A HOLOGRAPHIC SYSTEMATIC APPROACH TO ALLEVIATE MAJOR DILEMMAS IN MUSEUM OPERATION

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ABSTRACT

The objective of this presentation is to introduce to the cultural community the beneficial role of the systematic use of holography related techniques regarding art conservation decisions. It is well known that works of art and museum items are susceptible to deterioration due to the very fundamental and unavoidable operation system of museums worldwide; such as: exhibitions, transportation, environmental and climatic changes. In every of the above mentioned cases art objects are undergoing chemical, physical and structural alterations. The issue of main importance is whether these changes can be kept in-between safety limits avoiding thus irreversible changes, which thereafter affect the integrity of the object. In this context techniques that can assess the best handling prior to any damage should be adopted, developed and integrated in museum safety polices. Holography related techniques are completely non-destructive and can acquire three-dimensional information about the shape and the displacement of the object having no dependence on surface roughness or texture therefore not requiring any object preparation at all. By manipulating holography' s main arrangement repetitive and routine examination of artworks is possible. The information can be digitized and image processed for further analysis with user-friendly available software. To the best of our knowledge such a systematic preservation approach is missing from the conservation strategies. Following is a brief description of holography and holographic interferometry and then some experimental examples, and at last but not the least, applications and prospective for art conservation.

I. INTRODUCTION TO HOLOGRAPHY

By means of holography the whole information of light reflected by an object can be recorded. The term 'whole information' indicates both amplitude and phase information of the light. In order to produce a hologram, a single beam of mutually coherent and monochromatic light (Laser) is divided into two beams, the one directed to the subject matter (object beam) and the other is driven to be reflected by a mirror (reference beam). Both beams then, are directed to the plane of the photosensitive medium (Fig. 1a). The two beams interact under rather strict conditions to form an interference pattern, and although the wavefronts continue to travel at the speed of light, the pattern itself is stationary. As a result, the record on the emulsion of the photosensitive medium of this stationary pattern (primary fringe pattern) is possible and

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contains all the phase information. During reconstruction only the reference beam illuminates the film reproducing by diffraction the subject wave-field, thus the 3D scene (Fig. 1b).

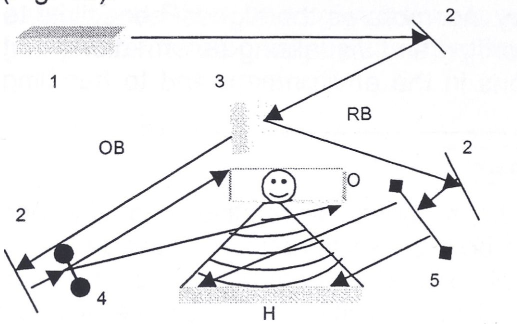


Fig. 1a. Recording of a hologram. (1) laser, (2) mirrors, (3) beam-splitter, (4) diverging lens, (5) collimating lens, OB: object beam, RB: reference beam, H: holographic plate, O: object.

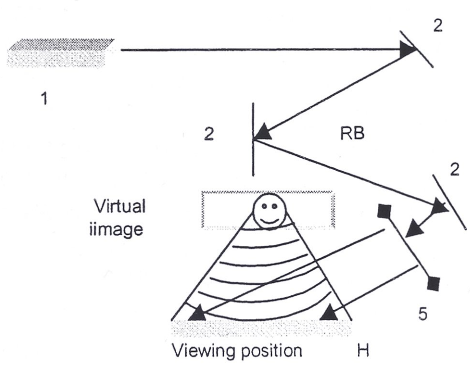


Fig. 1b. Reconstructing a hologram.

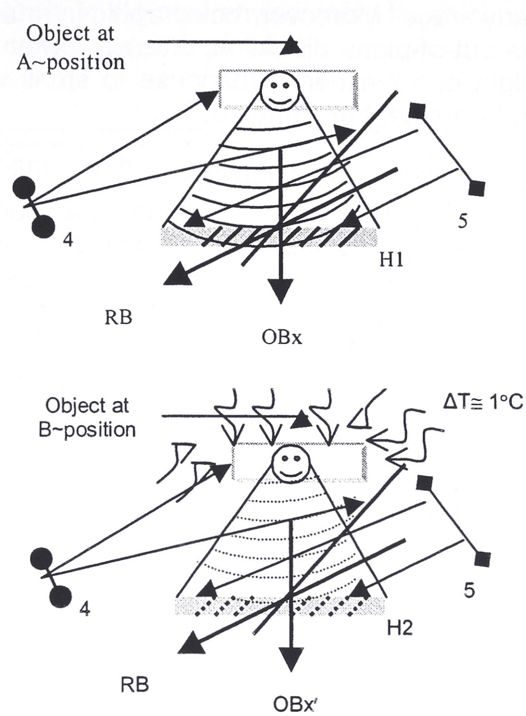


Fig. 1c. Recording a holographic interferogram in an initial and displaced position. The pathlength difference results to visible fringes (OBx′-OBx=dx)

The underlying principle of holographic interferometry is the sequential record of optical wavefronts, which can be later reconstructed simultaneously. Holographic interferometry is the result of causing two primary fringe patterns in a hologram to form a secondary interference pattern. This can be achieved when two wavefronts of the scene are made to superimpose in order that the two sets of primary fringes to generate a much larger pattern of secondary fringes. Therefore, in order to get interferometric evaluation of the subject matter a second exposure is made subsequently on the same plate, with the subject slightly deformed. Because the first and the second optical waves represent the light scattered to the hologram plane by the object before and after has been slightly deformed, what is implicitly being recorded is the phase difference of these waves (fig. 1c). During reconstruction both wave fields interfere. Consequently the resulting intensity is modulated by a fringe pattern, called holographic interferogram. Bright fringes are contours of constant values of phase difference, which are even-integer multiples of half a cycle. Dark fringes are contours of constant value of phase difference, which are odd-integer multiples of half a cycle. This phase difference is related to physical quantities such as displacement, strain and stress. The resulting permanently recorded fringe pattern contains all the information about the change in shape of the seen surface of the object under test. The displacements that holographic interferometry shows are very small of the order of a few micrometers; which means that in order to get interferometric evaluation using holography only the small changes that might occur in the subject matter should be recorded.

Therefore Holographic interferometry is completely non-invasive, non-destructive and non-contacting; therefore, the method can safely test art works and ancient artifacts for incipient faults or damage (1-5), allowing corrective measures to be applied at an early stage. Moreover, holographic interferometry incorporates the highest sensitivity to the out-of-plane distortion, offering a way of recording and visualising deformations that might occur either in response to small variations in the environment and to handling and treatment procedures.

II. EXPERIMENTAL CASES

(a) From the environmental considerations those of relative humidity and temperature are most often considered because both cause dimensional responses (in humidity sensitive materials) with respect to atmospheric variations. Most museum objects, artifacts and works of art are composed of humidity sensitive materials that respond dimensionally to variations in humidity (H) and temperature (T). Of the two factors, humidity and temperature, the former, specifically relative humidity (RH) influences dimensional changes, with subsequent loss in strength properties and damage. These effects are not usually perceptible at first, but the cumulative effects eventually become accessible to conservators. The relative humidity is the dominant factor that affects the structural changes and strength properties of an object. Therefore, it is of main importance to explore ways of recording RH change and induced deformation at a level that is imperceptible under normal testing conditions, and this can be a basis for a whole field of holographic applications in art conservation. Established inspection methods in conservation of art works cannot result in adequate responses to describe the artifact behavior because they are mostly invasive and of long duration, often demanding destructive dimensional changes. Hence, the inherent properties of hologram recording and the manipulation to generate visible interference fringes provide suitable for environmental effects measuring systems (6, 7).

In this example a double exposure holographic interferometric inspection, based on the monitoring of RH/T conditions in a chamber where organic specimen were present, was designed to show a measure of the speed and the degree of interaction between relative humidity and materials' dimensional changes. Rather than a restricted investigation the aim was to match the experiment to observe changes in materials as might occur in the normal life of a Museum artifact. This might involve display in a gallery, then removal to another gallery within the Museum and then perhaps sent on loan to an exhibition in a foreign gallery with an abrupt change of climate. In order to induce the specimens to simulate fast within the above general terms, the experiment started from slow rates of RH change and gradually increased to more rapid change and finally altered abruptly. By means of alternative use of a continuous wave and a pulse laser that give different duration of exposure times and exposure intervals has been provided interferometric record of the diverse responses. The interferograms were recorded while the specimens were in the process of stabilising from one environment to the other. The fringe density occurred in the interferograms indicate the accommodation process of materials in the new environment in terms of safe or alarming RH change.

The way that materials change shape with variation in environment appears to be closely related to ageing. This factor, in combination with repeatable changes, appears to accumulate tension in the structure of the material even when macroscopically it presents little or no dimensional change. The environmental history of the object is related closely to the ultimate safety of changes. The diagram shown in figure 2 resulted from the holographic interferometric measurements indicates the alarming values of structural displacement when RH change exceeds 10%. Up to 10-15% RH value the change is kept smooth and the response of the material linear. After

15-20% RH value the change becomes abrupt and materials reaction becomes non-linear. Thereupon, appear to be more critical the rate of change than the value of extreme changes. Suggesting as reasonable way of removing an art object from an established RH to be to give it time to adapt slowly in the new environment to which it is going to be transported, by changing the environment equally slowly.

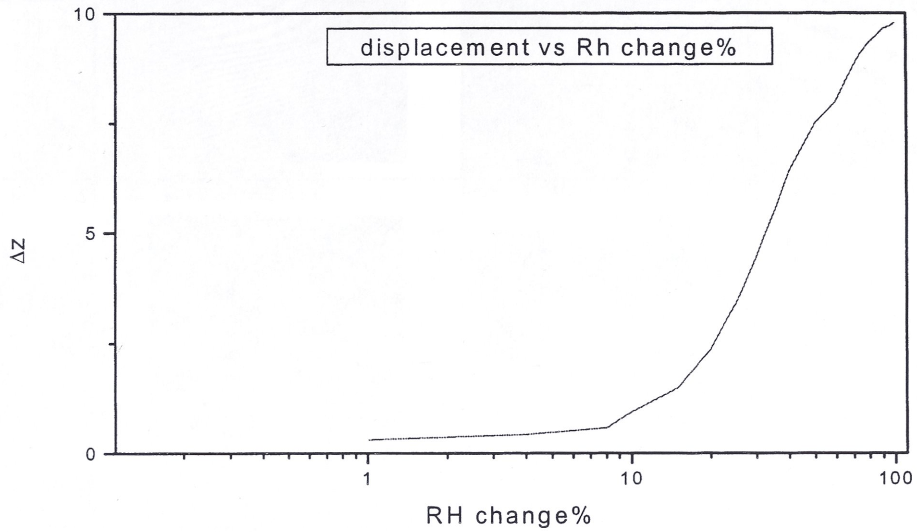


Fig. 2. The diagram of the relative displacement of samples due to RH% change. When RH change exceeds ~10% the rate of the structural changes throughout the volume of the material in equilibrium process is abruptly increased.

Keeping data over periods of assigned equilibrium time as a response to a constant value of stress (e.g. change of RH%) results in a comparative graph about the material. The graph can be an annual indication of the accommodation capabilities of the object. The repeatability of holographic interferometry and its fast responses are among its main advantages permitting routine or seasonal examination of artworks.

(b) Another important issue for museum and galleries is the objective and reliable diagnosis of hidden defects. The exact location and size of flaws underneath the surface of the artwork is critical for restoration priorities, insurance and loan strategies. Holographic interferometric non-destructive testing can provide a detailed topographic map of surface and subsurface different type of flaws. Such a detailed topography can provide accurate comparison to a later stage of the artwork, e.g. after an exhibition tour or a loan to another gallery. The fringe pattern exhibited by holographic interferometric investigation on models with induced defects and from real artworks can be categorised in five main classes corresponding to types of flaws occurred in artworks, e.g. worm-tunneling, detachment between lateral surfaces, non-homogeneous material properties, weak points, cracks, inclusions (8, 9). In addition recent advances on post-analysis of holographic interferograms based on specially designed algorithms, now commercially available, enable extraction of the continuos phase distribution carrying all the necessary information about the shape and the displacement of the object (10).

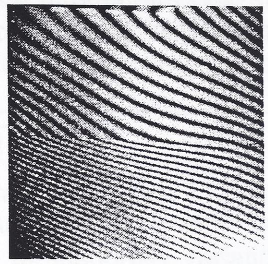
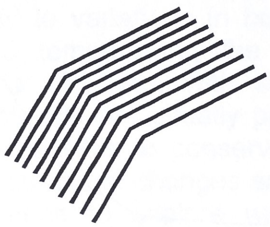
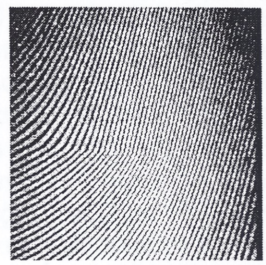
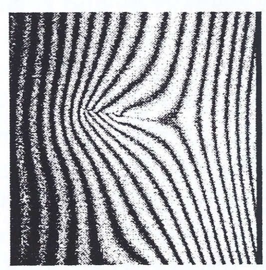
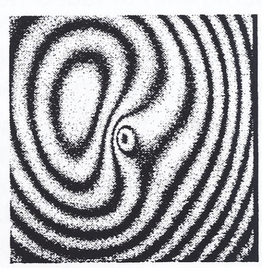
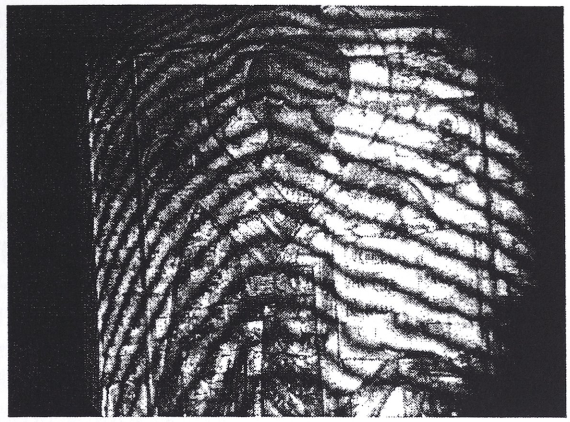
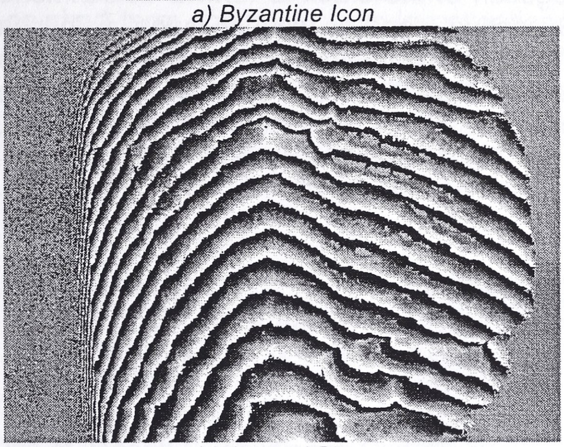
Symptom	Fringe Pattern	Interferogram	Expected Flaw
Compression: loal spatial frequency change	Grafikname: Erstellt in: Erstellt am:		material separation, weak point
Bend: noncontinuous direction change			local separation, void, crack under the surface
Groove:systematic and directed fringe deformation	Grafikname: Erstellt in: Erstellt am:		extended separation,
Displacement: displaced fringes, local cut	Grafikname: Erstellt in: Erstellt am:		crack on the surface
Eye: circular/elliptical patterns	Grafikname: Erstellt in: Erstellt am:		void, inclusion local separation

Fig. 3: Fringe pattern classes which are indicative for material faults (8)

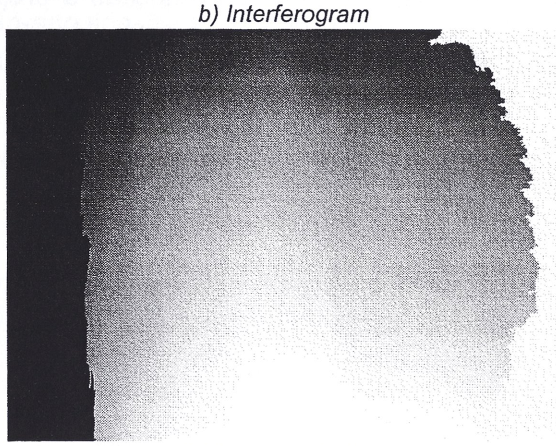
a) *Byzantine Icon*



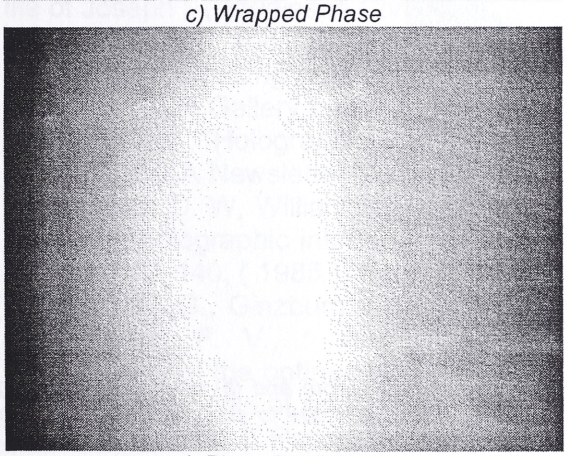
b) *Interferogram*



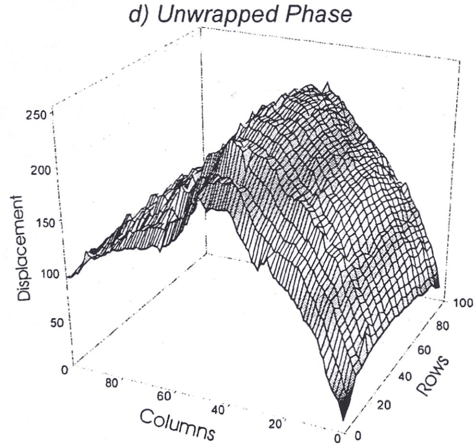
c) *Wrapped Phase*



d) *Unwrapped Phase*



e) *Plane-fitted Phase*



f) *Pseudo-3D-Plot*

Fig. 4: Processing the holographic interferogram of Saint Nicolas Byzantine with FRINGEPROCESSOR™.

Furthermore, the fringe analysis is processed by conversion of the fringe pattern into continuos phase map from the quasi-sinusoidal character of the intensity distribution, which is applicable onto a great variety of fringe patterns. Therefore, the fringe phase evaluation is allowed even for uneven and complicated interferograms from real artworks.

Results indicate that the diagnostic capability of holographic interferometry is of great value in art conservation. The obtained holographic interferograms trace through characteristic fringe features, the presence of known defects and reveal unknown ones. The knowledge-based-approach facilitates the isolation, localisation and quantitative evaluation. Further research targets to the acquisition and correlation of reference data and the further exploitation of the method towards diagnosis automation and user-friendly portable equipment.

(c) Holographic interferometry enables the investigation of effects in painted artworks induced by excimer laser assisted varnish removal operations (11-14). The primary interest is the assessment of damage due to generation and propagation of the shock waves through the medium. There are strong indications that the deterioration and formation of defects caused by the laser-assisted varnish removal at fluence from 0.29 – 0.55 J/cm^2, is related to the type of existing defects. In the case of existing crack, deterioration has been exhibited as a propagation of the crack to form a detachment. For multi-layered structures such as the Byzantine icons or wooden panel paintings existence of crack causes steady growth of delamination between the cracked and the successive layer. This is due to absence of adhesion at the cracked region. The observed, therefore, evolution to a well defined detachment is an expected deterioration. However, the laser-induced stress proves to accelerate the deterioration.

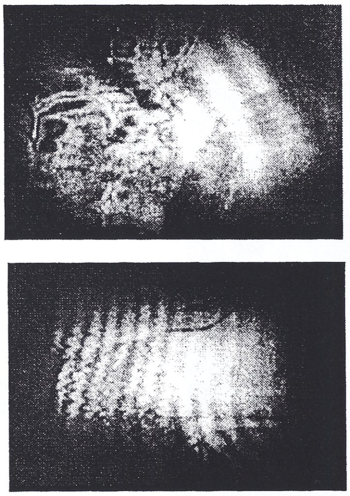


Fig.5. Details of holographic interferograms of a Flemish painting (a) before and (b) after laser cleaning. The closed curvelike structures at (a) are indicative of surface corrosion due to stain inclusions in outer varnish layer.

To compensate for this effect further experiments are scheduled to operate by continue manipulation of cleaning parameters. In the case of existing detachment there was evidence of recovering. The only known method for restoration of detachment -whether a crack exists or not- is a manually performed consolidation, which is based on restorers' experience. The result of the recovering of detachment after the laser cleaning is indicative to a positive photomechanical effect of the method on the artwork. To affirm and improve this positive performance of the method on this type of defect further experiments are also on schedule. Figure 5 illustrates a detail of a flamish painting before and after of laser-assisted varnish removal. The interferograms are indicative of the capability of the technique to assess recovering of defects and successfulness of the laser cleaning process. This performance encourages for utilisation to assess conventional restoration means such as the mechanical and chemical treatment of artworks.

III. SUMMARY

Holographic interferometry is a versatile method to improve art conservation assessment of damage, environmental procedures and comparative evaluation of restoration techniques. There is not currently a technique capable of such a broadly applicable performance and the consistency of results of holographic interferometry. The objective of the presented paper is to suggest to conservation discipline, for both prevention and diagnostic purposes, a non-invasive way to record data of materials or single objects by obtaining holographic interferometric information. Thus, each subject' s characteristic profile can be discovered to predict long-term patterns of behavior based on short-term non-destructive investigation. In addition, by keeping interferometric fringe data over the years an artifact' s deterioration can be foreseen well before its occurrence. Therefore, sensitivity to scheduled changes and damage would be both directly identifiable and preventable. In practical terms the artwork can be routinely examined and archives of the results can be retrieved and compared to the present state anytime that the diverse conservation demands should require.

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