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Vibration Monitoring in the Monastero of Santa Caterina (Palermo, Italy)

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***Abstract* – This article describes the application of a measurement system in the field of cultural heritage conservation, and, in particular, to a canvas painting applied on a wooden support. The artwork is placed inside a niche in the Monastero of Santa Caterina in Palermo (Italy). It is a historical painting by the painter Giuseppe Patricolo depicting the Deposition. Considering the presence of the wooden structure, it is important to measure mechanical vibrations that can in fact cause degradation phenomena in wooden structures. The main objective of the presented research is the characterization and observation of the performance of the measurement and monitoring system for assessing the health condition of artworks.**

I. INTRODUCTION

Preventive conservation defines strategies to minimise the risks to which works of art are subjected and is a fundamental element of museum policies and the management of collections. It differs from restoration, which is instead to be understood as therapeutic conservation in that its objective is the removal of the causes of deterioration and interventions to repair the negative effects produced on the work by these causes. Preventive conservation also has the specific objective of avoiding or delaying restoration. The latter, although often necessary, is still a costly and potentially invasive intervention. The main objective of preventive conservation is to adopt actions and technical precautions, applicable on an ongoing basis, aimed at preventing or reducing degradation phenomena by minimising risk factors and situations connected to the cultural heritage in its context [1,2].

The effects of degradation on works of art are all related to processes of a chemical or physical nature and originate from different causes [3]. The sources of risk are both numerous and variegated and can be attributed to environmental and other factors such as human and mechanical actions, as summarized in Table I.

Table 1. Degradation risk factors and related effects.

Factor	Effect
ENVIRONMENTAL CAUSES	
relative humidity (RH)	• variations in shape and size • chemical effects • biological deterioration
temperature (T)	• dimensional changes • accelerations of chemical and physical reactions • biological deterioration
lighting	• chemical effects • increase in surface temperature
pollutants and suspended particulate	• chemical effects • loss of surface material • development of microorganisms • changes in aesthetic appearance
OTHER FACTORS	
human agents	• theft • vandalism • unauthorized contact
mechanical agents	• shock • vibrations of the building and artwork structure • incorrect support conditions

The environmental factors of interest are temperature, relative humidity (RH), electromagnetic radiation and air quality both within macro-environments such as exhibition halls and storage rooms and micro-environments such as showcases, storage and transport containers. In this context, it is essential to measure these quantities to verify that the microclimate is suitable for conservation and in particular that the values and fluctuations of the various parameters remain within the established ranges. A correct preventive conservation plan also pays attention to aspects of collection management. Therefore, all possible actions must first be taken to avoid risk factors due to human agents such as theft and vandalism, as well as mechanical agents such as vibrations of the structure, support bases and during movement.

Degradation is a process of a cumulative nature both in terms of the number and intensity of individual events. A proper preventive conservation plan must simultaneously consider all causes of degradation and all risk factors [4]. Attention must also be paid to aspects of collection management and resource availability. The starting point for the definition of a conservation plan for a painting is the analysis of the state of conservation of the artefact and the environment in which it is located, as well as an overview of management procedures. In order to assess risks, it is essential to study the interaction of the artefact with the ambient, by monitoring environmental quantities (temperature, RH, lighting and air quality) in order to identify critical points and propose improvement solutions. This requires the intervention of qualified personnel and the use of appropriate instrumentation and procedures [5]. Risk assessment must take into account exhibition procedures, collection rotation, handling and transport of works, especially in the case of loans to other museums or for temporary exhibitions. In the latter case, it is of crucial importance to assess the vibrations to which an artwork may be subjected, especially for works of particularly vulnerable materials and with special structures such as the painting with a wooden support that is the subject of the study presented in this paper.

The vulnerability of paintings on wood is mainly due to two factors: the response to changes in temperature and RH, and the critical levels of strain at which materials begin to deform [6-8]. Considering that among the causes for which wood paintings suffer damage are accidents, improper handling, misguided conservation treatments, but also transport or loaned, there are four environmental conditions that should be considered when evaluating any painting for possible loan: RH, temperature, shock, and vibrations [9-12]. The research presented on this occasion is part of a larger project aimed at developing multi-parameter devices for microclimatic monitoring and the assessment of risk factors in confined environments of interest for Cultural Heritage as shown in [13]. In particular, this paper improves the latter manuscript focusing the attention much more on the aspect of the measurement approach and monitoring of mechanical vibrations in the Monastero of Santa Caterina in Palermo, Italy.

The novelty is also related to the specific artwork and its monitoring that was implemented with a smart measurement system for vibrations. It is worth to mention that the measurement methodology here presented allows the simultaneous assessment of variations in the main microclimatic parameters and in particular considering the vibrations to which the painting might be subjected.

II. MATERIALS AND METHODS

Any preventive conservation plan must take into account the specific features of the work of art, starting from its characteristics especially in terms of materials, construction technique and structure. The starting point is the current state of conservation, any deterioration phenomena already present and the major risk factors. This approach makes it possible to identify the monitoring strategy as well as the quantities to be measured and the devices to be used.

A. The painting under study

A complex painting exhibited at the Monastero of Santa Caterina in Palermo was identified as part of the activity performed. It is a painting on canvas applied on a wooden support, whose particular assemblage and shape determine a concave structure, 3 m high and 2.5 m length, inserted within a niche whose back, however, cannot be examined. The work of art is a Deposition (see Fig.1) executed by Giovanni Patricolo around the mid-1800s: the technique is probably a glue-on-canvas painting. The stratigraphy from the inside to the outside is composed by masonry, wooden boards, plasterwork, chalky mortar and painted canvas. Information was provided, based on close visual observation techniques, by the restorer in charge of the cleaning work and preventive conservation program involving the entire monastery and the works displayed therein. The mortar layer is thinner at the central boards where the curvature is less, while it becomes thicker as the line becomes concave and the curvature of the substrate more pronounced. This filled the space between the masonry and the wooden boards. The painting and the wooden support show clear signs of degradation. There are numerous cracks and lacerations in the canvas, particularly pronounced in the connection of the wooden boards, especially in the centre. The latter is a clear sign that the movements of the support were not in accordance with the different behaviour of the textile support. The forms of degradation produced on the front of the work are the result of an imbalance among the various elements of this complex stratigraphy, due both to the heterogeneity of the constitutive technique and structural elements and to the inappropriate coexistence with the various environmental and microclimatic factors. The devotional function of the work involved a certain number of anthropic factors that were inadequate for the preservation of the artefact. These included numerous splashes of water at the base of the work, which resulted in the formation of visible gorges that, due to capillary rise, compromised an important portion of the painting and swelling and dislocation of the wooden panels. This characteristic requires the addition of vibrations to the typical parameters of microclimatic monitoring.

The phenomena of degradation have led to a movement of the elements of the support between which an opening of approximately 3 mm has been created, thus offering an optimal position for the insertion of devices such as the board. Fig.1 also shows a zoom where the IoT system was installed inside the inlet. Direct measurement of any movement of the substrate can give an indication of shrinkage or expansion phenomena with swelling of the fibres followed by mechanical and structural alteration that can compromise the supporting function of the substrate. Simultaneous microclimate monitoring, which is possible with the available board, and environmental monitoring, with a common data logger or thermo-hygrometer, gives a measure of the changes in the equilibrium between the artefact and the site in which it is inserted. Further data is linked to the reading of seasonal thermo-hygrometric variations or changes linked to a discontinuous or uncontrolled flow of visitors.

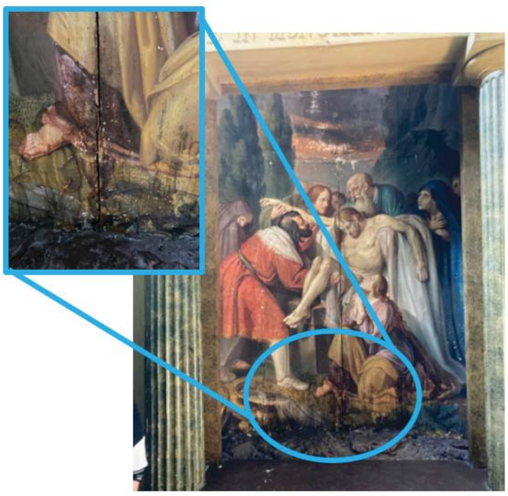

Fig.1 Giuseppe Patricolo depicting the Deposition, real painting and a zoom where the IoT system was installed inside the inlet.

B. The prototype for the laboratory tests

The installation of the board and the transmission of measurement data in a typical case is decisive to evaluate the goodness of the system in terms of feasibility, manageability, non-invasiveness and accuracy. In this way, it is possible to test its actual advantages and possible limitations, and to plan the system's upgrade to optimal operating standards. To this purpose, a preliminary test was carried out on a prototype with morphological and dimensional characteristics of the identified painting. The prototype consists of two wooden boards onto which, with a thermoplastic resin, an aged canvas was adhered. This last was recovered from an old piece of canvas lining in order to mitigate any movements inherent to a textile support that is younger and more reactive than the real case. The wooden boards of the prototype are mounted to create a gap of the same width as the one present in the work subject to in situ testing. Within this narrow 'opening' the board was inserted and several tests were accomplished, even under extreme stress conditions, to obtain useful information for the application on the work in the monastery.

C. Measurement device and Experimental setup

The measurement device is based on the STMicroelectronics STEVAL-MKSBOX1V1 wireless platform for monitoring of various physical quantities of interest and, in particular, it is capable to perform measurement of vibrations along three axes. A short-range wireless technology standard based on Bluetooth is used together with a suitable app as IoT solution. The vibration monitoring is pursued thanks to the adoption of an accelerometer managed by using an ultra-low-power ARM Cortex-M4 STM32L4R9 microcontroller for processing and operations. Fig.2 shows the block diagram of the considered system. As it can be noted the vibrations, which represent the measurand in the context of preventive conservation, can be induced by various sources (i.e. noisily environment, fruition, movements for transportation). The monitoring is addressed through the aforementioned IoT systems and the LIS2DW12 sensor was used to measure, along three axes, the vibration level. A 3.3 V 1000 mAh Li-Polymer battery was used as a power supply for the board which presents an ultra-low power consumption, less than 1 μA in low-power phase with low noise level (about 1.3 mg RMS). Fig.3 shows the board used during the characterization and the measurement campaign.

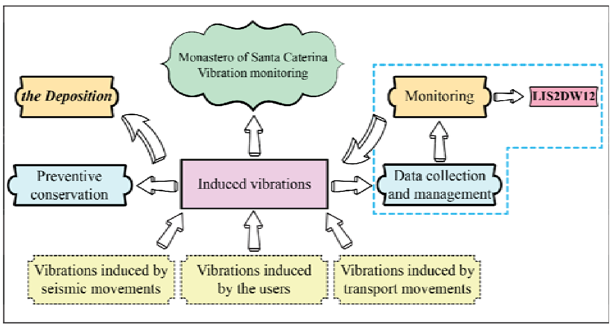

Fig.2 Schematic diagram of the IoT-based measurement system for vibration monitoring in the Monastero of Santa Caterina (Palermo, Italy).

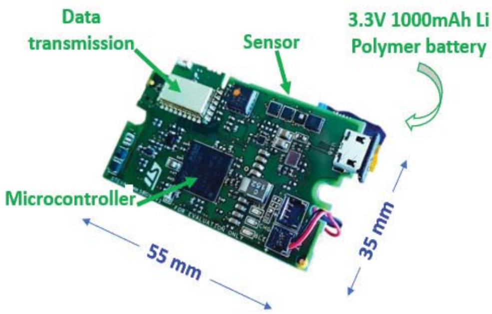

Fig.3 Picture of the IoT-based measurement system used to monitor the historical painting under analysis.

As already mentioned, a copy of Giuseppe Patricolo's painting (see Fig.4) was developed to emulate the real painting in the laboratory. After a laboratory characterization the monitoring of the real artworks was addressed as shown in the next section. Fig.5 shows the detail of the insertion of the device in the opening specially replicated in the prototype to reproduce the actual one in the painting under study.

The metrological characterization was pursued by using an electrodynamic shaker (TIRA TV 50009) to impose known vibration levels. A signal generators HP33120A was also used for impressing a suitable waveform to the shaker. Furthermore, a feedback accelerometer was used in order to monitor the impressed kinetic source (see Fig.6). After the laboratory characterization phase was completed, in situ measurements were carried out in order to identify the performance and limitations of the device for the measurement of microclimate parameter variations in terms vibrations.

Fig.4 Copy of the real painting used during the characterization of the measurement system. The picture also shows the location of the board in the structure.

Fig.5 Board insertion in the prototype for preliminary testing under artificial stress conditions. The cable was used during a programming step.

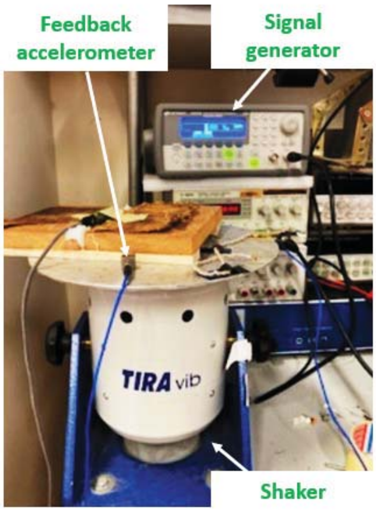

Fig.6 Schematic diagram of the IoT-based measurement system for vibration monitoring in the Monastero of Santa Caterina (Palermo, Italy).

III. EXPERIMENTAL RESULTS

The characterization was accomplished by using the experimental setup presented in section II. Various levels of vibrations were impressed by using the shaker, and various signals were used in order to emulate the attended kinetic source in the monastery. In this context, particular emphasis was given to wideband noise [14-18]. Fig.7 shows the noise level of the measurement system evaluated, as a function of the acquired samples, in absence of kinetic excitations. Fig.8 shows the calibration diagram which includes the transmitted output as a function of the level of vibrations. The study includes the mean value of the measurements, the solid line, as a function of the imposed values, and the uncertainty, described through the dotted lines. As usual in the field of vibration sensors [mg] units are used. The mg is 1/1000th of gravitational force. Both the results highlight a linear trend and the resolution estimated through the characterization corresponds to a level of vibrations of about 3.5 mg. Both the studies were accomplished in laboratory and through the adoption of the copy of the real painting presented in Fig.4. It is worth noting that the measurement system was also applied in the real artworks located inside the monastery. In this context, Fig.9 shows the Fast Fourier Transform (FFT) of the acquired vibrations. The graph evinces a wideband evolution, in accordance with vibrations which can be found in this kind of environments and having a low frequency distribution (less than 100 Hz).

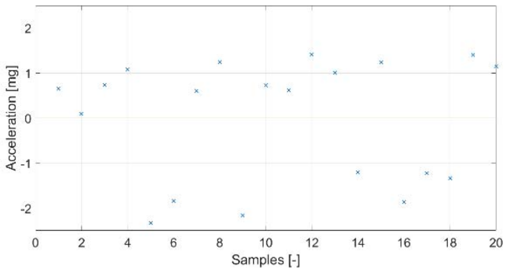

Fig.7 Evolution of the vibration in absence of external excitation. The graph evinces a noise level of about $3.5x10^{-3}$ g.

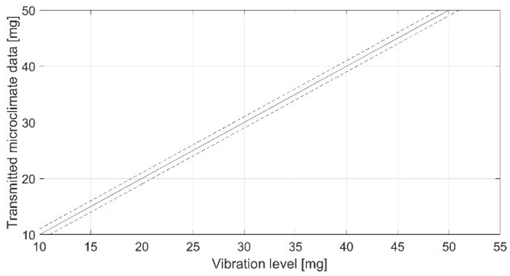

Fig.8 Characterization diagram of the considered measurement system.

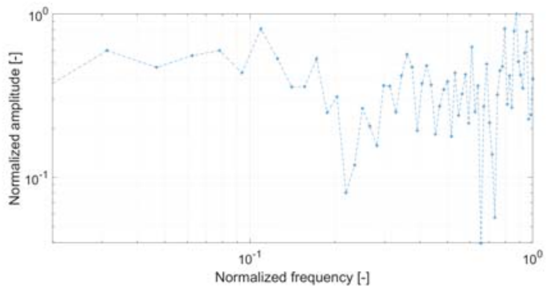

Fig.9 FFT of the acquired vibrations in the artwork considered. The normalizations were accomplished as respect the maximum values and a detrend function was applied.

Fig.10 shows the evolution of the vibrations as a function of the time. It can be noted a noisily evolution confirmed through the frequency response of the measurements.

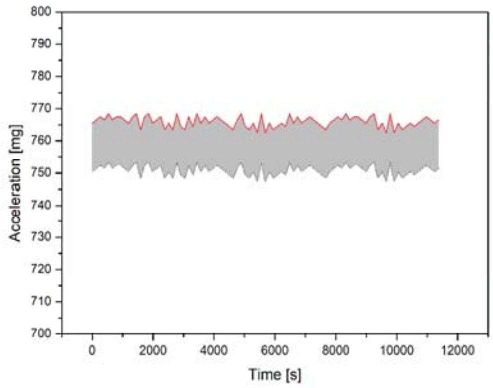

Fig.10 Acceleration evolution, along the main axis of vibrations, acquired in the Monastero of Santa Caterina and in particular it is the kinetic acceleration applied to the artwork as a consequence of external sources.

IV. CONCLUSIONS

Vibration is most commonly encountered in museums, historic houses and churches. Induced forces can cause direct damage to artworks, especially those with friable pigments or loose corrosion products. However, effective risk assessments for ambient vibrations caused by visitor circulation or for building work are hindered by a lack of published vibration damage level reference dataset related to museum artefacts.

Thickett [14] measured background vibration levels through a survey conducted at the British Museum's galleries induced by day-to-day activities, such as visitor circulation. Average accelerations between 0.006 g and 0.15 g were measured and the extremely localised nature of some vibrations was revealed. Damage caused by building work were also observed and monitored on artworks of different materials. Consequently, values between 0.2 and 0.6 g were considered as damaging vibration levels.

Standards for vibration levels likely to cause damage to building fabrics and nuisance to humans occupying buildings have been established [15-17]. However, it would appear to be a singular lack of data for other types of objects or situations commonly encountered in Cultural Heritage sites.

Panel paintings are reported to be susceptible to vibration damage, whose result is even more relevant for works with a complex structure such as the deposition exhibited at Monastero of Santa Caterina. The measurements carried out showed variations in vibration levels of 0.02 g, thus far from the situations of risk mentioned above. However, the monitoring was carried out at a time when the site was closed to the public for restoration work, hence the values measured should be considered minimum values.

The measurement system was characterized and its performance evaluated. The results obtained showed that the methodology used is suitable for monitoring vibrations in the field of Cultural Heritage because it allows measuring values in the ranges of interest. Future measurement campaign is aimed to extend measurement time and enable vibration monitoring following a systematic protocol, as in case of the Museum of the Viking Age in Oslo [18].

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