PORTO – PORTUGAL 2020, 6-10 JULY
10.21611/qirt.2020.107
15th Quantitative InfraRed Thermography Conference

Contribution to the improvement of the detection of defects located in heritage by stimulated infrared thermography associated with a spatial reassignment of the color dynamics of thermograms

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Abstract

In the context of the conservation of works of art from the cultural heritage, stimulated infrared thermography allows the non-destructive detection of the presence of defects invisible to the naked eye. However, images obtained with a thermal camera are sometimes difficult to interpret directly. Indeed, optical parasitic effects due to absorptivity variations in surface or excitation inhomogeneities can lead to detection artifacts. To reduce these effects, it's possible to use post-processing algorithms. The work we present here follows this framework. We show first theoretically, then experimentally, that a spatial re-allocation of the colorimetric dynamics of the obtained image makes it possible to significantly reduce these parasitic radiative effects. The theoretical study is based on a simulation, using finite element methods, the experimental part was developed on a plaster block containing 32 defects and a multicoloured paint layer.

1. Introduction

Stimulated infrared thermography applied to the preservation of heritage allows the non-destructive detection of defects invisible to the naked eye [1-72]. However, images obtained by thermography are sometimes difficult to interpret: optically-induced parasitic effects resulting from variations in surface radiative properties, or excitation inhomogeneities, can lead to detection artifacts. Researchers suggest the use of post-processing algorithms to remedy these difficulties. The work we present here falls within this framework. In the latter, we study the possibilities of a spatial re-allocation of the colorimetric dynamics of thermograms. The idea is a total re-allocation of the colorimetric dynamics for each color of the pictorial layer.

Our study is based on a theoretical study and an experimental study.

The theoretical study is conducted using finite element modeling of the photothermal experiment developed on a sample containing six defects and a bicolour paint layer.

The experimental study is conducted using the THERMO-ART system associated with the IR EXPLORER software package. The experimentally analysed sample is a plaster block containing 32 defects and a multicoloured paint layer.

The results obtained, at both theoretical and experimental levels, clearly show that a spatial redistribution of the colorimetric dynamics of the image obtained allows a significant reduction of the parasitic radiative effects and therefore a better detection of defects.

2. Theoretical study

The theoretical study we have developed is based on a modeling of the pulsed photothermal experiment applied to a sample containing six defects and a bicolor pictorial layer.

This theoretical sample is presented in Figures 1 and 2. It is a rectangular block of plaster (as its thermophysical properties are very close to those of a mural). Its geometrical dimensions are a length of 160 mm, a width of 120 mm and a thickness of 20 mm. Its thermophysical properties are a thermal conductivity of 0.4 W/mK, a density of 1100 kg/m3, a heat capacity of 830 J/kg K, i.e. a thermal diffusivity of 4.38 10-7 m2/s. In order to simulate the presence of displacements, we considered six air gaps placed in this sample. We considered that these defects were parallelepiped and had the same geometrical dimensions. Their length and width are equal to 20 mm. Their thickness is equal to 4 mm. Their depths vary from 2 mm to 12 mm in steps of 2 mm (the sample is scanned from top to bottom and then from left to right). The thermophysical properties taken into account for these defects are those of air at 20°c: a thermal conductivity of 0.026 W/mK, a density of 1.17 kg/m3, a heat capacity of 1006 J/kg K or a thermal diffusivity of 2.22 10-5 m2/s. Finally, in order to simulate the optical effects induced by the paint layer, we divided the surface of our sample into two parts. The first covers the defects located at 4 mm, 8 mm and 12 mm depth. The second part covers the defects located at 2 mm, 6 mm and 10 mm deep.

On the other hand, we have imposed on the second one a flow 1.5 times more energy than on the first one. The type of excitation signal considered is a crenel. Its duration is equal to 2 seconds. The analysis time is 200 seconds. The acquisition frequency is equal to 1 Hz. The energy power set is 1500 W. We considered, a model without losses. Finally, the resolution of the differential system associated with the problem was done using the finite element method.

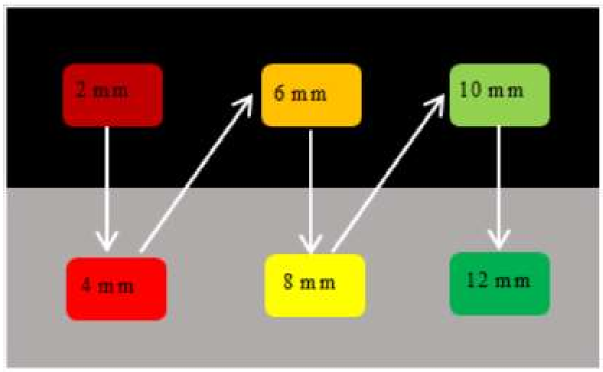

Fig. 1. *The theoretically studied sample (top view)*

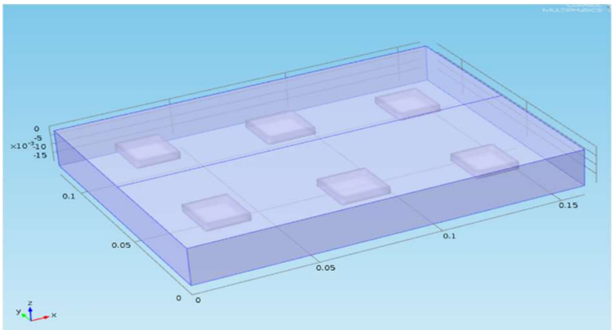

Fig. 2. *The theoretically studied sample (side view)*

Figure 3 shows an example of a theoretical thermogram obtained. This is the instant of observation t = 200 s after the end of the excitation. It first clearly shows larger photothermal signatures at the defects, which allows their detection. He then shows that these signatures are all the weaker as the depth of the defects increases. Finally and most importantly, it shows the presence of two bands, blue and red, due to the inhomogeneity of the energy deposit. The latter clearly disturbs the detection of the defects.

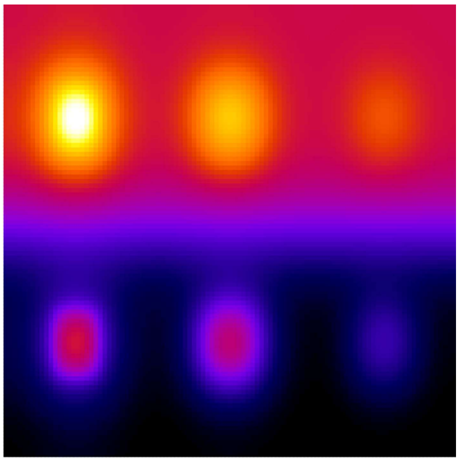

Fig. 3. *Example of a theoretical thermogram obtained (t= 200 s)*

In order to reduce this disturbing effect of the paint layer, we proceeded to a spatial reallocation of the color dynamics of the thermograms. For this, we considered the visible image of the sample surface. The latter was then spatially cut out according to the colour of the pictorial layer. In our case study, this led to the definition of two spatial zones (figure 4).

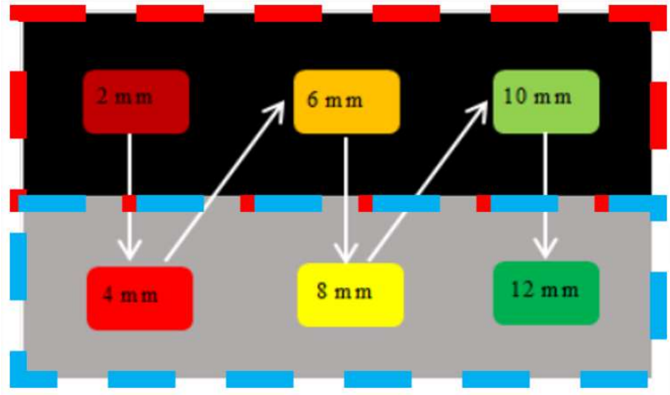

Fig. 4. *The two areas of analysis chosen*

The data cube of the thermographic film was then cut successively according to these two areas. For each of these areas, the entire dynamic range of the digital coding was reallocated. An example of the result obtained is shown in Fig. 5. This is the spatial reallocation of the thermogram colour dynamics shown in Fig. 3. This figure clearly shows the interest of this post-processing technique. Indeed, photothermal signatures appear more important at the position of these defects. These signatures are always correlated with the depth of these defects. It shows finally and above all, the notable reduction of the disturbing effect of the pictorial layer on the detection of defects.

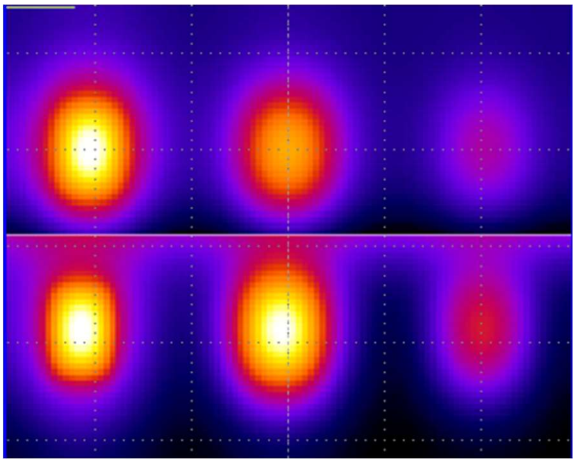

Fig. 5. *Example of theoretical thermogram obtained after post-treatment (t= 200 s)*

3. Experimental study

As the results obtained during the theoretical study were very encouraging, we proceeded in a second stage to an experimental study.

The sample studied is a block of plaster (because its properties are close to those of a mural painting) containing 32 defects and a multicoloured pictorial layer (figures 6 and 7). Its dimensions are a width of 68 cm, a height of 50 cm and a thickness of 5 cm. The back side of this sample was manufactured in order to introduce 32 defects. These are 2 mm thick polystyrene inserts positioned 5 mm deep (pictorial layer). The diameter of these defects is 30 mm.

The paint layer includes 20 different colour space zones. 10 areas have an approximate size of 16 cm * 16 cm. The other 10 areas have a dimension of roughly 8 cm * 6 cm.

Defects are evenly distributed throughout the sample in order to cover the total surface area of the sample.

Fig. 6. *The sample studied (front view)*

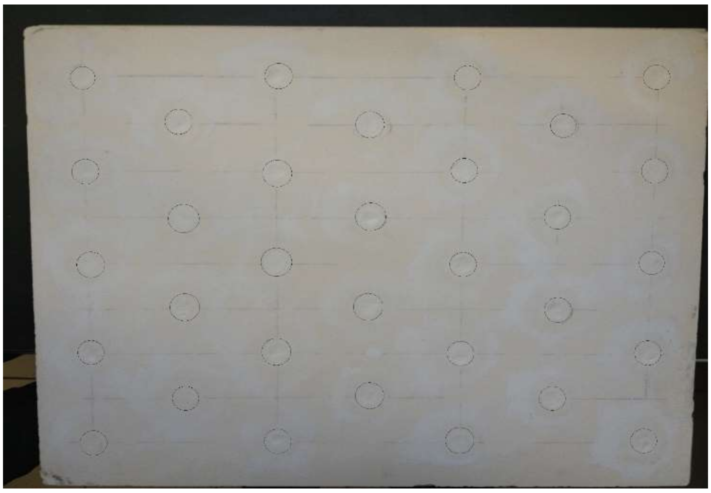

Fig. 7. *The sample studied (rear view)*

The experimental device used is the "THERMOART" system (Figure 8). This device is divided into three parts. The first part is the excitation source. Among all the options offered by the "THERMOART" system, we have chosen to use a pair of 500-watt halogen lamps. They are placed on either side of the infrared acquisition system and about 50 cm from the sample being studied. The excitation angle is about 45 degrees to the normal direction of the test sample.

The second part of the "THERMOART" system is the infrared collection optics. This consists of an infrared thermography camera type FLIR SC 655. The reason for choosing a bolometer camera is that wall paintings are thermally slow materials. It is also explained by the moderate cost of the instrumentation. This camera is also placed at about 50 cm from the sample under study (between the halogen lamps). Note that the optics of the camera has an optical aperture of 50 degrees, in order to observe the entire sample.

The last part of the "THERMOART" system is a computerized data acquisition and processing system. For the acquisition, we used the FLIR Researcher 2.10 software package. As regards data processing, we used the "IREXPLORER" software package developed at the ITHEMM laboratory and in the process of technology transfer (URCA / CICRP / SATT nord, figure 10). The spatial reallocation function of the software's colorimetric dynamics was used.

Fig. 8. *The "THERMOART" system used*

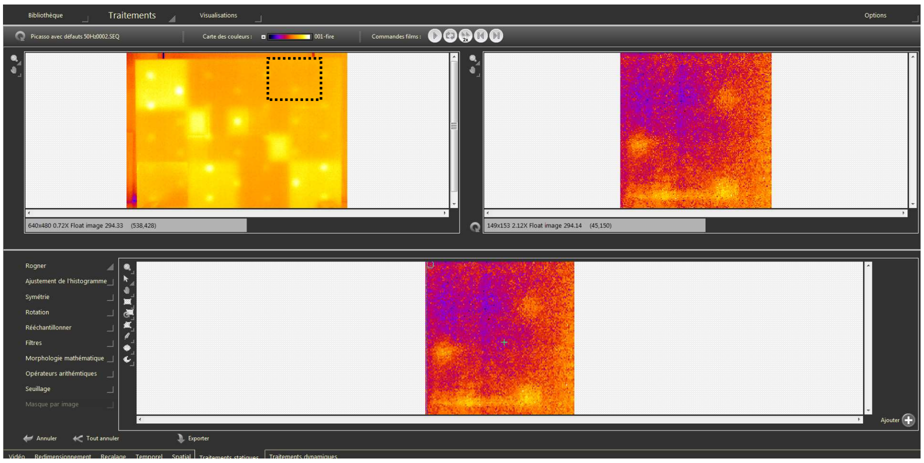

Fig. 9. *The "IREXPLORER" software package used*
(Treatment of the upper right green square of the multicolour sample analysed)

Finally, the excitation and analysis conditions selected are: an excitation time of 60 seconds and a total analysis time of 180 seconds.

The best experimental thermogram obtained from this analysis is shown in Figure 10. This figure shows that the method allows the detection, with more or less contrast, of almost all the defects located in the sample studied. It also shows that the parasitic effects induced by the pictorial layer perturb the detection of defects because they significantly affect the contrast.

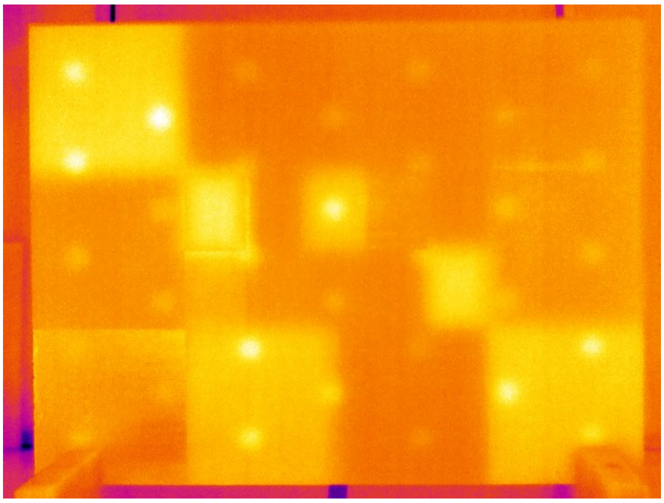

Fig. 10. *raw experimental thermogram obtained during the analysis of the multicoloured plaster block.*

In order to try to improve the detection of these defects, we proceeded to a spatial reallocation of the colorimetric dynamics of the previous thermogram. For this we proceeded as a theoretical study. The areas of spaces considered are the different rectangles of colours which were treated one after the other. We have successively attributed to them all the dynamics allowed by the digitization and we have reconstructed the synthetic thermogram presented on figure 11. This figure clearly shows that this post-processing of the data allows a notable improvement in the contrast of the photothermal signature of the defects and thus a better detection of the latter.

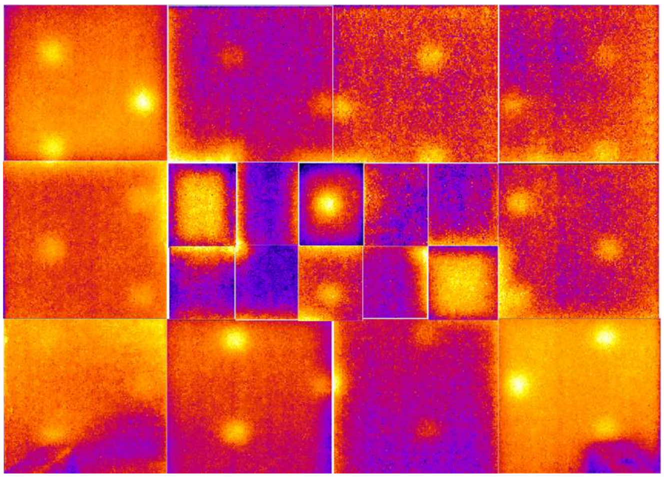

Fig. 11. *result obtained after spatial reallocation of the colorimetric dynamics of the thermogram resulting from the analysis of the multicolored plaster block.*

4. Conclusion

The work presented in this study aimed to approach the possibilities of a particular signal processing: the spatial reallocation of the colorimetric dynamics of experimental thermograms in order to improve the detection of defects located in heritage wall paintings. It is more particularly the parasitic effects induced by the pictorial layer (multicoloured by nature and therefore not absorbing the exciter flux in the same way) that we wish to reduce.

With the help of two theoretical and experimental studies, we have clearly shown that this numerical tool allows a notable increase in the photothermal contrast located in the plumb line of the defects studied and a significant improvement in the possibilities of detection of the latter.

These studies carried out in laboratories on representative martyr samples now need to be developed for in situ analysis of works of art from the cultural heritage. Studies in this direction are under way.

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