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Inspection Method by Comparing CAD Figure with Processed Image

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We propose the recognition method of bridge soldering base metal on the circuits by comparing CAD figure and input image of image processing to locate the soldering iron tip accurately to secure the high quality. Firstly, three dimensional CAD assembly drawing of circuits which are assembled perpendicularly in each other is projected on an imaginary two dimensional screen which is vertical to the optical axis of the camera. The projected image is used as the standard CAD figure to inspect the location of the bridge soldering base metal. The positions among the bridge soldering base metals show the line state. So this line (connecting line) is used as the reference line to inspect the location of the bridge soldering base metal. The characteristics of the standard figure are represented by the connecting line, edge line and center points of base metal. Secondly, the position and gradient of connecting line among bridge soldering base metals in the input image is estimated. And the position of base metal and assembly accuracy of circuit units are calculated by comparing the shape and position of each base metal with its standard figure based on the connecting line. Furthermore, the length between the opposite edges of the base metals are calculated to inspect the positions and the assemble accuracy of circuit units.

1. INTRODUCTION

In the case of a soldering process, the positions of circuit units which are assembled perpendicularly to each other should be estimated accurately to increase the quality of soldering[1]. Image processing is used to inspect the soldering position in two dimensions. But image processing is not used to recognize positions of assembled circuit units in three dimensions. Three dimensional CAD information (3D CAD) are used to recognize the sort, position and direction of assemble circuit units in the intelligent robot system, but it is not used to inspect the bridge soldering base metals which are assembled perpendicularly in each other.

So, we propose the recognition method of the location of bridge soldering base metal by comparing CAD figure and input image by image processing.

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2. STANDARD FIGURE BY CAD

The 3D CAD informations, that is, vertexes and planes in the DXF file[2] are used to make a standard figure for the bridge soldering base metal as follows.

(1) A virtual space showed in Fig. 1 is set in the computers. The coordinate system of the virtual space is defined as (IX,IY,IZ), and IZ is defined as the axis which is passed though the focus of camera. The coordinate system of an input image of the image processing is defined as (i,j).

(2) 3D CAD figure is rotated and moved in the virtual space. The axis (IX) is fixed to the connecting line of bridge soldering base metal and the origin of the coordinate system (IX,IY,IZ) is fixed to the center of the connecting line. And rotated 3D CAD figure is mapped on the imaginary screen which is vertical to the optical axis of the camera and whose position is put as $(0,0,SC)$. So, 3D CAD figure[3] is transformed into the two dimensional figure (2D figure) which is seen from the position $(0,0,D)$ of camera.

(3) The transformed 2D figure is defined as the standard figure (Fig. 2). The circuit units in the standard figure are defined as P_l $(l=1,2)$ and base metals in the standard figure are defined CPR_{ls} $(s=1,2,\cdots,NR_l)$. CH_{ls}, CL_{ls} (CLX_{ls},CLY_{ls}) and $CR_{ls}(CRX_{ls},CRY_{ls})$ are defined as the height, the left edge and the right edge of the base metal. And the center of base metal $PS_{ls}(PSX_{ls},PSY_{ls})$ is determined by CL_{ls} and CR_{ls} by the equation (1).

$$PSX_{ls} = (CLX_{ls} + CRX_{ls})/2 \quad , \quad PSY_{ls} = (CLY_{ls} + CRY_{ls})/2 \qquad (1)$$

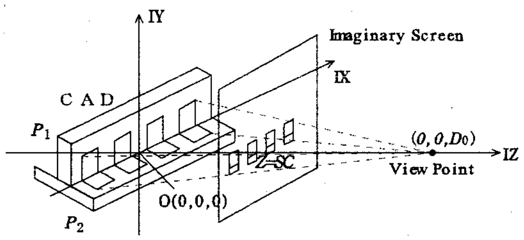

Fig. 1 Location of 3D CAD figure and imaginary screen

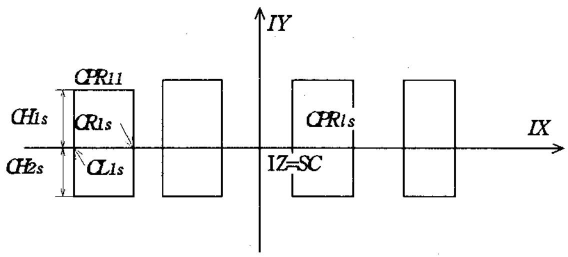

Fig. 2 Standard figure on imaginary screen

3. CHARACTERISTICS OF INPUT IMAGE

3.1 Connecting Line

The connecting line is estimated from the input image of the bridge soldering base metal. The connecting line in the input image is showed as a thick line. The coordinates of the upper and lower sides of the connecting line are estimated by input image. Their coordinates of j axis at the point a on i axis are defined as UJ_a and DJ_a. And the center coordinate (M_a) of connecting line at the point a on i axis is calculated by the equation (2).

$$M_a = (UJ_a + DJ_a)/2 \qquad (2)$$

The equation of the connecting line is estimated from the point (a,M_a) by the linear regression method as the equation (3).

$$j(i) = a_0 i + b_0 \qquad (3)$$

3.2 Center of Base Metal

The base metal in the input image is showed as PR_{ls} $(s=1,2,\cdots,NN_l)$. The center of the base metal is estimated from the edge of base metal of the input image.

3.2.1 Recognition of Soldering Base Metal Based on Connecting Line and Noise Elimination

(1) A line which crosses the connecting line vertically is given by the equation (4) at the point (i_1,j_1) on the connecting line.

$$i=i_1-a_o(j-j_1) \qquad (4)$$

For the base metals (PR_{1s}) in the upper side of the connecting line, the point (ii, jj) is satisfied the equation (4) and $jj \leqq jj_0$. And the number $(NS_{1s}(i_1))$ of points which satisfy $S(ii, jj)=255$ is calculated by the equation (5) using the binary image $(S(ii, jj))$ [4].

$$NS_{1s}(i_1)=\left\{\begin{array}{l|l}\text{The number of points} & jj\leqq j_0\\ \text{which satisfy } S(ii,jj)=255 & ii=i_1-a_0(jj)\end{array}\right\} \qquad (5)$$

For the base metal in the lower side of the connecting line, the number $(NS_{2s}(i_1))$ is calculated by the equation (6).

$$NS_{2s}(i_1)=\left\{\begin{array}{l|l}\text{The number of points} & j_0\leqq jj\\ \text{which satisfy } S(ii,jj)=255 & ii=i_1-a_0(jj)\end{array}\right\} \qquad (6)$$

(2) The base metal is determined in the input image by comparing $NS_{ls}(i_1)$ and TS showed in Fig. 3 . Where, the limited value is defined as TS.

① If $NS_{ls}(i_1) \geqq TS$, the line passes though the base metals.

② If $NS_{ls}(i_1) < TS$, the line does not passe though the base metal, and $S(ii, jj)$ is put as 0.

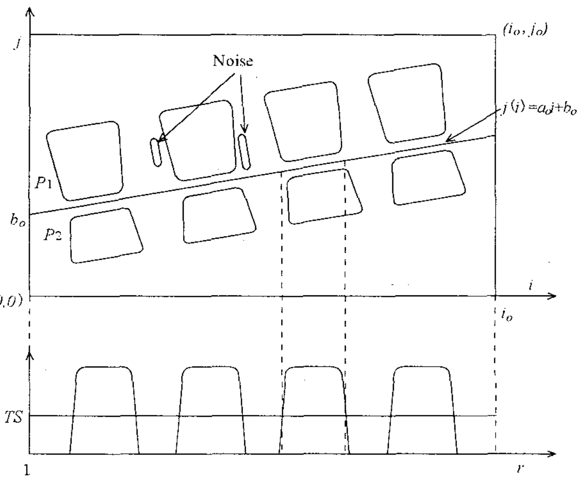

Fig. 3 Range of soldering base metal and noise elimination

3.2.2 Edge of Base Metal

The edge of base metal (PR_{ls}) is estimated by comparing $NS_{ls}(i_1)$ and TS. The left edge (RC_{ls}) is calculated by the equation (7) showed in Fig. 4 . In the same method, the right edge (DC_{ls}) is calculated by the equation (8). And the coordinates of RC_{ls} and DC_{ls} on the connecting line are defined as $RC_{ls}(IRI_{ls},IRJ_{ls})$ and $DC_{ls}(IDI_{ls},IDJ_{ls})$.

$$NS_{ls}(RC_{ls}-1) < TS \leqq NS_{ls}(RC_{ls}) \qquad (7)$$

$$NS_{ls}(DC_{ls}) \geqq TS > NS_{ls}(DC_{ls}+1) \qquad (8)$$

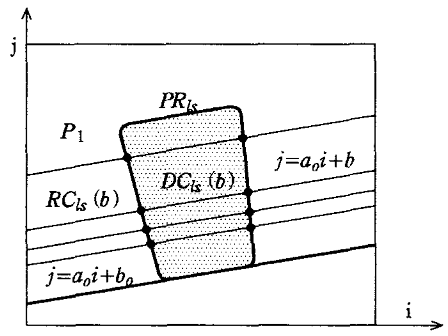

Fig. 4 Edge of base metal

3.2.3 Center of Base Metal on Connecting Line

The center $(PLC_{ls}(PMI_{ls},PMJ_{ls}))$ of the base metal on connecting line is estimated using the coordinates of the left and right edge by the equation (9). And the average coordinate $(AC_o(CI_o,CJ_o))$ of the all centers (PLC_{ls}) is calculated by the equation (10).

$$PMI_{ls}=(IRI_{ls}+IDI_{ls})/2 \quad , \quad PMJ_{ls}=(IRJ_{ls}+IDJ_{ls})/2 \qquad (9)$$

$$CI_0=\sum_{l=1}^{2}\sum_{p=1}^{NR_l}PMI_{ls} \,/\, (NR_1+NR_2) \quad , \quad CJ_0=\sum_{l=1}^{2}\sum_{p=1}^{NR_l}PMJ_{ls} \,/\, (NR_1+NR_2) \qquad (10)$$

3.2.4 Center of Base Metal

A vertically line which passes though the point PLC_{ls} and crosses the connecting line vertically is estimated. The upper and lower edges of base metal are searched on the vertically line. And the upper and lower edges of base metals are defined as $CU_{ls}(CUI_{ls},CUJ_{ls})$ and $CD_{ls}(CDI_{ls},CDJ_{ls})$. And the middle point of them is defined as the center of base metals. The center of base metal is defined as PC_{ls} (PCI_{ls},PCJ_{ls}).

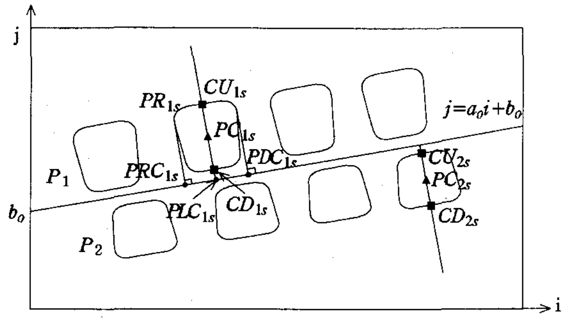

Fig. 5 Center of soldering base metal

4. INSPECTION OF LOCATION OF BASE METAL

The assembled angle and the gap between bridge soldering base metals which are assembled perpendicularly to each other are influenced to the connecting line that is recognized by comparing the standard figure with the input image. So the standard figure is adjusted to the size and direction for the input image.

4.1 Adjusting Standard Figure to Input Image

The standard figure is varied the size and the direction to coincide the input image.

4.1.1 Size of Standard Figure

The center of the standard figure should be adjusted to the centers PC_{ls} which is estimated by the input image. The view point D_0 is estimated as follows.

(1) The distance $(d(PC_{ls},PC_{ls'}))$ between centers of base metals on the P_1 and P_2 in the input image is calculated by the equation (11).

$$d(PC_{ls},PC_{ls'})=\sqrt{(PMI_{ls}-PMI_{ls'})^2+(PMJ_{ls}-PMJ_{ls'})^2} \qquad l=1,2\ ,\ S=1,2,\cdots,NR_l \tag{11}$$

(2) The center of the base metal on the standard figure is defined as PS_{ls} (PSX_{ls},PSY_{ls}). This center (PS_{ls}) is corresponded to PC_{ls} of the input image. And the distance $(DD(PS_{ls},PS_{ls'}))$ between centers of base metal on the standard figure is calculated by the equation (12).

$$DD(PS_{ls},PS_{ls'})=\sqrt{(PSX_{ls}-PSX_{ls'})^2+(PSY_{ls}-PSY_{ls'})^2} \qquad l=1,2\ ,\ S=1,2,\cdots,NR_l \tag{12}$$

(3) The distance ratio (R_c) of the standard figure and the input image is calculated by the equation (13). The average of all combinations is calculated to improve the accuracy. And the position D_o of the camera is calculated by the equation (14) using the distance ratio R_c.

$$Rc=\left\{\sum_{\substack{S'=1\\S'\neq S}}^{NR_1}\sum_{S=1}^{NR_1}d(PC_{1s},PC_{1s'})\ /\ DD(PS_{1s},PS_{1s'})\right\}\ /\ NR_1(NR_1-1) \tag{13}$$

$$+\left\{\sum_{\substack{S'=1\\S'\neq S}}^{NR_2}\sum_{S=1}^{NR_2}d(PC_{2s},PC_{2s'})\ /\ DD(PS_{2s},PS_{2s'})\right\}\ /\ NR_2(NR_2-1)$$

$$Do=\frac{SC}{1-Rc} \tag{14}$$

4.1.2 Direction of Standard Figure

The center of base metal on connecting line of standard figure is defined as PS_{ls} (PSX_{ls},PSY_{ls}). This center (PS_{ls}) is corresponded to one (PLC_{ls}) of the input image. And the point of average $(AD_o(DX_o,DY_o))$ is calculated by the equation (15) from all centers $(PS_{ls}(PSX_{ls},PSY_{ls}))$. The Angle (θ_z) between the connecting line (the equation (3)) and axis i is calculated by the equation (16). And the standard figure is rotated θ_z to overlap the input image at the point $AD_0(DX_0,DY_0)$.

$$DX_0=\sum_{l=1}^{2}\sum_{p=1}^{NR_l}PSX_{ls}\ /\ (NR_1+NR_2) \quad , \quad DY_0=\sum_{l=1}^{2}\sum_{p=1}^{NR_l}PSY_{ls}\ /\ (NR_1+NR_2) \qquad (15)$$

$$\theta_z=tan^{-1}(a_0) \qquad (16)$$

4.2 Inspection of Assemble Accuracy

The standard figure is compared with the input image to inspect the assemble accuracy and judge the quality of the bridge soldering base metals. And the position of iron tip and soldering motion of a robot are determined using these results.

4.2.1 Assemble Quality of Soldering Base Metals

The quality of an article is judged by the assemble accuracy. The reference points of the input image and the standard figure are defined $AC_0(CI_0,CJ_0)$ and $AD_0(DX_0,DY_0)$ which are the position of average by all centers of base metals on the input image and the standard figure. The maximum gap (MD) between the center on the connecting line of standard figure (PS_{ls}) and input image (PLC_{ls}) is calculated by the equation (17).

$$MD=\max_{\substack{l=1,2\\ 1\leqq s\leqq NR_l}}\{LL_{ls}\} \qquad (17)$$

$$\text{where } LL_{ls}=\sqrt{(PMI_{ls}-PSX_{ls}+(CI_0-DX_0))^2+(PMJ_{ls}-PSY_{ls}+(CJ_0-DY_0))^2}$$

(1) If $MD \leqq R$, this circuit unit is good conditions and continue the follow process.

(2) If $MD > R$, this circuit unit is defective and the unit is not performed the soldering process.

Where, R is defined as a permitted limit.

4.2.2 Gap Between Two Circuit Units

The positions $ARC_l(ACI_{ls},ACJ_{ls})$ and $ADC_l(ADX_{ls},ADY_{ls})$ (l=1,2) of average are calculated by (18) using the center (PLC_{ls},PS_{ls}) of base metals. And the gap between the assembled positions of circuit units P_1 and P_2 is estimated using these positions.

$$ACI_l=\sum_{s=1}^{NR_l}PMI_{ls}\ /\ NR_l \quad , \quad ACJ_l=\sum_{s=1}^{NR_l}PMJ_{ls}\ /\ NR_l \qquad (18)$$

$$ADX_l=\sum_{s=1}^{NR_l}=PSX_{ls}\ /\ NR_l \quad , \quad ADY_l=\sum_{s=1}^{NR_l}PSY_{ls}\ /\ NR_l$$

The gap (GU) between two circuit units is calculated by the equation (19) using the average positions.

$$GU=\sqrt{(ADX_{1s}+ADX_{2s})^2+(ADY_{1s}+ADY_{2s})^2} \qquad (19)$$

4.2.3 Assembled Angle Between Two Circuit Units

(1) Center of upper edge

The center $PF_{1s}(PFI_{1s},PFJ_{1s})$ of the upper edge of base metals (PR_{1s}) is estimated in Fig. 6 as follows.

(a) The two lines which crosses the connecting line vertically and passes through the point on the left edge (PRC_{1s}) or the right edge (PDC_{1s}) are estimated. And the searching area is defined as the area which is between these lines.

(b) The point (i_1,j_1) is defined as a point which exists between PRC_{1s} and PDC_{1s} on the connecting line. And the line which crosses the connecting line vertically and passes though the point (i_1,j_1). The upper edge (FTJ_{1s}) of the base metal is estimated by the equation (20),

$$FTJ_{ls}(i_1)=max\{j \text{ value}\,|\,S(i,j)=255,\ j_1\leqq j\leqq j_1+w_1,\ i=i_1-a_0(j-j_1)\} \qquad (20)$$

$FTI_{1s}(i_1)$ is defined as i value which is corresponded to $FTJ_{1s}(i_1)$. In Fig. 6, the average value of ($FTI_{1s}(i_1)$, $FTJ_{1s}(i_1)$) is calculated, and the center $PF_{1s}(PF_{1s},PFJ_{1s})$ of upper edge is calculated by the equation (21).

$$PFI_{1s}=\sum_{i_1=PRI_{1s}}^{PDI_{1s}} FTI_{1s}(i_1) \;/\; (PDI_{1s}-PRI_{1s}+1)$$

$$PFJ_{1s}=\sum_{i_1=PRJ_{1s}}^{PDJ_{1s}} FTJ_{1s}(i_1) \;/\; (PDJ_{1s}-PRJ_{1s}+1) \qquad (21)$$

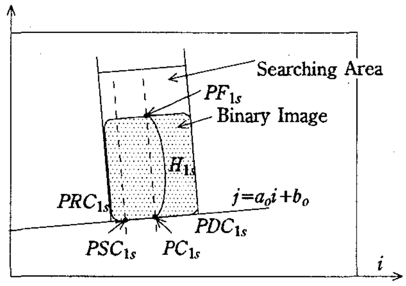

Fig. 6 Distance between center of upper edge and connecting line

(c) The center PF_{2s} (PFI_{2s},PFJ_{2s}) of the base metal (PR_{2s}) is calculated by the same method.

(2) Estimation of Assembled Angle of circuit units

The distance (H_{ls}) between the center of upper edge and connecting line is calculated by the equation (22) using the length and width (α,β) of 1 pixel. The distance (L_{ls}) which is corresponded H_{ls} at the 3D CAD figure is estimated. And The assembled angle (θ_0) between two circuit units (P_1,P_2) is calculated by the equation (23) showed in Fig. 7 .

$$H_{ls}=\frac{|a_0\cdot\alpha\cdot PFI_{ls}-\beta\cdot PFJ_{ls}+b_0|}{\sqrt{a_0^2+1}} \qquad (22)$$

$$\theta_0=\sum_{s=1}^{NR_1}\theta_{ls} \;/\; NR_1 + \sum_{s=1}^{NR_2}\theta_{ls} \;/\; NR_2 \qquad (23)$$

where, $\theta_{ls}=\sin^{-1}(H_{ls} \;/\; L_{ls})$

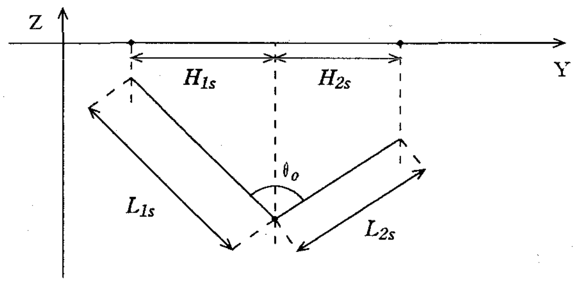

Fig. 7 Assembled angle

5. SOLDERING PROCESS

The position and motion of soldering are estimated by the gap and the assembled angle between two circuit units based on the connecting line.

5.1 Position of Soldering Iron Tip

The position SD_s (SDX_s,SDY_s) of soldering iron tip is determined as the middle point of center of upper (PC_{1s}) and lower (PC_{2s}) base metals, and SD_s (SDX_s,SDY_s) is calculated by the equation (24).

$$SDX_s=(PCI_{1s}+PCI_{2s}) \;/\; 2 \quad , \quad SDY_s=(PCJ_{1s}+PCJ_{2s}) \;/\; 2 \qquad (24)$$

5.2 Motion of Soldering

The rotation angle of soldering iron tip is modified to contact the tip and bridge soldering base metals using assembled angle between two circuit units. So the rotation angle $M\theta$ of soldering iron tip is calculated by the equation (25) using the assembled angle θ_0 and the angle $T\theta$ of soldering iron tip showed in Fig. 8 .

$$M\theta=\theta_0-T\theta \qquad (25)$$

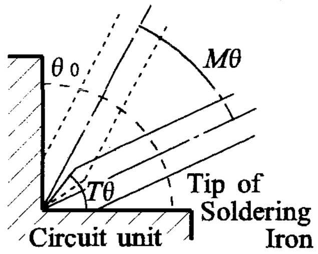

Fig. 8 The rotation angle of soldering iron tip

6. CONCLUSION

We propose the recognition method of bridge soldering base metal by comparing CAD and input image of image processing. Firstly, the 3D CAD information is transformed into 2D standard figure. Secondly, the input image is represented by the connecting line, center and edge of base metal. Thirdly, the gap and the assembled angle between two circuit units based on the connecting line are recognized by comparing the standard figure with the input image. Finally, The robot system with the proposed method is developed to solder accurately.

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