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THz reflectometric imaging of contemporary panel artwork

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***Abstract*—Terahertz time-domain reflectometry has been applied to the investigation of a tempera panel replica. The technique has given useful information about the surface as well as the internal structure of the artworks. Ultrathin layers of leaf gold are penetrated by THz radiation, revealing the underlying wood structure.**

I. Introduction and Background

Terahertz time-domain imaging enables a combination of tomographic and spectroscopic information of objects under investigation, and has recently become a powerful tool for artwork investigation. The technique is evidently interesting for conservation science [1], being capable of investigating surface and buried layers noninvasively, and it has been succesfully applied for panel paintings investigation [2, 3]. In this study, terahertz time domain reflectometry has been applied to the investigation of the surface structure and hidden features of a tempera panel replica.

II. Results And Discussion

The tempera panel investigated (Fig. 1(a)) was realized by students of "The Royal Danish Academy of Fine Arts" (Copenhagen, Denmark), almost twenty years ago. The applied painting technique faithfully reproduces the indications of the famous Cennino Cennini treatise, the "Book of Art", written at the beginning of the fifteenth century. The replica has great value since many constituent layers were intentionally left exposed. A cloth piece was applied on the wooden support, and then covered by the ground layer (animal glue and plaster mixture). The ultramarine pigment was applied mixed with egg on a first drawing sketched by pencil. A golden finish, realized through the application of gold leafs on a red bole layer, frames the pictorial scene. We employed a portable THz imaging instrument (Picometrix T-Ray 4000) for the data acquisition.

Fig. 1(a) shows the visible image of the panel, and Fig. 1(b) shows the grayscale terahertz reflection image of the difference between the extrema of the electrical field, recorded in time domain. Contrast enhancement has been obtained by contrast-limited adaptive histogram equalization (CLAHE), a well known computer processing technique used to improve local contrast in images. In the THz grayscale images presented here, higher reflectivity values appear whiter, lower value appear darker.

The terahertz reflection image (Fig. 1(b)) shows the grain of the wood located behind the ground layer and, interestingly, also partially under the gilding. This is due to the extremely small thickness of the gold leaves which can typically range between 0.01 - 0.125 µm (thinner than or comparable to the skin depth of gold in the THz range), enabling a small amount of THz light to penetrate through the gold.

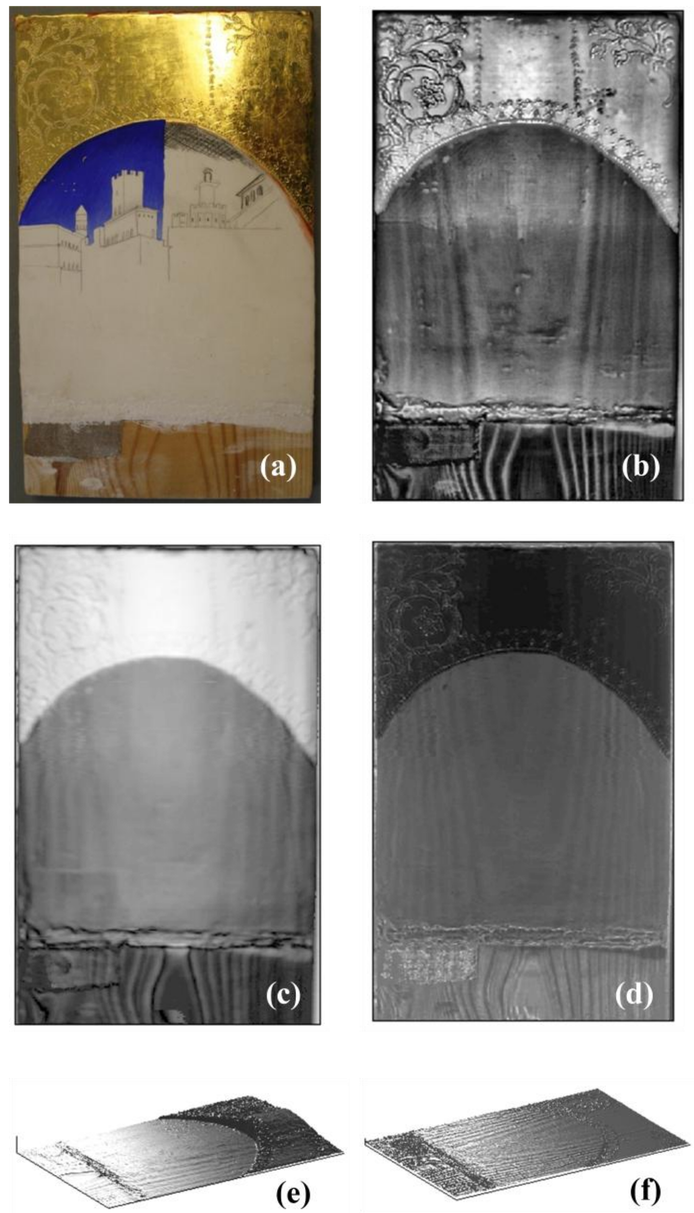

Fig. 1 (a) Visible-light photograph of a tempera panel replica. (b) Image of reflected main THz signal strength. (c) Image of percentage reflectance (vs aluminum) of the panel painting at 0.75 THz. (d) Image of pseudo-absorbance, calculated at 0.3156 terahertz. (e) 3D plot of reflectance of the panel painting at 0.75 THz. (f) 3D plot of pseudo-absorbance, calculated at 0.3156 terahertz.

The presence of the pictorial layer in the THz image (Fig. 1(b)) is detected due to the different thickness and density of the thin brushstrokes and the higher reflectivity of the painted area compared to the adjacent ones, related to the higher surface smoothness (lower grain size of the pigment compared to the one of the plaster and presence of glossy binder in the pictorial layer). The high reflectivity of the wooden panel behind has the effect of partly masking this superficial layer.

After having defined a suitable time window around the maximum of the reflected signals recorded for every pixel, the signals have been Fourier transformed. Reflectance and pseudo-absorbance (the logarithm of the reciprocal reflectance) at different single frequencies have been calculated, as well as the integral of the spectral amplitude over different frequency ranges. Fig.1(c) shows the reflectance (with plane aluminum as reference) of the panel at 0.75 THz. Despite the low resolution, at this frequency the profile of the canvas partly hidden behind the plaster layer is much more evident. A logarithmic intensity transformation has been used for image details and contrast enhancement. Fig. 1(d) shows the pseudo-absorbance value, calculated at 0.32 terahertz; at this frequency the contrast between the canvas (uncovered) and wood is maximized and this parameter, resulting as a negative image of the reflectance, emphasizes this dissimilarity. The 3D representations of the reflectance at 0.75 THz and the pseudo-absorbance at 0.32 THz are shown in Fig. 1(e) and Fig. 1(f), respectively. Both the 2D and the 3D representation highlight the visibility of the wood grain, clearly visible even when imaged through the gold leaf layer.

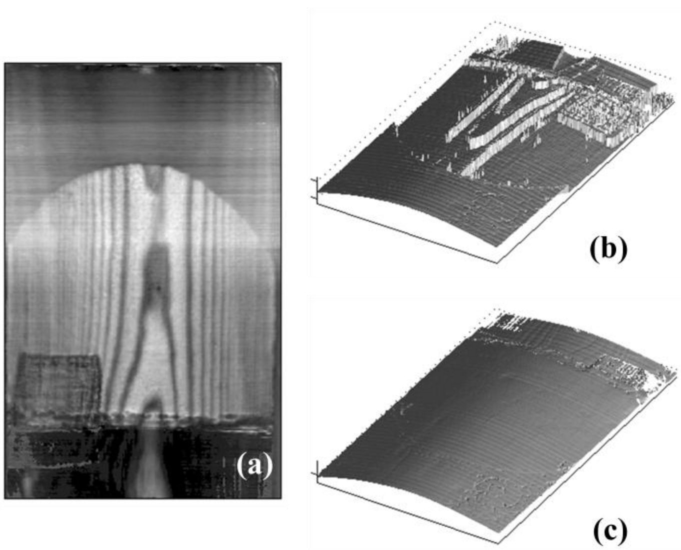

Fig. 2 (a) Image of delayed reflection signal strength. (b) Depth profile of the panel painting, recorded by time-of-flight THz reflectometry. (c) Surface profile of the panel, recorded by time-of-flight THz reflectometry.

The localization of the hidden part of the canvas has been realized in two different ways. First imaging the power integration of the signals, at 20 picoseconds after the main reflection, opening a time window (Fig. 2(a)), and then imaging the time-of-flight of the signals reflected at the ground/canvas or ground/wood interfaces. When these reflections have not been individuated because they are undistinguishable from the noise, the time-of-flight of the signals reflected at the air/panel interface has been used instead. Fig. 2(b) shows the resulting 3D time-of-flight image. If the refractive index of the ground layer of the panel is known, it is theoretically possible to measure the thickness of the buried canvas since the optical path difference corresponding to the time delay is related to the object thickness and refractive index. The relief appearance of the wood in Fig. 2(b) may be due to the fact that the dielectric parameters of the plaster and the denser structure of wood are very similar, so that a significant reflection at the interface between these two media cannot be detected. Fig. 2(c) shows a time-of-flight image of the surface shape of the panel, for a better comparison with Fig. 2(b). The third (Z) axis represents the time-of-flight of the reflected signal, and the 3D representation thus gives detailed information about the shape of the convex surface of the tempera.

In conclusion, we have used a THz imaging device for detailed inspection of the surface and internal structure of a tempera panel replica using different image parameters. The technique has been able to detect the presence of a partially hidden canvas layer, invisible from the surface of the ground surface. It has been shown that terahertz radiation can penetrate extremely thin gold leafs, thus being capable of investigating the integrity of the underlying layer while still clearly identifying the golden finish itself. In this study the pseudo-absorbance parameter has been used to image an artifact and, resulting as a negative of a reflectance image, it has provided enhancement of details. Depth and surface profiles have been plotted using the time-of-flight of the reflected signal at different media interfaces.

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