Combing Automated Advanced Process Control with Feedback to Revolutionize the Printed Circuit Board Assembly Process

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ABSTRACT

With a shortage of highly-skilled employees for printed circuit board assembly, the electronics industry faces a severe challenge, which is being complicated with a high turnover rate as employees jump between companies or simply become misaligned with the organization. While leading industry organizations like IPC and SMTA are tackling the issue head-on with education and training programs, a need exists for equipment suppliers to cooperate with other industry leaders and organizations to adopt Machine-to-Machine (M2M) communication standards. Initiatives like the IPC Connected Factory Exchange (CFX) and the IPC-Hermes-9852 standard underpin the efforts within the industry, and many companies are working together to develop standards to create seamless production.

Guided in part by Industry 4.0, these M2M communication standards are quickly altering the manufacturing process by improving metrics like first pass yield and throughput by applying autonomous process adjustments. Far beyond an automatic line changeover, this bi-directional communication allows equipment to automatically adjust production parameters to increase board quality and lower costs by eliminating rework and scrap.

Building on our expertise and testing, this presentation will explore Industry 4.0, and then explore how Advanced Process Control (APC) can increase production yields and reduce defects. Specifically, the presentation will discuss how APC improves process repeatability by automatically adjusting component placement to the paste, rather than to the pad location. Moreover, it will show how APC will identify a shift trend and implement further position correction by using true 3D measurement data from the Automatic Optical Inspection (AOI) system. While a smart factory will help resolve the skilled employee challenge, it will also revolutionize process optimization.

Key words:
3D Measurement, Automatic Optical Inspection AOI, Artificial Intelligence AI, Advanced Process Control APC

INDUSTRY 4.0 DISCUSSION

Big Data is the foundation for Industry 4.0, so advanced inspection systems must evolve from simply judging “Pass/Fail” tools into highly intuitive, dynamic decision-making systems, which emphasizes the need for reliable, traceable data. Artificial Intelligence (AI) engines can empower tools to help customers analyze and optimize the production process by managing process data from connected SPI and AOI systems.

When we look at the optical inspection market growth trajectory, we can see how process challenges helped create innovations. For example, Solder Paste Inspection (SPI) has undergone a shift from 2D to 3D, because the 2D inspection technologies manufacturers traditionally used to collect solder deposit images could not solve shadowing problems. Thus, companies developed 3D SPI to capture the printed solder paste height to accurately measure the total volume of paste printed. Several years later, we see the same need for surface mounted component inspection with AOI systems.

As today’s board complexity is increasing with more components, more solder joints, higher density, and shrinking package technologies such as 0402 metric (01005 imperial) and even 0201 metric (008004 imperial) microchips (Figure 1), 2D AOI technology using grey-scale image analysis or angled camera view of color images may no longer be a practical possibility. Most decisions made are based on a “good-bad” comparison of reference images, which can easily be affected by variables like component surface finish, board condition, component proximity, and more.

Figure 1: Using a ballpoint pen for reference, the image compares 0201 metric (008004 imperial) component with an 0402 metric (01005 imperial) and an 0603 metric (0201 imperial) component [image courtesy of ASM Assembly Systems GmbH]

Although 2D AOI is still a major technology in the market, more manufacturers are adopting 3D AOI to increase board quality. The benefits are clear: putting rock-solid faith in inspection tolerances and reducing efforts to constantly debug inspection programs. Moreover, measurement data generated from 3D AOIs provides meaningful insights about the process and helps eliminate the root causes of a defect. The 3D SPI, together with 3D AOI, enables manufacturers to accurately control and monitor the solder printing and component placement processes.

But with so much data, engineers are hard pressed to collect, process, and implement all the data using traditional techniques and software. Artificial intelligence and deep learning lay the foundation for machines to learn from the vast amounts of process data collected by adjusting the output based on the data inputs and performing tasks to help engineers perform tasks more intelligently. The many examples we hear about like computers playing chess or autonomous (self-driving) vehicles use deep learning to achieve tasks by processing large amounts of data and recognizing patterns in the data.

This is ideal for volume PCB production and helps create a data set for a Smart Factory. From statistical process control to instant program refinements, AI-powered platforms can intelligently apply real-time data to improve production processes. Going beyond smart factory solutions, manufacturers can use the same technology to optimize the process and adjust process parameters by exercising complex machine-learning algorithms.

Realizing a smart factory means taking a practical approach to process and systems, while examining areas to improve productivity. Combining machine learning with 3D measurement data generated during inspection helps manufacturers define inefficiencies and boost line efficiency. Machine learning uses programmed algorithms that receive and analyze input data to predict output values within an acceptable range. As new data is fed to these algorithms, they learn and optimize their operations to improve performance, developing intelligence over time.

For example, some tools allow manufacturers to simultaneously deploy programs and inspection conditions across multiple lines, which enhances productivity and, more importantly, data integrity with consistent performance. Operators can further improve line maintenance with other tools for real-time monitoring to instantly display relevant process parameters at remote locations for immediate analysis and action. What's more, combining multipoint views from SPI, Pre-reflow AOI, and Post-reflow AOI with real data management and monitoring allows operators to determine actionable insights to optimize the processes. However, the adaptation of AI-powered process tools takes optimization to a higher level.

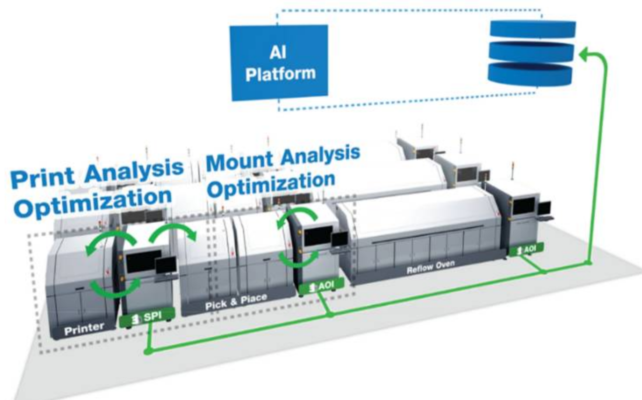
Converting all the data requires a simulation tool to review identified defects with accumulated historical data from PCBA lines, while avoiding unnecessary downtime. Software tools can reliably allow manufacturers to predict the effects from fine-tuning without stopping the line. Moving forward, an AI-powered platform can autonomously render complex process optimization decisions typically reserved for dedicated process engineers. Embracing the connectivity can create a smart factory. For instance, software modules can exercise complex algorithms to develop closed-loop process recommendations. The Machine-to-Machine (M2M) connectivity drives the smart factory vision one step further by enabling automatic SMT line maintenance. Finally, combining inspection with printers and mounters can enable the network tools to connect and simplify communication across the entire PCBA line.

Defining the correct process parameters often requires a high degree of expertise, because of the various environmental considerations affecting the process. Using AI-powered systems and M2M connectivity, manufacturers can link inline inspection systems with the associated printer and mounters in the line to overcome the challenges. Figure 5 shows how automated machine learning can already match the results from process experts, and this will only improve.

ADVANCED PROCESS CONTROL METHODOLOGY

Reliable AOI methods have become powerful, economical complements to traditional test strategies. AOI can be used successfully as a process monitoring tool for measuring printing, placement, and reflow performance. Some advantages include:

- Detecting and correcting SMT defects during process monitoring is less expensive than after final test and inspection, where repairs are typically 5 to 10 times more costly



- Detect trends in process behavior, such as placement drift or incorrect mounting, earlier in the overall process. Without early inspection, more boards with the same defect could be rejected during functional test and final inspection
- Identify missing, skewed, or misplaced components with incorrect polarity earlier in the assembly process when component placement is verified before reflowing

Yet, a single inspection system has limitations, especially when there is limited or no communication with the balance of the line. In this setup, it simply cannot optimize a printed circuit board assembly (PCBA) process. Equipment suppliers must cooperate to achieve communication for a zero-defect future. M2M connectivity can optimize the process by exchanging real-time SPI and AOI measurement data with other machines in the production line. This real-time feedback includes measurement data such as offset, volume, height, area, and warnings to other systems, while analyzing trends to optimize the process and identify trends. The connected systems can automatically define correlations between the processes.

For instance, the PCBA industry has many studies and documentation detailing how the solder reflow process can help position surface mount components normally on the pads, even if component placement is off pad. However, the trend to shrink components to 0.3mm bumps or 0201M microchips is opening doors to explore how process controls can improve yields in high-density placements.

Enter Advanced Process Control (APC), a proven control and optimization technology delivering measurable and sustainable improvements in production yield. Most engineers will agree that stabilizing control loops, with underutilized or ineffective process time and strong process interactions is exceedingly difficult. APC has become a standard solution for realizing stable control processes – and quite simply – APC is the added value upgrade to a process automation system. APC collects and analyzes solder and component location data from an inspection system, and then sends the recommendations across the line to printers or mounters for automatic implementation, as Figure 2 shows.

Figure 2: Theoretical SMT Line using Advanced Process Control Active Feedback between solder paste printer, solder paste inspection (SPI), component mounter, and automated optical inspection (AOI) systems

In this hyper-competitive world, manufacturers place ever-challenging demands on process solutions. Manufacturers want to monitor and adapt the process to achieve zero defects by accessing all the data – anytime, anywhere. They must also cope with shorter life cycles, so inspection solutions should be able to collect and analyze a large amount of data to produce traceable results.

APC PRINTER FEEDBACK RESULTS

The continued demand for smaller, lighter, and smarter electronic devices has led to an increasing use of smaller components. These shrinking packages force smaller aperture designs and finer solder paste, which have made stencil printing a highly-sophisticated process with a tremendous impact on production yields. In fact, 70 percent of all PCB assembly defects are primarily due to problems directly associated with the solder printing process. Manufacturers must ensure the optimal printing paraments are consistently applied during production.

An enhanced APC solution, formed of interlinking software modules, can actively optimize the printing process by combining real-time printing information with SPI measurement data. More advanced software automatically performs Design of Experiment (DOE) intended to complete a detailed SPI result analysis using advanced diagnostic algorithms and noise filtering models, and then recommends the ideal print parameters.

In the testing, the software conducted an automatic DOE by changing the screen printing parameters. When handling two parameters, it needed 11 prints. For three parameters (Printing Speed, Printing Pressure, and Separation Speed), it would require 17 prints, as was used in the results shown in Figure 3.

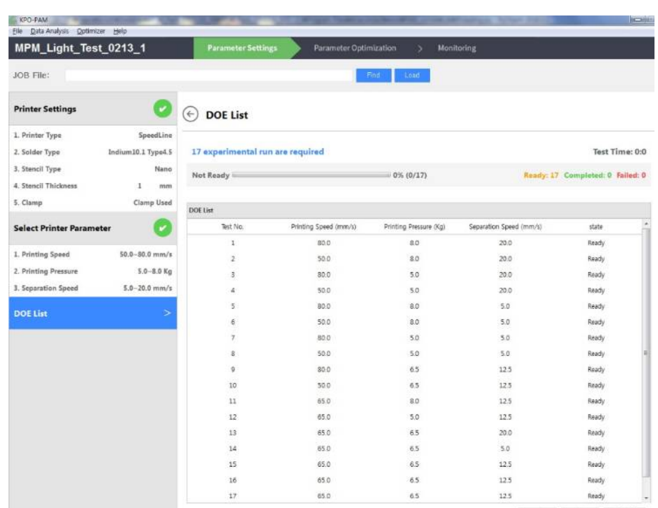


Figure 3: Three printer parameters (printing speed, squeegee pressure, and separation speed) were all considered in this test run of 17 PCBs

The software triggers the SPI to send the information to the screen printer to automatically adjust the parameters. The Max and Min values for printing pressure, printing speed, and separation speed can be set when adjusting the printer parameters as shown in Figure 4.

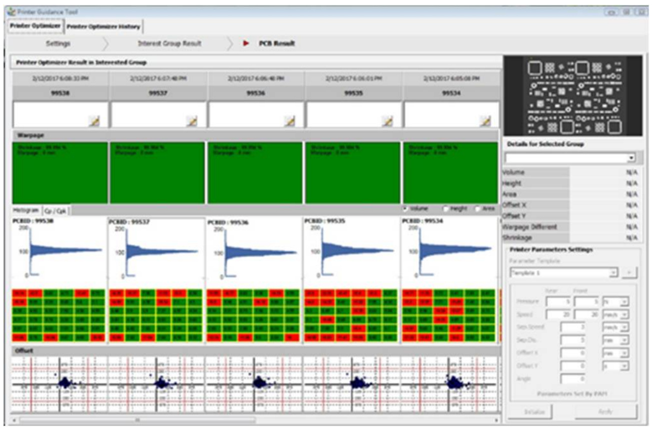


Figure 4: Automatic print process data analysis by SPI machine with feedback to printer

Once the system defined the optimum values for the printer parameters, ten boards were printed and analyzed. The volume histogram and the X-bar & sigma chart of 10 boards show that the screen printer quality between the engineer and the KPO module is almost identical. The blue colored histogram in Figure 5 represents the optimization completed by an engineer with 25 years of intensive print process expertise. The green colored histogram in the same figure represents the optimization completed autonomously by the software. The results are virtually identical.

Figure 5: Advanced APC test results comparing human (blue) and software (green) printer optimization

Other software can use multiple anomaly-detection algorithms to actively optimize the print process and further reduce false calls. Ideally, the software will evolve to autonomously generate optimized models and fine-tune the process parameters in real-time using actual results. While the software modules would each provide standalone process benefits, the combined power of an AI-powered software suite would ensure the highest process reliability and production flexibility without dedicated resources and expertise. This will be validated with additional testing as the features evolve and mature.

APC MOUNTER FEEDBACK RESULTS

With the benefits of printers communicating with solder paste inspection machines known, what about mounters and automatic optical inspection? Connecting mounters with inspection and measurement solutions provides obvious benefits, but when integrated with APC (Advanced Process Control) systems it can improve yields, especially in high density boards. The mounters use the received data to update the placement program; thereby, ensuring the components are placed onto the solder deposits rather than onto the substrate pads. This approach to placing components on the printed solder uses the self-alignment principle to increase production yields and reduce defects. As shown in Figure 6, when solder is off pad due to myriad reasons and components are placed to the pre-defined placement location in the program, self-alignment is not effective. During reflow, components will shift off pad or bridge with other pads; thereby, causing rework or scrap.

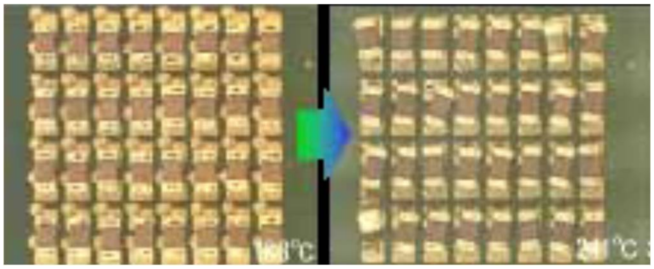


Figure 6: Traditional Chip Placement onto Pads (before and after reflow) [Images courtesy of Panasonic System Solutions Company of North America – Process Automation or PSSNA-PA]

Alternatively, APC-controlled placements will maximize the self-alignment principle. Using APC to mount microchips onto the solder instead of the pad will increase yields and quality. Figure 7 shows a set of test results. Using this advanced communication, the 3D AOI can feed corrected mounting position values to mounters, which ensures the pick and place machines mounts the components in the correct position. This improves process repeatability by automatically adjusting placements and identifying trends to make further positional corrections.

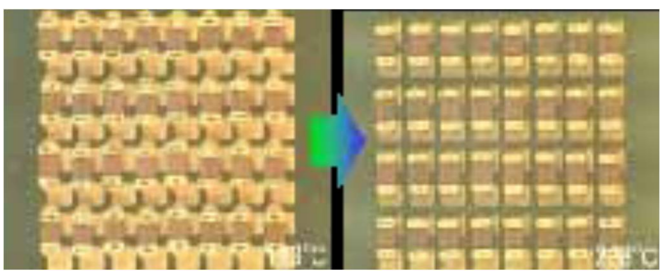


Figure 7: APC-controlled Chip Placement onto Solder (before/after reflow) [Images courtesy of Panasonic System Solutions Company of North America – Process Automation or PSSNA-PA]

Using real data from quantitative measurements, certain 3D AOI system can feed correct mounting position values to component mounters and ensure components are mounted in the targeted position as intended. This type of feature, also known as APC-MFB (Advanced Process Control-Mounter Feedback), improves process repeatability by automatically adjusting component placement to the paste, rather than to the pad location (Figure 8). Moreover, APC-MFB will identify the shift trend and conduct further position correction by using true 3D measurement data from the AOI system.

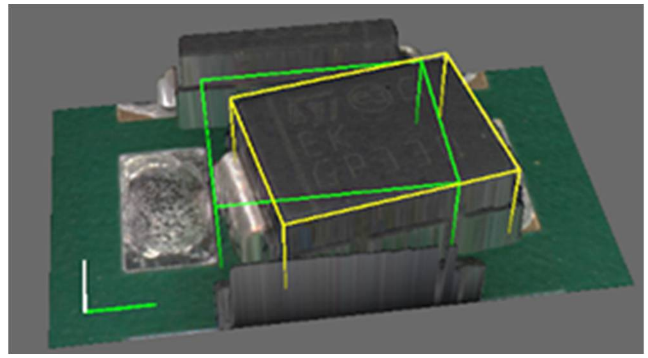


Figure 8: Example of pre-reflow 3D inspection detecting part skew, which is fed back to mounter

Connecting inspection systems with mounters can help achieve complete line communication and further enhance the value of the inspection process. For example, M2M connectivity optimizes the process by exchanging real-time measurement data between printers, SPI, mounters and AOI systems. The systems feed offset and warning data to other systems, while analyzing trends for process optimization and traceability. Combined this process provides unsurpassed performance power.

Communication between equipment will improve process repeatability by automatically adjusting component placement to the solder deposit, rather than to the pad location. This advanced process further improves microchip mounting reliability. Figure 9 charts dramatic improvement across five different defect types when a manufacturer uses advanced process control in production compared to a conventional placement approach with no communication between systems. Networked intelligent systems that allow real-time results to be correlated, calculated, and visualized will become even more essential in the Smart Factory.

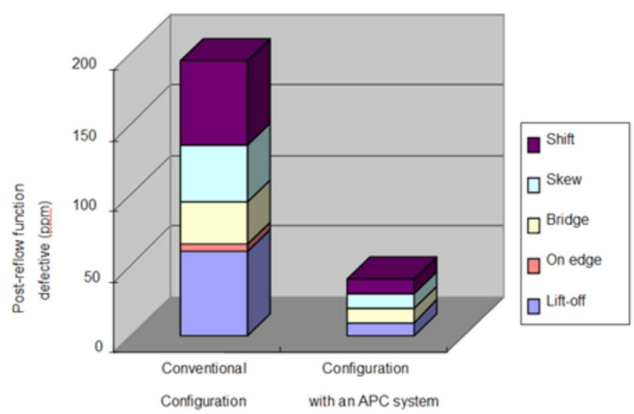


Figure 9: Post-reflow Defect Reduction Effects in an SMT PCBA lines using Advanced Process Control

CONCLUSION

The electronics industry is facing a chronic skilled employee shortage. Job hopping and employee misalignment lead to high turnover, which further compounds the challenge. The leading industry organizations like IPC and SMTA are tackling the issue head-on with education programs and training initiatives, it is not enough. While the lack of skilled labor remains a challenge, Industry 4.0 and its associated benefits will help advance the industry. Equipment suppliers need to work diligently to accelerate M2M communication standards to help the situation. Initiatives like the IPC Connected Factory Exchange (CFX) and IPC-Hermes-9852 underpin the efforts within the industry to develop standards and create a Smart Factory.

These M2M communication standards, guided in part by Industry 4.0, are quickly altering the manufacturing process by improving metrics like first pass yield and throughput by applying autonomous process adjustments. Far beyond an automatic line changeover, this two-way communication with suppliers will allow the equipment to automatically adjust production parameters to increase board quality and lower costs by eliminating rework and scrap. As part of this mission, advanced process control with interconnected PCBA equipment will revolutionize process optimization and lay the foundation for the smart factory.

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