Solder Paste Inspection Technologies: 2D-3D Correlation

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Abstract

It is understood that the solder paste printing process presents far more opportunities for defects than any of the other individual Surface Mount Technology (SMT) Manufacturing Processes. In addition, transition to lead free solder paste and use of miniature components, has increased the complexity of the printing process. It has been proven that the lead free solder pastes do not spread or "wet" as well as tin lead solder pastes. In general a more accurate printing process is required in a lead free process. This has pushed the manufacturer to implement some type of post-print inspection.

The impact on the overall process must be considered when implementing in-line solutions for inspection. Factors that should be considered are, accuracy and repeatability, capability to evaluate all three Regions of Interests (ROI), cost of implementation, and speed. The three regions of interest (ROI) include the solder paste on the printed circuit board pad (both 2D and three 3D can be considered here), the region between the printed circuit board pads, and the region between the stencil apertures. Budget considerations may drive customers to consider in-line sampling techniques versus in-line 100% inspection. Sampling options today include SPI (Solder Paste Inspection) systems, both 2D or 3D, or within-printer 2D inspection.

This paper describes correlation between a true 2D area measurement (e.g. printer) and a height map generated area from a SPI system. In addition, this paper will explore the correlation between area/volume measurements and bridge detection between 2D/3D techniques. The ultimate goal is to arm the process engineers with information that can be used to make decision that will impact defects, cost, throughput and Return On Investment.

Key words: Solder Paste Inspection (SPI), 2D & 3D inspection, Lead free, Region Of Interests (ROI), Correlation

Introduction

Today, with the push towards smaller, lighter and more functional hand held devices; every millimeter of the PCB is utilized, creating high board density with mixed components. These components could range from ultra small components such as 01005 passives to ultra fine pitch QFP to larger power supply devices. The mixed solder volumes needed to produce a reliable board combined with lead free processing and requirements for high throughput poses a daunting challenge to the process engineer.

The solder paste print operation is widely recognized as a primary source of defects in surface mount assembly. One approach to increasing the yields associated with the solder paste deposition process is to detect print defects immediately after the print operation and reject defective boards before the placement of components. This enables SMT manufacturers to save time otherwise wasted in the assembly of defective boards and avoids costly rework. Whether or not a defect is reported at any specific site, SPC data can be collected and used to monitor and correct undesirable trends before they become critical to the process.

Solder paste inspection systems can be classified into two major categories, in-printer inspection and end of process inspection. This inspection system can be further broken down to 2D (area coverage) or 3D (height/volume coverage) inspection. Both processes have their own advantages and disadvantages. The area coverage data (2D) can be obtained from a true X-Y paste coverage information or through a height map from a 3D inspection. A literature survey shows there is very little to no information available in the public domain that correlate a true 2D area measurement with an area measurement through height generated data. A detail discussion of both methods is given below. Here we attempt to provide the process engineer with information based on sound experimental data to make an informed decision in regards to what works best for his/her process.

Comparison of 2D and 3D Area Measurements

The solder paste area measurement is highly influenced by the technique used to collect the image of the solder paste deposit. Since solder paste deposits are rarely shaped like perfect cylinders or cubes, area measurements based on 2D images will typically be slightly larger than area measurements based on 3D images. The question here is could they be correlated in a sound statistical manner that will provide us with a reliable prediction model? Here we attempt to answer that question.

2D area measurement technique:
To measure area using 2D inspections, an image is acquired using a camera and some illumination scheme. The image represents the reflectivity and possibility of color of the solder paste and its surrounding PCB (printed circuit board) area. To determine area, image processing algorithms are applied to the image to segment the solder paste from the surrounding image that is typically comprised of copper traces, bare FR4, solder mask and silk screen. These images can be acquired through various schemes such as contrast based or textured base inspection. In a contrast base image processing, a gray scale comparison technique is used to distinguish paste from the surrounding. On the other hand, texture base analysis uses a unique image texture of solder paste to discriminate the solder paste from it surroundings. Figure 1a and 1b shows a typical example of both contrast base and texture base images.

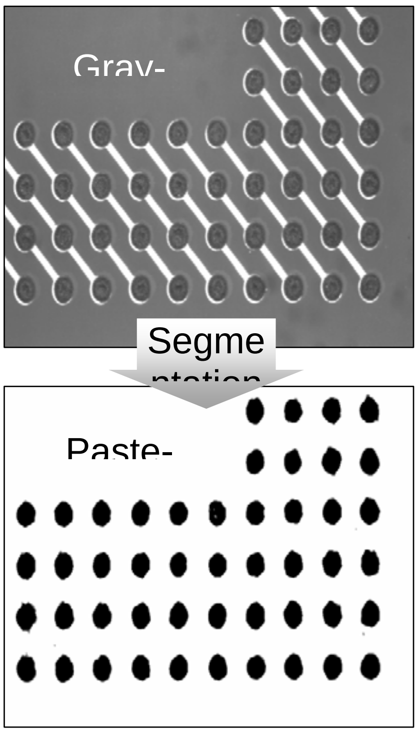

Figure 1a. Contrast base, gray scale image

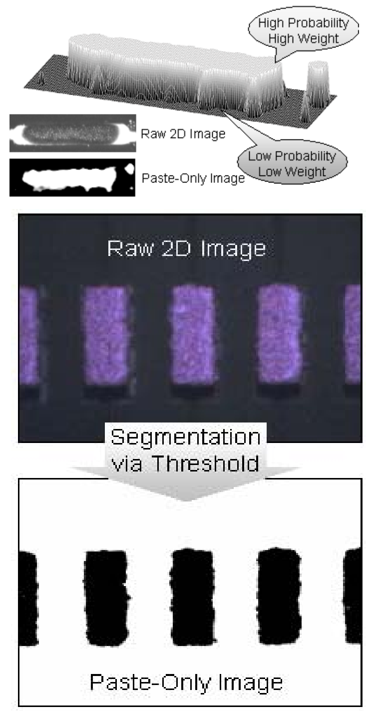

Figure 1b. Textured base image

Figure 2a shows a 2D image of four solder paste deposits. After segmenting the solder paste, the mask areas shown in Figure 2b can be used to determine the area of the solder deposit. Since the area reported by the 2D image area measurement is determined by a top view of the solder paste, the reported area will represent the total area of the solder deposit regardless of the shape or height of the solder deposit. The performance of the 2D area measurement is determined by the ability of the segmentation image processing algorithm to discriminate between the solder paste and surrounding surfaces.

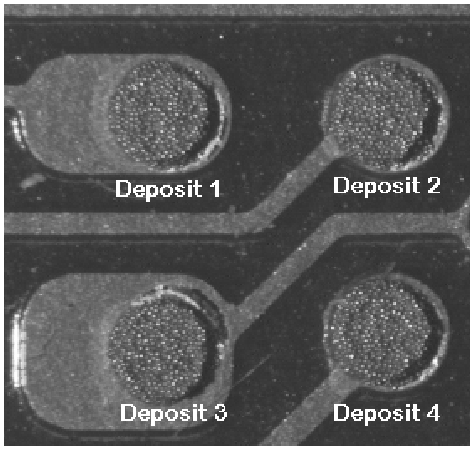

Figure 2a. 2D image of solder paste deposits

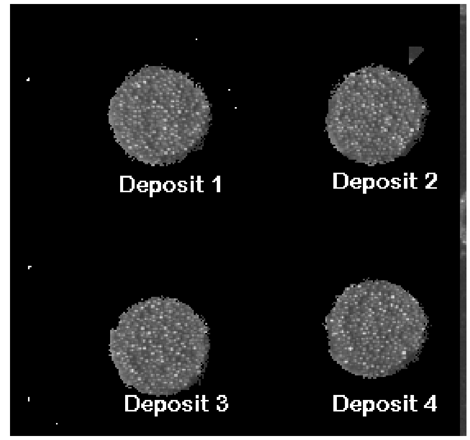

Figure 2b. Segmented 2D image of solder paste deposits

3D area measurement technique
3D area measurements are based on a height image where the image represents the height of the solder deposits at each pixel. Once the 3D image is acquired, the solder paste deposit is segmented from the surrounding PCB by determining which areas of the 3D image are higher than the surrounding PCB. The process of determining what areas are “higher” than the surrounding PCB typically requires determining a height threshold that will reliably segment the solder paste. This segmentation process is straight forward and is not affected by the color, texture or reflectivity of the surrounding PCB.

Figure 3a is a height map of solder paste deposits where the value (i.e. intensity) of each pixel in the image represents the height of the object at the position in image. Brighter pixels represent higher points in the image. Figure 3b shows the height map segmented using a threshold of approximately 50% of the height of the deposit. As in the 2D measurement, once the solder paste is segmented, the calculation of the area of the deposit is straight forward.

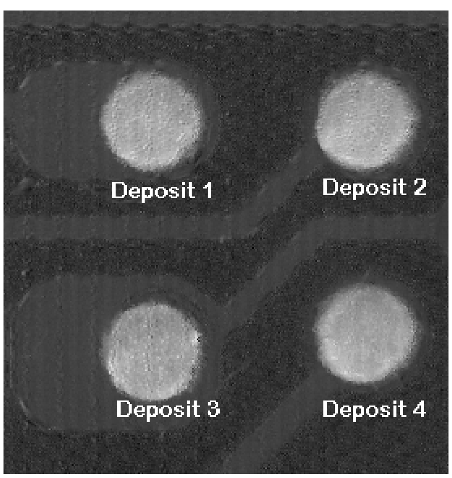

Figure 3a. Height map of solder deposits

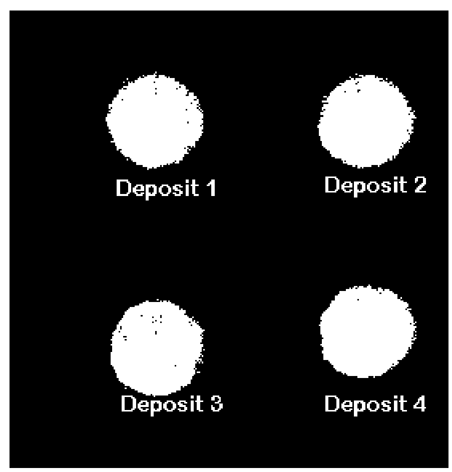

Figure 3b. Segmented Height map

Since 3D area measurements require a threshold to be determined, the reported area will be affected by the shape of the solder paste deposit. This effect is usually small but measurable. Figure 4 shows the height image of the solder deposits in perspective view. The shape of the solder deposits is shown to have slightly angled sidewalls. Typically, a height threshold is chosen that determines the area represented by the sides of the deposits. In essence, the reported 3D area is the area of a cross section of the solder paste at the threshold height.

Figure 5 shows the report area for the four deposits in figure 4 as a function of the threshold height. In this case, any threshold between 2 and 6 mils will effectively segment the paste. Height thresholds below 2 mils may be unreliable since the height map may contain height artifacts near the solder deposit that are not part of the deposit such as solder mask over copper traces.

Since 3D area measurements represent an area of a cross section of the deposit, 3D area measurements will typically be smaller than the 2D measurements, which find the area of all solder paste.

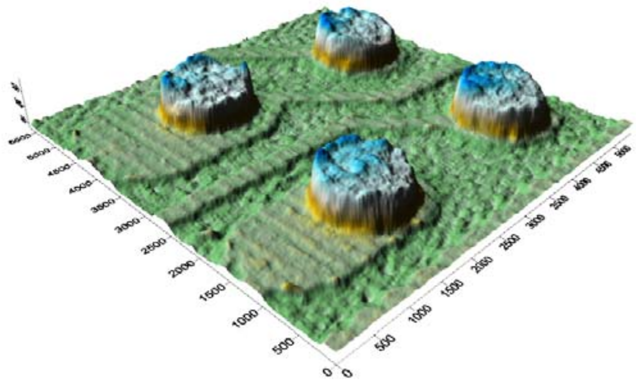

Figure 4. Perspective view of height map showing solder paste deposit shape

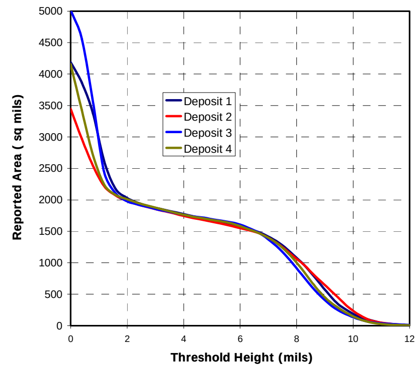

Figure 5. Effect of threshold height on reported area

Experimental Statement and Objective

As discussed above, the various inspection techniques that affect the solder paste transfer measurement are the use of 2D or 3D inspection technique. 2D inspection techniques are capable of providing the transfer area information only, while 3D inspection techniques provide additional information such as height and volume transfer. While the volumetric transfer is considered to be of more informative than area transfer, there is not a well-known supply of data comparing and contrasting the two techniques.

The primary objective of this study is to correlate the area transfer data obtained from a true 2D measurement technique with the area measurement obtained from a 3D height map through a series of controlled experiment. In addition, an attempt has been made to correlate area measurement with the volume measurement to provide the readers a tool to determine when area measurement can be used to monitor and control the printing process.

Experimental Methodology

The test vehicle used in this study is shown in figure 6. The test vehicle is a 10” x 8” x 0.062”, four layer FR-4 board with ENIG surface finish. The test vehicle included a wide range of commercially available components and packages. The list of components included in this study is shown in table 3. An MPM Accela printer was used to conduct all printing and in-printer 2D area inspection. CyberOptics SE300 SPI system was used to inspect the boards off-line to provide 3D area map, height and volume data. Table 1 shows the print parameters used in this experiment. 4 boards were printed using 3 mil Efab stencil and Type 4 solder paste. To reduce the print direction noise both forward and reverse squeegee strokes were incorporated into this experiment. Prior to the experiment, a Gage study was conducted on both the Accela inspection system and SE300 to ensure measurement repeatability.

Gage Study

A gage study was conducted on both systems by printing the test board with previously optimized print parameters and measuring the board 30 times in a series. Several components were inspected to cover large to small pad size. The result from this study is presented in table 2. As it can be seen, both Accela and SE300 provides a P/T ratio of <10%. Since a P/T<10 is considered to be exceptional, we were very pleased with the inspection systems repeatability. Detail discussion of the significant of P/T ratio is beyond the scope of this discussion. Readers can refer to various literatures for detail discussion.

Table 2. Gage repeatability of SE300 and Accela

Component type	Feature	SE 300, P/T ratio in %	Accela, P/T ratio in %
BGA 225-1	Volume	5.32	
	Area	3.79	9.12
	Height	3.87	
QFP 208-3	Volume	7.99	
	Area	11.50	5.48
	Height	0.99	
R0402-1	Volume	6.23	
	Area	8.65	
	Height	6.83	
R1206-1	Volume	4.03	
	Area	2.74	
	Height	2.92	
R0805H-1	Volume	4.61	
	Area	3.62	7.55
	Height	3.98	

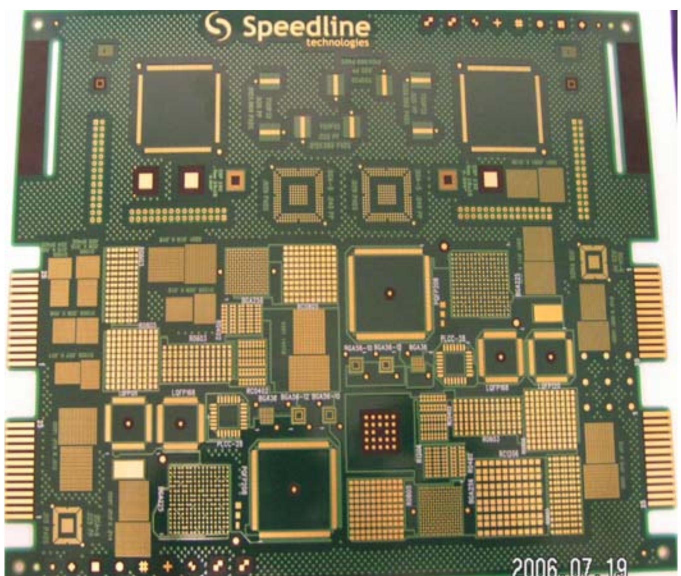

Figure 6. Test vehicle

Result and Discussion

As it can be seen from figure 6, that the test vehicle includes ultra small component such as 01005 to larger BGA and 1206 passives. For shake of simplicity, the smallest component included in this study was R0201. A list of components included in this study is shown in table 3.

Table 3. Components used in the correlation analysis

Component Type	**BGA 225**	**BGA256**	**PLCC28**	**QFP 160**	**QFP208**	**R0603**	**R1206**	**R0201**

Figures 7 and 8 show typical run-chart plot for area measurement from both 2D and 3D methods. As it was predicted, area data from the 3D method shows consistently lower value than the 2D method. Trend line for both sets of data is similar in nature. This will lead one to believe there might be a strong correlation between the two methods.

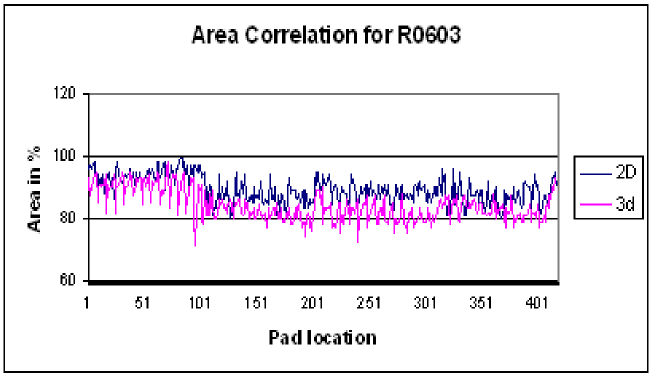

Figure 7. 2D-3D Area correlation for R0603

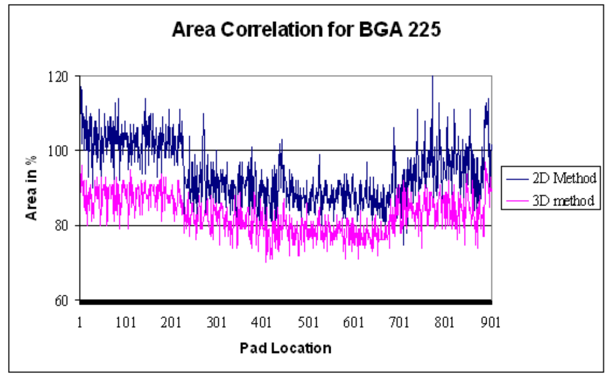

Figure 8. 2D-3D area correlation for BGA225

In order to better understand the correlation between these two inspection system a simple linear regression analysis is used here to develop a prediction model and understand the extent of predictability. Regression analysis is a statistical tool that quantifies the relationship between two or more variables/data set. Regression analysis is generally used to investigate and model the relationship between a response variable and one or more predictors. Linear regression method, which is the most commonly used regression technique, mathematically finds a straight line that approximates the information in a group of data points. In today's readily available statistical software package, regression analysis has become more mainstream to understand and predict behavior of a dependent variable based on the behavior of an independent variable. For this current discussion, MiniTab was used to conduct the regression analysis and the result is given in figures 9-10 and tables 4-5.
Figure 9 shows residual plot for R0603 and figure 10 corresponds to the residual plot for BGA225.

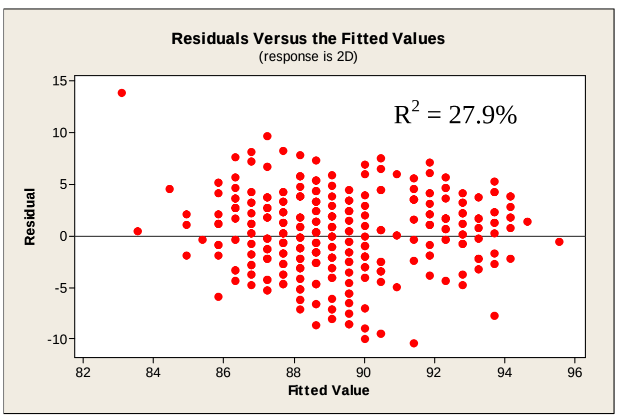

Figure 9. Regression analysis for R0603

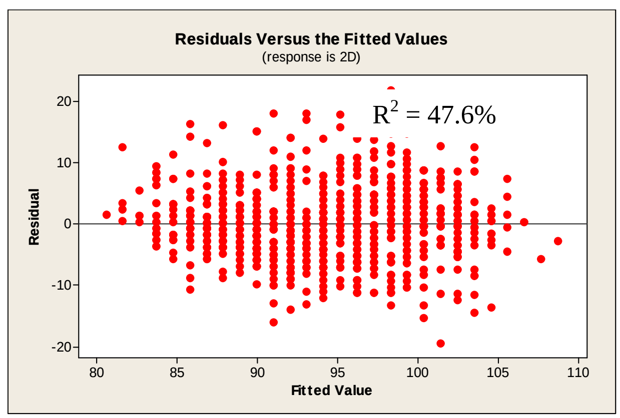

Figure 10. Regression analysis for BGA225

Table 4.

Regression Analysis: 2D versus 3D
For R0603

The regression equation is
2D = 50.2 + 0.462 3D

Predictor	Coef	SE Coef	T	P
Constant	50.240	3.066	16.38	0.000
3D	0.46236	0.03634	12.72	0.000

S = 3.62639   R-Sq = 28.1%   R-Sq(adj) = 27.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2128.4	2128.4	161.85	0.000
Residual Error	414	5444.4	13.2		
Total	415	7572.7			

Table 5.

Regression Analysis: 2D versus 3D
For BGA 225

The regression equation is
2D = 7.46 + 1.04 3D

Predictor	Coef	SE Coef	T	P
Constant	7.465	3.018	2.47	0.014
3D	1.04371	0.03638	28.69	0.000

S = 5.67006   R-Sq = 47.8%   R-Sq(adj) = 47.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	26458	26458	822.96	0.000
Residual Error	898	28870	32		
Total	899	55328			

As it can be seen from table 4 and 5 the P-value for both R0603 and BGA225 is less than 0.05 indicating 2D and 3D area measurements are statistically different. The R^2 value, which is the square of the correlation coefficient (r) indicates that for R0603 approximately 30% of the 3D area data can be predicted by the 2D data while approximately 50% of the BGA225 3D data can be predicted by the 2D data.

In some cases, depending on the application requirement, one may consider substituting one method over the other due to budget, floor space and process requirement consideration. 2D-3D area correlation between the BGA appears to be much stronger than the R0603. This can be explained by the fact that the R0603 pads are much smaller in size and more challenging to inspect. Error associate with these two methods magnifies as the absolute size of the paste deposition decrease. This scaling effect is consistent with the prediction that the shape of the deposit has a strong influence on area measurements based on 3D height maps since smaller pads and round pads are more susceptible to edge effects.

A similar analysis for 2D-3D area and true Volume correlation is presented in figures 11-14. Here we see the trend as was present in the area correlation. The correlation between area and volume appears to be better than 2D-3D area correlation as is evident by R^2 value of higher than 50%. Since a R^2 >90% is considered to be a strong correlation, we can safely conclude the correlation is moderate.

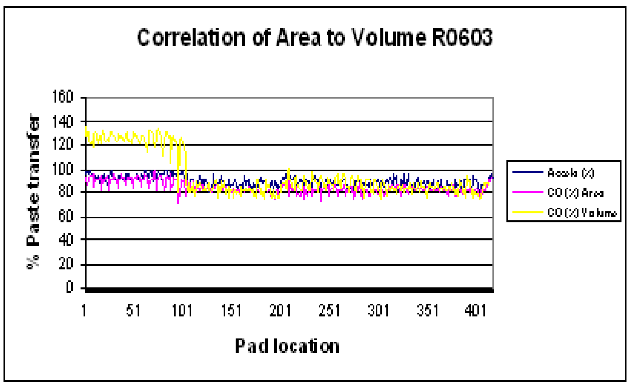

Figure 11. Area and Volume Comparison for both Accela and SE300

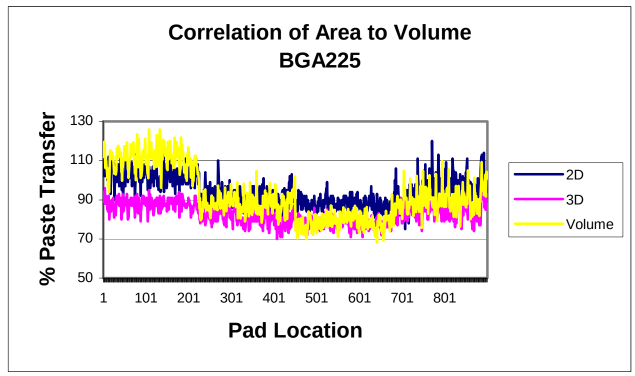

Figure 12. Area and Volume comparison for both Accela and SE300

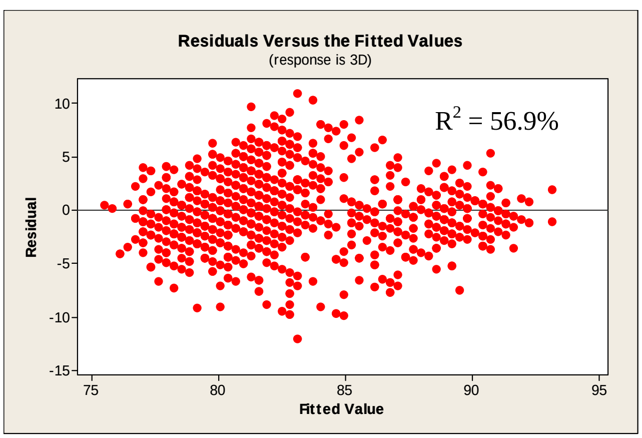

Figure 9. Regression analysis for R0603 in respect to volume.

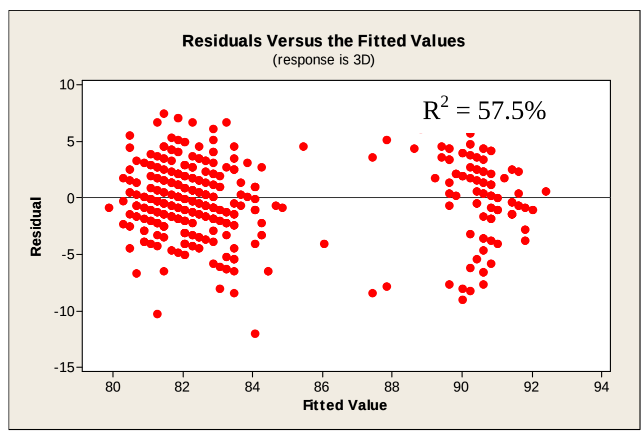

Figure 10. Regression analysis for BGA225 in respect volume.

Table 6

Regression Analysis: 3D versus Vol
For R0603

The regression equation is
3D = 65.3 + 0.199 Vol

Predictor	Coef	SE Coef	T	P
Constant	65.3305	0.8222	79.46	0.000
Vol	0.199067	0.008530	23.34	0.000

S = 3.19490 R-Sq = 57.1% R-Sq(adj) = 56.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	5559.1	5559.1	544.61	0.000
Residual Error	410	4185.0	10.2		
Total	411	9744.1			

Table 7

Regression Analysis: 3D versus Vol
For BGA225

The regression equation is
3D = 54.8 + 0.304 Vol

Predictor	Coef	SE Coef	T	P
Constant	54.8440	0.8098	67.73	0.000
Vol	0.303748	0.008715	34.85	0.000

S = 3.39046 R-Sq = 57.5% R-Sq(adj) = 57.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	13965	13965	1214.89	0.000
Residual Error	898	10323	11		
Total	899	24288			

Summary

Based on the experimental results and analysis, we can summarize as follow:

- Based on the R^2 value, which is the square of the correlation coefficient, it can be concluded that there is a weak correlation between 2D and 3D area measurement. Usually, a strong correlation is exists when the $R^2 > 90\%$. We see with larger pad sizes, the correlation is stronger. We also observed (not included in this paper) the correlation is strongly depended on, not only the pad size but also the aperture shape. However, the ratio of the 3D to 2D area data can change depending on shape – both 2D and 3D and the relationship between the shape and this correlation factor is a topic of further study.

- As predicted, there is an inevitable bias between 2D and 3D area measurements, with 2D consistently measuring a slightly larger area. One observation that should be mentioned here is that for very small pads sizes the results we report here show a different trend. As pads get smaller, other effects such as pixel quantization, edge irregularities and the actual size of the solder balls at the edge of the pad start to effect the measurement. We have seen evidence of this phenomenon for much smaller pad size and will be reporting it at a future date.

- Correlation between 2D area and volume appears to be stronger than the 2D area versus 3D area correlation.

- Some bimodal structure in the correlegram (figures 9 and 10) shows one board possibly having a different print characteristic, which is a possible investigation for future work.

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