XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

AN ACTIVE APPROACH FOR HIGH RESOLUTION MEASUREMENT OF TECHNICAL SURFACES

W. Osten, D. Kayser and W. Jüptner
BIAS - Bremer Institut für Angewandte Strahltechnik
D-28359 Bremen, Germany

Abstract: The wide scale inspection of extended technical components with respect to the recognition of typical surface features (shape, texture, roughness) needs the combined application of different measurement techniques together with new tools for the consistent analysis and description of the measuring results. The new concept of scalable topometry meets the demands of wide scale surface topometry. Controlled by the evaluation of scale-independent surface features based on fractal geometry, different measurement techniques with subsequent lateral and depth resolution are applied to the surface. As result a complete description of the surface is delivered taking into account special regions of interest. The choice and orientation of the special measurement technique is supported by a new feature extraction method called the fractal pyramid. The advantages of the new concept are demonstrated on example of a ceramic plate with surface faults.

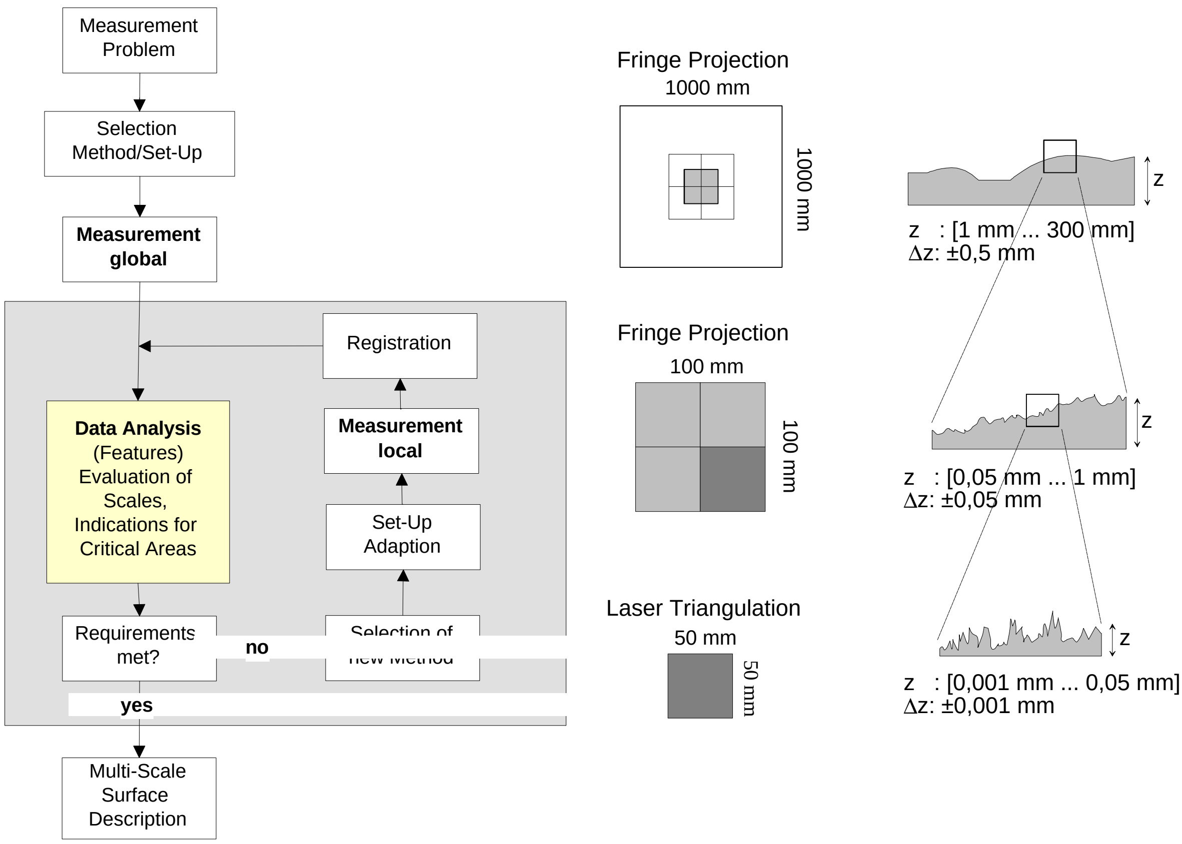
Keywords: Topometry, Shape Measurement, Fringe Projection, Flaw Recognition, Features, Fractal Geometry, Scale Behaviour

1. INTRODUCTION

Optical metrology offers a lot of efficient methods for the investigation of the surface shape over a wide scale. However, each technique delivers a limited resolution in a fixed scale range only and often a compromise between depth resolution and lateral extension of the inspected area is necessary. But in numerous applications the depth range to be measured covers such a broad scale that obviously a single method can't bring the solution. Therefore the wide scale and high-resolution measurement of extended and free formed technical surfaces needs the combined application of different methods [1]. Such a sequence of measurements means a systematic and active choice of both methods and setups based on the analysis of the measurement results in the subsequent measurement steps as well. This approach ensures that the measurements made in different scales are not independent from each other.

2. ACTIVE AND SCALABLE TOPOMETRY

The concept of *scalable topometry* is introduced to accomplish the task of gathering complete surface information of the object under test. It puts the idea of the iterative improvement of the accuracy of the measurement data into practice. The active and problem-specific application of different measurement techniques and setups with adapted efficiency and resolving power is of great importance for the concept. The decision for the method to be applied in the next step is made after the analysis of the data with respect to requirements of the measurement task, Fig. 1a. In the first step the entire object surface is measured at the highest possible resolution, Fig. 1b. The data are analyzed with respect to the requirements which have to be met within the measurement process. The main goal of the analysis is to describe the surface topology (global shape, small deviations from the wanted shape, surface defects and microstructure/roughness), to detect problem areas and to accomplish object scale discrimination. By problem areas we denote areas where the measurement accuracy is not sufficient to resolve all surface details due to limitations of the applied technique or to the setup. We apply methods of *fractal geometry* to analyze the surface properties and to use unique features with respect to a consistent description of the surface topology in different scales. The choice and orientation of the special measurement technique is supported by a new feature extraction method called the fractal pyramid [2]. Using this method indications can be derived with respect to the above mentioned problem areas. A key feature for this indication process using the fractal pyramid is the violation of self similarity during moving down the scales.



a) Active driven feedback loop b) Principle of scalable topometry

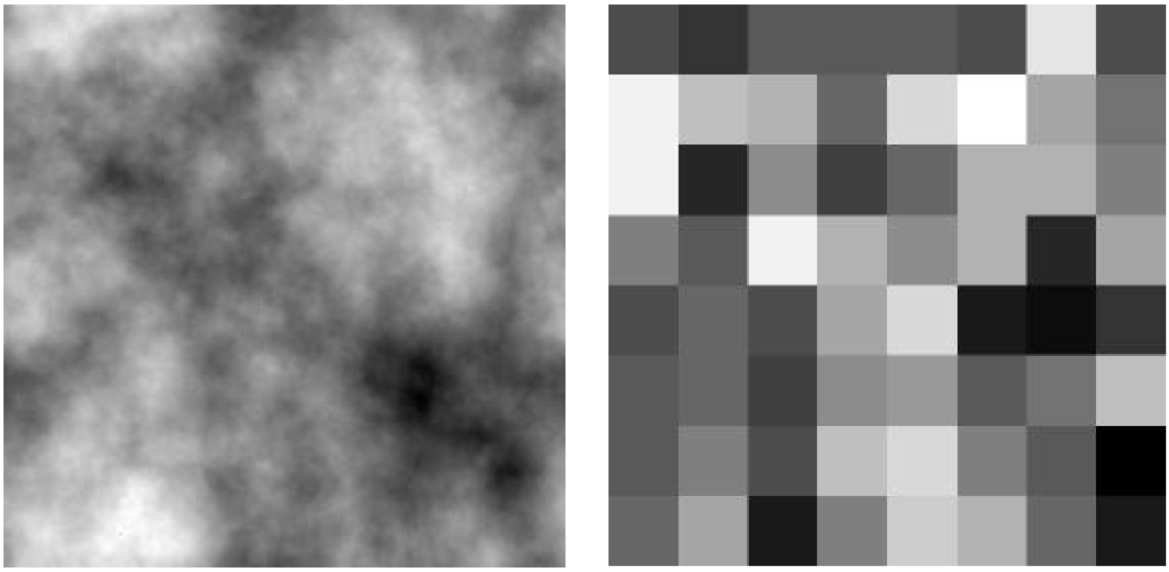
Figure 1. Stepwise improvement of height resolution by scalable topometry

The active controlled repetition of the processes of data acquisition and surface analysis with respect to the given surface evaluation requirements represents an essential feature of the proposed measurement concept. The measurement data obtained in several scale ranges have then to be combined to enable a consistent representation, visualization and reconstruction of the whole object. In order to determine the necessary geometrical transformations, either surface analysis is used to localize systematic object structures or the object is covered with some marks. Then the data are transformed with respect to a uniform coordinate system with a variable resolution defined grid spacing and the entire object surface is reconstructed in a patch work manner. Each patch, consisting of higher resolution data, is stuck on the corresponding grid points of the surface, assembled in the preceeding reconstruction step.

3. THE FRACTAL PYRAMID

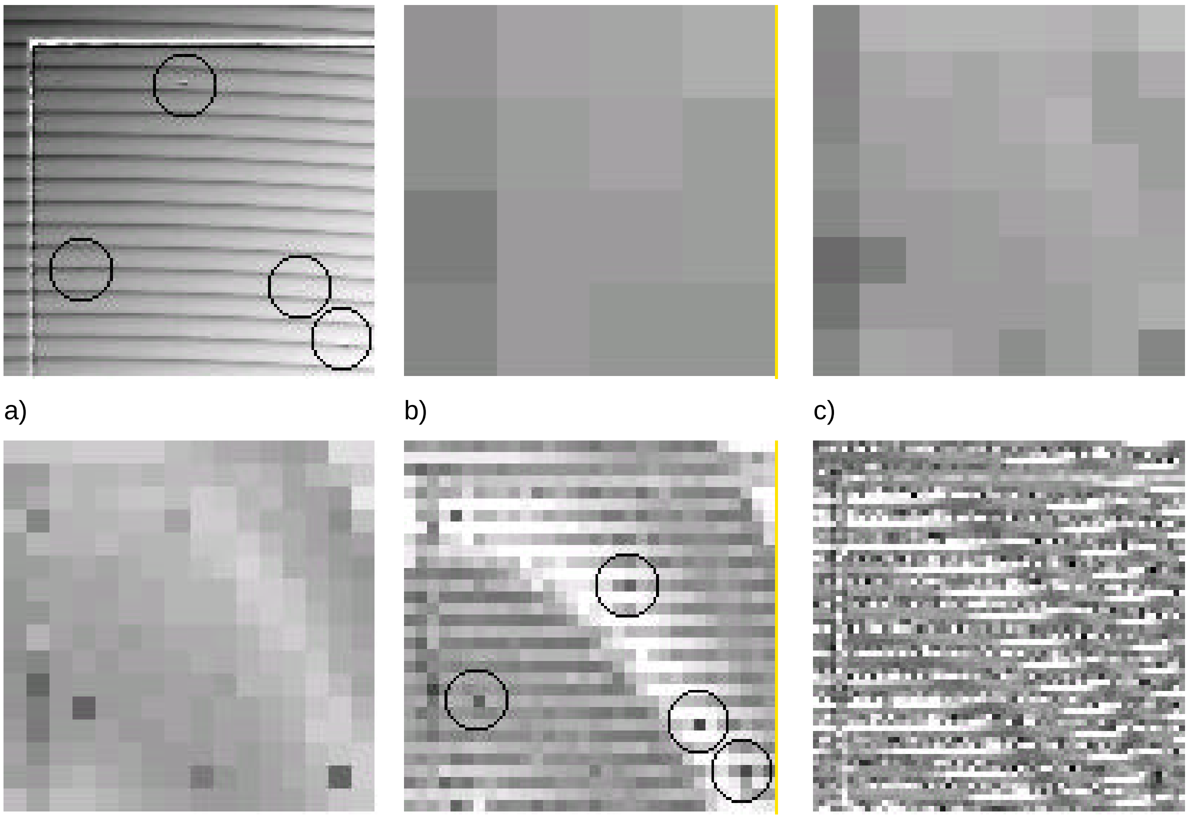
For the indication of local critical areas the determination of a single (global) fractal dimension is not sufficient because no local information is contained. To preserve local information and retrieve indications about deviations of fractality/self-similarity on different scales we introduced the concept of the fractal pyramid [2,3]. It starts with partitioning the surface in squares and determining the fractal dimensions in all of them, Fig. 2.

A pyramidal structure is generated starting from the top of the pyramid with the global dimension by diving the image into a regular mesh and scaling down by increasing the number of squares. If we use a fractal surface as input there is no significant change in the fractal dimensions from scale to scale. But if there is a feature violating self-similarity in the image it appears in the pyramid in the layer representing the scale of its extension. To illustrate this behavior we applied the fractal pyramid to an object with sinusoidal surface profil, Fig. 3. The marked faults are hardly visible in the 8x8 layer, becoming stronger in the 16x16 layer and are partly vanishing in the 32x32 layer. The sinusoidal structure is coming out in the 32x32 mesh and retains in higher resolutions. However, one can see that the faults in the surface can be clearly distinguished from the global structure in layer e). The recognized areas with violated self-similarity give the necessary indications for choice and local orientation of the subsequent surface sensor.



a) b)

Figure 2. Fractal surface (a) and its fractal pyramid (b) on the scale r=0.125. The fractal dimension is coded as gray value at the corresponding position in the input image



a) b) c) d) e) f)

Figure 3. Fractal pyramid: a) object with sinusoidal surface profil having local faults marked by circles, b) – f) fractal pyramid layers starting from 8x8 till 64x64

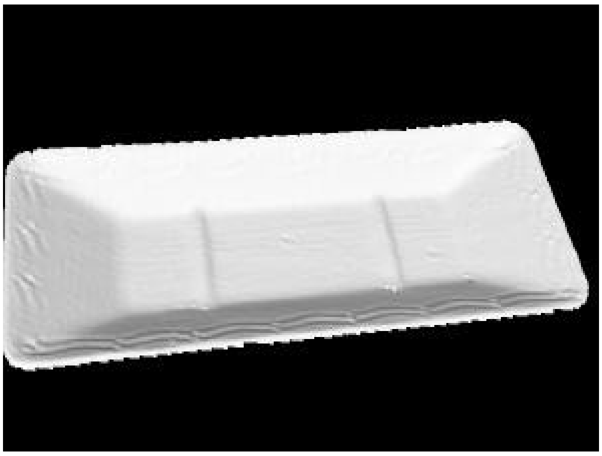
4. EXPERIMENTAL VERIFICATION

As test object a ceramics shell having the dimensions 400mm x 200mm x 20mm was used. The surface shows several local spots with lateral dimensions in the range of 500µm and a depth of about 20µm to be measured. Table 1 contains the applied measurement techniques with their lateral and depth resolutions.

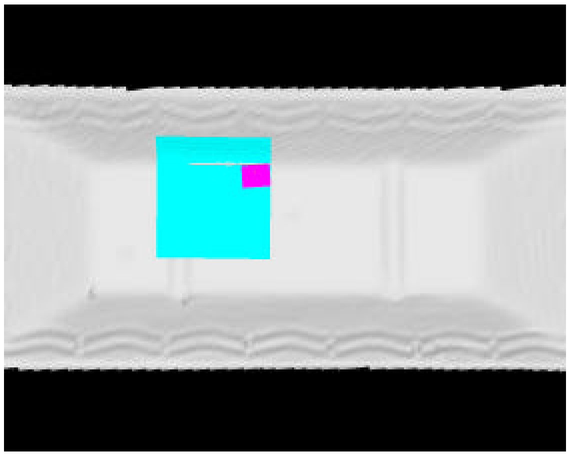
Table 1. Applied measurement techniques for the combined measurement of the ceramics shell within different scale ranges (method 1 and 2: BIAS Bremen, method 3 and 4: made by ITO Stuttgart)

Nr.	Method	Lateral Resolution	Depth Resolution
1	macroscopic finge projection	0,5mm	100µm
2	Laser-triangulation	50µm	10µm
3	microscopic fringe projection	10µm	1µm
4	confocal mikroscopy	0,5µm	20nm

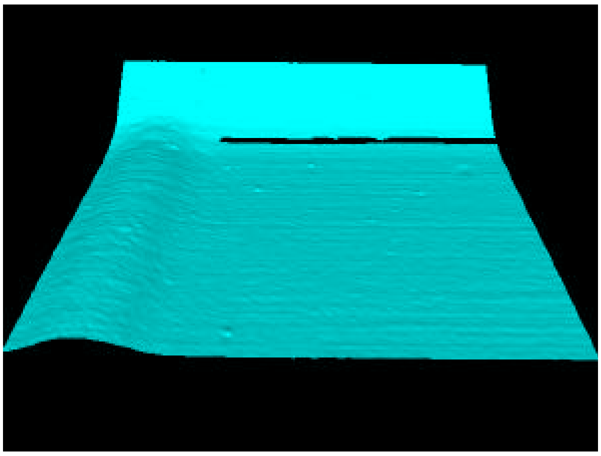
Figure 4 shows the range image of the ceramic plate and the intermediate results by applying different sensors with increased lateral and height resolution to the identified regions of interest such as a local crater



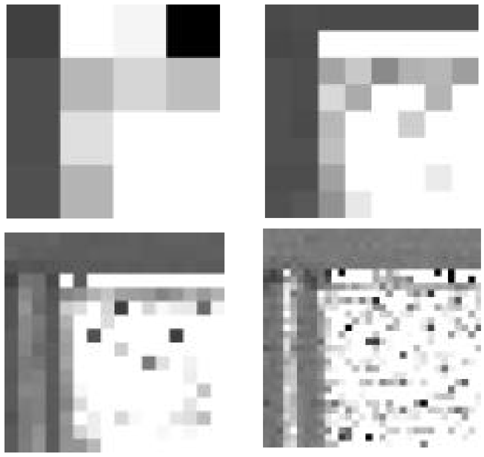
a) Range image of the whole shell measured with macroscopic fringe projection



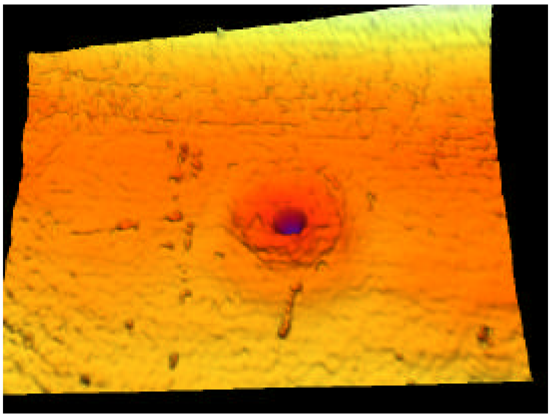
b) Shell with measured segments



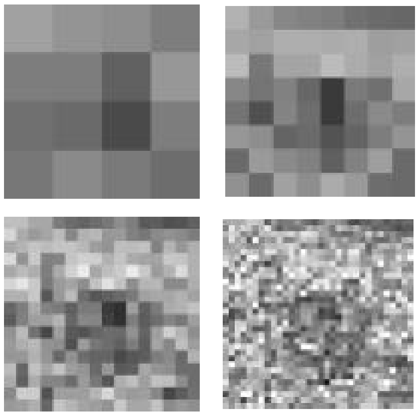
c) Patch measured with laser triangulation sensor



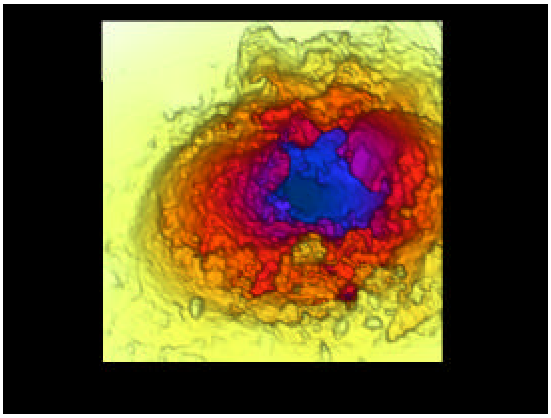
d) Fractal pyramid



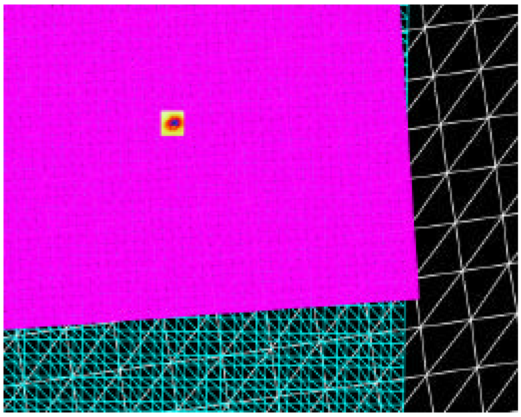
e) Patch measured with microscopic fringe projection



f) Fractal pyramid



g) Final patch measured with confocal microscopy



h) Surface meshes used for the applied measurement techniques

Figure 4. Range images of the ceramic plate with different resolution

5. CONCLUSIONS

A new measurement strategy for the high resolution inspection of technical components was proposed. This strategy is characterized by the systematic combination of different measurement techniques with respect to the entire inspection of a surface within a wide scale. An important property of this approach is the controlled application of the sensors. Sensors with increased lateral and depth resolution are applied only in such regions where a feature extraction process returns corresponding indications. This feature extraction process uses methods of fractal geometry by testing the violation of self-similarity in the data of the object on different scales of resolution.

ACKNOWLEDGMENT

This work was supported by the German Ministry of Education, Science, Research and Technology with grant No. 13 N 6695. The cooperation with R. Windecker/ITO Stuttgart, who performed the measurements using microscopic fringe projection and confocal microscopy is highly acknowledged.

6. REFERENCES

[1] P. Andrä, E. Ivanov, W. Osten, Scaled Topometry - An Active Measurement Approach for Wide Scale 3D Surface Inspection. Proc. Fringe´97. Akademie Verlag Berlin, Berlin 1997, pp. 179-189
[2] D. Kayser, W. Osten, T. Bothe, Fault detection in gray-value images of surfaces on different scales. Proc. SPIE 3744, 1999, pp. 110-117
[3] W. Osten, P. Andrä, D. Kayser, Hochauflösende Vermessung ausgedehnter Oberflächen mit skalierbarer Topometrie. Technisches Messen 66(1999)11, pp. 413-428

AUTHORS: Dr. W. OSTEN, Dipl.-Phys. D. KAYSER, Prof. Dr.-Ing. W. JÜPTNER, BIAS, Klagenfurter Str. 2, D-28359 Bremen, Germany, Phone Int ++49 421 2185051, Fax Int ++49 421 2185063, E-mail: wolfgang@uni-bremen.de