Adaptive optical 3D-measurement with structured light

J. Gerber, R. Kowarschik*, G. Notni, W. Schreiber

Fraunhofer-Institute for Applied Optics and Precision Engineering
Schillerstrasse 1, D-07745 Jena
*Institute of Applied Optics, University Jena, Froebelstieg 1, D-07743 Jena, Germany

The basis of the described 3D-measurement system is the method of fringe projection in combination with the principle of uniform scale representation /1/, /2/, /3/. The measurement is characterized by the exclusive use of phase-measurement values for the coordinates of each point. To obtain the phase-measurement values the object under test is successively illuminated with a grating structure from at least three different directions with a telecentric system. A CCD-camera records the intensity distribution of the fringes intersected by the object. It should be pointed out that the values of all coordinates (x,y,z) have the same accuracies.

The object to be measured and the CCD-camera are both mounted on a rotation table, turning both of them with respect to the fringe-projector about an axis. The rotation axis makes a constant angle α with the projection direction. With at least $i = 3$ different angle values θ_i the linearly independent absolute phase values are obtained, which are necessary for the coordinate calculation (applying gray-code in conjunction with four 90 degs phase-shifts). In our setup we can choose up to $i = 15$ rotation angles, so that awkward areas of the surface, like zones with either specular reflection or shadows, are shifted over the surface and have nearly no influence on the results of measurements. So, we obtain the 3D-coordinates of a single patch of the object.

We have expanded the system to include a second rotation axis, where the object can rotate within the measurement volume. The CCD-camera will then get different views of the object. The second rotation axis is tilted against the first axis by an angle δ. Depending on the class of objects there are different possible tilt-angles δ. Typically we choose $\delta = 30°$. By rotating the object around the first axis with a rotation angle γ_j (j = number of patches) it is possible to measure the object from different viewpoints, whereby for each patch or viewpoint the procedure described above is used. For a convenient handling of the data-set the restriction $j \leq 8$ is used. The actual rotation angles θ_i and γ_j were measured with angle encoders. The free geometric parameters (grating periode Λ and projection angle α) and the orientation in space of the second axis are gauged before the measurement procedure as described below. By measuring a number of patches we have the problem of transforming them from a local coordinate system into a global one. The combination of the different patches into one coordinate system without interactive user help was solved by developing a calibration method for the second axis. In combination with an absolute phase measurement all patches were measured in a known space orientation, so that we obtain the 3D-picture by rotation of each patch around the second axis. Correlation methods or special points are not necessary. To obtain the 3D-orientation of the second axis one can use a calibration procedure with a special calibration body whose 3D-coordinates are measured for different rotation positions whereby the second axis has to cross the plane near the centre.

Figures 1 to 6 show some examples of the 3D-coordinate measurements.

Acknowledgements
Part of this work was financially supported by the Deutsche Forschungsgemeinschaft (Grant-No., Ko 1556/1-4.

/1/ Gerber, J., Kühmstedt, P., Kowarschik, R., Notni, G., and Schreiber, W., SPIE Vol. 2342 (1994) p. 41-49.
/2/ Schreiber, W., Notni, G., Kühmstedt, P., Gerber, J., and Kowarschik, R., SPIE Vol. 2782 (1996) p. 620- 627.
/3/ Schreiber, W., Notni, G., Kühmstedt, P., Gerber, J., and Kowarschik, R., Akademie Verlag Berlin, Series in Optical Metrology Vol. 2 (1996) p. 46-51

Part of the 18th Congress of the International Commission for Optics: Optics for the Next Millennium
San Francisco, California • August 1999 SPIE Vol. 3749 • 0277-786X/99/$10.00

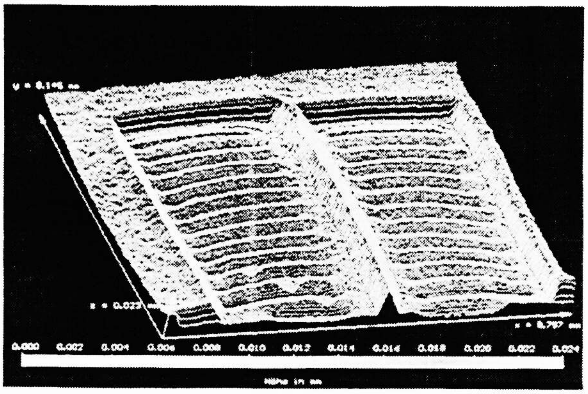

Fig. 1: Ceramic chip (8.8 x 8.1 mm^2), maximum height: 0.024 mm.

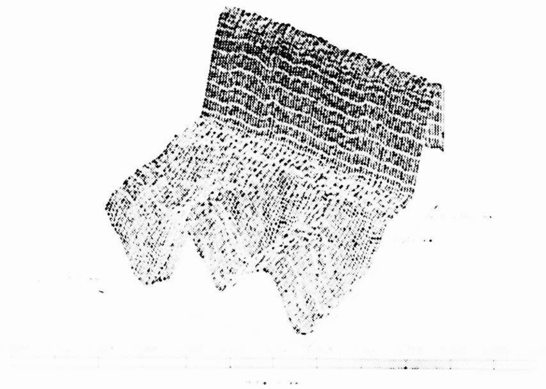

Fig. 2: Detail of the chip (Fig. 1) with zoom (2 x 1.4 mm^2).

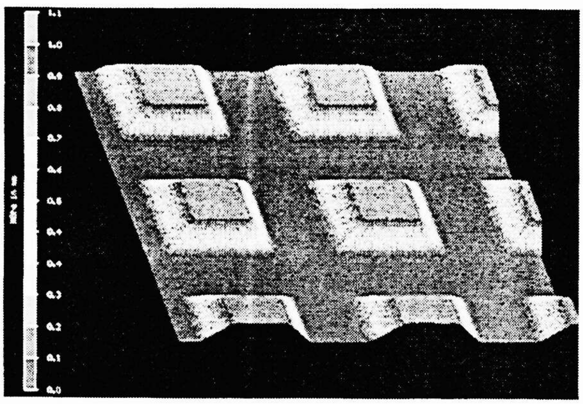

Fig. 3: Ceramic component (10 x 10 mm^2, maximum heigth: 1.1 mm.

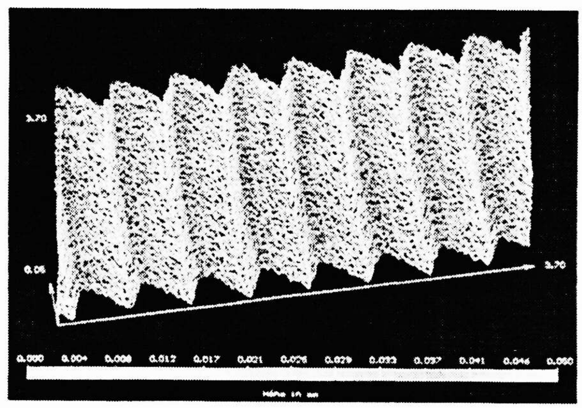

Fig. 4: Front-milled metall surface (3.7 x 3.7 mm^2), groove depth: 0.050 mm.

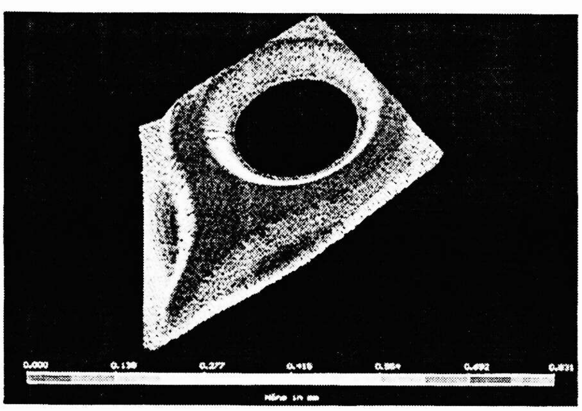

Fig. 5: Metall cutting tip, area of measurement: 20 x 15 mm^2.

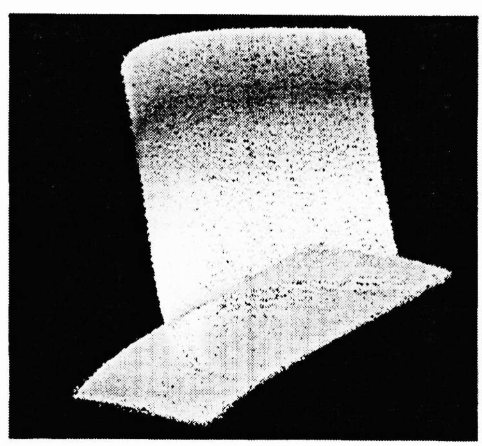

Fig. 6: Turbine blade, volume of measurement: 30 x 25 x 12 mm^3, 8 positions of the camera.