EVALUATING AND IMPLEMENTING POST-PLACEMENT/PRE-REFLOW INSPECTION

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ABSTRACT

This paper examines the process real-world SMT manufacturers are employing to evaluate, select and implement automated optical inspection (AOI) systems for post-placement/pre-reflow inspection during the PCB assembly process. A case study from a prominent European SMT manufacturer describes the process used to evaluate a post-placement/pre-reflow AOI system. Traditional, algorithm-based AOI techniques are briefly described and evaluated, along with their strengths and limitations. A new AOI methodology, called statistical appearance modeling, and a stereo-vision inspection machine are briefly described and compared to traditional AOI systems. Examples of payback and ROI calculations and analysis are highlighted. The system requirements are specified and the actual results of the AOI performance trial are summarized. Other relevant topics include analyzing GR&R, interpreting SPC data, and implementing post/placement/pre-reflow AOI.

INTRODUCTION

Reliable AOI methods have become powerful, economical complements to traditional test strategies. AOI is being used successfully as a process monitoring tool for measuring printer or component-placement machine performance. Some real-world advantages include:

- Detecting and correcting SMT defects during process monitoring is far less expensive than after final test and inspection, where repairs are typically 5 to 10 times more costly. Plus, trends in process behavior – such as placement drift or incorrect reel mounting – can be detected earlier in the overall process. Without early inspection, far more boards with the same defect would be rejected during functional testing and final inspection.
- Missing, skewed, misplaced components or components with incorrect polarity are detected earlier in the assembly process when component placement is verified before reflow.

EVALUATION OF A POST-PLACEMENT/ PRE-REFLOW AOI SYSTEM

The SMT manufacturer evaluated an adaptive, knowledge-based AOI system. Their objective was to realize some or all of the following benefits by including AOI in their SMT manufacturing line for post-placement/pre-reflow inspection:

- Continual process improvement
- Reduce cost of test and repair
- Increase test capacity
- Complementary testing
- Increase throughput
- Reduce cost of test
- Reduce cost of repair
- Reduce inspection labor
- Reduce repair labor
- Reduce time to market for new product

The following is a brief look at traditional algorithm-based AOI techniques and how they compare to adaptive, knowledge-based AOI systems; it is used as a preliminary basis for a complete AOI evaluation.

Evaluating Traditional Image Analysis Techniques

Today there are many well-established image analysis techniques in common use, 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.

A number of established image analysis techniques have been put together to form specific algorithms for different types of components. Any or all of these algorithms can be combined to provide recipes for complex components. However, this can result in many diverse recipe algorithms (typically 200 to 300) that require extensive programming by engineers when changes or adjustments are needed. Also, when a vendor modifies a standard component, the associated algorithm may need to be revised, either by the AOI supplier or the user. Again, this requires more programming time. Finally, the appearance of components of the same type can vary significantly from example to example, thus making it difficult for algorithm-based systems to recognize these variations.

Because exact matches of the component template pattern are rarely found, similar matches are picked up that are fairly close to the template. Even the appearance of apparently simple components can vary hugely, and this is what often causes a conventional inspection method to make a “false call”. As shown in Figure 1, the appearance of a simple component – such as a 0805 chip capacitor – can vary widely within a single production run.

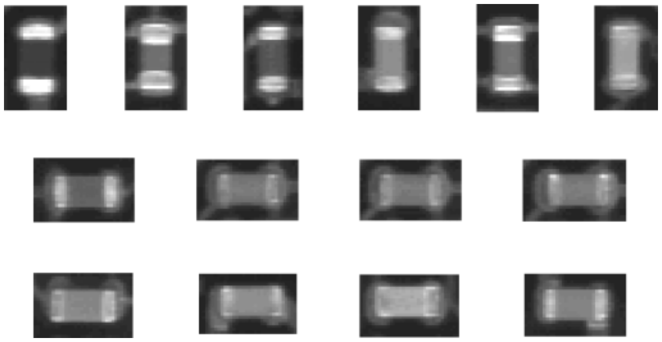

Figure 1. Appearance Variations in 0805 Chip Capacitors

Comparing Adaptive, Knowledge-Based AOI to Algorithm-Based Methodology

Several AOI vendors have broken away from traditional methods of image processing and are utilizing adaptive software techniques instead. This leading-edge approach to AOI methodology is designed to detach users from the complexities of algorithm-based techniques. By showing a series of examples of an object to be identified, one 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 turning.

How SAM Works

The SAM software works by making a flexible mathematical model of a particular object. It is shown different good examples of a certain object, and it successively refines its estimate of what the object should look like and how its appearance can legitimately change due to natural variations is size, shape, color and surface patterns. Unlike existing recipe approaches, which demand algorithms based upon what users think they know about how components vary, SAM is an empirical approach that demands no inherent understanding by the user or inspection system of what it’s deciding. All the user is required to do is draw a box around the target object and then show 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.

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.

Certain types of allowable component color variation, for example, are caused by overshadowing or the overexposure effect of neighboring larger components and are practically impossible to accommodate with a traditional algorithm. Because SAM works out what image permutations are allowed, users do not have to rely on algorithms that require extensive programming or vendor-supplied algorithm libraries for different components.

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 simply recognizes such differences as just another form of legitimate variation.

AOI Machine with Stereo-Vision

Traditional AOI systems cannot fully accommodate natural three-dimensional variations in a PCB’s appearance due to localized warp and stretch.

Even physically clamping a board cannot guarantee absolute flatness. Traditional AOI methods usually use telecentric lenses that are designed to optically remove the effects of parallax and therefore perspective. Although this eliminates optical parallax errors, measurements between one point and another that should follow the curve of a board’s surface are actually made by measuring straight lines across the chord of the surface. This causes severe measurement inaccuracy and automatically removes valuable information about the shape of a board’s surface.

By combining the SAM technique with a stereo-vision arrangement of two rows of cameras, you have a complete AOI system that can measure and accommodate the heights of objects and surfaces and, as a result, mathematically flatten circuit boards.

This combination of SAM modeling techniques (using adaptive, knowledge-based software) and stereo-vision imaging technology has demonstrated accuracy and repeatability far superior to existing AOI techniques.

Establishing a Benchmark

The SMT manufacturer performed in-circuit tests (ICT) and functional tests on PCBs as preliminary benchmarks for subsequent evaluation and testing of the AOI system. The defects that would be detected earlier in the process (post-placement/pre-reflow inspection) if the SAM AOI system were deployed included: missing part, damaged part, misplace part, wrong part and reversed polarity. As highlighted in Figure 2, the actual total percentage of placement-related defects that would be detected and eliminated earlier in the process by SAM AOI added up to 59 percent of the total defects identified.

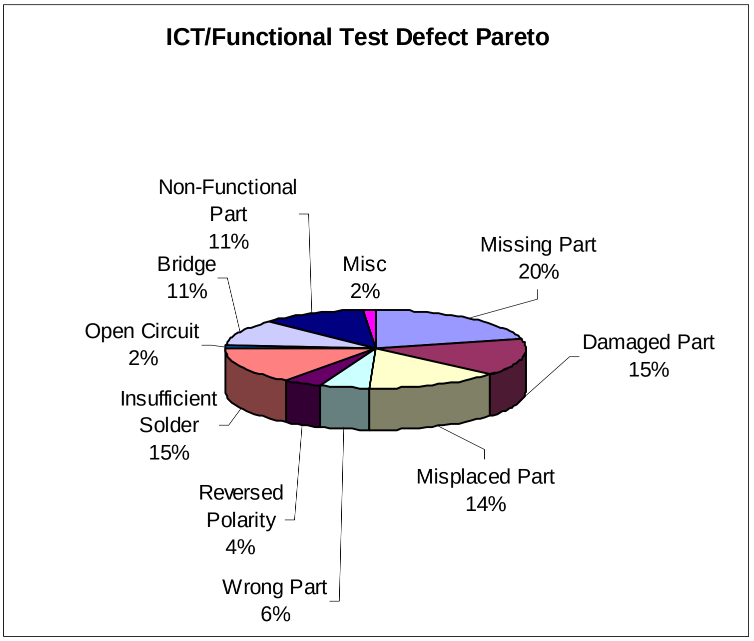

Figure 2. Placement-Related Defect Chart

Calculating Payback and ROI

By taking data from a defect Pareto chart (see Figure 2) and determining how many defects could be reduced or eliminated using AOI, it is possible to calculate the resulting savings and payback period. Cost savings achieved by reducing testing, minimizing rework and eliminating scrap are typically sufficient to pay for the AOI system in less than one year.

Evaluating and Measuring AOI System Performance

During trials performed at the SMT manufacturer, the following paragraphs summarize the system requirements that were specified and the final results that were achieved for the SAM AOI system.

System Requirements

- Software: UNIX/NT
- Programmed using CAD
- Repeatability: <10µm dynamic test (1 board tested 20 times)
- Accuracy: <15µm dynamic test (1 board tested 20 times)
- Test time: <40 seconds
- Programming time: <30 minutes
- Detect post-placement defects: missing component, wrong orientation, wrong component, damaged component, wrong position
- False calls: <100 ppm
- Record results against barcode

SAM-Based AOI Results

- Repeatability: 2.9µm in x-axis; 3.5µm in y-axis
- Accuracy: 8.2 µm in x-axis; 6.86 µm in y-axis
- False calls: 42 ppm
- False accepts: 0 ppm
- All faults found on known defective boards.
- Average test time: 35 seconds

PERFORMING A GR&R STUDY

To control a process, you first must be able to produce repeatable and reproducible results.

There are many ways to analyze GR&R (gage repeatability and reproducibility). Some use measurement-range calculations and others involve a more complex statistical analysis, such as ANOVA calculations. These can be performed from within SPC (statistical performance control) packages or are available in AOI systems with a built-in capability. However, a simple and quick repeatability check can be performed using just ASCI data and a spreadsheet.

GR&R tests are designed to evaluate how consistently a system performs. Repeatability tests involve inspecting a PCB multiple times and measuring how much the results differ over these inspections. A minimum test inspects the same board 20 times. Reproducibility tests are designed to evaluate the effect of physical changes between measurements. Examples include re-calibration, power-cycling the system and removing/replacing the board. These two tests are usually performed simultaneously.

Once the board has been inspected 20 times and all tests are completed, a spreadsheet can be constructed as shown in Table 1. AVERAGE provides the overall standard deviation (SD) for the board.

Table 1. Example GR&R Spreadsheet

	A	B	C
1	CREF	SD x	SD y
2	C101	SD x	SD y
3	C102	SD x	SD y
4	C103	SD x	SD y
.	.	.	.
.	.	.	.
.	.	.	.
59	U999		.
		=AVERAGE(B2:B59)	=AVERAGE(C2:C59)

INTERPRETING RESULTS OF SPC DATA

The aim of AOI (or any visual inspection) at the pre-reflow stage of the production process is twofold:

1. To screen for defects, to correct them prior to reflow and thus reduce the cost of rework, which can cost up to 10 times more than in-process repairs.
2. To monitor the process looking for trends or process metrics that indicate a process is becoming out of control.

With the information provided by a pre-reflow AOI machine, several attributes and variables can be monitored:

- Evaluate placement machine performance by determining placement position: (x, y, θ)
- Find placement defects such as incorrect components, wrongly-oriented components, missing components, etc.

These metrics can be analyzed in many different ways.

Why Use SPC?

Statistical Process Control (SPC) is a method of monitoring a process to decrease the number of defects by correcting problems as soon as they occur. With an ideal process, every component placed would be exactly at its CAD co-ordinate. However, no component is ever placed perfectly; there is always a positive or negative offset from its nominal CAD position, to some degree.

In this ideal process, if successive random boards are taken and each component offset is examined, then a high proportion of the offsets would be small, a lesser proportion would have larger offsets, and an even smaller proportion would have the largest offsets.

If this is the case, standard statistical methods can be applied to the distribution. To produce the lowest number of defects possible, every placement should be within 6 (±3) standard deviations (sigma) of the nominal position. Statistically, if you ensure this, your defect rate should be around 4 parts per million.

The measurements of component-placement positions can be analyzed to monitor whether the process is conforming to the six-sigma philosophy.

Monitoring Placement Machine Performance

Using Trend Charts

Trend charts are used to take the average of all component offsets in a particular axis for each board and plot them against time. They are used to look for trends and compared to an upper and lower specification. A trend upwards or downwards signifies that there is a systematic error in either the placement machine or another upstream process. Upper and lower specification limits are typically based on ±3 standard deviations from nominal, based on the process width. A run of boards that consistently fell outside the upper or lower specification limits would be deemed a process out of control and would require remedial action.

It is possible to look at the offset for a particular circuit-reference, component type or components placed by a particular nozzle or machine and examine the x an y offsets over time. However, due to the large quantities of components on modern circuit boards, this is impractical due to the huge volumes of data generated. Typically, the types of problems that would cause an individual component or component type to be consistently failing would be better monitored through the use of a Pareto chart.

Figure 3 shows a mean y offset from nominal for the last ten boards inspected.

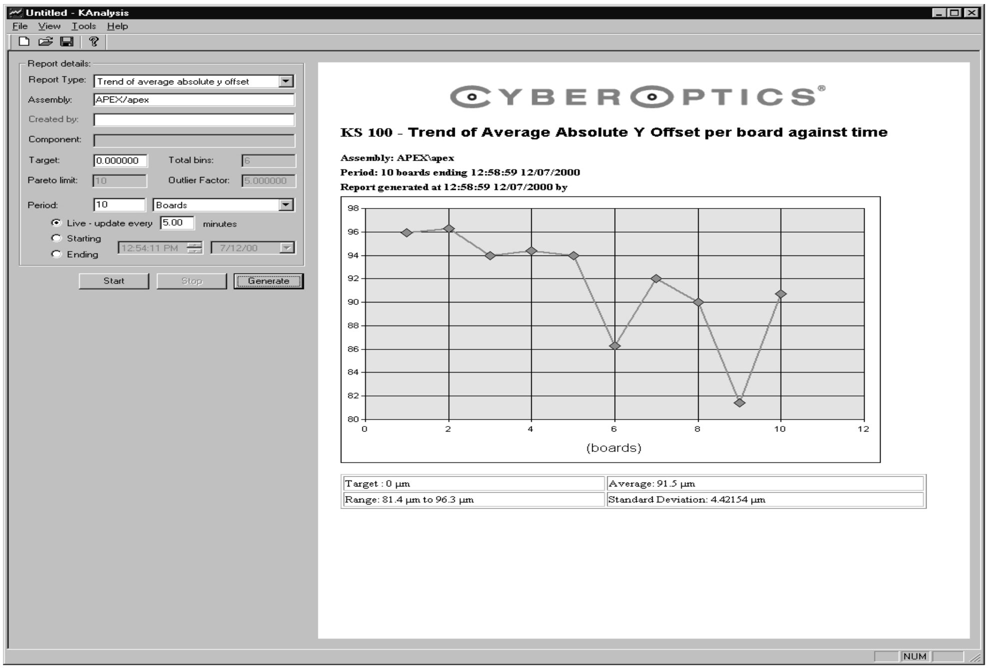

Figure 3. Example Trend Chart

There is a common set of alarms used within the electronics industry that alerts an operator or an engineer to a process out of control. For example, an alarm would be where successive board-average offsets trend upwards or downwards, and where a particular board-average offset breaches an upper or lower control limit.

There are some obvious, practical benefits to maintaining a controlled process. Consider a mobile-phone assembly line where a phone board is placed every 10 seconds. If a nozzle is broken, a defective board is created every 10 seconds. The options are:

- **Have no inspection**. In which case, the faults will not be detected until ICT or functional test. This could mean hundreds of defective boards have been produced.
- **Have inspection but no SPC**. Rely on a human realizing that a particular defect is present on every board.
- **Use SPC to analyze the inspection results**. The faults would be caught and, after the designated number of repetitions of the same faults, an alarm will sound indicating that there is a systematic error in the process.

Using Scatter Plots

Scatter plots of x and y offsets for a particular board are typically based on the individual component offsets for a single board or an average for each board's x any offsets over time. They can be presented in either Cartesian or polar co-ordinate systems. The ideal process has a very tight distribution of points centered on the origin of the co-ordinate system. If the cluster of offsets is offset from the origin, there is a systematic error in an upstream module. This could be a faulty nozzle, a fiducial found incorrectly by the placement machine, or the board may have been moved prior to inspection such that components have all shifted on the solder paste.

Figure 4 shows the scatter plot of x and y offsets for a particular board. Each point represents a component offset. This particular chart shows that the placement machine is well centered about the nominal as the majority of the points are close to the origin (or nominal). There are several outliers here to the right, which may represent components that are not placed within their tolerance.

The standard deviation of each board's average offsets or individual component offsets over time can be monitored to ensure that the process is operating to within a 6-sigma tolerance.

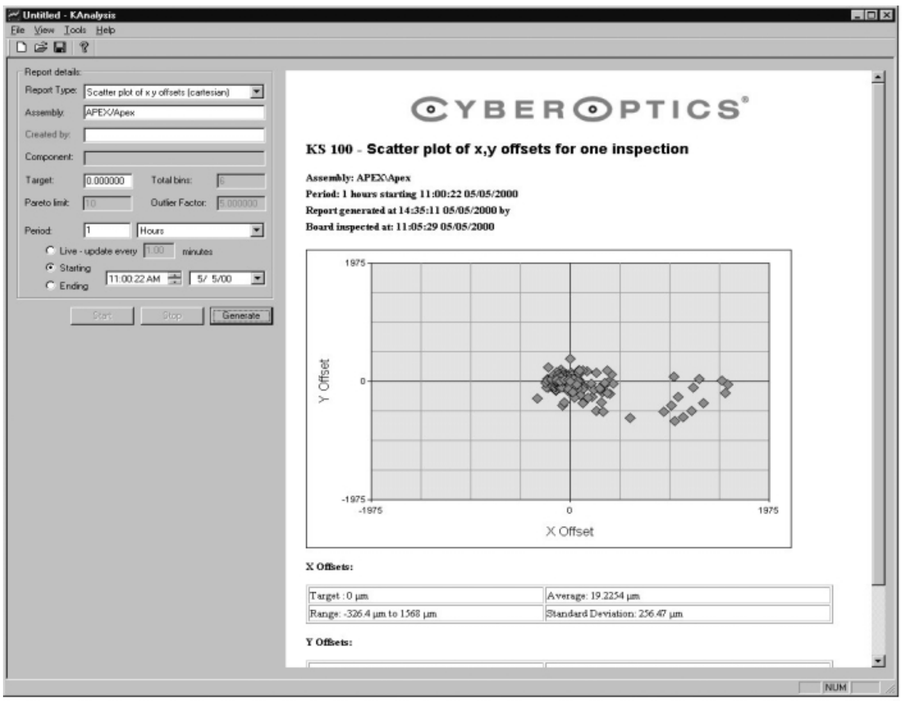

Figure 4. Example Scatter Plot

Detecting Faults with Root-Cause Analysis

Using Pareto Charts

Pareto charts allow operators and engineers to assess at a glance whether there are any systematic errors within a process. As well as positional-placement errors, there can be several attributes that may be incorrect: the component may not be present; the wrong component may be present; or it may be placed with the wrong orientation.

By building Pareto charts based on these attributes, it is possible to determine what the most common faults are and address their causes, move onto the next most common faults and address that cause, etc. Further root causes can be diagnosed by tying the Pareto charts to particular component types, nozzles, circuit references, etc.

Figure 5 shows a Pareto chart of failures broken down by circuit reference and by defect category. It shows that within the last hour, the most frequent failures were component 7C27 being missing (twice), component 8U12 placed incorrectly (twice) and 8U14 having the wrong device once. From this it is possible to conclude that there may be a problem with these particular components and, consequently, to investigate the cause to reduce defects and to improve quality.

Ultimately, yield is the primary concern. To monitor where the problems in a process occur, yields should be monitored at every stage of the process, because the overall yield will be less than the yield at the worst stage of the process.

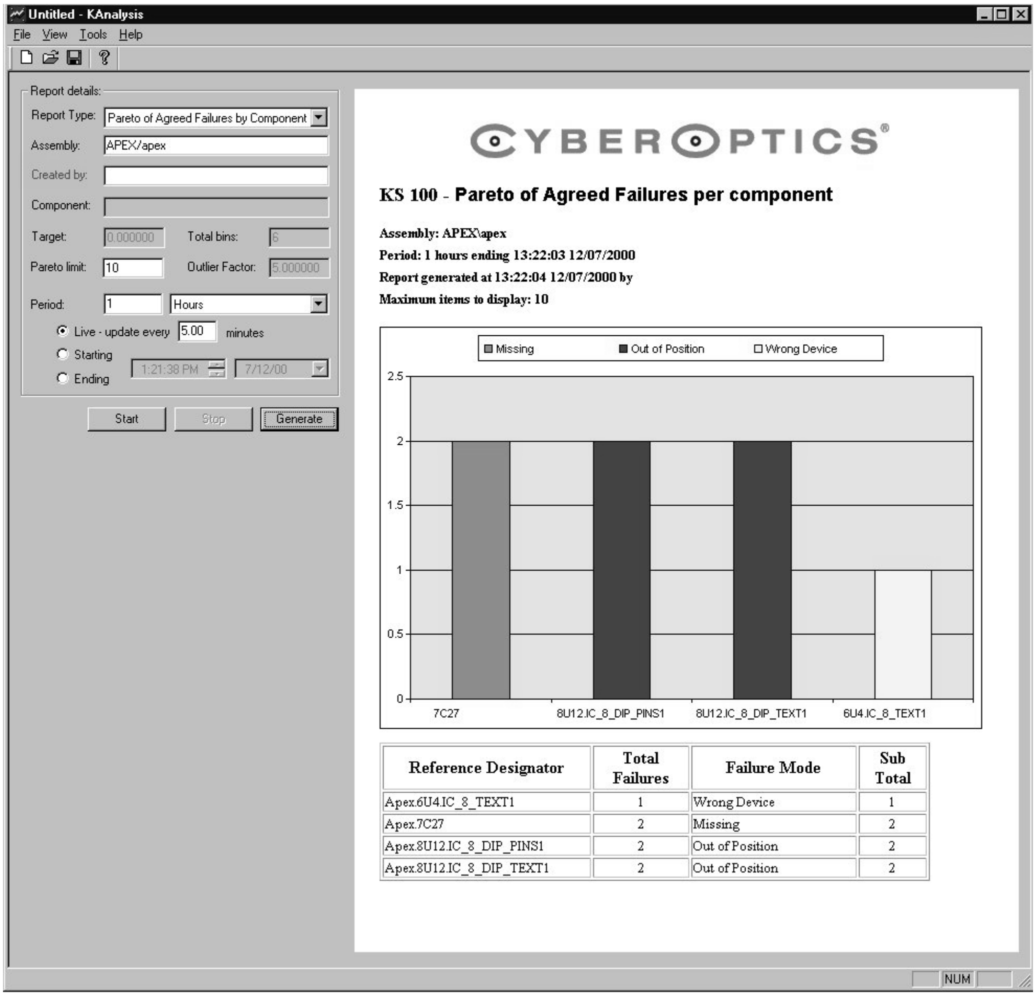

Figure 5. Example Pareto Chart

IMPLEMENTING PRE-REFLOW AOI

Typically, a pre-reflow AOI system is positioned directly prior to the reflow oven. In this position, the AOI system can inspect 100 percent of the placed components. Two different configurations are commonly used:

1. Implement an offline rework loop
2. Have an inline rework station directly after the AOI equipment

When using a rework loop, boards are inspected and the results tagged with the board barcode number. Failed boards are diverted using a turntable to a repair station with a barcode reader. The rework operator can either manually scan or automatically scan the failed board barcode. The results (and sometimes images of the faults) are then displayed on the rework station and guide the operator through the correction process. After rework, it is advisable to send the board back through the AOI machine to ensure that the rework that has been done has not generated any more defects.

Having an inline rework station after the AOI equipment means that when a board fails, the line is brought to a halt until the board has been repaired. A similar approach uses barcodes to locate the appropriate result and display the faults graphically on the inline rework station.

CONCLUSION

Evaluation of AOI systems is an important step in improving the quality of a production line. Ensuring system accuracy/repeatability and monitoring other attributes -- such as false-call rates -- produces SPC data that can be used to identify and correct faults. The payoff is improved yields and reduced costs.