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TILT DETECTION OF CONNECTORS USING PHASE SHIFTING

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ABSTRACT

AVI's are playing important roles in quality inspection in the electronic industry. Most existing AVIs are single overhead camera and are incapable detecting 3D defects. This work presents solving the shortcoming stated using an angle fringe projection. This work was done using a non-collimated light source, whereas other researches on surface metrology usually used collimated light source. For precise surface or height measurements collimated light or laser source is commonly used. , this work has demonstrated a successful manipulation of the non-collimated light source in height measurement by calibration of the illumination angle and development of the reference table.

KEY WORDS Automated Visual Inspection, Fringe Projection, Non-Collimated Lighting.

1 INTRODUCTION

Inspection has long been an integral part of quality control in many industries ranging from agricultural to the high-end electronic industry. The process of determining if a product deviates from a given set of specification is defined as inspection [1]. Inspection involves measurement of specific part features such as surface finish and geometric dimensions [1]. Human inspectors have been predominantly carrying out the visual inspection tasks in most industries. However requirements of the modern manufacturing environment have intensified the usage of automated visual inspection (AVI) systems (also known as automated optical inspection (AOI) system). The main requirement of modern manufacturing demand for the emergence of machine vision systems is the trend towards total quality that is products with zero defects [2]. Work done by Guerra and Villalobos (2001)[3] is the closest to the subject of this research. The objective of their work is to develop a 3D inspection system for surface mount devices (SMD) assemblies that are reliable and inexpensive. The inspection operation presented in their paper consists of detecting the presence and absence of components. The components inspected here are chip resistors, chip capacitors, small outline transistors (SOT) and Capacitors. This system utilizes sheet-of-light triangulation technique, whereby the board is illuminated with laser. The geometric properties of the system are utilized to calculate the height values for each reflection of the sheet-of-light. The other papers dealing with 3D inspection of PCBAs, which are remotely related, are work carried out by Kelley et al. (1988)[4] and Svetkoff and Doss (1987)[5]. Both the papers describe work done on single spot laser beam triangulation technique to obtain range values. The major drawback with this method is only one range value per frame can be obtained at one time. This will consume a lot of time to inspect even selected components on a typical computer motherboard.

2 EXPERIMENTAL SETUP

Figure 1 shows the experimental setup prepared for this work. The camera is at the right angle of the field of view (FOV). The mirror is placed on a turn table to facilitate phase-shifting process. This setup was done on a rigid optical table. Alignments and right-angle determination was addressed by using water levelers. The camera used here is KODAK DC120 and the non-collimated light source is from the slide projector. The mirror mounted on the turntable is to apply phase-shifting method on the fringe projection.

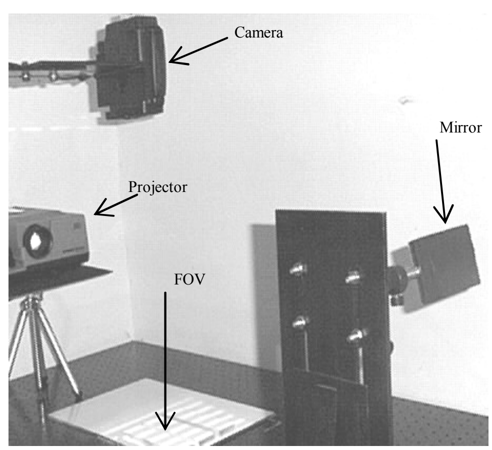

Figure.1: An image of the experimental setup.

2.1 Application of the phase-shifting method

Fringe pattern is a sinusoidal coded wave function and can be represented by the grayscale intensity distribution *G(i,j)* at a given pixel position *(i,j)*. This function can be expressed as [6]:

$$G(i,j) = A + B\cos\phi(i,j) \tag{1}$$

where A is the uniform background intensity, B is the amplitude of the sinusoidal light and $\phi(i,j)$ is the phase angle at *(i,j)*. A phase map can be obtained by evaluating $\phi(i,j)$ from Equation (1). To achieve this, the fringes are shifted in three steps of 2π/3. This will produce three different fringe patterns with varying intensities given by

$$I_1(i,j) = A + B\cos\phi(i,j) \tag{2}$$

$$I_2(i,j) = A + B\cos\left[\phi(i,j) + \frac{2\pi}{3}\right] \tag{3}$$

$$I_2(i,j) = A + B\cos\left[\phi(i,j) + \frac{4\pi}{3}\right] \tag{4}$$

In the second step (Equation 3) the fringes shift from the original state by 2/3 spacing, and in the third step (Equation 4) fringes shift by 4/3 spacing from original state. Equations (2), (3) and (4) can be solved for $\phi(i,j)$, resulting in [6]:

$$\phi(i,j) = \tan^{-1}\left[\frac{\sqrt{3}\left[I_3(i,j) - I_2(i,j)\right]}{2I_1(i,j) - I_2(i,j) - I_3(i,j)}\right] \tag{5}$$

The value of $\phi(i,j)$ in equation (5) is given within $\pm\pi$, but by considering the signs of the numerator and denominator it is possible to determine where it lies between 0 to 2π. The projections of the fringes were shifted by using mirror mounted on a rotary stage as shown in Figure 4.3. Figure 2(a) shows an image of the four glass blocks without the fringes. Figure 2(b) - (d) show images of fringes projected on to the glass blocks and shifted by 2π/3 in stages. Figure 2(e) shows the phase map obtained after applying Equation (5) to images 2(b) – (d).

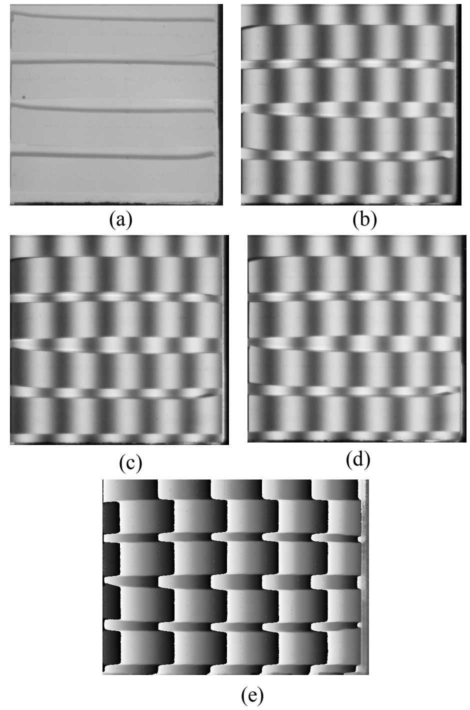

Figure. 2: (a) Solid blocks without fringes, (b) to (d) image of blocks with fringe projection: the fringes being shifted by 0, 2π/3 and 4π/3 respectively, (e) phase map produced from images (b)-(d).

3 CALIBRATION OF ILLUMINATION ANGLE OF NON-COLLIMATED LIGHT

3.1 Introduction

Structured lighting techniques are used vastly in the study of surface metrology. Phase shifting fringe projection is one of the commonly used methods for this purpose. For precise surface or height measurements collimated light or laser source is commonly used. The advantage of using collimated light is that it has uniform angle of illumination over the surface.

To name a few, researchers such as Yoneyama et.al (2003)[7], Ngoi et.al (2001)[8] and Hobson et.al (1997)[9] used collimated light source in measuring surface profile. The disadvantage of using collimated light is that the coverage area is small compared to non-collimated light source. Non-collimated source is a diverging source ray and illuminates a large area. The variation of the illumination angle over the surface of the object must be determined before measurements can be made when non-collimated source is used. This is referred to as illumination angle calibration. The calibration involves finding a relationship between the illumination angle and length distances on a flat block surface. This part of the work was done to generate a reference table. Here, an equation for the illumination angle and the distance on a block surface can be obtained by interpolating the values in the reference table for block heights where calibration was not done.

3.2 Theory

Fringe projection technique can be used for measuring surface profile of an object. The detailed information of the surface profile is contained in the fringe pattern change. Measurement of the absolute height of a block using fringe projection includes calculating the distance δx between the break of a ray on the block surface and on the flat background as shown in Figure 3. In Figure 3, a projector projects a collimated light source, which is reflected by a mirror onto the block surface. Calculation of the fringe shift δx will enable the computation of the height of the block, y, given by the triangulation equation,

$$y = \frac{\delta x}{\tan\theta} \tag{6}$$

where θ is the angle of projection of the collimated light.

Figure 3 shows a schematic diagram of a projector projecting non-collimated light source onto a block surface. The illumination angle θ varies along the length of block surface L as shown. This angle must be known at each point on the block surface for accurate absolute height calculation using Equation (6). In fringe projection the shift of fringe δx on the block surface relative the background caused by the block height y. The shift value and illumination angle must be known in order to calculate y. The distance δx can be determined by measuring the shift of the non-collimated ray on the block surface compared to the background. In order to determine θ along the block surface a relationship between θ and L (from origin O as shown in Figure 4) must be established. The equation formulated from the relationship will enable the calculation of θ for all fringe breakpoints on the block surface. Using the phase-shifting technique on the fringe projection a phase map can be produced. A phase map would enable precise calculation of δx.

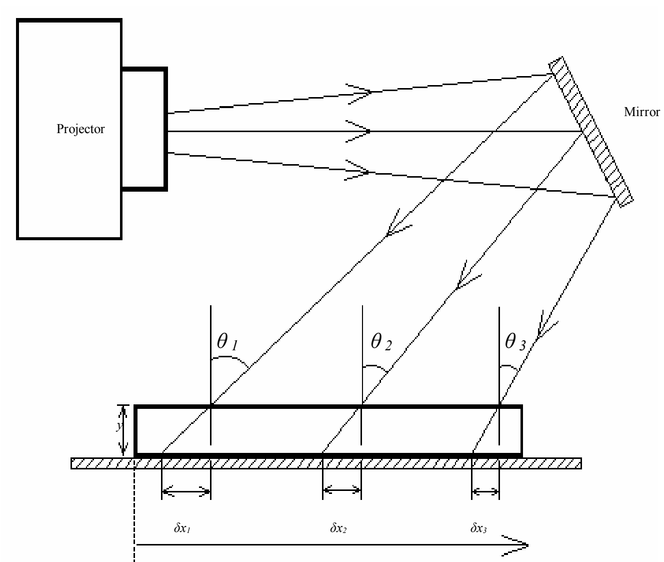

Figure. 3: Non-collimated light illuminating block surface.

3.3 Development Of Reference Table

The illumination angles of the non-collimated light for a given height on the surface of the block need to be determined before calculation of block tilt. The objective of this experiment is to determine the relationship between θ and the block distance L mm from the origin O (Figure 3). At different block heights, the relationship between θ and L will vary. Therefore, each time the block height measurement needs to be done, the illumination angle calibration has to be carried out for the specific height. In this section, illumination angle calibration was conducted for different block heights. This was done by using six pieces of glass plates of an approximate thickness 2 mm each. The calibration was initially done at 2 mm height, on a single piece, than increased until all six pieces were placed together (12 mm). Glue was not used to attach the pieces. The heights of the glass block pieces were also measured using laser instrument. This method was used to obtain a reference table for the relationship of θ and L for any height within 12 mm. The reference table will obviate the need to conduct illumination angle calibration for every height investigated. Interpolation within the reference table will provide the θ-L relationship for a particular height. The data after linear-fitting was compiled into a table. This data was used as a reference for any investigated height within 11.57 mm. Interpolation was done on the reference table to obtain the relationship between θ and L for a particular height. The linear fitted graphs are shown in Figure 4.

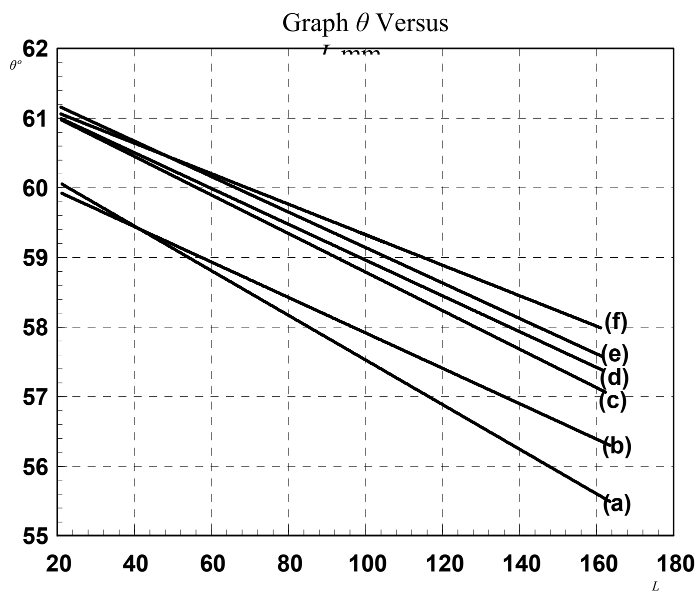

Figure.4: Graph plots after linear-fitting for relationship between θ and L for heights: (a) 2 mm, (b) 4 mm, (c) 6 mm, (d) 8 mm, (e) 10 mm and (f) 12 mm.

3.4 Verification of illumination angle calibration across the field of view

It is known that the relationship between θ and L varies with height. The illumination angle of a non-collimated light source also varies across the field of view (FOV). In this section an equation relating θ and L was formulated from the reference table. This equation was derived for a fixed location in the FOV. The θ derived from this relationship was used in Equation (6) for absolute height calculation of four solid glass blocks, which were positioned across the FOV. The height measured using the phase-shifting technique will determine the extent of illumination angle (of non-collimated light source) variation across the FOV. In this experiment four pieces of solid glass blocks of an approximated thickness 6 mm were used. The actual heights of each glass block were measured using the laser instrument at selected points of a 10 mm interval. The average height of the four solid blocks respectively are 5.72 mm, 5.70 mm, 5.81 mm and 5.73 mm using laser instrument. The average height of all the four blocks is 5.74 mm. Illumination angle calibration has been done for the height of 5.73 mm. The difference between the total average height of the four blocks and the height the illumination angle calibration was carried out was 0.01 mm. Therefore, interpolation need not be done, as the height is nearly equal. The equation derived for the illumination angle at height 5.73 mm is given by:

$$\theta = 61.572 - 0.0277L \tag{7}$$

The least squares method was used to get the best-fit straight line of the block heights. Values of total sum of residual ($\sum \grave{e}$) will determine the difference between the actual height and predicted height. Tables 1(a), 1(b), 1(c) and 1(d) respectively show the data obtained after linear-fitting for blocks 1, 2, 3 and 4. The average $\bar{y}$ value for block 1, 2, 3, and 4 are the same at 5.88 mm. Values for sum of residual $\sum \grave{e}$ are –0.05, 0.02, -0.14 and 0.05, and standard deviation values are as follows 0.02, 0.02, 0.005 and 0.02. Values of $\sum \grave{e}$ are all near 0, which shows that there is much uniformity in the actual measured height data. The difference for all four block between measured height (by laser instrument) and mean calculated height (using phase shifting technique) for blocks 1, 2, 3, and 4 are respectively 0.16 mm, 0.18 mm, 0.07 mm and 0.15 mm. The maximum difference is 3.16% of measured value between laser instrument and phase-shifting method, and the minimum difference at 1.2% as shown in Table 2. The results from this experiment proves that the illumination angle does not vary much across the FOV, hence the relationship derived for θ and L vertically can be used. This experiment also shows the difference in the height calculation is neglible and it obviates any neccessity to find the relationship between θ and the distance across the FOV. The phase-shifting technique measurement was veified using the laser instrument. The validity of the laser mesurement was checked by measuring all the four solid blocks height using MU-Checker instrument. The height of the blocks were measured at nine points spaced at an equal interval of 20 mm. The average height of each block measured using MU-Checker are 5.78 mm, 5.76 mm, 5.79 mm and 5.79 mm. The difference in measurement of both the instruments are 0.06 mm, 0.06 mm, 0.02 mm and 0.06 mm. The measurements by the MU-Checker proves that the laser instrument's measurement can be used for verification of the phase-shifting measurement technique.

Table 1: (a) Data of block 1, (b) Data of block 2, (c) Data of block 3 and (d) Data of block 4 after linear-fitting.

$\bar{y}$	5.88		$\bar{y}$	5.88
$\sum \grave{e}$	-0.05		$\sum \grave{e}$	0.02
SSE	0.18		*SSE*	0.20
SD	0.02		*SD*	0.02
(a)			(b)	
$\bar{y}$	5.88		$\bar{y}$	5.88
$\sum \grave{e}$	-0.14		$\sum \grave{e}$	0.05
SSE	0.009		*SSE*	0.23
SD	0.005		*SD*	0.02
(c)			(d)	

Table 2: Difference analysis of height measurement between laser instrument and phase-shifting method.

	Block			
	1	2	3	4
Average height laser measurement (mm)	5.72	5.70	5.81	5.73
Average phase-shifting measurement (mm)	5.88	5.88	5.88	5.88
Difference (%)	2.80%	3.16%	1.20%	2.62%

4 RESULT & ANALYSIS

The experiments were now conducted on four sets of glass blocks. Tilts were introduced in three of the glass blocks, while one was maintained in the horizontal position. The block maintained horizontal was referred to as the reference block. The first experiment has set of spacers of thickness 1.0 mm, 1.2 mm and 1.4 mm which were used to introduce the tilts in blocks A, B and C respectively. The second part of the experiment was conducted by changing the spacer thickness for block A, B and C with 0.5 mm, 1.3 mm and 1.5 mm thickness respectively. These values were chosen because in the industry tilt does not occur at extreme heights and if it does the test fixtures would be able to test them, hence it would be detected. The tilted block heights were then measured using the laser instrument. The height data from the laser instrument was then used to verify the phase shifting height calculation. The height was measured on the block top surface at a total of 17 points spaced at an equal interval of 10 mm. This height data of laser measurement was also linear fitted using the least square method, and tilt angle was obtained from the gradient of the linear fitted data. The verification was done by comparing the tilt angle values of both methods. The tilt angle calculated using phase shifting technique was compared to the tilt angle calculated using laser measurement. This comparison determined the accuracy of the phase shifting technique. The height for 17 points was measured using the laser instrument on each of the tilted blocks. The data was linear fitted and the tilt angle was calculated from the gradient value of each tilted block data set. For the first experiment the tilt angle calculated for both phase-shifting and laser measurement is shown in Table 3 shows tilt angle comparison between laser and phases shifting measurement. The angle calculated from laser measurement is denoted as θ_{LS} and angle of phase shifting measurement is denoted as θ_{PS} Table 4 shows the results for the second experiment. The result in this part of the experiment agrees with the trend of the first part. The difference increases with the increment of the height. However, for the small angle measurement there is no error in measurement between phase shifting and laser methods. Figure 5 shows the phase map derived for the second set of spacer experiment. The vertical white lines indicate the distance the phases have shifted in reference to the reference block.

Table 3: Tilt angle comparison between laser and phase-shifting computation for first set spacer thickness.

	Experiment First Set Spacer		
	Block A	Block B	Block C
θ°_{PS}	0.46	0.63	0.82
θ°_{LS}	0.46	0.57	0.72
Difference	0 %	11 %	15 %

Table 4: Tilt angle comparison between laser and phase-shifting computation for second set spacer thickness.

	Experiment Second Set Spacer		
	Block A	Block B	Block C
θ°_{PS}	0.26	0.75	0.91
θ°_{LS}	0.26	0.65	0.75
Difference	0%	10%	16 %

This part of the results is to demonstrate the phase shifting technique capability in detecting tilt on actual PCBA. However, due to the underside component and protruding leads on the underside of the PCBA, detailed verification on measurement comparison cannot be done. The best horizontal position was created for the PCBA by attaching several bolts of an approximated thickness 11.76 mm underneath the PCBA. Figure 6 shows a plan view of the connectors investigated. A total of five PCI connectors were inspected. Connectors A, B and C were in horizontal position. Connector D and E were tilted, with the highest tilt on connector E.

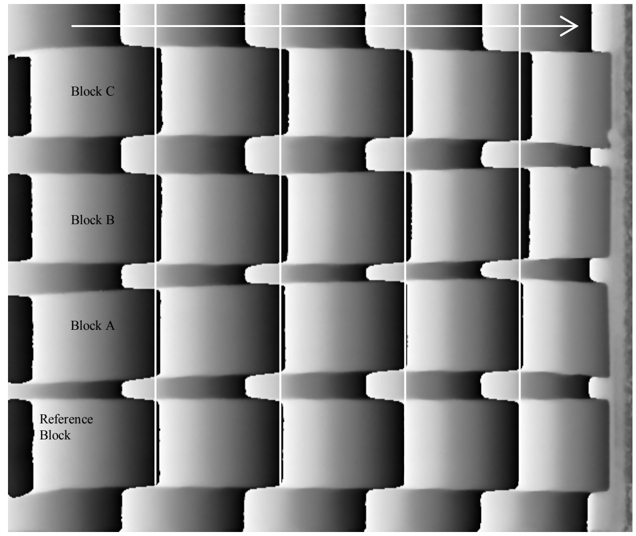

Figure 5: Phase map of blocks using the second set spacer thickness.

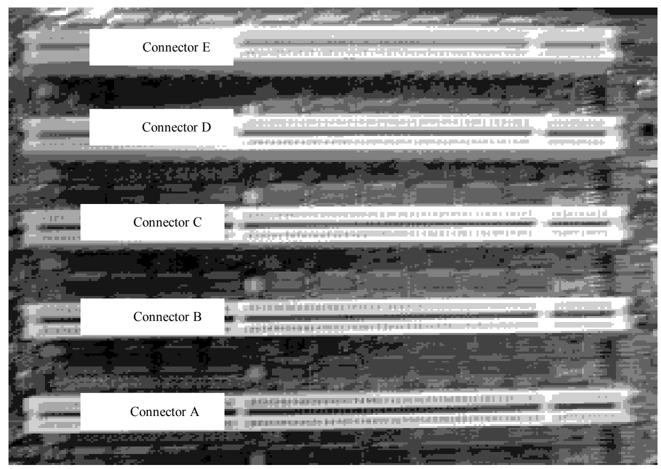

Figure 6: Plan View of Actual Connectors in a PCBA.

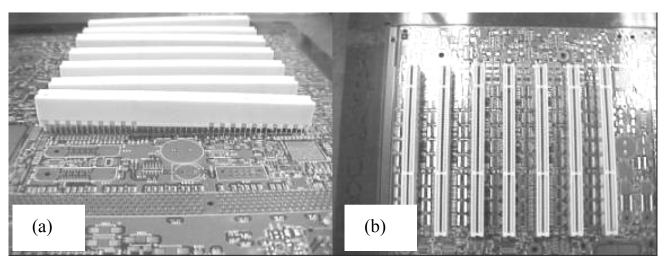

Figure 7: (a) Connector tilt as in side view, (b) Tilted connector seen directly overhead

Using the laser instrument, each connector was measured at the both ends of the edge relative to the reference connector. The height difference between each end for a connector was divided by the total length, which is 128 mm. Inversing, this value in a sine function would provide the approximated tilt angle value. The angle value approximated for connectors B, C, D, and E are 0.01˚, 0.01˚, 0.05˚ and 0.20˚ respectively. Figure 8, shows the phase map produced on the actual connector images. Using the phase shifting technique the tilt angle calculated for connector B, C, D and E were –0.01˚, 0.02˚, 0.08˚ and 0.54˚ respectively. The result shows that connector B and C are nearly horizontal, D has minimal tilt and E has the highest tilt. This result was obtained after linear fitting process on the data.

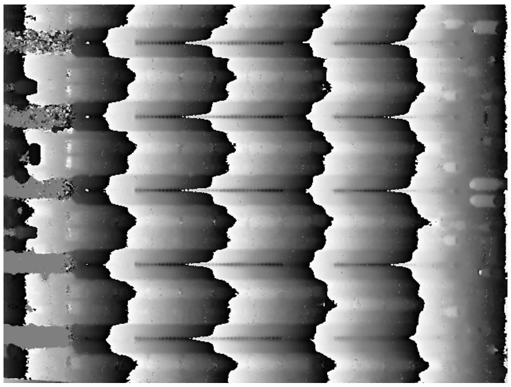

Figure 8: Phase Map image on the actual connectors.

5 CONCLUSION

This proves phase shifting technique is reliable in measuring small tilt angle. This result shows there is a consistency with the first part of the experiment. With the trend of miniaturization for the surface mount industry, this proves critical in measuring defects even for surface mount device connectors. There are also connectors without leads protruding that are surface mounted. Such connectors are commonly used on miniature PCBA i.e. laptop computer motherboards. The tilt defect in these boards would be at a small angle. Vision system reliability on small tilt angle measurement would be an important factor for inspection of such defects in these connectors. The last part of the work in to demonstrate the effectiveness and reliability of this method in detecting tilts on actual connectors on a PCBA This work was done using a non-collimated light source, whereas other researches on surface metrology usually used collimated light source. However, this work has demonstrated a successful manipulation of the non-collimated light source in height measurement by calibration of the illumination angle and development of the reference table. The development of the reference table obviates the necessity to calibrate the illumination angle for every height investigated. The derivation for relationship of θ-L for an investigated height is limited to the maximum height level of illumination angle calibration done for the development of reference table.

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