scheme are highly dependent on the position accuracy of X-Y table. In a practical application with the OSJIS, the scanning scheme for obtaining the feature values should be considered the position error of X-Y table.

Finally, in real field, many defective solder joints can be found in actual production PCBs. Here, we considered only three classes such as normal, insufficient, excess soldering condition. Some other defects such as bridges, overhang, high lead, no solder, no component may need a different type of an inspection system. Further research is required to develop a system that can detect such defects.

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