Abstract—The solder paste depositing inspection is very important in the process of Surface Mounting for print circuit board (PCB). An integrated inspection approach based on the machine vision was presented in the study. The method developed in this paper can identify the major defects of the solder paste depositing, such as displacement, deficiency, excess, bridge and overflow. Firstly, position compensation is applied to improve the inspection accuracy. Secondly, an image enhancement algorithm based on the texture is developed, which can enlarge the differences of the grayscale values between the PCB images and the solder paste images. Thirdly, the images of the printed PCB are analyzed by using the particle analysis method and the two-dimensional (2D) inspection results are obtained. A pseudo three-dimensional (3D) inspection approach is further proposed to identify the defects in the 3D state. Finally, experiment results are presented, which illustrate the validity of the approach.

Keywords—machine vision; inspection; solder paste depositing

I. INTRODUCTION

The screen printer is one of the key equipment of the SMT industry [1]. Its performances directly affect the subsequent handling and the product quality. Thus, it is necessary to inspect the Printing Circuit Board (PCB) after screen printing. It was reported that 50-70% PCB assembling defects were from the stage of solder paste depositing [2]. The inspection of the solder paste depositing is one of the most important stages in the process control of SMT production line [3]. The defects of solder paste depositing include displacement, deficiency, excess, bridge, overflow, and so on. The typical inspection methods for the solder paste depositing include manual inspection, the laser scan inspection [4] and the inspection based on machine vision [5]. The manual inspection is a popular method because of its simple operation; however, it has many serious disadvantages, such as low efficiency and high probability of misjudgment. The laser scan approach provides more detailed defect information because of its 3D inspection function. However, the 3D model of the solder paste is acquired by point or line scans of a laser [6], so the inspection very slowly. Furthermore, the laser scan device is expensive. The method based on machine vision has the merits of high inspection accuracy and speed, thus it can be used in PCB solder paste depositing inspection of the screen printer. Moreover, no extra hardware cost is needed, because the approach can make full use of the existing hardware resource of the vision system of the screen printer.

The main procedures of solder paste inspection based on machine vision include image acquisition, image enhancement and defect analysis. In order to improve the performance of this inspection approach, the position compensation method is utilized to determine precise position before acquiring PCB images. An image enhancement method based on texture is developed, which can enlarge the differences of the grayscale values between PCB base images and solder paste images. In addition, the printed PCB images are analyzed by using the 2D inspection algorithm based on the particle analysis method. A pseudo 3D inspection approach is applied to inspect the defects of solder paste depositing in volume. Finally, the experiment results illustrate the validity of the proposed method.

II. THE SCREEN PRINTER WORKFLOW

As one of the key equipments, the main function of the solder paste screen printer is to deposit the solder paste on PCB precisely. The screen printer is composed of conveyer, squeegee system, machine vision system and planar 3 degrees of freedom (DOF) adjusting unit, etc. The machine vision system is used to align the PCB and the stencil, and to inspect solder paste depositing. A cycle of work flow of the screen is shown in Fig. 1. The position and pose of the PCB is not fixed after being loaded by the conveyer. Thus, the machine vision system need to measure the marks positioning by pattern matching so that the printer can find the differences of the position and pose of the PCB and the stencil. Then, these differences can be compensated by use of the planar 3-DOF adjusting unit.
III. POSITION COMPENSATION

As shown in Fig. 1, the inspection program needs to be configured prior to inspection. The inspection program configurations include the setting of inspection sites, threshold values, image enhancement parameters, and so on. The inspection performance will be affected by the differences of the position and the pose between the PCB for configuration and the inspecting one. Here, a position compensation method is used to compensate the differences of the position and pose comparing with the PCB prior to the images acquisition. These differences are approximated equal to coordinates difference of the two marks of the PCBs, as shown in Fig. 2. The $\theta$ and $s$ can be calculated by the following equation:

$$
\begin{bmatrix}
    m_i' = Tm_i + s \\
    m_j' = Tm_j + s
\end{bmatrix}
$$

where $m_i$ and $m_j$ represent the coordinates of mark1 and mark2 in the inspection program configuration, respectively. $m_i'$ and $m_j'$ are the coordinates of mark1 and mark2 in inspection, respectively. $s$ is the shift vector and $s=(Ax, Ay)^T$. $T$ is the rotation matrix which can be expressed as:

$$
T = \begin{bmatrix}
    \cos \theta & -\sin \theta \\
    \sin \theta & \cos \theta
\end{bmatrix}
$$

From equation (1), one can find that there are 3 unknown variables and 4 equations. The $\theta$ can be calculated easily by using the trigonometric function, then, the over constrained problem can be solved by using the least square method. The applying of the method of position compensation method can improve the inspection accuracy.

IV. IMAGE ENHANCEMENT

Compared with the solder paste and the base of the PCB, the grayscales value of the pad is much higher. The difference can be distinguished easily by using a threshold function. But the grayscales of solder paste and the base of PCB are very similar, and their histograms are even partially overlapped. To accurately distinguish the image of solder paste and the base of PCB, an algorithm based on texture was presented in this section.

![Image of solder paste. The (a) is the solder paste image by magnified 4 times, pitch=0.3mm, and the (b) is the solder paste image acquire by the vision system, pitch=1.0mm.](image_url)

As shown in Fig. 3 (a), the solder paste is mainly composed of little balls and its image has pit texture. However, the image of the PCB base and pad is very smooth. According to this feature, the images can be enhanced by increasing the solder paste grayscale value.

It is well known that the texture of the image can be evaluated by an n-order statistical moment of the histogram which can be expressed as [7]

$$
\mu_n = \sum_{i=0}^{L-1} (z_i - m)^n p(z_i)
$$

where $z_i$ is a random variable indicating intensity, $p(z_i)$ is the histogram of the intensity levels in a region, $L$ is the number of possible intensity levels, and $m$ is the mean value of grayscale.

However, the histogram does not externalize the position of pixel information. Thus, the images need to be separated into $x \times y$ parts before using n-order statistical moment, $\mu_n(x, y)$ is the n-order value of row $x$, column $y$ part of the image. The enhancement algorithm base on n-order statistical moment can be written as...
\[
g(i, j) = f(i, j) + \mu(x, y) \\
g(i, j) = f(i, j)
\]

where \(f(i, j)\) is the image without enhancement, \(g(i, j)\) is the image with enhancement, and \(h\) is a weight.

This algorithm can enhance the images by increasing the grayscale of the solder paste part, so the solder paste and the base of PCB can be distinguished easily. The enhanced images can be separated into pad particle, solder paste particle and dark loop around solder paste particle by using a multi-thresholds function.

V. INSPECTION METHOD

A. 2D Inspection Based on Particle Analyze method

The Particle analysis method has many advantages, such as simple and high speed. Furthermore, many particle factors are shift, scaling and rotation invariant. Thus, the particle analysis approach is suitable for 2D inspection.

The defects of solder paste depositing can be inspected by analyzing the position, area and shape of the particles of solder paste and pads, which can be expressed by the following factors [8].

Center: center position of the particle.
\(A\): area of the particle.
\(A_h\): area of the hole in the particle.
\(A_{CH}\): Area of the particle Convex Hull.
\(P\): Length of the outer boundary of the particle.

Hydraulic Radius: The particle area divided by the particle perimeter.

Heywood Circularity Factor: \(HC=\rho(2\pi A)\), Perimeter divided by the circumference of a circle with the same area. The closer the shape of the particle is to a disk, the closer the Heywood circularity factor is to 1.

\(I_o\): moment of inertia with respect to the \(x\) axis.
\(I_y\): moment of inertia with respect to the \(y\) axis.

Type Factor: \(TF = A^2 / (4\pi \cdot sqrt(I_{xx} \cdot I_{yy}))\), the type of the particle.

Packing Ratio: \(PR = A / (A + A_h)\), it is used to judge whether deficiency of solder paste exist or not.

The values of the factor mentioned above are inputted to the defect analyzer after being calculated. The defect analyzer is used to determine the defect existing or not by using a synthesis weight method. The defect analyzer can find out the defects of the solder paste, such as displacement, deficiency, excess, bridge and overflow. Though the 2D inspection method can determine most of the solder paste depositing defects, it can not inspect the volume defects of solder paste depositing.

B. Pseudo-3D inspection

Note that the 3D inspection algorithm can find out the defects of paste dose in volume, however, it needs a laser scanner and it is relatively slowly. To overcome these disadvantages, a pseudo-3D inspection approach was used in order to calculate the volume ratio by creating a simple 3D model of the solder paste depositing.

As shown in Fig. 3 (b), there is a dark loop around the solder paste. One reason for the dark loop is that the PCB is illuminated by the coaxial illuminator of the vision system, thus the ray is perpendicular to the PCB according to the principle of reflection. If only the ray is perpendicular to the surface, the reflected ray is captured by the camera, so the image is bright; otherwise the image is dark, as shown in Fig. 4 (a).

![Figure 4: 3D Model of Solder paste. The (a) is the side view and the (b) is the top view.](image)

As shown in Fig. 4(b), \(A_p\) is the area of particle of the pad, \(A_h\) is the area of particle of the solder paste and \(A_d\) is the area of particle of the dark loop around the solder paste. The volume ratio of the solder paste deposit can be obtained by

\[V_s / V_t = 1 / 2(A_p + (A_h + A_d) \cdot h (A_h \cdot h) = (1 / 2A_h + A_d) / A_h \]

where \(V_s\) represents the actual volume of the solder paste and \(V_t\) is the theoretical volume of the solder paste.

The defects can be found out by a threshold according to the volume ratio. This pseudo-3D inspection method can be carried out fast compare with the laser scanner inspection.

VI. EXPERIMENT AND ANALYSIS

In order to verify the performance of the integrated method, some experiments have been carried out. The machine vision system was shown in Fig. 5, the vision system includes a NF-PCI409 image acquire card, two Tel-CO6630I cameras, two AlwyVision-COR30 coaxial illuminators. The solder paste is lead free.
Fig. 7 shows the misalarm rates of solder paste depositing defects for four kinds of electronic component. From this figure, one finds that the misalarm rates reduced by using position compensation and texture-based image enhancement method.

Table I shows the misalarm rates of five defects of solder paste depositing for four electronic components, two kinds of chip and two kinds of ICs. One can finds that the misalarm rate of the displacement defect is the highest and is related to threshold value set by user. Whilst, the defect misalarm rate of the small and round pads is higher.

The results of pseudo-3D inspection are shown in Fig. 8. Using pseudo-3D inspection algorithm measure the chip 1005 and chip 0402 fifteen times. The results show that the fluctuation range of the volume ratio described in equation (2) is from 50 to 110. Therefore, it can be concluded that the 3D inspection method is stable.

<table>
<thead>
<tr>
<th>Defect type of solder paste</th>
<th>Chip 1005</th>
<th>Chip 0402</th>
<th>IC QFP</th>
<th>IC BGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Deficiency</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Excess</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Bridge</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Overflow</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 6. Histogram of the image of the solder paste and PCB

Figure 8. Pseudo-3D Inspection Results
VII. CONCLUSION

An integrated inspection method of solder paste depositing based on the machine vision was presented. To improve the positioning precision of the inspection locations, the position compensation method was performed. A texture-based algorithm is also proposed to enlarge the differences of the grayscale values between the solder paste and the PCB base, which makes the multi-threshold method more stable and precise. Furthermore, the 2D and pseudo-3D inspection approach can be used to inspect the solder paste depositing defects effectively. The experiment results demonstrated the feasibility and robustness of the integrated method.

REFERENCES


