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A comparative study of infrared, terahertz and air-coupled ultrasonic NDT for cultural heritage

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Abstract

This work is based on a comparative study of three Non-destructive Testing NDT techniques for the inspection of an old book that was bound in the XIXth century. Infrared thermography (IRT), terahertz time-domain spectroscopy (THz-TDS) and air-coupled ultrasonic C-scan (ACU) were used to retrieve both damages and defects in the book cover. Then, the results were compared and analysed; in addition, specific defects were determined and explained via a comparison. Advanced image processing techniques were applied in order to highlight the shapes of subsurface features.

1. Introduction

NDT has magnificently been described into cultural heritage (CH) field recently. In fact, the detection of subsurface defects such as splitting, cracks, tunnels caused by wood-worms, foreign materials due to ancient restorations are all concerns for restorers. Although an array of analytical techniques is useful in the cultural heritage field, the prevention can be considered the best practice nowadays. Thus, NDT (that do not require collection of material) is of paramount importance.

In this work, the authors studied the advantages of various NDT techniques for detecting the conservation status of an ancient book. Because ancient books may be damaged, defected and/or built with different materials, what is visible to the naked eye sometime doesn't exactly line up with the hidden reality. This explains why the use of NDT techniques exploring a large set of wavelengths (i.e., different depths in the sample under testing – SUT) is highly desirable.

In this extended abstract, infrared thermography (IRT), terahertz time-domain spectroscopy (THz-TDS) and air-coupled ultrasonic C-scan (ACU) were used to retrieve damages from the book cover side. Interestingly, additional defects were also detected because the SUT was handmade. Image processing techniques including Fast Fourier Transform (FFT), peak-to-peak and time-delay analysis in time domain were applied to the raw images to highlight the shapes of subsurface features. Finally, a comparative study of these techniques was conducted to summarize pros and cons.

2. Materials

In this study, the SUT is an ancient book. It look like a children's book, published in Paris, France. The translated title (from French to English) shown on the book cover means «The little illustrated student». It belonged to Dr. Xavier Maldague's grandparents; the book was preserved in his parents' house. The purpose of the present study is the detection of possible damages and defects, as well as the evaluation of sub-surface features by trying to understand the execution phase of that time. In particular, the width of the book is 18 cm, the length is equal to 27 cm, and the height is 3 mm (book cover).

3. Results and discussion

Fig. 1 represents the result of inspection from the front side of the book cover acquired in frequency domain (0.1Hz); in particular, a series of black dots in the amplitude result (see the orange dotted rectangle for reference) are evident. They can also be seen in Fig. 2; presumably, they are related to a variation of the heat conduction caused by defects due to woodworms. Also, an irregular pattern (see the red dotted oval on the right side of Fig. 1) in the phase image resembles to a crack. As part of it, the whiter curved line (i.e., a part of the crack) may acts as starting point for a possible humidity ingress. Seeing the phase result of THz (Fig. 3(d)), this defect is still detectable (see the red dotted oval for reference) at the same position. Since this defect become evident only at higher frequencies, it should be located near the front side of the book cover.

Moreover, there are two black dots in the phase result of Fig. 1; the first one located below the letter “T” (pointed out by a blue arrow), and the second one inside the laurel wreath (see the yellow dotted circle). The latter cannot be seen to the naked eye in the photograph taken from the front side of the book cover. They should be foreign materials added accidentally during the manufacturing of the book. However, these two signals also appear in Fig. 2 and Fig. 3. Fig. 2 shows the THz-TDS inspection results. The time-domain peak-to-peak imaging reflects the absorption characteristic of the sample for the entire THz radiation. Therefore, dark points in the peak-to-peak imaging can surely be linked to different absorption coefficients of the material inspected with respect to the surrounding area. In the time-delay imaging (based on a correlation among the thickness and the refractive index information of the sample), the dark points matching with the whiter areas. This indicates a different thickness due to the longer time delay.

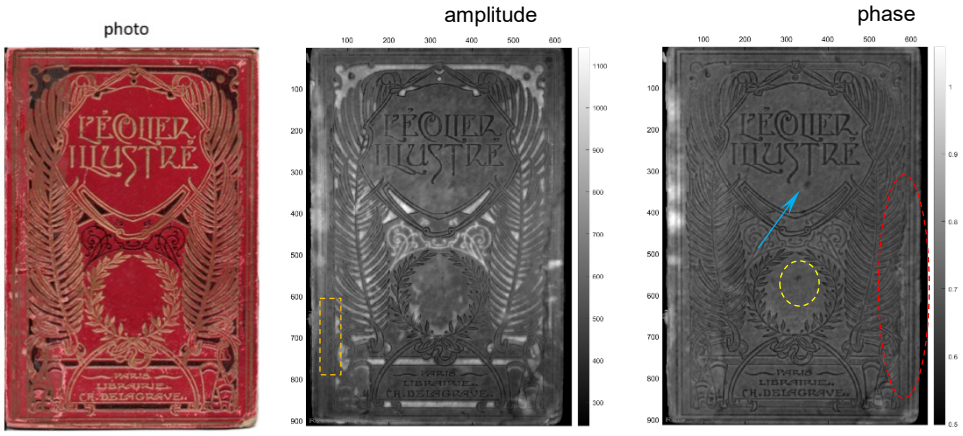

Fig. 1. *IRT: front side photograph (on the left), amplitude (at the center) and phase (on the right) result at 0.1Hz.*

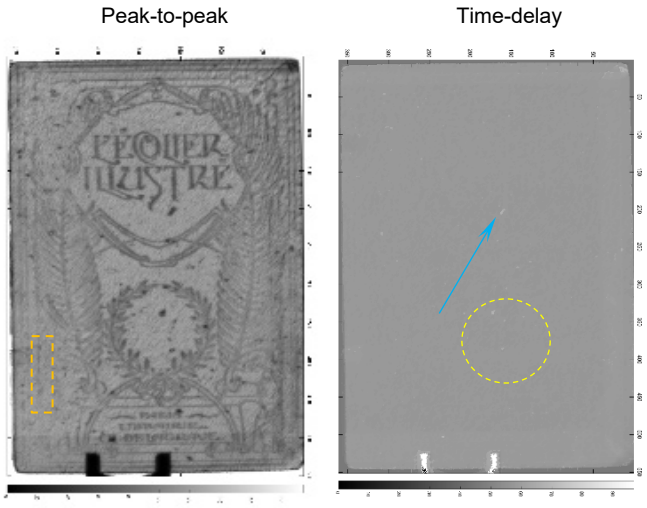

Fig. 2. *THz-TDS: peak-to-peak (on the left) and time-delay (on the right) result.*

In the amplitude image of THz technique (Fig. 3a and 3b), the dark points appear more evident at lower frequencies; this means that they are located deeper. Fig. 3(c) and 3(d) show the phase results at 0.28 THz and 0.79 THz, respectively. They are related to the refractive index at the corresponding frequencyy providing thickness information. The signals discussed above can be detected more clearly in Fig. 3(c) having a higher resolution.

In addition, in the time delay imaging (Fig. 2), the pattern on the book is obscure. This is caused by the limited depth resolution. In this case, paper can be considered as a random assembly of individual particles, namely fibres and pigments; thus it is hard to measure the propagation of light in paper. However, it is possible to say that the resolution in depth is larger than the thickness of the pattern printed on the book cover.

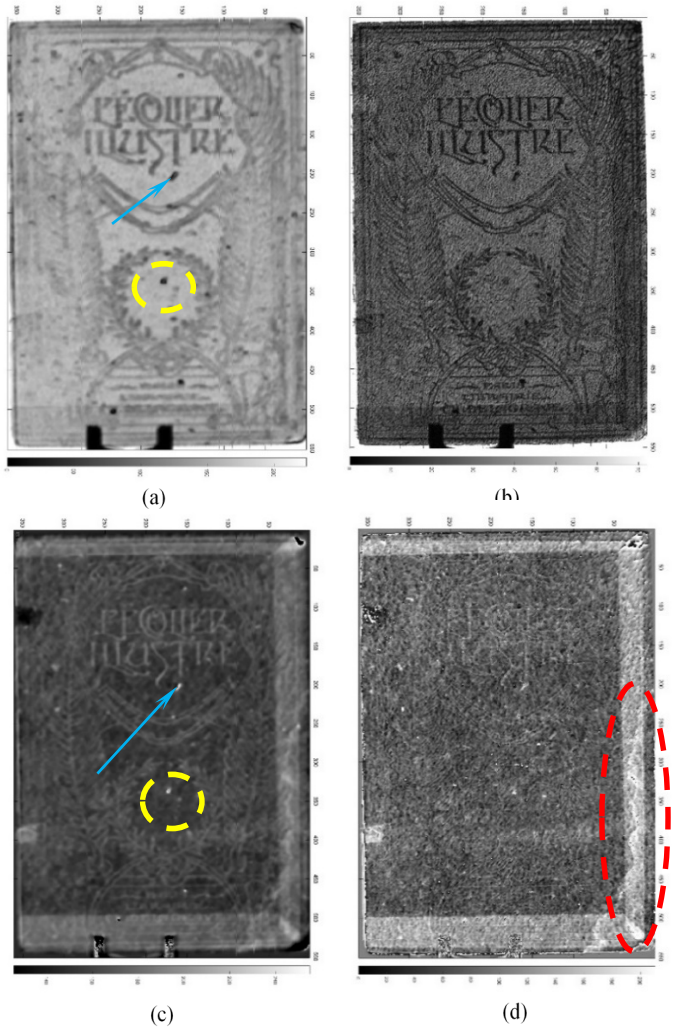

Fig. 3. *THz-TDS frequency domain: amplitude results at (a) 0.28THz and (b) 0.80THz, and phase results at (c) 0.28THz and (d) 0.79THz.*

4. Conclusions

In this work, both IRT and THz techniques were able to retrieve interesting information concerning materials forming the entire book cover. In particular, IRT shows the material thermal properties from a qualitative point-of-view. It should be noticed that THz technique can be used to analyse absorption coefficients related to materials, as well as the refractive indexes linked to its thickness. Moreover, while IRT shows interesting details at high resolution (thanks to the thermal camera used), THz results display several information concerning the identification of defects. FFT were used in all methods by providing both amplitude and phase patterns.

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