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Comparative examples of the evolution of thermal cameras in artwork diagnostics: an experimental perspective

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Abstract. In cultural heritage diagnostics, thermographic methods have gained great importance. The main reasons for their widespread use are the ability to allow remote and wide-field imaging of hidden features (such as structural defects, materials diversity, and deep alterations) as well as the vast possibility to gain additional information through quantitative data processing. The technological evolution of thermal cameras has also played a very important role.
In this article, we want to discuss the effect that this evolution has had on cultural heritage diagnostics. We will do this from an experimental point of view, i.e., by comparing on laboratory models and then in a real case, the behavior of different thermal cameras.

Keywords: IR thermography, thermal cameras, cultural heritage.

1 Introduction

Nondestructive diagnostic techniques for cultural heritage are very important tools [1,2]. Among them, infrared methods are of great interest. They can be broadly classified in two categories: methods based on the reflectance response of the materials (i.e., reflectography) [3,4] and methods based on the thermal emissivity response of the surface (i.e., thermography) [5,6].

Reflectographic methods in the traditional band up to 2.5 μm can "see" pictorial features below the surface, such as preparatory drawings and repaintings [7-9]. The approach based on the reflectance response has been recently extended to the MWIR band (from 3 μm to 5 μm), allowing to detect features not visible otherwise [10,11].

Thermographic methods, in the MWIR and especially in the LWIR range (from 8 μm to 12 μm), can be used to recover information about deep structures, such as internal defects and lack of homogeneity [12-15]. To extract more information, different methods can be used together, e.g., coupling holography and thermography [16-20] and reflectography and thermography [21-25].

As said, in cultural heritage diagnostics thermographic methods are extensively studied. Main reasons for their widespread use are the ability to allow remote and wide-field imaging of hidden features (detachments, cracks, materials diversity, and deep alterations) as well as the vast possibility to gain additional information through quantitative data processing. Examples of different artworks investigated by IR thermography are frescoes, panel paintings, mosaics, ancient books, statues, and buildings.

The technological evolution of thermal cameras has also played a very important role. In recent decades, IR cameras shifted from expensive, difficult to use and heavy systems to more affordable, usable, and portable ones. Recently, thermal cameras also entered the consumer market as low-cost cameras (e.g., FLIR C2, SEEK Shoot), and smartphone accessories (e.g., FLIR One, SEEK Compact) [26,27].

In this paper, we want to discuss the effect of this evolution on cultural heritage diagnostics. We will do this from an experimental point of view, i.e., by comparing on laboratory models and then in a real case, the results obtained by different thermal cameras.

2 Thermal cameras

		Year	Image Resolution	Temperature Range	Thermal Sensitivity / NETD
FLIR T1020		2021	1024 x 768 Ultra Max 2048 x 1536	-40 – 2000 °C	<20 mK @ 30°C
FLIR S65 HS		2005	320 x 240	-40 – 1500 °C	<50 mK
Avio TVS-2000MkII		1995	256 x 200	-40 – 300 °C	<100 mK @ 30°C
FLIR One		2016	80 x 60	-20 – 120 °C	<100 mK

Fig. 1. The thermal cameras used in this work with their main features.

The thermal imaging cameras used in this work, shown in Figure 1, can be considered representative of different generations of devices. The AVIO thermal imaging camera, from 1995, is characterized by rather low resolution and thermal sensitivity, for the current possibilities, but above all it presents low portability due to its size and the need for Stirling cooling of the sensor.

The FLIR S65 HS, about a decade later, has better thermal sensitivity, increased resolution, and excellent portability. It can be connected to a PC. The currently available FLIR T1020 offers the same excellent portability, greater flexibility due to interchangeable optics, improved thermal sensitivity and exceptional resolution. Finally, the FLIR One, a smartphone accessory, has been included as an example of a consumer market device, characterized by relatively low performance but exceptional size and portability with an extremely competitive cost.

3 Artwork models

Laboratory models are very useful in artwork diagnostics. Usually, they are realized with the same techniques and materials of original artworks, but they also include typical defects, whose nature and location are, therefore, well known.

The two models used in this work, a fresco, and a painting on wood, were made in our laboratory between 1995 and 1998. They were later used extensively also by other research groups. The dimensions of the models are the following:

- painting on wood: 21.5 cm (H) x 15 cm (L) x 1.8 cm (W)
- fresco: 41.5 cm (H) x 27 cm (L) x 9 cm (W).

Details on the models are given in [16, 17] while examples of experimental results can be found in [16, 17, 28, 29]. Figure 2 shows the model of the painting on wood.

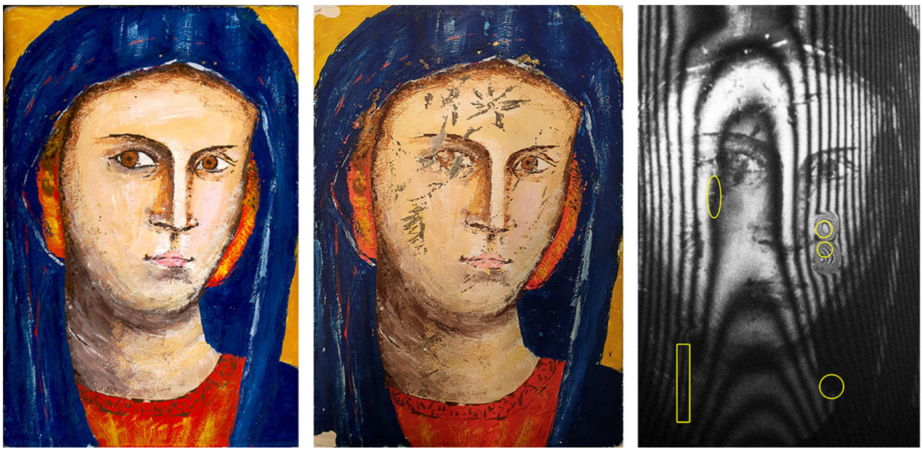

Fig. 2. The wooden painting model in 2000 (left), in 2022 (center) and inspected by holographic interferometry with defects position shown.

Figure 3 shows the model of the fresco. As can be seen, the models degraded with years.

Fig. 3. The fresco model in 2000 (left), in 2022 (center) and inspected by holographic interferometry with defects position shown.

4 Experimental results

In this section we provide a comparison of the experimental results obtained by different thermal imaging cameras, first on laboratory models and then on a real case.

4.1 The wooden panel model

It was realized on old poplar wood using the traditional techniques, thus on layers of canvas, gesso, and glue. Detachments were simulated by inserting thin mylar sheets between the layers. The approximate positions of the defects are shown in Fig. 2, right. Details about their estimated dimensions are given in [28,29].

Figure 4 shows a first comparison of the experimental results that clearly highlights one of the major differences between the instruments: their resolution. For all images, we referred to native resolution.

The resolution of the FLIR T1020 is about 10 times larger than that of the FLIR S65 HS. This is a major improvement. In artwork diagnostics, there are several techniques (e.g., traditional photography, reflectography…) that offer very high resolutions. Thermography cannot compete with these but recent instruments, of which the T1020 is an example, improve the situation considerably. T1020 also offers an image enhancement technology, Ultra Max: a series of images are acquired in a rapid burst and then combined into a single new image with higher resolution.

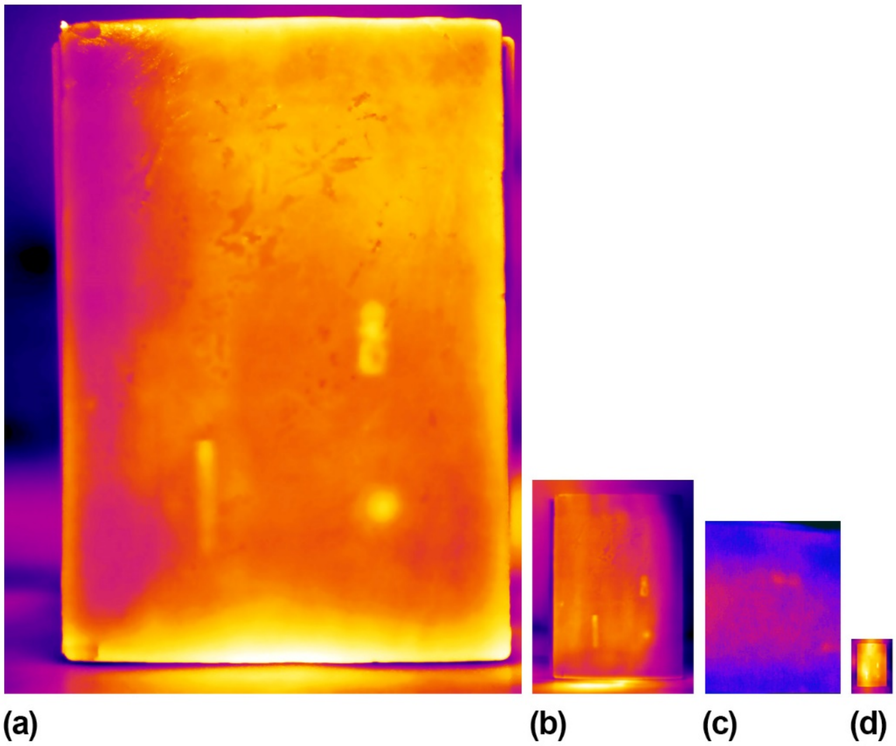

Fig. 4. Experimental results on the wooden painting, obtained by the different thermal cameras, are presented. Images dimensions are proportional to the resolution of the devices. (a) FLIR T1020; (b) FLIR S65 HS; (c) AVIO TVS-2000MkII; (d) FLIR One. For ease of comparison, (c) is rotated of 90° counterclockwise.

To better compare the results, in Figure 5 the images are presented with the same dimensions.

The first remark concerns the FLIR One. Despite the poor definition and the lower thermal sensitivity, the device is still able to reveal the defects. Therefore, this type of cameras can be useful for a first screening. Thanks also to their low cost, they can contribute to a wider diffusion of the technique. However, any more serious investigation requires better performing devices. AVIO, a camera now more than 20 years old, also suffers from rather low sensitivity and resolution.

The results of the T1020 and S65 HS seem similar at first glance, however the T1020 is a much better performing instrument. Its higher resolution is decisive when magnifying the images. In addition, the defects of this laboratory model are rather large, and thus relatively easy to reveal.

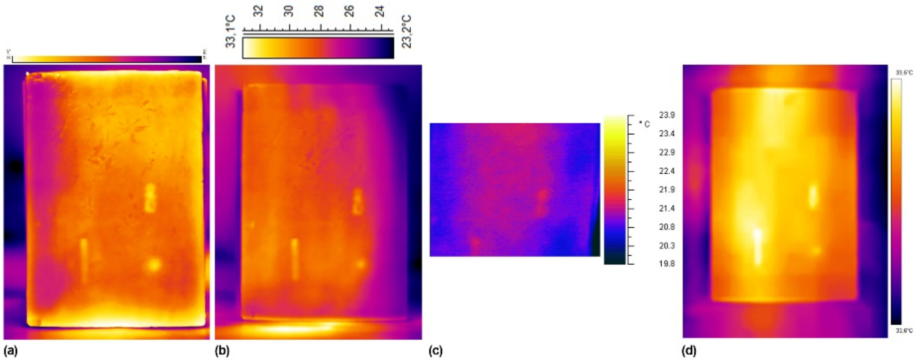

Fig. 5. Experimental results on the wooden painting, obtained by the different thermal cameras, are presented. (a) FLIR T1020; (b) FLIR S65 HS; (c) AVIO TVS-2000MkII; (d) FLIR One.

4.2 The fresco model

This model was realized with non-homogeneous material of the support, to simulate typical irregularities of ancient walls. Four defects were originally inserted (D1-D4 in Fig.3, right): two air voids and two sponges. Details about their dimensions are given in [17].

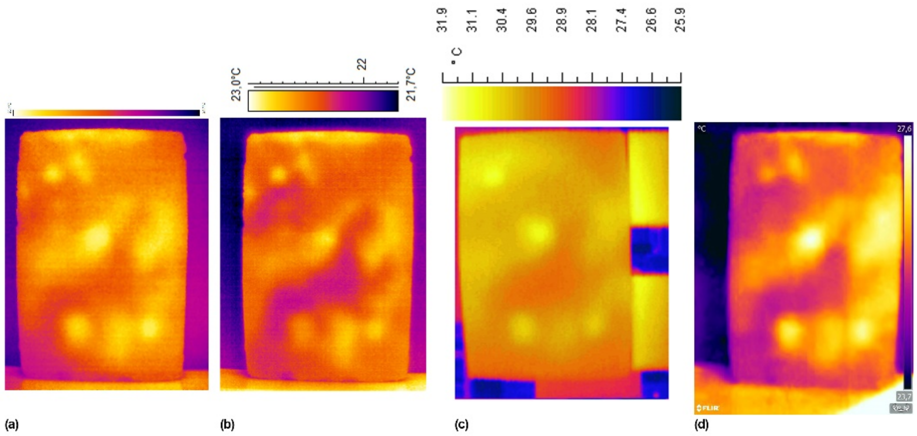

Fig. 6. Experimental results on the fresco model, obtained by the different thermal cameras, are presented. (a) FLIR T1020; (b) FLIR S65 HS; (c) AVIO TVS-2000MkII; (d) FLIR One.

Figure 6 shows the comparison of the various results obtained on the fresco model. The general remarks made above during the discussion of the results on the panel painting model can be repeated here.

Furthermore, as mentioned, the laboratory models have degraded over the years. This has led to the appearance of defects not initially present in the model.

4.3 A real fresco

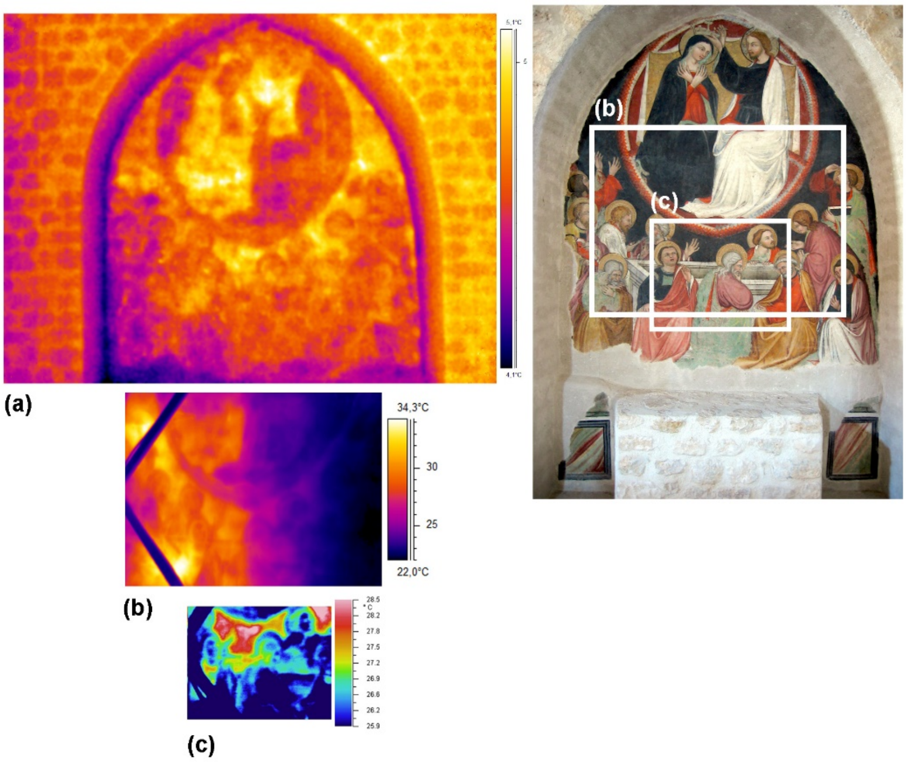

Fig. 7. Experimental results on a real case, obtained by the different thermal cameras, are presented. (a) FLIR T1020; (b) FLIR S65 HS; (c) AVIO TVS-2000MkII.

The selected fresco is in the Basilica of Santa Maria di Collemaggio in L'Aquila and was found during restoration work in the 1970s, which, by dismantling the Baroque, restored the church's naves to their original Romanesque style.

The painting in the second niche in the side wall of the right aisle depicts the Assumption and Coronation of the Virgin (see Fig. 7, right), a work of extraordinary beauty. There is no certain information about the author or the year of its creation, but it can be dated to the first half of the 15th century. According to some, it was painted by the Venetian Iacobello dal Fiore in 1430.

Figure 7 shows preliminary results obtained by T1020 compared with older ones by S65 HS and AVIO. Even from these very first results, the great advantage of the higher resolution is evident. While maintaining approximately the same definition as the S65 HS, it is possible to investigate a much larger area without the need for mosaicking. Alternatively, smaller areas can be investigated in greater detail, or a mosaic of images can be created to achieve very high resolution.

Considering quantitative thermography, we believe that high resolution images with high thermal sensitivity will be of great help in diagnostics. Some difficulties may arise due to the computing resource required in the case of long sequences of images.

5 Conclusions

Thermography has developed considerably over the last decades. There have been major advances in both hardware, i.e. thermal imaging cameras, and software, with the introduction of many algorithms for quantitative analysis of thermal images. The sector has also benefited from important developments in image processing and calculation tools.

From the point of view of the evolution of the imaging instruments, there has been a shift from expensive, bulky, heavy instruments with quite low thermal resolutions and sensitivities to more usable and better performing cameras. In addition to top-of-the-range instruments for research purposes, much cheaper devices have also been introduced, including thermal imaging cameras for smartphones, which can be integrated or used as accessories.

In this paper we have considered some of the effects that this development has had on thermographic diagnostics for cultural heritage. We adopted an experimental point of view, thus comparing the results obtained using 4 different thermal cameras, produced in the last 25 years, which we have considered representative of the instruments of their generation.

Generally speaking, the four IR cameras performed from reasonably well to very well on our 2 laboratory models (a painting on wood and a fresco, investigated since the late 1990s). There are clear advantages in using very high-performance instruments such as the T1020, however its cost, which is still rather high, makes it an instrument not suitable for widespread use by museums and restorers. Its great performance will be useful to research groups and important restoration project on famous artworks.

On the other hand, even an apparently modest instrument such as the FLIR One, at a cost comparable to a mid-range smartphone, proved capable of providing some information. Since thermal imaging cameras of this type already offer higher performance than the FLIR One, we believe that they can contribute to the widespread diffusion of thermographic investigations and constitute a starting point for acquiring more skills in the field and then moving towards more powerful devices.

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