3D-Surface Metrology

Active inspection of three-dimensional objects using a multi-sensor measurement system ......................................................... 24
Supported by: Baden-Württemberg Stiftung
Project: “AMuPrüf”

Advanced signal evaluation and line sensors for chromatic confocal spectral interferometry (CCSI/LCSI) ........................................... 27
Supported by: DFG (OS 111/21-1/2/3)
Project: “Chromatisch-konfokale Spektral-Interferometrie zur dynamischen Profilierfassung”

Design and fabrication of a hybrid hyper-chromatic lens for confocal sensors .......... 29
Project: “R&D-Study for ProMicron, Germany”

GPU accelerated ray tracing ................................................................. 30
Supported by: BMBi (FKZ 13N7861)
Project: “PräziLED”

Model based characterization of confocal measurement systems .......................... 31
Supported by: BMBF (FKZ 13N10386)
Project: “OptAssyst”

Optical low-cost sensor system for the control of pump rates ............................ 32
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”

itom – measurement and laboratory automation software .................................. 33

Vertically integrated array-type mirau-based OCT system for early diagnostics of skin cancer (VIAMOS) ................................. 34
Supported by: EU (Call FP7-ICT-2011-8).
Project: “Vertically Integrated Array-type Mirau-based OCT System for early diagnostics of skin cancer”

In-situ surface metrology: Integration of a white light interferometer into a high precision grinding machine for diamond tools .................. 35
Supported by: BMWi (FKZ 16IN0519)
Project: “iTool”
Active inspection of three-dimensional objects using a multi-sensor measurement system

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

In the manufacturing process of components with complex three-dimensional surfaces, there is a growing demand for consistent quality control, calling for fast, reliable and flexible inspection systems. Considering complex objects, it is a common insight, that this demand cannot be met in a single measurement step. Instead, different inspection steps have to be applied to different sub-regions on the object. Within these sub-regions, defects with varying characteristics, regarding e.g. their size or their general form, have to be detected and analyzed. In order to realize such a manifold inspection task, a flexible multi-sensor measurement system is implemented. It may consist of a set of different sensors, each having individual properties that are located at different positions in the area of conflict consisting of the resolution, measurement speed and field size.

The focus of the project “AMuPrüf” lies in the development of a flexible inspection system for finding different defects on the surface of small gears. At first, a meshed model of the gear is created based on the common set of parameters, like its module or number of teeth. The surface of the gear can now be split into some main functional sub-regions, where each region must confirm a certain set of specifications. The objective of the overall inspection system is to verify these given specifications. An example might be that no defects of the general type “scratch” must be on the surface whose dimensions exceed a given limit.

In order to realize a successful and flexible system for inspecting varying specifications, the following challenges have to be considered and overcome:

Usually, large areas have to be searched for very small defects. Additionally, the size and shape of each defect may also vary with respect to the type of gear or specification. Due to the limited space-bandwidth-product of optical sensors, it would need a lot of time in order to sample the whole surface with a high-precision sensor. To balance this conflict, a multi-scale measurement strategy with multiple sensors fused in one system is utilized to characterise the surface at different scales. This strategy follows an iterative exploration strategy, where a combination of a coarse scale sampling together with an adapted data analysis (indicator function) provides hints where defects may lie, such that the system only needs to resample these regions of interest with sensors working in finer scales until the final result can be achieved.

A hardware assistant system helps the user to select an appropriate set of sensors including their ideal parameterization for realizing this multi-scale inspection system with respect to the given general task.

Due to the complex surface structure of objects like gears, a high precision positioning system together with an appropriate software package is needed in order to optimally position the object with respect to each sensor. Additionally, an enhanced extrinsic calibration strategy has been developed, such that the relative position of each sensor in one global coordinate system is known. Then, the data sets, acquired at different positions and in different scales, can be merged together in one common system and compared with the given model of the inspected object.
The demonstrator for the inspection of gears is based on a modified Mahr MFU 100 (Fig. 1.) which contains three translational axes and one axis of rotation. The mounted sensors are one scalable fringe projection microscope (based on a Leica microscope MZ 12.5) whose magnification can be switched between 0.8x and 10.0x. Additionally, the sensor in the finest scale is a chromatic confocal point sensor CHRocodile E (Precitec).

Figure 2 shows an example for detecting a scratch on one face of a gear using the multi-scale inspection strategy. The fringe projection microscope samples the surface with a low magnification in order to obtain a quick overview measurement that is afterwards correlated with a polygonal model of the gear. Based on the model, the faces are indicated and measured again with a more precise sensor. Then, another indicator function marks a sub-region, where the given specification (here: a scratch...
on the surface) is possibly not met. By repeating this procedure using the scalable sensor, the final decision is taken in the third scale, where the defect can be clearly resolved and characterized.

For an automatic and optimal definition of appropriate indicator functions, a software assistant system has been developed. The input to this system is a library of real measurement data together with marked defects in each image. Using an optimization algorithm based on genetic programming, a chain of basic image processing steps together with the appropriate set of parameters is selected, such that the marked regions are automatically determined out of the training data set. An example for the indication of a scratch in the intensity image of one single acquisition is depicted in figure 3.

Finally, the actuators, sensors and assistant systems are combined in one complex software, which still is under development and further has to be equipped with a field of view planning in order to optimally position the sensor with respect to the object’s surface, considering the shape and local gradient of the object as well as the general visibility of the region by a certain sensor at a specific position.

Supported by: Baden-Württemberg Stiftung
Project: “AMuPrüf”

References:


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 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. Hence 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 visualised 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 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 optical spectrum employed and the axial range of the detector is decoupled from the limited depth-of-focus.

Fig. 1 shows the current Linnik-type set-up, where CCSI can easily be compared to standard Chromatic Confocal Microscopy (CCM), using the same optical components and a shutter to switch the reference arm on (CCSI) or off (CCM). An axial measurement range of 18µm up to 100µm is achieved with 50x/0.8 NA or 20x/0.46 NA microscope objectives respectively, where a spectral range from 810 nm to 870 nm is provided by a Superluminescent Diode (SLD).

As shown in Fig. 2, the evaluation of the wavelets envelope from a CCSI measurement shows the same result as a CCM measurement. Utilizing the interferometric information with a lockin phase evaluation leads to a significantly better result.

**Fig. 1:** Linnik-type demonstrator setup for direct comparison of CCM and CCSI.

**Fig. 2:** Measurement of resolution standard Simetrics RS-N at 4µm pitch with CCM and CCSI, evaluating both, envelope and lockin phase.
Furthermore, the Laterally Chromatically dispersed, Spectrally encoded Interferometer (LCSI), a new concept of a one-shot line sensor based on spectral interferometry has been presented. In this design, the spectral separation by a blazed grating leads to an illuminated line of about 1mm length, where every point is spectrally encoded. Thus, the interference signal depends on both, the lateral position and the optical path difference (OPD) induced by the height profile of the specimen. The OPD is usually retrieved from the derivative of the phase term of the signal. In LCSI, for all n pixels of the spectrometer, this derivation leads to a differential equation, which for a single shot measurement can be solved, if a raw estimation on the monotonicity of the phase evolution can be derived from a priori information. Based on first order taylor approximation, one gets n-1 additional equations, leading to an underdetermined system of linear equations. At least one additional equation is needed to retrieve a solution. In many cases, this additional equation can be derived from a simple model of the measured surface, e.g. symmetry considerations. By this approach, precise results can be achieved as shown in Fig. 4.

If the specimen is slightly shifted, every point is illuminated by a second wavenumber, leading to another set of equations. Due to the slight shift, the wavenumber is also only changed by a low value, thus the Signal-to-Noise Ratio drops significantly.

To overcome this limitation, in the current project (DFG OS111/21-3), the LCSI setup will be expanded by a second light source as shown in Fig. 3. The spectral distribution will feature a peak wavelength of 415nm and a bandwidth of about 20 nm. Thus, both light sources can use the same blazed grating for spectral separation. As both light sources provide an independent set of equations, local measurement errors do not globally compromise the result and the measurement principle gets more robust.

Supported by: DFG (OS 111/21-1/2/3)
Project: “Chromatisch-konfokale Spektral-Interferometrie zur dynamischen Profilerfassung”

References:

Design and fabrication of a hybrid hyper-chromatic lens for confocal sensors

W. Lyda, F. Schaal, C. Pruß, W. Osten

Chromatic confocal microscopy is a single shot measurement principle which offers fast, accurate and robust measurement data. In the past years several commercial point and line sensors with submicron accuracy and nanometer resolution for shop floor environment were developed. To take advantage of this high resolution the actuators of the inspection systems have to meet tight requirements on straightness and flatness. The high price of such systems limits their deployment to medium and large production facilities.

The objective of the overall project was to develop an add-on sensor module based on chromatic confocal microscopy for commonly used shop floor microscopes to reduce the necessary capital investment for such type of sensors.

On sub-contractual basis ITO designed and fabricated the hyper-chromatic element for the chromatic dispersion. The element consists of a positive refractive lens and a diffractive optical element (negative Fresnel-lens). By balancing the refraction power of both elements for the center wavelength the measurement range of the sensor is centered around the focal plane of the classical bright field illumination of the system. To switch between classical bright field illumination and point-wise distance measurement mode the element was mounted into the DIC prism revolver of the microscope (see Fig. 1).

The optical element was fabricated at ITO. It is a hybrid diffractive/refractive lens, where the diffractive structures were fabricated on the planar side of a plano-convex lens. Core of our CGH fabrication is the laser writing system CLWS300, a flexible high precision tool that works in polar coordinates, comparable to a DVD writer. This working principle offers the advantage of a high, continuous scanning speed and facilitated fabrication of rotationally symmetric structures. Yet the system is not limited to writing circles but allows to write arbitrary structures such as linear gratings, microlenses or angular scales. It is capable of writing both binary and blazed diffractive optical elements. Blazed structures are written in grayscale mode where the writing beam intensity is varied with the moment up to 256 levels.

The substrate size can vary from a few millimeters to 300 mm in diameter. The shape can be rectangular, round or any other reasonable outline. The system allows substrate thicknesses up to 25 mm.

The resulting photoresist profile is then either used directly (e.g. for mastering) or is transferred into the fused silica substrate using dry etching (RIE).

Fig. 1: Design of the hybrid optical element based on a diffractive optical element with negative focal length and a refractive lens with positive focal length. The combined focal length for the design wavelength is zero

Fig. 2: Chromatic dispersion of the hybrid element.

Project: “R&D-Study for ProMicron, Germany”

References:
Ray tracing is still the most widely used simulation method in designing and analysing macroscopic optical systems. Over the last years several extensions to include diffractive optical elements into ray tracing simulations have been developed, thereby further broadening the application range of ray tracing. However, the fundamental function principle of ray tracing, i.e. propagating light as a set of mutually independent rays through optical systems, implies a nearly perfect linear relationship of computational load to the number of surfaces in the optical system and the number of rays traced through the system. Especially in Monte Carlo based stray light analysis, where a huge number of rays has to be traced non sequentially, this linear relationship is a big issue even on todays computer machines.

Within the BMWi project “Präzisions-Charakterisierung von weißen LEDs und LED-Beleuchtungen” a GPU accelerated ray tracing tool was developed, that utilizes the massively parallel architecture of modern graphic cards to speed up the ray tracing calculations. With this approach it was possible to accelerate the simulation of the spectrometer system that is depicted in Fig. 1 by a factor of up to 50 depending on the number of rays involved in the simulation (see Fig. 2).

This GPU accelerated ray tracing tool, that we call MacroSim, has evolved into a general purpose ray tracing program, that is capable of accelerating both, sequential and non sequential simulations. It offers an intuitive graphical user interface to create a model of the optical system and parameterize the simulation. It can read the popular glass catalogs from Zemax, that describe the optical properties of typical glass materials. Additionally, it is fully integrated in the institutes measurement program "itom", thereby enabling seamless integration of simulated sensor signals into the signal processing chain of real sensor systems.

MacroSim has been released under an open access license according to the popular LGPL license. The source code can be accessed online at https://bitbucket.org/mauchf/macrosim. Therefore we hope that it will find an active community and form the basis for new computation intensive applications of the ray tracing simulation principle.

Fig. 1: Rendered view of spectrometer system as displayed in our GPU accelerated ray tracing software MacroSim. The diffraction grating surface is highlighted in green.

Fig. 2: Tracing time for spectrometer system in dependence of the number of rays, that are traced. Red and blue lines represent the GPU accelerated and the CPU based code respectively. Note that both axis are scaled logarithmically.

Supported by: BMBi (FKZ 13N7861)
Project: “PräziLED”

References:
The actual form of the microstructure of mechanically highly challenged surfaces determines their functionality and therefore a fast and reliable quality control is crucial for manufacturers of such surfaces. While inspection of such surfaces has been traditionally done with tactile stylus systems, confocal microscopy as well as scanning light interferometry became more and more popular for such inspection tasks over the last years. These systems measure contact free and fast. However, they have been characterized in the past mainly on optically smooth surfaces and their behaviour when measuring rough surfaces is sometimes surprising and always depends critically on a number of parameters that can be set by the user of the measurement system, e.g. numerical aperture of the objective etc. This leads to strongly varying inspection results depending on the type of measurement system that was used and the actual parameters that were chosen by the technician, who was doing the measurements.

Therefore, within the BMBF project “Anwenderorientiertes Assistenzsystem zum sicheren Einsatz optischer Abstandssensoren” an assistance system for optical surface measurements is being 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.

As a first step we developed an improved signal model for confocal sensors, that is able to predict object depending artifacts. Fig. 2 illustrates such an artefact in a confocal measurement of the PTB chirp calibration standard. We have shown that confocal sensors rely on the fact that the overlap of the illuminating wave-front and the specimens surface is maximum if the specimen is in the focus of the sensor. However, as is illustrated in Fig. 1, for curved surfaces this overlap might become maximum for out of focus positions. This leads to deterministic measurement errors that depend on the particular shape of the specimens surface and results in a lateral resolution of confocal profilometers that is worse than that of confocal imaging devices. Knowledge of this effect will be used to effectively assist the user of confocal sensors when planning measurements and will help to accurately estimate the remaining uncertainty in confocal surface topography measurements.

Supported by: BMBF (FKZ 13N10386)
Project: “OptAssyst”

References:
Optical low-cost sensor system for the control of pump rates

K. Körner, W. Lyda, W. Osten

For the enhancement of a one-way dosing pump, we investigated approaches for the highly resolved optical measurement of the position of the piston, see Fig. 1. The main objective is to ensure a high resolution and a low measurement uncertainty in the rate of fluid delivery from 10 µl/min to 100 ml/min with the same pump module. The industrial application requires both, a very robust and a low-cost solution.

So we applied a low-cost microscopic approach with a small magnification that directly detects the illuminated lip of the moving seal of the pump. For achieving the aims mentioned above, the resolution of the position of the sealing lip has to be in the submicron range. That means sub-pixel accuracy. For this, we use a correlation based method in a sequence of images of the sealing lip for precise detecting the motion of this lip in combination with a Lab-view control loop.

First, we applied a commercially available telecentric lens for detecting the lip position. Fig. 2 shows the calculated movement of the sealing lip in the liquid medium Lipofundin at a pump rate of 5 ml/h, and Fig. 3 presents the calculated mass of the shifted medium over time. Considering linearity, both curves are the same. However, there is a significant difference of about 6% between the optical measurement and the measured mass of a scale. Further investigations showed the not negligible influence of the evaporation of the water content in Lipofundin in our experiments. Another error in measurement is probably caused by synchronization problems of Labview during load stroke of the metering pump.

Secondly, we designed, manufactured and tested a telecentric optical stage with two diamond turned lenses made of acryl glass (PMMA) for proving a low-cost approach for mass production. First results show the technical applicability of that approach.

A very first market analysis of the necessary sensor components including LED illumination and microcontroller provided evidence: The costs for the whole sensor system will not exceed 100 € in case of mass production (1000 sensors a year).

There are widespread application fields for this technical concept also where aggressive fluids have to be used, for example in medical care, chemical industry, biotechnology or pharmacy.

Fig. 1: One-way pump element (syringe) with an optical low cost sensor (courtesy of HSG-IMAT).

Fig. 2: Optically detected and by a Labview program calculated shift of the sealing lip in the liquid medium Lipofundin, pump rate 5ml/h. (pump system: HSG-IMAT).

Fig. 3: Calculated mass over time of medium Lipofundin, pump rate 5ml/h (pump system: HSG-IMAT).

References:

Both the development of new optical sensors and the operation of such systems for instance in a laboratory environment require a fast and flexible software system. This software has to be able to communicate with a wide range of different hardware systems, such as cameras or actuators and should provide a diversified and as complete as possible set of evaluation and data processing methods. Additionally, the rapid prototyping of modern measurement and inspection setups requires a system, where parameters or components can easily be changed at runtime, necessitating the availability of an embedded scripting language. Finally, when operating a measurement system, it is also desirable to extend the graphical user interface by system adapted dialogs and windows.

Since no commercial software system fits all these requirements within the desired performance and quality parameters, a group at ITO started to design and program the new measurement software “itom” in 2011, partially inspired by the former ITO-software “m”.

It mainly consists of four pillars:
1. The core application with its graphical user interface (GUI) gives access to the most important functions of “itom” without further need for scripting or programming any code.
2. The plugin system. The main idea behind “itom” was to keep the core application thin. Therefore, “itom” can be extended by external libraries (plugins), that are dynamically loaded at runtime. One group of plugins provides access to any hardware systems “itom” should be able to communicate with. Other plugins contain data processing and analysis algorithms as well as complex user interfaces like windows or dialogs. The last group of plugins provides plotting and figure components in order to show live images of cameras or visualize other data structures.
3. The popular and powerful scripting language Python is embedded in “itom”. It is possible to use Python and the functionalities provided by such freely available modules as Numpy, Scipy or Matplotlib, within “itom”. Additionally, a Python-module itom acts as an interface to the core application “itom” as well as its plugins. The scripting system provides full development functionality, including language support and debugging.
4. Measurement systems can be extended by their own GUIs. A WYSIWYG design tool is available, allowing connection of interface elements to scripted functionalities. As a result, users can configure the appearance of their measurement system to optimally enable or protect the underlying functionalities.

The application “itom” itself is programmed in C++ using the open source framework Qt. This framework enhances the functionality of C++, mainly by providing a cross-platform GUI, allowing “itom” to run on both Windows and Linux operating system. The design of “itom” focuses on the support of modern, multi-core processors by making extensive use of multi-threading, effectively running script execution, hardware control and algorithmic plugins each in their own separate threads. As a result, computationally demanding algorithms can be executed or an actuator can slowly move while the main application is still kept reactive.

The core application of “itom” is released under the open source license LGPL. The sources can be freely downloaded from the internet at https://bitbucket.org/itom.

---

**M. Gronle, C. Kohler, M. Wilke, W. Lyda, H. Bieger, W. Osten**

"itom" – measurement and laboratory automation software
Vertically integrated array-type mirau-based OCT system for early diagnostics of skin cancer (VIAMOS)

W. Lyda, T. Boettcher, J. Krauter, W. Osten

Skin cancer is one of the most commonly diagnosed type of cancer with an increasing number of cases in the last years. Most cases are caused by over-exposure to UV-light. If the cancer is untreated, it becomes fatal. If the cancer is diagnosed in an early state, it can be treated effectively. Hence an efficient and easy-to-use diagnostic tool is necessary.

The current state of the art is a visual inspection either by clinicians or self-examinations. If cancer is assumed, the potential melanoma is removed and a traditional biopsy is applied as a reference diagnosis. The drawbacks of this technique are the long diagnosis time of several days to weeks and the invasiveness of the procedure, but the advantages are a good image quality and high contrast between malignant and benign tissue. Hence non-invasive imaging methods have been developed.

Two methods which match the requirements on the resolution are confocal microscopy and optical coherence tomography (OCT). Both offer a resolution down to some microns and sufficient penetration depth. They offer a non-invasive 3D-visualization of the human skin. While confocal microscopy offers a higher resolution, OCT has a higher penetration depth along with a short data acquisition time.

The disadvantage of the current systems is the high system cost up to 100 k€, limiting the application to bigger hospitals.

The project VIAMOS aims to reduce the cost of such OCT systems dramatically. Therefore a small handheld, low-cost, OCT device will be developed which is 10 times cheaper and 150 times smaller than current systems. This will be achieved by modern 3D-packaging techniques and direct integration of wafer level optics and micro mechanical optical systems like the system architecture based on a parallel Mirau layout developed in the EU-project “Smar-thies”. The targeted measurement volume is 5 mm x 5 mm x 0.5 mm with an acquisition time under 20 seconds. The challenge will be to cope with the low contrast between different kind of tissue compared to biopsy.

The project consortium brings together academic institutions, research institutes and industrials partners, experienced in the field of MEMS & MOEMS, photonics & OCT, microscopy, system integration and dermatology.

More information under www.viamos.eu.
Diamond tools are used to fabricate sophisticated optical surfaces on plane and curved substrates. One production technology is for example fly-cutting for ultra-precision turning and grinding. By these techniques the shape of the Diamond tools are often directly transferred onto the substrates. For example, such tools are needed for the production of micro lens arrays, lenticular screens or intraocular lenses. However, the fabrication of high precision optical surfaces on such substrates is limited by the supply with commercial Diamond tools. The limitation is the ability for the production of accurate and precise tools. Most diamond tools are fabricated by grinding and polishing. But the measurement of the produced tools is carried out after the fabrication process. Due to a tight tolerance zone, there can be a high rate of waste.

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 in-situ 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 visual inspection tool.

The visual inspection tool 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 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. Therefore 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 automation of the measurement procedure is desirable.

Institut für Technische Optik, Annual Report 2011/2012

References:


