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Terahertz frequency modulated continuous wave imaging for nondestructive evaluation of painting and multilayer parts

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ABSTRACT

Art conservation terahertz (THz) diagnostics is an increasing field since THz imaging systems are commercially available. Since most of these experiment are done using femtosecond laser base time domain systems, we present in this paper how we can use frequency modulated continuous wave system to evaluate painting during restoration process.

Keywords: terahertz imaging, art restoration, easel painting, frequency modulated continuous wave, non destructive test, millimeter wave.

1. INTRODUCTION

1.1 Context of the study

Cultural heritage conservation science benefits from terahertz applications improvements in imaging and spectroscopy and is now one of the application perspective of terahertz science and technology[1]. Several examples of applications of terahertz radiation have been shown in recent years such as terahertz imaging mural paintings [2–4], oil art historic painting[5], painting on metal [6] or icon painting using terahertz time domain imaging [7]. In this paper, we focus on non destructive test during restoration process using frequency modulated continuous wave system (FMCW). Paintings of museums or individuals undergo aging over time and art restorer repair these defects using techniques that respect the history of the work. Before restoration, non destructive techniques like ultraviolet (UV), infrared (IR), visible light and X-rays are commonly used to analyze these defect. In a previous work, we have shown that it is possible to detect defects by using terahertz radiation in the context of a restoration of a painting with a speed increase compared to time domain imaging[8-9]. In this paper, we show some new results after restoration and compare results from different paintings.

1.2 Experimental systems

We use in this study two main terahertz imaging systems. First, we use a frequency modulated continuous wave system (FMCW). It allows to radar system to take three-dimensional images of objects. FMCW radar generates a continuous ramp of frequencies and then received from any objects the reflection or the transmission signal. It can modulate its operating frequency during the measurement, which means the transmission signal is also modulated in frequency or in phase. In this method, a signal frequency is linearly periodically swept. As shown on figure 1, when an echo signal is received, it accumulates a time delay Δt due to propagation like the pulse radar technique. The second terahertz system, described in [6], is a time domain imaging system (THz-TDI) from Teraview company (TPS 3000) working in reflection mode with a range of working area of 30 × 30 cm and with a frequency from 0.1 to 3 THz. The spatial resolution is from 3 mm to 100 µm depending on the frequency.

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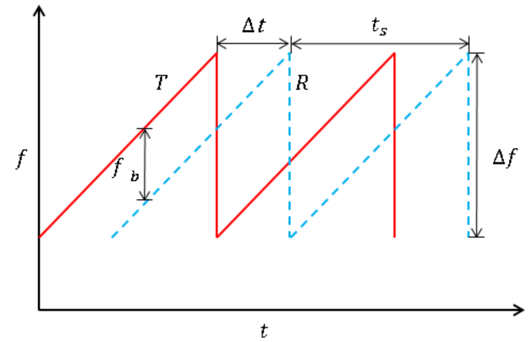


Figure 1 : Basic principle of FMCW representing frequency of the signal as a function of time. Red curce correspond to emited signal and blue to received signal. Time of flight of electromagnetic wave can be calculated from frequency difference of these signals.

2. RESTORATION OF A PAINTING HAVING VOIDS AFTER RELINING

2.1 The painting before restoration

Painting analyzed is an oil painting on canvas depicting a young erudite woman. Painting on figure 2 was analyzed using both FMCW and pulsed imaging. We analyzed and characterized of each type of defect, particularly voids between painting and canvas and underlining glue discontinuities. The terahertz imaging and spectroscopy are likely to be an efficient method for restoration of artwork. FMCW has shown capability to do fast imaging of large painting and detect structural defects, while time domain imaging can be used on limited surface of interest to obtain higher resolution and better multilayer extraction.

Figure 2 : On the left : photography of the painting with white light. We can observe at the right of the painting some cracks. On the right: 300GHz reflection image of the painting. Center: image fusion between visible and millimeter wave. We note the excellent correlation between both and the precise localization of the different defects.

Time domain imaging using Teraview TPS 3000 system allows doing imaging with frequency between 100 GHz and 3 THz in reflection. Figure 3b shows a scan of the head of the painted woman. We can see on figure 3c that the void at the left of the head can be visualized in a crossectional view. This confirms the nature of the void detected with FMCW system.

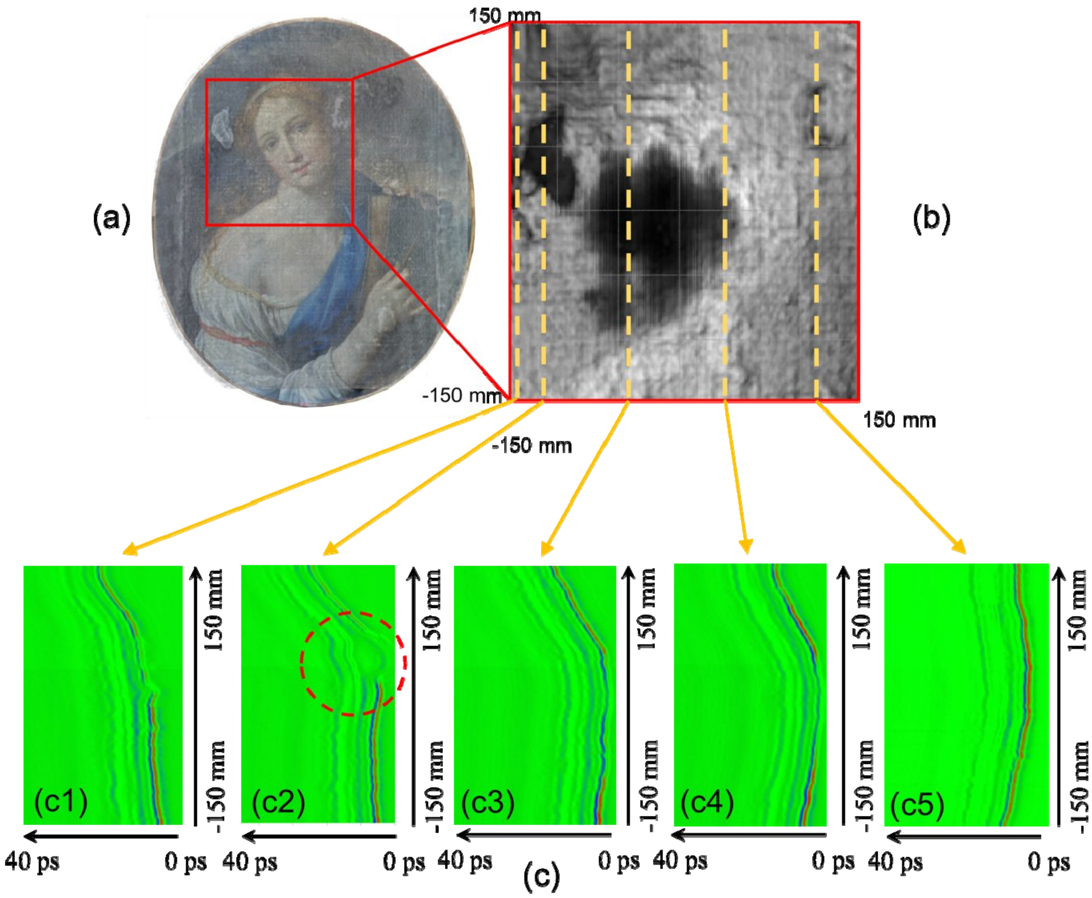
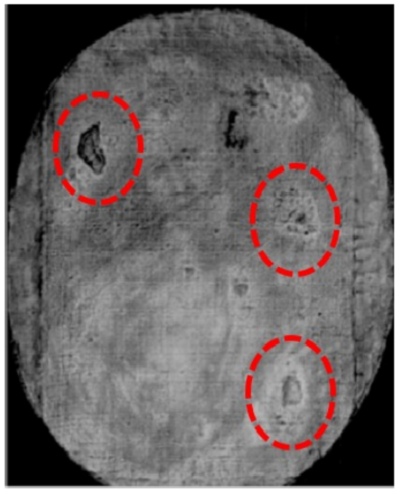


Figure 3 : Analysis of the void at the left of the head
(a) superimposition of the visible image with the signal 300 GHz in reflection
(b) THz time domain image with max peak size parameter
(c) B-scan in the vertical axis for 5 different positions. We can see a space in c2, which corresponds to the position of the void.

2.2 The painting after restoration

The painting was restored with a refixing and a gluing of the pictorial layer on the canvas. For this, there was an injection of rabbit skin glue on the zones of air bubbles inside to join the canvases together. This technique of restoration allows repairing locally the painting avoiding a total relining. We can see on figure 4 that voids have been filled and no longer appears on the image made after restoration.



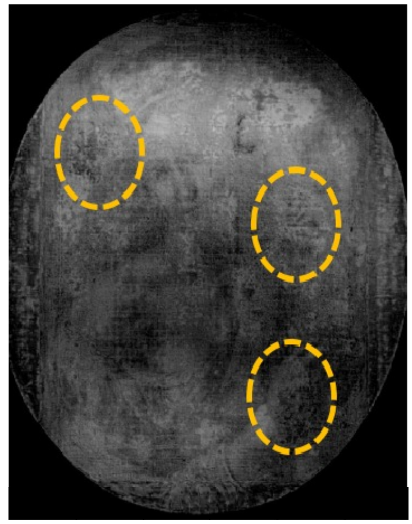


Figure 4 :
On the left: 300GHz reflection image of the painting before restoration. The surrounded areas are air voids between the pictorial layer and the canvas
On the right: 300GHz reflection image of the painting after first step of restoration. The surrounded areas have been restored

3. RESTORATION OF A PAINTING WITH SURFACE DEFECTS

3.1 The easel painting

The painting has been recently restored because of its problematic preservation conditions. In fact, the surface of the painting was found uneven, due to the severe distortions of the frame. Some regions of the painting were showing swelling, while the restorer has detected lifting and flaking of the paint layers, cracks and detachments between the paint layers and between the surface layers and the inner ones. The varnish was yellowed because of aging (Figure 5a).. The conservation treatment consisted in re-adhering the lifted flakes by an adhesive, filling of the inner cracks by filler injections and filling the surface one by a paste filler. The painting distortion has been mechanically reduced. It has been cleaned, pictorially retouched and a new varnish layer has been applied at the end. Figure 5b shows the painting after the structural intervention and figure 5c after the pictorial integration and the application of the final coating.

Figure5:(a)Visible RGB image of the painting before the conservation

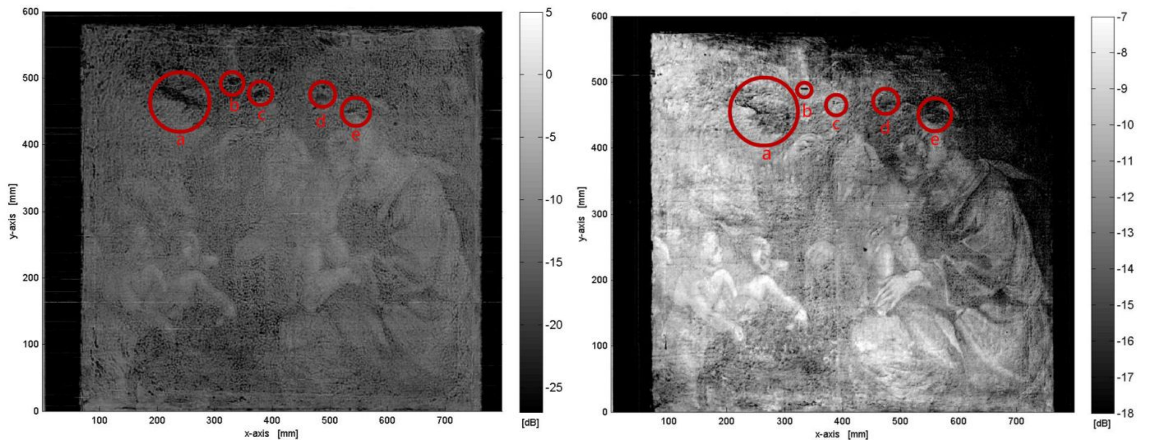
Figure5:(b)Visible RGB image of the painting after the structural treatments

Figure5:(c)Visible RGB image of the painting at the end of the conservation treatment

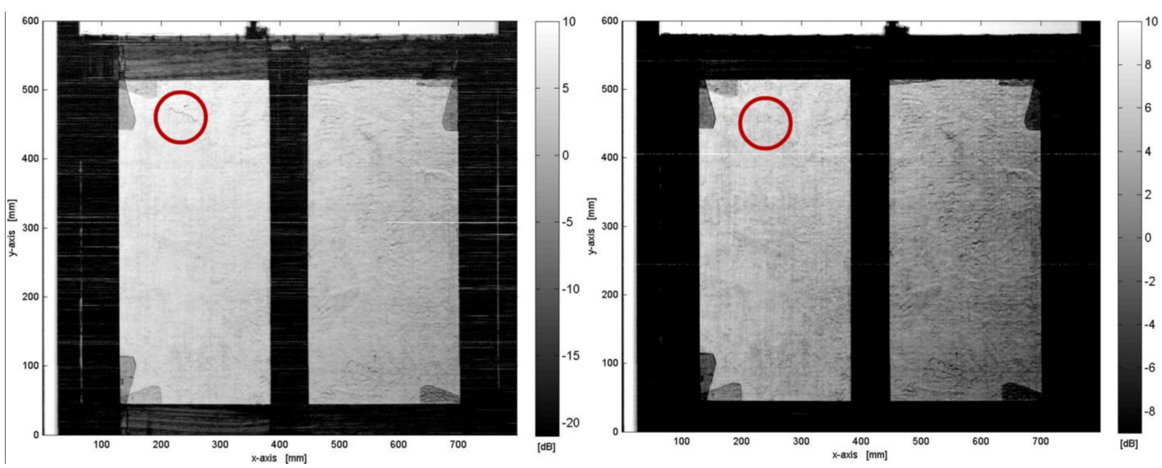
3.2 FMCW analysis before and after restoration

After the paint losses have been filled by the restorer with a filler (compare with Figure 5), the reduction of the dark areas in the reflection THz image is evident (Figure 6a and figure 6b, red circles named a-e), thus providing a confirmation of the success of the filling treatment to the restorer in charge of the intervention. The painting has been scanned before the restoration intervention, after the structural intervention and at the end of the conservation intervention. For data acquisition we used the SynViewHead 300 GHz in both transmission and reflection (normal incidence).

Figure 6(c) and (d) represent the THz transmission images (maximum amplitude of the transmitted signals) of the painting acquired before and after the restoration intervention respectively. The wooden frame of painting is clearly visible in this acquisition mode. A distinct line can be seen in the THz transmission image acquired before the conservation intervention (Figure 6c, red circle), which is compatible with a subsurface crack of the paint material at that location. Also in this case, the THz transmission image of the subject after the in-depth filling operation (Figure 6d) shows that the previously detected crack is not anymore present, confirming again the success of the restoration treatment.



a.Reflection mode with resolution of 3mm on Jan.17th   b.Reflection mode with resolution of 2mm on Mar.12th



c.Transmission mode under 300GHz   d.Transmission mode under 300GHz

Figure 6 :300GHz images of the painting before (a reflection ,c transmission) and after restoration (b reflection ,d transmission)

4. CONCLUSION

We have demonstrated that Frequency Modulated Continuous Waves terahertz (300 GHz) can be proficiently used for detecting conservation problems such as paint layer losses and subsurface cracks in easel paintings. In connection to the mentioned preservation problematics commonly encountered in easel paintings, we have demonstrated that the system can be efficiently used for monitoring and evaluating the associated conservation treatments.

5. REFERENCES

[1] Mittleman, D. M., "Perspective: Terahertz science and technology," J. Appl. Phys. **122**(23), 230901 (2017).

[2] Doria, A., Gallerano, G. P., Giovenale, E., Casini, A., Cucci, C., Picollo, M., Poggesi, M., Stefani, L., Fukunaga, K. and Tamassia, M., "Vis-NIR Hyperspectral and Terahertz Imaging Investigations on a Fresco Painting on 'Tavella' by Alessandro Gherardini," J. Infrared, Millimeter, Terahertz Waves **38**(4), 390–402 (2017).

[3] Jackson, J. B., Mourou, M., Whitaker, J. F., Duling, I. N., Williamson, S. L., Menu, M. and Mourou, G. A., "Terahertz imaging for non-destructive evaluation of mural paintings," Opt. Commun. **281**(4), 527–532 (2008).

[4] Dandolo, C. L. K. and Jepsen, P. U., "Wall Painting Investigation by Means of Non-invasive Terahertz Time-Domain Imaging (THz-TDI): Inspection of Subsurface Structures Buried in Historical Plasters," J. Infrared, Millimeter, Terahertz Waves **37**(2), 198–208 (2016).

[5] Dong, J., Locquet, A., Melis, M. and Citrin, D. S., "Global mapping of stratigraphy of an old-master painting using sparsity-based terahertz reflectometry," Sci. Rep. **7**(1), 15098 (2017).

[6] Koch Dandolo, C. L., Gomez-Sepulveda, A. M., Hernandez-Serrano, A. I. and Castro-Camus, E., "Examination of Painting on Metal Support by Terahertz Time-Domain Imaging," J. Infrared, Millimeter, Terahertz Waves **38**(10), 1278–1287 (2017).

[7] Skryl, A. S., Jackson, J. B., Bakunov, M. I., Menu, M. and Mourou, G. A., "Terahertz time-domain imaging of hidden defects in wooden artworks: application to a Russian icon painting," Appl. Opt. **53**(6), 1033–1038 (2014).

[8] Guillet, J.-P., Roux, M., Wang, K., Ma, X., Fauquet, F., Balacey, H., Recur, B., Darracq, F. and Mounaix, P., "Art Painting Diagnostic Before Restoration with Terahertz and Millimeter Waves," J. Infrared, Millimeter, Terahertz Waves **38**(4) (2017).

[9] Koch Dandolo C,Guillet JP,Ma X,Fauquet F,Roux M.,Mounaix P,"Terahertz frequency modulated continuous wave imaging advanced data processing for art painting analysis",Optics Express26(5) 5358-5367