Advances in AOI technology make machines more cost effective

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Choosing an optical inspection machine for PCB board inspection is a daunting task. There are many vendors in the marketplace that claim to perform the same or similar tasks such as solder joint inspection or post-place inspection. However, the machines in the marketplace are constructed of different hardware and software components such as cameras, lighting, algorithms, and programming paradigms. To make matters more confusing these systems are offered all at a variety of prices. Many PCB manufacturers face significant cost pressures. As a result of these pressures and a difficulty discerning between offerings, the manufacturers may choose to pick the lowest priced offering for such machines. The standard way to measure the cost of the machine is the base price for the system. However, manufacturers using such machines in the long-term have found there are hidden-costs to some of these systems which include programming time, program maintenance, and program transportability, which must be added to the base price. Recent advances in technology have significantly reduced the hidden cost of these programming issues by allowing machines to automatically tolerate variations. Additional advances have allowed these machines to be more reliable and provide variable (measurement) data as well as attribute (defect) data that is accurate and repeatable. These data can be fed back into the process to tune production lines and head off defects before they occur, thereby reducing rework and scrap and ultimately reducing costs. In this paper, we will survey some of the technological advances that have led to these two significant cost saving features in order to allow manufactures to make the best cost decision when purchasing an AOI machine.

The barriers to a company entering the AOI market are very low. Almost anyone with a camera and a flashlight can do so. Color cameras and LED lighting make it easy to take good pictures of PCBs. The big question is how to choose from all of these AOI options. In a world filled with flashy images, customers often judge a machine based on how the images look and the hardware configuration. This is because hardware is easy to describe and evaluate and images are easy to see. Image quality is often confused with inspection quality. While it is important that a system provide good images, these images need to be processed by good software algorithms for any inspection to occur. The inspection algorithms inside the machine are the determinants for false calls, false accepts, and programming time. If executed poorly, the software can add a significant hidden cost to the base price of the machine. The difficulty is that it is hard to understand exactly what the software's capabilities are, in order to judge if it can provide good levels of inspection over long periods of time.

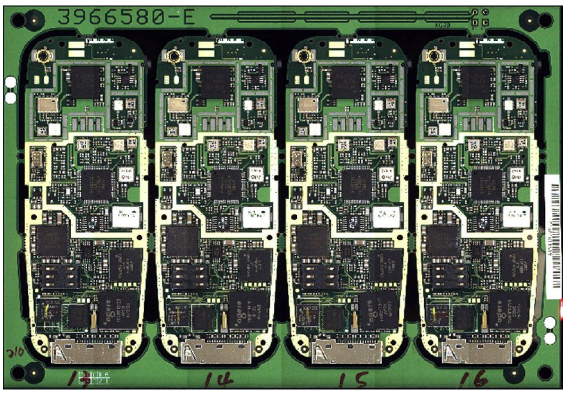

Figure 1- New advances in color cameras and lighting systems make brilliant color images easy to obtain. However, the important part of an inspection machine is the software that processes these images.

The field of AOI has focused mainly on hardware development, because hardware was the limiting factor for most machines for decades. With the advent of new advances in cameras, lighting, computers, and memory, the door has opened up to providing more sophisticated software algorithms. However, most AOI vendors still retain their limited software options and prefer to focus on hardware improvements.

The most popular software algorithm for analyzing images is correlation. Image correlation matches a known good image of an element of a PCB to a new element of a PCB under test by comparing the two in a pixel by pixel manner. The sum of the differences of either the luminance or color is indicative of whether the match is good or not. The technique requires a threshold to determine if the stored image is sufficiently similar to the new image in order to output pass or fail. This technique works very well when the boards or elements on the board look exactly the same as the saved image. However, if good board elements change in appearance this technique breaks down resulting in false calls or false accepts.

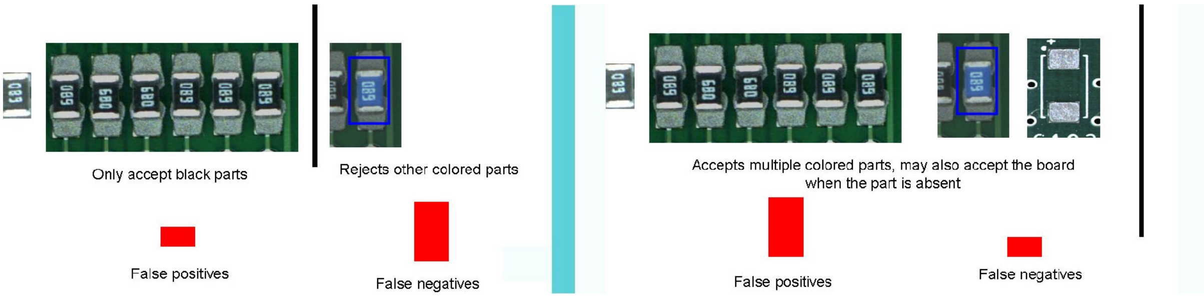

Figure 2- The figure shows the results of image correlation on matching of a black component to other components. On the left is an example where the threshold (noted by the black line) is high. Here, all black parts are accepted, but the same part in blue is rejected. Thus, false positives are low and false negatives are high. The right panel shows a case with low threshold. Now the black parts, blue parts and cases where the part is truly absent are accepted. In this case false positives are high and false negatives are low. Finding a happy medium is difficult.

Many hours of programming can be spent tweaking the algorithms' thresholds to find a good threshold for each element that is inspected. However, the end result is that brittle algorithms result in hidden costs to the customer that are not apparent until the customer tries out the machine for an extended period of time. False calls, False accepts, and significant programming time add to the economic bottom line in terms of machine cost. Not many people add the cost of these issues into the base price of the machine. In fact, some of these issues cause people to abandon the machines, which means the machine is now a 100% liability.

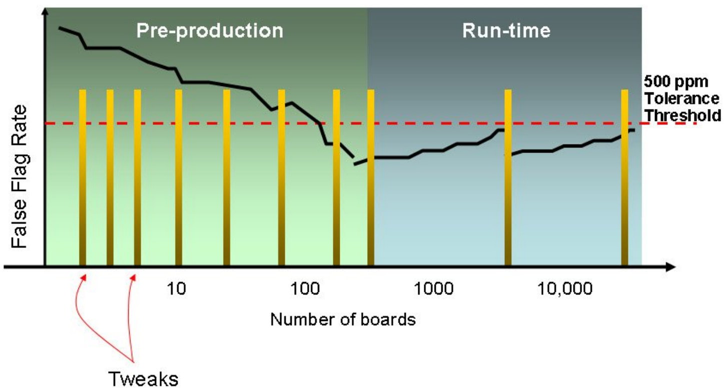

Figure 3- Brittle algorithms, like the one described above, cause programmers of AOI systems to constantly have to make adjustments to program to try to keep the false flags low. This activity, known as "tweaking", can cost a significant amount in terms of man-hours.

The reason systems need constant tweaking is to handle the large amount of variability on a printed circuit board. PCBs can change color. The same part can change color or have oxidized leads. The pads can change material and the paste brick can have different configurations. Components of the same type can change size significantly and have different markings. Yet all of these changes are still acceptable variations of the same printed circuit board. If almost everything on the board can change, how can a system decide what is good and what is bad.

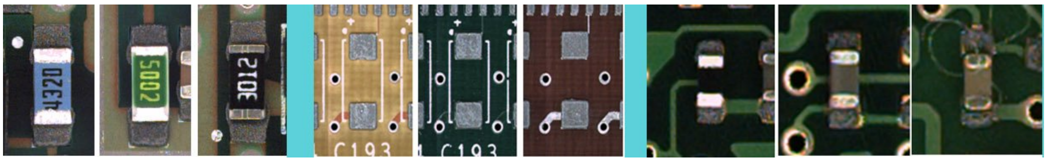

Figure 4 - Significant acceptable board and component variations, for AOI machines, result in false calls, false accepts and sometimes endless programming time.

The main thing that one needs to do in order to make these machines less brittle is to automatically handle variations. This is something that the human brain does easily. The brain is able to recognize objects, such as faces, even though they may be viewed under different lighting, at different angles, in different contexts, etc.

Figure 5- It is easy for us to see that these are images of the statue of David even though they differ in their pose, illumination, and background.

Recent advances in our understanding of how the brain works provide us with some insights into how to make less brittle AOI machines. New imaging modalities give us unprecedented views into how the brain processes visual information. One of the most relevant findings, in the context of AOI systems, is that the brain tends to encode information in a qualitative way. For images, what this means is that the brain "remembers" if a region in the image is brighter or darker than an adjacent region rather than calculating and storing the absolute value, brightness or color, of that region. Additionally, the regions the brain processes are rather large.

We can use this idea of qualitative or relative relationships to create models of elements on a PCB board. This image representation is known as Configural Recognition ™ and was developed at the Artificial Intelligence Laboratory at MIT. Let us use a capacitor as an example to see how this representation allows for more tolerance of acceptable variations. In order to build an inspection algorithm for the capacitor, we can represent the capacitor and the background as a set of regions. We can describe "good" capacitors with a language that describes how the regions are related. For instance, a capacitor can be described as having two endcap regions, two paste regions, a body region and three background regions (two on the side and one underneath). Generally, when the capacitor is present the paste is darker than the endcaps, the body is different from the background and the body is different from the endcaps. These relationships are all valid when the part is present even if there are changes in the absolute body color, luminance of the endcaps and paste, and color of the board. Most of these relationships are not valid when the part is not present. Thus, the language allows for built in tolerance to normal process variation, but it still can differentiate cases of unacceptable variation.

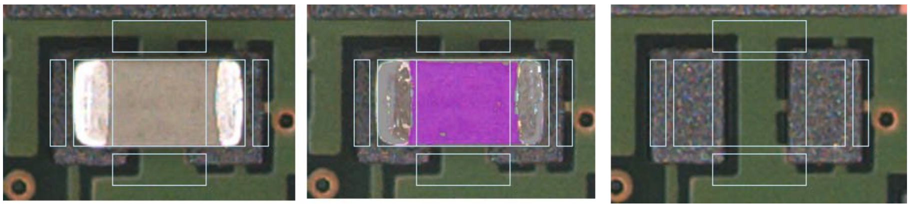

Figure 6- A qualitative model for a capacitor consists of regions and relationships between the regions.

We have incorporated ideas like this into our Landrex Optima ™ Series of post-place inspection systems. We found that utilizing such ideas lead to a three-fold reduction in false calls and false accepts. Even more importantly, since the machines are able to adapt to acceptable variation automatically, the result is a system that is easy to program and requires little maintenance work on the part of the programmer. Compared to systems that require constant tweaking, this is a great cost savings.

However, there is another side of the equation to look at, which is how to deploy AOI machines. Many people use them as quality gates and place most of them post-reflow. With inspection and test at the end of the line, many bad boards can be built before an issue is found. Often, issues found at the end of the line are not reported back to the in-process team because of poor communication or lack of time. We have been working for the last seven years to understand how manufacturers can use data about their manufacturing earlier in the build process in order to fix defects before many occur or even to prevent defects from happening. In our study we found that many manufacturers do not realize that their first-pass yield often drops dramatically over time. This results in significant rework, which can cause field failures, or scrap, leading in turn to high manufacturing costs.

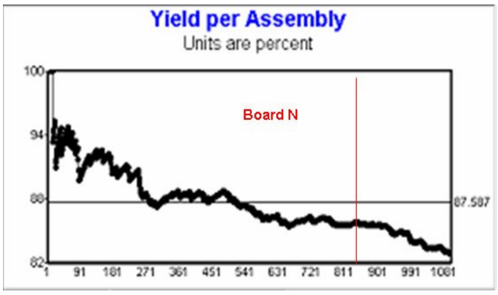

Figure 7- Most customers are surprised to find that their first pass yield declines significantly over time. Manufactures can significantly benefit from using AOI tools that can provide both measurement (variable) data and defect (attribute) data and by deploying these tools earlier in the process. Measurement data provides quantitative information about a line's performance. Problems can be analyzed quickly and resolved. Measurement data also allows one to find problems before they occur.

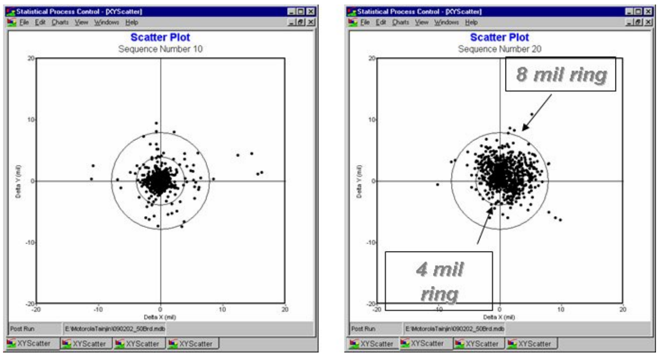

Figure 8- The scatter plots above show the dx, dy locations for every part on a board. The two rings denote displacement at 4 mils and 8 mils away from the desired center location. The plots are from the same type of board from two different lines with the same configuration of paste and placement machines. The measurement data shows that the line on the left has a tight placement process, but high gross defects. These defects can be easily identified and fixed. The line on the right has better performance in terms of gross defects, but is likely to go out of control. Thus, by fixing the issues with the second line, a manufacturer can prevent gross defects before they actually occur.

We evaluated the benefits of more advanced image analysis techniques as well as process control techniques in a 5 month study at a customer site using the Landrex Optima ™ 7200 post-place machine. The customer measured the defects before and after introduction of the machine. The result was an order of magnitude decrease in defects. In addition, after initial program creation and debugging session, no additional changes were made to the program. This led to significant cost savings by reducing rework, scrap, and manpower.

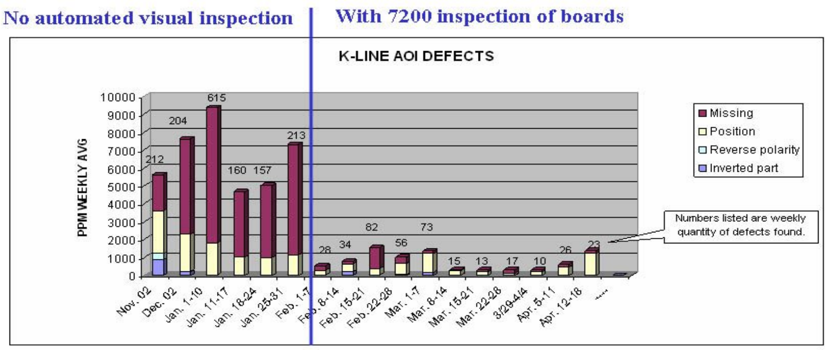

Figure 9- Long term study of the effects of using both more sophisticated AOI machines and process control techniques. The graph shows the number of defects found before and after introduction of the machine and the process control techniques.

Through these examples we hope to have shown that manufacturers can significantly reduce costs by deploying AOI machines with algorithms that can automatically handle normal process variation, that can provide measurement as well as defect data, and that can be deployed earlier in the line to enable process control measures.