ADVANCES IN AUTOMATIC OPTICAL INSPECTION: GRAY SCALE CORRELATION vs. VECTORAL IMAGING

Vectoral Imaging, SPC & Closed Loop Communication: The Zero Defect SMD Assembly Line

Mark J. Norris
Vision Inspection Technology, LLC
Haverhill, MA
mnorris@vitechnology.com

ABSTRACT
Gray scale correlation is giving way to new technologies such as Vectoral Imaging. These new methods of identifying and inspecting components during PCB assembly are solving major drawbacks such as time needed to program, program transportability and reliability. These new methods combined with full SPC capability, will allow companies to see trends and find errors before they occur. In order to fully use these new capabilities, AOI manufacturers are working with Screen Printer and Pick & Place manufacturers in order to close the loop using software, which communicates from the AOI directly to the process.

Key words: AOI, Inspection, Vectoral Imaging, Synthetic Images, SPC, Pick & Place, Closed Loop.

BACKGROUND
The use of new methods to inspect printed circuit boards using alternative technologies to Gray Scale Correlation are slowly being accepted as a breakthrough in Automatic Optical Inspection. For years, Gray Scale Correlation and pixel counting have been the mainstay of most optical inspection applications. Despite the need for faster more accurate solutions, AOI manufacturers were slow to respond to this demand, which has created a void in the market and a distrust of AOI in general, which is only now being overcome and at a very slow pace indeed. The need for AOI is obvious and widely accepted, however the number of companies actually implementing this technology correctly and to its full capabilities are few and far between. Simply implementing vision at the end of the line after reflow, as a guard against defects is not the solution. Although this may help to optimize the use of ICT by detecting all of the cosmetic errors such as missing components, bad polarity, incorrect values, tombstones and other visible errors, it is not enough to really implement process control or full real time SPC capabilities. Companies are accepting more and more the need to bring AOI into the assembly process instead of at the end, and we see AOI being used post print, post chip shooter and pre-reflow. In order to gain the maximum benefit from such implementation, it is necessary for the AOI to not only detect defects after the fact, but to be able to communicate with the upstream and downstream assembly products in order to make changes as the process deviates from the acceptable but always within the upper and lower control limits. It is necessary for communication software to be developed which will enable the AOI to tell the upstream equipment what has happened to the process and for the upstream equipment to make the necessary changes in order for the process to remain stable. Only if manufacturers work together to achieve this goal will we really see the full benefits of AOI and the arrival of the zero defect SMD manufacturing line.

GRAY SCALE CORRELATION
Using Gray Scale Correlation, most systems store an image that is considered to be an acceptable representation of the component to be inspected. This image is later compared to other images during production and a comparison of the levels of gray of each pixel and the number of pixels that match the stored image defines whether it is worthy of being considered a good enough match to be recognized.

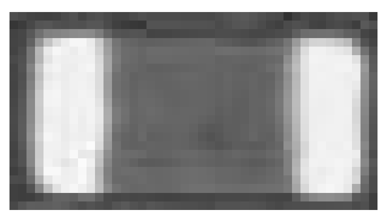


Figure 1. Above is a pixelized image of a chip capacitor used by gray scale correlation.

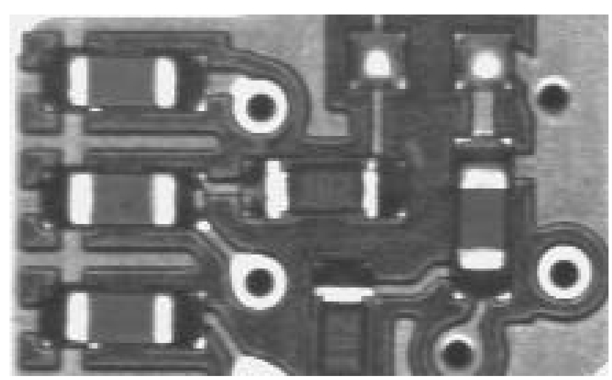


Figure 2. Run time image of a board to be inspected.

When using a stored image when inspecting a board such as that depicted in Figure 2, the results are quite acceptable although problems may occur with the rotated components.

However using this method would not work when inspecting components such as those shown in Figures 3 and 4 as although they are similar components they are radically different in there appearance. This is a standard in the industry and an issue that will not go away as components differ dramatically both in design, color and to some extent shape.

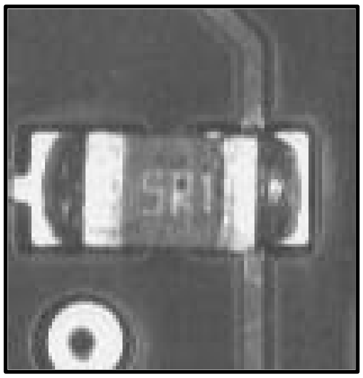


Figure 3. Image of a dark bodied component.

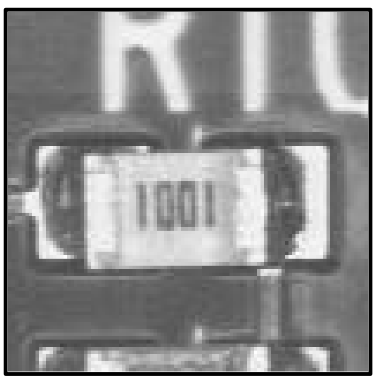


Figure 4. Image of a light bodied component.

Other problems that exist when using gray scale correlation are issues with background color and inclusions in the image. We can see from Figure 5 that although the same component may exist at several places on the PCB, the image due to background color or inclusions in the image will falsify the results obtained and create false errors.

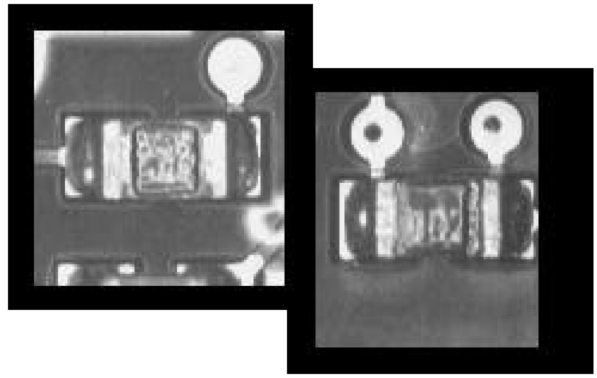


Figure 5. Similar components at different positions on the PCB, resulting in different images.

For more detailed information concerning the different methods used by Gray Scale Correlation and the drawbacks to each method, please refer to previous papers presented by the author.

VECTORAL IMAGING TECHNOLOGY

After a detailed and extensive look into all of the different methods available, it was clear that for the application of in-process inspection of components on a printed circuit board, none of the existing methods would give the ease of use, repeatability and robustness required by the industry. Over the past two years, a new technology has emerged as a real solution to the requirement of inspecting populated printed circuit boards at speeds compatible with today's high-speed production lines. This new technology is Vectoral Imaging.

Locating Vectors compared to Counting Pixels

As we can see from the Figure below, pixel based technology will try to recognize an object by counting pixels and comparing it to a stored image. This method is relatively slow and is adversely affected by changes in color, background, size and rotation.

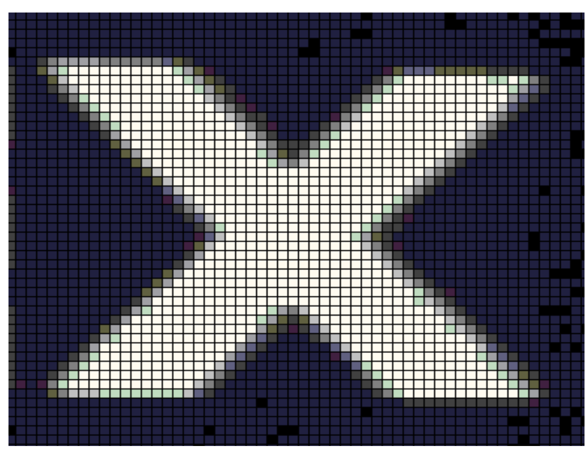


Figure 6. Pixelized image of an object.

Vectoral Imaging approaches the problem with a completely different method in order to overcome the problems of grid based pattern analysis. Vectoral Imaging converts the pixel grids provided by the image sensor into geometric features.

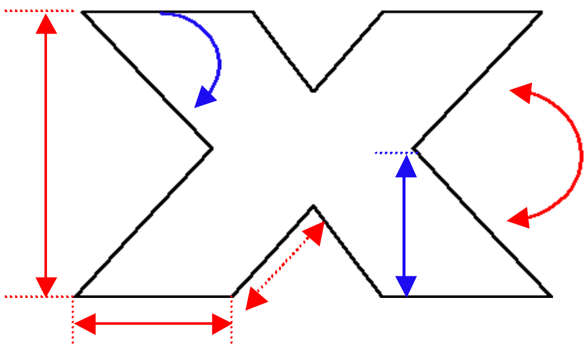


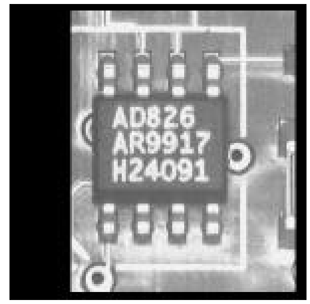
Figure 7. Vectoral analysis of the same object showing relationships between features. These relationships still exist regardless of scale or object position.

Vectoral Imaging is a pattern location search technology based on geometric feature extraction rather than absolute gray scale pixel values. Patterns are not dependent on the pixel grid. A feature is a contour that represents the boundary between dissimilar regions in an image. Features can be line segments, arcs, angles and open or closed geometric shapes.

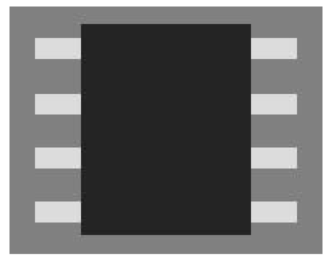
By using geometric features, the image analysis is not affected by color changes or non-linear changes in size such as those found with components due to manufacturing variations. Jedec and IPC standards allow for changes in both the size and shape of components, which are acceptable to the industry. Any vision system used for this application has to take this into account as well as the changes in appearance due to vendor variations and different manufacturing processes.

Synthetic Models

Because Vectoral Imaging uses geometric features and mathematics to represent an actual image model, it is also possible to generate purely mathematical models, or "synthetic models," of the pattern to be located. The use of these synthetic models minimizes the effects of variations of lighting and background, as the model is not connected to the environment. The models can be generated by using the data from IPC or JEDEC component specification sheets; or from actual component images taken by the equipment.



P8



P9

Figure 8. P8 represents an actual S08 package and P9 is a synthetic model of an S08 package.

This allows the user to have a very robust library of Synthetic Models for each component, which can be modified easily on site or downloaded from the Internet. The greatest advantage of the Synthetic Models is the transportability and the capability to be used universally. A user with several machines will have the capability to use the same library of synthetic models on every machine. The library can be stored on a network at a central location and models downloaded as required.

The goal of Vision…Data Collection.

Using these new faster and more reliable methods leads us to the overall goal of what is trying to be achieved by implementing vision. That is the collection of data both on the machine for immediate process intervention, on the rework station for repair and analysis of defects and even further, the implementation of a true SPC Statistical Process Control of the line.

Information Available on the AOI System.

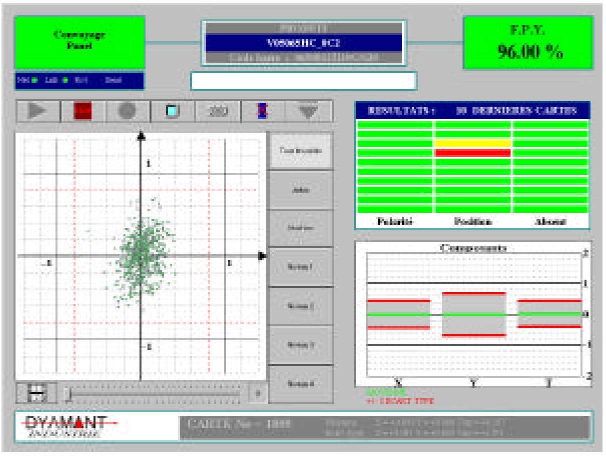


Figure 9. Production Mode Screen of AOI System.

It is of the utmost importance that an operator has access to the information necessary at all times in order to be able to make a decision as to the actions to be taken. A glance at this information will allow him or her to know the exact state of the process and to decide if and what corrective action should be taken on the equipment upstream such as the placement machines or screen printer. Figure 9 shows us the information available to the operator on the AOI while in production.

In Figure 9 we are shown the graphical interface that the operator can see at all times during production on the AOI. This GUI shows several important sources of information that can be expanded upon at will. The top right hand corner of the screen shows the FPY % or first pass yield currently of the SMD line. This gives an immediate situation of the overall process capacity. Below this we see a table that represents the status of inspection on the last ten boards. Each column represents defects such as missing components, bad placement or polarity errors. A green bar represents no defects on that board while a yellow bar represents a status of nearing the acceptable limits but still within the tolerances. A red bar signals that a defect has occurred, while two consecutive identical defects would result in a flashing red bar. These defects can be expanded upon by clicking on the red bar to show the defect screen as shown below in Figure 10.

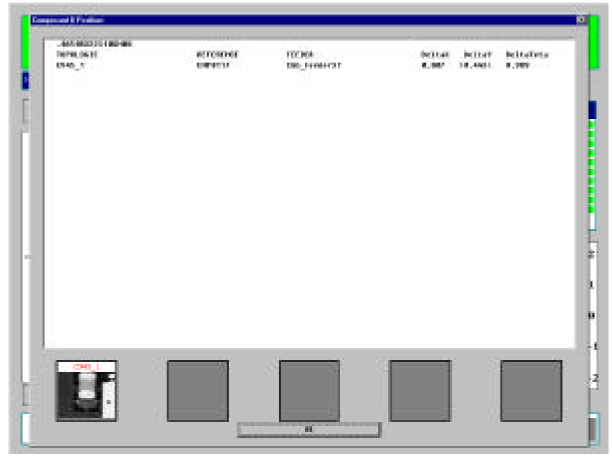


Figure 10. Defect Detail Screen on AOI System.

Here we can see that the topology, component reference, the placement machine and feeder location are all shown for that defect. At the bottom left hand corner of the screen we show the actual picture as taken by the AOI of that defect so it can be looked at in more detail and a decision taken as to what remedies may be necessary. By supplying all of this information an empty feeder or a defect with the placement head on a pick & place machine can be quickly detected and traced to the source.

Looking once again at Figure 9 we also see at the bottom right hand corner the average and standard deviation of the placement is shown in X, Y and Theta. To the left of the screen we can see a Scatter Chart, which shows the accuracy of the placement in regard to the tolerances. This scatter chart can be used to show the placement accuracy of all of the components, a particular Jedec type, a particular machine or even a particular head or even a feeder. These can all be pre-programmed into the system when programming the board and by importing the feeder file from the pick & place machine.

This data is all user definable and can be configured at will by the operator or by the process engineer. This information can also be made available at other locations over the network.

AOI Repair Station.

Finding defects and showing data is one thing, but supplying additional data and graphical help to the repair station operator is a necessary part of the AOI software. Information must be clearly shown which will help the operator to decide what repair actions are necessary and to be able to log them for future reference. Figure 11 shows the information supplied on the repair station when a defect occurs.

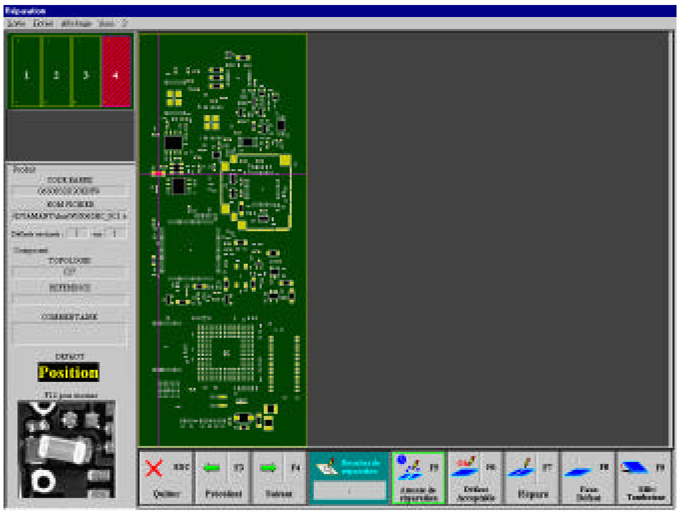


Figure 11. Repair Station Defect Location Detail Screen.

This screen shows the operator in the top left hand corner a graphical representation of the PCB Panel and indicates in red on which board of the panel the defect exists. Below this, the barcode reference as well as the program name, component reference and topology are noted. To the right of this table of information, a graphical representation of the singulated board is shown with the exact location of the defect in red and a cross hair for location reference. In the bottom right hand corner of the screen, a picture of the actual defect is shown for reference. Along the bottom of the screen, action buttons are available so that the repair operator can record what actions were taken, repair, accept or false failure, so that all repair actions are recorded and logged for future reference, including the name of the operator and the time, date stamp.

Supervisor Software.

Additional supervisor software, which can be installed at any location in the factory over the network, is another way of using the data collected by the AOI. A simple mouse click will give the engineer a complete record of all of the defects on a particular machine or line for the time and date requested. Defects for the past hour, day, week or month by defect type and or component type can be shown at the request of the process engineer so that analysis of the current defects can be carried out and decisions taken as to the corrective actions necessary. Figure 12 shows a typical screen from the supervisor, showing defects on a line over a given period.

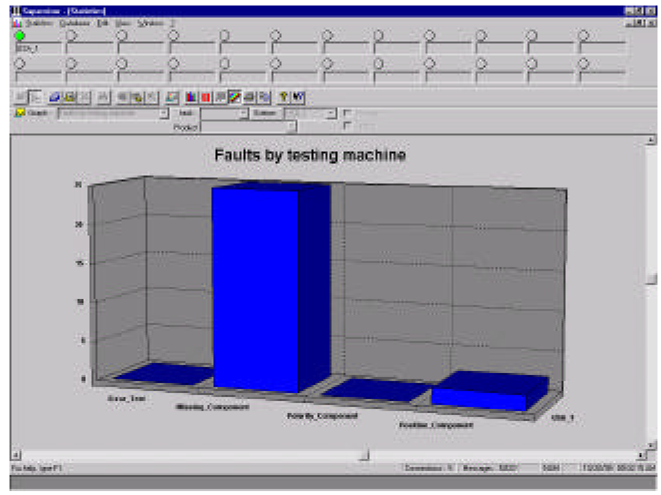


Figure 12. Graph of Failure Data By Defect Type.

By using very simple 3D bar charts, an instant and clear view of the defects on a line can be shown in real time and updated constantly.

Statistical Process Control

Collecting real time data on the machine, the repair station, or even off-line with a supervisor software is a real step forward in implementing real process control in today’s demanding assembly environment; but it is still not enough if we are to reach our goal of the zero defect line. The data collection methods shown so far, only give us data of actual defects, which exist in the process, and allow us to solve the problems after they have occurred. However, the real goal is to implement a real time SPC data collection system, which will enable us to see problems before they have an adverse effect on the quality of the process.

“Vision is not seeing what we can see, but seeing what we cannot see.”

By implementing a full SPC package into the AOI machine, we will be able to track solder paste deposition and component placement in real time. This information will allow us to study the process as it happens and to detect trends automatically. As a trend occurs, which in standard SPC practices is seven measurements of data, the SPC software can log the occurrence of the trend and send the information to the required location. This might be on the desktop computer of the process engineer. This engineer is able to have the SPC data sent directly to his screen in real time as an icon at the bottom of his desktop. The full screen showing the actual data and graphs is only activated if the software sees a trend. In Figure 13 we can see a screen showing a trend occurring of incorrect placement. In this case the trend has not been recorded yet as only six occurrences have happened so far.

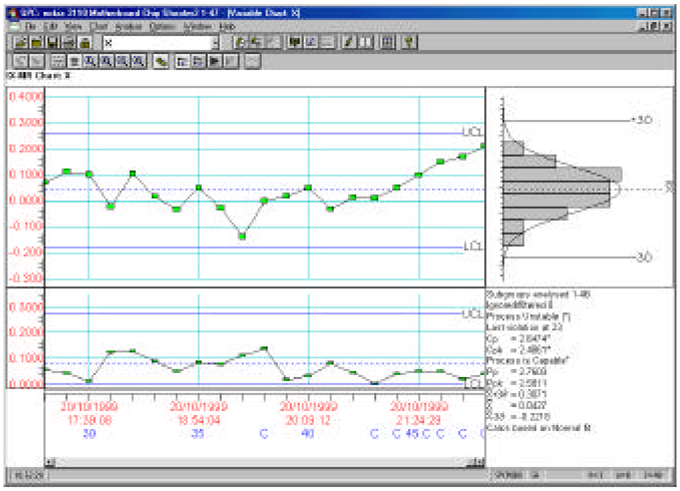


Figure 13. X Bar and R Chart for SPC Analysis.

The layout of the SPC data as well as the criteria of collection and methodology are all defined by the engineer and can be selected at will.

In Figure 14, we can see that the seventh occurrence has taken place and a trend has been recorded. This information is immediately sent to the engineer so that corrective action may be taken.

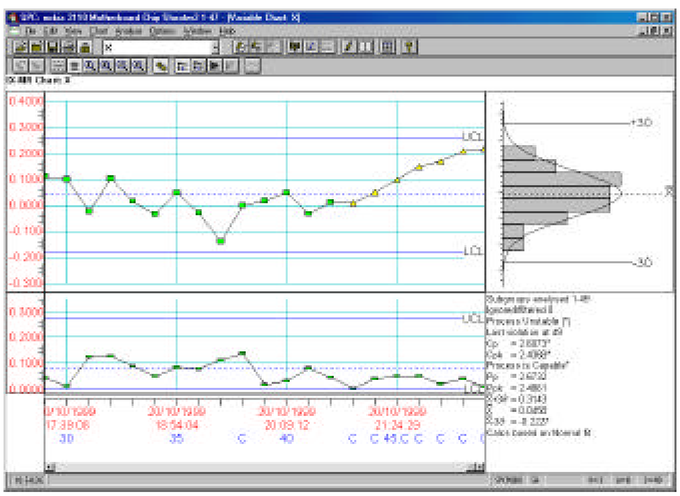


Figure 14. X Bar and R Chart for SPC Analysis – as seventh event defines an SPC "out of control" situation.

We can notice in Figure 14 that although an out of control situation has been detected, the process is still within the upper and lower control limits and the line is still producing good product. This means that we are able to detect a possible cause for concern, before the problem affects the production. By using the other data available to him or her, the engineer can trace the source of the trend and take the corrective action necessary. This may be the replacement of a defective placement nozzle, the cleaning of a stencil or preventive maintenance on the production equipment.

However, what happens if the engineer is absent and is not in front of his or her PC to see the situation occurring? It is possible to program the SPC tool, so that in the case of detection of a trend, the software can automatically send out an email to predetermined recipients, send an SMS text message to a mobile phone or in the worse case scenario, stop the production. In Figure 15, we can see that the corrective actions necessary have been carried out and the process is back in control without having affected the product integrity and without producing bad product.

The Future Zero Defect Production Line.

In order to take all of this one step further, a concerted effort by both the AOI manufacturers and the other equipment suppliers must be undertaken. If we are to use the data collected by the AOI system to create a zero defect line which is able to take corrective actions automatically, it is necessary for the production machines both upstream and downstream to communicate in real time with the AOI system. Imagine the future capabilities, when due to information received from the AOI system the screen printer can be informed that the stencil needs to be cleaned or the pick & place machine can carry out an automatic calibration of the pick up head or the camera to nozzle offset. Other specific production goals could be implemented such as in the case of mobile phone production. One issue today, is the placing of shields on boards that have placement or solder paste defects. In the future, the AOI could instruct the downstream machine not to place a particular screen and identify the board on a panel that needs repair before the shield is placed.

CONCLUSION

The technology exists today to create the zero-defect line, but whether it becomes a reality or not will depend on the capability of the different equipment manufacturers to work together to develop the necessary software communication tools. Third party software suppliers also have a role to play, as this could become an integral part of their packages and the next step with protocols such as GEM/SECS II. Organizations such as SMEMA could also play a role in making sure that the equipment manufacturers all agree on one protocol so that all AOI systems could communicate with all the other equipment available. It is important at the same time that the manufacturers play their role in defining what is required, and better understand proper utilization of an AOI system. The days of using AOI exclusively at the end of the line are already behind us. AOI should not solely be used to detect defects after they occur but to prevent defects before they occur. If this is understood by all of the parties involved, and corrective measures are taken to move AOI to a pre-reflow position, it can be utilized to truly control the SMD production. Subsequently the entire electronics manufacturing industry is heading for the dreamed about solution:

"**The zero defect production line.**"

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Other people who I cannot mention but who know who they are.

Other papers by the same author

"Ensuring quality with in-process inspection for PCB assembly. Implementing (AOI) Automatic Optical Inspection, where, when and how?"

"Advances in Automatic Optical Inspection: Gray Scale Correlation vs. Vectoral Imaging."

MARK NORRIS is the CEO of Vision Inspection Technology, LLC, 179 Ward Hill Ave., Haverhill, Mass. 01835, USA; (978) 372-1230; Fax: (978) 372-1767; E-mail: mnorris@vitechnology.com.