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Results of the Italian neu_ART project

A Re¹, F Albertin¹, C Bortolin², R Brancaccio¹, P Buscaglia³, J Corsi², G Cotto^{1,2}, G Dughera¹, E Durisi^{1,2}, W Ferrarese^{1,2}, M Gambaccini⁴, A Giovagnoli³, N Grassi³, A Lo Giudice^{1,2}, P Mereu¹, G Mila^{1,2}, M Nervo³, N Pastrone¹, F Petrucci⁴, F Prino¹, L Ramello⁵, M Ravera³, C Ricci¹, A Romero^{1,2}, R Sacchi^{1,2}, A Staiano¹, L Visca^{1,2} and L Zamprota^{1,2}

¹ Istituto Nazionale di Fisica Nucleare, Sezione di Torino, via Pietro Giuria 1, 10125 Torino, Italy

² Dipartimento di Fisica Sperimentale, Università di Torino, via Pietro Giuria 1, 10125 Torino, Italy

³ Centro Conservazione e Restauro “La Venaria Reale”, Piazza della Repubblica, 10078 Venaria Reale, Torino, Italy

⁴ Dipartimento di Fisica, Università di Ferrara and Istituto Nazionale di Fisica Nucleare, Sezione di Ferrara, Via Saragat 1, 44100 Ferrara, Italy

⁵ Dipartimento di Scienze e Tecnologie Avanzate, Università del Piemonte Orientale, Viale Teresa Michel 11, 15121 Alessandria, Italy

Email: alessandro.re@to.infn.it

Abstract. The neu_ART project aims at developing *state of the art* transmission imaging and computed tomography techniques, applied to art objects, by using neutrons as well as more conventional X-rays. In this paper a facility for digital X-ray radiography of large area paintings on canvas or wooden panels and for the X-ray tomography of large size wooden artifacts, recently installed in a protected area, is presented. The results of a K-edge radiography facility that will soon be installed in the same area are also shown.

1. The neu_ART project

The neu_ART project (“neutron and x-ray tomography and imaging for cultural heritage”), financed by the Piedmont region (Italy), is a collaboration among the University of Torino, the Istituto Nazionale di Fisica Nucleare (INFN) and the restoration centre CCR “La Venaria Reale”. Among the goals of this project is the construction of an integrated X-ray imaging system for computed tomography (CT) and digital radiography (DR) of big artworks and of a facility for K-edge radiographies of small portions of paintings. The benefits of such imaging techniques in the field of cultural heritage are widely acknowledged [1,2]. Their application is useful as preliminary step for a restoration intervention, giving significant data about conservation, history and structural technique.

2. X-ray digital radiography

The instrument provides high quality radiographic images of paintings up to 3×4 m² by scanning horizontal slices of their surface with an X-ray linear detector. The painting is positioned vertically in front of a motorized mechanical system allowing to select the height to be scanned. A horizontal axis, with an accurate speed control, synchronizes the detector movement with the image acquisition software. The speed can reach values up to 6.5 m/min, depending on the intensity of the signal.

The X-ray source, used both for DR and CT, is a General Electric Eresco 42MF4. It has a Tungsten anode with a focal spot size of 1.5 mm and a maximum current of 4.5 mA at the upper voltage of 200 kV, increasing to 10 mA at lower operating voltages. The detector for radiography is a Hamamatsu C10650: it's a linear TDI (Time Delay Integration) CCD detector, coupled with a fiber optic plate and a scintillator. It features a CCD 22 cm long with a pixel size of 48 μm for a total pixel number of 4608 \times 128 and is designed for operations with X-ray energies lower than to 95 keV.

The instrument was tested on a painted wooden panel (dimensions: 30 \times 41.5 \times 3.5 cm³) realized by the CCR (figure 1a): it's a copy of a Gentile da Fabriano where materials and techniques match those used by the author. The X-ray radiography (figure 1b) was obtained with a tube voltage of 80 kV and a current of 7 mA by placing the tube and the panel at a distance of about 160 cm and 2 cm from the detector respectively. The detector scanning speed was 1 m/min. The aim of this radiography was to check how many information useful to a restorer could be obtained to evaluate the condition of conservation of the object. From the radiography several important features can be observed: the painting was realized on two tables joined together by a radiopaque glue (the bright line in the center of the figure) and by three wooden pins of different shapes (figure 1e); the construction technique of the frame (figure 1c); wooden dowels were placed instead of a knag (figure 1d). Note that despite the high X-ray energy, necessary to transverse the thickness of the panel, prevents a good contrast on thin layers, the pigment layer is clearly visible in some parts of the painting (figure 1b), especially where Pb white is used for the flesh tones.

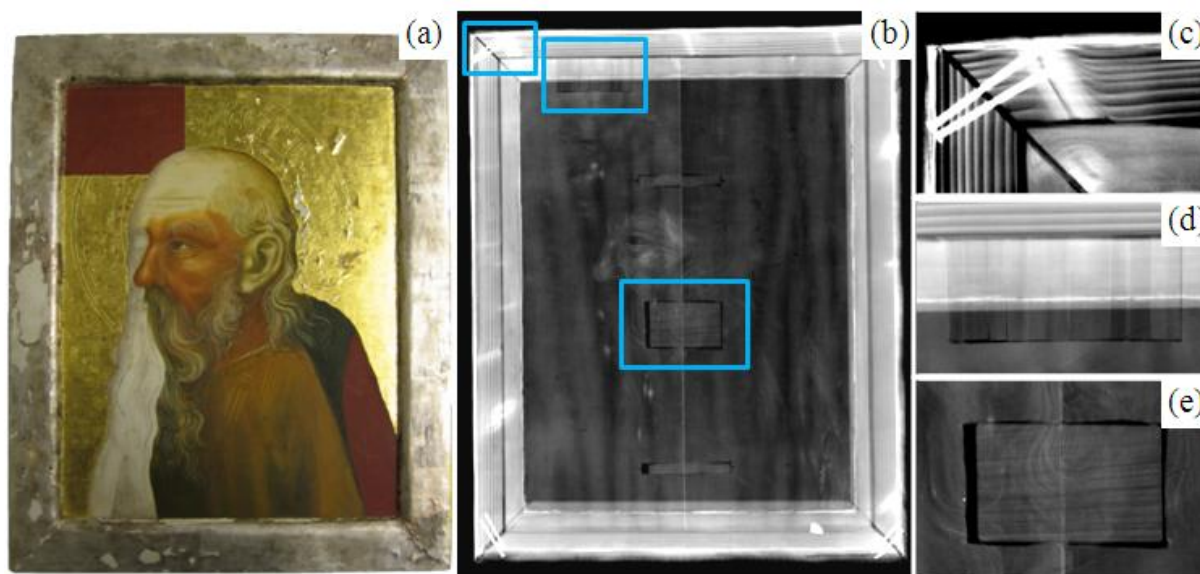


Figure 1. Copy of a wooden painted table by Gentile da Fabriano (a) compared to the X-ray radiography (b) with some enlarged details: nails in the frame (c); wooden dowels (d); wooden pin (e).

3. X-ray computed tomography

The CT is conveniently used in many of the restoration activities at CCR, especially where wooden sculptures, furniture, paintings on panel and ceramics are involved. It provides more information with respect to DR, especially for those objects in which the three dimensional information is important. It allows studying the executive and assembly techniques for both wooden sculptures and furnishing without actual dismounting, providing the possibility to discriminate the presence and the location of different materials, as different wooden species, and to evaluate thickness and dimensions of the various parts.

The mechanical system and the X-ray tube used for the CT are the same described in section 2 with the addition of a rotary stage of 160 cm diameter to rotate large objects in small steps with high precision. The dimensions of the objects to be analyzed require using high X-rays energies. To override the energy limitations of the detector used in DR (see section 2), a different detector able to

operate up to the maximum tube energy of 200 keV was selected: a Hamamatsu C9750-20TCN linear detector with 2560 pixels of $200 \times 200 \mu\text{m}^2$ each, with a total length of 51.2 cm.

The setup was tested on a sample prepared to simulate typical wooden widths of an empty statue or furniture: it's a piece of poplar (figure 2a) with a maximum width of about 25 cm and four steps of about 5 cm each. The CT was obtained operating the tube at a voltage of 180 kV and a current of 5 mA, placing the tube and the center of the rotary stage at distances of 295 cm and 80 cm from the detector respectively. The detector speed was of 5 m/min and 720 radiographies were acquired, one each 0.5° . The CT reconstruction [3] was performed with a non-commercial software-utility developed by Dan Schneberk of Lawrence Livermore National Laboratory (USA). One of the radiographies is shown in figure 2b: it reveals some features of the wood, but it's impossible to determine at which depth they are. In the CT reconstruction (figure 2c) many more details as tree-rings, knags, cracks are clearly visible and their position can be precisely determined.

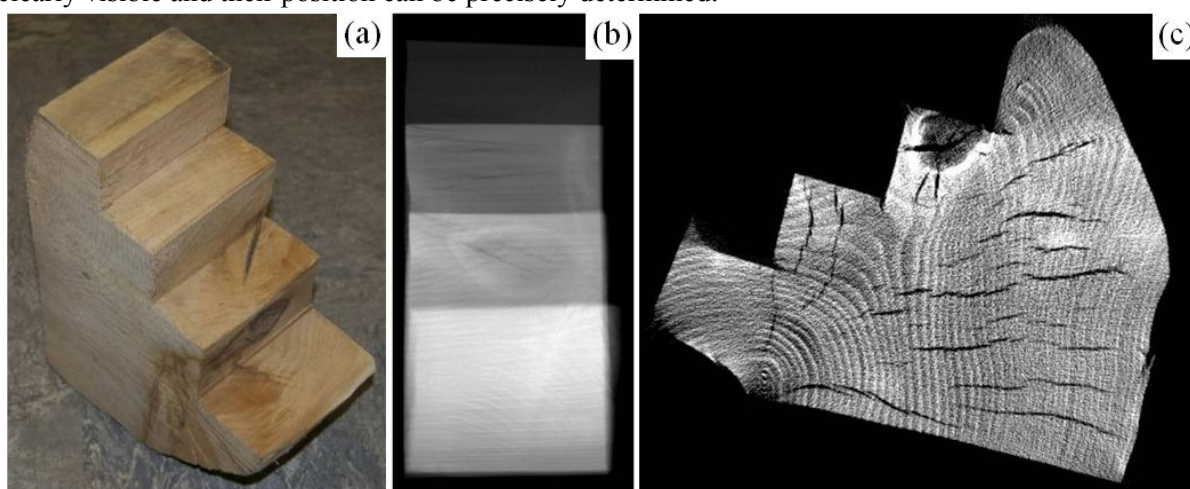


Figure 2. A wooden step sample (a), X-ray radiography (b) and tomographic reconstruction (c).

4. K-edge radiography

The K-edge technique [4-8] takes advantage of the sharp rise of X-ray absorption coefficient of an element, the K-edge discontinuity, to map it on the whole surface of the painting. Each pigment is characterized by one or more elements; mapping an element means finding the spatial distribution of that pigment. The procedure requires two quasi-monochromatic X-ray images (in the energy range of 8-40 keV) above and below the K-edge energy of the element under investigation. This leads to a significant variation of the target element signal, maintaining almost unchanged the response from the background. A quasi-monochromatic X-ray beam can be achieved via Bragg diffraction of a standard X-ray beam on a mosaic crystal [9]. The images are processed by a subtraction algorithm [4] to obtain two new images: one gives the mass density distribution (g/cm^2) of the element under study and the other gives the distribution of all other materials in the sample.

The results presented in this paper were obtained using an X-ray source, installed in the LARIX Laboratory of Ferrara Physics Department. A SSD detector was used to perform X-ray imaging [10,11]: it consists of 512 Si-strips, 1 cm thick and $300 \times 100 \mu\text{m}$ pixel size. It is an edge-on detector and it works in single photon counting mode. The edge-on configuration allows a larger penetration thickness to increase efficiency in the 20-40 keV energy range. To ensure a very small dead area, the detector is cut perpendicular to the strips at only 20 μm from the end of the strips. Counting measurements were carried out by comparison with a CZT detector to compute the SSD efficiency which resulted $(81 \pm 4)\%$ at 9 keV and $(88.3 \pm 1.4)\%$ at 26.7 keV.

Elemental distributions on test objects and canvas with different pigment layers were achieved. At lowest energy, elemental mapping of Cobalt (7.7 keV K-edge energy) and Copper (8.97 keV) on Smaltino (potassium glass containing cobalt) and Azurite ($2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$) painting layers was

performed (figure 3a). According to the Lehmann algorithm, the element distribution (g/cm^2) on the analyzed surfaces is presented using a grey level scale: higher grey levels correspond to a greater quantity of the element under study; in the same figure the average Co and Cu contents in each pixel column are shown. The diagnostic potential of this technique to separate and map different elements is shown in figure 3b, where the elemental mapping of Antimony (30.49 keV K-edge energy) and Cadmium (26.71 keV) on superimposed layers of Naples Yellow ($\text{Pb}_2\text{Sb}_2\text{O}_7$) and Cadmium Red (CdS) is presented.

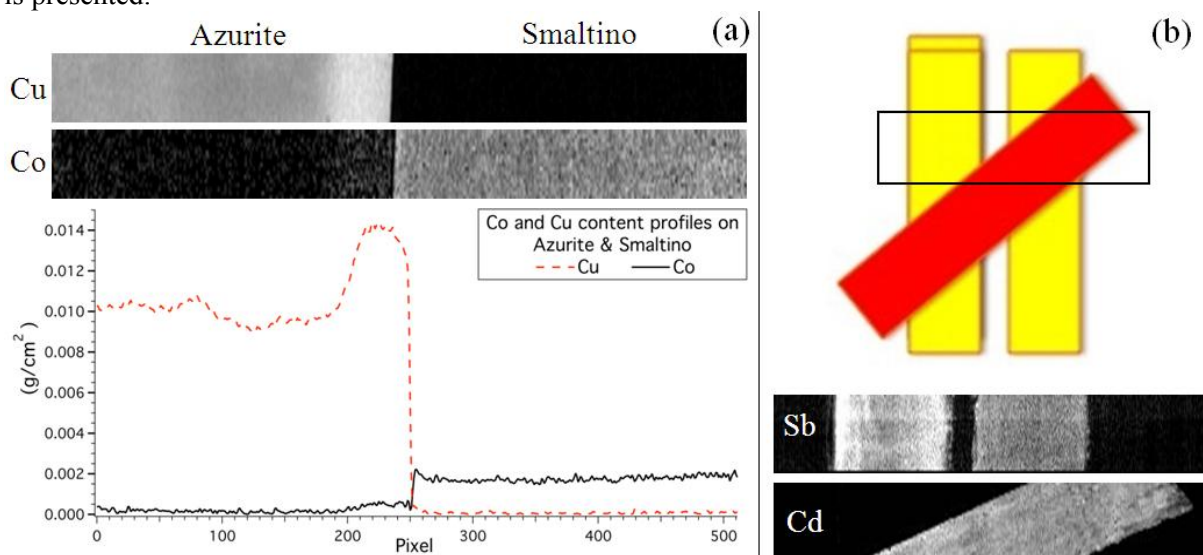


Figure 3. (a) images of Cobalt and Copper distribution detected in the Azurite (left) and Smaltino (right) target objects; in the graphic the average Co and Cu content measured on images is shown; (b) target object structure: a single Cadmium Red pigment layer (diagonal); double (on the left) and single (on the right) Naples Yellow layers pigments (vertical). Sb and Cd detected in the imaged frame.

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