X-RAY DIGITAL RADIOGRAPHY AND COMPUTED TOMOGRAPHY FOR CULTURAL HERITAGE

FRANCO CASALI

Department of Physics, University of Bologna (Italy)

email: Franco.Casali@bo.infn.it

Abstract

X-ray detection systems for high resolution Digital Radiography (DR) and Computed Tomography (CT) have been developed at the Physics Department of the University of Bologna. The research target is the development of systems to be applied in cultural heritage conservation and industrial radiology.

In the field of cultural heritage, different kind of objects (ancient necklaces, paintings, bronze or marble statues) have to be inspected in order to acquire significant information as the method used to assemble, the manufacturing techniques or the presence of defects. These features could be very useful, for example, for dating works of art or determining appropriate maintenance and restoration procedures. Among the advanced methods available, 3D CT can be successfully used for the investigation of ancient works of art because it preserves their integrity and provides images of inner parts, which are otherwise not visible.

KEYWORDS: COMPUTED TOMOGRAPHY, CULTURAL HERITAGE, DIGITAL RADIOGRAPHY, MICRO-TOMOGRAPHY

KULCSSZAVAK: SZÁMÍTÓGÉPES TOMOGRÁFIA, KULTURÁLIS ÖRÖKSÉG, DIGITÁLIS RADIOGRÁFIA, MIKRO-TOMOGRÁFIA

Introduction

Several high-resolution CT systems have been developed to investigate objects of different sizes (from micro to macro) at the Physics Department. For example, we have carried out the micro CT reconstruction of Roman human tooth with dental caries (found in the “Isola Sacra” necropolis); as well as the cone beam CT analysis on an Egyptian cat-shaped coffin exhibiting the inner mummy; up to the CT study of an large ancient globe (2 m of diameter). This globe was created by a Dominican monk, Egnazio Danti, around 1567 and is located in Palazzo Vecchio, at Florence. The very high resolution reached investigating small objects is an important result other than tomography on a big object, like the globe, is an absolute innovation. A 3D CT investigation is being in project to determine how much deterioration has occurred on the ankles of David, the towering marble figure sculpted by Michelangelo, a very exciting purpose that we will achieve in collaboration with Lawrence Livermore National Laboratory.

A new linear array detector for high resolutions and low dose digital radiography for painting was realised. This new instrument is able to acquire radiological image with an amount of dose one hundred times reduced less than standard film. The system was tested on a benchmark panel with some pigments provided by the "Opificio delle Pietre Dure" (OPD) a well known Restoration Centre in Florence. The resolution and the image contrast reached by the scanning system were superior to that of the common film systems used at the Institute. Moreover, in collaboration with the National Gallery of Bologna and OPD, was performed an X-ray investigation of the inner structure of two small painted "tablets", made of wood, and recognised as an artwork of Gentile da Fabriano, an important painter of the XIII century. Different techniques were used: conventional film radiography, digital radiography and computed tomography, the latter two with innovative equipment of the Department of Physics in Bologna.

Material and Methods

Methods of diagnosis based firstly on X-ray digital radiography (DR) and then on computed tomography (CT), are more and more used for the conservation and restoration in the cultural heritage field. This kind of analysis can help also to understand the construction techniques and the “history” of the object under examination (Casali 2006).

As the size of objects of cultural interest varies greatly, from small fragments to large works of art, it is necessary to develop measurement systems for each typology of objects. For small objects (i.e. fossil teeth and ancient jewels) it is necessary to use high spatial resolution detectors, for big or thick objects it is necessary to use very efficient detection systems. The detectors developed and used, at the Physic Department the University of Bologna, can be one dimensional (linear detectors) as well as two dimensional (planar detectors).

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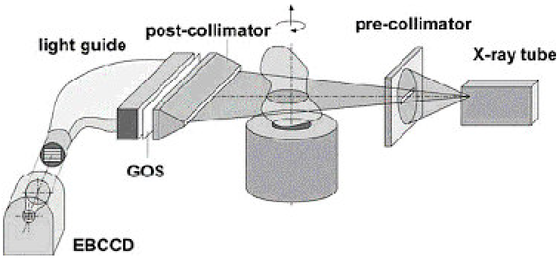

Figure 1.

Scheme of the linear detector set-up

A scheme of the linear detector set-up is shown in **Fig. 1.** The device consists in an X-ray generator, a pre-collimator, a mechanical translation stage, a post-collimator and a strip of Gd_2O_2S:Tb. This scintillator is optically coupled with the photocathode of an EBCCD camera through a coherent image light guide made of thin glass fibres. The most new feature of the system (patented by the University of Bologna) is the ‘‘optical guide-EBCCD camera’’ combination. The input end of the optical guide, at the head of the detector, is 129 mm wide and 1.45 mm high. The output end of the optical guide has approximately a square shape and fits into the 1 in. diameter photocathode of the EBCCD camera. The guide is composed of seven 18.4 × 1.45 mm^2 bundles, about 50 cm long. Each bundle transports the light in a coherent way to preserve spatial information. The EBCCD camera is provided with a high voltage tube as in a conventional image intensifier. The difference is that electrons hit directly the substrate of the CCD that is sealed inside the tube. In this way a higher conversion efficiency and a higher gain (up to 2000) are obtained. Moreover, the EBCDD camera is compact and small with respect to a conventional image intensifier (Bettuzzi et al. 2004).

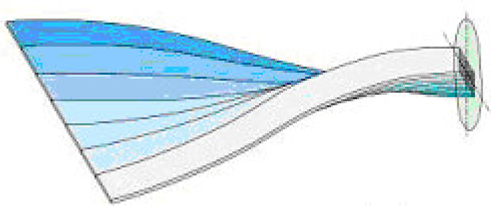

Figure 2.

Rectangular-to-linear fibre optic adapter: the linear input face is converted on a rectangular exit

Figure 2 shows a picture of the fibre optic adapter. It is made of glass microfibres, each one with a diameter of about 20 µm. The microscopic size of the fibres provides a great flexibility to the adapter. The bundles are aligned on the input face, by thus allowing a linear scanning geometry. On the other hand, the fibre-optic bundles are stacked at the exit, in order to fit the shape of the photocathode of the EBCCD camera.

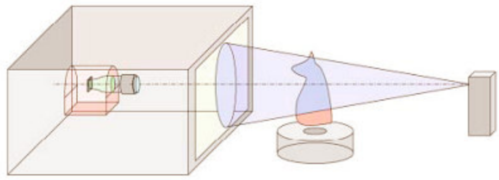

Figure 3.

Diagram of the intensified TC system

A diagram of an example of the two-dimensional detection system configuration is shown in **Figure 3**. A 30×40 cm^2 GOS screen is mounted on the entrance window of a large box that both acts as a support and provides proper shielding for the detection system. By changing the distance between the EBCCD and the scintillating screen and adopting a suitable lens on the photocathode, it is possible to obtain high resolution images of a smaller area and a radiographic zoom of a specific zone. The set-up is similar to that of the micro-CT system, but this intensified system permits investigation of bigger objects with a resolution of about 200 µm (depending on the magnification factor, (Pasini et al. 2004)).

Moreover the characteristics of the X-ray source are equally important. In fact, for doing DR or CT with spatial resolution of the order of 10 – 20 mm, it is necessary to use the so-called microfocus, having focal spot not larger than 5 mm. Recently more sophisticated X-ray tubes have been developed having focal spots not larger than 1 mm (nanofocus).

The X-ray sources of interest can be summarised thus:

- X-ray tubes (from 5 kV to 450 kV) with the versions micro- and nanofocus;

- linear accelerators (from 2 to 15 MV);

- synchrotron light (from 5 keV to 100 keV).

For light energy X-ray CT we have used a 9MV linear accelerator of Aviogroup-Rome. With that source we did a CT of an old Roman jug with bronze coins (**Fig. 4.**).

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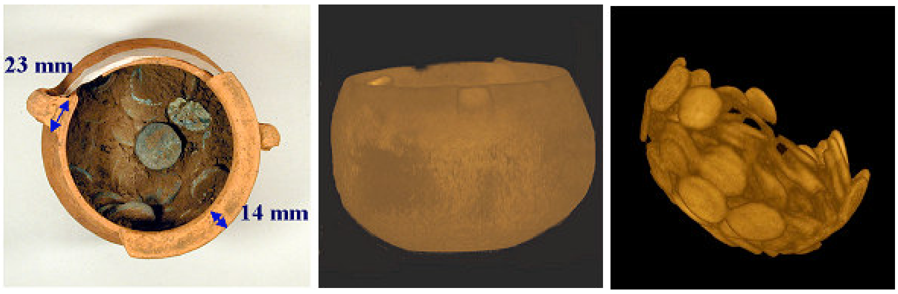

Figure 4.

Picture of the old Roman jug with bronze coins (left), CT images showing the jug and the inner coins (right)

Results

In the last few years at the Physics Department of the University of Bologna, X-ray detection systems for high resolution DR and CT have been developed and successfully employed for the analysis of samples of different size and composition. For example, in the framework of a collaboration between and the Archaeological Museum of Bologna and the Physics Department, important archaeological findings and works of art have been investigated by means of Digital Radiography and Computed Tomography. In particular, these methods have been used to inspect bronze object of the Etruscan section (Rossi et al. 1999, **Fig. 5**) and small mummies from the Egyptian Collection (**Fig. 6**).

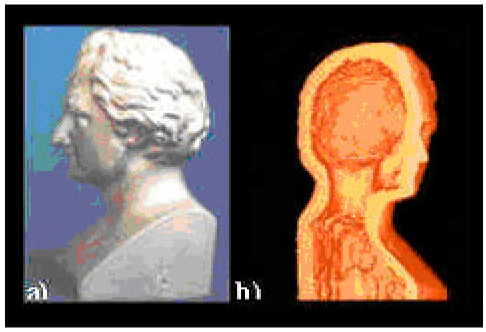

Figure 5.

a) Small Etruscan bronze head, b) 3D Computed Tomography

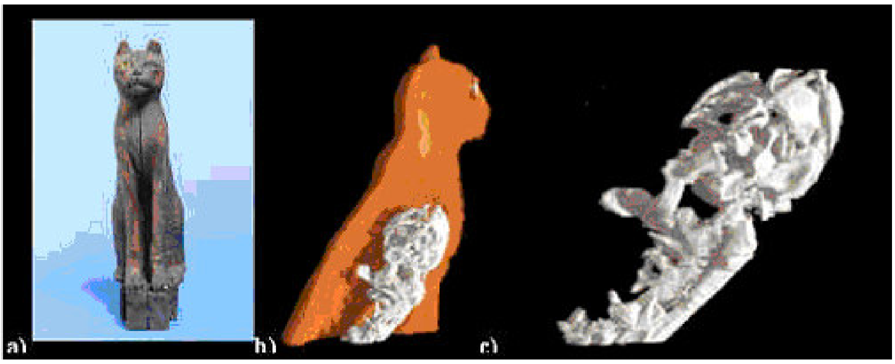

Figure 6.

a) Egyptian cat-shaped coffin with a cat mummy included inside,

b) 3D Computed Tomography,

c) zoom of internal skeleton.

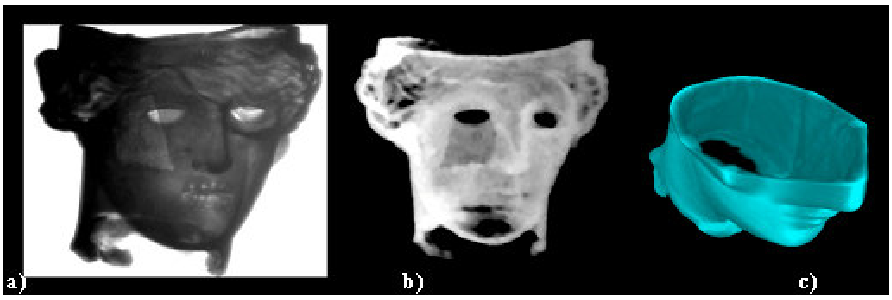

Figure 7.

a) Greek Bronze Head

b) Digital Radiography

c) 3D elaboration

Other investigations have been carried out in collaboration with the Getty Conservation Institute (GCI) of Los Angeles (**Fig. 7**) using an X-ray tube up to 450 kV. With GCI is going to start a research program focused on CT of an ancient bronze statue for trying to understand the welding technique of Romans and Greeks.

In the frame of a collaboration between OPD and the National Gallery of Bologna, a comparison has been performed between the digital radiography (Rossi et al. 2000) and the traditional radiography with films, with the conclusion that the DR has the same resolution as the traditional one but with much less radiation dose released to the painting (**Fig. 8**).

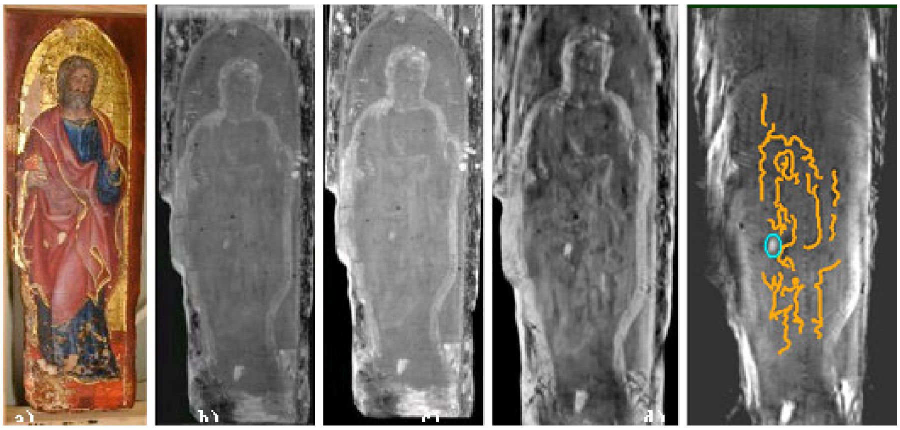

Figure 8.

Painted "tablets", artwork of Gentile da Fabriano:

a) Picture,

b) Conventional film radiography,

c) Digital Radiography with our System,

d) Digital Tomography with our System (section)

e) Warm holes and pipes, CT section.

The developed systems have a strong sensitivity to low flux X-ray radiation. For this reason it is possible to obtain a significant reduction of the absorbed dose.

Among the examined works of art, it is worth mentioning the big globe built in 1567 by the Dominican monk Egnazio Danti and located in Palazzo Vecchio, at Florence, Italy (**Fig. 9/a**). A restoration project is ongoing for returning the globe to its original magnificence; within this project, a CT of the globe was achieved, for exploring the nature and the conditions of the inner structure. The main problem of getting a complete CT was related to the large size of this masterpiece (220 cm in diameter) and to the need of achieving an in situ analysis in a museum with a lot of visitors. For these reasons an ad hoc experimental apparatus was realised and set-up at Palazzo Vecchio. The 3D CT reconstruction of the globe has clearly shown the entire inner structure that was never seen before (**Fig. 9/b**, Casali et al. 2005).

Conclusions

The digital radiography and computed tomography are two new and interesting fields of non-destructive evaluations and a tools for scientific investigations.

For example, the 3D CT reconstruction of the globe clearly shows the entire inner structure, how it was deformed during time, how it could be restored. All the inner structure, made of iron with a total weight of about 350 kg, was estimated from the segmented 3D reconstruction. Another important application is the study of the metal fusion technique used by the ancient artists (Greeks, Etruscans and Romans). Moreover the 3D CT image can help the restores in designing the restoration and conservation of ancient bronze statues.

Figure 9.

a) The big globe built in 1567 by the Dominican monk Egnazio Danti and located in Palazzo Vecchio, at Florence, Italy (left);

b) The 3D inner structure reconstruction of Danti's globe (right).

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It should however be pointed out that the CT technique is difficult and expensive. In fact, for having good CT images, many hundred of radiographies are necessary with the use of very expensive equipment for moving the objects with a precision of a few microns (Rossi et al. 2002, Rossi et al. 2004).

The easiness with which CT can be performed in the medical field may be misleading: medical CT was optimised for the human body (composed mainly of water) and cannot be successfully used on bodies with different density. In order to perform good, non-destructive evaluations, the most suitable DR or CT system (source, moving equipment, detector and elaboration software) must be carefully chosen to avoid obtaining meaningless results (Casali et al. 2003, Casali 2006).

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