COVER STORY

A USEFUL SUPPLEMENT TO IN-CIRCUIT TEST (ICT), AUTOMATED OPTICAL INSPECTION (AOI) ACCURATELY IDENTIFIES AND RECOGNIZES COMPONENT VARIABILITY ON PRINTED CIRCUIT BOARDS (PCB), THEREBY IMPROVING OVERALL SYSTEM PERFORMANCE.

By Bob Ries

With today's increasingly complex PCBs and solid-state components, traditional ICT and functional test programming are becoming laborious and time consuming. PCB manufacturers find it difficult to gain physical test-probe access to dense, fine-pitch boards using bed-of-nails test fixtures. Writing functional test programs for complex boards is a formidable task, and the test fixtures for these boards are expensive and time consuming to fabricate. To overcome these hurdles, AOI proves to be a useful supplement to ICT and functional test.

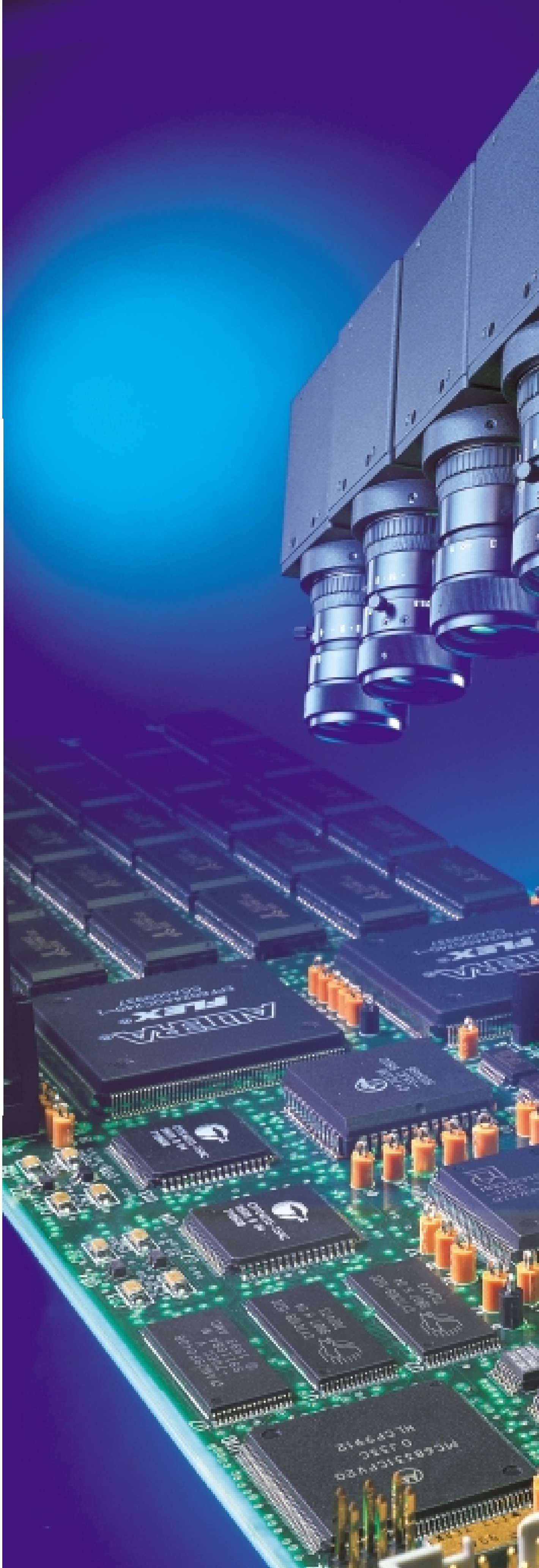
Human inspectors still perform most inspections, but smaller and smaller board features have made manual inspection unreliable, subjective and prone to the same cost and quality control problems associated with hand assembly. Human inspection has a low repeatability level, particularly from operator to operator, and visual fatigue inevitably leads to missed defects. For these reasons, AOI gradually is replacing human inspection on the assembly line.

AOI Advantages for PCB Assembly

Visually inspecting features and electronic devices on a board typically is straightforward. The shape, size, color and surface characteristics of components and the underlying PCB are well defined, and the components can be found in predictable locations on a board's surface. Because of this simplicity, the automatic inspection of PCB assemblies became one of the first industrial applications for computerized image-analysis techniques over 25 years ago.

Powerful AOI techniques prove to be economical, reliable complements to traditional test strategies. AOI is being used successfully as a process-monitoring tool for measuring printer or component placement machine performance. Practical advantages include:

- Detecting and correcting PCB defects during process monitoring is far less expensive than after final test and inspection, which typically is up to ten times more costly.
- Trends in process behavior — placement drift or incorrect reel mounting — can be detected and corrected earlier in the overall process. Without early inspection, far more boards with the same defect repeated would be rejected during functional testing and final inspection.



NEW ADVANCES in AOI Technologies

- Missing, skewed, misplaced components or components with incorrect polarity are detected earlier when AOI is used for component placement inspection after components are placed but before reflow, reducing costly post-reflow rework.
- Post-reflow AOI is less expensive than X-ray inspection for detecting solder joint defects such as bridges, broken joints, dry joints and other flaws. However, solder joint inspection is arguably the most difficult task for algorithm-based AOI systems because of the wide range of acceptable appearance variables.

Traditional AOI System Limitations

Basically, all AOI methods can be described as the acquisition and digitization of an illuminated image of a board through an array of cameras or sensors, which then is analyzed and compared to a previously defined "good" image. The illumination can come from a range of sources such as white light, light-emitting diodes (LED) and lasers.

Today, there are many well-established image analysis techniques used, including: template-matching (or auto-correlation), edge detection, feature extraction, gray modeling, Fourier analysis, shape, optical character recognition (OCR) and many more. Each technique has strengths and limitations.

Template-matching

Template-matching determines what the image of a desired object, such as a chip capacitor or quad flat pack (QFP), looks like on average, and uses that information to create a rigid pixel-based template. This is run across the board image, in the vicinity of the expected object location, to find something that is the same. The search is stopped when all points in the region of interest have been evaluated and the location at which there is the smallest difference between the template and image is found. Such templates are created for each object to be inspected, and an inspection program for an entire board is built up by using appropriate templates in the appropriate positions to find all required components.

Because components rarely match the template exactly, templates are designed with a certain amount of leeway to identify matches whenever the component image is fairly close to the template. If the template is too inflexible, it may make a "false call" on a component. If the template has been relaxed to accept a wide variety of possible variations, this also may lead to false calls.

Algorithms

Often, several popular image analysis techniques are combined in a "recipe" to create an algorithm specifically suited to a particular component type. On a complex board with dozens of components, this can result in a multitude of diverse algorithms that require extensive reprogramming by engineers when changes or adjustments are needed. For example, when a vendor modifies a standard component, the algorithm recipe for that component may need adjustments that consume valuable programming time. Also, the appearance of the same component type can vary significantly from example to example. Over time, as new variations appear, the user must adjust or "tweak" the algorithms to accommodate all possible variations.

An 0805 chip capacitor, for example, can be categorized as being of a certain size and rectangular shape, with two bright edges enclosing a darker area in the middle. Yet, the appearance of this apparently simple component can vary widely when inspected optically within a single production run, as shown in Figure 1.

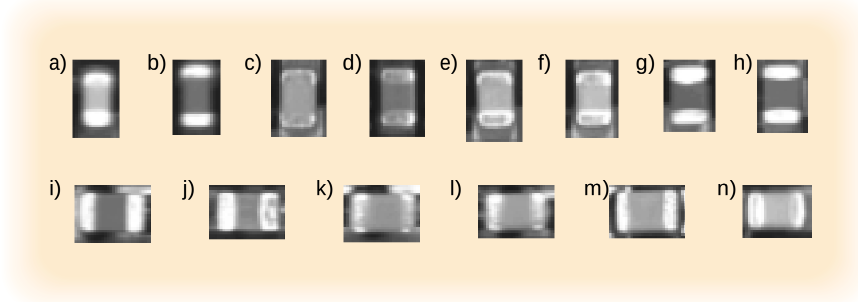


Figure 1. Appearance variations in 0805 chip capacitors.

Traditional, algorithm-based AOI methods often are too rigid to accommodate legitimate variations, such as contrast, size, shape and shade. Even trivial components can be difficult to reliably find and inspect, thus causing "false rejects" where components are present but the system cannot detect them. Also, because the differences between acceptable and unacceptable images often are quite subtle, the algorithms cannot differentiate, causing "false accepts" where genuine faults are not detected.

To resolve some of these issues, the user has to be reasonably knowledgeable in the image analysis field. Plus, conventional AOI techniques demand continual and extensive reprogramming. Users need to fine-tune their AOI method constantly to accommodate legitimate variation. All of this can take between one to two days for minor tweaking and several weeks when creating and optimizing an inspection program for a new board.

Adaptive, Knowledge-based AOI

Several AOI vendors have broken away from traditional methods of image processing and are using adaptive software techniques instead. One method* is designed to detach users from the complexities of algorithms. By showing a series of examples of an object to be identified, this method uses a surprisingly straightforward mathematical technique called statistical appearance modeling (SAM) to automatically work out for itself how to recognize legitimate image variations. Unlike algorithm-based methods, the SAM technique uses adaptive, knowledge-based software to work out variations. This dramatically reduces programming time and virtually eliminates everyday fine tuning. In fact, this method typically returns false call rates that are between 10 to 20 times better than existing AOI methods.

How SAM Works

After being shown a series of known good examples of a particular object, SAM software builds a flexible, mathematical model of the object. As it examines more samples, the software successively refines its estimate of what the object should look like and how its appearance can legitimately change because of natural size, shape, color and surface pattern variations. Unlike existing recipe approaches, which demand algorithms based upon what users think they know about component variance, SAM is an empirical approach that demands no inherent understanding by the user or inspection system of what it is deciding. The user draws a box around the target object and then shows the AOI system a series of examples. By observation, the SAM software immediately develops a detailed model of what to look for in an acceptable object.

A SAM model is created during a training cycle, where examples of a desired component type are stored and analyzed, and the most significant variance modes are identified. This allows the AOI system to characterize the way in which the component varies and possible future variances. The SAM model then is evaluated against an image of where the component is expected to be. If the component's appearance is within the limits defined by the variance modes in the model, the software confirms the component's presence and its location is compared against positional tolerances. As new examples and images are added to the SAM model, the model observes the variations and adapts to incorporate all the visual differences it sees among good images. This also increases the system's ability to discriminate between acceptable and unacceptable images, causing the false call rate to improve over time as the system learns more.

Unlike recipe methods that use a rigid template approach, SAM allows the AOI machine to determine for itself which aspects of a component's appearance can vary and by how much, with no direct input from the user.

In a real-world environment, the SAM system must look at about 20 PCBs to have seen most of the variation it likely will encounter. During this training cycle, user feedback is required. The software will flag borderline components that appear to be failing and ask the user for verification so that the SAM model can be adjusted accordingly.

Accuracy, Repeatability and Flexibility

Many traditional AOI systems rely heavily on detecting component edges to achieve accurate and repeatable measurements. Once edges are detected, imposing a geometrical model on these edges typically generates the component coordinate on a board's surface. The edges, however, are quite hard to find using vision technology. Because component edges are not perfectly straight, any attempt to fit a straight line to such an edge can be problematic. Also, edges tend to be dark regions sitting on dark backgrounds, and accurate identification is prone to pixel noise variations.

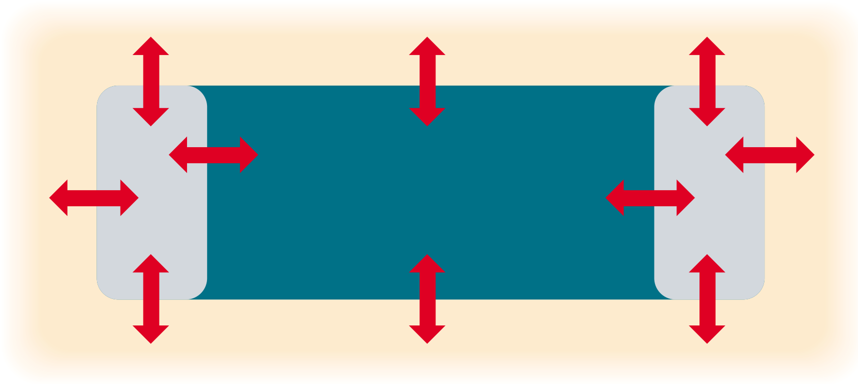


Figure 2. SAM adjusts for best component position and grayscale variations.

Pixels cannot be made small enough to avoid some pixel-splitting effects, in which an object's details sit between two pixels. Using edge-based recipe methods, a good vision system yields a repeatability in which one standard deviation corresponds to around 1/10th of a pixel. The SAM technique, however, offers repeatability in which one standard deviation corresponds to 1/20th of a pixel. The total variability in component location is less than 3/10ths of a pixel, thus improving the accuracy and repeatability when matching to a component.

When examining a specific component type, the SAM model is inherently flexible. In an attempt to fit a legitimate component of significantly differing appearance (e.g., a rigid traditional method), it tends to slip and slide about in X- and Y-axis in an attempt to achieve an optimal fit by adjusting the position, the only available variable parameter. By fitting an appropriate SAM model to the component — whose variability is controlled to allow only those appearances that realistically can occur — the appearance is adjusted to the best position without compromising the X and Y location.

Certain allowable component color variations, for example, are caused by overshadowing or overexposing neighboring larger components and practically are impossible to accommodate with a traditional algorithm. Because SAM works out the image permutations allowed, users do not need to rely on algorithms that require extensive programming or vendor-supplied algorithm libraries for different components (Figure 2).

The SAM method effectively recognizes logo and text variations on components and boards. Traditional OCR-based techniques have difficulty coping with variations in printing quality or appearance, but the SAM method recognizes such differences as just another form of legitimate variation.

Stereo-vision Optics

Traditional AOI systems cannot fully accommodate natural three-dimensional (3-D) variations in a PCB's appearance because of localized warp and stretch, as shown in Figure 3.

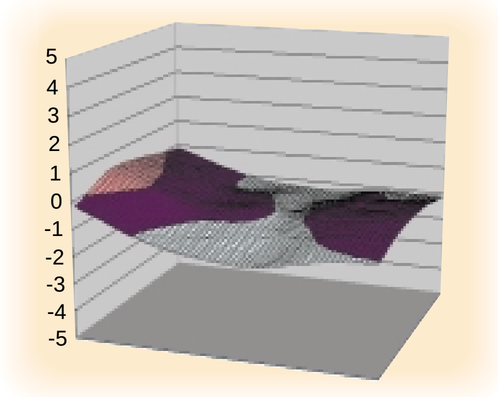


Figure 3. Topology of a typical PCB (accentuated Z-axis).

Even physically clamping a board cannot guarantee absolute flatness. Existing AOI methods usually use telecentric lenses to optically remove the effects of parallax and perspective. Because the effects of height on perspective are removed, objects at the image's edge appear as if they are on the same plane as objects in the center. Although this eliminates optical parallax errors, measurements between one point and another that should follow the curve of a board's surface are instead made by measuring straight lines across the surface chord. This causes significant measurement inaccuracy and automatically removes valuable information about the board surface shape.

By combining the SAM technique with a stereo-vision arrangement of two rows of cameras, the complete AOI system can measure and accommodate object and surface heights and, as a result, mathematically flatten PCBs. These angled cameras give two perspectives of the object, which then calculate a PCB height map or 3-D surface topography. The precise X and Y position of any component on a board also is calculated by taking into account its height above the board's surface.

Some AOI machines use a standard board conveyor to move the PCB under the cameras, which are lighted by simple high-frequency fluorescent tubes. As the board is indexed on a conveyor and passed under the camera array, a photo-mosaic image of the PCB surface is constructed by joining rows of image stereo pairs. This photo-mosaic image then is synthetically flattened and analyzed in real time.

This combination of SAM adaptive modeling techniques and stereo-vision imaging technology has demonstrated accuracy and repeatability superior to existing AOI techniques. This new AOI technology has proven to be ideally suited for accurate and reliable post-placement and post-reflow component verification and PCB inspection.

Conclusion

Existing AOI algorithm-based systems have difficulty dealing with the degree of appearance variation that occurs in today's PCBs and solid-state components. They are dependent upon software algorithms that need continual adjustment, and they require specialized engineering expertise to keep them running successfully.

The combination of the SAM modeling technique and the stereo-vision machine technology, however, offers built-in flexibility to accurately identify and recognize legitimate variability in the component appearance on a PCB. This improves overall system performance, decreases false calls, reduces user programming involvement and virtually eliminates the need for ongoing software engineering support. SMT

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