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Man Versus Machine

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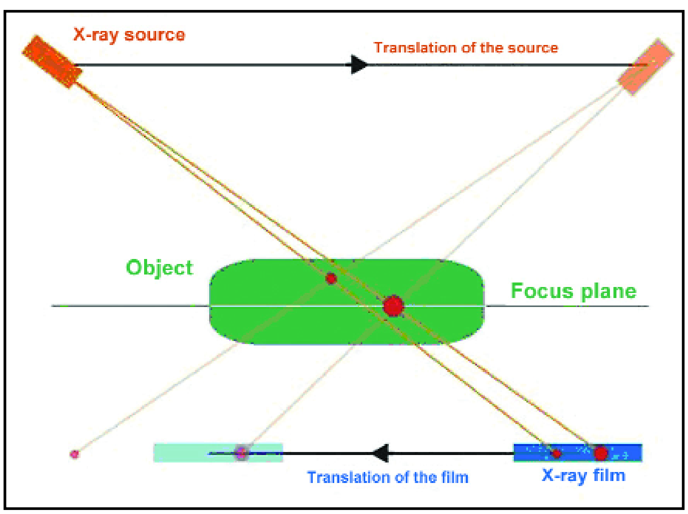
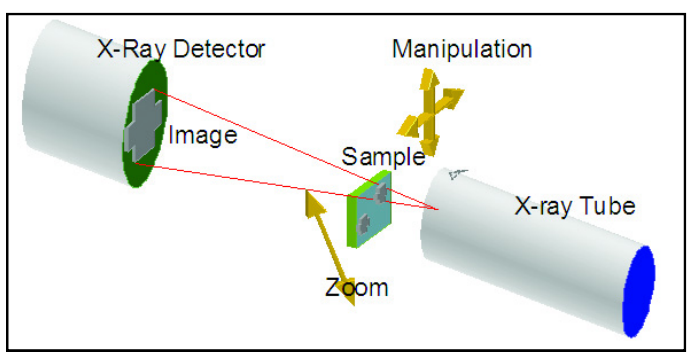
The question is still unanswered: In the man-vs-machine competition, who will be the ultimate winner? Machines and automation continue to advance, and to take over more functions once performed by men and women. A prime example is today's automobile, which includes many mechanical and electronic aids, from power-assisted steering and temperature control to parking assists. The near future will see vehicles equipped with autonomous control systems rather than having humans driving the car. Noted English theoretical physicist, Professor Stephen Hawking from the Centre for Theoretical Cosmology of Cambridge University, has foretold a future where machines and artificial intelligence (AI) replace men: "It (AI) will take off on its own and redesign itself at an ever-increasing rate. Humans are limited by slow biological evolution, so couldn't compete and would be superseded."



Basic principle of laminography. Features in the focus plane are always projected on the same position of the detector. Features outside this plane are blurred.

The debate over the roles of men versus machines in x-ray inspection systems has been waged for some time. This debate involves whether inspection of electronic components, such as printed circuit boards (PCBs), is better with or without human participation. In particular, debates have compared the merits of fully automated in-line two-dimensional (2D) and three-dimensional (3D) x-ray inspection systems versus off-line 2D inspection systems. The in-line inspection systems can proceed without human involvement while the off-line systems enlist a human decision-maker as part of the inspection process, once again fueling the debate of man versus machine.

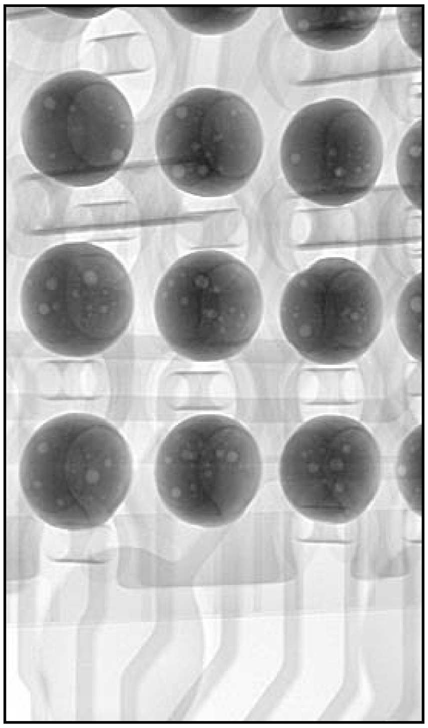
Some believe a human interface is not required for such electronic device and PCB inspections while others believe that the human interface assists in separating good electronic parts from bad ones. This debate is essentially about whether a fully automated inspection system can be consis-

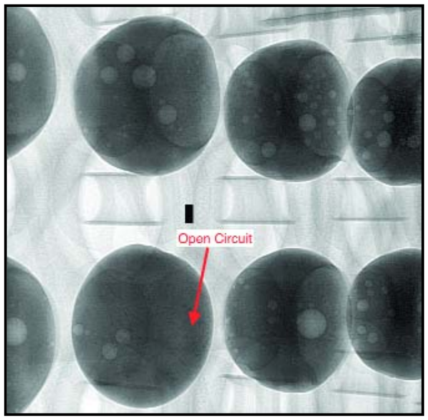


In general, for off-line 2D x-ray inspection systems, x-rays pass through a sample and are collected on a detector, with magnification possible.

tent and accurate enough to operate without allowing failures to pass or improperly failing parts that should be passed. In contrast, does an off-line inspection system, by including a human operator at the system's graphical user interface (GUI), provide greater flexibility and inspection performance and a greater number of accurate calls.

In-line computed laminography 2D and 3D systems have been used for many years to inspect PCBs while off-line 2D x-ray systems have also been used for some time for electronic inspection. As an example, Fein Focus x-ray inspection systems from YXLON International GmbH have been in use since the 1970s with the technology evolving steadily since that time. In general, x-ray inspection systems have been available in in-line and off-line configurations with significant differences between the two approaches. In-line systems provide high throughput with high repeatability and with no human intervention, although such systems require proper programming and fine tuning for optimum results. In addition, a production line can come to a full halt with the failure of an in-line x-ray inspection system. An off-line 2D x-ray inspection system requires an operator to make critical decisions in many cases. Such an off-line inspection system can zoom in and show various angled views to permit an operator to fully in inspect potential failures. The speed of a 2D off-line system is limited, however, and the system is not really fast enough to perform 100-percent inspection for any applications but small batch shops.





An off-line x-ray inspection system was used for an angled view (left image) and a close-up view (right image), where an open-circuit failure is visible to a human operator. Such a system offers the control and advantage of enabling investigation of potential failure sites.

Computed Laminography

Computed laminography was originally developed for medical imaging using x-ray technology. A patient is studied by moving an x-ray source across a patient's features of interest, and exposing the x-ray energy through the patient to an x-ray-sensitive film. A sharp image of the patient's features of interest is produced on the film within what is known as the focus plane. Other images of other features may also be produced during the scan, but they are blurred if they are outside of the focus plane. When this technique is applied to inspecting a PCB, only one layer of a PCB can be imaged per scan.

In today's digital laminography systems, the x-ray-sensitive film is replaced with a digital flat panel detector which acquires many images during the movement of the x-ray source. By means of computer processing, clear images within the focus plane and blurred images outside of the focus plane are superimposed to create a tomogram image similar to the classic film-based method.

However, by applying an appropriate computer-programmed shift before superimposing the various images, it is possible to obtain sharp images from many multiple layers of a PCB and to produce a full 3D image of object under inspection, even a multiple-layer PCB. This reconstruction technique is known as tomosynthesis.

Reconstruction Techniques

Tomosynthesis is a simple and fast reconstruction technique for computed laminography inspection systems, although it has drawbacks. Because it mimics classical blurring laminography methods, it suffers equally from the blurring artifacts of those approaches. Since the magnification of inspected features should not change during acquisition of those feature images, this imposes restrictions on the scan geometry. The image quality of computed laminography inspection systems can be improved by using a filtering technique similar to that used in filtered back-projection methods for computed tomography reconstruction, with limitations. Still, such filtering allows tomosynthesis to be effectively used for high-contrast electronic inspection, such as in x-ray inspection of PCBs.

Another reconstruction method for improving x-ray inspection image quality is through the use of algebraic reconstruction techniques (ART). The use of ART both improves image quality and allows a general relaxation of geometrical constraints during x-ray-inspection data acquisition. In contrast to x-ray-inspection systems with tomosynthesis, which simply superimposes projections, x-ray-inspection systems with ART model the entire physical process of x-ray projection by means of a system of linear equations. The object space being inspected is represented by small cubic-volume elements known as called voxels (a word formed from "volume" and "pixels"), each representing the x-ray attenuation of an object of interest at the corresponding position of the x-ray source. Every x-ray path from the source through the object onto the detector pixel is represented by an equation. The total attenuation of the x-ray beam passing through the object under inspection is known from the detector image. The trick of this method is to determine the individual attenuations of each voxel the ray passes. This reconstruction process is essentially a matrix inversion. True inversion methods would take extremely long times to compute a result because of the tremendous number of variables involved, on the order of 10^9 variables.

Faster reconstruction can be achieved by implementing the reconstruction algorithm on graphics processing units (GPUs). The massively parallel architecture of a GPU is uniquely suited to the application of simple but data-intensive computations like ray tracing and back-projection computations. By using GPUs, the reconstruction time is on the order of minutes, enabling the practical use of ART for electronic applications. When comparing laminography reconstructions by back-projection and by ART using the same projection data, the algebraic reconstruction provides greatly improved image quality when inspecting the solder connections of electronic components. In general, these in-line inspection systems are complex and require advanced software programming and a great deal of computer processing power, by contrast with 2D off-line inspection systems and approaches that are largely operator-driven that depend on human involvement.

Off-Line X-Ray Inspection

The operating principles of 2D x-ray inspection systems are similar to in-line 3D x-ray inspection systems, where a source fires an x-ray beam through a sample under inspection and some radiation is absorbed by the sample and some reaches a collector or detector. The higher the atomic number of the material under inspection, the greater the amount of absorption. As a result, when the radiation strength is converted into a grey-scale image, an operator can interpret the image on the inspection system's monitor. For more detailed inspection of a PCB or assembly, the sample, the x-ray source, and/or the x-ray detector can be rotated and the sample moved closer to the tube for higher magnification, allowing an operator to view a potential fault in greater detail than with in-line systems.

Off-line 2D x-ray inspection systems include a great deal of automation to assist an operator and void measurements, such as identifying missing bridges and balls. But off-line x-ray inspection systems focus a great deal on producing a high-quality image to allow a human operator to make the most-informed possible decision on a potential fault for a PCB or assembly being inspected. Many high-performance 2D x-ray inspection systems can display features below one micron, which is considerably greater resolution than provided by typical in-line x-ray inspection systems. Such 2D x-ray systems are also capable of high levels of magnification, in contrast to the fixed magnification levels of in-line x-ray inspection systems. The in-line x-ray inspection systems are generally designed with lower magnification in support of a larger field of view (FOV) for faster inspection times than off-line systems.

In summary, in-line x-ray inspection systems depend on skilled programmers to create effective software in support of systems that must determine whether an inspected PCB or assembly is acceptable or not, using advanced algorithms. These systems typically rely on analysis of measurements taken at reasonably low magnifications with information from only some slices through a PCB or assembly being inspected.

An off-line approach relies on the capability of an inspection system to display PCB faults and the ability of an operator to decide what is acceptable and what is a failure, using zoom views, angled views, measurement algorithms, filters, contrast stretch, and other techniques. All of the tools available allow the inspector to make an informed decision on whether the inspected portion of a PCB is passable or is a fault. An off-line inspection approach can provide more flexibility than an on-line approach in the search for PCB faults, especially for applications where a missed fault may result in dire consequences, such as when that part is for an automatic braking system (ABS) PCB in an automobile.

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