



annual report
2009 / 2010

INSTITUT FÜR
TECHNISCHE OPTIK
UNIVERSITÄT STUTTGART



Universität Stuttgart

INSTITUT FÜR TECHNISCHE OPTIK
UNIVERSITÄT STUTTGART

Prof. Dr. W. Osten



Pfaffenwaldring 9
D-70569 Stuttgart
Tel.: +49(0)711 685-66075
Fax: +49(0)711 685-66586
<http://www.uni-stuttgart.de/ito>

ANNUAL REPORT 2009/2010

3D-Surface Metrology

Active Exploration: A Multi-Scale Measurement System for Defect Detection.....	24
<i>Supported by: DFG (OS 111/18-3)</i>	
<i>Project: "Neue multiskalige Mess-, Steuer- und Prüfstrategien für die Prüfung von Mikro- und Nanosystemen in der Produktion"</i>	
Chromatic confocal spectral interferometry (CCSI)	27
<i>Supported by: DFG (OS 111/21-2)</i>	
<i>Project: "Chromatisch-konfokale Spektral-Interferometrie zur dynamischen Profilerfassung"</i>	
Combination of rigorous coupled wave analysis and high speed non sequential raytracing for high accuracy modelling of array spectrometers	28
<i>Supported by: BMBi (FKZ 13N7861)</i>	
<i>Project: "PräziLED"</i>	
Concepts for the integration of optical sensors into machining processes	29
<i>Supported by: Graduate School of Excellence advanced Manufacturing Engineering GSaME</i>	
Hybrid simulation for model based characterization of optical measurement systems	31
<i>Supported by: BMBF (FKZ 13N10386)</i>	
<i>Project: "OptAssyst"</i>	
InSitu surface metrology: Integration of a white light interferometer into a high precision grinding machine for diamond tools	32
<i>Supported by: BMWi (FKZ 16IN0519)</i>	
<i>Project: "iTool"</i>	
Optical measurement system for estimation of the position of the piston in a one-way dosing pump	34
<i>Supported by AIF, IGF-No.: ZN09560/09, ITO project No.: 16653 N</i>	
<i>Project: "Optical measurement system for estimation of the position of the piston in a one-way dosing pump"</i>	

Active Exploration: A Multi-Scale Measurement System for Defect Detection

A. Burla, W. Lyda, T. Haist, W. Osten

Inspection of modern high quality components often requires measurement technologies with sub-micron resolution for surface characterization at wafer scale level. The limited space-bandwidth-product of optical sensors however enforces a conflict between large measurement field, high measurement resolution and short measurement time. To balance this conflict an intelligent measurement strategy with multiple sensors fused in one system is utilized to characterise the surface at different scales.

The strategy pursues a multi-scale active exploration strategy, where coarse scale sampling provides an initial outline, followed by more detailed samples at higher resolution scales. Sensory and positioning data are processed step-by-step as they are acquired and merged using intelligent data fusion methods in order to find defects on the measured object and gradually improve the accuracy as more data becomes available. Task specific, coarse-scale indicator functions are used to select fine-scale features for further investigation (Fig. 1).

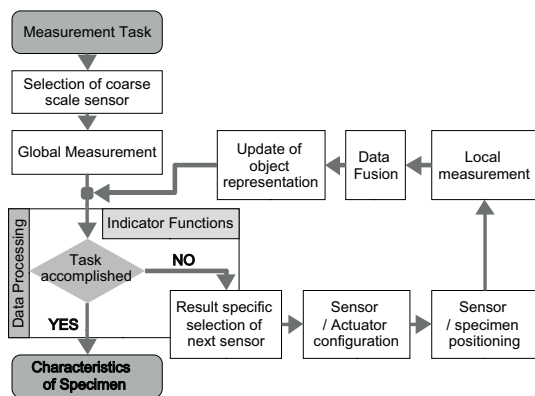


Fig. 1: AMMS-strategy.

This general design of an Automated Multi-Scale Measuring System (AMMS) was elaborated and realised in a prototype based on a modified Mahr MFU 100 armed with three different sensors (Fig. 2) for inspection of microlens arrays and micro electro-mechanical systems (MEMS). A video microscope is used to receive an initial outline of the specimen which is followed by high

resolution measurements with a confocal scanning microscope and a confocal point sensor. The lateral resolution of the sensor systems ranges from 13 μm over a field of 18 x 12 mm^2 with the video microscope down to 0.6 μm with the confocal point sensor. In the middle scale the confocal microscope offers a variable lateral resolution from 10 μm down to 2 μm depending on the used front lens. This demonstrator was realised in cooperation with the Institute for System Dynamics (ISYS).



Fig. 2: Automated multi-scale measurement system based on a modified Mahr MFU 100.

For the communication between different scales, indicators are used. These Indicators are deviations from the expected measurement results, giving a hint for an unresolved defect on the specimen in the actual sensor scale. For an exact classification of the possible defect, further measurements in finer scales are needed. Hence in a step by step process the indicator functions provide the locations of the indicators for finer scale measurements. This effective method uses fine-scale sensors only when they are needed, balancing the conflict between measurement time, resolution and measurement

field. With three different sensors measuring a specimen for defects, different indicator detection functions are required to process the data at every sensor scale.

For the purpose of evaluating the AMMS-concept microlens arrays and MEMS were used as measurement objects, due to the wide bandwidth of possible defects and defect sizes. On microlens arrays, three distinct defect types were considered: 1) point-like defects, such as minute particles, dust, speckles, etc. 2) one-dimensional defects, including cracks, scratches, fine fibres, etc., and 3) irregularities in the shape and size of the microlenses, including missing or partially missing microlenses. Several indicator algorithms were developed to accurately detect flaws and defects on the surface of the micro lens arrays. These algorithms were also tested for reliability with different surface and shape defects, simulated using synthetic data based on mathematical methods.

The indicator algorithms for the inspection of micro lens arrays include Fourier self-filtering, two-point statistical texture featuring, scratch detection, normalized cross correlation and Fourier descriptors. These algorithms are parameterised according to the type of defect.

For the MEMS-inspection the used indicator algorithms are based on wavelet transformation, correlation and local thresholding. Further indicators include local roughness and the variation in the confocal raw signal.

A crucial point in the AMMS-strategy is the automatic selection of sensors and indicator evaluation algorithms and the task dependent adaption of their parameters. Therefore we introduce two assistant systems (hardware assistant and software assistant), which help in choosing the most suitable components depending on the task considering the properties of the object (e.g. material, surface roughness, etc.) and the defects (e.g. defect types, dimensions, etc.). The hardware assistant system uses general rules of thumb, sensor models/simulations and stored expert knowledge to specify the most suitable sensors along with their parameters and the hierarchy (if necessary) in a multiscale measurement system. The pur-

pose of the software assistant system (SAS) is to automatically generate and optimize image processing algorithms necessary for defect/indicator identification. For this purpose, a stochastic evolutionary method called genetic programming is used. SAS is a learning based system which uses training input and a flexible fitness function to iteratively generate and evaluate the algorithms. Training input contains several measured or simulated measurements along with user generated defect binary masks (indicating defect positions). The Fitness function is weighted combination of specificity, sensitivity and sum of absolute differences. The user will then be able to use the algorithms generated by the SAS based on the training input to identify defects on new measurements. Fig. 3 shows the basic principle of the SAS.

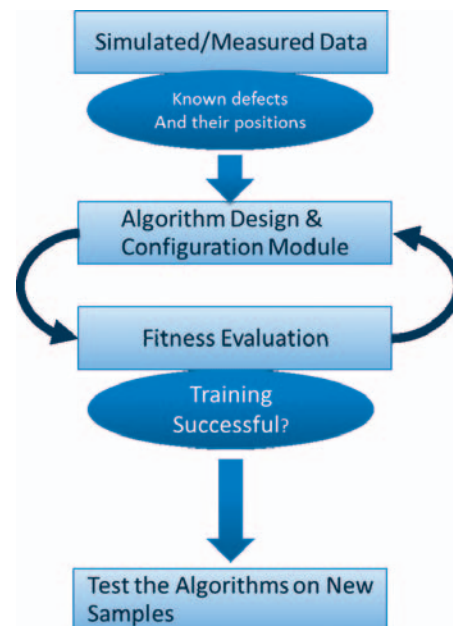


Fig. 3: Basic working principle of the software assistant system.

A simple language parser has been implemented to translate the user specifications into machine readable instructions (C++ functions). These instructions are further used for selecting and optimizing the components. The optimization criteria can be freely assembled in the user specifications. Up till

now, first assistants for fringe projection, video microscopy, and confocal microscopy have been implemented using C++. It was verified experimentally, that the results from the hardware assistant and from a human expert match for a sample inspection task for detecting surface scratches. For the SAS, it is important to properly choose the training input as well as the optimization parameters like population size, crossover rate, mutation rate, etc. Proper training requires enough measurements/simulations of all possible types of defects. The assistant system is currently implemented using OpenCV in combination with C++.

Fig. 4 shows a measurement of a microlens array measured using a confocal microscope with 20X magnification, here the task was to detect lenses which have form defects. The SAS was able to generate an algorithm to indicate the defects (see Fig 5).

Future work is focused on the transfer of the AMMS-strategy to more complex technical objects. Therefore the field of view planning, data fusion and the sensor registration data have to be improved.

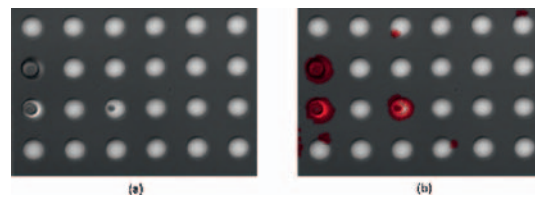


Fig. 4: (a) A real measurement of a microlens array measured using a confocal microscope with 20X magnification, (b) successfully indicated lens defects (algorithm shown in Fig. 5).

Supported by: DFG (OS 111/18-3)

Project: "Neue multiskalige Mess-, Steuer- und Prüfstrategien für die Prüfung von Mikro- und Nanosystemen in der Produktion"

References:

- [1] Lyda, W.; Zimmermann, J.; Burla, A.; Regin, J.; Osten, W.; Sawodny, O.; Westkämper, E. "Sensor and actuator conditioning for multiscale measurement systems on example of confocal microscopy," Proc. of SPIE, 738903-738903-11, 2009.
- [2] Burla, A.; Haist, T.; Lyda, W.; Osten, W. "Fourier descriptors for defect indication in a multiscale and multisensor measurement system," Optical Engineering, vol. 50, p 043603, 2011.
- [3] Lyda, W.; Burla, A.; Haist, T.; Zimmermann, J.; Osten, W.; Sawodny, O. "Automated Multi-Scale Measurement System for MEMS-Characterization," Proc. of SPIE, 7718-15, 2010.
- [4] Burla, A.; Haist, T.; Lyda, W.; Osten, W. "An assistance system for the selection of sensors in multiscale measurement systems," Proc. of SPIE, 77910I-77910I-10, 2010.
- [5] Burla, A.; Lyda, W.; Osten, W.; Regin, J.; Westkämper, E.; Zimmermann, J.; Sawodny, O. "Reliability Analysis of Indicator Functions in an Automated Multiscale Measuring System", tm – Technisches Messen 77, Oldenbourg Wissenschaftsverlag GmbH, 493-499, 2010.
- [6] Burla, A.; Haist, T.; Lyda, W.; Aissa, M.; Osten, W. "Assistant systems for efficient multiscale measurement and inspection" Proc. SPIE 8082, 808202, 2011.



Fig. 5: Automatically generated algorithm for lens defect detection on microlens arrays measured using a confocal microscope with 20X magnification (see Fig. 4).

Chromatic confocal spectral interferometry (CCSI)

W. Lyda, M. Gronle, D. Fleischle, W. Osten

Chromatic confocal spectral interferometry (CCSI) is a hybrid measurement method for fast topography measurement without mechanical axial scan. The CCSI-method combines the advantages of the interferometric gain and accuracy with the robustness of confocal microscopy. A one shot measurement is achieved by using chromatically separated foci in the object space and a spectral detection of the white light signal.

In common used spectral interferometers (SI) the measurement range is given by the depth of focus leading to a restriction of the numerical aperture. The combination of chromatic separation and confocal filtering decouples the measurement range from the depth of focus, which yields to higher numerical apertures and improved lateral resolution in comparison to common SI-sensors. The advantage of this method is the single shot retrieval of depth positions by either confocal signal analysis or optical path evaluation. Therefore CCSI is qualified for high resolution topography measurements of reflecting and scattering objects.

The discrepancy of the limited axial-range in previously reported SI-schemes can be visualized as follows. The reference field contains a planar wave front, while the detection wave front acquires a rigorous curvature, when the object lies beyond the depth-of-focus, if aberration effects are neglected. Optical interference between those two fields leads to a reduced contrast of the modulated spectral signal. In the CCSI scheme, presented here, the axial-range of the detector is expanded due to the chromatically-dispersed foci (20 μm axial range with 0.6 NA were reported) by means of a diffractive optical element – DOE. If the object lies within the dispersed focus spectrum, a sharply focused spectral component gets reflected and this induces a high-contrast wavelet in the spectral domain. The amplitude of this modulation remains constant within the entire range of the employed optical spectrum and the axial range of the detector is decoupled from the limited depth-of-focus.

In this project, the CCSI-method was both experimentally and theoretically addressed. The CCSI principle has been implemented in

two prototype setups: a Mirau-type interferometer (0.6 NA) and a fibre-based interferometer (0.95 NA).

On the basis of topography measurements performed on technical objects, the error budget of the fibre-based interferometer was analysed. A reduction of measurement errors in comparison to the known chromatic-confocal principle was achieved. These results demonstrate the applicability of this method for the optical detection of objects with rough surfaces and limited reflectivity as well as strongly curved optical surfaces.

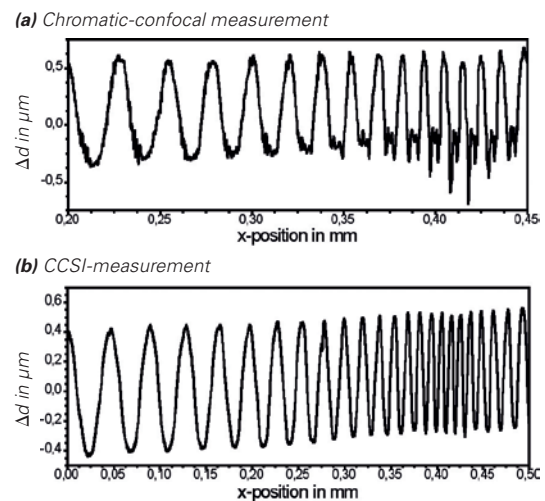


Fig. 1: Measurement of a chirp comparison standard (by PTB-Braunschweig) with chromatic confocal microscopy (a) and CCSI phase evaluation (b) showing reduced overshooting in the CCSI-measurement.

Supported by: DFG (OS 111/21-2)

Project: "Chromatisch-konfokale Spektral-Interferometrie zur dynamischen Profilerfassung"

References:

- [1] German patent DE 103 21 895 B4.
- [2] European patent EP 1 805 477 B1.
- [3] German patent DE 10 2008 020 902 B4.
- [4] Papastathopoulos, E. et al., Optics Letters 31, 589 (2006).
- [5] Lyda, W. et al. In: Proc. of SPIE 7432, DOI: 10.1117/12.826902 (2009).
- [6] Lyda, W. et al., 111. DGAO-Conference, B31 (2010).
- [7] Lyda, W. et al., Proceedings of ISMTII 2011, (2011).

Combination of rigorous coupled wave analysis and high speed non sequential raytracing for high accuracy modelling of array spectrometers

F. Mauch, W. Lyda, W. Osten

In the course of the BMBi project "Präzisions-Charakterisierung von weißen LEDs und LED-Beleuchtungen", a simulation scheme for simulating a linear grating spectrometer with high precision and high speed was developed.

The performance of high end spectrometers is typically limited by stray light in the optical system. Figure 1 shows the optical setup of a typical array spectrometer in Czerny-Turner configuration. Figure 1 also shows the ray paths for monochromatic illumination of seven diffraction orders of the grating. All the rays hitting the spectrometer housing will be scattered diffusely and may ultimately still reach the detector.

In order to model this behaviour of the spectrometer with high accuracy, a RCWA simulation using an AFM scan of the grating surface was used to rigorously calculate the efficiencies of the diffraction orders in dependence of the wavelength of the illumination. Furthermore stray light measurements were conducted to phenomenologically account for the diffuse scattering of the grating and the spectrometer housing.

This data was used to create special reflectance functions for the grating and the housing parts for a non sequential ray tracing model of the spectrometer system. However in order to simulate intensity distributions with a SNR of 104, that are typical in spectrometers, at least 108 rays are required to reach the detector.

Tracing times for raysets of that size manifest a serious bottleneck in the systematic optimization of spectrometers. Therefore a non sequential ray tracing tool was developed that is highly specialized for simulating intensity images. The tool can be executed using either a single CPU, multiple CPUs in parallel or modern graphics processing units (GPU). Figure 2 shows the computation times of this tool in comparison to the commercial software ASAP. At a raynumber of 108 the developed tool running on GPU is about 400 times faster than the commercial tool. E.g. the simulation of monochromatic illumination that took a little more than 3h with ASAP on an Intel i7 machine with 3.2 GHz could be done in about 30 s using a GTX460 graphics card.

Future work will elaborate on possibilities to use this kind of high speed simulation for automated stray light optimization of general optical systems.

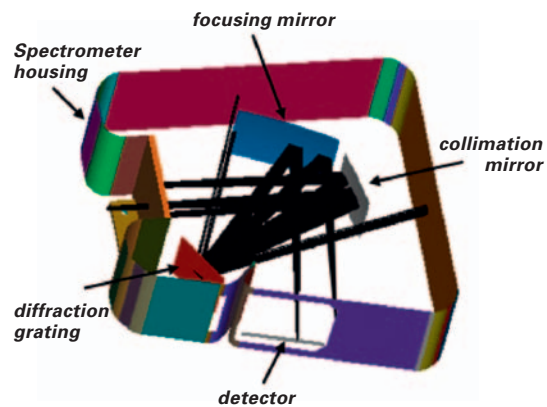


Fig. 1: 3D plot of the Simulation model of the spectrometer in ASAP.

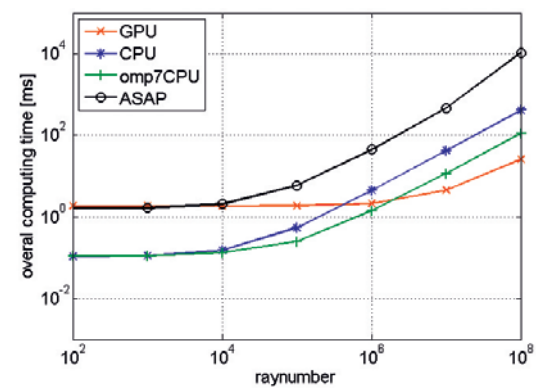


Fig. 2: Comparing overall computation times. GPU, CPU, omp7CPU and ASAP indicate simulation running on GPU, a single CPU core, 7 hyperthreading cores on 4 physical CPU cores and the commercial software ASAP running on single CPU core respectively.

Supported by: BMBi (FKZ 13N7861)
Project: "PräziLED"

References:

- [1] Mauch, F.; Lyda, W.; Osten, W.; Krug, T.; Häring, R. "Combining rigorous diffraction calculation and GPU accelerated non-sequential raytracing for high precision simulation of a linear grating spectrometer", Proc. SPIE 8083, 2011.

Concepts for the integration of optical sensors into machining processes

D. Fleischle, W. Lyda, W. Osten

In manufacturing monitoring and inspection an essential task is to maintain a high product quality. Therefore a variety of systems (e.g. tactile systems, acoustic systems, optical systems) is used. However there is still a lack in controlling the product quality near the production machine. For the selection and the design of an appropriate monitoring strategy the specification of the applied sensors is of crucial importance.

Optical sensors are in general suitable to measure quality relevant features. But they are often not robust enough, to use them in harsh environments such as the workshop floor. However to detect as early as possible if quality runs out of specification, the high resolution of optical measurement systems is often not needed. In these cases optical sensors can be implemented successfully even if their measurement uncertainty is increasing due to the harsh environment. To verify this hypothesis an evaluation of environmental influences has to be made and a comparison between the acceptable and still achievable measurement uncertainty has to

be made.

A classification of sensor systems used for monitoring of manufacturing processes can be obtained regarding their degree of integration (fig.1):

- separated measurement (off-line), where the measurement device is separated from the production
- machine integrated measurement (in-situ), where the monitoring system is implemented into the production process, but it is still separated from the machining process.
- tool integrated measurement (in-process), where the sensor is implemented as near as possible to the machining process or even in the machining tool.

The case of in-process monitoring implements the shortest feedback loop and even a process control during machining can be established.

But the measurement system has to deal with the environmental influences. To know what precision and measurement uncertain-

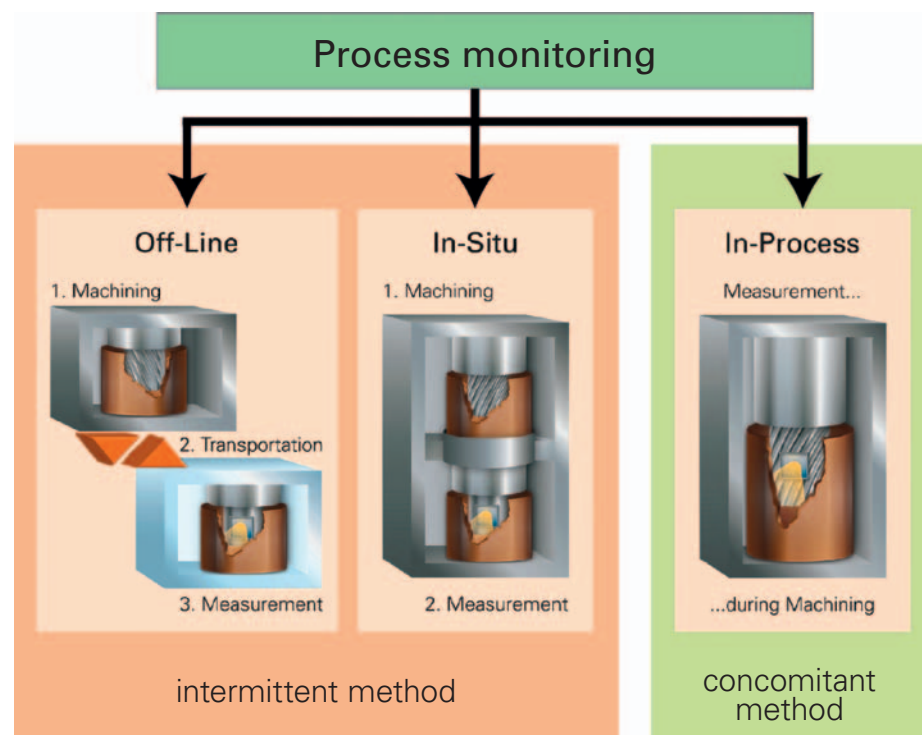


Fig. 1: Different degrees for the integration of optical sensors into production processes.

ties are reachable an accurate consideration of the impact of the environmental influences has to be obtained. To come to a schematic consideration of all relevant error sources, the problem should be simplified into different parts of the process to obtain the topography description. In Fig. 2 this process is displayed. The sensor signal is given by the interaction of the specific answer of the sensor system, the response of the reflected light by the object and the influences of the environment. In the measurement obtained in the production machine the fusion of sensor data and machine data has to be considered. With the investigation of the influence of these parameters the estimation of the achievable measurement uncertainty in the production process is possible.

To investigate into the behaviour of the measurement a simulation tool was developed. With this ray-based simulation it is possible to analyse the resulting signal of optical sensors. For example in Fig. 3 the signal of a chromatic confocal sensor for the measurement of rough surfaces is shown. In the figure the simulation of a rough surface is compared with a measurement of a randomly rough surface.

Furthermore an investigation into the influence of environmental impact is possible. For vibrations the resulting standard deviation for different measurement times for a superposition of sinusoidal vibrations with a frequency of 50 Hz to 5 kHz is shown in Fig. 4. It is obvious that with an increasing integration time the standard deviation is decreasing due to averaging of the vibration.

Supported by: Graduate School of Excellence advanced Manufacturing Engineering GSaME

References:

- [1] Fleischle, D.; Lyda, W.; Mauch, F.; Osten, W. "Optical metrology for process control: modeling and simulation of sensors for a comparison of different measurement principles", Proc. SPIE 7718, 77181D-12 (2010).
- [2] Fleischle, D.; Lyda, W.; Mauch, F.; Osten, W. "Conceptual consideration for the process integration of optical sensors", Proc. SPIE 8082 (2011).

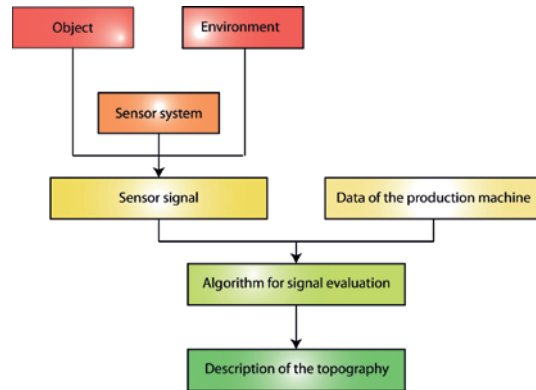


Fig. 2: Schematic signal formation process to obtain the description of object topography.

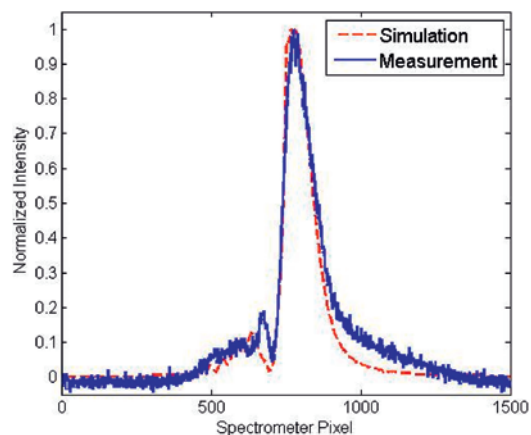


Fig. 3: Simulation and measurement with a chromatic confocal sensor of a rough surface.

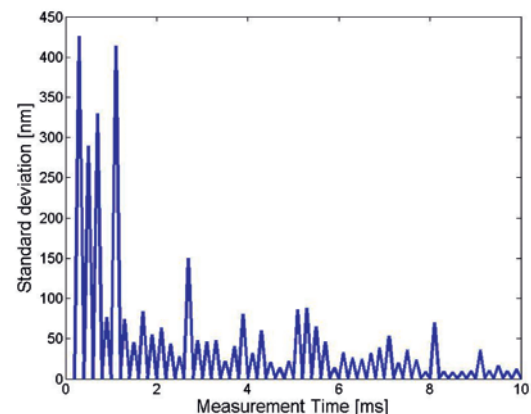


Fig. 4: Simulated standard deviation of a chromatic confocal sensor for a superposition of sinusoidal vibrations with frequencies of 50 Hz to 5 kHz.

Hybrid simulation for model based characterization of optical measurement systems

F. Mauch, D. Fleischle, M. Gronle, W. Lyda, W. Osten

Within the BMBF project “Anwenderorientiertes Assistenzsystem zum sicheren Einsatz optischer Abstandssensoren”, an assistance system for optical surface measurements will be developed. It will assist the user to optimally configure a confocal microscope or a white light interferometer for a specific measurement task. Furthermore, this assistance system will give a traceable estimate of the uncertainty connected to a given measurement. This is of special interest to car manufacturers that want to characterize functional surfaces with optical sensors. While the collaboration partners including several industry partners as well as the Institut für Messtechnik und Sensorik and the Fraunhofer IPT are jointly working on the complete process from desired surface features to a measurement of these features (see figure 1). ITO is focusing on the signal chain from the real surface towards the measured surface with a confocal microscope.

As a prerequisite for this, a simulation scheme has to be developed that is able to correctly predict the behaviour of the various sensor configurations in realistic measurement situations. In particular, this simulation scheme has to be able to reproduce effects related to rough surfaces, surface edges, aberrations in the optical system and diffraction at apertures of the optical system. These specifications manifest a dilemma for choosing an appropriate simulation method. While rigorous methods such as finite difference techniques are able to describe the interaction of a light field with a microstructured surface correctly, their application to simulating optical systems covering a volume exceeding a few cubic micrometers is hopeless. Ray tracing methods on the other hand are widely applied in designing and analyzing optical systems, but offer no obvious mechanism to describe diffraction effects. Unfortunately, combining both simulation methods is far from trivial.

As first steps the measurement of a perfect mirror with a confocal microscope was successfully simulated using conventional ray tracing (see figure 2). However, as the imaging properties of the micro lenses in the microscope are highly diffraction limited,

the detection pinhole had to be chosen an order of magnitude smaller than in reality. Furthermore a tool was developed that uses standard graphics cards (GPU) to trace rays depending on the application up to 100 times faster than on CPU based tools (see figure 3).

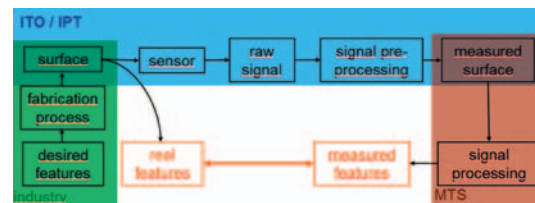


Fig. 1: Project structure showing the competence fields of the project partners

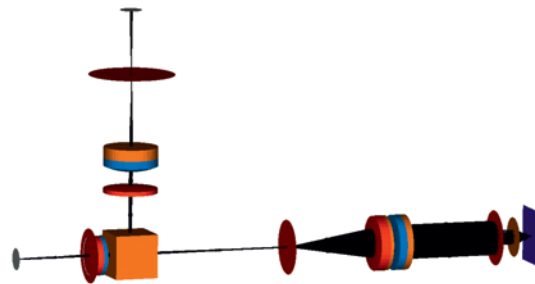


Fig. 2: 3D plot of the Simulation model of a confocal microscope with rotating microlens array showing the ray paths for one microlens in ASAP.

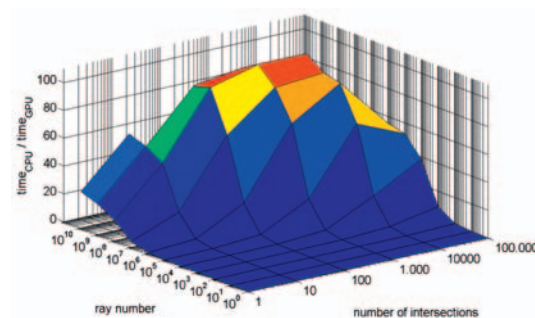


Fig. 3: Comparing computation times for nonsequential raytracing on GPU and CPU depending on the number of rays and the number of calculated intersections.

Supported by: BMBF (FKZ 13N10386)

Project: “OptAssyst”

References:

- [1] Mauch, F.; Lyda, W.; Osten, W. „Parallelisierte Strahldurchrechnung auf modernen Grafikkarten für optische Simulation und Design“, Proc. DGaO 2011.

InSitu surface metrology: Integration of a white light interferometer into a high precision grinding machine for diamond tools

R. Berger, D. Fleischle, W. Lyda, W. Osten

Diamond tools can produce sophisticated optical surfaces on plane and curved substrates. The production techniques are for example fly-cutting for ultra-precision turning and grinding. At these techniques the shape of the Diamond tools are often directly transferred onto the substrates. For example, such objects are needed for the production of micro lens arrays, displays or intraocular lenses. Therefore, the development of new innovative optical surfaces on such substrates is limited by the supply with commercial Diamond tools, by the supply with the machines, which produce such Diamond tools, and last but not least by the supply with the measurement technique for these manufacturing machines. To give the Diamond tools a predefined shape, they get grinded and polished.

In the BMWi InnoNet-project iTool, eight project partners from industry and research institutes worked together to develop a six-axis machine with an integrated optical measurement system for the manufacturing of freeform Diamond tools (see fig. 1). The manufacturing process is intermitted by several measurement cycles. The results of the measurements have to be compared with the required geometrical design form of the Diamond tool to be produced. Then a dataset with new control parameters will be transferred to the six-axis manufacturing machine.

The concept for an optical measurement of the Diamond tools on the production machine consists of the selection of an appropriate measurement principle and the development of a measurement procedure. Our choice is a combined system, which uses digital image processing and white-light interferometry (see fig. 2). The basis for this system is a MarSurf WS1 white-light interferometer from the Mahr GmbH. A separate LED-illumination is mounted in front of the optical measurement system to have a transmission light device for the digital image processing.

The digital image processing with the transmission light device is used for the measurement of Diamond tools with a small radius, since their tool flank does not reflect enough light back to the objective, when



Fig. 1: Six-axis machine with an integrated optical measurement system (source: IPT, Aachen).

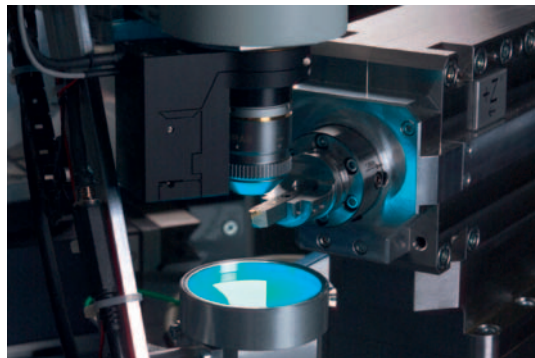


Fig. 2: Optical measurement system consists of a white-light interferometer with a transmitted light device for digital image processing (source: IPT, Aachen).

this part of the Diamond tool is illuminated through the objective. At Diamond tools with a bigger radius and with sections of plane tool flanks, the white-light interferometer can be used to get measurement results with a resolution in the nanometer range. For example, the shape of the cutting edge can be extracted from the topography measurement, since this parameter is an intersection of the 3D-shape of the measured Diamond tool. To acquire all data points along the tool flank, the point clouds of several topography measurements, achieved by the white-light interferometer, are automatically stitched together.

In Fig. 3 a measurement of a diamond tool is shown. This measurement was obtained with digital image processing by edge detection. To sample the whole object it was necessary to obtain a stitching of several measurements. To estimate the vertex radius of this tool a fitting of a circle was obtained. Thus a value of 1,023 mm was determined for that radius.

However the measurement is obtained by the use of the axis of the production machine. This axis has a certain error. But if a precise measurement has to be obtained, the implied error due to axis uncertainty has to be known. There for a simulation investigation into the resulting standard deviation in the measurement depending on the uncertainty of the machine axis has been implemented. In Fig. 4 the results of a simulation are shown.

Future work will investigate the reliability of the complete measurement system and its actuators in respect to the environment. Furthermore a complete automatisisation of the measurement procedure is desirable.

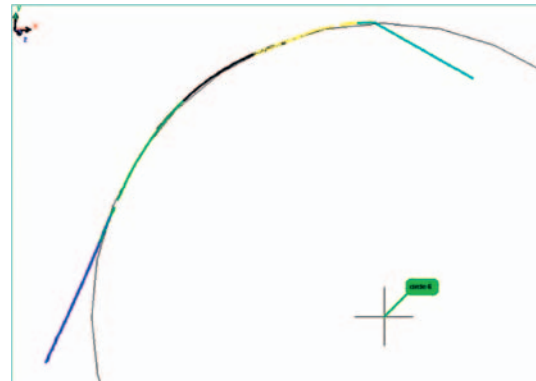


Fig. 3: Stitched measurement of a diamond tool and fitting of a circle to estimate vertex radius.

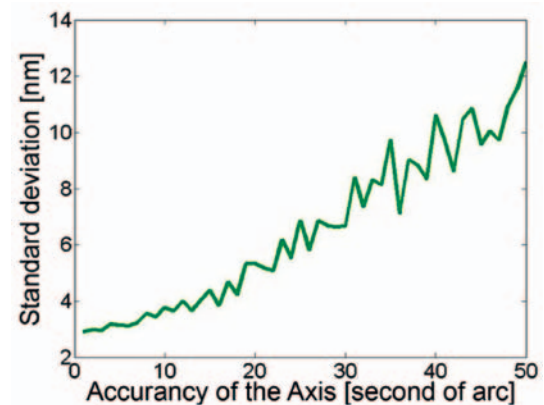


Fig. 4: Simulation of resulting standard deviation in measurement depending of accuracy of machine axis.

Supported by: BMWi (FKZ 16IN0519)
Project: "iTool"

Project partner: Fraunhofer Institut für Produktionstechnologie, Aachen; Mahr GmbH, Göttingen; IMOS Gubela GmbH, Freiburg; UPT-Optik Wodak GmbH, Nürnberg; Diamant-Gesellschaft Tesch GmbH, Ludwigsburg; LT Ultra-Precision Technology GmbH, Herdewangen-Schönach

Optical measurement system for estimation of the position of the piston in a one-way dosing pump

K. Körner, A. Burla, W. Lyda, W. Osten

We investigate approaches for the highly resolved measurement of the position of the piston in an one-way dosing pump, see Fig. 1. The main objective is to ensure a low uncertainty in the rate of delivery from 10 $\mu\text{l}/\text{min}$ to 100 ml/min with the pump module. Here, the independence of the measurement from pressure, viscosity, temperature, and colour of the fluid media is of special interest. The planned industrial application requires both, a robust and a low-cost solution that does not allow any modification of the pump construction produced a million times every year.

So we focused our efforts in the project to a VGA-Webcam-based microscopic approach that directly detects the lip of the moving seal of the pump.

In a very first experiment, the whole pump was shifted with a precision stage. A sequence of 200 images was recorded, where in each image, the syringe head is moved 0.5 μm relative to its previous position.

Two methods have been used to detect the motion in the sequence of images.

1. Correlation Based Method:

In this method, the motion of the syringe head is estimated based on the image gradient and cross correlation. The first image in the sequence is considered as the reference image. For every row of the image the edge of the syringe head is estimated using a gradient filter. The resulting gradient row is then correlated with the corresponding gradient row of the reference image. The position of the corresponding correlation peak indicates the shift of the syringe head in that row. This process is performed for every row and on the basis of the mean shift of all the rows, the position of the syringe head in this image is computed.

In order to acquire sub-pixel accuracy the centroid of the correlation peak is used. Measurement images can be cropped based on Region of interest to eliminate errors due to false edges originating from the print on the syringe.

2. Mean Gradient Method:

In this method, the mean shift relative to the reference image is estimated based on just the gradient operation. The average of the centroids computed around the peak po-

sitions of every row gradient is considered as the shift of the syringe head in this image.

Fig. 2 shows the calculated position of the moved lip (with the whole syringe) over about 4 pixels of the VGA-Webcam. Every camera pixel is covered by a single micro lens. Therefore, the fine structure of the camera is also detected. These results suggest that interpolation methods can deliver a sub pixel resolution, also for an unsteady shape of a shifting lip under pressure in a medium.

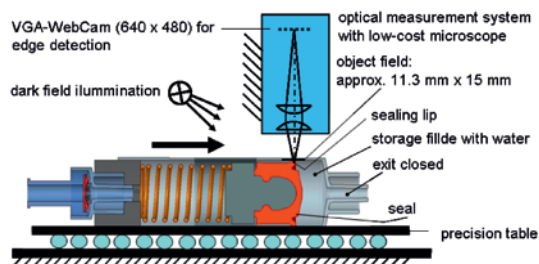


Fig. 1: One-way pump element (syringe) with optical measurement system (courtesy of HSG-IMAT, University of Stuttgart).

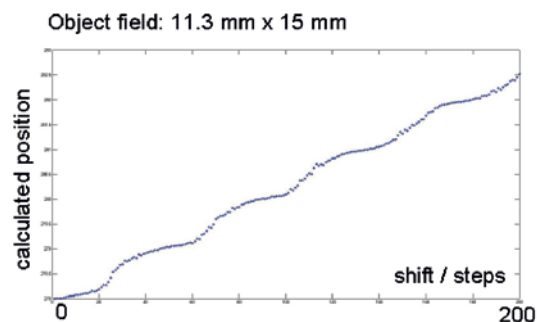


Fig. 2: Shift of the sealing lip of the one-way pump element (syringe) over about 4 pixels of a VGA-WebCam, signal evaluation was performed by the correlation based method.

Supported by: AIF, IGF-No.: ZN09560/09, ITO project No.: 16653 N
Project: "Optical measurement system for estimation of the position of the piston in a one-way dosing pump"

Project partner: HSG-IMAT, University of Stuttgart

