Terahertz time-domain imaging of "The Last Supper"

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***Abstract*—The terahertz time-domain imaging technique is applied to investigate the internal structure of "The Last Supper", a masterpiece wall painting of Leonardo Da Vinci. The experimental results support the estimated internal structure based on previous studies by using fragment samples during the last conservation.**

I. Introduction

THE Last Supper (1494-1497, Museo del Cenacolo Vinciano, Milan, Italy) by Leonardo Da Vinci is one of the most important mural paintings in the history, and the painting technique is considered to be different from the common fresco technique, based on the previous investigation using limited number of small fragments taken from the painting. By using terahertz time-domain imaging, we expected that the layer structure of the preparation layers would be revealed, which would provide useful information to investigate the painting technique of the masterpiece.

II. Experimentals

Terahertz (THz) time-domain imaging has been used for internal structure observation of various artworks over the past 10 years [1, 2]. Fig. 1 shows the system used in this study (TeraMetrix T-Ray 5000, Luna Innovations), which was placed on an electromotive lift (Banfi S.r.l.) to observe selected painted areas which are approximately 4 m above the ground. The distance between the painting and the sensor head was maintained at less than 100 mm during the measurement of the four areas of 300 mm x 220 mm.

Fig. 1. Photographs of THz imaging system and electromotive lift.

III. Layer Structure of the "Last Supper"

A typical reflection signal at the position of the originally painted area is shown in Fig. 2(a). The first reflected pulse marked in a red oval line is generated at the originally painted surface, i.e., bright blue area in Fig. 2(b). According to the previous investigation [3], this original color is painted on lead white and calcium-based ground coatings (approximately 0.02 mm in total) on calcium-based preparation layer. The individual layer of paint and ground coatings cannot be easily recognized by THz imaging, due to the lack of its resolution.

The second reflection pulse marked in a yellow oval line appeared 2 to 10 ps after the first peak. The second reflection is considered to be generated at the interface surface of top preparation layer made of mortar with fine sand and/or marble powder. Assuming that the refractive index of this layer is similar to that of a common mortar, the estimated thickness of this top-preparation layer is approximately 1 mm. The third small reflection pulse marked in a blue oval line appeared 40 ps after the first peak. It suggests the presence of another bottom-preparation layer on the base mortar (intonaco).

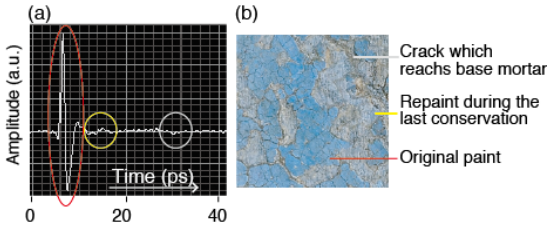

Fig. 2. THz time-domain reflection signal of "The Last Supper", (a) typical output signal from originally painted area, (b) visible surface features.

Fig. 3 describes an example of THz reflection imaging results of the Last Supper. The THz reflection image (Fig. 3(b)) is obtained by integrating the power of the reflected pulse over the entire time window at each point, using a 1 mm step, in the area in Fig. 3 (a). Here, the originally painted part is missing together with the upper-preparation, in the area indicated as the circle A and the rectangle B, so that the first reflected pulse in the missing area is generated at the bottom preparation layer. The cross-section images shown in Fig. 3 (c) clearly show the missing parts. Although the surface condition strongly affects the THz image, similar internal layer structure was observed in each observation area. The reflection signal from the originally painted area is large, as shown in the rounded rectangle area C in Figs. 3(b) and 3(c). Thus, the THz area image could be used to identify the remaining area of the original painting. These experimental results confirm that this painting has a different internal structure than common murals painted in the traditional fresco technique, as estimated in previously studies.

Based on a typical cross-section image shown in Fig. 4(a) and the microscope observation of fragment samples performed

in previous investigations [3], the layer structure near the surface of this painting is estimated as shown in Fig. 4(b). A bottom-preparation layer, which is thinner than 'giornata' for the common fresco technique, was made with fine sand aggregate on the base mortar (intonaco) layer. Then, another top-preparation layer was made with fine sand and/or marble powder as aggregate. To paint with pigments and binders, such as animal glue, ground coatings with white pigments including calcium carbonate or lead carbonate were added. Since the total thickness of ground coatings and paint layer is less than 0.1 mm [3], it is extremely difficult to distinguish each layer by THz imaging.

In order to examine the effectiveness of THz technology on such a specially created artwork and wall paintings in general, we fabricated a model shown in Fig. 5(a), focusing on the top-preparation area, which was formed with marble powder as the aggregate of which grain size is less than 10 microns. The thickness was either 0.5 mm or 1 mm. The base mortar was made with common sand-aggregate, containing a missing area on a brick plate. Ground coating with lead- and calcium-based white pigments were painted with animal glue, as well as blue pigments in some areas on the top. Although the THz waves are greatly attenuated inside the base mortar (intonaco) layer, as shown in Fig. 5(b), the top-preparation layer was clearly observed, and the difference in thickness was recognised. This result supports the estimation described in Fig. 4.

IV. Inside the Preparation Layers

One of the advantages of the time-domain imaging is that the condition of the mortar layer can be examined by extracting area images at given depths. For example, the authors proved that the mortar layer of a Japanese mural painting in the 8th century had an internal air gap [5]. Fig. 6 shows example images of the observation area shown in Fig. 3 (a). The high reflection from the originally painted area disappears at the depth of 0.3 mm, and the image becomes relatively homogeneous. Although no significant peaks appeared inside the mortar layers, tool-mark like images appeared at the depths of approximately 1 mm and 3.5 mm, which correspond to internal interfaces.

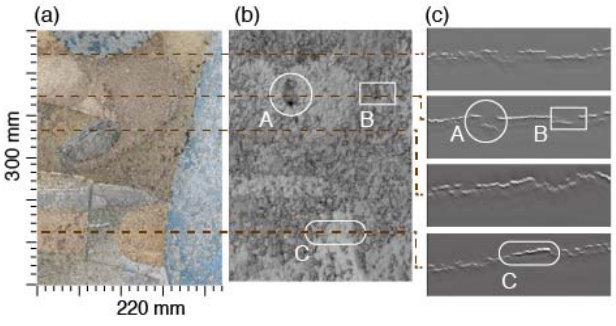

Fig. 3. Examples of THz time-domain imaging of "The Last Supper", (a) one of the observation areas, (b) a THz area image, (c) cross section images along the dashed lines in (a) and (b).

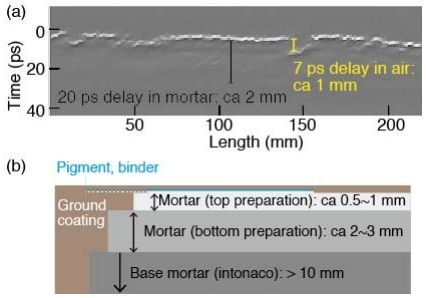

Fig. 4. Estimated layer structure near the surface, (a) cross section image, (b) model of layers from base mortar to painting.

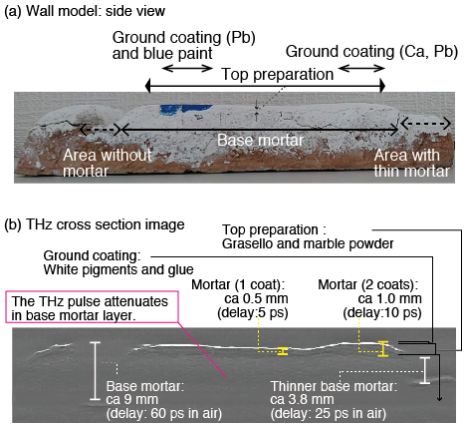

Fig. 5. A model experiment for internal layer observation, (a) side view of the specimen, (b) a cross-section image.

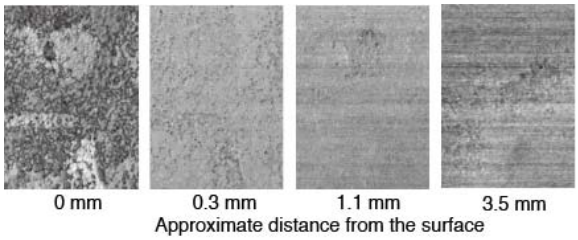

Fig. 6. THz area images at each depth.

V. Conclusions

The mural painting "The Last Supper" by Leonardo Da Vinci was investigated using the THz imaging method. Although it is essential to use various examination methods to understand the painting technique, the preliminary results support the hypothesis on the internal structure estimated from previous studies which used a limited number of small pieces taken from the painting.

References

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