HOW X-RAY TECHNOLOGY IS IMPROVING THE ELECTRONICS ASSEMBLY PROCESS

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ABSTRACT

It was 1895 when Wilhelm Roentgen discovered a mysterious light that allowed him to see through things – and called it x-rays. Since then, x-rays have been adopted in a wide range of applications in the electronics assembly process. Instead of taking a "deep-dive" in one aspect of x-ray inspection, in this paper we'll cover a broad range of applications:

- Electronic component inspection.
- Real-time defect verification.
- Counterfeit detection.
- Component counting and material management.
- Reverse engineering.
- 2D, 2.5D, and 3D x-ray inspection.
- Voids, bridging, and head-in-pillow failures in bottom terminated components
- Design for manufacturing (DFM) and design for x-ray inspection (DFXI).
- Artificial Intelligence

We will also discuss how artificial intelligence (AI) is changing the way we think about x-ray inspection. Things we would never dream of doing just a few years ago are now reality by combining AI and x-ray inspection. Moreover, we will show you a series of real-life cases on how our team of AI scientists is using AI to solve the most challenging applications in x-ray inspection. And beyond x-ray inspection, we'll examine how AI is forever changing the way in which we manufacture and inspect anything.

Key words: X-ray, Radiography, NDT, Counterfeit Detection, Reverse Engineering, DFM, DFXI, Artificial Intelligence

INTRODUCTION

X-ray inspection of electronic components is now standard practice for any company working in the electronics industry. The most common uses include process verification, quality assurance and failure analysis. X-ray inspection is versatile enough that it allows the user to perform all of these functions with the same tool. The following information describes many challenges facing the electronics industry and how x-rays can provide the solution.

ELECTRONIC COMPONENT INSPECTION

Principles of X-ray Inspection

Destructive testing works well in many applications, but it takes time, labor, and complicated tools. Electronic components are often so small, that any destructive method of inspection will damage what needs to be inspected. Non-Destructive Testing (NDT) is any analysis performed on a component without damaging it. X-rays are ideal for anyone working in the NDT field. They allow users to visually inspect products that are hidden, encased, or otherwise inaccessible to other means of inspection.

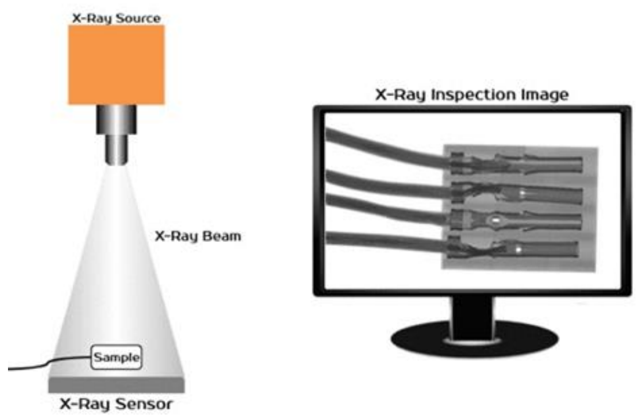

Figure 1. Priciples of X-ray Inspection

REAL-TIME DEFECT VERIFICATION

There are several steps required to produce a completed printed circuit board (PCB). Many various species of defects can be incurred in any one of these steps. For example, during the solder past application process defects such as excess solder, solder bridges, or insufficient solder can occur. During the component placement, there is misalignment, polarity and missing components defects. During the reflow process we find such issues as voiding, bridging, solder balls, excess solder, and insufficient solder.

Applying the use of x-ray inspection, we can catch these issues to verify the correct process is being used. Often with new builds the process must be tuned with adjustments to heating profiles, solder amounts, paste coverage, etc.. Performing an x-ray analysis to examine the many possible defects such as voiding, bridges, or opens will aid the process engineer in developing the correct process. This is called process verification and enables the engineer responsible to perform a quick analysis in order to make the necessary changes.

After the correct process is in place PCB's are in mass production, x-rays inspections can then be used to continually analyze the product and provide statistical process control through quality metrics. This real time data will show any shifts in quality or new defect identification. Using x-rays allows for trends to be observed and acted upon in the most efficient manner.

COUNTERFEIT DETECTION

With the surplus of electronics dumped into the market, there are huge amounts of scrap, often containing obsolete parts. Component harvesting is therefore a large job market in lower wage economies. Pressure to reduce cost for an OEM has lead to more and more internet purchases for critical components. Expensive components can therefore be extremely valuable and bring with them the threat of counterfeits. Radiography (or x-ray inspection) is a ubiquitous technique to all recent and upcoming counterfeit detection standards, including IDEA 1010B, CCAP 101, AS5553, AS6081, and AS6171.

One specific technique to identify counterfeit components using x-rays is to utilize an exemplar sample x-ray image to compare with the suspect lot. The comparison process, whether manual or automated using computer imaging techniques, will easily identify components that do not conform to a known good supply. Even if a known good x-ray image is not available, it can be very beneficial to check for lot conformity. Any variances observed within the same lot, should be flagged as suspect.

Some common trends that are easily identified using x-ray imaging are: inconsistent die size, missing dies, inconsistent lead frame, broken/missing wire bonds, and inconsistent die attach voiding. A non-conforming sample can be seen Figure 2. In this case, the component was mixed in with the lot of good samples, which stresses the importance of performing 100% inspection.

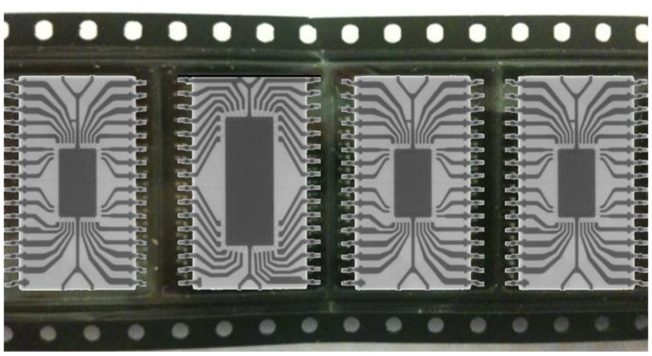

Figure 2. Example of Counterfeit Component

COMPONENT COUNTING AND MATERIAL MANAGEMENT

Inventory is a crucial aspect of any manufacturing operation. Too much is wasted money sitting on the shelves, too little can lead to costly stoppages and down time. This places increasing pressure on an organization to keep the optimal amount in stock and the ability to track quantities in the most efficient way possible.

X-ray imaging can play a key role in component counting. As most components are stored on reels containing thousands of parts, traditional part counting methods is a time intensive process. The reels must be placed on a counter, spooled, run onto an empty reel, and then re-spooled onto the original wheel. This method fails to count any missing components or other anomalies that may exist on a reel. By using x-rays, an entire reel can be imaged without even removing it from its packing, further reducing the risk for loss. Individual components can be counted, and identified in seconds. The x-ray system used can then transfer that data to the manufacturer's inventory management system to help aid in real time data analytics.

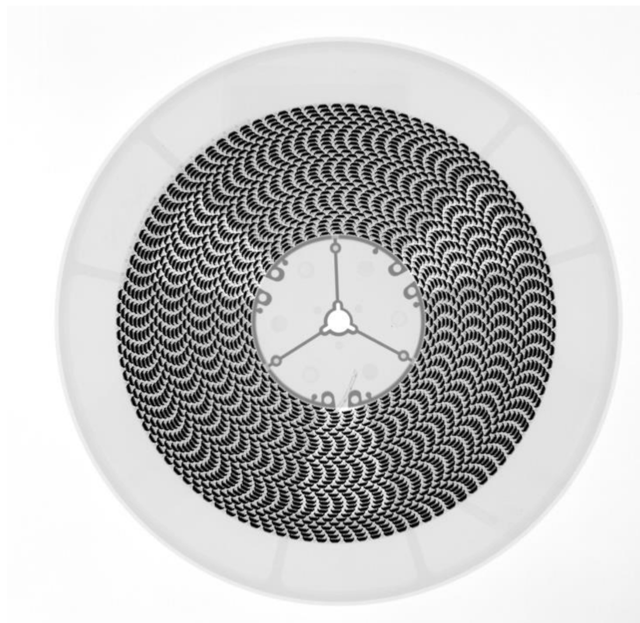

Figure 3. X-ray Image of Components on aReel

REVERSE ENGINEERING

As product development budgets shrink and part obsolescence becomes common place, many organizations are finding the benefit of disassembling older products to determine how it works and if the same thing can be made again, cheaper and/or better. This process is called reverse engineering.

Reverse engineering a populated printed circuit board (PCB) can be time consuming and difficult as a tremendous amount of care must be taken not to damage the board. Components must be de-soldered and removed to establish a BOM, then to determine the correct schematics, layers of the board must be imaged, and then carefully ground away to expose the next layer. As this is a destructive process rendering the product useless, it is often regarded as unacceptable. X-rays allow for the imaging of components and separate board layers without damaging a single component. Using a combination of 2D and 3D x-ray imaging, this process may only take a matter of minutes rather than a matter of days.

2D, 2.5D, AND 3D X-RAY INSPECTION

The terms 2D and 3D are thrown around in sales channels to promote different x-ray features, often leading to competing organizations involved in a spec war, so what do they really mean. To explain the difference, the fundamental concept of x-ray images must be revisited as seen in Figure 1. When a sample is placed within the field of view of an x-ray sensor being illuminated by an x-ray source, the different density features of the sample will block photons, resulting in a shadow of the sample being broadcast to the x-ray sensor. This shadow is then displayed as a 2D x-ray image. It is a planar view of a sample part located within the path of the x-ray. No height or depth can be perceived using this technique.

To achieve 2.5D x-ray imaging, the orientation of the sample with respect to the x-ray path must be adjusted. This is simply a 2D image that provides a 3-dimensional perception. For example, if a sample is rotated on an axis perpendicular to the x-ray path within a live x-ray feed, the object is perceived as rotating 3D object. 2.5D imaging is powerful because it allows for oblique views providing information on the depth or height of an object. One major benefit of 2.5D imaging is that stacked components can be separated, revealing possible defects that are other-wise indistinguishable within simple 2D imaging.

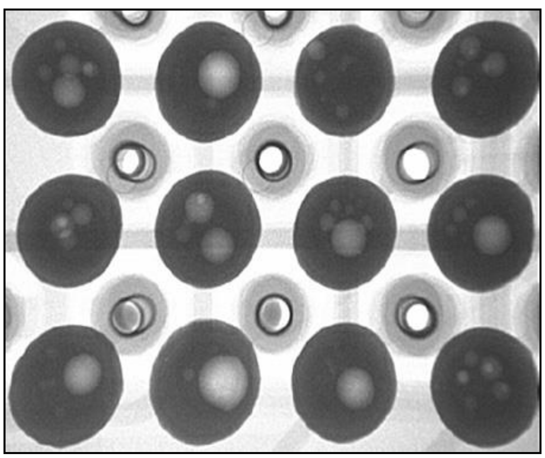

Figure 4. 2D X-ray Image

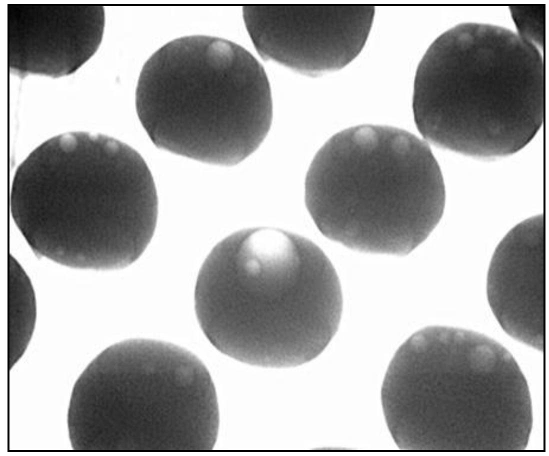

Figure 5. 2.5D X-ray Image

3D x-ray inspection is also known as Planar Computed Tomography (CT). A much more costly and time intensive process, the concept of CT refers to using a computer to build a volumetric recreation of the object being analyzed. Often used for reverse engineering, CT will allow the user to look inside a solid object, acquire cross sectional data in any orientation, and perform measurements and analysis on internal structures.

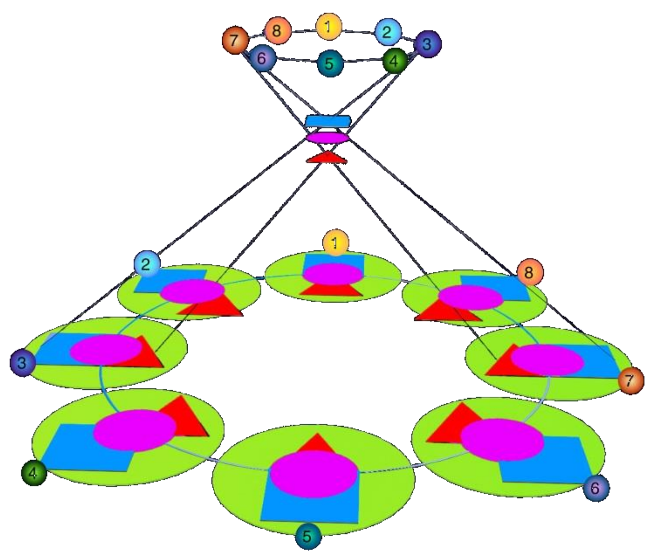

Figure 6. Principles of CT

To create a CT model, multiple x-ray images must be taken of a single object from different orientations. This can be accomplished by rotating the x-ray source and sensor about an object, or rotating an object within the x-ray path. These images are then analyzed and combined to create the 3D volume. The more images taken, the more accurate the model. Once the model is built, it can then be used to analyze the object in ways that traditional 2D and 2.5D would be very difficult. The ability to create cross sections of the object allows for the reverse engineering of multi layered PCBs. Measurements can also be taken of micro cracks in solder connections.

Figure 7. 3D Reconstructed Volume

VOIDS, BRIDGING, AND HEAD-IN-PILLOW FAILURES ON BOTTOM TERMINATED COMPONENTS

The increasing abundance of Bottom Terminated Components (BTC) has taken place because PCB real estate is precious. To make the most use of space, electronics are miniaturized and condensed to fit in the smallest surface area. BTCs such as ball grid arrays (BGA), quad-flat no-leads (QFN), and light emitting diodes (LED) make this miniaturization possible. Connections to the PCB are located on the bottom side of the component, and not to the sides. This makes inspection for the quality of the connection difficult.

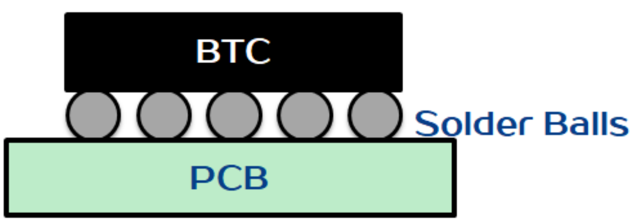

Figure 8. Diagram of Bottom Terminated Component

X-ray imaging techniques with high levels of magnification and multiple angle viewing allow for a full inspection of these otherwise hidden solder joints. Voiding in the solder joint is one of the simplest defects to analyze and measure. Many x-ray analysis software packages are equipped with a void analysis tool that will highlight the areas of less density (voids) and give the percentage of total area. This capability allows the end user to attach a quantitative measurement to the quality of the product.

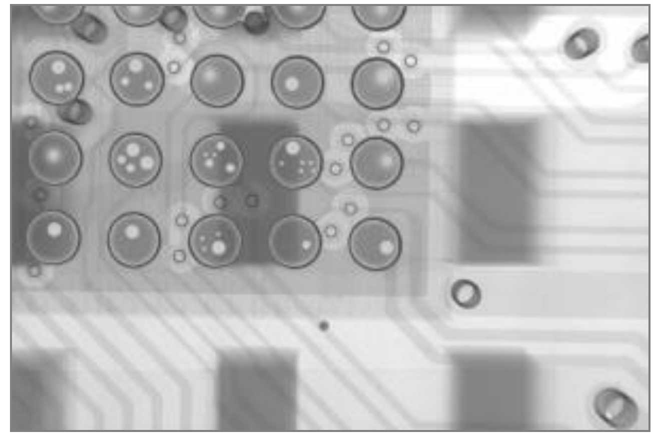

Figure 9. Voiding on BGA

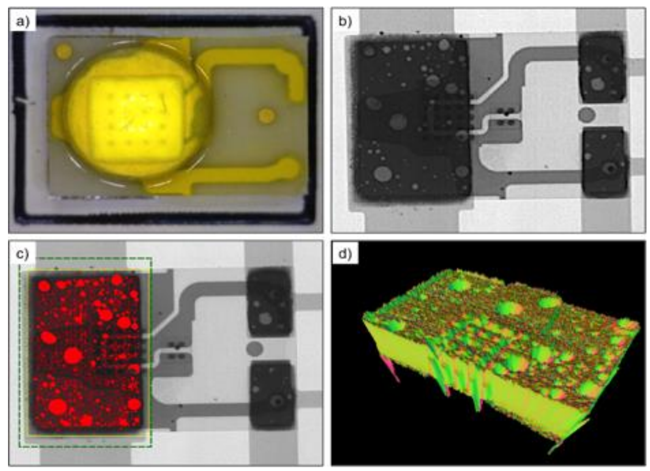

Figure 10. Voiding Analysis on LED

Other common defects found on BTCs are opens, solder bridges creating shorts, and irregular shapes indicating planarity issues.

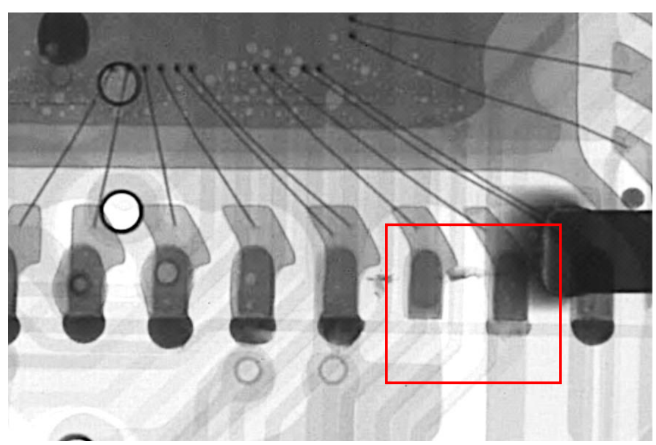

Figure 11. Open Connection on a QFN

Head-In-Pillow occurs when the solder ball on a BGA is not compressed onto the pad during the reflow process. This results in a condition where the solder ball may be making contact, but is not adhered to the pad. Electrical signals could be intermittent, and heat dissipation would be compromised. To detect head-in-pillow, a high magnification x-ray system with versatile sample manipulation is required. The sample must be moved into a unique orientation so that the profile of the ball can be imaged without being overlapped with any other component feature obstructing the view.

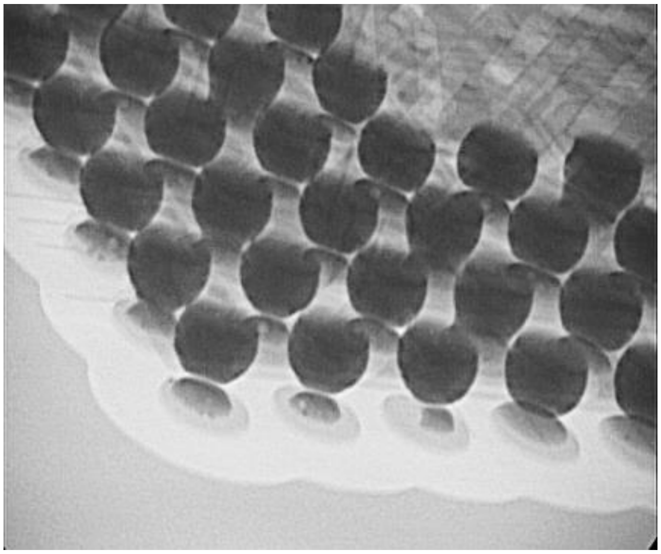

Figure 12. Head-In-Pillow Defect on BGA

DESIGN FOR MANUFACTURING (DFM) AND DESIGN FOR X-RAY INSPECTION (DFXI)

The requirement for BTCs to be inspected by x-ray imaging has given the PCB designers a new challenge. Not only must a new board layout save space and meet the requirements of the product, but it also must be designed so that the entire manufacturing process is as quick and efficient as possible. This includes quality inspections. In the previous section, the basic difference between 2D, 2.5D, and 3D were explained, one of which being time to inspect. If 2.5D and 3D x-ray inspections are required, these processes bring with them additional time, cost, and quality. Ideally products would only require 2D x-ray inspection for the highest throughput. However, with 2D x-ray inspection, any overlapping components within the field of view, will present additional issues with the inspection process.

The following images show examples of the difficulties encountered when inspecting PCBs that were not DFXI. Figure 13 shows a two sided PCB with a BGA on one side, and capacitors and other components located directly on the other side. The overlapping components require 2.5D or 3D inspection to differentiate features where defects may be occurring. Multiple sided boards, stackable components, and heat sinks all add to challenges for x-ray inspection. Taking these aspects into consideration will aid in the

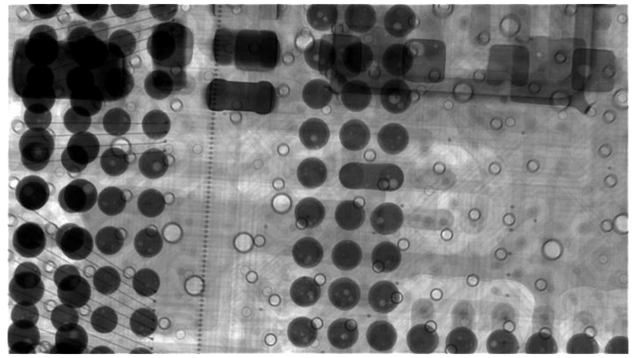

Figure 13. Capacitors Under a BGA

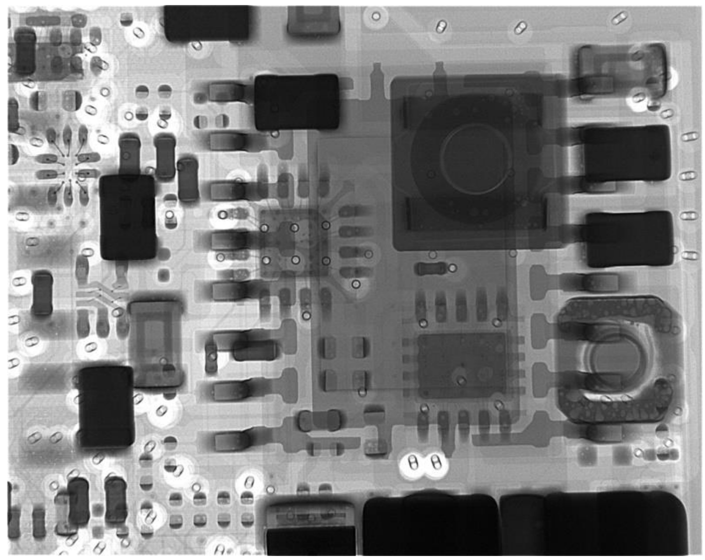

Figure 14. Complex Construction

ARTIFICIAL INTELLIGENCE

As new technology becomes available, it is vital to explore its possible effects and advancements to current processes. Recent developments in Artificial Intelligence (AI) are transforming the x-ray imaging industry. By applying techniques and algorithms used in machine learning, x-ray images can be analyzed in way never before possible.

AI works by a learning process. The algorithms are fed a number of variables and outcomes associated with these variables. With enough inputs, the system will learn the correlating factors and then be able to predict the outcomes based on the input. For example, to create a model that classifies x-ray images as “PASS” or “FAIL”, a number of pre-designated images must be uploaded into an image database. The software algorithms will then learn the features of the images that designate it “PASS” or “FAIL”. As larger quatities of images are fed into the learning database, the confidence in the resulting prediction will increase.

One of the issues with automated x-ray inspection (AXI) is that it is limited in the natural variability that may occur. Perhaps it can be trained to only inspect solder voiding on BGAs, but it will not flag debris in a product. With artificial intelligence, we can now account for known, and unknown failure modes. Also, reliability is often placed on the opertator of the machine to make a pass/fail judgment call. Operators are subject changing personel, level of experience, and the human condition. Machine learning can perform these functions at incredible rates, and is not subject to exhaustion.

The following images show a real case study performed on mobile phones. A large number of images classified as “good” and “bad” were fed into a database. This database of images was used to create a model that would analyze and classify new images. Figure 15 shows how this AI model can correctly locate and flag missing screws on the PCB inside the phone.

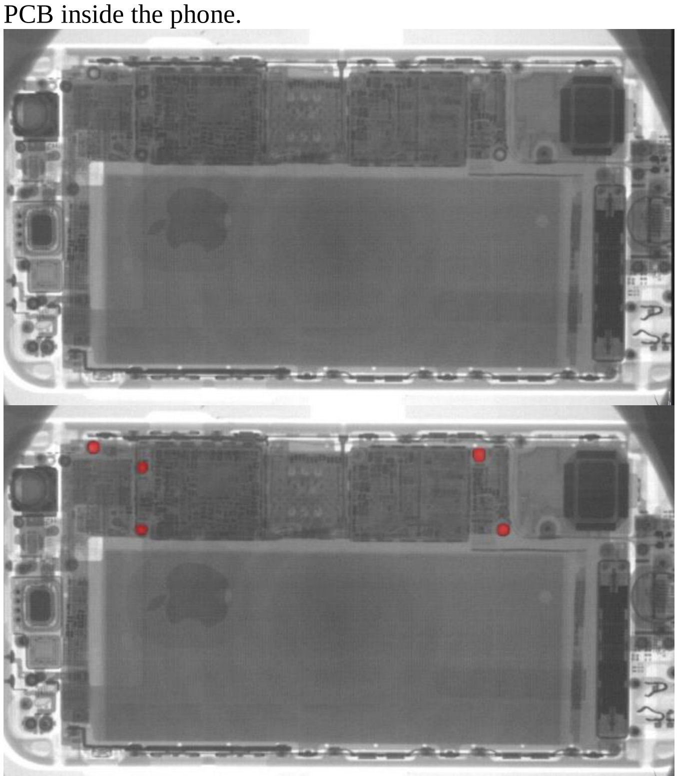

Figure 15. Using AI to locate missing components

The next study is a medical device packaging application. The device must be packed in such a way it can not be subjected to additional strain weakening the structure of the tubing inside. The AI model can pick up any kinks in the tubing and flag the location.

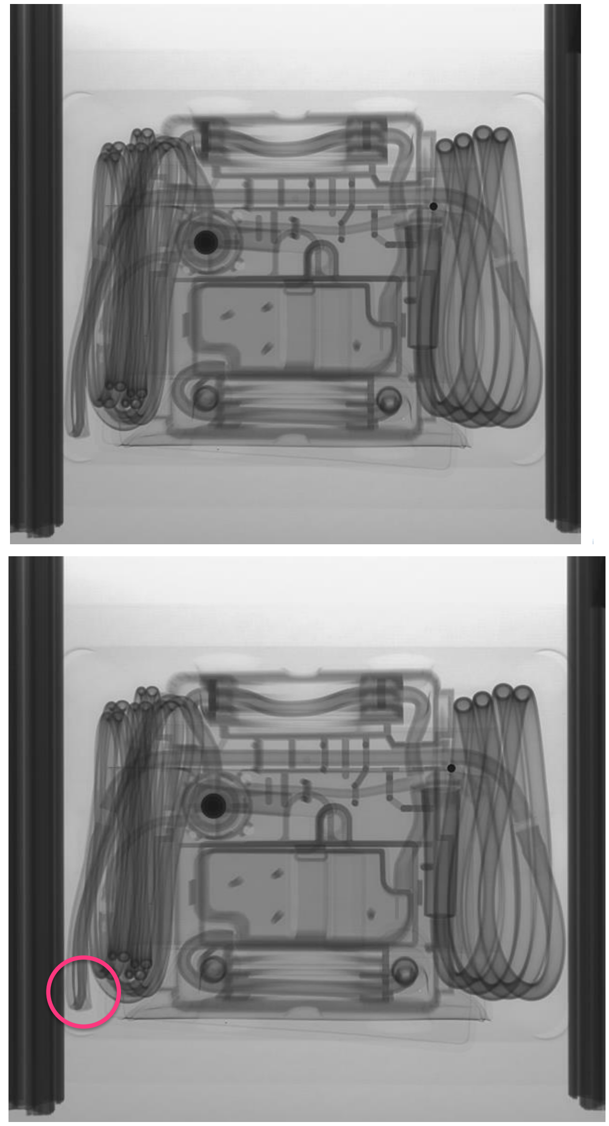

Figure 16. Using AI to identify product failures

Embracing AI is required for any technology company to stay relevant. As the entire electronics industry moves toward Industry 4.0, AI will increase process efficiency, improve communications, and decrease costs.

CONCLUSION

Electronics assembly has advanced in several ways over the last several decades. With miniaturization necessary to make major advancements, the processes and standards used in manufacturing must be tightly controlled. X-ray imaging allows the internal inspection of products without any damage to the part. As more complex products are created, the technology behind x-ray inspection is also developing to keep pace. The advancements in AI and other image processing techniques will continue to push electronics manufactures to design for, and assemble the highest quality product.