The Application of Machine Vision to IC Surface Inspection

Yi-Chan Chung, Chih-Hung Tsai, and Yu-Tang Lin

Department of Industrial Engineering and Management
Ta-Hwa Institute of Technology
1 Ta-Hwa Road, Chung-Lin
Hsin-Chu, Taiwan, ROC
Tel: +886-3-5430-466
E-mail: ietch@thit.edu.tw

Abstract

During IC inspection, which includes the two parts of Mark and Lead, the deviation of IC on the tape occurring in high speed movements usually generates light reflection effect, which in turn causes errors in IC recognition as measured by machine vision system. This research filters the light reflection effect by developing standard components, identifies the correct position of IC Lead, hence fixes the measurement errors or non-measurability caused by light reflection, avoids the resulting discontinued operation of measuring system, and improves the productivity.

Key Words: Light Reflection, Lead, Mark

1. Introduction

The chip manufacturers in Taiwan play an important role in global electronics industry. Taiwan IC industry's market share in the world is growing as well. As a result, domestic demand for IC packaging has increased. IC packaging can be considered a bridge between IC chip and system product. There are several derivative products of SMT packaging technology such as SOP (Small Outline Package), SOJ (Small Outline J-Lead), PLCC (Plastic Leaded Chip Carrier), and QFP (Quad Flat Package). Compared to the old packaging technology of PTH (Pin through Hole), these derivative products have the characteristics of smaller scale, shorter Lead distance, and better heat emission. On the other hand, though, they require higher precision in dimension. Therefore, the early IC surface inspection method of combined human and mechanic measuring is no longer applicable, which generates the need for a better inspection system. IC inspection is primarily Lead inspection and Mark inspection, where Lead inspection is more critical. IC Lead inspection has been widely implemented in the industry. It can be performed in two ways. One is on-tray inspection, for instance, the patented laser inspection technology developed by RVSI and VIEW. The other is to pick up IC from the tray and send it to a platform for inspection, for instance, ICOS system. However, the speed of laser inspection is too low whereas the second way is embedded with the potential risk of collision during shipping process. In particular, if any collision happens when IC is being shipped back to the tray after inspection, the defective products cannot be detected any more. With the concerns described above, a technology that employs machine vision for inspection has been developed. It performs faster than laser inspection and can finish inspection on the tray or tape, even though some other issues still remain unresolved.

Many manufacturers provide the IC with the same material number for packaging. However, the different machinery and material used by different manufacturers generate varying printing effects on Mark inspection regardless of the same material number, for instance, different font size, or even inconsistent font for the identical letters. The printing quality of Mark is generally inspected through identifying any mixed materials. However, the problems mentioned above with detecting identical letters hinder further printing quality inspection. Tapping machine performs inspection while it does packaging; therefore, IC shows a forward momentum on the tape due to the laws of inertia, which in turn pushes IC's Lead close to the edge of the tape. The material of the tape used, if light reflection produced, will cause problems with identifying the tip of IC Lead, as shown in Figure 1. To fix the problems, operators are often seen stop running the machine and adjust IC's position on the tape before re-measuring, which substantially reduces the productivity of the machines.

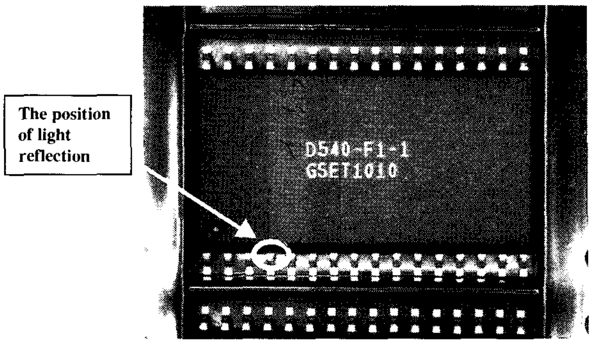


Figure 1. IC's light reflection produced on the tape

With the problems mentioned above, IC packaging manufacturers are usually prohibited from fully utilizing the productivity of tapping. This research attempts to provide a solution to the light reflection effect and thus avoid the unproductive time required for operators to stop the machine and adjust IC's position on the tape. In addition, comprehensive solutions to both tape and reel will be proposed in this research by using Cognex's OCV tool to inspect IC's Mark. This research has the following three objectives: (1) exploring the IC inspection items of tape and reel, and their definitions; (2) studying the effects on tape caused by light reflection; (3) analyzing the research results and making recommendations, providing comprehensive solutions to tape and reel.

2. Research Scope and Limits

1. CCD image specification is RS170 gray image of 640x480 pixels, captured by Cognex 8100M frame grabber coupled with its OMI program library.
2. The image is computed by Windows NT 4.0 operating system and Win32 code written by Visual C^{++}6.0, employing the capture function of the frame grabber and such tools as Patmax, Gblob, and Caliper. Self-finished programs complete the remaining calculations [6].
3. In order to avoid the flashing effect of light, we use the variability in measured results to confirm and thus reduce the variation in measurement caused by the flashing light.
4. In order to prevent errors or deviation in correction, pixel is used as the measuring unit. No other correcting unit is used.
5. With regard to the image deviation attributable to light source, this system does not handle the overly dark image of the Lead on IC's both sides caused by uneven lighting causes. Hence, special attention is called for in selecting light source so as to warrant a clear image of the Lead on IC's both sides.

3. Methodology

3.1 The Measuring Procedure for Tape and Reel

(1) Search for the fixed position: The fixed position of the overall IC is located and used as a reference point for Pin 1, Mark, and Lead.

(2) Pin 1 inspection: Pin 1 provides the basis for judging if IC is inverted. Mark cannot

be used to identify inverted image if any since Mark itself may turn upside down in printing.

(3) Mark inspection: The inspection is done to detect if any materials are mixed in use.

(4) Lead inspection: The inspection focuses on the geometric properties of the Lead, for instance, Lead length and Lead width.

(5) Spare bag inspection: There are spare bags at the front and back end of the tape. Action is taken to check if the spare bags are under normal conditions, with no unwanted stuff in.

3.2 Measuring Items of IC Geometric Properties and Their Definitions

(1) Lead Tip: the middle point of every Lead (as shown in Figure 2).

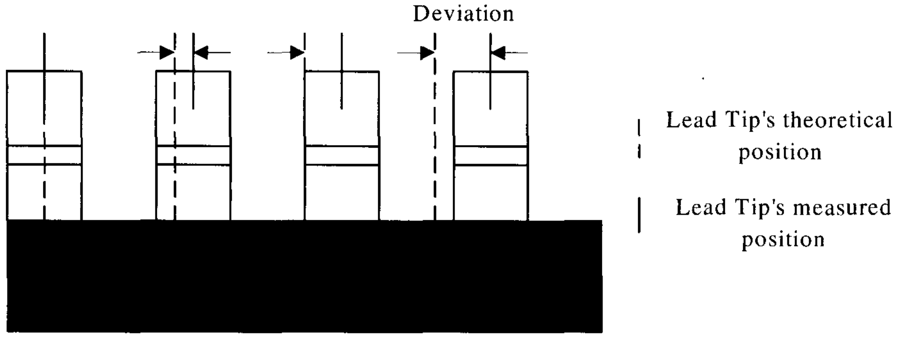


Figure 2. Illustrative Chart of Lead Tip

(2) Lead Pitch: the distance between the middle points of every Lead (as shown in Figure 3).

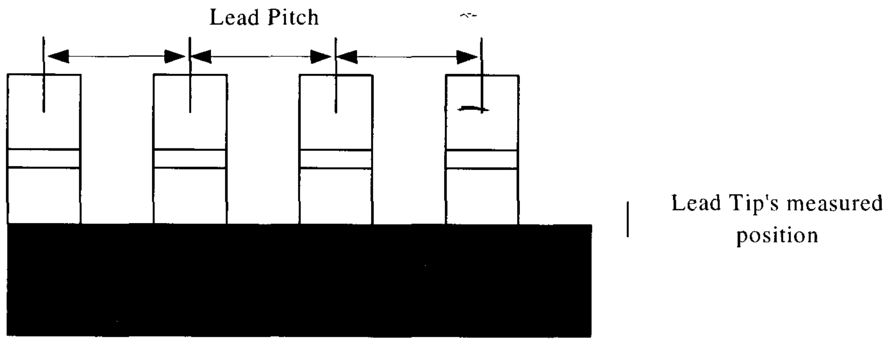


Figure 3. Illustrative Chart of Lead Pitch

(3) Lead Length: the distance from Lead Tip to Lead Body (as shown in Figure 4).

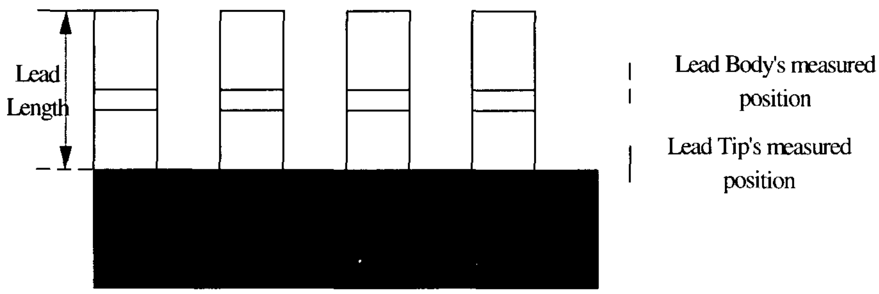


Figure 4. Illustrative Chart of Lead Length

(4) Lead Skew: the distance between Lead Tip's theoretical position and Lead Tip's actual measured position due to the skewed Lead (as shown in Figure 5).

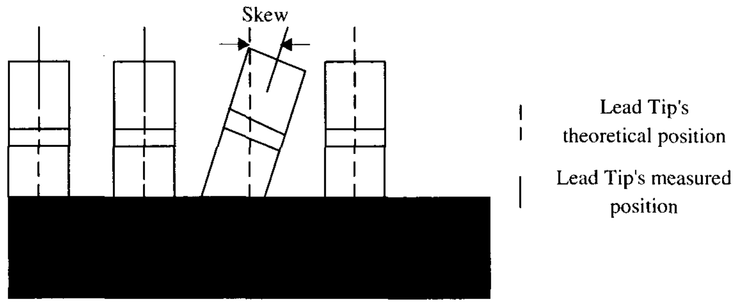


Figure 5. Illustrative Chart of Lead Skew

(5) Lead Span: the distance between the two ends of Lead Tip (as shown in Figure 6).

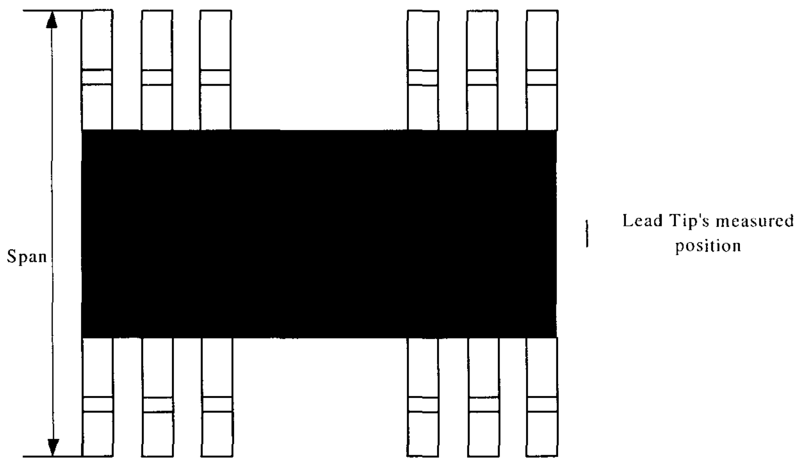


Figure 6. Illustrative Chart of Lead Span

3.3 The Measuring Procedure for Mark

In the training process, we could learn the contents of the Mark on IC in advance and use as standards for comparison in inspection. The result is deemed correct when it matches the preset standard. Otherwise, it is incorrect. Two methods are involved in this training process:

(1) Pattern matching: Compared to the image obtained from the training process, the similar patterns in terms of scores, which are also affected by light source and printing quality, are used as the benchmark for comparison. For instance, the difference in scores between the number "1" provided by manufacturer A and manufacturer B may be greater than the difference in scores between the English letter "C" and "G" provided by manufacturer A. However, the former should be accepted as good whereas the latter should be returned as defected.

(2) Letter matching: In the training process, in addition to the pure memorized image comparison described above, certain meanings can be given to every image. For example, Image 1 represents C, and Image 2 represents G, and so on. A relativity matrix can be built after the training process is completed (as shown in Table 1). Take the score of 80 on both vertical axis C and horizontal axis G, for example, it means that the score for Image G inspected by C's trained pattern is 80. Applying the matrix to calculations in inspection can avoid the errors occurring in the first training method of pattern matching, that is, it can be determined "**C**" is "**C**" and "**G**" is "**G**". Moreover, this method can also reduce the variation in printing results of the same words by different manufacturer [6].

Table 1. Mark's letter relativity matrix

	C	**G**	**2**	**S**
C		80	50	45
G	80		35	35
2	50	35		80
S	45	35	80	

3.4 The Measuring Procedure for Lead

The Lead tip can be easily detected in absence of light reflection. The existence of light reflection can mislead the identification of Lead tip's position (as shown in Figure 7).

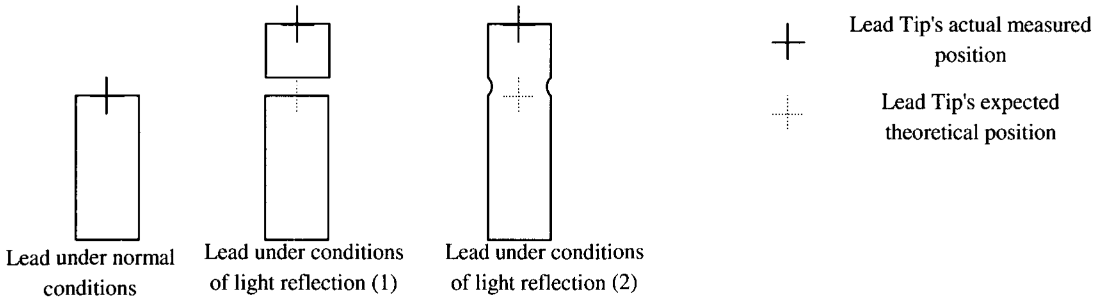


Figure 7. Illustrative chart of Lead's length under normal conditions and light reflection

Under normal conditions, Lead tip can be found by calculating Lead's left, right, and upper edge. Light reflection causes errors in judgment, especially under the conditions of light reflection (2). IC may be detected as defect due to Lead tip's calculation error. Because the inspection machine follows the procedure to move, stop, and inspect. When the machine stops moving, IC continues moving forward by the laws of inertia until it hits the tape and thus causes light reflection. As this situation happens frequently, the productivity of tapping can hardly be improved. In order to solve this problem, we break up the search for Lead tip into the following steps:

(1) Establishing a standard Lead tip database: This step can be accomplished by diagrammatic data input or golden sample, that is, the position represented by the dotted lines in Figure 7.

(2) Searching for Lead's position: The position data of Lead tip developed from the above can provide us a range to seek Lead and the search for Lead completes locating Lead. In this way, the problems arising from the conditions of light reflection (1) can be resolved.

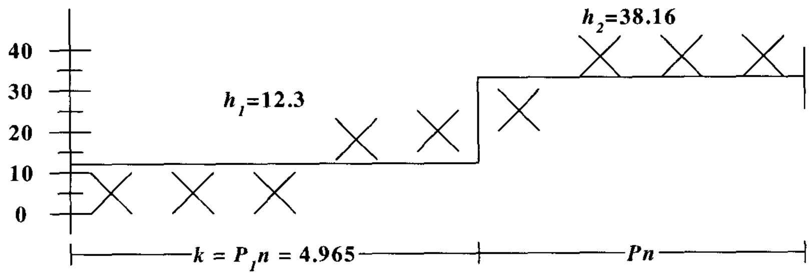
(3) Computing edge: After the search for Lead tip is completed, the positions of edges and points are computed by sub-pixel using the edge and point closest to the Lead tip's benchmark data as the basis for computation.

3.5 Edge Location to Sub-pixel Values - Tabatabai's One-Dimension Rule [1, 4, 5]

When a sampling scanner scans a trapezoid edge with no noise, we use a set of numbers x_i, i = 1, 2, ...n to represent the results, as shown in Figure 8. They are monotonous non-decreasing or non-increasing.

10 10 10 15 20 30 40 40 40

(a)



(b)

Figure 8. Class 1 gray value distribution [1]

On the other hand, an ideal edge is represented by a set of h_1 gray class values followed by another set of h_2 gray class values, as shown in Figure 8 (b). A computing formula is defined such that the actual scanned edge data (as shown in Figure 8 (a)) are used as input to generate an ideal edge (as shown in Figure 8 (b)) output. The computation steps are described below:

(1) Calculating the sample input's moments of the first three classes:

$$\overline{m}_i = \frac{1}{n}\sum_{j}^{n} x_j^i \; ; \; i = 1,2,3$$

Where n is the number of sample data,

x_j is the gray value of jth data,

and m_i is Class i's moments.

(2) Defining k is the number of h_1 values in the ideal edge dataset, then probability P_i is:

$$p_i = \frac{k}{n} \text{ and } \sum_{q=1}^{2} p_q = 1$$

(3) Solving the following three equations to keep the first three moments between input and output constant:

$$\sum_{q=1}^{2} p_q h_q^i = \overline{m}_i,\ i = 1,2,3,\ \text{where } P_1,\ h_1 \text{ and } h_2 \text{ are unknown.}$$

(4) Obtaining the solutions to the above three equations:

$$h_1 = \overline{m}_1 - \overline{\sigma}\sqrt{\frac{P_2}{P_1}},\quad h_2 = \overline{m}_1 - \overline{\sigma}\sqrt{\frac{P_1}{P_2}},\quad P_2 = \frac{1}{2}\left[1 - \overline{S}\sqrt{\frac{1}{4+\overline{S}^2}}\right]$$

Where $\overline{S} = \dfrac{\overline{m}_3 + 2\overline{m}_1^3 - 3\overline{m}_1\overline{m}_2}{\overline{\sigma}^3}$, $\overline{\sigma}^2 = \overline{m}_2 - \overline{m}_1^2$.

(5) Once P_i is solved, k can be computed as $k = nP_i$ (which could be a non-integer value). Then we define the position of the edge "v", where $v = k$. The first pixel is located at $j = ½$, and every following pixel takes an integer position. Hence, we can obtain the sub-pixel value of an edge (that is, the edge does not necessarily have to be at one sampling location). The length of input data does not restrict this method. Meanwhile, the location of the edge found by this method does not change as it expands, shrinks or shifts, in other words, the location found will not change if the sampling values are multiplied or added by a same amount simultaneously. We input the data from Figure 8 (a) into equation $\overline{m}_i = \dfrac{1}{n}\sum_j^n x_j^i\ ;\ i = 1,2,3$; the first three classes' moments of sample inputs can be obtained as $\overline{m}_1 = 23.888889$, $\overline{m}_2 = 736.111111$, $\overline{m}_3 = 25930.555556$.

In order to calculate $\overline{\sigma}$, bring $\overline{m}_2$ and $\overline{m}_1$ into equation $\overline{\sigma}^2 = \overline{m}_2 - \overline{m}_1^2$, solve

$$\overline{\sigma}^2 = \overline{m}_2 - \overline{m}_1^2 \Rightarrow \overline{\sigma} = \sqrt{\overline{m}_2 - \overline{m}_1^2} = 12.862041$$

Bring $\overline{\sigma}$, $\overline{m}_1$, $\overline{m}_2$ and $\overline{m}_3$ into equation $\overline{S} = \dfrac{\overline{m}_3 + 2\overline{m}_1^3 - 3\overline{m}_1\overline{m}_2}{\overline{\sigma}^3}$, solve

$$\overline{S} = \frac{\overline{m}_3 + 2\overline{m}_1^3 - 3\overline{m}_1\overline{m}_2}{\overline{\sigma}^3} = 0.207586$$

Bring $\bar{S}$ into $P_2 = \frac{1}{2}\left[1-\bar{S}\sqrt{\frac{1}{4+\bar{S}^2}}\right]$, solve

$$P_2 = \frac{1}{2}\left[1-\bar{S}\sqrt{\frac{1}{4+\bar{S}^2}}\right] = 0.448381$$

Solve the location of the edge v,

$$v = n\times(1-P_2) = 9\times(1-0.448381) = 4.965$$

The above illustrates the problem-solving process for Figure 8 (a). Be cautious that gray class distribution is from small to big, that is, the integers are distributed from 0 to 255. Special attention needs to be paid to the position computed from the reverse distribution. In the early example, if the data are distributed as 40, 40, 40, 30, 20, 15, 10, 10, 10, even though the computed result will be the same, the story told by the result will be completely different.

3.6 Data Selection in Measuring

Based on the analysis of the measuring items of IC geometric properties and their definitions, we have found that once the Lead tip's data are obtained, we can compute the values of the other items such as Lead pitch, length, skew, and span. Therefore, in this research, comparisons are performed after Lead tip is located.

4. Experiment Results and Discussion

The experiment is conducted on SOP 32 Pin in three groups: (1) IC under static conditions without light reflection; (2) IC under static conditions with light reflection; (3) The actual measured results of 1,000 pieces of IC. In Group 1 and 2, the same IC is computed 1,000 times under different light reflection conditions. In Group 3, the actually measured normal IC whose position is adjusted in operating practice at the expense of operation stoppage due to light reflection effect during inspection is measured again in the experiment. The resulting value is the difference between the actual inspection and the gold sample of the Lead tip, measured in pixels.

4.1 The Measured Results of IC under Static Conditions without Light Reflection (as shown in Table 2)

Table 2. The measured results of IC under static conditions without light reflection

Group 1		**Upper Lead 1**	**Upper Lead 2**	**Upper Lead 3**	**Upper Lead 4**	**Upper Lead 5**	**Upper Lead 6**
	Average	0.0135	0.0259	0.0228	0.0220	0.0114	0.0109
	Maximum	0.0267	0.0321	0.0452	0.0392	0.0380	0.0330
	Minimum	0.0005	0.0002	0.0001	0.0050	0.0026	0.0010
		Lower Lead 1	**Lower Lead 2**	**Lower Lead 3**	**Lower Lead 4**	**Lower Lead 5**	**Lower Lead 6**
	Average	0.0101	0.0101	0.0201	0.0212	0.0321	0.0225
	Maximum	0.0411	0.0309	0.0315	0.0310	0.0481	0.0420
	Minimum	0.0010	0.0030	0.0041	0.0022	0.0011	0.0009
		Upper Lead 7	**Upper Lead 8**	**Upper Lead 9**	**Upper Lead 10**	**Upper Lead 11**	**Upper Lead 12**
	Average	0.0201	0.0121	0.0105	0.0206	0.0115	0.0112
	Maximum	0.0310	0.0390	0.0215	0.0309	0.0299	0.0350
	Minimum	0.0010	0.0009	0.009	0.0015	0.0022	0.0052
		Lower Lead 7	**Lower Lead 8**	**Lower Lead 9**	**Lower Lead 10**	**Lower Lead 11**	**Lower Lead 12**
	Average	0.0115	0.0109	0.0105	0.0222	0.0214	0.0105
	Maximum	0.0375	0.0400	0.0299	0.0400	0.0512	0.0485
	Minimum	0.0023	0.0012	0.0007	0.0010	0.0023	0.0005
		Upper Lead 13	**Upper Lead 14**	**Upper Lead 15**	**Upper Lead 16**		
	Average	0.0141	0.0146	0.0224	0.0221		
	Maximum	0.0290	0.0285	0.0353	0.0411		
	Minimum	0.0007	0.0005	0.0002	0.0001		
		Lower Lead 13	**Lower Lead 14**	**Lower Lead 15**	**Lower Lead 16**		
	Average	0.0331	0.0242	0.0221	0.0101		
	Maximum	0.0510	0.0425	0.0356	0.0311		
	Minimum	0.0013	0.0015	0.0011	0.0005		

4.2 The Measured Results of IC under Static Conditions with Light Reflection (as shown in Table 3)

Table 3. The measured results of IC under static conditions with light reflection

Group 2		**Upper Lead 1**	**Upper Lead 2**	**Upper Lead 3**	**Upper Lead 4**	**Upper Lead 5**	**Upper Lead 6**
	Average	0.0569	0.1659	0.1228	0.1320	0.2814	0.1009
	Maximum	0.1267	0.3121	0.3452	0.2392	0.4380	0.1930
	Minimum	0.0105	0.1002	0.0701	0.0505	0.1026	0.0210
		Lower Lead 1	**Lower Lead 2**	**Lower Lead 3**	**Lower Lead 4**	**Lower Lead 5**	**Lower Lead 6**
	Average	0.2101	0.2101	0.3201	0.2212	0.1321	0.2225
	Maximum	0.3411	0.3090	0.4315	0.3310	0.3481	0.3140
	Minimum	0.0910	0.1030	0.1041	0.0922	0.0011	0.1009
		Upper Lead 7	**Upper Lead 8**	**Upper Lead 9**	**Upper Lead 10**	**Upper Lead 11**	**Upper Lead 12**
	Average	0.0801	0.0910	0.1050	0.2206	0.1256	0.1620
	Maximum	0.3310	0.3230	0.3215	0.3309	0.2299	0.2350
	Minimum	0.0901	0.0500	0.0509	0.1015	0.0922	0.0552
		Lower Lead 7	**Lower Lead 8**	**Lower Lead 9**	**Lower Lead 10**	**Lower Lead 11**	**Lower Lead 12**
	Average	0.2115	0.1930	0.3105	0.3022	0.1914	0.3105
	Maximum	0.3375	0.3400	0.4299	0.4400	0.3051	0.4485
	Minimum	0.0602	0.0812	0.1007	0.0610	0.0523	0.1005
		Upper Lead 13	**Upper Lead 14**	**Upper Lead 15**	**Upper Lead 16**		
	Average	0.2641	0.2146	0.2240	0.2221		
	Maximum	0.3290	0.3285	0.4353	0.4411		
	Minimum	0.1007	0.0905	0.1002	0.0801		
		Lower Lead 13	**Lower Lead 14**	**Lower Lead 15**	**Lower Lead 16**		
	Average	0.2331	0.3242	0.3221	0.2010		
	Maximum	0.3510	0.3925	0.4356	0.3311		
	Minimum	0.1013	0.1815	0.1501	0.1005		

4.3 The Measured Results of 1,000 Pieces of IC (as shown in Table 4)

Table 4. The measured results of 1,000 pieces of IC

Group 3		**Upper Lead 1**	**Upper Lead 2**	**Upper Lead 3**	**Upper Lead 4**	**Upper Lead 5**	**Upper Lead 6**
	Average	0.2135	0.3510	0.34228	0.1930	0.3014	0.4010
	Maximum	0.7267	0.6321	0.54042	0.4092	0.50380	0.7030
	Minimum	0.1005	0.1092	0.2031	0.0950	0.1296	0.2001
		Lower Lead 1	**Lower Lead 2**	**Lower Lead 3**	**Lower Lead 4**	**Lower Lead 5**	**Lower Lead 6**
	Average	0.50101	0.4101	0.3020	0.1912	0.2321	0.3225
	Maximum	0.7011	0.6309	0.5315	0.3310	0.50481	0.7420
	Minimum	0.2001	0.2030	0.1431	0.1002	0.1011	0.1209
		Upper Lead 7	Upper Lead 8	Upper Lead 9	Upper Lead 10	Upper Lead 11	Upper Lead 12
	Average	0.40201	0.3021	0.3015	0.2206	0.5015	0.4023
	Maximum	0.6310	0.7390	0.5215	0.5039	0.7299	0.8350
	Minimum	0.2210	0.2009	0.2309	0.1015	0.3022	0.3052
		Lower Lead 7	**Lower Lead 8**	**Lower Lead 9**	**Lower Lead 10**	**Lower Lead 11**	**Lower Lead 12**
	Average	0.3910	0.4010	0.3315	0.4023	0.3021	0.2915
	Maximum	0.7375	0.7400	0.5599	0.6040	0.6512	0.50485
	Minimum	0.0623	0.2012	0.2307	0.2210	0.20023	0.1105
		Upper Lead 13	**Upper Lead 14**	**Upper Lead 15**	**Upper Lead 16**		
	Average	0.4041	0.4016	0.3124	0.3921		
	Maximum	0.7290	0.5985	0.6353	0.5411		
	Minimum	0.2007	0.2045	0.2089	0.1001		
		Lower Lead 13	**Lower Lead 14**	**Lower Lead 15**	**Lower Lead 16**		
	Average	0.3331	0.2942	0.3221	0.4010		
	Maximum	0.6651	0.5425	0.6356	0.7311		
	Minimum	0.2013	0.0950	0.2111	0.2005		

4.4 Experiment result discussion

In Group 1's experiment results, the variation from the maximum value to the minimum value is 0.0497 pixels, which indicates stable light source with the maximum variation of 0.0497 pixels. When the variation in the measured value is greater than 0.0497 pixels, it is attributed to unstable light source and not considered. Comparing the results from Group 2 and Group 1, the newly calculated Lead tip's position is at most 0.4 pixels away from that under static conditions without light reflection. In the experiment with 1,000 pieces in Group 3, operation is never discontinued for adjustment as a result of light reflection. The inspection results of Mark are correct and thus not listed and explained.

5. Conclusions

From the above experiment results, we know that light reflection certainly affects the measuring process and the difference between Group 1 and Group 2 in experiment is 0.4 pixels, which compared to the degree where Lead tip can not be accurately located due to light reflection in current industry practice, has improved significantly. The application of Cognex's OCV tool and comparison by relativity matrix has reduced the error in Mark's position recognition. Since this research does not involve printing quality inspection but only determines if the letter itself is correct, all the results are correct and no associated data can be provided for comparison. This research is focused on the inspection procedures for tape and reel and aims to improve the situation where machine operation is discontinued for adjustment due to light reflection. Using external hardware to overcome light reflection falls outside of this research. Appropriate light source coupled with filter can filter some light reflection but not eliminate it. The method proposed in this research, if applied in addition to appropriate light source and filter, can effectively improve the productivity of tapping machines and substantially reduce the situation under which productivity cannot be fully utilized as operation is discontinued from time to time.

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