# A Portable Electronic Speckle Pattern Interferometer with Integrated Topometric Surface Analysis


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Electronic Speckle Pattern Interferometry (ESPI) is a well-proven tool for detection of sub-micrometer surface movements to indicate and localize material defects and elasticity properties. A portable ESPI measuring system for non-destructive testing is presented which has been optimized for mobile operation in the field of cultural heritage protection.


## 1 Introduction

Electronic Speckle Pattern Interferometry (ESPI) is a well-proven tool for detection of sub-micrometer surface movements to indicate and localize material defects and elasticity properties. The usage of spatial phase shifting techniques allows to measure deformations with a single interferogram image [1]. A portable ESPI measuring system for non-destructive testing is presented which has been optimized for mobile operation in the field of cultural heritage protection. By splitting the ESPI set-up into two separate units for illumination and monitoring linked by an optical fiber a very flexible usage of the set-up in different environments and for various applications is achieved. The image processing component is based on a digital camera interface standard and allows the unit to be controlled by a notebook computer. Various camera types can be used without the need to adapt hardware and software components. Furthermore, an additional camera can be integrated to perform photogrammetric calculations of 3D surface coordinates of the object under investigations which opens up the possibility to take into account a spatially varying sensitivity vector of the interferometric measurement [2].

## 2 Experimental Methods

The illumination units' light source is a Coherent Compass 315M-150 Nd:YAG-Laser (doubled frequency, $\lambda$=532 nm, $P_{L,cw}$=150 mW). Approximately 10 % of the laser power is coupled into a single mode fiber and used for the reference wave.

The monitoring unit contains a CCD-Camera (Sony XCD-X700 b/w, IEEE 1394 „FireWire") and an imaging system consisting of two lenses which are adjustable for variable imaging fields. The maximum field is limited by the available laser power.

The dimensions of the set-up are 400x180x200 $mm^3$ for the illumination unit and 500x180x200 $mm^3$ for the monitoring unit respectively. The camera can be used wih any deskop or notebook computer that is equipped with an IEEE 1394 interface. A non-transparent acrylic housing is used to protect the components.

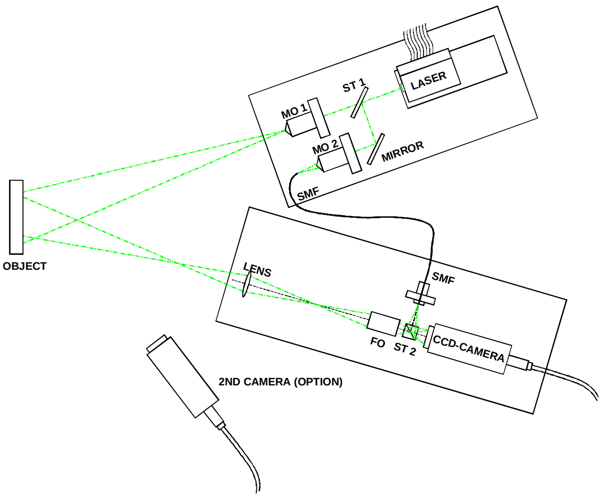


***Fig. 1** Fig. 1: Mobile ESPI setup with optional 2nd CCD-camera for additional photogrammetric measurement. BS1: Beamsplitter 90/10; BS2: Beamsplitter 50/50; FO: Photo lens; MO: Microscope lens; SMF: Single mode fiber.*

## 3 Results of the Characterisation/Optimisation

A mechanical force was applied to a metal plate to create a reproducable phase difference pattern.

The mean deviation $\sigma_{\Delta\phi}$ of the smoothed phase difference compared to the original represents the noise of the measured data.

The lowest noise was measured with a speckle size of $d_{sp}\approx2$ pixel and a horizontal spatial carrier frequency of $\nu_H\approx120$ fringes/512 pixel. The contrast of the intensity of reference and object wave should be $I_R/I_O=4\pm1$. It was found that ambient light has no important impact on measured data (Fig. 2).

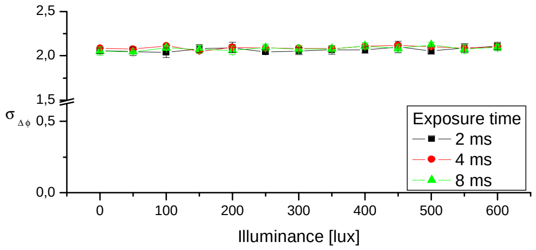


***Fig. 2*** *Sandard deviation $\sigma_{\Delta\phi}$ of the measured phase difference vs. the illuminance of ambient light.*

## 4 Applications in Cultural Heritage Diagnostics

The setup was developed to be used outside the laboratory. Fig. 3 shows the results of the analysis of a socket of sandstone. The measurement has been carried out in a chiseler‘s shop at the Academy Of Arts And Crafts in Raesfeld, Germany.

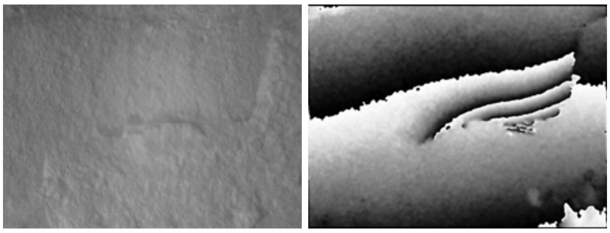

***Fig. 3*** *Left: White light image of the analysed area of the sandstone socket. Right: Smoothed phase difference pattern of the same area.*

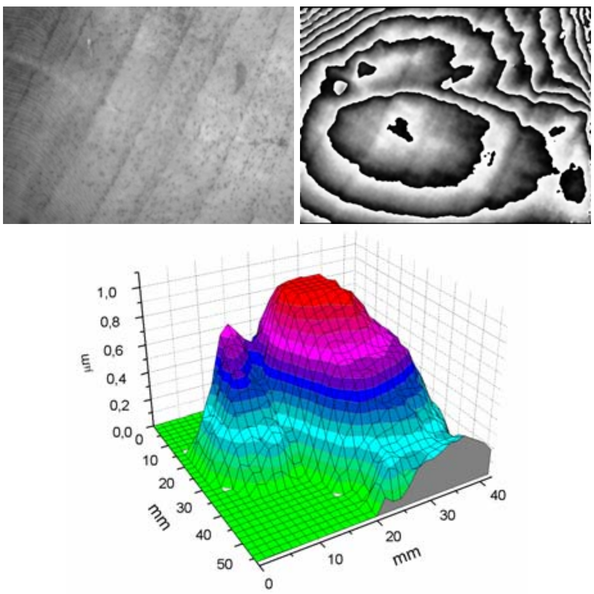


***Fig. 4*** *Upper left: White light image of the analysed area of an ancient wooden panel; Upper right: Smoothed phase difference of this area; Bottom: Pseudo-3D displacement diagram of the measured surface.*

Fig. 4 shows the results of the analysis of an ancient wooden panel. The surface was also stimulated by applying warm air. On the side of this panel a crack was visible which was hidden on the front side by a coating. As shown in Fig.4 a detection and visualisation of the invisible parts of the crack was possible by using the ESPI technique.

Another analysis was carried out in cooperation with the University Of Applied Sciences of Münster. Fig. 5 shows the surface deformation caused by a laser cleaning process. The surface deformation is caused by the impact of the lasercleaning pulses. A deformation of approx. 0.5 m is detected in Fig. 5.

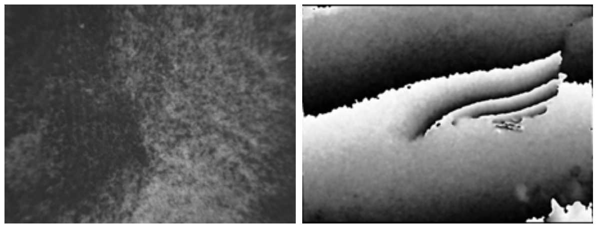

***Fig. 5*** *White light image of a sandstone surface and smoothed phase difference of the same area shortly after a laser cleaning process.*

Fig. 6 shows the results of an analysis of a Madonna head made of sandstone. The surface was stimulated by applying warm air and a second camera was used for photogrammetric 3D calculation. By texturing the calculated 3-dimensional grid with the ESPI-measured phase difference the deformations of such a non-planar surface can be interpreted more easily.

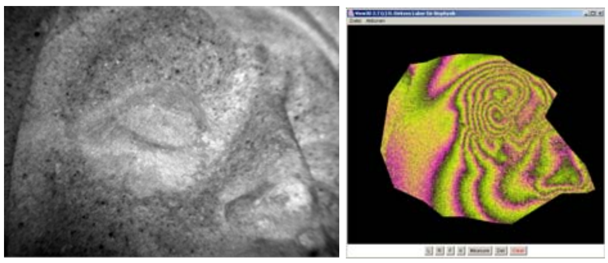

***Fig. 6*** *White light image and 3D model textured with the phase difference of a head made of sandstone.*

## References


[1] B. Kemper; J. Kandulla; D. Dirksen; G. von Bally: Optimization of spatial phase shifting in endoscopic electronic speckle pattern interferometry. *Optics Communications* 217, 151-160 (2002).

[2] D. Dirksen; J. Gettkant; G. Bischoff; B.Kemper; Z. Böröcz; G. von Bally: Improved Evaluation of Electronic Speckle Pattern Interferograms by Photogrammetric Image Analysis. *Optics & Lasers in Engineering* (2005) in print.


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