LEADING X-RAY TECHNOLOGIES FOR NDT

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ABSTRACT
Digital Radiography is becoming increasingly popular in the service of art. Although X-ray NDT is not new to the world of art and architecture research, the use of Digital Radiography is. Even so, it is becoming increasingly popular, as X-ray film manufacturers move on to a more digital world. Museums, antique dealers, restorers, experts, auction houses, galleries, universities and institutions all use the information that an X-ray image can reveal about pieces of art, antiques and archeological artifacts.

Portable Digital Radiography (DR) systems take this new technology to the edge and provide the highest image quality and most comprehensive information possible in X-ray today. Case studies of paintings will demonstrate how Digital Radiography comprehends a significant upgrade from the older, more familiar, film X-ray and film replacement techniques.

Vidisco’s portable large area flat DDA imager, Flash X Pro offers a large imaging area combined with a lightweight robust configuration that is ideal for NDT X-ray of art. Testing is conducted efficiently on site, so that priceless artifacts need not be moved. Inspection is discrete and time to results is immediate (see Figure 1). 16 bit dynamic range and excellent signal to noise ratio (SNR) provide exceptional results. Images are created upon request on a laptop screen on the spot for instantaneous analysis.

This article will show the benefits of working with portable digital radiography in the service of art and heritage conservation. Various examples will show material identification, x-ray details of production and origin or date of supplies, as well authenticity and authentication of art and archeological objects.

GENERAL
Non destructive testing is becoming more and more prominent in the world of art analysis and inspection. As the phenomenon of fraud expands, testing and authentication become more important to museums and to private collectors alike. Restoring labs also enjoy the benefit of NDT when they look to conserve priceless objects. X-ray inspections allow us to see the invisible. We can learn about the structure of an object in order to better understand how to prevent its further deterioration and conserve it, or in order to place it in the correct historical art context and evaluate it. The use of X-ray in the inspection of art and artifacts is not new. The use of portable DR inspection systems is new in this field, and it brings with it many simplifications to the inspection processes which contribute to shortening the time to results.

Although this is still a learning process, it seems that portable systems can reduce museum lab NDT costs and also enable testing in locations that do not maintain an X-ray lab. Thus private collectors and small institutes may benefit from this new tool. This article will describe the main principle of portable DR systems based on an amorphous silicon imager and will show results from inspections conducted with such a system in the Tel-Aviv
Museum of Art, the Brooklyn Museum, the National Gallery in Washington, the Metropolitan Museum in New York, USA and CIRAM - the Laboratory for Art’s Sciences, located in France. We will demonstrate X-ray images, alongside pictures of original works of art and artifacts while sharing the discoveries made during these examinations.

**Figure 1: Inspection of a Large Painting On-Site, Minimal Transport and Maximum Discretion**

**HOW DO AMORPHOUS SILICONE FLAT PANELS WORK**

The Amorphous Silicone Digital flat panel is composed of a scintillator and an array of Amorphous Silicon (a-Si) photodiodes. The X-ray tube sends a beam of X-ray photons through a target. The photons that were not absorbed by the target reach the a-Si flat panel and strike the layer of scintillating material that converts them into visible light photons. The light photons reach the photodiodes which convert them into electrons that activate the pixels in the amorphous silicone. The electronic data that is generated from this process is converted to a digital signal that is received by the computer and the software converts this information into a high quality image. See Figure 2.

**Figure 2: Amorphous Silicon (a-Si) Flat Panel Structure (source: Thales)**
The newest a-Si detectors can generate a digital image of 16 bit (65,536 grey levels) with 3.5lp/mm resolution. Thus the quality of the image and the information it contains is unprecedented. However, a (museum) laboratory that wants to include this cutting edge technology in its services should not settle for buying an off the shelf detector (usually designed for the medical industry) and hope to get such a level of results. In order to make the most out of the detector capabilities it is best to purchase an entire inspection system, into which an a-Si detector has been integrated in full. Such a system may function well with the X-ray source available in the laboratory and with its proprietary software and the integration knowledge of the manufacturer; one may indeed look forward to outstanding NDT X-ray results. A portable X-ray inspection system based on a-Si flat panels can bring excellent quality X-ray inspection to any location, as the following examples will show.

TEL AVIV MUSEUM OF ART
The restoration department of the Tel-Aviv Museum of Art is faced daily with the concerns of art evaluation, authentication and conservation. NDT has become an important tool to learn the details of each new object that comes into the lab. Authentication criteria and manufacturing techniques are researched on a continual basis. The Oil Painting and Paper restoration specialists in the museum’s lab explain their major concerns [1]: “Consolidation and restoration efforts must be differed from Pentimenti and intended corrections. Reconstructions must be examined to discover deceitful assemblies and fraud. Painting characteristics and layers must be exposed in order to learn more about a painting before its restoration. Paper making methods and details of paper fibers can determine origin and authenticity of a parchment”. X-ray is an inspection method that can help study all these aspects in an art object and provide the knowledge that the restoration team needs to reveal for their work.

Different Pigment Materials
The Jan Lievens 1626 oil painting on canvas called “The Angel Releases Peter from Confinement” was inspected to ensure it is indeed a work from this esteemed artist. The painting is known to have been divided to parts and smuggled by a Russian Kozak in the Second World War, so it was necessary to verify that it is indeed Lieven’s work. A portable 200kV X-ray source was used with a portable flat a-Si imager. An X-ray of 40 pulses (≈2.8 seconds) was shot. The levels of White Lead paint used to create light on the faces of the characters in the painting were corresponding to the usual method of the artist, thus enabling to remove the initial fear of fraud. In addition a paint scratching effect in the beard of the older man could be clearly seen in the X-ray. This technique too is typical for Jan Lievens (see Figure 3).

![Figure 3: Jan Lievens Oil on Canvas 16th Century; Painting and Corresponding X-ray Image](image-url)
Layers of Painting and Sub-Paintings
An X-ray inspection of oil on canvas painting by Moshe Castel, “Synagogue on Saturday” from the beginning of the twentieth century was conducted to assess a suspicion that a sub painting exists. The restoration team at the museum had already examined the layer structure of the paint and came to the conclusion that there is more than one layer to this painting. They wanted to know what was hiding behind the external layer and ensure that there was no fraud.

Using a large area portable Amorphous Silicone DR system, 6 X-ray images of this painting were taken in the form of a grid with overlapping parts (see Figure 4). The darkened frame indicates the size of each image taken (28cmX40cm). The overlapping areas are indicated with stripes. The numbers show the order of taking the images. Each image was taken using the same level of exposure. A 270kV portable, pulsed X-ray source was used and shot 40 pulses (=2.8 seconds) for each image. The source was located at about 1.20m away from the painting. The flat panel was directly behind the painting.

![Image Grid Map](image)

This Image grid map was important for the assembly of the X-ray result of the entire image. Using professional NDT X-ray software, a complete image was stitched out of the six parts. The stitching was done automatically by the software, first stitching together the three images on the right (images 1-3), then the three images on the left (images 4-6) and then stitching together the two combined images. The result revealed a portrait of a lady under the scenery painting (see Figure 5).

![Castel Painting and Corresponding X-ray Images in the Xbit Pro Software Screen](image)
The entire process of taking the images and assembling them together took less than 15 minutes. Most of this time was required to set the imager in place for each image. The X-ray images were generated immediately on a laptop screen and stored in a database in automatic sequence. External images taken during the work were stored together with the corresponding X-ray results for better documentation. Despite the fast inspection time, the quality of the X-ray results was excellent. Images containing 14 bit dynamic range (16,384 grey levels) shows every nuance and detail in the hidden image.

**Dating Canvases**

As part of a project launched by the Van Gogh museum in Amsterdam to chronicle all the paintings by the esteemed painter throughout the world, Digital Radiography was the chosen technology for the inspection of Van Gogh paintings in the Tel Aviv museum of art. The high quality X-ray image reveals the canvas structure in great detail and allows for exact dating of the canvas according to its weaving patterns (see figures Figure 6 and Figure 7).

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**Figure 6:** "The Spinner" by Van Gogh with Corresponding X-ray Image in Xbit Pro Software Screen

**Figure 7:** The "Shepherdess" Van Gogh with Corresponding X-ray Image
THE METROPOLITAN MUSEUM

Another example of speed achieved without compromising image quality comes from the Metropolitan Museum in New York. Figure 8 shows a digital scan of film X-ray (a) and an X-ray image taken with a portable a-Si flat panel (b) of a tin bronze statue. Table 1 contains the imaging conditions of the images in Figure 8.

<table>
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<th>Conditions</th>
<th>Image a (Left)</th>
<th>Image b (Right)</th>
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<tbody>
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<td>Seifert Eresco</td>
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<tr>
<td>mA of X-ray source</td>
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<td>Distance between source and detector</td>
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Table 1: Metropolitan Museum Imaging Conditions

Although the energy level was lower with DR, the exposure time is shorter. The image is sharper and contains more elaborate details of the statue structure.
THE BROOKLYN MUSEUM

The Brooklyn Museum in New York [2] owns and uses a portable DR system in combination with a Seifert X-ray source. Using a portable X-ray system to examine a mummy is especially efficient, as the system can be set up around the examined artifact, allowing for minimum moving of the object. Figure 9 shows an X-ray image that was taken using a 270kV portable pulsed X-ray source with an exposure of 10 pulses (~0.7 seconds). The dog mummy X-ray image reveals a break in its neck. It is assumed this was done intentionally when the owner of the dog died, so that the canine could be buried with its master.

![Figure 9: Dog Mummy X-Ray](image)

THE NATIONAL GALLERY IN WASHINGTON D.C

The National Gallery in Washington D.C restoration staff was confronted with an especially difficult challenge; a small Lead Bronze Statue, a Renaissance masterpiece, by Antico. Despite the hard to penetrate material, an X-ray taken with a portable a-Si system was able to discern the exact inner structure of the statue (see Figure 10). A Balteau 320kV X-ray source was used and exposed the statue to an X-ray for 3.5 seconds. This Status is of vital importance because the artist who made it, Antico, is known to have brought back antique Bronze casting methods (Indirect Casting) again into use in the Renaissance period. The X-ray of the screw seen joining the foot served to assist in dating the statue.

![Figure 10: Antico Lead Bronze Sculpture, X-ray Image](image)
CIRAM
CIRAM, the Laboratory for Art’s Sciences, in France specializes in analysis, datation, tracing and securing of works of art and archeology [3]. In one case portable DR system was used to inspect Ivory statuettes in order to create an X-ray “fingerprint” of the artifacts for their future identification (see Figure 11).

![Figure 11: Unique Finger Print of Ivory Statuettes](image1.png)

An X-ray of an antique rifle enabled the CIRAM specialists to see the mechanism of the object (see Figure 12). This helped understand its manufacturing technique and from this its antiquity could be determined. Placing artifacts in the correct context of time and iconography is an important part of documentation and evaluation of such objects.

![Figure 12: Rifle and the X-Ray Image of its Mechanism](image2.png)

PRIVATE COLLECTORS
Innovative thinking has led Vidisco to combine between portable X-ray flat panel based inspection system and portable wall screening equipment to conduct NDT inspections of large artifacts. This equipment has been recently tested successfully on a painting belonging to a private collector (who at this time wishes to remain anonymous). The painting was placed between the two conveyors that make the so called wall screening system. The conveyors are light and easy to unpack and mount; hence they can be taken to any inspection sight. The conveyors carry the a-Si flat panel and the X-ray source in a synchronized fashion; on both sides of the inspected object (see Figure 13). The X-ray images are taken systematically, and the data is stored in sequence. The location of the X-ray source and flat panel is controlled automatically.
A Surprising Discovery
A large painting which originated from Alsace province in France was inherited by an Israeli family [4]. There is no knowledge as to the artist’s name but the painting is estimated to be approximately 240 years old. The painting showed two figures, a man and a woman, but its context was unclear. It was because of this that the owner first X-rayed the painting in the 1950’s. This X-ray uncovered a third figure of a holy man standing between the two visible figures. It was however assumed that the hidden figure was part of a previous painting and not connected to the couple. Following this discovery the top layer was removed from the middle figure in the area between the two other figures. In 2009 this painting was examined again with Digital Radiography. One again the methodology of the grid was used to document all parts of the painting (see Figure 14).
The sensitive flat panel system was able to generate a much more elaborate X-ray image, which exposed for the first time the true connection between all three figures (see Figure 15). The X-ray shows that the middle figure of the holy man is covering the hands of the couple, as if blessing them in marriage (in this area a painted correction layer of the couple holding hands alone still remains). It is now clear that the painting is depicting a marriage ceremony and that Jesus is blessing the newlyweds. The painting has been in Jewish ownership for many years and it is assumed that the figure of Jesus was hidden for religious reasons.

![Figure 15: Oil Painting and Corresponding X-ray taken with a Digital Radiography System](image)

**PORTABLE DR INSPECTION BENEFITS**
The DR system basic setup is similar to that of any X-ray inspection system in that the inspected object must be placed between the X-ray source and the a-Si panel, which receives the X-rays and turns them into an image (see Figure 16). The benefits however are great.

![Figure 16: Setup for DR Inspection](image)

The first major difference is the amount of detail and information that is produced by these super sensitive panels is very high. Advanced software offers a Window Leveling tool that one can change the spectrum of grey levels that is viewed on screen (while raw data remains untouched) and thus extract different layers of information while taking only one X-ray shot. With film one would have to take more than one image, develop it and then compare the results manually. The films also need to be stored.
The digital image can be enhanced with graphic tools such as adaptive histogram and 3D embossing effect along with the already mentioned Window Leveling, in order to maximize the information that can be extracted from an image for immediate and detailed analysis. All data is digital and easily documented in a data base. Storage room is no longer required and chemical materials for film development are no longer in use.

An advance X-ray inspection software can work with many types of X-ray sources, continuous or pulsed, and it controls the overall exposure level by changing the number of pulses/ the time of exposure and the distance between the X-ray source and the inspected object. With portable a-Si panels, only a few seconds of exposure are required in order to penetrate oil paintings. This maximizes the safety of the operator and that of the environment. With film it would take about ten times longer and require using a higher kV to reach the same level of saturation (equivalent to film density).

Portable pulsed X-ray sources allow for reduced safety distances. This allows for flexible inspection on site without having to clear the inspection area in a wide radius. This enables inspection of artifacts where they are located, and reduces the need to move artifacts to a minimum. The system can be placed “around” the inspected object and sometimes the object need not be moved at all (see Figure 1).

CONCLUSION
Even when a restoration laboratory has limited means it can reach maximum results with a portable DR system. These systems are smaller than and not as costly as X-ray laboratories and yet they offer high quality imaging that allows for effective inspection without compromise.

The mobility of the systems allows the flexibility of conducting efficient and effective X-ray inspection anywhere (in a lab or outside). The systems provide images upon request and results on site, enabling immediate analysis. There is no longer a need to work “in the dark” while waiting for the development or scanning of film or film replacement. The image is available immediately on screen and the inspector can continue to work already knowing what the image entails.

Portable DR systems are safe to work with for the operator and require minimum evacuation of the location when conducting an inspection. The fact that images are gained digitally also spares the need for film development and is hence environmentally friendly, as no chemicals are used.

Due to the many advantages of portable DR systems for Art inspection, as presented above, it is expected that these systems will emerge in this market as a useful and popular inspection tool.

END NOTES
1. Special thanks to the restoring team at the Tel-Aviv Museum of arts for opening their doors to us and having an open mind toward innovation in the field of inspection. To Sharon, Dafna, Chasia, Maya and Dr. Doron, your cooperation is highly valued. We learned a lot!
2. We thank Mr. Ken Moser and the restoration staff at the Brooklyn museum
3. We thank the team at CIRAM for showing us some of the inspections conducted with flat panel systems.
4. Special thanks to the Zakin family, the owners of the “Couple with Jesus” Painting for sharing their exiting story and permitting publication of the findings.

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