ADDRESSING HIGH PRECISION AUTOMATED OPTICAL INSPECTION CHALLENGES WITH UNIQUE 3D TECHNOLOGY SOLUTION

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ABSTRACT

Driven by the continued decrease in the size of electronics packaging, combined with the increase in density, there is a critical need for highly accurate 3D inspection for defect detection.

Using multi-view 3D sensors and parallel projection, it is possible to capture more of the board at a faster rate as compared to serial image acquisition which is more time-consuming. Precise 3D image representation can then be generated using sophisticated fusing algorithms that takes the multiple captured images and fuses them into one precise 3D image. The result is high speed 3D inspection.

Multi-reflection suppression (MRS) technology enables highly accurate 3D measurement by meticulously identifying and rejecting reflections caused by shiny components and reflective solder joints. MRS algorithms use a very rich data set from multiple cameras at every location. Combined with sophisticated algorithms that fuse the image data from multiple cameras, multiple reflections are effectively suppressed. By contrast, 3D sensing solutions that use triangulation illumination without MRS run into measurement accuracy issues since solder joints create multiple reflections that can corrupt height image. This technology is a key building block for achieving high accuracy at production speed in an Automated Optical Inspection (AOI) system.

Keywords: AOI, 3D sensing, SPI, multiple reflection suppression

CHALLENGES OF IMAGING SMT ASSEMBLIES

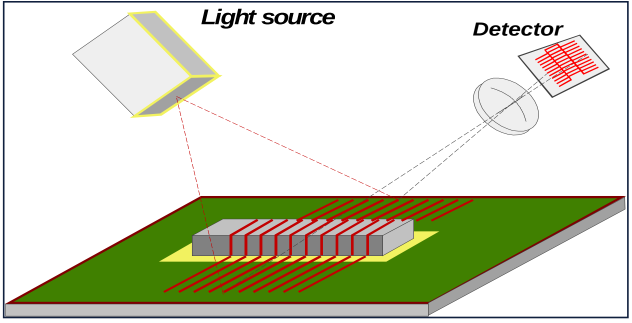
Many inspection challenges exist when inspecting SMT assemblies. The root cause of some of those challenges are imaging related, while others are inspection algorithm related. The addition of 3D imaging to the AOI market has solved some inspection deficiencies present in 2D AOI systems by providing the much-needed height information to the inspection algorithms to find height related errors like lifted leads and package co-planarity. However, accurately imaging in 3D the surfaces of SMT assemblies presents additional challenges to the inspection system.

For over 15 years, vendors have offered 3D inspection to the Solder Paste Inspection (SPI) market, yet the AOI market has only recently begun to benefit from mainstream 3D inspection. This delay was overcome primarily due to breakthroughs in sensing and computing technology. Following is a sampling of obstacles to high quality 3D inspection.

Multiple Reflection

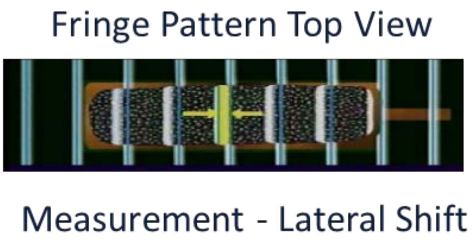
Most modern 3D systems rely upon some form of triangulation sensing, usually phase profilometry, to obtain the speed and accuracy necessary for SMT production.

Figure 1. Projected light and receive optics



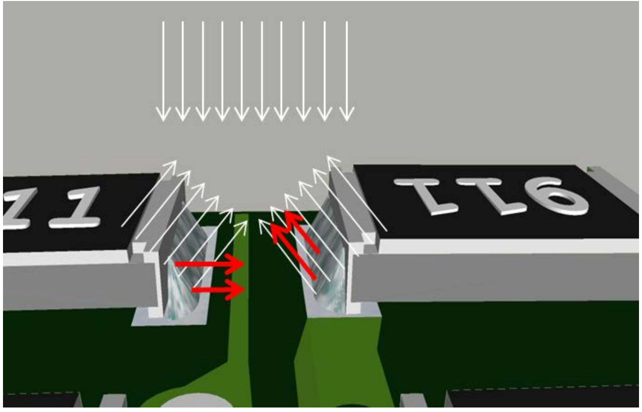
The projected light and receive optics are positioned at an angle and the detected displacement determines the object height as shown in Figure 1. The range of this sensing technique is determined by the distance of displacement before the next fringe is reached as illustrated in Figure 2. This is the height range. Design factors like triangulation angle and fringe frequency contribute to the overall height range.

Figure 2. Fringe pattern



The solder and components on finished circuit boards have many specular surfaces compared with solder paste which is quite diffuse. Solder joints, tinned leads, metal oscillators are just a few of the surfaces that have very mirror-like appearances. These mirror-like surfaces tend to reflect not only back to the detector, but also have a strong reflection off of each other. This is quite pronounced in solder joint which are very near each other.

Figure 3. False signals due to reflective surfaces

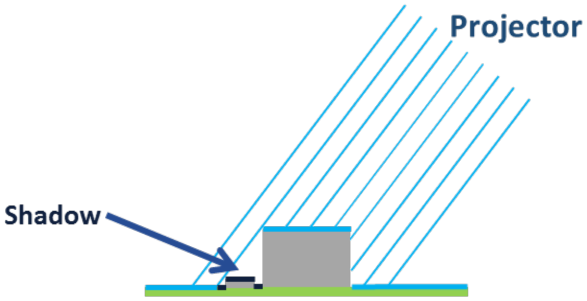


The return of false signal due to the reflection from one solder joint to another in Figure 3 causes corruption of the height values in this very important solder joint inspection region.

Tall Components

The height of solder paste is typically very low with almost all stenciled paste below 750µm and most much lower. Shadowing from one solder paste pad to another is not a concern. Many assemblies at the AOI process, especially in automotive and industrial environments, contain capacitors and connectors which can be well over 30mm tall. Triangulation sensing angles needed to provide adequate height accuracy will have blind areas on the circuit board near these tall components. A shadow effect is a real concern as illustrated in Figure 4.

Figure 4. Shadow effects due to tall components



Additionally, it is necessary to inspect near the base of tall components so the ability to overcome “blinds spots” is critical.

Besides shadowing, tall components present a challenge for 3D sensing by exceeding a normal fixed range. As mentioned previously, solder paste heights are relatively low and triangulation sensing with a single fringe frequency will provide acceptable measurement accuracy. To increase the height range, a designer could either decrease the triangulation angle, or reduce the fringe frequency. Both of these techniques will reduce the height accuracy degrading inspection performance.

Inspection Speed

Another challenge befalling 3D AOI inspection systems involves all the additional image acquisition on processing required to keep up with product speeds. It is common for the number of images required to obtain information for height reconstruction be an order of magnitude higher than the number of images necessary to perform 2D only inspection. The amount of image processing also grows commiserate with the number of images taken and additional inspection tasks performed.

In some factories, 2D AOI inspection is barely keeping up with tact times. For others, adding 3D inspection pits the process and quality engineers in conflict with the production managers responsible for line utilization and production capacity. The compromise is choosing a strategy to determine points to degrade inspection performance by inspecting with 2D only. These decisions will be made on a field of view level to reduce the number of acquired images further complicating and compromising the inspection capability.

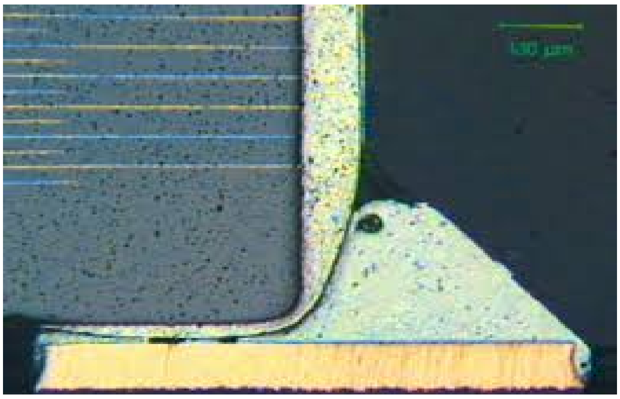
A solution that eliminates the need to compromise inspection quality to meet production demands is preferred.

Non-Parameterized Shapes

In 2D inspection, almost every attribute can be described in dimensions of X and Y. There may be some shapes that are difficult to represent with straight lines and curves, but most objects conform to those constraints in 2D space. In 3D, the extra height variable presents an added complexity in describing surfaces and it does not take long for the height function to become mathematically complex.

In SPI inspection, this shape analysis complexity is addressed by presenting the relevant summary measure of volume. This same volume summary measure can work for some AOI inspection types like THT and lead toe solder joint measurement, however, visible volume is not a true indication of a good solder joint. There could be strong heal wetting pulling a majority of the toe solder away, or the right amount of solder, but no wetting as in a cold solder joint.

Figure 5. Cold Solder Joint



A majority of components do look like well-behaved boxes and cylinders that can easily be mathematically described in 3 dimensions with length/width or diameter and a single height. However, there are a large number of components types that do not fit that description well (chamfered edges, LEDs, push-buttons, etc.). The ability to characterize a complex shaped component with a minimum amount of programing is important.

SENSOR ARCHITECTURE OVERCOMING ACQUISITION CHALLENGES

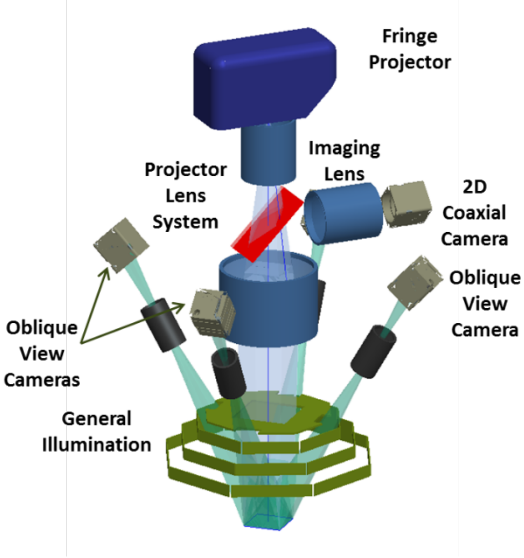
Many of the challenges described above are related to the ability to obtain high-quality accurate 2D and 3D input images for high quality accurate inspection output results. The primary contributor is the sensor design.

Parallel Image Acquisition

3D phase shift profilometry (sometimes referred to as 3D phase shift Moiré) has a unique potential for both speed and accuracy, if applied properly, compared with other 3D technologies such as white light interferometry or confocal scanning. Even still, the two factors that typically limit inspection speed for phase shift technology are the image acquisition time and also the amount of time to process the images. For example, it is not uncommon for a 3D phase shift Moiré system to sequentially acquire 32 or more images of different fringe patterns with multiple frequencies and from four projection directions.

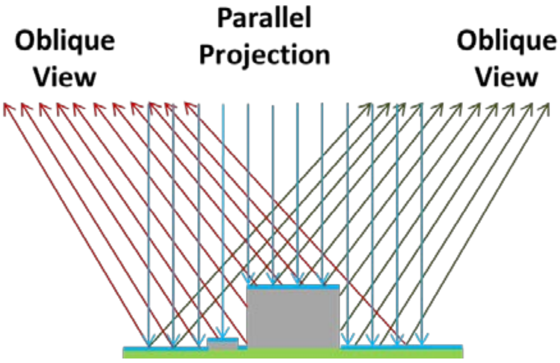
To address the requirement for improved acquisition speed, the 3D phase shift profilometry system can be architected with a single fringe projector and multiple oblique viewing cameras as shown in Fig 6. Since each of the oblique cameras can acquire the image of a particular fringe pattern simultaneously, this results in a degree of parallelization in the image acquisition with a typical 4X reduction in image acquisition time.

Figure 6. Sensor architecture



The entire 3D field of view is completely illuminated by the vertical projector with no areas of shadow. The projected fringes are then imaged simultaneously by the oblique view cameras as illustrated in Fig 7.

Figure 7. Vertical projection with oblique view cameras

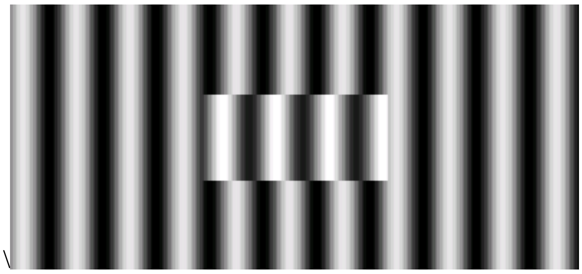


Although there is a tremendous speed advantage to the multiple camera architecture, it can be seen from Figure 6 that the X,Y coordinates for a given camera pixel are a function of the Z height. To overcome this challenge, the 3D phase shift profilometry system must accurately calibrate the X,Y locations for every pixel in every camera throughout the entire Z measurement range. This essentially amounts to calibrating the ray slope for every camera pixel. If the calibration is performed accurately, then the X, Y locations may be unambiguously decoded to micron level accuracies.

Detecting and Suppressing Multiple Reflections

3D phase shift systems project fringe patterns onto the object surface to be inspected. The fringe pattern images are distorted by the surface topography. It is exactly these distortions that are quantified in order to measure the 3D surface topography. For example, the fringe pattern in Fig 8 is distorted by height of a rectangular block.

Figure 8. Fringe Pattern Distortion



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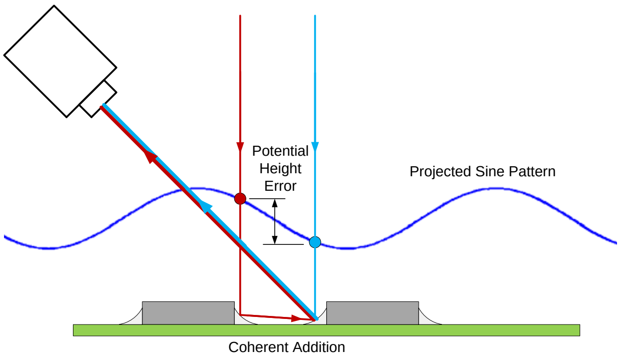
Multiple reflections will disturb the fringe patterns and cause erroneous height measurements unless their effects can be suppressed. The 3D phase shift profilometry system is able to suppress potential height measurement errors induced by multiple reflections by careful analysis of the image data sets from multiple cameras and multiple fringe pattern frequencies and directions.

Both low and high frequency patterns are required for tall components and connectors (e.g. 25 mm tall) in order to unwrap the fringe pattern phase and determine absolute height. However, the multi-path reflections from lower frequency patterns can severely corrupt the reported phase as shown in Figure 9. Here a multiple reflection adds coherently to the direct reflection. The potential height error is shown and is influenced by the relative strengths of the direct reflection and the multi-path reflection. These effects are also more severe for closely spaced components and highly reflective features.

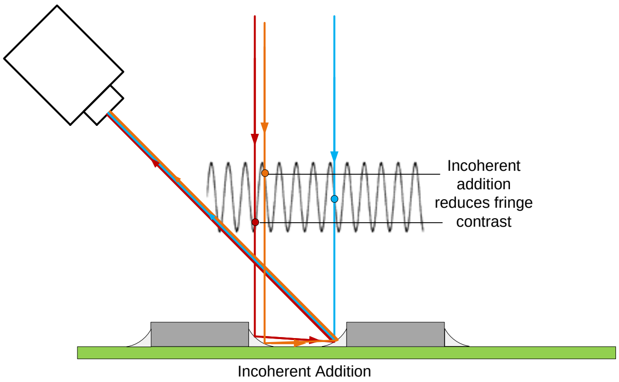
Figure 9. Multi-path reflections of a lower frequency pattern



In general, data from locations of high fringe contrast are most reliable when there are no multi-path reflections. However, multi-path effects from lower frequency patterns also have high fringe contrast, but can severely corrupt the reported phase as seen in Figure 9.

Multi-path reflections of a high frequency fringe pattern is shown in Figure 10. The multiple reflections from many locations add incoherently to reduce the fringe contrast, but disturb the phase very little.

Figure 10. Multi-path reflections of a higher frequency pattern



Since each oblique view camera will be affected by a multiple reflection differently, the individually reported heights from different oblique cameras will differ for the location of a multiple reflection. This fact can be used during analysis to identify areas of multiple reflections. To suppress the effects of multiple reflections, a rich data set of the fringe contrast, the effective surface reflectance, and calculated phase are analyzed for each frequency pattern from each of the oblique view cameras. These data are combined, or fused together, to suppress the disturbances of severe multi-path reflections.

INSPECTING NON-PARAMETERIZED SHAPES

Inspecting objects with well-defined length and width is relatively simple in the 2D domain. As long as there is decent contrast between the component and the substrate PCB, various methods can be used to find the dimensions of length and width and tolerance to the expected values.

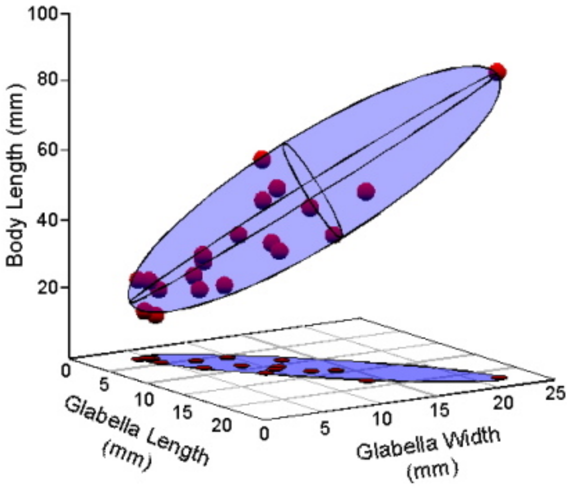
Finding the length and width of components is even easier in the 3D domain as the component has height and the substrate does not, therefore, the visual clutter on the PCB (pads, silkscreen traces, soldermask) does not interfere with finding the component extents. An added benefit to this is that it is possible to discover components without any size information because the height is distinguishable from the panel.

Inspecting components with constant height in 3D is straightforward to model by fitting a plane and using the height and angle of this plane to determine if the component is the proper height and check for co-planarity.

Inspecting components with complex shapes in both 2D and 3D domains are more difficult and common algorithms are not suitable. Describing parameters and tolerances expands exponentially as complexity grows. More appropriate techniques exist such as Principle Component Analysis (PCA) which is designed to automatically discover and model the important attributes of complex shapes. It finds links of variation in visual attributes that are not obvious, but key in describing the object.

A more popular application for PCA is facial recognition software, which automatically learns key attributes of a face and can “recognize” the face even when making different expressions. The PCA shown in Figure 11 is modelling the relationship between the glabella (flat area between eyebrows) with nose length. For this particular face, exceeding the norms of this relationship would fail the recognition.

Figure 11. PCA of a face



Principle Component Analysis can also be applied to the height images from a 3D AOI system to “learn” the 3D shape of an electronic component. This PCA model can then be applied during inspection to validate the shape of component (SMT/PHT lead, solder joint, any shaped component) and flag when it does not match “normal” parameters. This model training occurs without explicitly specifying these parameters.

CONCLUSION

Many factors need to be considered when selecting an Automated Optical Inspection system. Inspection performance in terms of accuracy of result and speed of inspection require close consideration. Technologies used by the AOI vendor are critical in excelling in both these areas in order to provide true height measurement and meet production speeds.

New capabilities in AOI systems with the advent of 3D imaging will increase inspection confidence in users that have been elusive until now. This will enable improved quality and understanding of electronic assembly process which will improve yield and manufacturers’ profits.