A Technique to Support the Restoration Activities of Archaeological Discoveries

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***Abstract* – In this paper the authors propose the use of passive and active thermography to support the restoration of archaeological discoveries. Archaeological restoration is a time-consuming activity entailing high costs. Therefore, the possibility to schedule restoration when it becomes necessary is an important goal. In addition, to guide the restorer on the parts of the archaeological heritage which require urgent maintenance can be a significant support. The proposed technique allows to detect the damaged parts due to material alterations like alveolisation processes, erosions, deposition of iron oxide, defects, fissures, and material irregularities. By evaluating pixel by pixel, the temperature deviation around the known equilibrium value, it is possible to map the material alterations or the parts affected by decay states. Such material alterations are often invisible to the naked eye especially at their onset. This technique allows to highlight the material alterations on the artefact surface by characterizing the emissivity changes. Experimental results on an ancient medallion and on fragments of a marble sarcophagus are reported to prove the relevance of the proposed methodology.**

I. INTRODUCTION

Restoration of archaeological heritage is a complex task due to costs and time needed. Tools supporting restorers during such activities could reduce costs. At the moment, restorers use visual inspection to identify the parts that require maintenance. Thermography can be a useful tool to inspect the surface of the archaeological and historical discoveries to detect material alterations due to alveolisation processes, erosions, deposition of iron oxide, defects, fissures, and material irregularities. The natural degradation process of material needs periodic monitoring and maintenance activities, [1]-[5]. The aim of the authors is to propose a measurement methodology to support the heritage restoration reducing costs and scheduling activities only when they are necessary. The use of sensors or transducers for monitoring heritage over time introduces further costs due to maintenance and calibration of instrumentation and computing resources [6], [7]. Therefore, the use of alternative measurement techniques for one-shot measurements is recommended. The authors propose a thermography-based technique to evaluate the conservation state of the archaeological discovery so to schedule the next restoration activity, [8], [9]. Thermography is a diagnostic technique used in several application fields such as the environmental one, [10], [11], biomedical one [12] and industrial one. The authors in previous works have proposed the use of thermography for diagnosing the conservation state and for detecting surface cracks and defects of archaeological discoveries. The technique reported in the following concerns the scheduling of the restoration activities.

Italy, Greece and Egypt hold a huge amount of historic/archaeological and architectural sites and discoveries, [13]. The preservation of their integrity over time is important to preserve the proof of cultural heritage of peoples and nations, [14]. Thermography is an effective and non-invasive tool able to assess the integrity state of archaeological heritage detecting defects, erosions, fissures, damages, and material irregularities without any risk for the investigated object, [15], [16]. Technological advances allow thermal camera to measure surface temperature with high resolution and accuracy, so even low temperature gradients can be observed.

The suggested methodology uses the emissivity property. Different materials have different emissivity values, [17]-[20]. Material alterations entail changes in the original emissivity of the material. Therefore, alveolisation processes, erosions, deposition of iron oxide, defects, fissures, and material irregularities can be easily characterized by observing changes of emissivity in the object. Since the radiance of the observed scene is converted in temperature values according to the emissivity, changes of emissivity are cause of apparent changes of the surface temperature of the object. As a consequence, if the object (made of a single material) is in thermal equilibrium, any temperature gradient can be considered the effect of material alterations. In presence of material alterations, the thermographic image is characterized by changes of the colour of the pixels having different emissivity. Consequently, material alterations due to different conservation or decay states can be easily detected by evaluating pixel by pixel the temperature deviation around the known equilibrium value. This assumption has been verified in previous works by authors so to validate the theory, [21], [22]. The proposed approach has allowed us to correlate the changes of emissivity with the integrity state obtaining interesting information on the discovery deterioration over time.

In this paper the technique is used to support the restoration activities in order to schedule the next intervention by restorer when it is necessary so guiding he/she about the parts which require more attention.

The paper is organized as follows. In Section II, the thermography theory and the discoveries under test are described. Section III describes the experimental results. Finally, conclusions are outlined in Section IV.

II. THERMOGRAPHY AND CASE STUDY

Infrared radiation (IR) is characterized by wavelengths belonging to the interval $(0.78\,\mu m - 1\,mm)$ of the electromagnetic spectrum. Any object absorbs and emits thermal energy in the IR range. A thermal camera is able to measure the radiance emitted by the captured scene and to convert it in temperature values. Assumed that h is the Planck constant, c is the velocity of light in vacuum, k is the Boltzmann constant, according to the Planck's Radiation Law reported in the following:

$$W(\lambda, T) = \frac{2\pi h c^2}{\lambda^5}\left[\exp\left(\frac{hc}{\lambda k T}\right) - 1\right]^{-1} \quad (1)$$

the radiance W depends on the wavelength of radiation λ and on the thermodynamic temperature T of the object. To evaluate the temperature of the object, the emissivity ε_λ has to be known. The emissivity depends on the material which forms the surface coating of the object. By obtaining this information, the thermal camera converts automatically the radiance into temperature pixel by pixel so creating the thermographic image.

Two case studies have been investigated. Both discoveries are preserved in the *Archaeological Museum Antiquarium Leucopetra* at Lazzaro, Reggio Calabria, Italy. The first one is a bronze medallion depicting Saint Sisinnius on horseback, led by an angel, striking a female demon with a spear. The object dates back to the 6th century after Christ and was usually used in battle as a good luck amulet, see Figure 1 for reference.

The second one concerns some fragments of a marble sarcophagus date back to the second and third centuries after Christ depicting a hunting scene, see Figure 2.

Fig. 1. Bronze amulet dated back to ancient Rome.

Fig. 2. Fragments of marble sarcophagus dated back to ancient Rome.

The amulet and the sarcophagus parts have been analysed by using a *Thermal Infrared Camera FLIR x8400sc*. It is a high performances camera mounting an Indium Antimonide (InSb) detector with an image resolution of 1280x1024 pixels, a spectral range from 1.5 µm to 5.1 µm and a temperature resolution smaller than 18 mK.

Fig. 3. Infrared thermal imaging camera, FLIR x8400sc.

Passive and active thermography techniques have been used in order to highlight material alterations and irregularities. Passive thermography allows to measure the radiance of the object without using any external thermal excitation system. Typically, this technique is used to analyse the temperature gradient distribution over time. It allows to obtain preliminary information on the emissivity changes in the object surface so detecting surface material alterations due to alveolisation processes, erosions, deposition of iron oxide, defects, fissures, and material irregularities. Active thermography needs an auxiliary thermal solicitation system to analyse the thermal response of the object over time. This technique allows to obtain relevant information about the object in presence of parts having a different thermal response. It provides detailed information on the extent of the material changes and the progress over time, so deciding about the urgency of the restoration. The two techniques offer complementary information supporting the decisional process and the activity of the restorers.

III. EXPERIMENTAL RESULTS

In this Section, preliminary experimental results on the above case studies are reported. The first case study concerns the bronze amulet. Figure 4 shows a thermographic image of the amulet. At a first glance, it is possible to observe the presence of specific parts of the discovery having different apparent temperature values. That is the result of changes of emissivity due to material alterations: deposition of iron oxide and cracks. An IR lamp has been used to study the thermal response of the amulet. For example, three Regions of Interest (ROIs) have been selected in order to evaluate the temperature trend of: the original material (green ROI); the oxidized material (red ROI); and the cracked material (black ROI). Figure 5 reports the temporal plot of the thermal response of the three ROIs over time. The plot highlights clearly the different response of the three material alterations to the same external solicitation.

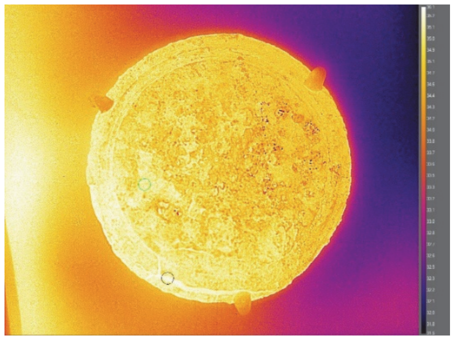


Fig. 4. Infrared thermal image of the bronze amulet.

In detail, the oxidized regions are characterized by a low apparent temperature and by a low gradient value so showing a slow response to external solicitation.

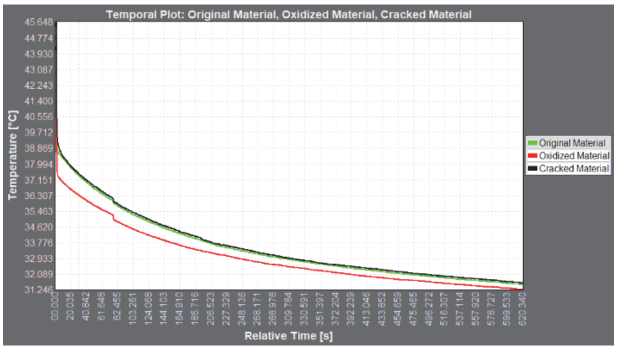
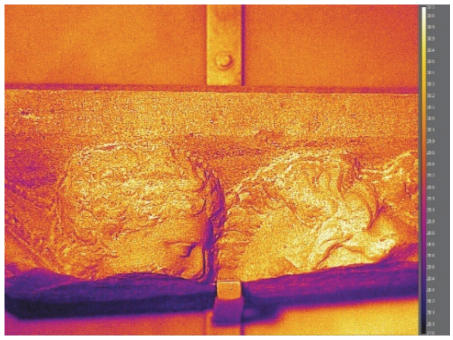


Fig. 5. Temporal plot of thermal response of the bronze amulet.

The following Figures show the thermographic images of some fragments of the sarcophagus.



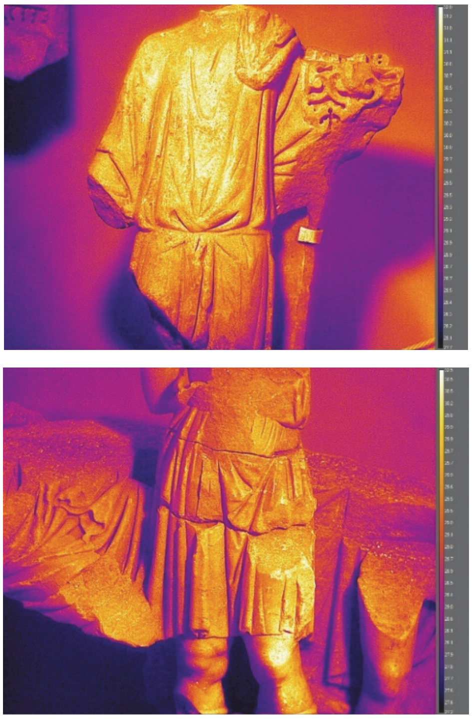


Fig. 6. Thermographic images of marble sarcophagus.

Figure 7 reports the thermal response of a specific fragment of the sarcophagus. Three ROIs having different material alterations have been selected. The plot shows the potentiality of the proposed technique to detect material alterations by observing different responses to external thermal solicitations. In detail, the fragment has been irradiated by means of an IR lamp in two different intervals (from 0 s to 10 s and from 20 s to 90 s). The black line (central trend) describes the temporal response of a fragment part without any material alteration, so it represents the reference trend describing the regular response of the marble. The red line (upper trend) describes the response of a fragment part with alveolisation, and the green line (lower trend) describes the response of a part with erosion signs.

Although the passive thermography allows us to detect easily changes of emissivity by observing colour changes in the thermographic image, this technique does not allow to understand the evolution over time of the integrity state of the discovery. Otherwise, the possibility to compare different thermal responses collected over time at different instants allows us to highlight possible changes about the conservation state of the discovery, so optimizing the schedule of the restoration activities when the material degradation overcomes specific thresholds.

A further experiment has been carried out on a sarcophagus fragment representing the head of a dog, see Figure 8. The methodology developed in [22] has been applied to evaluate the deterioration state of the discovery.

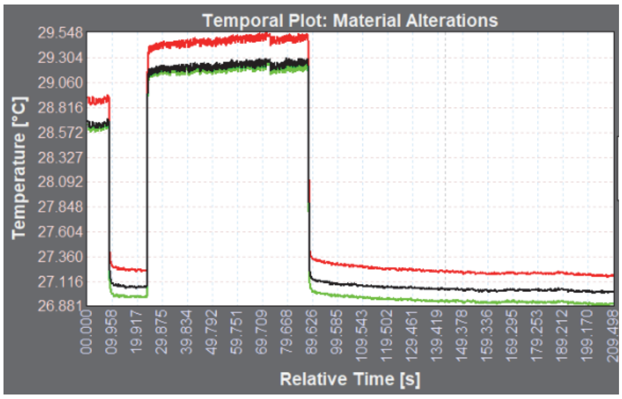


Fig. 7. Temporal plot of thermal response of a fragment of the marble sarcophagus. The black line (central trend) describes the regular response of marble without any material alteration, the red line (upper trend) describes the response of marble with alveolisation, and the green line (lower trend) describes the response of a marble part with erosion signs.

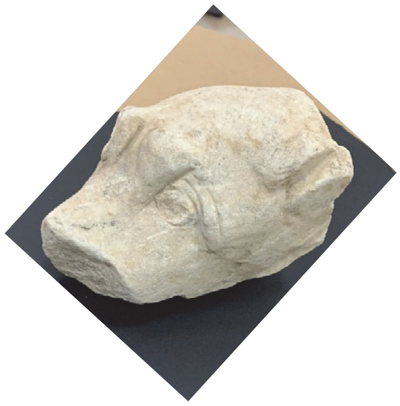


Fig. 8. Fragment of a dog head.

The emissivity of the marble has been measured in order to detect the fragment parts having the best conservation state in compliance with its original state. The estimated equilibrium temperature of the marble is equal to 26.3°C, and its evaluated original emissivity value is equal to 0.89.

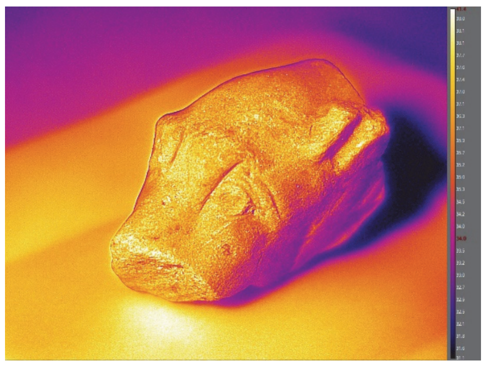


Fig. 9. Thermographic image of a marble dog head.

This value has been taken as reference to evaluate the deterioration percentage of the sculpture. The emissivity changes have been computed and compared to the reference value. The analysis of the thermographic image in Figure 9 allow us to assert that about 68% of the fragment surface (front part) maintains its original state, whereas 32% of its surface has signs of deterioration due to different decay processes.

The reported experimental results show the feasibility and potentiality of the thermography. Future works will be focused on the definition of a model in order to define the best suitable restoration interval according to the kind of material alteration and to the change of the thermal response to external solicitations over time.

IV. CONCLUSIONS

In this paper the authors have described an original use of thermography to assess the conservation state of archaeological discoveries in order to support the restoration activities over time. The aim of the proposed procedure is to analyse the thermal response to external solicitations in order to detect changes in the temperature distribution. Material alterations, such as alveolisation, erosion, damages, and deposition of iron oxide, are cause of changes of the material emissivity. This involves changes in the apparent temperature of the discovery surface. Therefore, thermographic images can offer an effective map of the material alterations based on changes of image colour. In addition, the thermal response to external solicitations provides useful information to schedule the next restoration of the discovery so guiding the restore about the parts of the discovery which require prompt restoration. The comparison over time of different thermal responses of the same object allow to obtain quantitative information on the severity of the degradation process so deciding about the next restoration. The proposed technique has been tested on two case studies concerning discoveries made of bronze and marble that date back to ancient Rome and preserved at the *Archaeological Museum Antiquarium Leucopetra* at Lazzaro, Reggio Calabria, Italy. Thermographic images have allowed us to correlate the temperature changes to the material alterations. Results have shown the effectiveness of the proposed technique to provide information on the deterioration state of the discovery.

To use the proposed technique, it is necessary a thermal camera with high resolution and performances. For example, the use of a camera with cooled infrared detector is suggested in order to assure suitable values of *Noise Equivalent Temperature Difference* (NETD) and accuracy. According to authors' experience, best results can be obtained on discoveries made of marble, wood, metal and paintings.

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