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Characterization of Feather Art against Mechanical Vibrations using Machine Vision for Applications in Heritage Conservation

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Abstract: - This article presents an experimental study on the measurement of mechanical vibrations in feather art using a vision-based system. An algorithm was developed to analyze the dynamic behavior of feathers under vibration by acquiring high-speed images and processing them to quantify the displacement of the barbs. The results show a nonlinear relationship between feather agitation and vibration frequency, with a resonance peak around 10 Hz. This approach offers a more precise solution than traditional methods based on accelerometers or laser sensors, providing key information for the conservation of feather art.

Keywords: Conservation, Feather Art, Flexible Multibodies, Machine Vision, Mechanical Vibrations.

I. Introduction

Feather art is a highly sensitive cultural manifestation, characterized by the use of delicate and structurally complex feathers to create ornaments and artistic objects. Due to the fragile nature of the materials involved, these works exhibit significant susceptibility to mechanical vibrations. Feathers, because of their biological composition, are extremely lightweight and have a flexible and porous structure, making them especially vulnerable to dynamic disturbances. When exposed to vibrations during transport, display, or handling, mechanical forces can induce deformations and irreversible damage, such as the fracture of the barbs or the separation of feather rows. This sensitivity necessitates the application of advanced measurement techniques, such as vision-based systems, to monitor and mitigate the harmful effects of vibrations.

Feathers, as structures composed of barbs and rachis [1] and [2], can be modeled as an assembly of flexible multibody systems with multiple degrees of freedom. Each segment of the feather has the capacity to move and deform independently in various directions under mechanical excitation. This structural complexity prevents the use of conventional vibration measurement methods, such as accelerometers or laser position sensors, which require fixed contact points or lines of sight to achieve accurate measurements. Accelerometers, being point-based devices, cannot capture the distributed deformation along the entire feather, while laser position sensors have limitations in simultaneously capturing movements across all parts of the assembly. In this context, vision-based systems emerge as a powerful alternative, enabling the real-time visual tracking of the dynamic behavior of each part of the feather. Through high-speed image analysis, it is possible to measure the amplitude and frequency of vibrations at multiple points, providing a more comprehensive and precise representation of the dynamics involved in these flexible bodies.

II. Literature Review

The measurement of mechanical vibrations using computer vision has been addressed in various scientific studies in recent years, leading to advances in the precise capture of the dynamic behavior of complex structures. Improvements in visualization techniques for vibration measurement have been proposed, as mentioned in [3]. Specialized algorithms for digital image processing have also been developed to mitigate issues such as phase noise, phase instability, and phase unwrapping [4]. Computer vision techniques have been successfully applied to measure the vibration of beams as an alternative to piezoelectric sensors [5]. Additionally, advancements have been made in monitoring the condition of wind turbines by measuring mechanical vibrations using computer vision [6]. Other researchers have applied binocular vision techniques to measure vibrations in civil structures without the need to place markers on the structure, enabling a more indirect measurement approach [7] and [8].

Given the success of these methods in the aforementioned applications, we hypothesize that computer vision could be equally effective in measuring vibrations in feather art, where feathers exhibit complex dynamic behaviors and multiple degrees of freedom. This technology would allow for the precise visualization and quantification of

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the mechanical responses of feather art to vibrational excitations, significantly contributing to its understanding and conservation.

III. Methodology

The displacements in the barbs of feathers during vibration generate complex movements with multiple degrees of freedom, making it difficult to accurately capture their dynamics using conventional instruments such as accelerometers, which only provide point measurements, or laser sensors, which are limited to fixed lines of sight. To overcome these limitations, a computer vision system has been implemented, enabling continuous detection of vibrations in each captured video frame. This approach offers the advantage of simultaneously monitoring different points on the feather barbs, providing a complete visualization of the vibratory behavior. Through image processing, it is possible to track the displacement and deformation of each part of the assembly in real-time. Subsequently, the obtained data is analyzed using statistical methods, allowing for a detailed quantification of the amplitude, frequency, and direction of the vibrations. This surpasses the restrictions imposed by traditional measurement methods and offers a more precise characterization of the vibratory phenomenon in flexible bodies such as feather art.

The vision algorithm used in this study is based on recording the vibratory behavior of the feather over a period of 10 seconds. Subsequently, each frame of the recording is processed sequentially. The first step in the processing involves complete segmentation of the feather, where various regions are differentiated using a color-based identification technique. Once the feather is separated from the background, the image is converted to monochrome, facilitating its analysis. In the next phase, the number of pixels that make up the feather in each frame is calculated, allowing for a quantitative representation of its instantaneous geometry. The algorithm performs two key comparisons: the first evaluates the variation in the total number of pixels between consecutive frames, which allows for the detection of changes in the visible extent of the feather. The second comparison analyzes the variation in the relative geometry of the feather over time, using the processed monochrome image to identify deformations or displacements in the barbs. This approach provides precise measurement of displacements under the studied vibration conditions, enabling a detailed characterization of the dynamic response of the feather. Figure 1 shows a representative section of the algorithm programmed in the LabView environment.

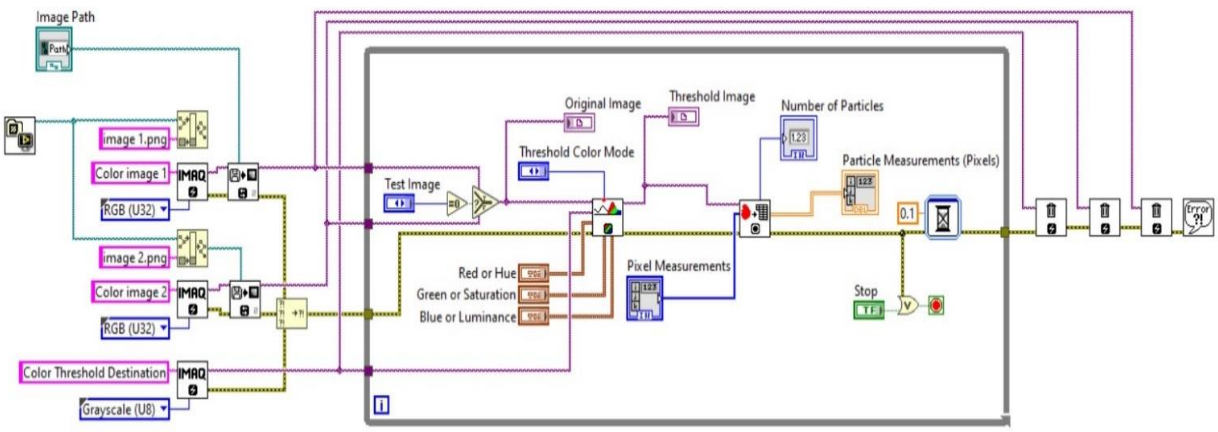

Figure 1. Section of the program that generates a monochrome image and calculates the number of pixels.

To ensure proper image acquisition without shadow interference, a strategic lighting arrangement was used around the feather. This lighting system eliminates shadows cast on the object, improving the accuracy of the visual analysis. Before conducting the vibration tests, a reference capture of the feather in a static state is taken. From this image, the parameters of hue, saturation, and luminance are adjusted to optimize segmentation and tracking during processing. These adjustments are crucial for ensuring precise identification of the feather in subsequent images, as both lighting conditions and the natural colors of the feathers can vary significantly depending on the type of feather and the test environment. Control over these parameters allows for greater consistency in data acquisition, preventing errors in processing due to changes in lighting or color variations, which is essential for obtaining accurate vibration measurements. An image of the user interface is shown in Figure 2.

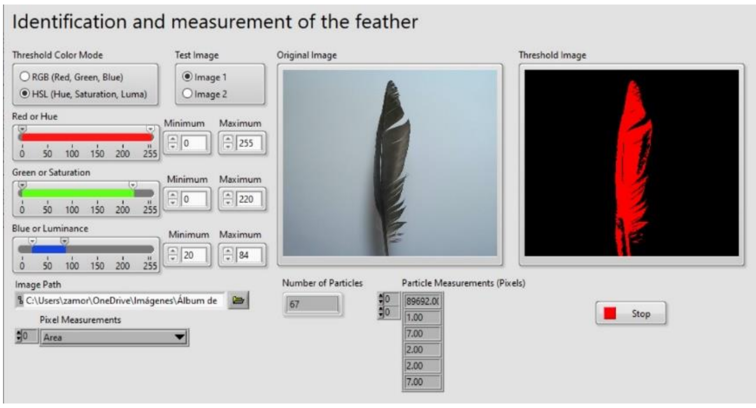

Figure 2. Graphical user interface where images are processed.

To induce vibrations in the feather, a shaker can be used, a device commonly employed to generate controlled vibratory motions. However, in this study, a specialized machine was designed and developed to more precisely adapt the testing conditions to the unique characteristics of feather art. This equipment, whose construction and operation are the subject of an independent study, consists of a mechanism that allows both the amplitude and frequency of the applied vibrations to be adjusted. The machine was designed to provide precise control over sinusoidal and linear vibrations, ensuring the replicability of the tests and the safety of fragile objects like feathers. Its use allowed the creation of a specific test environment for this study, ensuring that the vibration conditions were representative and reproducible for the experiments conducted. An image of the experiment set up diagram is shown in Figure 3.

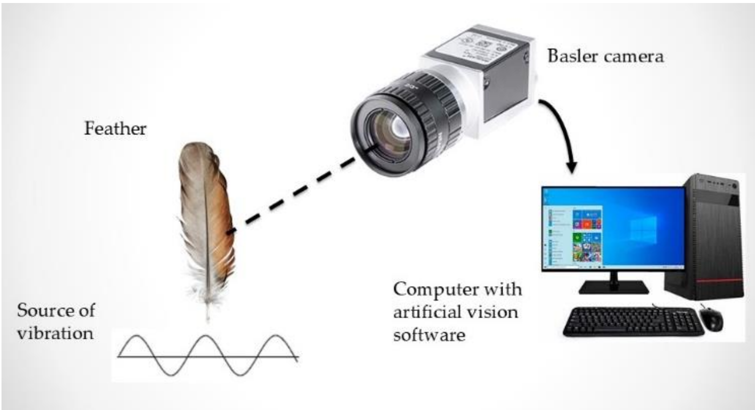

Figure 3. Diagram of the experimental set up.

The experimental protocol developed for this study involved setting a constant vibration amplitude and adjusting the excitation frequency on the vibration machine. Each test was conducted by subjecting the feather to vibration for a period of 10 seconds, during which video footage was captured at a speed of 227 frames per second (fps) using a high-speed camera. After each test, the vibration frequency was adjusted, and the procedure was repeated, resulting in a series of 10-second recordings corresponding to different frequencies. The videos obtained were then processed using the specialized software described, employing computer vision techniques to analyze the vibratory behavior of the feather at each frequency studied.

For image capture and processing in this study, an industrial Basler camera model acA1440-220uc was used, capable of recording at high speed with a resolution of 1440 x 1080 pixels and 227 frames per second, enabling a detailed analysis of the feather's vibrations. The camera was connected to a custom-built workstation running on a Windows operating system, equipped with an Intel Core i7-13700F processor to handle the intensive calculations required by the computer vision algorithm. The computer was also equipped with 32 GB of DDR5 RAM to support real-time processing of large volumes of data, and an NVIDIA RTX A2000 graphics card to accelerate image processing and result visualization. Additionally, a 1 TB solid-state drive (SSD) was incorporated to ensure fast data transfer and storage, facilitating efficient analysis of the experiments. This hardware configuration was specifically selected to guarantee optimal performance in the vibration tests and high-resolution image processing.

For this study, pigeon feathers (Columbidae) were selected due to their accessibility and structural characteristics, which serve as a representative model for the dynamic behavior of feather art. However, this methodology is adaptable to feathers from various bird species and of different ages, including those found in ancient feather art created by civilizations across different regions of the world. The ability to test feathers from diverse origins provides the opportunity to study how species-specific traits and material degradation over time influence their response to mechanical vibrations, offering valuable insights for the conservation of cultural artifacts.

IV. Results

The change in the feather's area in the monochromatic image, obtained through the computer vision algorithm, was used as a quantitative measure of the agitation level induced by different vibrational frequencies. As the vibrational frequency increases, a significant variation in the feather’s projected area is observed, reflecting the displacement and deformation of its barbs. This phenomenon indicates the feather's sensitivity to mechanical vibration, particularly at frequencies near its resonance modes. Figure 4 presents experimental results showing the relationship between the agitation level, measured as the percentage change in the feather's area in the image, and the applied vibrational frequencies, while maintaining a constant amplitude of 10 mm.

It is observed that the feather's agitation level varies non-linearly with the increase in vibrational frequency. The experimental data reveal a clear rise in agitation as the frequency approaches 10 Hz, where a peak is recorded, indicative of a resonant behavior typical of flexible structures such as feathers. Beyond this frequency, the agitation progressively decreases as the frequency continues to rise, suggesting a reduced transfer of vibrational energy to the feather's barbs at frequencies higher than its resonant point. This non-linear behavior is critical for understanding the dynamics of feather art when subjected to mechanical vibrations.

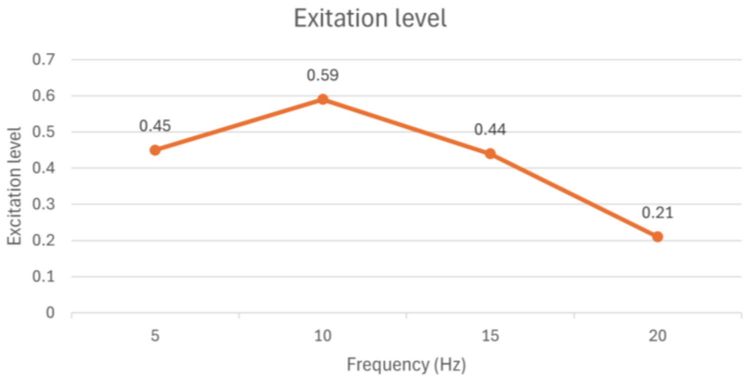

Figure 1. Graph of the agitation level with respect to the vibration frequency

V. Conclusion And Further Research

The presented study has enabled the characterization of the dynamic response of feather art to mechanical vibrations using a vision-based approach. The results show that feather agitation does not follow a linear behavior with respect to vibration frequency, reaching a maximum around 10 Hz, corresponding to a resonant phenomenon. This peak in agitation indicates a high sensitivity of feather art to specific frequencies, implying that during handling and conservation of these objects, it is crucial to avoid frequencies near resonance to minimize the risk of damage. The developed methodology, which combines a high-speed image acquisition system and processing algorithms, has proven to be an effective tool for measuring the vibratory behavior of flexible bodies like feathers, providing a more detailed perspective than traditional point-based sensor methods.

This study opens the door to new lines of research focused on optimizing and applying the artificial vision system to other types of cultural artifacts sensitive to vibrations. A possible extension of this work includes the integration of advanced numerical models to predict the dynamic behavior of feathers under various environmental conditions, such as changes in temperature or humidity, which could also affect vibrational dynamics. Additionally, improving the spatial resolution of the image acquisition system is foreseen to detect more subtle displacements in different parts of the feather. Another aspect to develop is the creation of an automated framework for real-time monitoring of heritage objects' vibrations during transport or exhibition. Finally, the generalization of this approach will be explored to apply it to other organic and fragile materials found in cultural heritage, enhancing conservation and handling protocols.

The technology developed in this study, based on computer vision for measuring mechanical vibrations, has potential applications beyond feather art conservation. It can be extended to other flexible or multi-body flexible materials, such as textiles, biological tissues, and lightweight structural components. These materials, like feathers, exhibit complex dynamic behaviors under mechanical excitation, making traditional sensors inadequate for capturing their full vibratory response. The ability to accurately monitor and quantify deformations and displacements in real-time could enhance the preservation and structural integrity of cultural artifacts, optimize the performance of flexible engineering structures, and contribute to advances in fields such as biomechanics and material science, where precise dynamic characterization is crucial.

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