

Optical methods for violin diagnostics

Vito Pagliarulo¹, Massimo Rippa¹, Chiara Saltarelli¹, Antimo Di Meo¹, Dimitru Scutelnic², Claudia Daffara², Melania Paturzo¹

¹ *Institute of Applied Sciences and Intelligent Systems “E. Caianiello” of CNR, Via Campi Flegrei 34, Pozzuoli (Na), Italy*

² *Dept. of Computer Science, University of Verona, Str Le Grazie 15, Verona, Italy*

Abstract – Wooden musical instruments are objects that require careful construction and maintenance and are subject to wear. The possibility of having diagnostic techniques available is useful for their restoration. In this work, the use of optical techniques for the diagnostics of an early 1900s violin is tested. In particular, the results obtained with shearography, thermography and 3D scanning will be shown and discussed.

I. INTRODUCTION

Violins have always been an object of great interest. Famous violinists and famous violins have always exerted great fascination. In this frame, novel and effective inspection tools and further investigation and analysis protocols are demanded for conservation and restoration. In general, several factors can affect violin integrity and “sound quality” such as fluctuations in environmental parameters (e.g., temperature, humidity, vibrations) or the presence of atmospheric pollutants. These factors can alter the structure or cause deformations in the different regions producing mechanical stress which in turn causes detachments and cracks [1]. Deterioration processes can become irreversible with time and therefore it is important to detect and prevent their formation as soon as possible using non-destructive methods. In this context, high-tech and innovative tools based on advanced sensors and imaging techniques play a key role.

In this work, different diagnostic techniques have been employed to analyze an early 1900s violin: shearography, thermography and 3D scan [2-5]. The results show that combining the potentiality of these methods of analysis allows to highlight the presence of different type of defects and anomalies providing important pre-restoration information. Additionally, data integration and visualization in full-field allows a valuable cataloging of conservation status details that could be beneficial for monitoring future deterioration.

II. EXPERIMENTAL SETUP

A. Shearography

Shearography is a real-time and full-field interferometric technique sensitive to displacement gradient (sensitivity = 10nm light phase reconstruction). The light, scattered from the object surface forms a speckle pattern which is imaged through a shearing interferometer, interferes with its shifted duplicate and produces a fringe pattern. This technique is based on a Michelson interferometer and a coherent laser beam to illuminate items that are subjected to static or dynamic displacement due to external perturbation. A computer-based system tracks and records the original and perturbed positions of the surface, allowing for continuous monitoring of surface reactions at different time points. The computer-driven recording process depends on multiple surface datasets known as phase maps, indicating the surface out-of-plane displacement derivative in space and time with varying operating parameters and induced excitation. Changes in strain on the wood can be caused by surface imperfections, flaws, damage, and overall dimensional movements like shrinkage or expansion. The setup of this work uses a 5 Mpixel CMOS camera sensor and laser diode array ($\lambda = 632$ nm) (class 1). The thermal loading is obtained by two halogen flood lights (2x1000W). The excitement is caused by heat stimulation at a distance of about 1 m.

B. Active Thermography

The experimental setup included a halogen lamp with adjustable power (maximum output: 1000 W) used to deliver 20-second thermal pulses, resulting in a maximum surface temperature increase of $\Delta T = 4$ °C. Thermal data were acquired using a FLIR X6580 sc infrared camera, equipped with a cooled InSb detector operating in the mid-wave infrared (MWIR) range (3.5–5 μ m). The focal plane array resolution is 640×512 pixels, the instantaneous field of view 0.3 mrad, and the noise equivalent temperature difference approximately 20 mK. A 50 mm focal length lens was used to capture thermal frames at a rate of 10 Hz, recorded before, during, and after heating over a total period of approximately 60 seconds. The ResearchIR software (FLIR Systems Inc., Wilsonville, OR, USA) was used to control the acquisition parameters in real time. The collected thermal sequences were subsequently processed to reconstruct thermal mosaics of both the front and back surfaces of the violin.

C. 3D Scan

3D-Scan is a technique able to capture what is within its field of view and measure the distance of points from a reference point on the scanner. The distances are converted into 3D coordinates that show the specific location on the object's surface being scanned. Several scans are required to accurately capture the object's shape, including its detailed engravings and reliefs and a customized scanning approach is employed for every item depending on the test results and scanning space accessible. In this work, a light-structured device has been employed. It operates with two cameras and the projector aligned parallel to each other, with a fast caption speed (16 FPS), a 3D sensitivity of 0.2 mm, and high-resolution texture (1.3 MP). The software enables the incorporation of photogrammetry texture to enhance detailed information while reducing data loss on surface geometries [5].

III. RESULTS AND DISCUSSION

In this section, we explore a combination of three methods for analyzing the violin artwork and compare the results. The early 1900s violin is shown in Fig. 1.



Fig. 1. Visible image of the back and front of the violin made by Alfredo Contino.

Fig. 2a shows the phase-map obtained by shearography of the front side of the violin. The measure, taken at a temperature of 24°C, highlights a small deformation (yellow arrows). Increasing the temperature (26°C), Fig. 2b, the deformation increases clarifying that the deformation is due to the structural reinforcements of the violin.

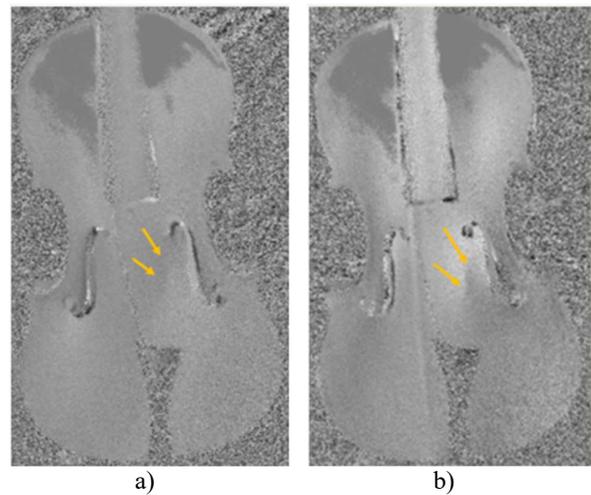


Fig. 2. Phase-maps acquired at a) 24°C b) 26°C. Yellow arrows indicate unexpected deformations.

Throughout the cooling process, from 26°C to room temperature, the wood begins to warp in certain areas of the violin that were previously unrecognized. Figs. 3a-b highlight these deformations.

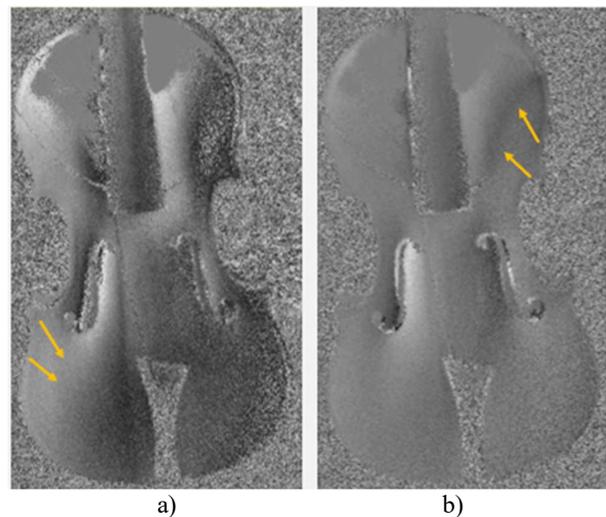


Fig. 3. Phase-maps acquired during cooling process from 26°C to room temperature. Yellow arrows indicate wood deformations

Looking at the back side of the violin, it is possible to note other anomalies. Fig. 4 shows the back site at 25°C. Yellow arrows indicate some distortions while yellow circles show a type of carvings or something within the harmonic box.

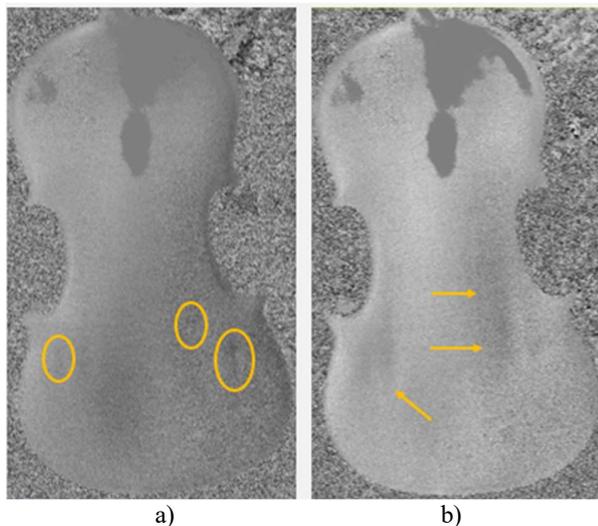


Fig. 4. Phase-maps acquired at 25°C of the back side of the violin a) carvings b) distortions.

Figure 5 shows the 3D model of the violin obtained with the structured light scanner. The 3D model provides not only geometric details but also the texture applied to it, which is essential information if there are intentions to restore the original color. Furthermore, these scanners enable the creation of a digital catalog, specifically for violins, which are quite fragile and require a controlled conservation environment.



Fig. 5. 3D model of the violin.

Active thermography was employed to perform a structural analysis of the violin under investigation. To enhance spatial resolution, the instrument was divided

into three sections for both the front and the back sides. For each of these sections, *Maximum Temperature Gradient* (MTG) maps were computed. These maps represent the induced thermal variation ΔT , calculated pixel by pixel using the following equation:

$$\Delta T(i,j) = T_{max}(i,j) - T_0(i,j) \quad (1)$$

where $T_0(i,j)$ is the temperature of the pixel at coordinates (i,j) in the frame acquired immediately before the external heating begins, and $T_{max}(i,j)$ is the temperature of the same pixel in the frame acquired immediately after the heating ends. Subsequently, the MTG maps obtained for each section were mosaicked to generate a single thermal map for the front and another for the back of the violin, shown in Fig. 6.

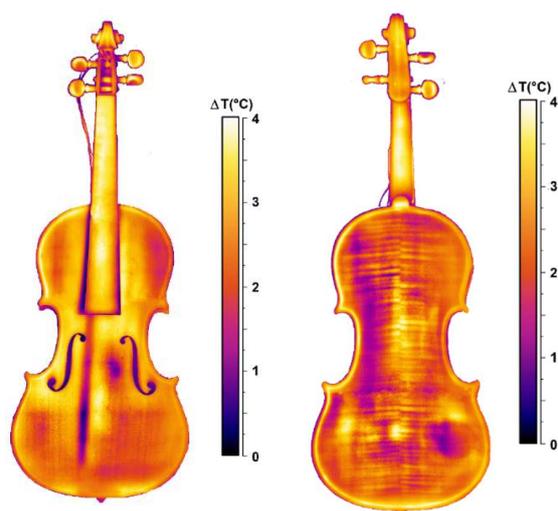


Fig. 6. MTG maps of the front and back sides of the violin obtained through active thermography.

The MTG map of the front side of the instrument generally shows non-uniform thermal gradients. In particular, it reveals the sub-surface presence of a vertical support bar, located near the right f-hole, characterized by lower ΔT values, running along the length of the violin's body. Additionally, an irregularly shaped area with an anomalous thermal response, located near the left f-hole, is also visible, similarly marked by low ΔT values.

The MTG map of the back side of the instrument also generally shows non-uniform thermal gradients. In this case, areas characterized by lower ΔT values are observed, likely due to worn regions of the wooden surface. The reduced thickness in these areas may allow for faster heat diffusion, resulting in lower temperature differences.

Finally, a software application has been developed for 3D visualisation of the violin and as basis for multimodal data integration, based on the high-precision geometric model obtained by the 3D Scan. The application, created with a graphical interface in PyQT (with the `pyvistaqt` QtInteractor extension for interactive management of 3D scenes), allows different types of information to be overlapped and compared interactively, ensuring spatial correlation between 3D geometry and two-dimensional measurements (e.g. thermographic data or interferometric speckle) [10]. In particular, `pyvistaqt` provides the QtInteractor class, which acts as a widget to integrate VTK (Visualisation Toolkit)-based interactive 3D rendering into a Qt5/PyQt application, leveraging PyVista's capabilities as a simplified interface. Although the complete integration of 2D data is still under development, the system will include a dedicated database for storing and searching datasets, storing not only the acquisitions but also metadata relating to the instrumentation used, the measurement parameters and the specific characteristics of the violin examined. This architecture makes the platform a tool that supports both research and restoration activities, enabling structured documentation and easy access to heterogeneous and complementary information. Figure 7 shows a screenshot of the developed software application.

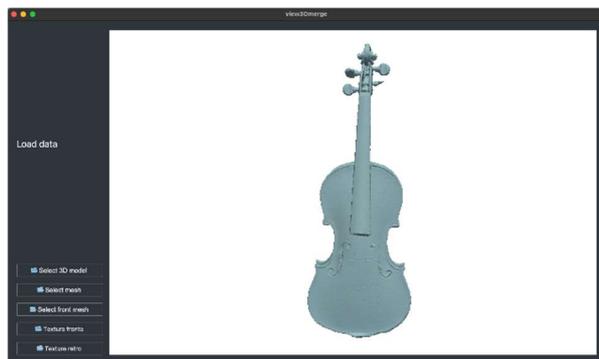


Fig. 7. Screenshot of the developed software application

IV. CONCLUSIONS

In conclusion, this work illustrates the combined use of three optical diagnostic techniques applied on a violin. All techniques are non-contact and full field. The results have shown how it is possible to combine the measurements to obtain information on the state of health of the violin, highlighting worn areas and others where stress is noted in the structure. This information can be of skillful use in the pre-restoration phase to evaluate the appropriate interventions.

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