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Editors

Fringe 2009

6th International Workshop on Advanced Optical Metrology

Springer

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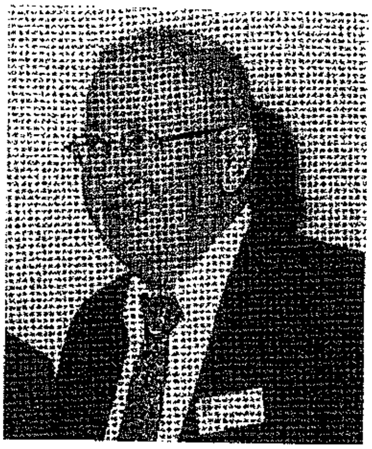

In Memory of Dr.-Ing. Hans Rottenkolber

(* 12.05.1937 - † 07.03.2008)

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Preface

21 years ago it was a joint idea with Hans Rottenkolber to organize a workshop dedicated to the discussion of the latest results in the automatic processing of fringe patterns. This idea was promoted by the insight that automatic and high precision phase measurement techniques will play a key role in all future industrial and scientific applications of optical metrology. A couple of months later more than 50 specialists from East and West met in East Berlin, the capital of the former GDR, to spend 3 days with the discussion of new principles of fringe processing. In the stimulating atmoshere the idea was born to repeat the workshop and to organize the meeting in an olympic schedule. And thus meanwhile 20 years have been passed and we have today Fringe number six. However, such a workshop takes place in a dynamic environment. Therefore the main topics of the previous events were always adapted to the most interesting subjects of the new period. In 1993 the workshop took place in Bremen and was dedicated to new principles of optical shape measurement, setup calibration, phase unwrapping and nondestructive testing, while in 1997 new approaches in multi-sensor metrology, active measurement strategies and hybrid processing technologies played a central role. 2001, the first meeting in the 21st century, was focused to optical methods for micromeasurements, hybrid measurement technologies and new sensor solutions for industrial inspection. In 2005 the fifth workshop was organized in Stuttgart, the capital of the state of Baden-Würthemberg and the centre of a region with a long and remarkable tradition in machine construction, vehicle manufacturing and optics. Thus after Berlin 1989, Bremen 1993, 1997 and 2001, Stuttgart was the third Fringe city where international experts met each other to share new ideas and concepts in optical metrology. And this will be continued in 2009.

This volume contains the papers presented during ***FRINGE 2009***. The focus of this meeting is especially directed *to digital wavefront engineering*, *resolution enhanced technologies*, 4D methods addressing applications *from macro to nano considering dynamic changes*, *sensor fusion* and new advances in *the unification of modeling, simulation and experiment*. Since optical metrology becomes more and more important for industrial inspection, sophisticated *sensor systems* and their applications for the solution of challenging measurement problems are chosen again as one of the central topics of the workshop. This extended scope was honored by a great response on our call for papers. Scientists from all around the world offered more than 150 papers. This enormous response demanded a strong revision of the papers to select the best out of the overwhelming number of excellent papers. The strong limitation of the number of papers which can be presented orally and discussed effectively during a workshop without holding parallel sessions was again an impotant orientation.

The papers presented in this workshop are summarized under 5 topics:

1. New Methods and Tools for Data Acquisition and Processing
2. Application Enhanced Technologies
3. 4D Optical Metrology over a Large Scale Range
4. Hybrid Measurement Techniques
5. New Optical Sensors and Measurement Systems

As in the former workshops, each topic is introduced by an acknowledged expert who gives an extensive overview and a report of the state of the art. The classification of all submitted papers into these topics was again a difficult job which often required compromises. We hope that our decisions will be accepted by the audience. On this occasion we would like to express our deep thanks to the international program committee for helping us to find a good solution in every situation.

The editors would like to express their thanks to all the authors who spent a lot of time and effort in the preparation of their papers. Our appreciation also goes to Eva Hestermann-Beyerle and Birgit Kollmar-Thoni from Springer Heidelberg for providing excellent conditions for the publication. Our deep thanks is directed to the members of the ITO staff. The continuous help given by Katharina Bosse-Mettler, Katja Costantino, Gabriele Grosshans, Heiko Bieger,. Valeriano Ferreras Paz, Erich Steinbeißer and Michael Warber was the basis for making a successful *FRINGE 2009*. Finally, our special thanks and appreciation goes to all friends and colleagues for sharing with us again the spirit of the Fringe workshops.

Looking forward to *FRINGE 2013*.

Stuttgart and Warsaw, September 2009

Wolfgang Osten and Malgorzata Kujawinska

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Tutorial

A virtual telecentric fringe projection system

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1 Introduction

Crank shafts are one of the most important components of a motor. Therefore the Collaborative Research Centre 489 "Process Chain for the Production of Precision Forged High Performance Components" (CRC 489), financed by the German Research Foundation (DFG), deals with the production of high precision forged crank shafts [2]. One topic of the subproject B5 "Geometry Analysis" is to build up a virtual multi sensor system, consisting of a fringe projection system, a shadow projection system and several linear axes. According to an estimation of statistical data such as the standard deviation it is useful to simulate the measuring procedure with a virtual multi sensor system [1]. In this paper the simulation model and the first simulation results will be presented.

2 Virtual fringe projection system

A fringe projection system consists of a beamer and one or more cameras. Common fringe projection systems use straight fringe patterns which are projected from the beamer onto an object [3]. Afterwards the deformed patterns on the surface of the measurement object are measured by the camera. In this simulation the general measurement process is inverted with the consequence that the camera pixels are projected onto the beamer stripes. To illustrate the virtual measurement process the characteristics of the simulation model and the optical way of the light rays should be pointed out at first. After that the simulation procedure and some results are explained.

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2.1. Simulation model

A combination of a pinhole and an object-sided telecentric lens was used for the model of the camera objective and a simple pinhole for the beamer objective, as shown in Fig. 1. To decide if a pixel is illuminated the light intensity, emitted from the beamer, reflected from the measurement object and absorbed from the camera, is weighted in respect to the reflexion angle (Fig. 1).

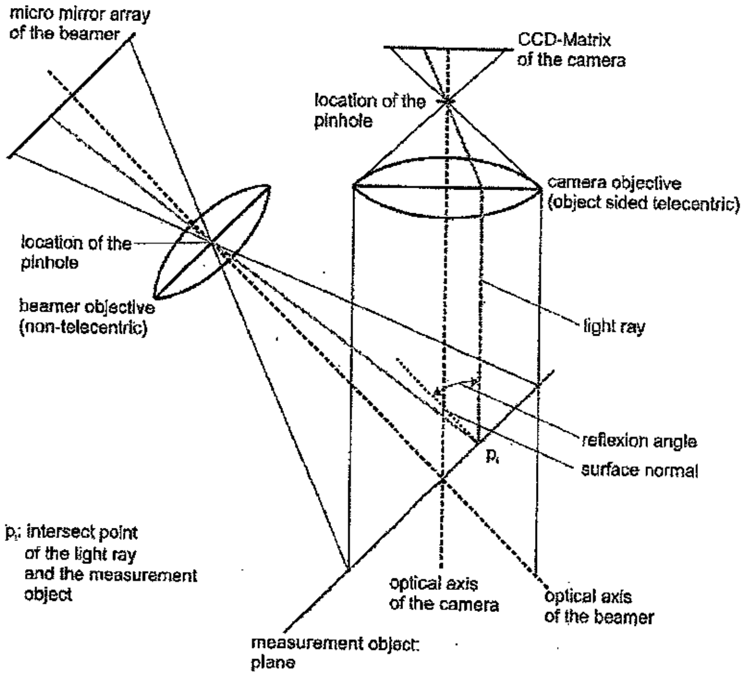

Fig. 1. Simulation model of the virtual fringe projection system

For the calculation of the reflexion angle it is necessary to acquire the surface normal of the measurement object at different points. Therefore a mathematical description of the object is required, which permits an easy calculation of the geometrical data. In this simulation the object is described by means of polygons so that a simple calculation of the normal is allowed. For the calculation of the surface normal the intersect point between the light rays and the measurement object is needed.

For this purpose the intersection points of the light rays and the camera objective is computed at first. After that the light rays run parallel to the optical axis of the camera and intersects the measurement object at point p_i. Therewith the surface normal at this point and the reflexion angle can be estimated.

2.2. Procedure of a simulation

The first step in the simulation is to calculate the intersect point for each light ray for all camera pixels with the measurement object, allegorised through polygons. Subsequently the beamer-stripe ϕ to the corresponding camera pixel, with regard to the weight of the reflexion angle, is estimated. Thereby a pair of values $\{i, j, \phi\}$ was generated, which can be used for the following simulation procedures, whereas i and j are the coordinates of the camera pixel and ϕ the phase of the beamer.

3 Comparison between simulation and real world system

To appreciate the quality of the virtual fringe projection system several fringe-sequences were generated using the real world system as well as the virtual system and detected by the real and the virtual camera. The differences between the measured and the calculated chart should constitute the accuracy of the simulation model, whereas the measurement object is allegorised by a plane which is orientated parallel to the beamer. After the measurement and the simulation the generated images were converted to binary images. Therefore a simple threshold was used.

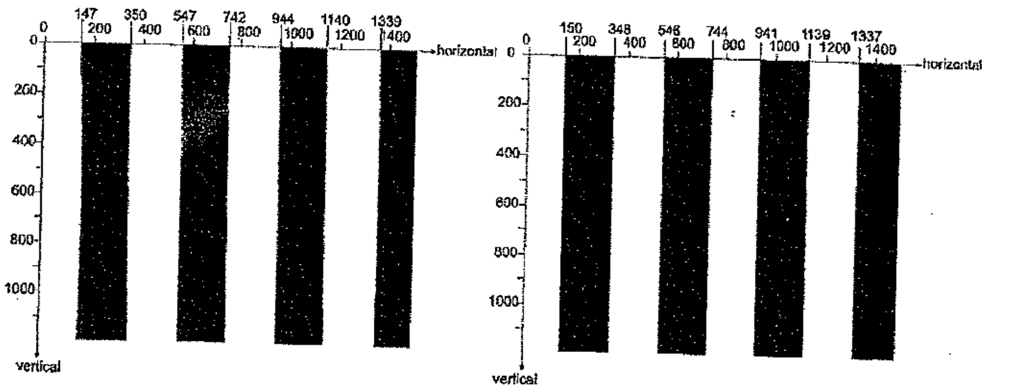

Fig. 2. Measured (left) and simulated (right) fringe sequenz

Fig. 2. shows the measurement and the simulation result. To compare the charts the position of the edges were established. As constituted in Fig. 2. the difference between the simulated and the measured result lies in the range of 3 pixels and is, relating to the great number of pixels (1188 x 1504), very small. The remaining deviation could be declared with the identified model parameters.

4 Conclusion and outlook

In this paper the simulation of the measurement process of a fringe projection system was described and a comparison between the virtual and the real world system was presented. The comparison from camera images of projected fringe sequences points out that there is a high accordance between the real and the simulation model.

In combination with monte carlo methods the model can be used to accomplish measurement uncertainties for several workpiece geometries. Furthermore it is possible to characterise the influence of the model parameters on the measurement accuracy. For example a relative motion between the measurement object and the fringe projection system can be simulated and the influence on the measurability can be examined.

To detect the geometry of a complex workpiece it is necessary to approach more than one position with the measurement object or with the measurement device. To fuse the measurement results to one global coordinate system the knowledge of the positions takes a significant influence on the accuracy of data fusion processes.

5 Acknowledgement

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