

A Novel Measurement Technique for Stencil Printed Solder Paste

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ABSTRACT

The printing process is the most critical step in surface mount assembly, with the highest fraction of defects attributed to it. To control and monitor printing, complex instrumentation is available for measuring the print consistency. Data from such techniques are essential in product development, SPC and quality control.

This report describes a novel robust method, which introduces critical variables defining print quality. Conventional measurement methods include only the volume and average height of solder paste. The limitations of using just these parameters are discussed and a new method is introduced. The latter processes height data from a scanned in two main steps. The first, matrix levelling, takes account of non-flat surfaces or related samples. The second is the calculation of PVO (pseudo-virtual object) parameters, deposited volume, PVO angle (related to slumping and bridging) and mean height. Major attributes of the proposed data analysis algorithm is its insensitivity to both the specific location of the printed deposit and the location of a specific defect. This algorithm coupled with variables defined in the analysis package delivers a new and flexible approach to printed media. Examples of modelled matrices are presented in the Appendix.

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Head, Materials Centre

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1. Introduction

The electronics assembly industry demands fast changeover with continuous improvement, and higher yields. As production yield is dependent on the number of product defects, these defects need to be identified, and corrective actions taken. Figure 1 presents a typical breakdown of defects from a surface mount assembly line, which shows solder paste printing process being responsible for the highest number of defects and consequent repair (rework). These repair operations increase cost, testing and production time. As the solder paste printing operation is at the beginning of production line (Figure 2) it is wise to inspect, and if necessary reject a printed substrate immediately after this step and reduce the number of defects entering rest of the production line.

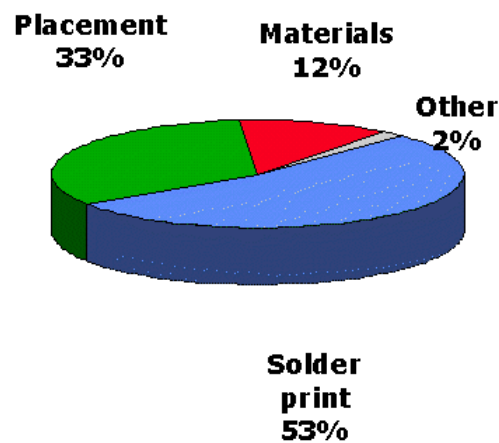


Figure 1: Typical breakdown of electronics production defects

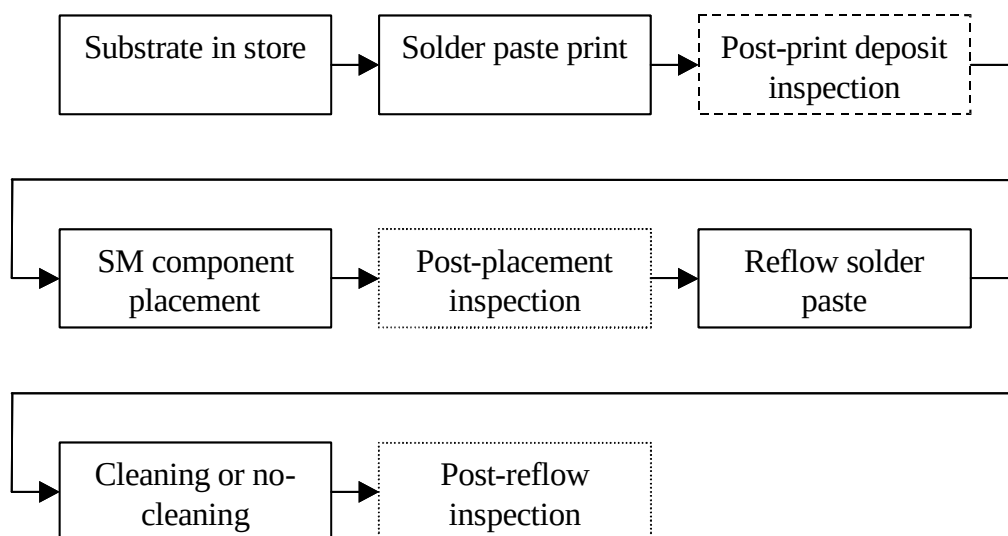


Figure 2: Surface mount assembly line

In Figure 3 a solder paste deposit printed on a copper substrate is shown, illustrating the typical wall slope after solder paste release from the stencil. This wall would ideally be perpendicular to the base plane, and a copy of the stencil aperture edge. As the solder paste comprises alloy particles suspended in gel, the cohesive forces help to retain the deposit shape and only minimal slump occurs before component placement. Slump is also partly restricted by the definition of the copper PCB pads.

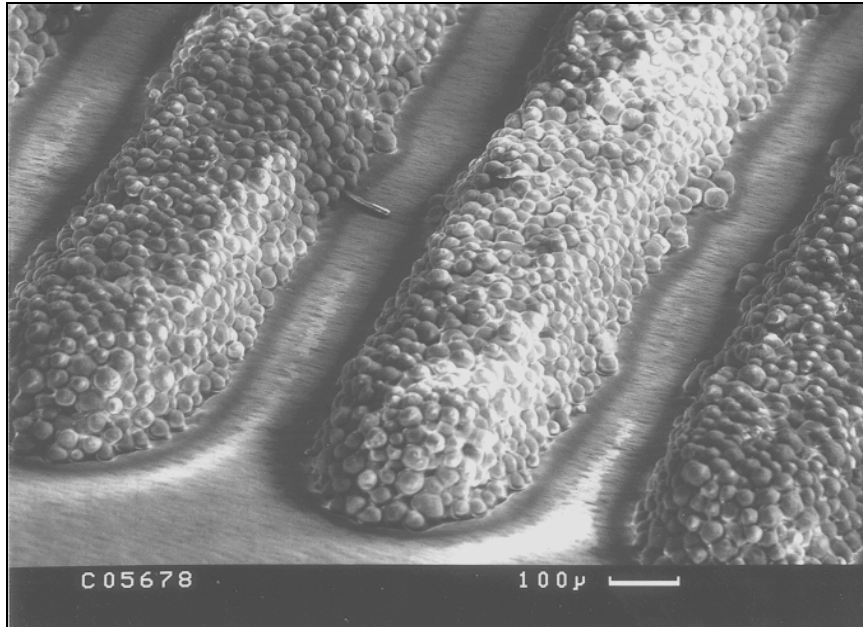


Figure 3: Solder paste deposits stencil-printed on Cu substrate

Previously, a method was described for measuring and interpreting data from solder paste height measurements ⁽¹⁾. Recently there has been more interest in measuring solder paste as part of SPC control and improved process yield ⁽²⁻⁵⁾. Here we discuss the various methods available and propose a new method that can handle print defects in a robust manner.

2. Measurement Techniques

Current techniques used for the measurement of paste height are of two types. The first is based on a camera system accompanied by a grid and collimated light source as shown in Figure 4. The light traces produced by grid slits are focused on surface features and when viewed from the top are deformed by the surface features. This deformation (L) can be detected using a camera system, and from the known angle α (usually 45°) the average feature height (H) can be calculated (Equation 1). This method of height measurement is based on static samples, and data acquisition time is determined by image processing routines.

$$H = L \cdot \tan \alpha \quad (1)$$

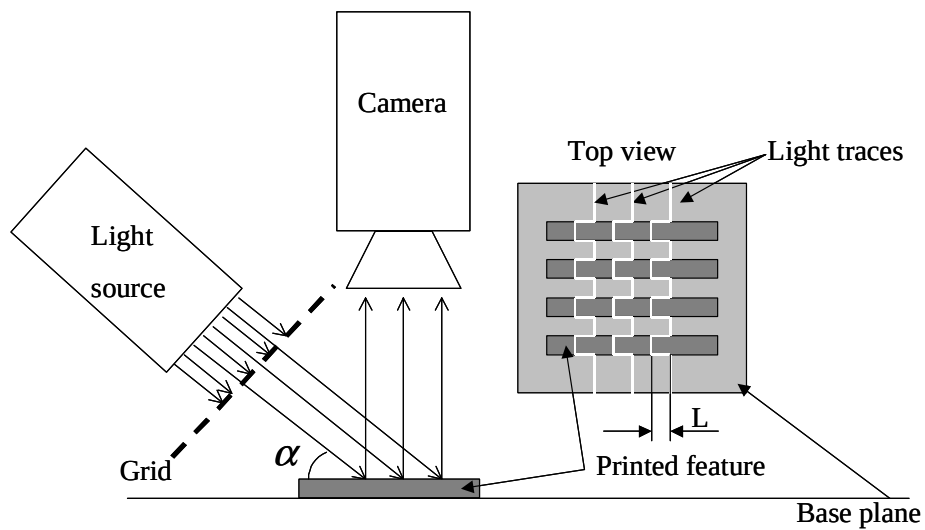


Figure 4: Schematic of camera based measurement system

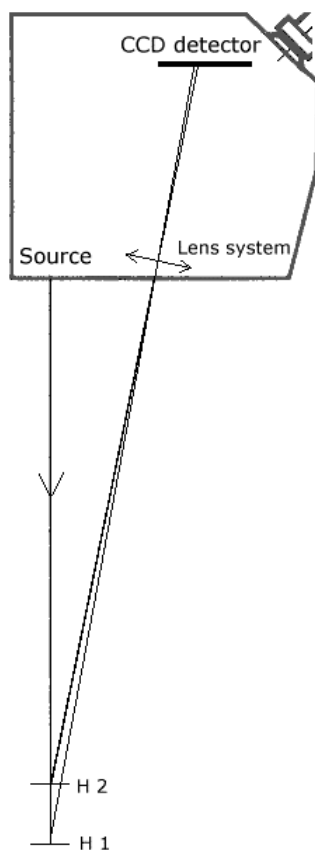


Figure 5: Schematic of laser displacement sensor and example of scanning measurement instrument

The second technique for height measurement is based on a triangulation (CCD laser displacement) method and uses a scanning of the feature with a single light beam. A semiconductor laser beam is reflected off the target surface, passes through a receiver

lens system, and is focused on a CCD sensing array. The CCD detects the peak value of the light quantity distribution of the beam spot for each pixel (individual CCD sensing element) within the area of the beam spot and determines the precise target position as illustrated in Figure 5. As the target displacement changes relative to the sensor head (H1, H2), the reflected beam position changes on the CCD array. These positional changes are analysed by the controller and transposed into the scanned feature height profile.

Data from any of the described systems can be stored in a two-dimensional matrix and processed with built-in algorithms to give characteristic feature dimensions. The accuracy of the measurement for solder paste deposits is typically between 1-20 μm , which is comparable to the solder particle size, i.e. minimal object size (solder balls with diameter of 25-40 μm). An example of scanned matrix contour plot of a printed deposit is presented in Figure 6.

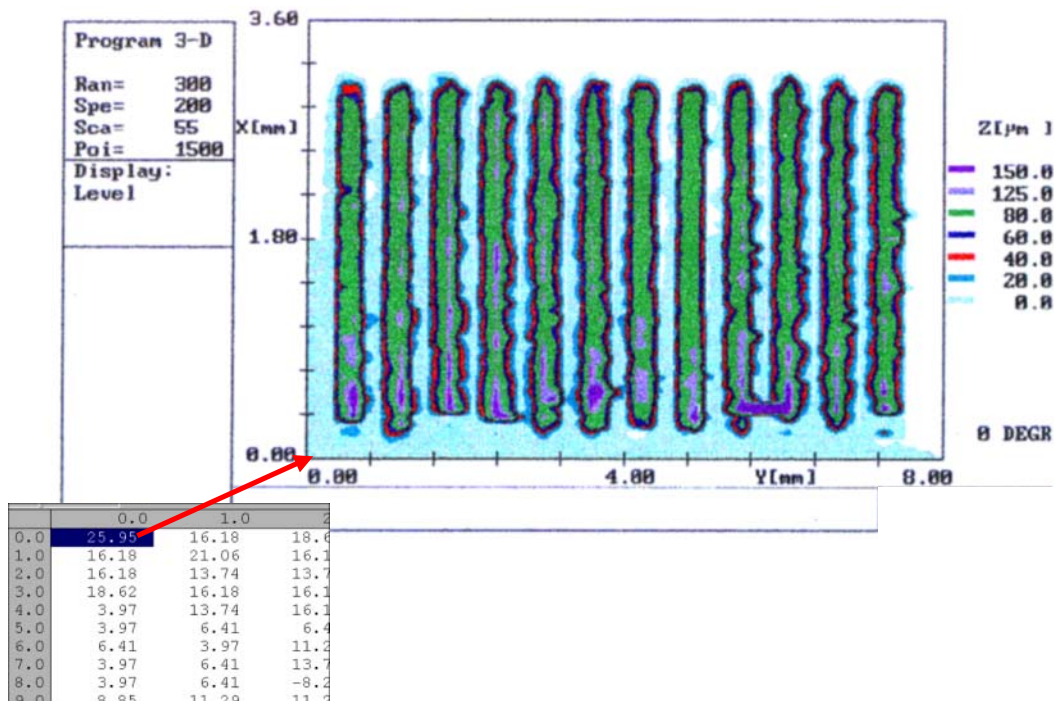


Figure 6: Example of contour plot of a scanned matrix

3. Output Characteristics

The current industry solder paste acquisition systems have a limited set of characteristic variables describing solder paste deposits. The main variable monitored by on-line or off-line instruments is **deposited volume**, which is often expressed as a ratio (or percentage) of absolute deposited volume to maximum possible deposited volume, relative to the stencil aperture.

The other frequently encountered characteristic variable of printed deposits is **the average height** of deposits. This parameter is particularly important in connection with known component co-planarity. If the average deposit height is greater than specified coplanarity range there is a minimal probability of open circuit between component leads and pad contacts on a PCB. The difficulty of obtaining this average height lies in specifying what the averaging algorithm uses for the measurement area and where the zero reference is taken.

Characterising a single solder deposit or an array of deposits requires certain decisions in terms of the measured area, e.g. how much of the area surrounding the deposit, should be included in the measurement. Measurements from the top of a solder deposit are demanding in terms of location of the deposit and the subsequent data manipulation. Including bare board around the deposit relaxes the alignment requirements, but does introduce into the data some matrix areas where no paste is printed.

Determining the average height is therefore not simply an average of the matrix. The paste free areas of the board must be filtered out prior to the calculation. This is achieved by specifying a base plane height (h_0), see Figure 7, and **including only** height points above this reference plane. The issue is how far should this reference plane be above the substrate surface without significantly influencing the calculated average height. In Figure 8 the average height is plotted as single data points for 100 scanned matrices (of similar solder paste prints) for incremental values of h_0 (for each value of h_0 there are 100 points in the column). The thin green line is the average for one of these data sets as h_0 is increased. The thick red line is a calculation of the average height for all 100 scanned matrices in the plot as a function of h_0 .

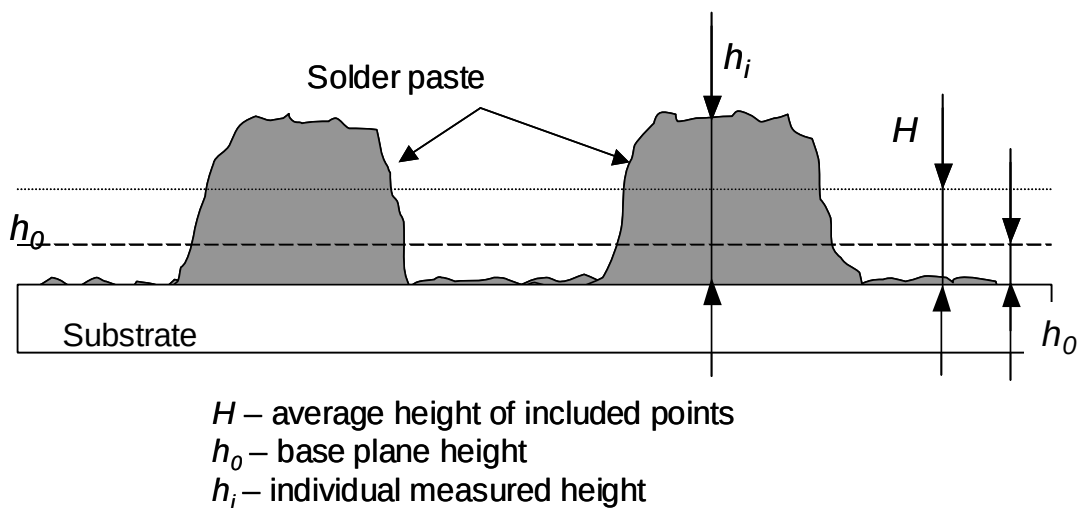


Figure 7: Schematic of average measurement

The equation to calculate H is given in Figure 8, and the second term $(1 + \text{sign}(h_i - h_0))$ acts as the filter so that all instances of $h_i < h_0$ do not contribute to the calculation of H . Both the green and red curves show that H is a function of h_0 , and hence there is a critical issue as to what the true height H actually is. It is clear that this is dependent

on the value of h_0 . Reducing h_0 to the point where individual solder particles are being measured around the main deposit, has the effect of bringing H down. Increasing h_0 removes the spurious inclusion of the bare board areas and H rises. Clearly there must be a region where h_0 is increased sufficiently that the incidence of odd solder particles is no longer an issue. This region in the example curves can be seen when h_0 is above $30\mu\text{m}$, and the tangent of H is a minimum. In this region H is also the least sensitive to the precise value of h_0 . Hence, for this particular example of a Type 3 paste, and this aperture array and using $150\mu\text{m}$ stencil h_0 should be set at $50\mu\text{m}$.

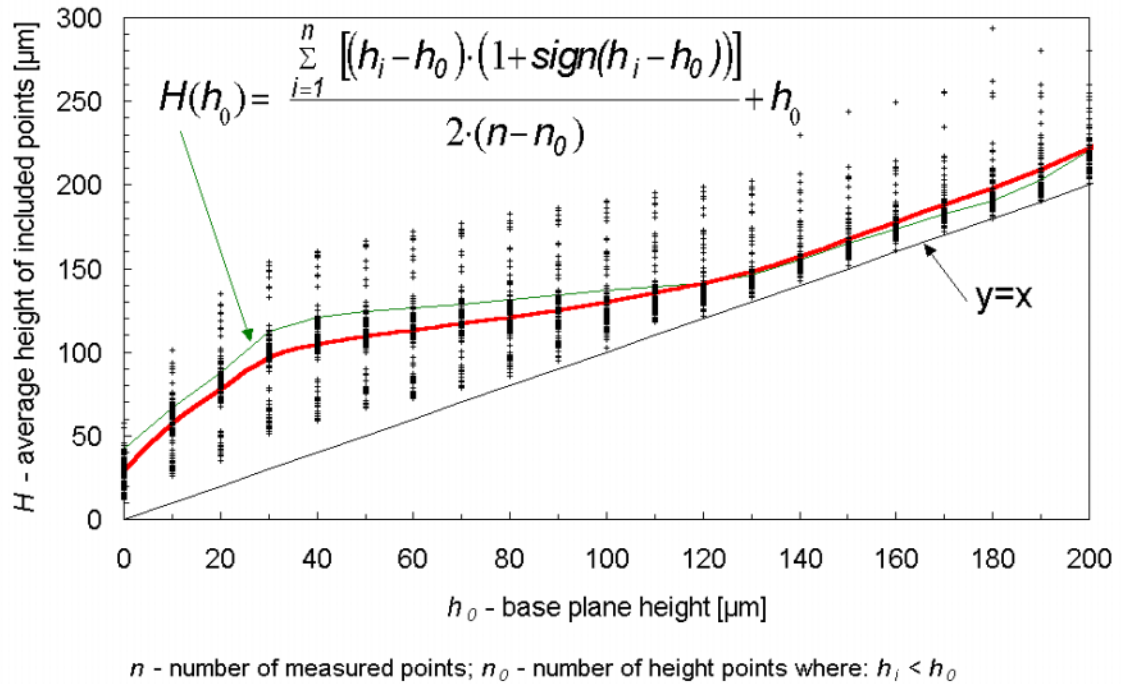


Figure 8: Average height calculation

As mentioned above the height data can be acquired from selected areas at the top of solder paste deposits, alternatively as shown in Figure 9, the whole print area of an aperture array can be scanned, and this includes paste free areas.

The boxes A to D depict possible locations where specific data can be collected. The calculated average heights for the selected areas are given in the Figure. Position A is at a local maximum, B is at a bridge, C is for a correctly aligned measurement along the entire length of a print, D shows misalignment of the measurement area. The technique of aligning the measurement area can clearly produce good results, but as selection D shows, misalignment can seriously affect the calculated value. The technique is widely used in industry where fast assessment of printed deposits is required, but the alignment can be a problem, and with setting up required for correct operation false measurements can be a concern. The most reliable method is to scan the complete deposit, which includes some of the surrounding board area, as shown in Figure 6.

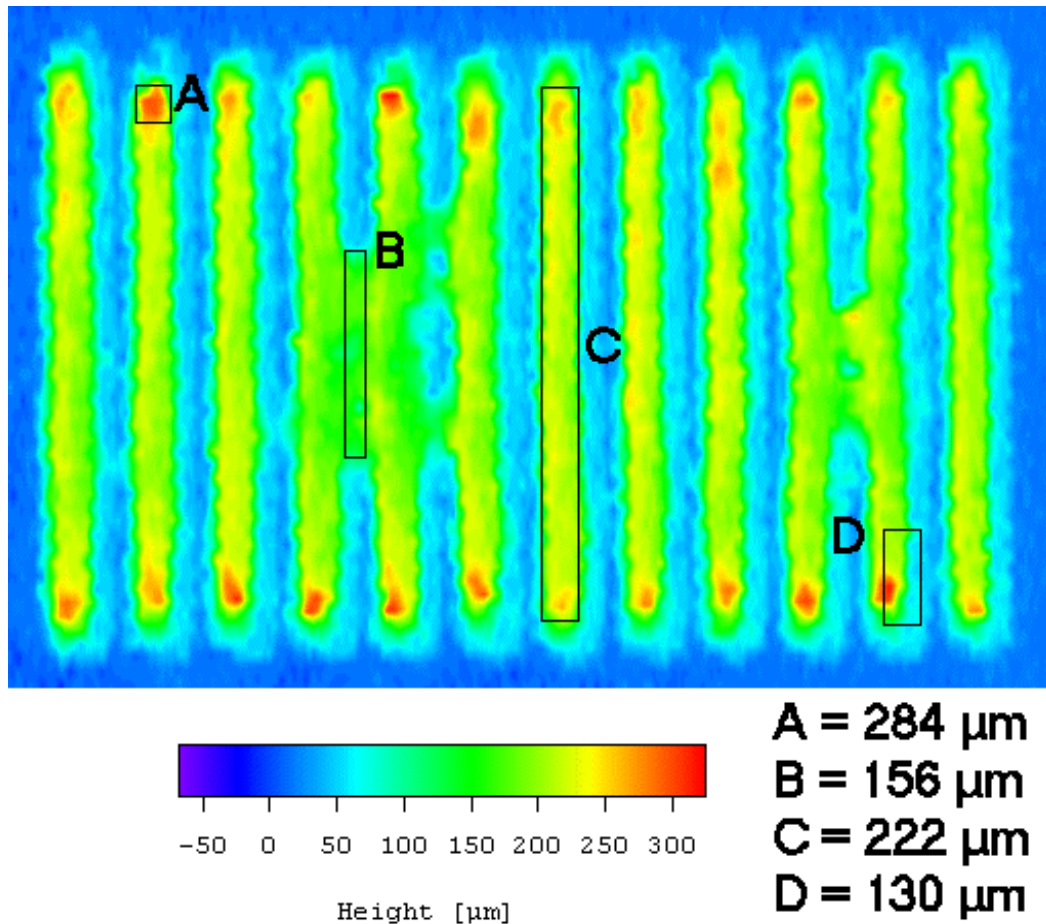


Figure 9: Scanned solder paste matrix of QFP printed features

Some advanced systems based on camera or single ray scanning are able to recognize the position and outline of features automatically, and calculate differences in volume, shape or even bridging and skips (missing volume in deposit). This approach is very demanding on both measurement and computation, and needs extensive library information if it is to interpret all printed features accurately. There is a trade-off between the time of building such a specialized model and its computational run time, with the intrinsic flexibility in the more straightforward measurement of total volume and height.

Practically, if a model struggles to characterise a sample print correctly the opportunity for errors to occur increases and the resulting accuracy of output parameters will decrease, or even crash the computing routine.

Therefore, the requirement to measure print features other than volume and height is very clear, but there is a considerable challenge to characterise such features effectively as the print definition deteriorates and correct identification becomes problematic.

3.1. *Requirements for robust output parameters*

The main requirement for making credible measurements is to reduce the impact of specific features, and allow robust measurements of volume and height that are not sensitive to localised anomalies in the print deposit. The method should also be capable of account of features such as bridging and skips. Any method should be intrinsically flexible and produce meaningful measurement parameters for a range of patterns; e.g. QFP, flip-chip, discrete chip components. For the key aspects height, volume and shape the analysis method should produce output parameters that are equivalent between different component patterns and are easy to assimilate and provide a suitable basis for comparison. The measured values should be on a continuous scale, so that pass/fail criteria can be set. An issue with some measurements is the alignment of the print with the measurement axis. A method that doesn't require the board or the print data within the matrix to be rotated to achieve alignment will clearly be advantageous. Finally, as with any kind of measurement a high signal/noise ratio is essential.

A new method for analysing the data matrix from printed deposits is now proposed.

4. Algorithm Description

The new method introduced here for processing height data from a scanned sample compromises two main steps:

1. Matrix levelling (triangulation levelling of the base plane)
2. Calculation of Pseudo-Virtual Object (PVO) parameters (volume, PVO angle, mean height)

The levelling stage is an important step to carry out, but most systems assume a flat substrate, and hence a uniform reference. In this procedure the matrix is levelled as a matter of routine.

4.1. *Matrix levelling*

The matrix levelling is based on a simple subtraction of a X-Y-wedge from the measured matrix. Three points (A, B and C) define the constructed plane as shown in Figure 10.

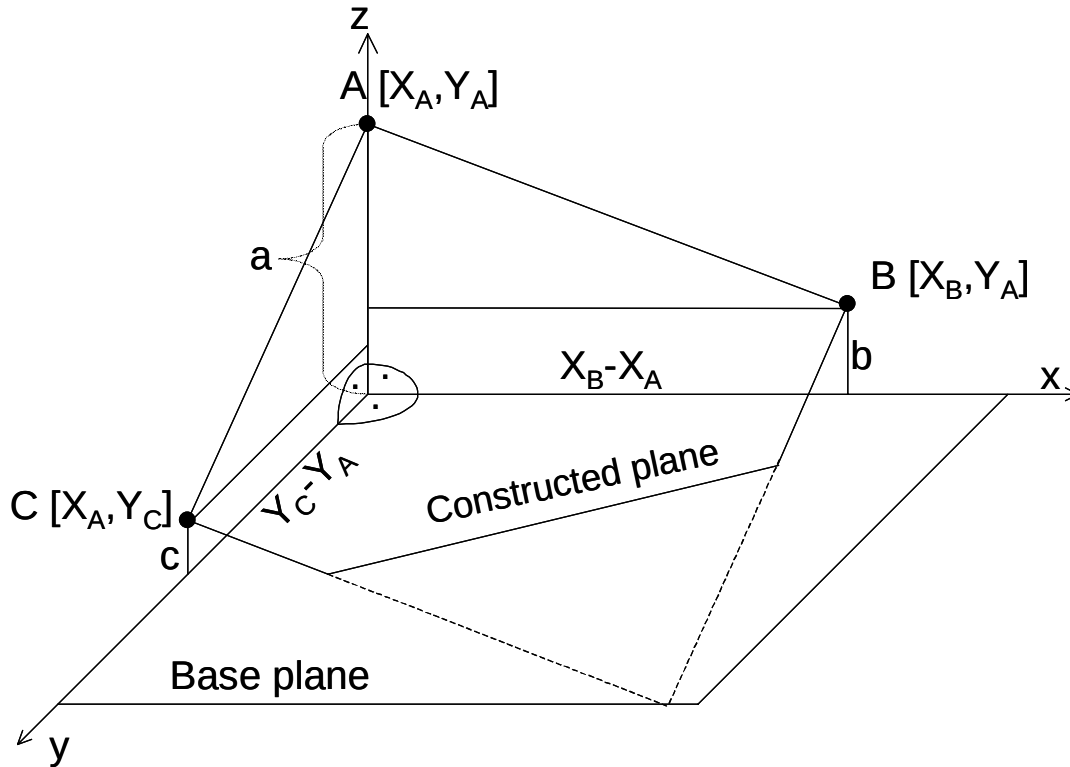


Figure 10 Schematic for matrix levelling

The wedge is calculated from heights a , b and c , and X and Y coordinate differences from the point A according to the algorithm in Figure 11. Point A is used to set the zero height point, and the rest of the matrix is levelled to this point. Locations of points A , B and C can be based on reference points (fiducials) which can be defined automatically or located by an operator at run time of the code. The values a , b , c can be calculated as the median of 3×3 sub-matrix, centred on the nominal positions. This improves the robustness, and removes problems with anomalous single values.

```

i, j    :matrix indexes
M, N    :matrix sizes
z(i,j)  :scanned matrix to be leveled
h(i,j)  :output leveled matrix
-----
a = z(x(A),y(A))
b = z(x(B),y(A))
c = z(x(A),y(C))
x12p = (b-a)/(x(B) - x(A))
x13p = (c-a)/(y(C) - y(A))
For i=1 to M
  For j=1 to N
    h(i, j) = z(i, j) - (a + x12p * (j-y(A)) + x13p * (i-x(A)))
  Next j
Next i

```

Figure 11: Example of a matrix levelling algorithm

4.2. *PVO (Pseudo-Virtual Object) calculation*

The levelled matrix can be processed in many ways, some of which were described in Section 3. The method described here is robust and flexible as required in Section 3.1. The “PVO” name is derived from the resulting computed object properties. Since the object is computer constructed it is called “virtual” and “pseudo” as it is a representation of deposited matter.

The calculation of PVO is based on analysing a matrix of the data and transposing this information into 3D symmetrical shape. An example of the transition between the two is illustrated in Figure 12 to Figure 13. The PVO is calculated on specified height ranges (or bins), for a solder paste application the range is typically 10 μm wide starting with 0-10, 10-20, 20-30 μm etc. Once the distribution height is known the PVO can be constructed around a cylindrical coordinate system with a base area equal to the scanned area. The PVO is shaped from discs, where the disc height is the mid height of the height range, and the disc’s radius is related to the square root of an area falling into the height range. The discs axes are co-located in the centre of the coordinate system and together they build a symmetrical shape (PVO), representing redistributed solder paste deposit as shown in Figure 13.

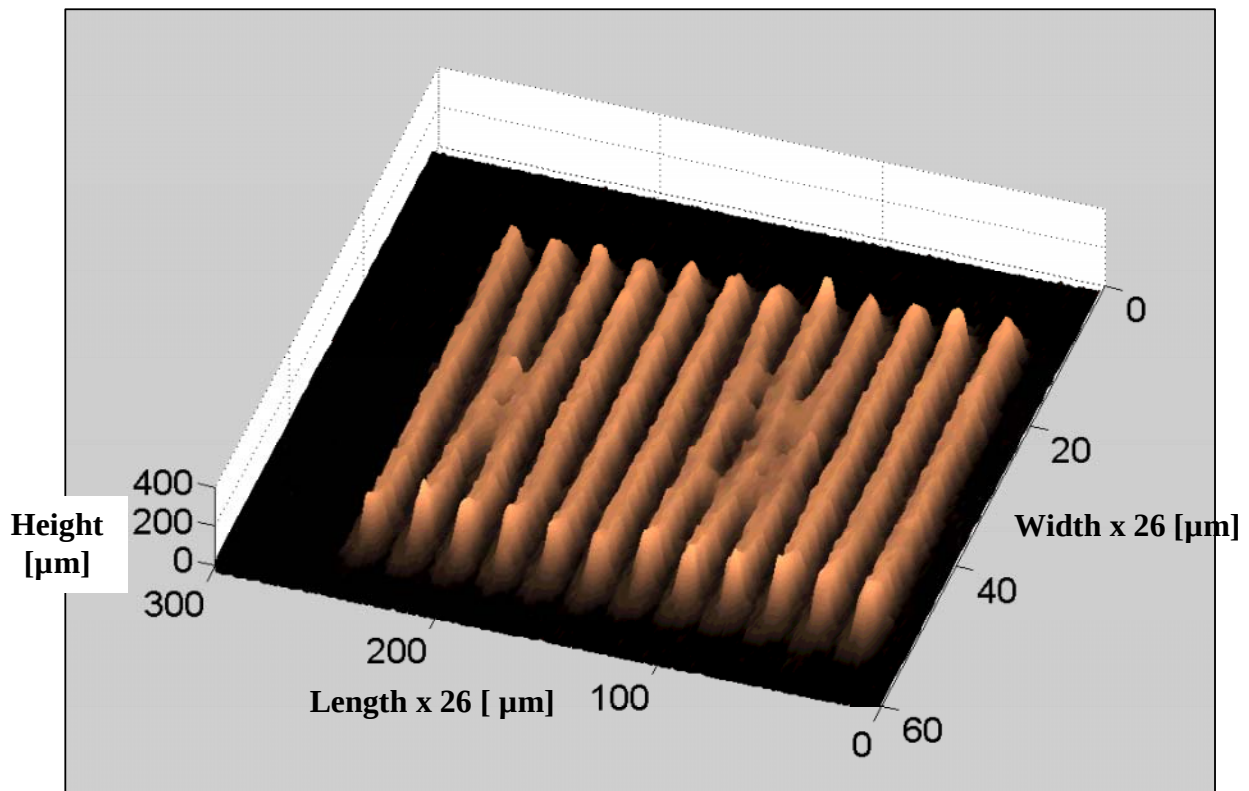


Figure 12: 3D example of a scanned matrix

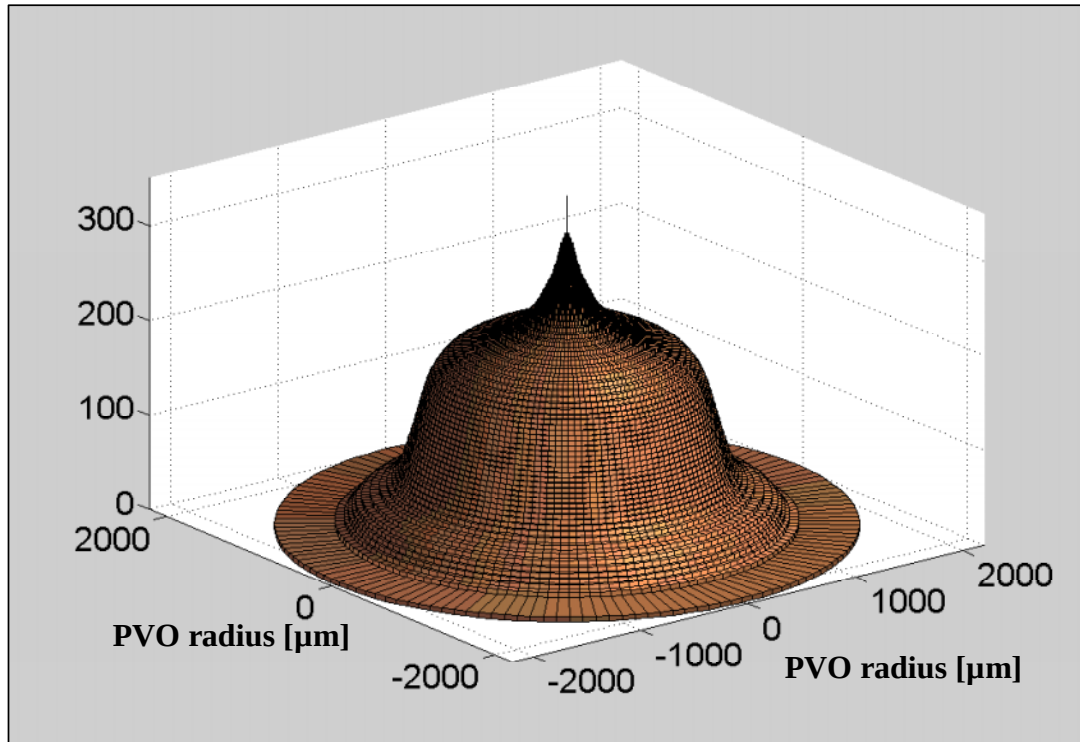


Figure 13: Example of PVO derived from Figure 12

4.3. *PVO parameters*

Parameters used for comparing print quality are defined in Figure 14. The main parameter, which can be directly compared to other methods, is **the deposited volume**. This can either be expressed as an absolute volume in mm^3 or ratio or percent of absolute deposited volume and maximum possible deposited volume (stencil aperture volume).

The parameter describing edge definition is called **PVO angle** and it is the tangential angle at the steepest point (inflexion point) of the PVO cross-section profile (blue line in Figure 14). The PVO angle is used in predicting slumping or bridging propensity.

For co-planarity issues there is a need to measure **the mean height** of a print. This is defined as a height with minimal tangential angle (red circle in Figure 14).

Further characterisation of the PVO profile is possible. As seen in the example (Figure 14) a hump around radius = $1500\ \mu\text{m}$ can be associated with propensity to **bridging** because the profile is crossing the ideal aperture radius. The left end of the curve represents a phenomenon called **“dog ears”**, which usually occurs at the end of printed deposits. These peak values can cause wet bridges after component placement.

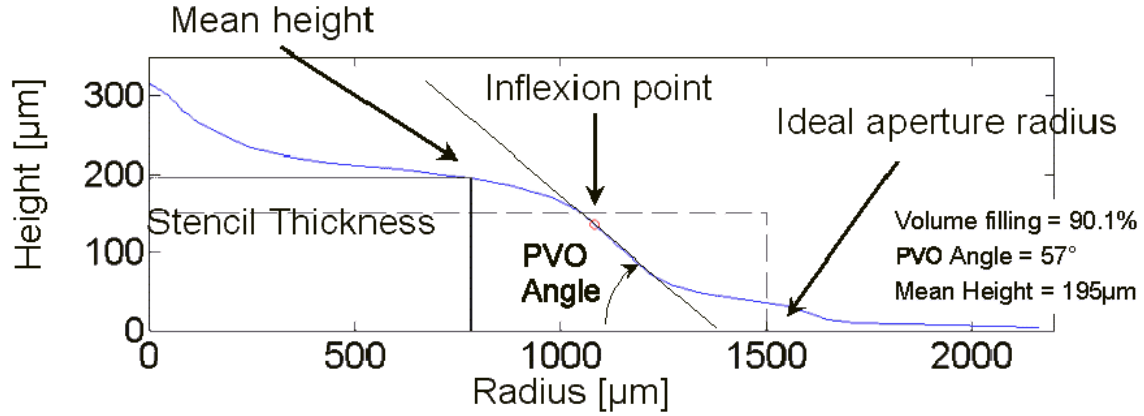


Figure 14: PVO profile and parameters definition

4.4. Correction of PVO angle

Where there are multiple similar features in a scanned matrix i.e. QFP deposits; the PVO angle has to be corrected for the number of features. This allows the PVO angles, from PVOs with different number of features or deposits, to be compared directly. The correction curves are plotted in Figure 15, using Equation 2.

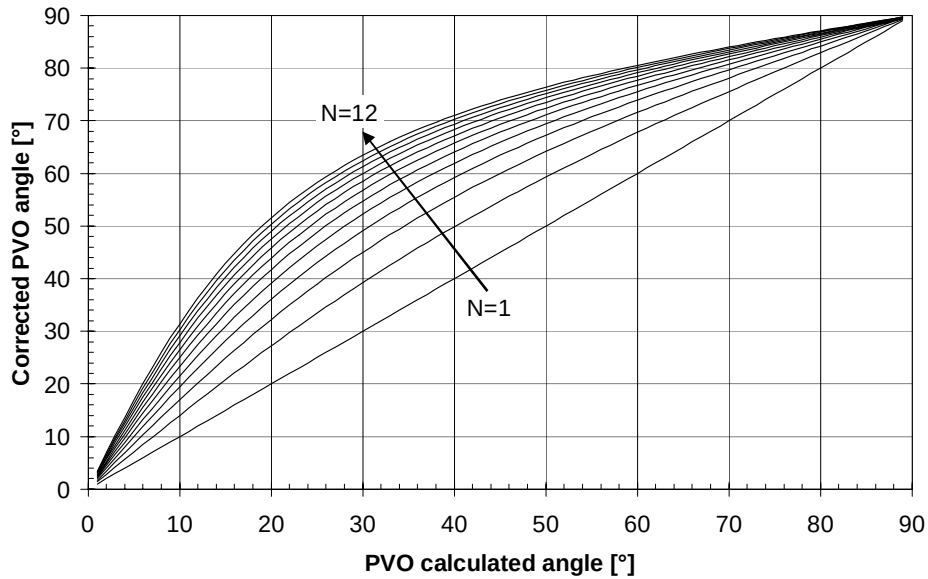


Figure 15: PVO angle correction for multiple deposits (N=1-12)

$$\alpha = \arctan\left(\tan(\alpha') \cdot \sqrt{N}\right) \quad \text{Equation 2}$$

Where:

α' is the calculated PVO angle for a single deposit

α is the corrected PVO angle for N features

N is the number of repeated features

5. Conclusions

- In measuring the quality of stencil printing of solder paste, there are significant limitations to those traditional techniques which consider only two metrics, deposited volume and average height
- The novel technique described here has successfully used a different approach for describing solder paste deposits. It employs two main steps
 - (i) matrix levelling, to take account of non-flat surfaces, rotated samples or even measurement noise.
 - (ii) calculation of PVO (pseudo-virtual object) parameters, deposited volume, PVO angle (related to slumping and bridging) and mean height.
- The new technique can be applied to other materials used in electronics production processes (e.g. SM adhesives and glob-tops)
- The major advantage of the algorithm used is its robustness and flexibility e.g. in accommodating non-flat surfaces and rotated samples.
- The tool is ideal for SPC in assembly or in materials production development.

Various examples of modelled matrices are given in the Appendix. In future work this encouraging new technique will be used on a range of scanning instruments to benchmark and analyse various aspects of stencil printing.

6. Reference

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7. Acknowledgements

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APPENDIX

In the following Figures, model matrixes of different shapes and their equivalent PVO representations are presented. An index of these is listed in the Table below.

Figure	Object	Description
16	Smooth cone	Simple shape for conversion to PVO, possessing a constant PVO angle
17	Cone with added noise	Cone from Figure 16 with added random noise ($\pm 5\mu\text{m}$)
18	PVO of noised cone	PVO, physical equivalent object to Figure 16
19	Single print deposit	Ideal single aperture print deposit ($20\mu\text{m}$ resolution)
20	12-aperture print	An array of 12 prints from Figure 19 with added noise ($\pm 5\mu\text{m}$)
21	PVO of Figure 20	PVO representation of good/ideal solder paste print
22	Print of 12-apertures with 9 bridges	Model of solder paste print with 9 bridges and random noise ($\pm 5\mu\text{m}$) without slump behaviour
23	PVO of Figure 22	PVO with noticeable increase in base diameter as well as a small step at half height. Compare this to the ideal print and PVO in Figure 21
24	Print of 12-aperture with bridges and “dog ears”	Severe bridging and peaks on one end of individual prints, plus random noise ($\pm 5\mu\text{m}$)
25	PVO of Figure 24	PVO showing increase in base diameter, a small step at half height and centre peak, features responsible for bridging and dog ears, respectively.
26	PVO profiles	Comparison of PVO profiles from Figure 21, 23, 24, with a detail of the PVO lines crossing the ideal aperture radius.

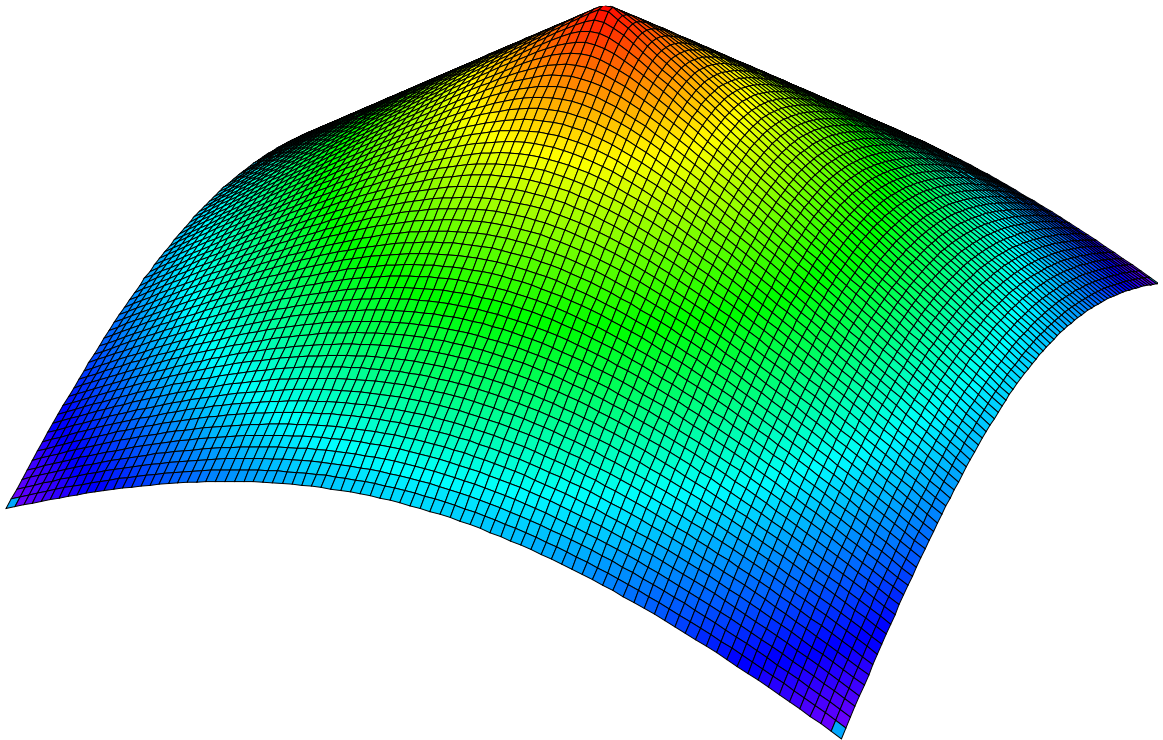


**Figure 16: Cone object used for constant PVO angle comparison
(matrix 171 x171) with 200 μm apex)**

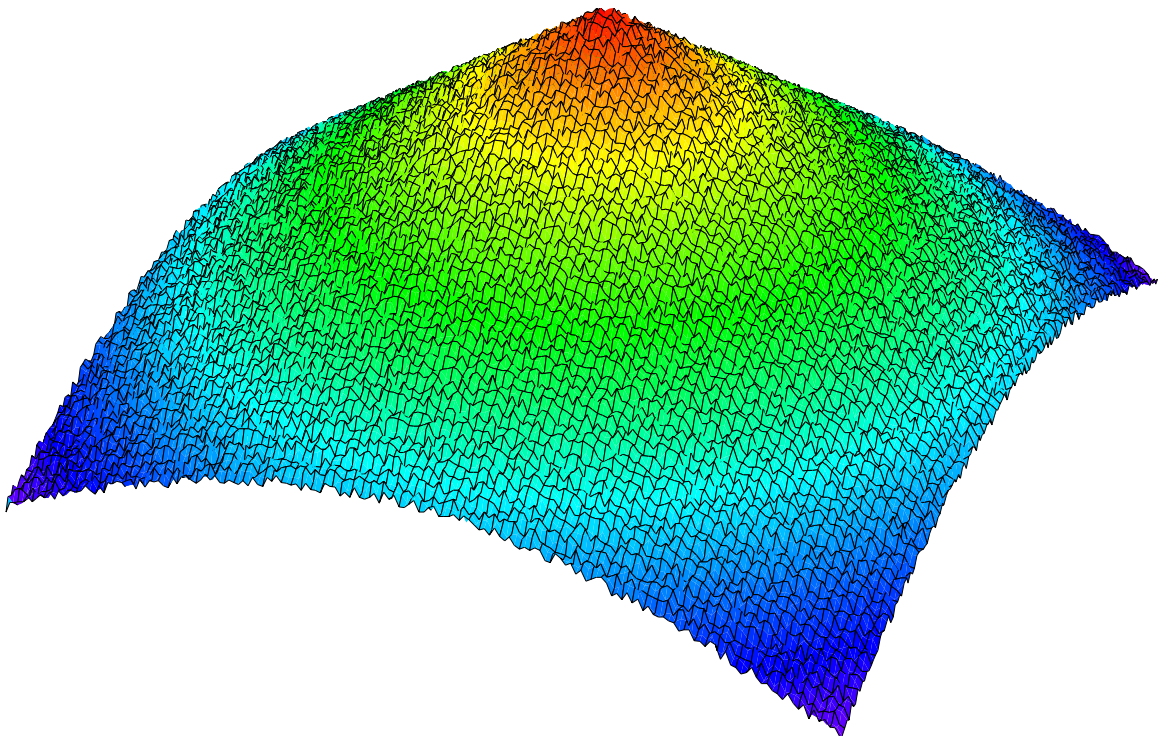


Figure 17: Cone object from Figure 16 with addition of $\pm 5 \mu\text{m}$ random noise

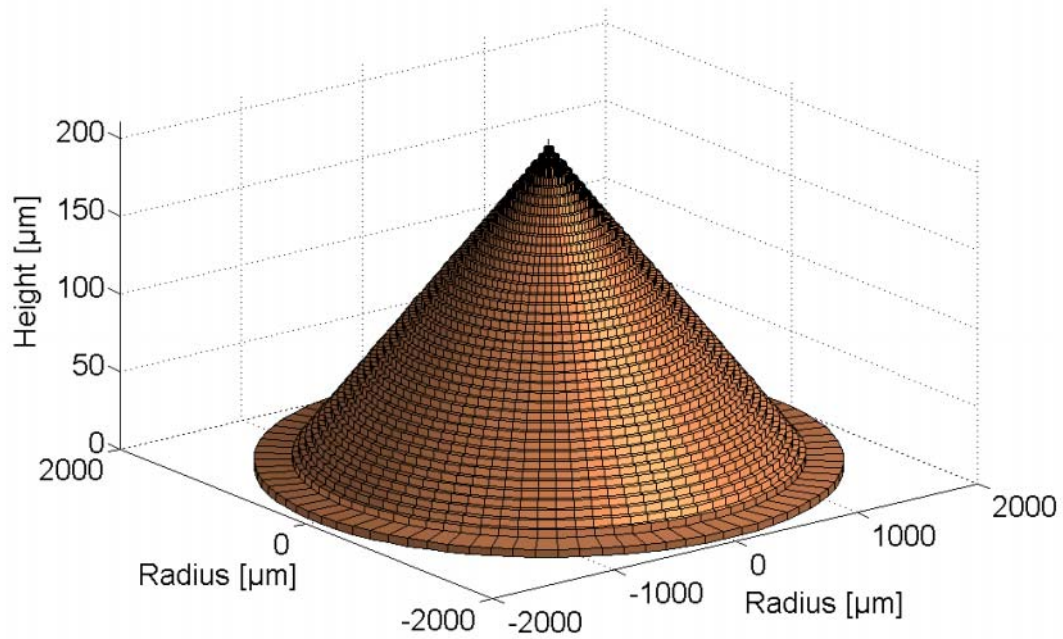


Figure 18: PVO calculated for cone object from Figure 17

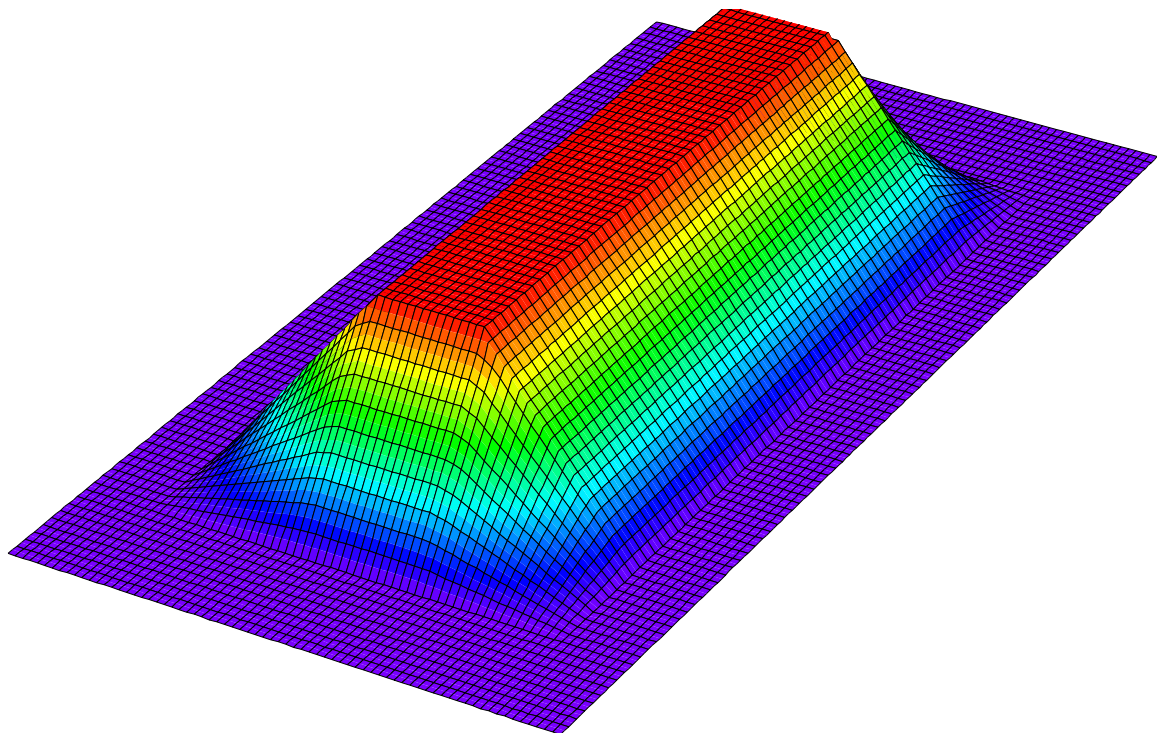


**Figure 19: Model of print deposit from a single aperture 2.640 x 1.06 mm
sampled in 20 μm steps**

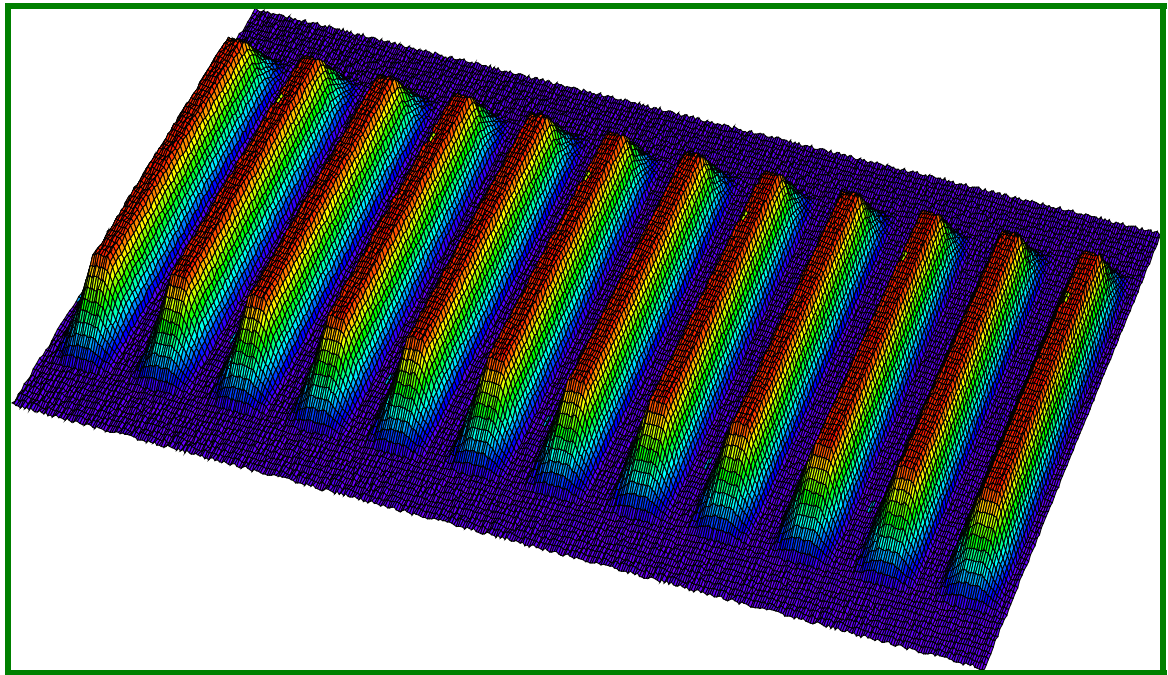


**Figure 20: Model of print deposit consisting of 12 apertures
with $\pm 5 \mu\text{m}$ random noise**

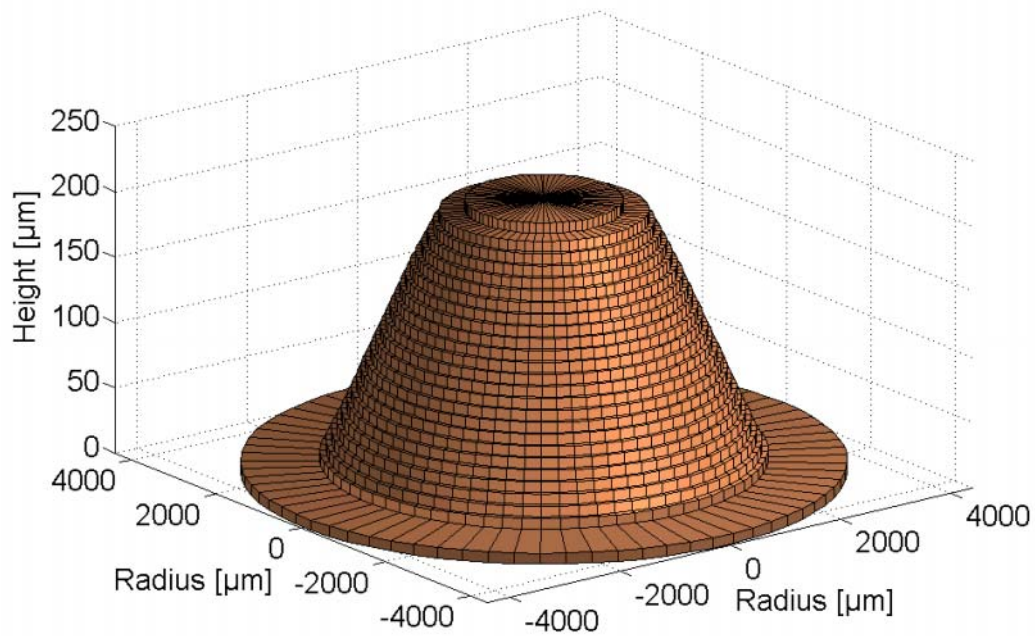


**Figure 21: PVO of model from
Figure 20**

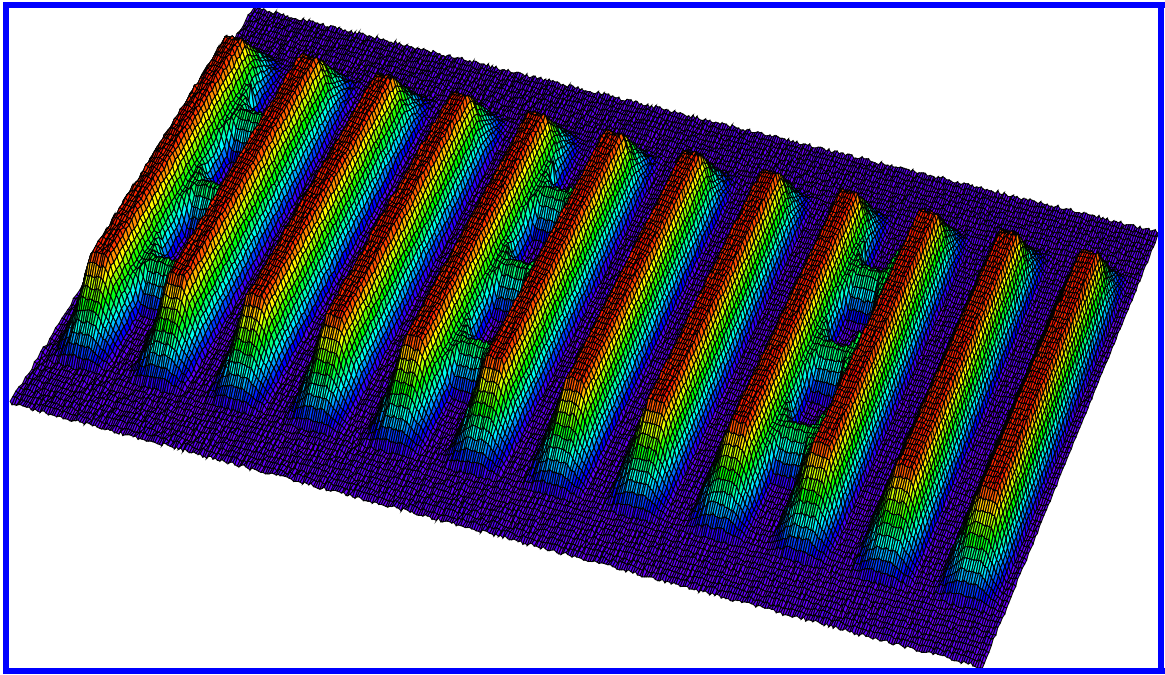


**Figure 22: Model of print deposit consisting of 12 apertures
with $\pm 5 \mu\text{m}$ random noise and 9 bridges**

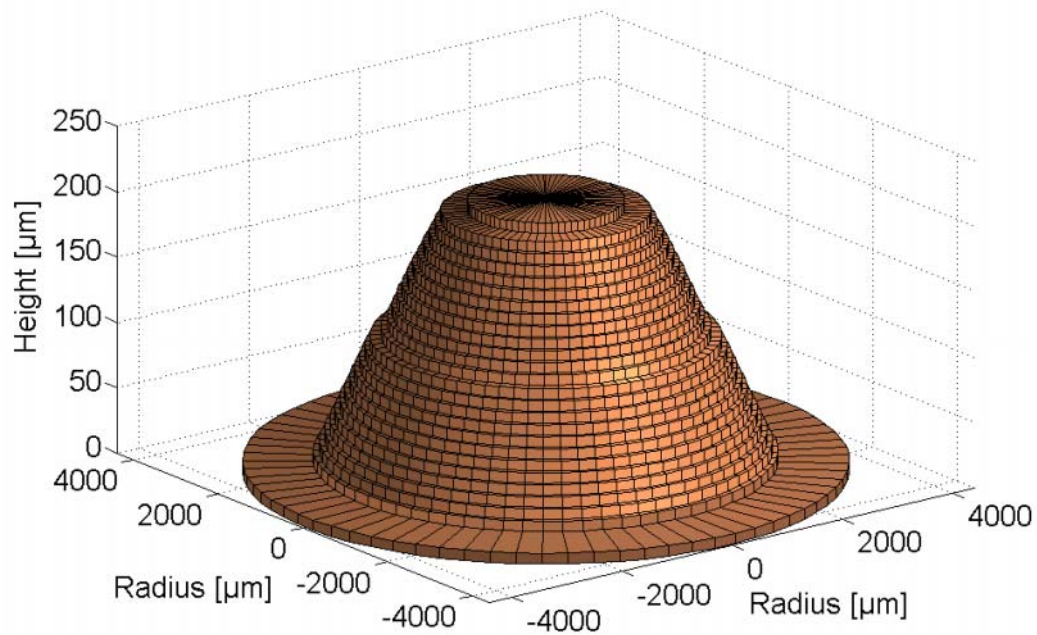


**Figure 23: PVO of model from
Figure 22**

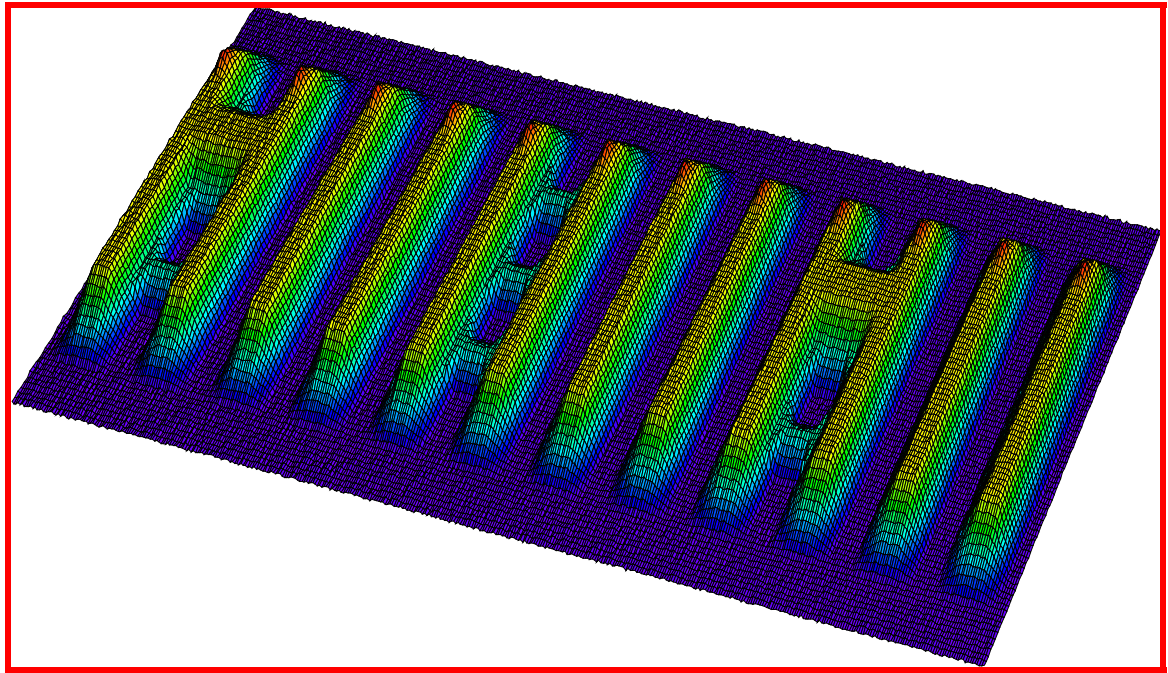


**Figure 24: Model of print deposit consisting of 12 apertures
with $\pm 5 \mu\text{m}$ random noise, 7 bridges and "dog ears"**

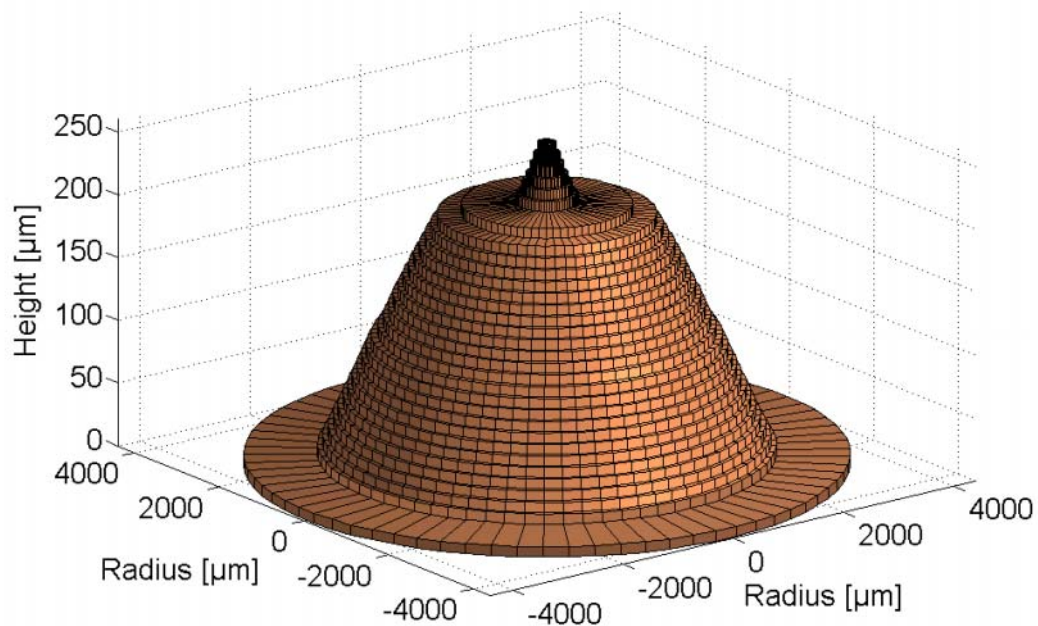


**Figure 25: PVO of model from
Figure 24**

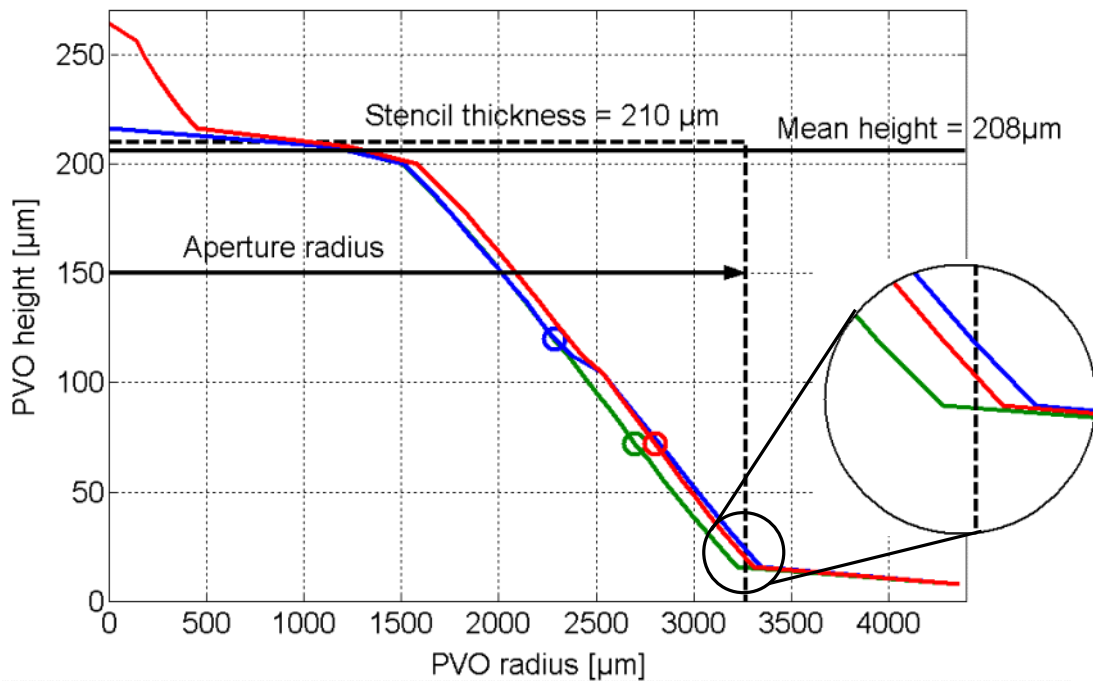


**Figure 26: PVO profile of ideal (green line, Figure 20)
and bridged (blue line, Figure 22) print deposit,
and bridged and dog ears (red line, Figure 24)**

In Figure 26 the differences between the curves is not great, but the precision in these curves is high and hence the differentiation seen is significant and can be used to interpret print defects.

Slump has not been modelled here due to difficulties in generating true slump on the starting print. Slump has a large effect on the PVO profile.