

Improved Efficiency Using Root Cause Failure Analysis

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Abstract

A PCB fails final test. Why? Was it the solder paste? The screen printer? The PCB assembly machine? The reflow oven or none of the above?

Unplanned downtime is a costly fact of life. In order to minimize the length of downtime it is necessary to have clear details on exactly what the source of the problem is, not just the symptoms. This information allows operators and maintenance personnel to go directly to take corrective steps more quickly and minimize downtime.

There are many machines and materials involved in the assembly of a complete PCB; screen printers, conveyors, pick and place systems, reflow ovens, Automated Optical Inspection (AOI), solder paste and components. Some of this equipment has the ability to check its results before, during or immediately after it has completed its task.

Until now there have been few real-time tools for the pick and place systems. In many cases, high speed movement on these machines makes it extremely hard to “see” exactly what is happening. Components misplaced by the assembly system could be caused by many different factors. Without tools to provide a clear view of very high speed placement, it is difficult to the cause of misplacement.

How much easier would this task be if operators and maintenance personnel are armed with detailed information on the nozzles, feeders, and actual images of the picking and placing of parts on the PCB?

This paper will discuss tools available for the placement machine to assist in root cause failure analysis (RCFA).

Introduction

Root cause failure analysis (RCFA) is the process of determining the source of a problem. In many industries, especially those involving complex machinery, it is common to use root cause failure analysis when problems occur. Why is RCFA so important? Efficiency and accuracy. When it comes to the complicated and expensive machines used in the PCB assembly process, downtime equals increased costs, lost profits, missed deliveries, lost opportunities or all of these. Better efficiency is one of the few ways to compete with lower labor cost manufacturers. With so many machines’ specifications looking so similar on paper, features that allow end users to improve efficiency in the production process are gaining importance in the selection process. The use of RCFA tools can assist in improving utilization, efficiency and maximizing profitability.

Several systems to improve the production efficiency of the placement machine have been introduced over the years. There are tools designed for the direct improvement of utilization and indirect improvement. Twenty years ago, few pick and place machines had quick change feeder trolleys. Why were they invented? To improve efficiency so the operator could change from one product to another faster. Intelligent feeders help the operator setup feeder trolleys offline and reduce the need for “buddy system” reviews of the feeder setup. Splicing feeders and tray changers that can have parts replenished without stopping the machine also were created. All of these systems were designed to directly improve machine utilization and are now common in the industry. Other tools such as self-calibrations are indirect efficiency improvement tools. They reduce the chances of an error or the time needed for maintenance, but do not directly impact utilization. One thing these systems all have in common is that they are designed to improve the efficiency of the *known* or *expected* downtime.

RCFA deals more with the *unplanned* downtime due to unknown or unexpected causes. A failure has occurred. The goal is to find the problem as quickly as possible and get the machine back into production. These tools can be separated into two categories also: after the fact and real time. After-the-fact tools include self-diagnostics that can be run after a problem occurs to see if a system is performing properly. Several tools exist to monitor machine performance in real-time such as tombstone detection and nozzle inspection, but these do not provide any insight into the *cause* of a problem. They only detect that there *is* a problem. Few systems exist to monitor the machine’s performance in real-time *and* provide useful

information as to the cause of a problem. Unplanned downtime could be dramatically reduced with better root cause failure analysis tools.

The key to improving efficiency when unplanned downtime occurs is root cause failure analysis; determining the exact source of the problem. Knowing exactly what is causing a problem will allow maintenance personnel to focus their efforts on a clear target rather than just following a checklist of possible problems. Many people have had the unpleasant, inefficient experience of talking to phone tech support personnel who run down a checklist of “possible causes” for different problems. But the reason the checklist is needed is that there is no data available about the root cause of the problem. Without knowing the root cause of any problem, maintenance personnel are essentially working with blindfolds on. New systems designed specifically to give better insight into problems can significantly reduce the time technicians need to spend diagnosing problems, and improve equipment utilization.

Defect Prevention in Assembly Lines

One of the most common errors from the placement machine is missing or incorrectly placed components. There are two main types of defect prevention systems found in typical assembly lines: systems built into a machine to check itself and stand alone equipment whose sole function is to check for defects. An example of a system within a machine to check itself would be post-print inspection on a screen printer. This system checks for defects after the printer has completed its task of applying solder paste to the PWB. This “post print inspection” cannot say *why* there isn’t enough solder paste in a certain location, only that there isn’t. Wouldn’t it be much more useful to know why there isn’t enough solder paste on the board? Clogged apertures, dry paste, squeegee pressure and many more problems could be the cause. Similarly, typical placement machines have several features to prevent defects, but most cannot provide insight as to *why* the defect occurred in the first place. Vacuum sensors are commonly used to detect when a component falls off the nozzle or isn’t released on the board. Lasers can check for tombstoning, dropped components, and even incorrect or damaged nozzles. But there are times within the production cycle when these sensors cannot provide useful root cause information. If the vacuum sensor reports an error, *why* did it occur? All the technician knows is that the required vacuum level was not achieved. Was the component not aligned with the pick position? Is there a problem with the vacuum system? Is the nozzle damaged? Is the feeder feeding correctly? Was the component even present at the pick position? All of these possibilities have to be considered, but each takes time to evaluate.

An example of a machine that is used solely to check for defects would be an AOI or SPI machine. These systems all check for problems that were caused by another machine in the line. They detect missing, incorrect or misplaced components, satisfactory solder joints, etc. AOI machines provide very useful evaluation of the final PCB, but also have limitations. Like the systems described above, they cannot tell *why* a component is missing or incorrectly placed. If an image shows a component placed at the wrong angle, why did this happen? Was the feeder loaded incorrectly? Was the production program written correctly? Was the component properly oriented in the tape, tube or tray? The images from AOI are only of the results, not the process. In addition, typically there is only one AOI machine for the entire line so when a component is missing, the operator doesn’t even know which placement machine should have placed the component. The key to improving the efficiency of troubleshooting a missing or misplaced part is having actual images to see what happened *during* the pick and place process.

Reasons for Failures

Focusing specifically on the placement machine, there are many reasons why a component may not be placed correctly on the PCB:

Damaged nozzle,

Feeder malfunction,

Component incorrectly packaged (wrong orientation in feeder),

Incorrect pick position teaching,

Incorrect component data,

Improper board support, or

Components sticking to the nozzle

Due to the high speed of today's placement systems, it is extremely difficult for an operator to know which of the above is actually causing the problems. Therefore they are required to follow a pre-defined list of troubleshooting steps to eliminate one possible cause after another. Throughout the process, they are completely unaware of the root cause. In the end, if they haven't found the problem, they just guess or use experience. This process is clearly imprecise and inefficient. Throughout the troubleshooting period, the machine is down and the line is stopped.

The time required to precisely locate the source of the problem could be dramatically reduced through better RCFA tools. One example is the use of simple pictures taken during the pick and placement process. Images of the various stages of the pick and place process instantly show the technician what happened and where the problem came from. This is made possible using tiny embedded high speed micro-cameras along with sophisticated image analysis. Along with the visual analysis by the technician, the software can provide automatic alerts when an error occurs and perform some RCFA on its own.

By capturing a series of images during the pick and placement operations, the technician can quickly see the following. While some of the questions below are the results and not the cause, they still help reduce the time the technician needs to diagnose the root cause of the problem.

Was the nozzle damaged when it picked the part?

Was the component present in the tape and uncovered by cover tape

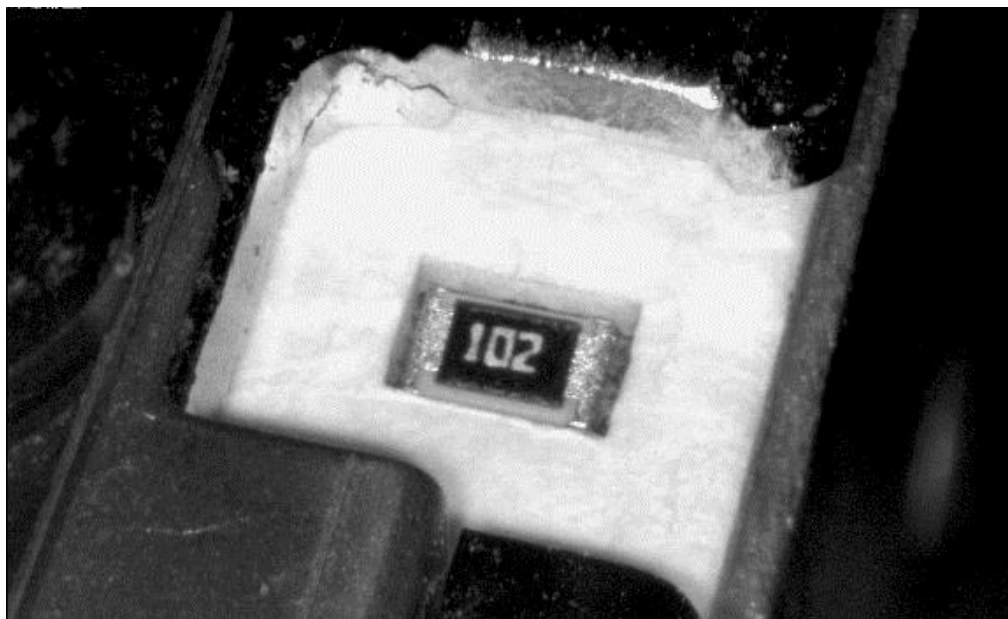


Figure 1 - Component present in tape and uncovered by cover tape

Was the component in the correct/expected orientation prior to pick?

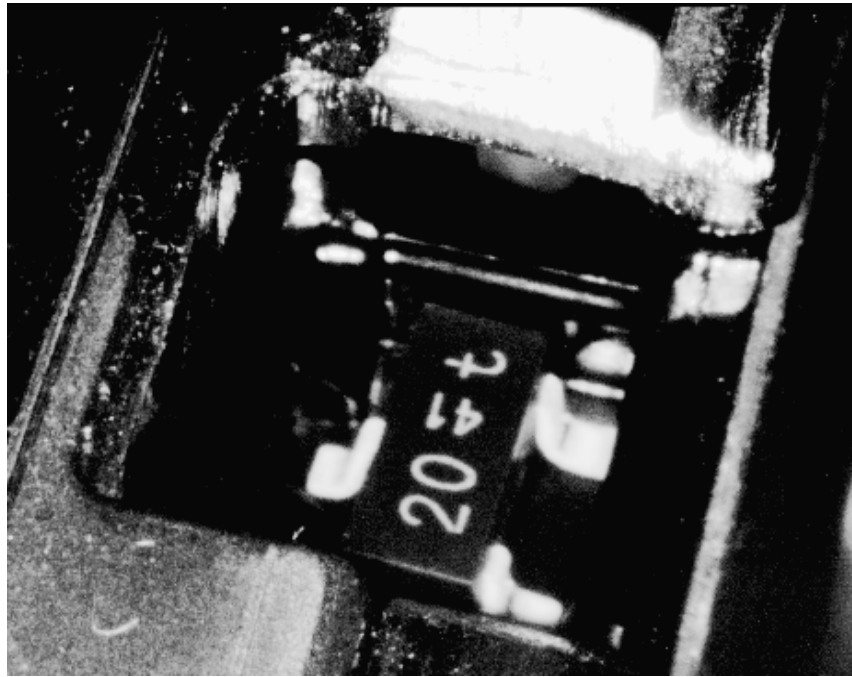


Figure 2 - Image of component in tape allows technician to verify component presentation angle

Was the cover tape properly peeled back?

Did the nozzle lift the part out of the tape successfully?

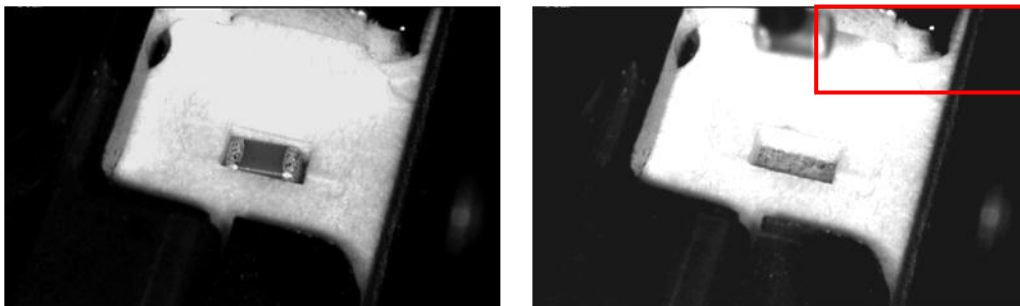


Figure 3 - Images before and after picking. Note that position on nozzle can be seen in the after image to confirm acceptable pick location

Does the position of the part on the nozzle indicate the pick position is good?

Was the part present and properly oriented on the nozzle just prior to placement?

Was sufficient solder paste present on the pads?

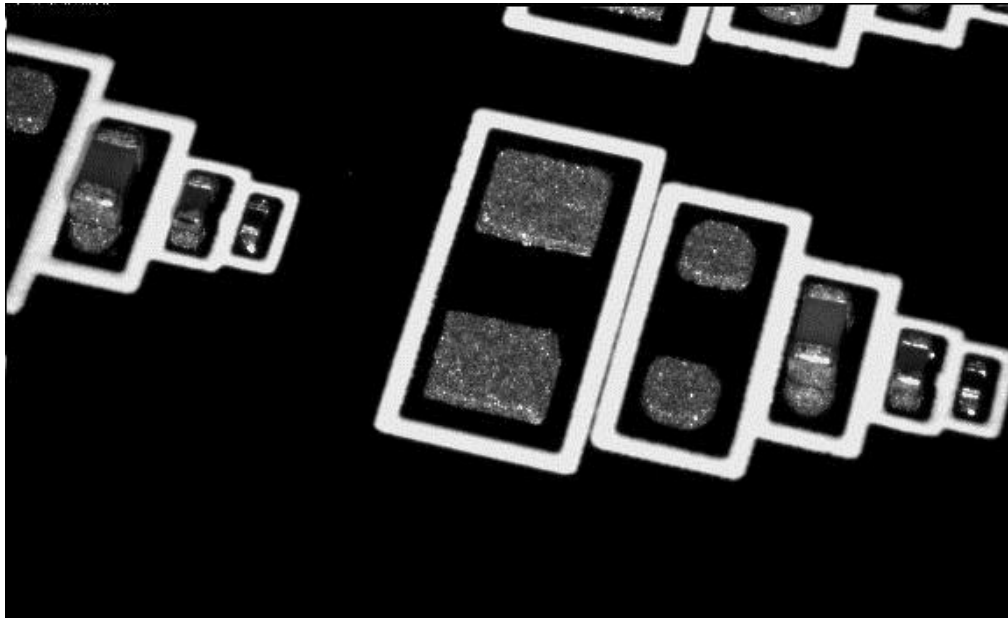


Figure 4 - Image showing solder paste prior to component placement

Did the nozzle come down enough/too much when placing the part?

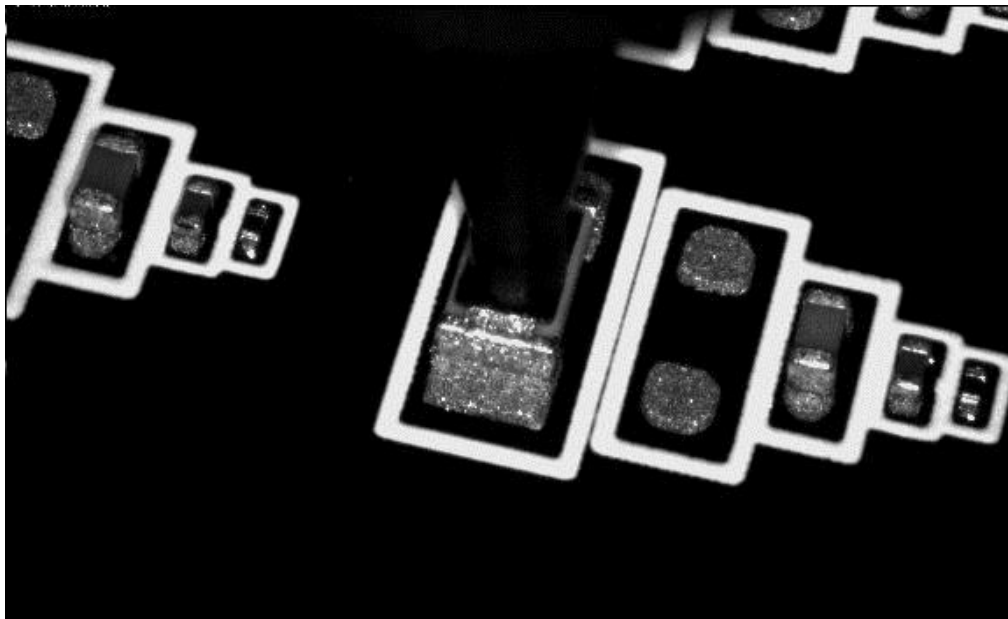


Figure 5 - Nozzle placing component on PCB

Did the component release properly when the nozzle moved up after placement?

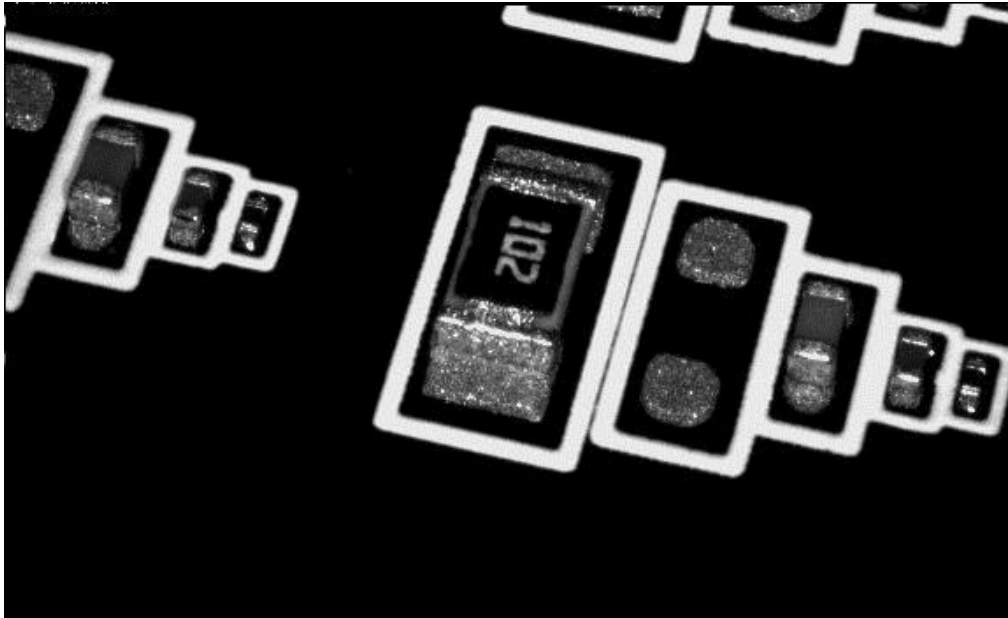


Figure 6 - Component placed on PCB correctly

In the time it takes to view a few pictures, the technician can accurately determine all of these points. The adage of a picture being worth a thousand words, or maybe a thousand seconds, is appropriate for this situation. Checking just a single item without the pictures would take as long as checking for all of these points with pictures.

Compare the process of isolating the problem for a missing component using improved RCFA tools versus manually in Table 1:

Table 1

Item	Using improved RCFA tools	Task with manual RCFA
Was the nozzle damaged when it picked the part?	Look at nozzle image for damage. Software identifies the nozzle used for the missing component automatically.	Look up which nozzle was used for the missing component Remove the nozzle from the machine and examine it
Was the component present in the tape?	Look at tape pocket	Almost impossible to determine during high-speed assembly. In some cases slow the machine down to watch.
Was the component in the correct/expected orientation prior to pick?	Look at orientation of component in tape in “before” pick image	Almost impossible to determine during high-speed assembly. In some cases slow the machine down to watch.
Was the cover tape properly peeled back?	Look at “before” pick image	Stop production and use teach camera to check pick position. If cover tape is present, it is likely the cause.
Did the nozzle lift the part out of the tape successfully?	Look at the before/after pick images. Software automatically detects when the part isn’t picked.	Use vacuum sensing and/or laser presence check.
Does the position of the part on the nozzle indicate the pick position is good?	Look at “after” pick image	Almost impossible to see on high speed machine

Was the part present and properly oriented on the nozzle just prior to placement?	Look at “before placement” image	Almost impossible to see on high speed machine
Was sufficient solder paste present on the pads?	Look at pads in “before placement” image	Use SPI machine or function on screen printer OR Check after using AOI or visual inspection
Did the nozzle come down enough/too much when placing the part?	Look at “during placement” image	Almost impossible to see on high speed machine
Did the component release properly when the nozzle moved up after placement?	Look at “after placement” image	Use vacuum and/or laser release check sensor

Technology

While RCFA is not necessarily a new concept, recent technology developments have made it much more affordable and effective. The use of digital cameras has exploded in recent years. Cell phones drove the wide-spread miniaturization of cameras to the point where it has become practical to embed them into very small spaces, including the placement head of a pick and place machine. Cameras are now widely used in situations where it isn't practical or possible for a human to watch something 100% of the time. Reports show that London has 10,000 security cameras throughout the city. Why? To help law enforcement find information that is simply not available using people on the street because it isn't practical or economical. This is why cameras are well suited. The days when a placement machine moved so slowly that a human could observe the process are long past. The movement of the typical pick and place machine is faster than any other machine in the production line, making it difficult to monitor the activity of the machine. The machine also moves over a large physical space making it impossible for a single camera to accurately see what actions are happening. Small, high speed cameras are needed and they have to be able to move with the placement head as parts are picked in one location and placed in another. Watching by eye would be extremely difficult due to the speed and design of most placement machines. A component may appear to bounce after placing, but did it happen because the part temporarily stuck to the nozzle? Or was there too much placement force and the component? The still images can show what is otherwise impossible to see.

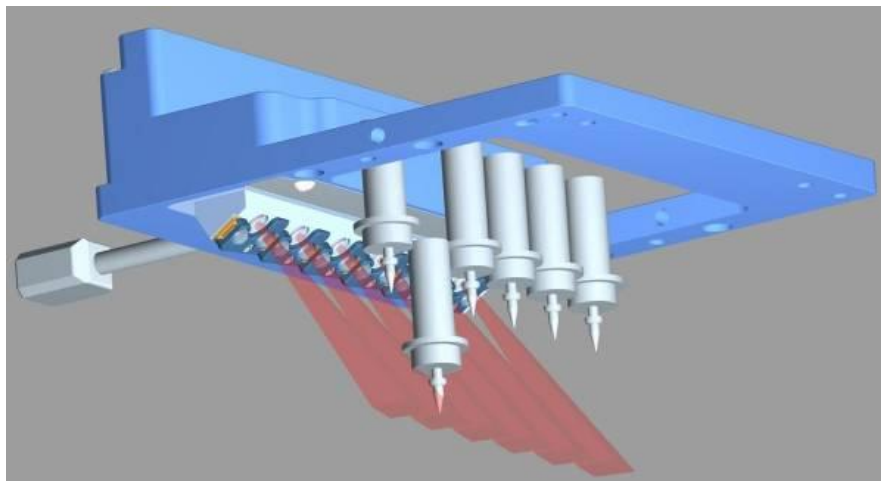


Figure 7 - Example of micro-cameras embedded into placement head

The size, field of view, and resolution are all critical technologies for the camera. It must be small enough to fit inside the placement head without adding significant weight which would impact the throughput or design of the placement head. The field of view must be wide enough to capture the component in the feeder and the component in the up position after being picked. At the same time, the resolution must be high enough to allow the image processing software to accurately detect even subtle differences required for accurate analysis.

While the images are the key to locating the root cause, the software is also critical in warning the operator of an error and providing analysis that may not be possible by eye. Powerful software analyzes each image to detect when the component is not picked, is not placed, and even calculates the amount of board deflection during placement. Through communication with the placement machine, it can also show trends such as identifying the feeders, nozzles, or placement sites experiencing the most problems. Although it is common for a placement machine to identify feeder experiencing higher than normal errors, nozzle and placement errors are not as easy for typical placement systems to identify. The analysis of the images is what makes these functions possible or more accurate. This information can also help the operator determine the root cause of problems more quickly.

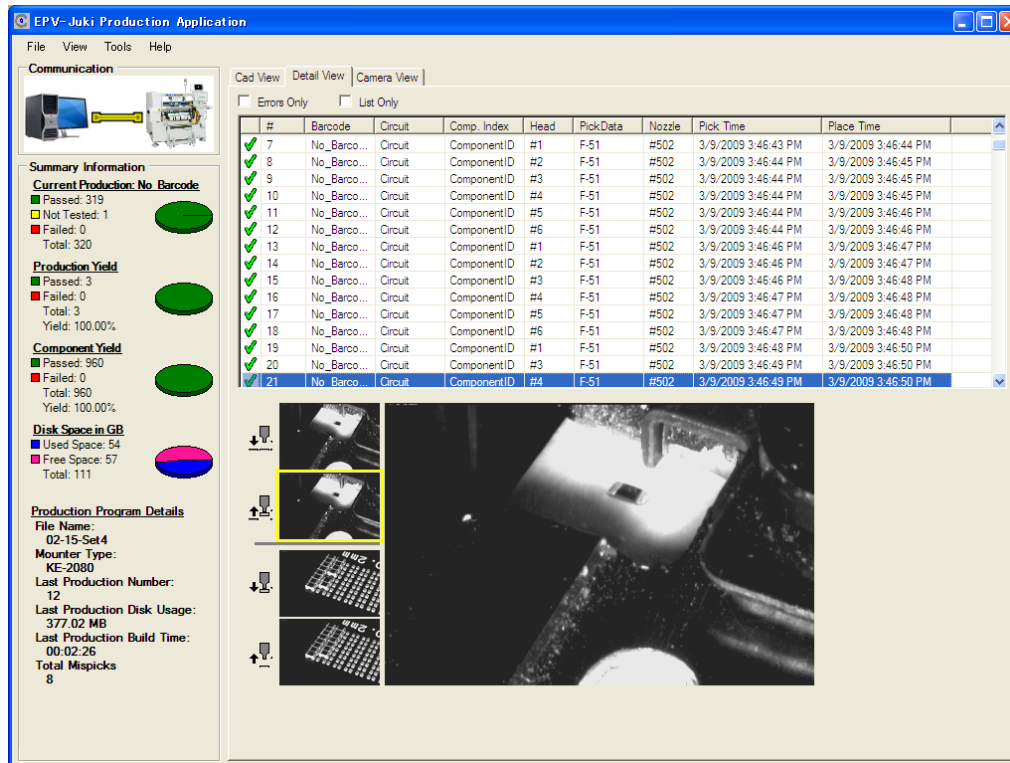


Figure 8 - Analysis software showing results of all placements on a PCB along with statistical data

Finally, the software must be accurately synchronized with the movement of the placement machine. Images must be captured in very high speed at very specific points in time; the exact moment the nozzle goes down to pick the part, the moment the head goes down to place the part, etc. This requires synchronization and very high speed communication between the camera software and placement hardware.

Conclusion

New tools are invented constantly to “make life easier”. In a production environment, this often translates to “more efficient”. A compound miter saw makes a carpenter more efficient in his work. E-mail makes communications more efficient. Root cause failure analysis is a tool that can be used in many situations and industries to improve efficiency of troubleshooting. Technicians can quickly find the source of problems so they can be fixed fast and fixed right the first time. Airplane black boxes and cockpit recorders allow investigators to determine what happened even when there is no one to tell them anything. Cars now have some similar functions. Now imagine if every airplane or car had a camera and showing the interior for crash analysis. It would probably be even more effective than a simple voice recording. Similarly useful tools are now available for the high speed SMT assembly line with the same benefits; clear and quick understanding of the root cause of the problem, which leads to improved efficiency in fixing the problem. While some sensors and self-diagnostic tools exist, they are generally do not focus on finding the root cause. Root cause failure analysis tools such as embedded

micro cameras to show the exact details of the pick and place process along with powerful analysis software can save a huge amount of time versus methods commonly used today and dramatically increase efficiency and equipment utilization.



Improving Efficiency with Root Cause Failure Analysis

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What is Root Cause Failure Analysis?

- Method of problem solving
- Focus efforts on core problem, not symptoms
- RCFA is *reactive*, BUT tools are *proactive*



Benefits of Embedded RCFA Tools

- Finds cause, not symptom
- Faster diagnosis of problems
- More accurate diagnosis of problems
- Zero additional programming time
- Reduced down time
- Increased efficiency and equipment utilization



Symptom vs. Cause

Symptom	Cause
Insufficient solder paste	Clogged aperture
Missing placement	Insufficient solder paste
Incorrect placement orientation	Incorrect orientation in feeder
Cold solder joints	Insufficient “soak” time

Stand-Alone Quality Tools

- Most tools do not identify the root cause
- Automated Optical Inspection (AOI)
 - Checks for component presence, value, orientation
 - Checks solder joints
 - Results only, no “cause”
 - Significant programming time
- SPI
 - Checks for sufficient solder
 - Results only, no “cause”



Embedded Quality Tools

- Vacuum sensing – generally do not know when or where error occurred
- Presence/absence check (camera or laser) – only useful for single function, not entire process
- Nozzle and feeder error statistics – do not give cause, only results



Possible Causes for Errors by Pick and Place

- Damaged nozzle
- Feeder malfunction
- Component incorrectly packaged (wrong orientation in feeder)
- Incorrect pick position teaching
- Incorrect component data
- Improper board support
- Components sticking to the nozzle

Problem: Missing Placement

With existing pick and place tools

- Problem discovered by AOI or manual inspection *after* reflow – rework required
- Check for sufficient solder
- Check feeder/tape
- Check pick position
- Check nozzle condition
- Check board support
- Total estimated time: 2-5 minutes

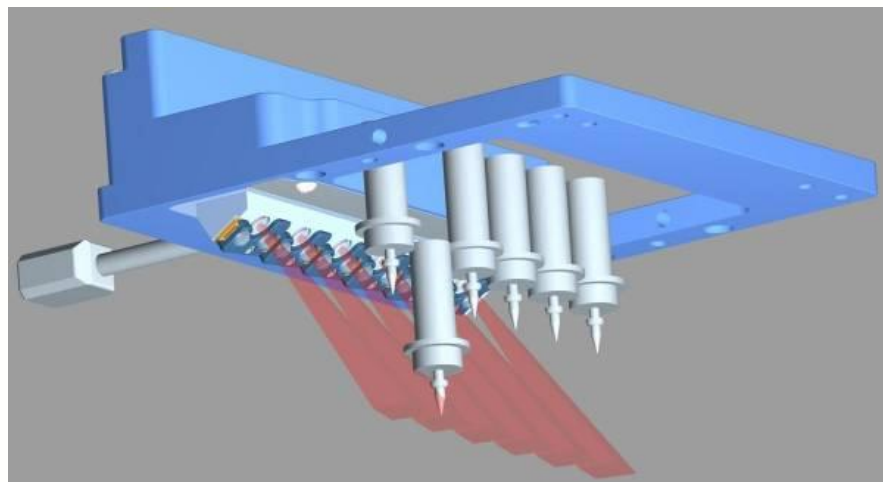
With new pick and place tools

- Problem discovered automatically *before* reflow – no rework required
- Examine placement images for:
 - Component presence in tape
 - Pick position
 - Sticky/broken nozzle
 - Solder paste
- Total estimated time: 15 seconds



Embedded Micro Cameras

- Nozzle tip and placement site both within field of view
- Cameras cover all nozzles
- Zero additional programming
- “See” what normally cannot be seen



Micro Cameras

- Latest technology makes embedding in the head possible
- Images
 - Part in tape
 - Tape after pick
 - Site before placement
 - Site during placement
 - Site after placement
- Automatic detection and alert of missing placement
- Automatic board deflection calculation
- Nozzle and feeder statistics
- “Replay” assembly of any PWB step-by-step



Sample Images of Pick Sequence

- Quickly confirm:
 - Part is in tape
 - Tape isn't covered
 - Nozzle picked part



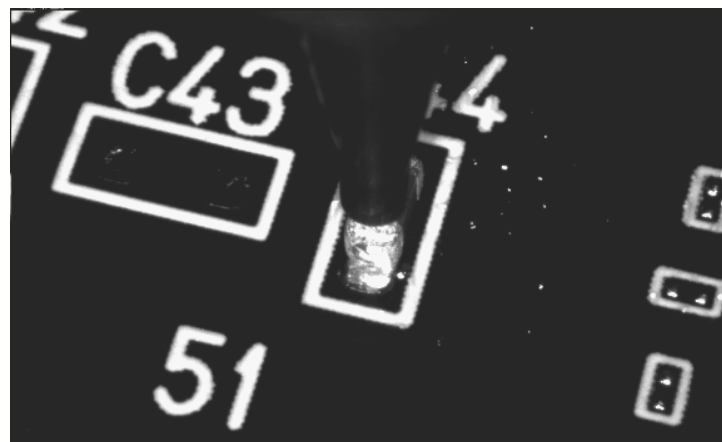
Before Pick



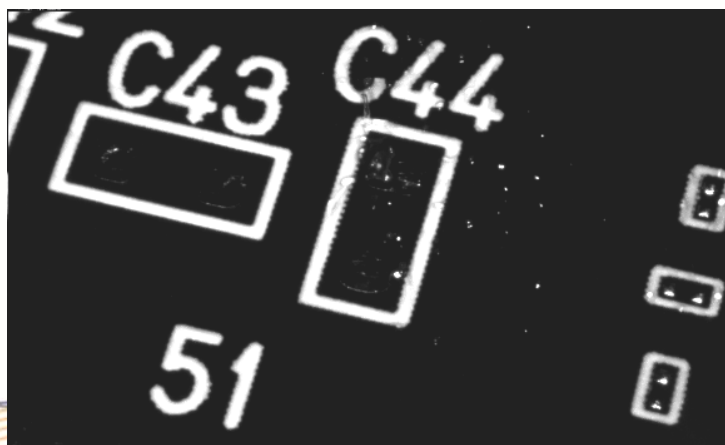
After Pick

Sample Images of Place Sequence

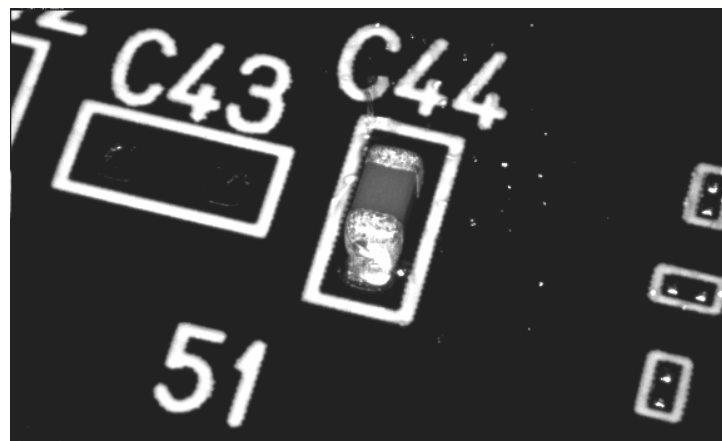
- Quickly confirm:
 - Solder paste on pads
 - No FOD
 - Nozzle condition
 - Part placed
 - Automatic board deflection calculation



During Placement



Before Placement



After Placement

Highly Detailed Movies for Difficult Problems

- Up to 16 images for each pick/place sequence

- Higher detail nearly shows “movement”



Summary

- RCFA reduces troubleshooting time
- RCFA reduces downtime
- RCFA improves chances of “fixing it right the first time”
- Embedded RCFA tools provide the best opportunity to improve efficiency

