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THERMOGRAPHY FOR NON-INVASIVE DIAGNOSIS OF CONSERVATION STATE OF ARCHAEOLOGICAL DISCOVERIES

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Abstract: The present paper discusses about the use of active thermography to assess the conservation state of archaeological discoveries and historic sites. The preservation of historical and archaeological heritage is today an open issue due to the amount of sites and to the costs of the current methodologies and technologies used. As a consequence, interventions are made only when a deterioration process is in progress. The use of non-invasive techniques is essential for such kind of applications in order to not compromise the integrity of the find. Thermography is a contactless measurement technique able to monitor thermal response of any object even during dynamical conditions. Its basic principle allows to evaluate the presence of humidity, cracks, variation of thickness, structural integrity, exposition to heat sources, previous restoration works not visible at naked eye. Therefore, this technique can be used to evaluate the integrity of buildings, statues, paintings, artifacts, etc…

The paper aims to describe how this technique is used to diagnose, monitor and preserve the conservation state of archaeological discoveries, sites and ruins. The considered application case concerns the Riace Bronzes, two bronze statues of the first half of the V century B.C. preserved in the *National Museum of Magna Græcia*, Reggio Calabria, Italy.

Keywords: archaeological discoveries; bronze statues; conservation state; active thermography; non-invasive measurement.

1. INTRODUCTION

Historical discoveries are an important part of cultural heritage. Ruins, sculptures, historical buildings and archaeological sites can be considered as a piece of the environment in which we live. This is particularly true when it is an integral part of a place or when it is brought to light after that for several years it was underground or in the abyss of sea. Often such discoveries are integrated in the environment as, for example, the pyramids in Egypt, the Colosseum or the archaeological digs of Pompeii in Italy. Their periodic maintenance and monitoring are crucial to assure the preservation for centuries and centuries. Italy has a wide cultural heritage of archaeological discoveries. Their conservation represents a significant time-consuming activity with huge economic costs.

Nowadays, transducers and sensors are widely used for monitoring the integrity of archaeological discoveries and for environmental applications, [1]-[3]. This represents an interesting application field for preserving archaeological heritage, nevertheless several perspectives and open research problems have to be investigated such as data processing, sensor failure and reliability, interface and signal treatment, Standards, fault-tolerance, maintenance, calibration and traceability issues. Not always the use of sensors is possible or feasible, due to the extension of the site or to the costs of development. For this reason, alternative techniques are today proposed and investigated in order to assess the state of conservation of finds. Some of such techniques are used in other sectors so as the medical one: tomography, x-ray, etc… The current main challenge is to define non-invasive, low-cost and effective techniques able to scan large surface in only one snapshot.

This paper aims to describe the potentialities of active thermography in monitoring archaeological discoveries and historic sites, [4]-[8]. Thermography is today widely used for environmental monitoring applications, [9], [10]. This technique can allow even to perform reliable and non-invasive diagnoses of the conservation state of finds. Due to its history, Italy is the country with the richest amount of historic/archaeological and architectural sites and finds. Thermography can be an alternative or complementary technique to invasive ones. The first use of this technique was made on historical buildings. Thermal imaging is an effective tool for detecting defects, fissures, irregularities without any risk for the investigated object.

A lot of other applications are possible in order to evaluate the conservation state of archaeological discoveries. By using an infrared thermal camera, it is possible to measure the electromagnetic radiation emitted in the infrared spectrum. The emitted infrared energy is a function of the object temperature. In this way, the processing unit converts the intensity of infrared radiation into temperature values so to generate an infrared image. Thermal cameras with high accuracy and resolution allow to measure the slightest changes and differences of temperature with a thermal sensitivity even of 15 mK. Advanced cameras can capture thermal images with high resolution of 1280x1024 pixels and with a frame rate of about 100 Hz. Highest performances can be obtained with an uncooled microbolometer detector.

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2. THEORY AND APPLICATION CASE

Any object is able to absorb or emit thermal energy in Infrared (IR) range if its temperature is over the absolute zero, [10]. IR spectral range is within the interval 0.78 μm – 1 mm of electromagnetic spectrum. The radiance W of any object depends on two main parameters: the wavelength of radiation λ and the thermodynamic temperature T of the object. The Planck's Radiation Law regulates such dependence according to the equation:

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

where h is the Planck constant, c is the velocity of light in vacuum, k is the Boltzmann constant.

Molecules may move in specific directions and vibrate, rotate, twist along an axis. This mechanical interaction allows the infrared energy to be transferred or absorbed.

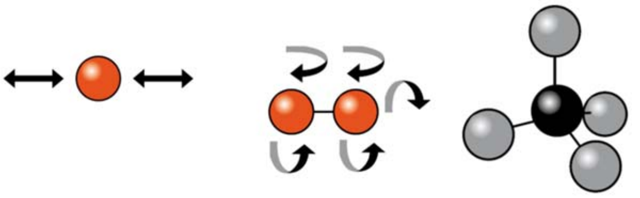

Fig. 1. Atoms interactions.

Such interaction increases with the increase of the object temperature. As a consequence the infrared energy emitted depends on temperature according to (1). In order to quantify the amount of radiated energy in relation to incident radiation energy, the object emissivity must be known. The emissivity value ε_λ can be estimated by the equation:

$$\varepsilon_\lambda = 1 - \tau_\lambda - \rho_\lambda \quad (2)$$

where τ_λ is the transmittance and ρ_λ is the reflectance of the object. A thermal camera is able to detect the object radiance and convert the scene into an infrared image, [10].

Fig. 2. Infrared thermal imaging camera, FLIR T640.

Several thermal imaging techniques have been defined according to the specific application and scope. The first classification concerns the passive and active thermography. Passive thermography is the basic technique. The radiance of the object is simply measured by using a thermal camera. In this way it is possible to analyse the temperature gradient distribution over time. Active thermography needs a thermal solicitation system in order to increase or decrease the object temperature by exchanging heat. In this way, it is possible to analyse the thermal response of the object over time. This technique allows to obtain relevant information about the object since parts with structural irregularities and different materials have a different thermal response over time. Other advanced techniques such as lock-in IR thermography and spectral thermography use specific processing algorithms to extract detailed information about the object properties.

Several applications are today possible: building diagnostics, medical imaging, night vision, nondestructive testing, surveillance in security, gas leaks detection, conservation states of archaeological discoveries, etc…

The considered application case concerns the use of this technique to diagnose, monitor and preserve the conservation state of archaeological discoveries, sites and ruins. In detail, the case study concerns the Riace Bronzes, two bronze statues of the first half of the V century B.C. preserved in the *National Museum of Magna Græcia*, Reggio Calabria, Italy, [11].

Fig. 3. Riace Bronzes, National Museum of Magna Græcia,[11].

These two statues have been discovered on the sea bottom near the town of Riace Marina, Italy, in August 16, 1972. It is supposed that their origin is dated back to the Greek Age. A first restoration of the two statues was performed in Florence between 1975 and 1980.

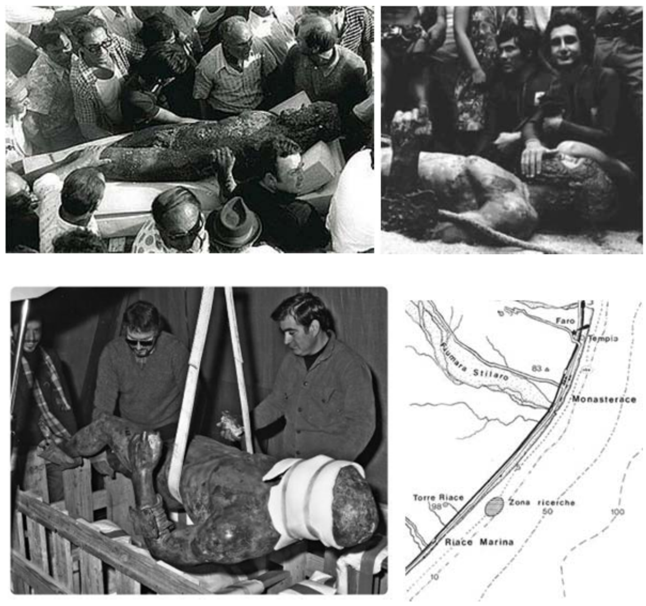

Fig. 4. Discovery of the Riace Bronzes, 1972, [11].

The restoration have allowed the cleaning of the external surface and removal of impurities from the statues. A

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second intervention of restoration was carried out in the laboratory located in the National Museum of Magna Græcia in the years 1992-1995 in order to empty the fusion earth inside the statues. The last restoration was recently completed between the years 2010 and 2013.

Fig. 5. Recent restoration, 2013, [11].

The two statues, denominated “the young” and “the old”, are respectively 1.98 m and 1.97 m high. Their mass is almost 160 kg. The main component material is the bronze, except for some silver, calcite and copper details. The layer has a very light thickness. The teeth of *Statue A* (“the young”) are silver.

Fig. 6. Statue A (“the young”), [11].

The nipples, lips and eyelashes of both statues are copper ones. The *Statue B* (“the old”) has traces of a copper cuff on the head. The eye sclera are of white calcite, and the iris is in glass pulp. The lacrimal caruncle is of a rose stone.

The analysis of the two statues has allowed to characterize several damaged parts and restoration interventions occurred during Roman time. For example, the right arm of the *Statue B* was broken and a second bronze fusion was made to repair the damage.

Fig. 7. Statue B (“the old”), [11].

3. THERMOGRAPHY AND RESULTS

Active thermography has been used to analyse the conservation state of the *Statue A*. Preliminary thermographic measurements were carried out on 10th July 2014 at the *National Museum of Magna Græcia*, Reggio Calabria, Italy. The aim of the present work is to use the active thermography in order to analyse thickness irregularities in a contactless and non-invasive way. Thickness irregularities have been characterized in each statue by using endoscopic tools during previous restorations. Each Statue has an average bronze thickness of about 7.5-8.5 mm.

Although experimentation is still in progress, by means of thermography, qualitative information has been obtained about the presence of abnormalities. Preliminary data have shown some hot points in *Statue A*. For example, in Figure 8, it is possible to see a detail of the *Statue A* abdomen.

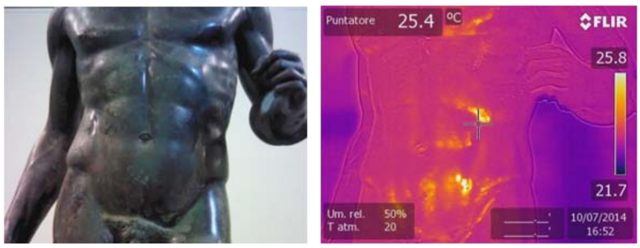

Fig. 8. Thermographic analysis of Statue A.

The image shows clearly some zones with higher temperature. The average temperature is equal to 25.4 °C. Figure 9 shows a zone with highest temperature level.

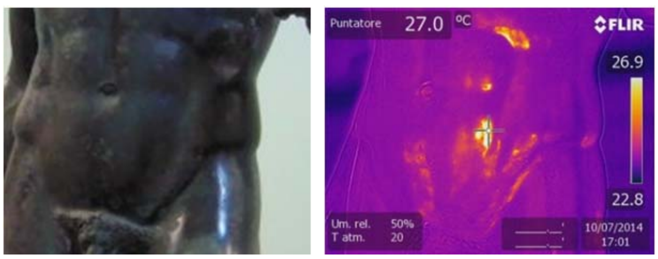

Fig. 9. Thermographic analysis of Statue A.

The hot point in Figure 9 has a temperature value of 27 °C. This high temperature level is sign of a thinner thickness of the statue since such regions have a fast thermal response in presence of external solicitation due to heat sources or generic thermal exchange.

The experimentation in progress aims to fix some problems occurred during the preliminary measurements. The use of a basic thermal camera has not allowed us to get detailed information about the statue irregularities. A further analysis will must evaluate the exact emissivity of the statue in order to improve the measurement accuracy. To this purpose, a thermal camera with high resolution and accuracy will be used. The experimentation will allow us to define an innovative model which will be able to estimate the exact value of statue thickness point by point by using information on the local temperature value of the point and the amount of external thermal solicitation.

4. ACKNOWLEDGMENTS

The images used in the case study have been collected in the *National Museum of Magna Græcia*, Reggio Calabria, Italy.

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5. CONCLUSIONS

In the paper, the authors have discussed about the potentialities of thermographic technique and its use for the monitoring of the conservation state of archaeological discoveries and historic sites. The costs of the current methodologies and technologies used in the practice make the preservation of historical and archaeological heritage an open issue. The use of non-invasive techniques is essential for such applications in order to not compromise the integrity of the find.

For such reason, the authors propose thermography as a contactless measurement technique able to monitor thermal response of archaeological heritage so to get information on the integrity of the find. This technique can allow archaeologists to diagnose, monitor and preserve the conservation state of archaeological discoveries, sites and ruins.

The considered case study concerns the Riace Bronzes, two bronze statues of the first half of the V century B.C. preserved in the National Museum of Magna Græcia, Reggio Calabria, Italy. Data of a preliminary experimentation carried out on 10th July 2014 have been reported. Further studies are currently in progress. Preliminary qualitative information has allowed the authors to characterize specific points of the two statues with thinner thickness. Future work will allow us to get a tri-dimensional model of thickens distribution for each statue.

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