

TeraPulse Lx for terahertz imaging of painting on canvas

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Abstract. The goal of this study was to detect and inspect the paint layers below the surface independently of any surface features. Using the for THz-TDS imaging system, we obtained contrast images of layers of paint applied to the back side of the canvas. The most difficult task that the researchers have set themselves has not yet been fully resolved. When we try to read the signatures through several layers of paint, background and canvas, we cannot get a clear image of the letters, but we can accurately determine the location of all the signatures.

1. Introduction

One of the most difficult problems for restorers and technologists is non-destructive studies of multilayer coatings. Traditional methods, such as x-ray radiography, infrared reflectography, give a summary picture of all layers and it is almost impossible to determine the sequence of layers and highlight the layer of interest. Terahertz (THz) radiation in the frequency range 0.1 - 10 THz began to be used for the analysis of works of art in 2006 [1, 2]. For this purpose, various THz devices have been tested. The most common systems at that time were terahertz time-domain spectroscopy (THz-TDS-based) systems. Due to the non-invasive properties of THz radiation, such systems allow obtaining data on the structure of an object of art. To obtain such data, it is necessary to detect the reflected THz signal coming from the inner layers of the research object [3-5]. To receive more details about the cultural heritage objects, such as replicas of panels and paintings, ceramic objects, mummies [6] and real paintings [7], continuous terahertz imaging systems (CW-THz) were tested. Just a few years ago, researchers began to apply in the work with objects of art frequency-modulated continuous-wave terahertz (FMCW-THz) systems, which were used to scan ancient mummified samples [8] and paintings [9]. FMCW-THz systems that operate in the reflection mode allows to detect the optical properties of the object structure with a high accuracy level [9] [10]. On the images of the paintings, received from the FMCW systems, the changes which have occurred with the painting over the years of its existence can be clearly seen. Modern terahertz systems for the diagnosis of objects are mainly based on the principles of THz pulse time-domain spectroscopy and raster-scanning focal-plane imaging (RSFPI). The widespread use of these systems is due to their coherent detection approach that allows to provide both the real and the imaginary part of index of refraction [11].

The main goal of this study was to identify layers of paint (test-object) below surface, using the THz object visualization system. In this work, we used a test object, a picture of a human head, (The State Russian Museum, Saint-Petersburg) to check the possibility of detecting inner paint layers



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using a THz imaging system. On the back of the test object were the signatures of the museum restorers. The signatures are made with paints of different colours and compositions. All signatures are covered with a thick layer of brown paint. This study was devoted to investigation of using a terahertz time-domain system for imaging a painting with features both on its surface as well as buried below its surface. Thus, we can demonstrate the efficiency of this method of detecting the inner layers of a picture without violating the integrity of the material. To solve this problem, we needed to make a scan from the front side of canvas, and detect structures on back side of canvas.

2. Materials and methods

It is convenient to study the properties of items of the museum collections and objects of cultural heritage on test-objects that imitate their internal structure, chemical composition, and optical properties in the studied range of electromagnetic waves. The test-object is a matrix material selected for reasons of its proximity to natural objects. Pure pigments without a binder are used as the simplest test-objects, which can be used to study the main parameters of reflection and transmission of electromagnetic waves of different wavelengths. The experiment can be complicated by adding a different type of binder (oil, glue, varnish, resin, wax, etc.) to the dry pigment in order to bring it closer to natural painting. The next step is the application of a pigment with a binder on various substrates that imitate the real bases of paintings and icons (canvas, wood, cardboard, metal, etc.). The most difficult stage, as close as possible to really works, is a creation of multi-layer test-objects, where the layer-by-layer structure of the painting will be reproduced: base, background, paint layer and varnish coating.

Together with the restorers of the State Russian Museum, a complex test object was made, which simulates real tasks that museum specialists must solve. As a basis, a piece of canvas was taken, covered with light background and a painting layer dating from the 19th century. On the back of the canvas, a red-brown background was applied, and on top of this layer was painted a man's head. After that, the sample was turned over and on the other side, our restorers of the oil painting wrote their names and surnames in various colors. When the signatures were dry, they were covered with a thick layer of brown paint so that the relief of the letters was not visible (fig.1). One of the signatures, which was painted in brown paint, was coated with green pigment.



Figure 1. Image of the reverse side of the canvas with signatures applied under brown and green layers of paint (a) and the front side of the canvas with the image of a human head (b).

A TeraPulse Lx system was used to produce ultrafast (~ 100 s fs) terahertz (THz= 10^{12} Hz) pulse incident through the front side of painting and to detect structures on the back side of painting (on canvas) whilst the THz beam was scanned across the painting. The system was also used to detect signatures and features hidden by the brown and green paint on the back side of the painting (on canvas). Traditional optical methods used in the museum do not allow this. Investigated object was a test-paint on canvas approximately 21×22 cm² with features on the front (portrait) and rear (painted stripes). The TeraPulse system had a peak spectral range 0.06 THz – 6.00 THz, peak dynamic range > 95 dB, and was operated in reflection mode using a scanning gantry with a maximum speed of 16 sec per cm², and user-adjustable spatial resolution in the range 0.25 - 0.50 mm, dependent in part on step size chosen.

3. Results and discussion

Two-dimensional images of different layers of the painting were detected and some features of layers were discovered. The figure 2 demonstrates an image of a front surface of a painting in visible spectral range and a THz image of its back-surface.

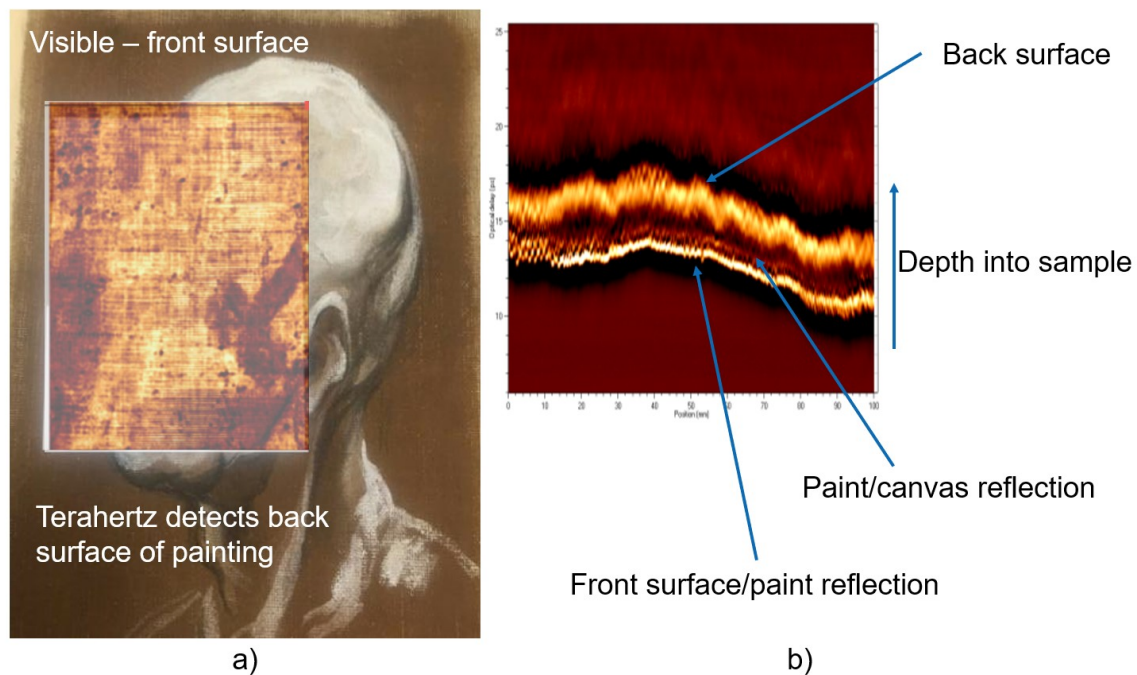


Figure 2. The result of THz visualization of the reverse side of the canvas (a), the highest contrast was achieved at a frequency of 0.5 THz. The right side of the image (b) shows the dependence of the optical delay (from 0 to 25 ps, Y axis) on the spatial coordinate (from 0 to 100 mm, X axis). This plot demonstrates the features of the structure of the object.

Features of the painting, which were located on the back side, were detected by scanning with THz incident through front surface of painting. THz images detected in this manner match the visible image done on the back side of object. In our work, we showed that the THz visualization method allows us to determine the location of signatures with high accuracy, despite two layers of painting, two layers of background and one layer of canvas. This method allows to obtain data on the structure of the layers of painting, regardless of what material is used as the basis, even with a metal plate basis.

4. Conclusion

In this work, we obtained THz images of hidden signatures that were left by museum restorers on the back side of the test-object's canvas. It was demonstrated that in the image obtained at a frequency of 0.5 THz, the layers of paint applied on the other side are clearly distinguishable. Due to the high sensitivity of THz radiation to the distinction between the optical properties of painting materials, this method allows to obtain detailed information about the structure of layers of such objects and determine the shape of invisible elements without damaging the canvas. Thus, the THz imaging method can be very useful in restoration work designing, determining defects in the structure of paintings materials, as well as when searching for hidden objects under layers of paint.

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