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Holographic monitoring of transportation effects on canvas paintings

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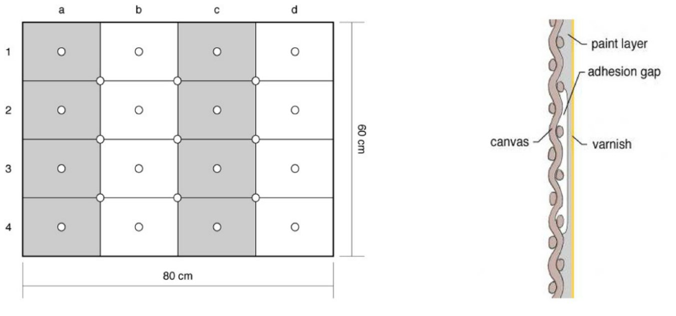
Digital holographic speckle pattern interferometry is used to locate areas at risk of deterioration in paintings due to vibration.

Handling and transportation of artwork exposes usually delicate and fragile pieces to harmful shock and vibration. As a result, cracks develop, which in turn may lead to paint loss because of reduced adhesion to the canvas. Despite multiple approaches to address this issue, only acceleration data during transport have been provided.[1,2] Additionally, while commercial sensors can be used to record the oscillation characteristics of vibration and shock, the impact of these remains undetermined. Thus, better understanding of crack mechanisms is needed to develop effective methods to prevent damage during transportation. Here, we use digital holographic speckle-pattern interferometry (DHSPI) to record the reaction of artwork to shock and vibration.[3–5]

We used DHSPI to record and reproduce phase differences of a divergent laser beam incident on the painting surface, which provides a topographical map describing surface deformation. This map—complete with contour lines, i.e., interference fringes—provides information about both internal and surface cracks. Specifically, the interference fringes result from the comparison of two holograms of the painting, one of the calm state and one of an excited (i.e., thermally expanded) state. These contour lines describe, in 3D, the deformation of the object's surface. This type of analysis is particularly useful because cracks resulting from vibrations are difficult to measure—especially in canvas paintings—as they are not easily detectable with precision. Additionally, DHSPI allows a large surface area to be examined and provides a level of detail unrivaled by other observational techniques.



(a) (b)

Figure 1. *(a) Principal areas of the sample painting used. Circles indicate the location of weak spots. (b) Principal construction of the sample painting.*

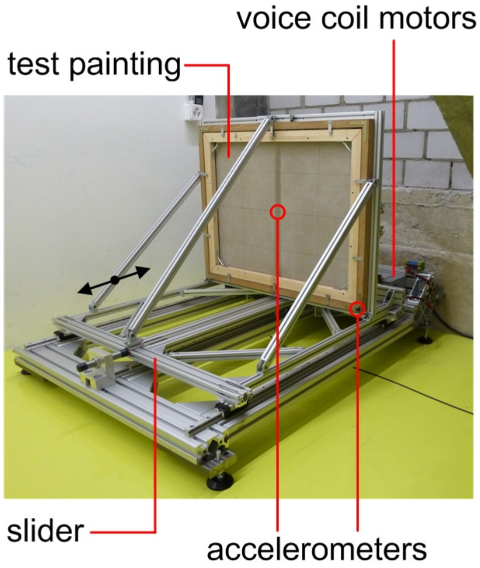


Figure 2. *The transport simulator used to impose vibrations on the sample painting.*

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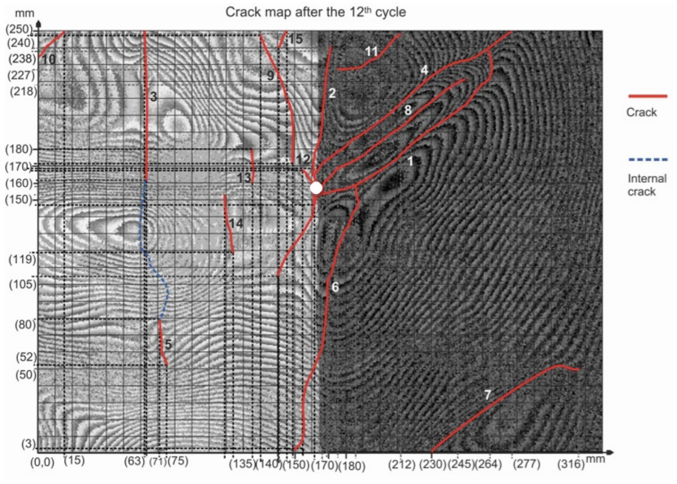

Figure 3. *DHSPI crack map of the canvas after the 12 cycles of noise. Red lines trace the surface cracks while the blue line traces an internal crack. The white dot denotes where the sensor was attached in the middle of the back side of the canvas.*

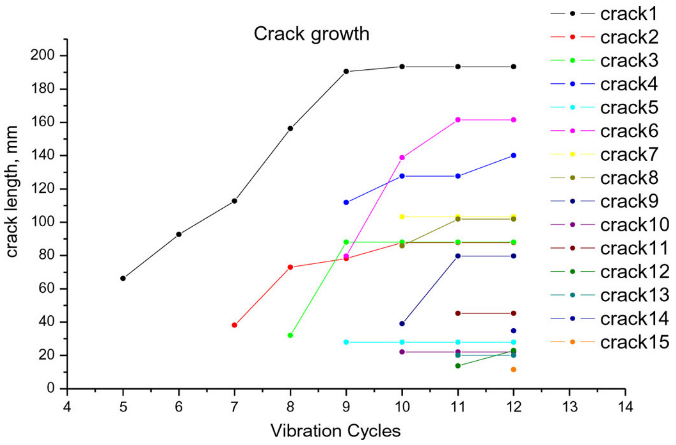

Figure 4. *Crack creation and growth with each vibrational cycle. Each cycle represents an increase in the amplitude of oscillation.*

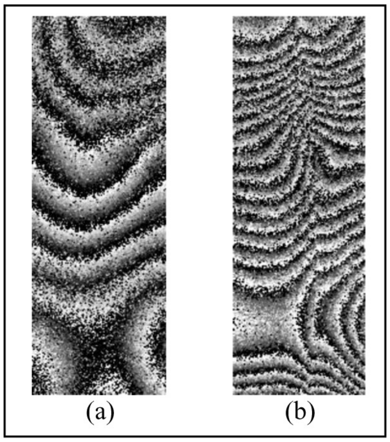
(a) (b)

Figure 5. *Part of the DHSPI around crack number three after the (a) third and (b) ninth vibration cycles.*

We began by constructing a sample painting (60 × 80cm) supported on linen canvas, sized with skin glue, two layers of gesso, and black acrylic paint. Within the structure, we integrated weak spots to imitate fragile paintings, which generally have structural weaknesses, such as imperfect adhesion of the paint layer and supporting fabric (see Figure 1). These weak spots are particularly susceptible to shock and vibrational emissions. We used a new transport simulator[6] capable of reproducing the arbitrary vibrations that are commonly recorded during real transport. The simulator consists of a slider capable of displacing the mounted test painting up to 70mm perpendicular to the canvas (see Figure 2). Additionally, we attached a sensor to measure the characteristics of the canvas oscillation in the middle of the backside of the canvas.

We applied random signals (i.e., noise) of frequencies between 1–50Hz lasting 10s with variable acceleration starting at 1m/s^2 (root mean square, rms). Twelve vibration cycles were applied, increasing acceleration by 1m/s^2 rms per step. However, because of the limitations of the instrumentation, we ran the final two cycles with 9m/s^2 rms acceleration. After each vibration cycle, we obtained two DHSPI measurements, one with and one without an applied thermal loading. The application of heat induces a slight expansion of the painting surface and assists in acquiring information about its internal structural condition. We used two infrared lamps with a maximum temperature increase of 0.7°C. We then interfered the hologram of the expanded surface with the hologram taken before thermal loading to generate interference fringes describing the surface deformation.

In all, we detected 15 cracks after 12 vibration cycles, with the first crack appearing after the fifth cycle (1–50Hz, rms $= 5\text{m/s}^2$, 10s duration). The interference fringes obtained provided the micrometric data that represents the deformation of the painting surface.[7] We studied the surface topology of the painting because the surface deforms according to the content of the internal bulk of the object. Thus, we could acquire information about its invisible structural condition by examining its surface. After each vibration cycle, we obtained a full DHSPI crack map (see Figure 3) from which we could measure the length of all the

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cracks as they developed (see Figure 4). Despite the sensor being lightweight, it has likely influenced crack formation around the center of the canvas (see Figure 3).

Importantly, we found indications in the contour DHSPI map of an internal crack (number three) before it reached the surface. We observed curved interference fringes with local changes in direction, which are to be expected where inborn cracks appear. After additional vibration cycles, this crack reached the surface—resulting in surface discontinuity—and its interference fringes were severely disrupted (see Figure 5). Thus, DHSPI can locate areas of future, visible/surface deterioration, which will assist conservators in preventing further deterioration.

In summary, we have simulated vibrations on a sample painting to better assess the effects of transportation, to record crack generation and propagation, and to locate areas at risk of future deterioration. This work will be particularly useful for risk assessments of the transport of fragile paintings. In the future, we will use DHSPI to further investigate areas at risk of future deterioration and conduct a systematic study to define the threshold limits of transport conditions to develop a safe transportation protocol for delicate artwork.

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