Quantitative Strain Measurement on Artwork by a Combination of Shearography and FEM-Simulation

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Abstract. We present a way to gain quantitative strain information in the shearographic inspection of artwork. A comparison with FEM-data can be used to obtain the quantitative strain. Therefore the displacement data from the simulations are used in a shearography-simulation. So typical defects on artwork can be detected and evaluated with respect to their criticality under environmental changes.

Introduction

The preservation of artwork is at the same time an important and difficult task. Especially the non-destructive detection and evaluation of hidden defects like delaminations is still very complex. A well investigated method for defect detection is the shearography [1-2]. This interferometric technique is based on the phase measurement by comparing the image with a slightly shifted copy of itself. After the recording of the phase the object is stressed by either thermal or mechanical loading producing a deformation of the surface related to the defect. The comparison of both phase-images gives then information about the defects under the surface.

For a small shear δx in x-direction the out-of-plane strain $\frac{\partial w}{\partial x}$ can be determined by the well-known equation:

$$\Delta\phi(x,y) \approx \frac{4\pi}{\lambda}\frac{\partial w}{\partial x}\delta x \qquad (1)$$

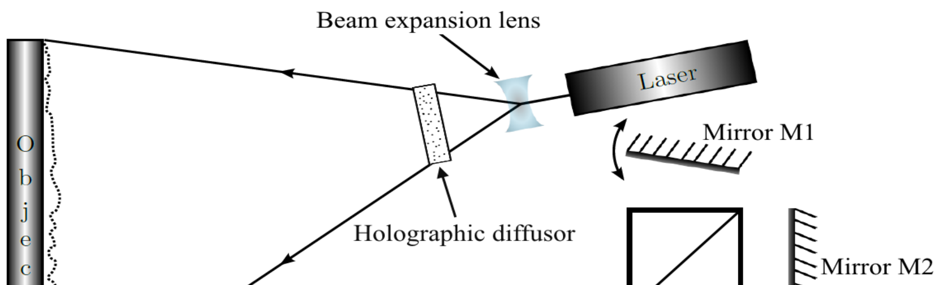
with the wavelength λ and the measured phase image $\Delta\phi(x,y)$.
Because the restoration of such defects is complicated an evaluation of the criticality is always necessary. A good indication is the amount of strain, which occurs due to the loading. Unfortunately the exact strain can only be determined using equation 1, if the amount of shear is infinitesimally small. This would lead to a bad sensitivity of the system and is usually not done in practice.
We propose a combination of FEM-Simulation, optical simulation and shearographic measurements to obtained quantitative strain amounts. Similar approaches were used in the past to calibrate shearographic systems [3]. In our case we generate a database of typical defects on artwork and use this database for the comparison with measured samples to determine the strain after the loading.

Experimental setup

The principle of the setup used for our experiments is shown in fig. 1. The light source is a frequency doubled Nd-YAG-Laser with wavelength 532nm and 400mW output power. To get rid of the gaussian profile and ensure a homogeneous illumination the laser beam is first expanded by a concave lens and then passes a engineered diffuser (*Thorlabs*), which generate a square, homogeneous light suitable for a good illumination of paintings. The tilted mirror M1 is responsible for the shearing, mirror M2 is mounted on a piezo stage, which can be controlled by the computer, while using a *P3-150 piezo controller* from *LINOS.* The camera is a *PCO 1200s* CMOS with 1280x1024 pixels and a maximum frame rate of 636Hz. As loading mechansim a infrared-lamp and a pressure chamber with *Vaccubrand 510NT* pump are used.

Simulation environment

The simulation procedure can be seen in fig. 2. For the FEM-simulations *comsol multiphysics* is used. The pressure chamber (with vacuum pump) is modelled by a constant under-pressure inlet. The pressure-compensation leads to warming of the chamber, which is also take into account. For the modelling of the IR-lamp a surface-to-surface radiation with constant emissivity is assumed. Due to the large distance (1m) other heat transfer processes like convection or conduction are neglected. After the deformation is determined by the simulations, the data is used for an optical simulation in *matlab.*



The so obtained phase-map $\Delta\phi(x,y)$ is converted into shearographic modulation fringes using I=cos($\Delta(x,y)$). To get a more realistic result a random speckle noise is added and computational phase-shifting leads to a noisy phase image. This phase image is afterwards filtered and demodulated with the same algorithms like the experimental phase image and leads so to a realistic result.

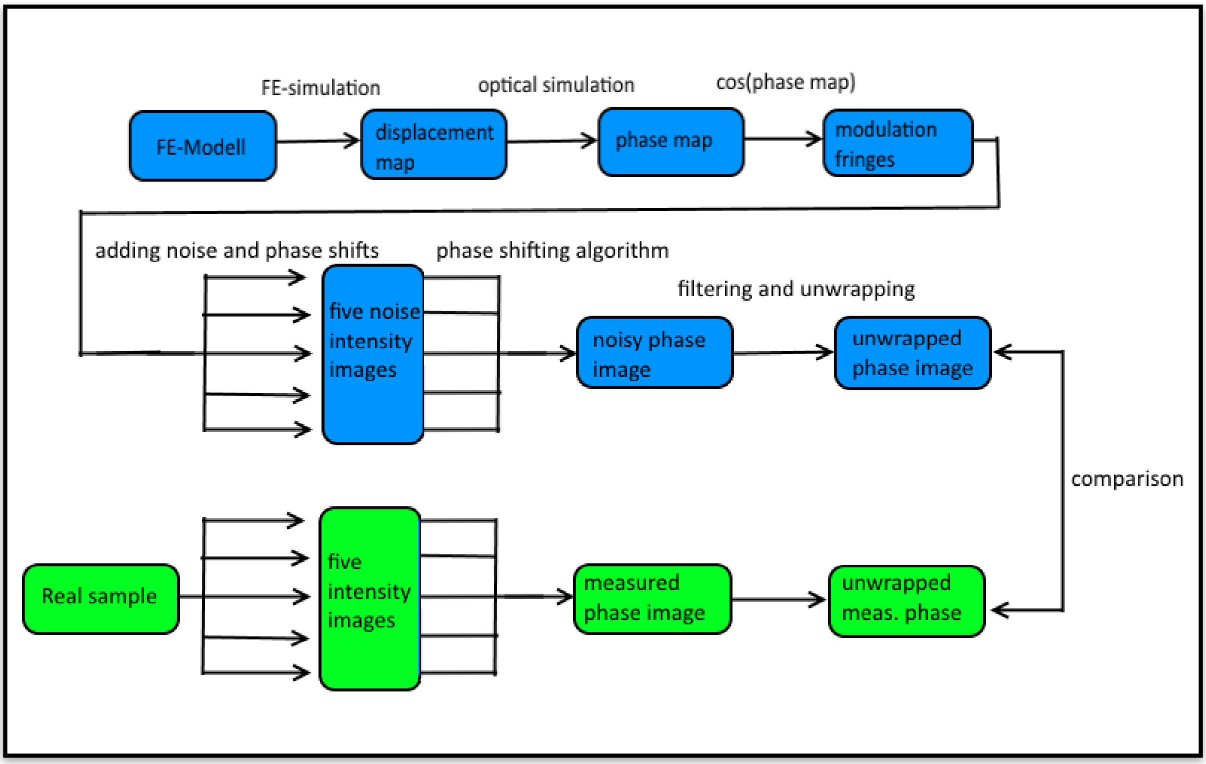


Fig. 2 Simulation process

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References

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