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Ancient enamel plate characterized by Time domain spectro imaging

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Abstract—We report on further development of terahertz systems for measuring the thicknesses and the detection of fracture in art science. Analysis of time-domain data is described and the results of measurements made on ancient enamel plate are presented. We also show X-Ray images and hyperspectral visible and infrared images to identify the pigments used. We also test the Z tracker developed by Teraview Ltd and demonstrate the possibility to perform THz imaging on non-flat samples.

I. INTRODUCTION

Terahertz (THz) waves have shown their capabilities to provide structural information of materials but also data about their chemical nature. While UV penetration length is limited to varnish layers, visible light to paint layers and infrared to *imprimitura* layers, THz wave can reach preparation layers and the substrate. In this paper, we analyze an ancient enamel plate made by Longwy Company to characterize the nature of the pigments, the different coloring technique and the thickness of this ceramic material. Chiefly, Terahertz time domain imaging (THz-TDI) is used to analyze paintings [1], [2] due to its penetration depth, complementary to X-rays, IR and UV methods. Mainly due to the coherent detection of the THz field, so the temporal -or spectral- transmitted or reflected THz beams could be used to construct a 2D or 3D [3] image by raster scan. Recent technological developments have focused on obtaining spectra of historical object (wall for example) in unflat conditions.

II. TECHNIQUE

The piece was created by special designers in the 18th century. To make ceramic objects by casting, they do not start from clay bread but from clay in liquid form. Here they used dehydrated clay that they will liquefy with water. This liquid clay will then be poured into plaster molds to take on a given shape. A plaster model is then made by the modelling workshop. This model, once molded, generates a hollow plaster mold into which the slip (a mixture of kaolin, clay and water) is poured.

The plaster of the mould, eager for water, sucks the liquid from the slip into contact with its surface: a crust forms along the walls of the mould. Once the crust reaches 7/8 mm in thickness, the mould is turned over, emptying the excess slip still inside. The piece then dries in the mould, then is removed from the mould and left to air dry for 24 hours. For plates, ancient and well-known technique which consists in shaping one's clay with the help of a machine called a potter's wheel was probably used. The machine will turn a part called *wrasse* on which the potter will place his clay and give it shape with the help of the rotation of the wheel. The piece is then fired at 1050°C overnight.

This white clay is called **biscuit**. The biscuit is printed with a line of black ink that repeats the decoration of the piece and partitions the colours, preventing them from mixing. Each cell created by the line is then filled by hand with coloured enamel using a drop-by-drop technique. As the drop of enamel dries almost immediately on contact with the biscuit, it is impossible to "paint" this piece, hence the use of the technique which consists of placing one drop of enamel next to another until the colour cell is completely filled. Once the piece is completely enamelled, it is fired at 750°C overnight. The piece is then retouched, requiring a second firing at 750°C, then gold is brushed onto the decoration and the piece is fired again, this time at 600°C.

For the experiment, THz pulses are generated by focusing ultrafast (100fs) pulses of near infrared light onto the gap between the electrodes at near infrared wavelengths (Lx Teraview). A signal-to-noise ratio (SNR) of around 80dB, limited by the thermal noise of the antenna, can be achieved.

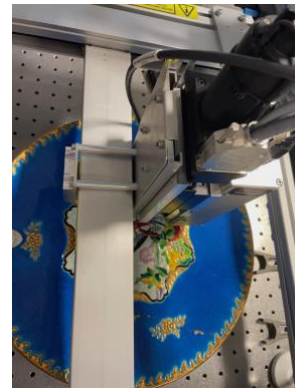


Fig 1 : Z tracker system during the experiment

The depth-of-field of the terahertz (THz) reflection module is limited, as a result of the comparatively long (0.1mm to a few mm) wavelength of the THz radiation used. In order to obtain the best possible lateral resolution, a short focal length must be used to focus the THz onto the target or sample. This results in a depth-of-field of a few times the wavelength. Ideally, when imaging a planar object, we want to keep the target surface within a few hundred microns of the focal plane. The standard TeraPulse Lx PolyScan gantry system [5] features a manual depth-adjustment to set the proximity of the sensor relative to the target surface (the focus). The PolyScan Head is described elsewhere [6] but consists of a terahertz emitter and receiver placed adjacent to each other and focused with either a 7-mm or 18.5-mm focal length lens. In these measurements we added a 3rd motion axis to the Lx PolyScan unit to permit automatic adjustment of the focal plane. In addition, we have mounted a laser-range gauge at a 30-degree angle near to the terahertz focusing optic. In order to keep the terahertz focus at the object

surface the instrument control system performs a raster scan with the laser range gauge some 10-20 scans before the terahertz focal spot. The software develops a topological map of the surface to be scanned. The position of the terahertz optics is updated continuously using the topological map. This keeps the terahertz beam focused onto the object surface. The software allows the User to either keep the focus at the surface of the object or to be offset from the focus by up to 3-mm to examine subsurface structure.

III. RESULTS

The figure 2 presents the central picture of the plate with a coloured “phoenix” in the center. The layer of coloured enamel is very thick and produces a volume and depth of colour that is generally impossible to reproduce in decorated earthenware.

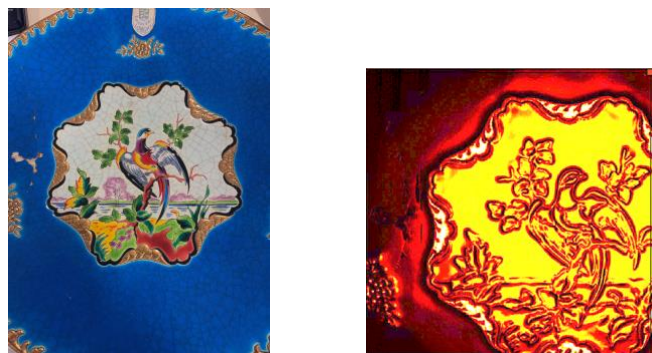


Fig.2 : Picture of the plate and THz image taking peak to peak signal as a display parameter .

Since the enamel layers present concave shape due to the molten procedure, the THz beam is partially reflected out the sensor and the outline of each enamel zone is detected. Moreover, some superficial painting add-on like small pink trees are not revealed with this display parameter but we will present this detection by selecting proper time slice display. It's noticeable to be able to image different part of the plate with a difference in altitude of more than one centimeter .

For instance, the fracture is clearly detected on the left part of the plate within the same scan.

To demonstrate the powerfulness of the Z scanner, fig. 3

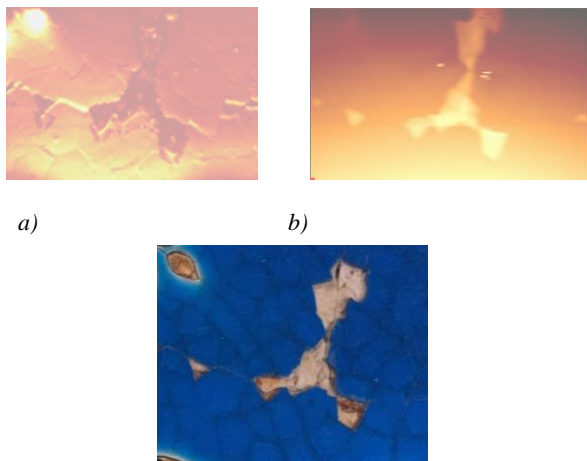


Fig 3 : Detail of a plate fracture showing the base ceramic material a) THz image, b) Height trajectory of the THz sensor, c) visible image

presents different images of the fracture. The difference of the height is about 8mm. We have verified the Z-axis surface tracking control loop stability by stimulating the control system with a series of step-changes in the target position with a logarithmic increasing range of step sizes. The step sizes range from 100 microns up to 20mm. The responsiveness of the control loop could be adjusted by a parameter set in the instrument configuration. Fig 3a shows the fracture area when the Z tracker is on. Fractures are clearly detected. The corresponding Z-height trajectory followed by the sensor head is shown in Fig 3b. By visual inspection, the actual trajectory is substantially similar to the measured surface. Note, the profiles are offset along the Y-axis due to the 10mm laser gauge.

IV. SUMMARY

We use a LX terapulse with a n automatic z-tracker z to find the best parameters to sense an ancient enamel plate in reflection mode. The reflected terahertz time domain waveform is acquired efficiently on large surface and with a difference in altitude of more than one centimeter. The outline of the enamel zone is well defined and some new details are found, especially the overlay decoration painting . We will also present the different layer thickness by inverse problem approach that allows accessing both the thickness and the optical response. Our results will be crossed with hyperspectral imagery for pigment identification and X Ray imaging of the plate.

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