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Optical Bi-Sensor-Method for In-Line Measurement of Objects with large Aspect Ratios

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Abstract:
At the Chair Quality Management and Manufacturing Metrology (QFM) a prototypic optical measurement method for in-line measuring of extruding with 800°C and movement speeds up to 10 m/s has been investigated and evaluated in the shop successfully [1]. The method combines multiple light-section systems and a shadow system for measuring concave extruding more accurate than before. The measurement uncertainties operate down to 10 µm in measurement ranges of 100 mm. The already evaluated method can fundamentally be used as well for measuring other objects, e.g. with high aspect ratios. The here presented approach shows that the measuring principle can be adapted for flat objects like textiles and carbon-fiber compounds in-process. The results contain information about the set-up, the adjusting, influence quantities, calibration of the measurement system and the user-interface as well as the measurement results and possibilities for further improvements.
Keywords: Optical Metrology, Data Fusion, Multi-Sensor-Measurement

Introduction

The control of semi-finished products during the process is an industrial challenge with rising importance. Because of economic reasons semi-finished products are often used for final technical products. Therefore in a first step the demands of the customer concerning accuracy of the parts and their efficient manufacturing must be fulfilled by high-quality and holistic measurements in order to monitor and control the process in-line. Unfortunately the in-line measurement of semi-finished products is quite difficult because of the fast running, swinging and with dirt afflicted measurement objects from steel, brass, aluminium, plastics or compounds. So, only non-contact measurement principles are suitable for high-measurement speed in 2D of the cross-section design and at the same time high potential for gaining robustness requirements. The last years at the Chair Quality Management and Manufacturing Metrology a prototypic multi-sensorial measurement system was built-up and evaluated. The objective was the combined measurement with two different measurement principles – the shadow method and the light-section method – and it was successfully validated as well in the shop. For the first run several profile types with diameters up to

100 mm and aspect ratios in square of 1:1 to 1:5 had been measured. In this contribution the system has been alternatively used for the measurement of objects with aspect rations of 1:100 to 1:1000 from materials like textiles and carbon-fiber tapes. The materials are increasingly used in the modern automotive sector and the aircraft industry. The presented results validate, that the fundamentals of an optical multi-sensor measurement system with merged data can as well be adapted to this products with different algorithms, measurement strategies, software adjustments and modified sensor configurations.

Fundamentals

The optical multi-sensorial measurement system consists of two different types of sub-systems: the scalar two-point information of the shadow method and the coordinate measurement principle from the light-section method which reconstructs the information of a distorted laser fan illumination on the surface of the part. Both methods deal with advantages and disadvantages which can be combined constructively. On the one hand the great accuracy of the shadow system can be used to calibrate the characteristic of real coordinate measurement. On the other hand form deviations can be accomplished with the light-section system. For a holistic view more than one light-section system can be applied with overlaps to each other of about 10 % and are reconstructed to the real form of the part. Especially for normal aspect ratios that is approved to be reasonable. For flat objects mostly only one side is necessary to measure in a first step. In a second step there is the need for information about the surface structure, the flatness and the shape of small surface zones. At the same time the angle over ground of the contour and the maximum wide is from main interest. The shadow system can measure the maximum boundary accurately, but if e.g. a fiber tape is tilt, the influence contribution would be dramatically if the angle information from the light-section system misses. In order to that the system – working in the combined mode – has additional value for measurements of coiling processes or automated railing. Therefore the measurement system has to be fundamentally re-adjusted for the use for small aspect-ratios.

Mock-up of the optical bi-sensor-measurement system

Hence the original prototype has been rebuilt and the individual measurement software – used for extruding with aspect ratios of 1:1 to 1:5 – has been modified for aspect ratios of 1:100 to 1:1000. The examinations point out that the method is suitable for endless in-line products like carbon tapes with requirements of high accuracy for the width, too. The resolution limit of the cameras of the light section system can be raised by adapted components like cameras or lasers. Therefore, more accurate results can be achieved, because the distances and the depth of field can be lower in opposite to the previous measuring task of extruding [7]. The prototypic measurement system is illustrated in Fig. 1.

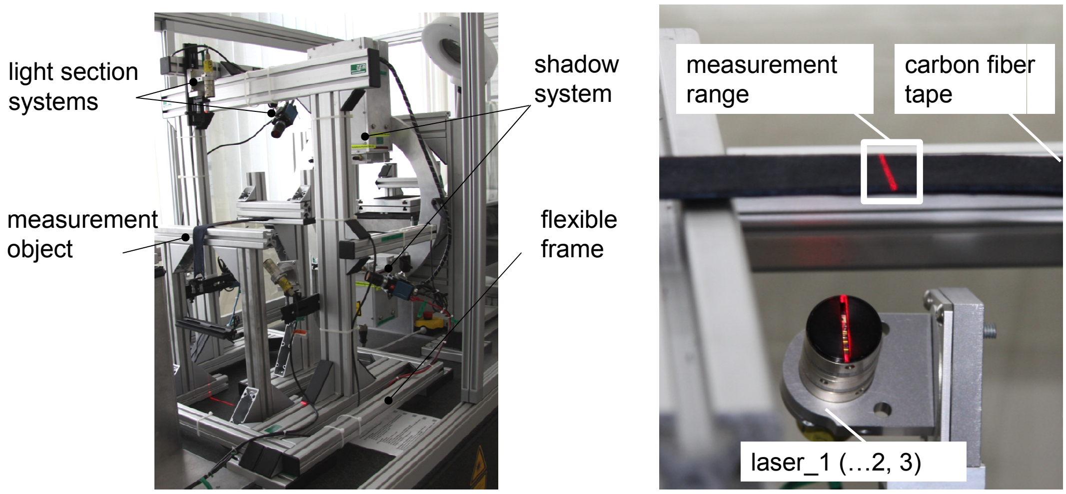


Fig.1: Optical bi-sensor measurement prototype, left: isometric view, right: carbon-fiber tape

Measurements and results

On the one hand simulations for the algorithms and the user-interface are presented. On the other hand referenced workpieces and calibrated test specimens – which are qualified on a much more accurate measurement system offline under laboratory conditions – are used for exploring the measurement deviations precisely [2], [3]. It is hardly avoidable that the both sub-systems measure in different planes. The difference in z-direction can be compensated by integrating over the distance and the knowledge of the materials moving speed. The three systems are arranged in a line with constant angles and distances as well as illumination overlaps of about 10 % what was carried out as reasonable from a couple of experiments.

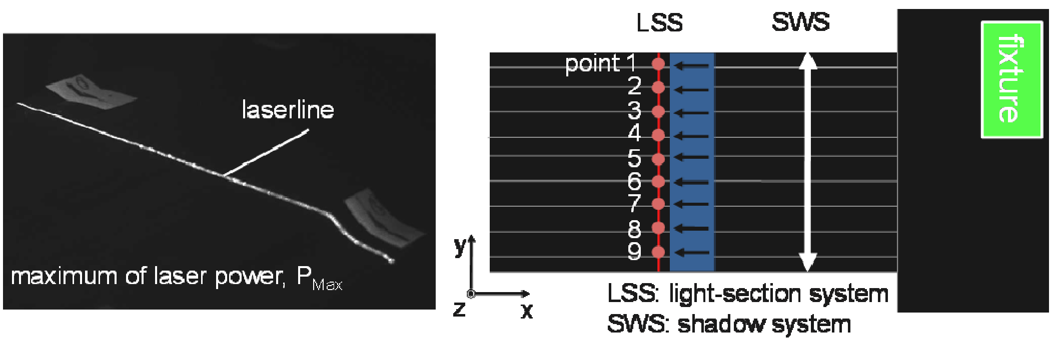


Fig.2: Measurement configuration: left: contrast of the laser line, right: measuring points

The presented results show, that the optical bi-sensor-measuring method is suitable for in-line products like fiber tapes, endless textiles and other flat shaped objects, see Fig. 2 and Fig. 3, with respect to [4]. The hereby gained measurement categories are length, roughness in several classical parameters (R_z, R_a, R_{max}) and the ripple content as well as the tipping of the whole product in relation to a reference plane (tangential deviation), [5], [6]. The arithmetic scallop height R_z is formulated in (1) with n as the number of measured points.

$$R_{Z(DIN)} = \frac{1}{n}\sum_{i=1}^{n} Z_n \qquad (1)$$

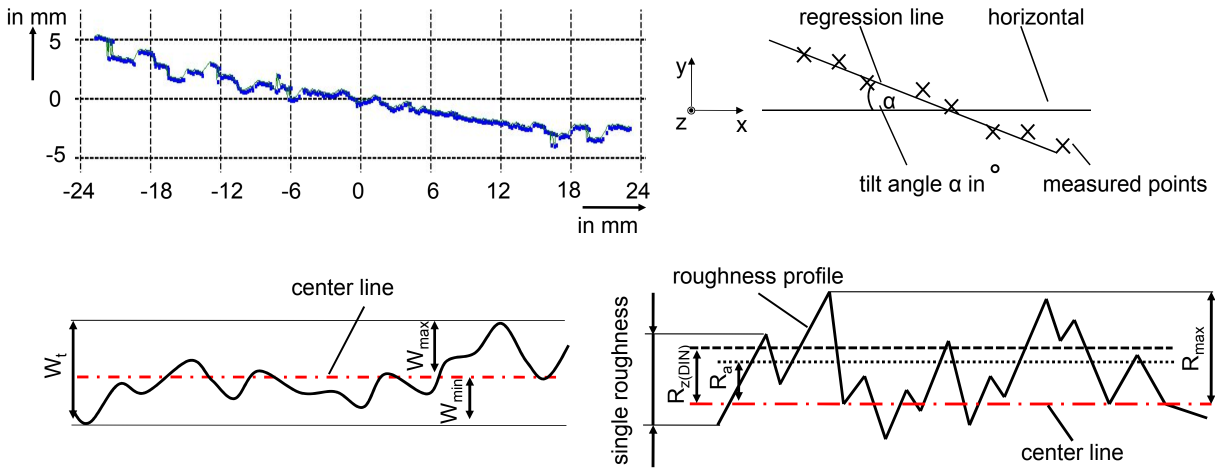


Fig. 3: Left upper: measured contour with basic form, right upper: principle of tilt measurement, bottom left: ripple, bottom right: roughness

In Table 1 the results for R_{max}, R_a, R_z are illustrated in Table 1 and shown as well in Fig. 4. The range for the tipping is quite high, because the object can swing with several degrees.

Table 1: Exemplary results for the optical bi-sensor-method for flat measurement objects

measured value	**R_{max} in µm**	**R_a in µm**	**R_z in µm**	**tipping in °**	**width in mm**
average value	219.23	105.02	210.04	+/- 0.0	9.90
standard uncertainty	0.43	0.17	0.35	+/- 0.1	0.01
range	1.71	0.69	1.35	+/- 5.0	0.02

The standard uncertainty is always smaller than 0.45 µm for the roughness measurements and always smaller 0.1 µm for the width measurements and the tipping for the fiber tape.

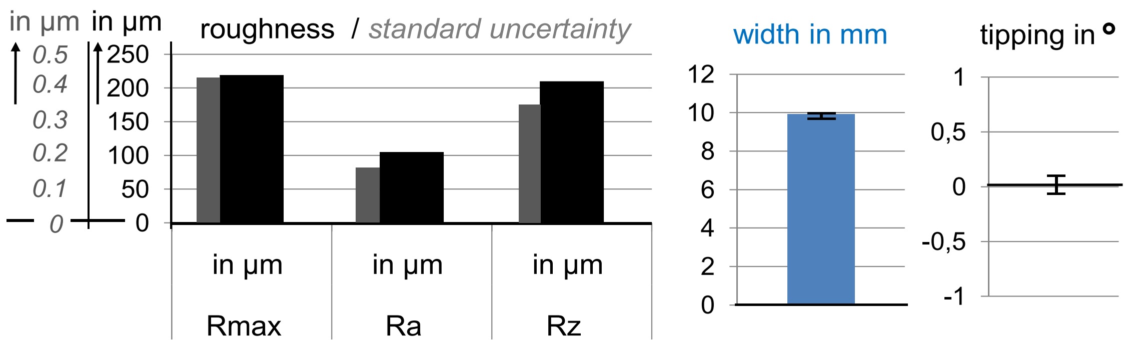
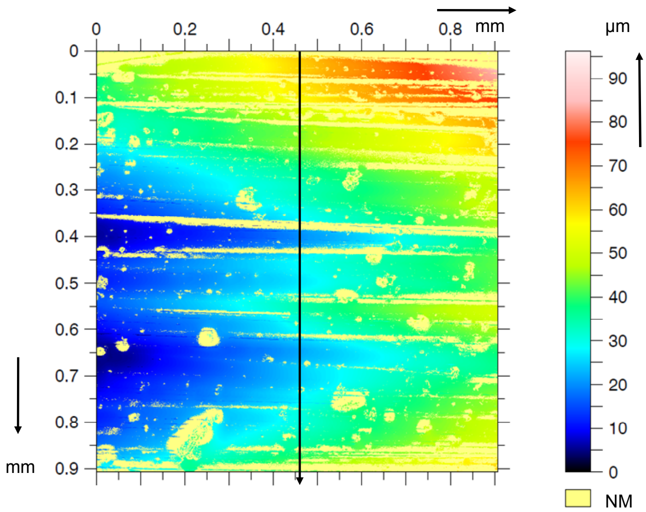


Fig. 4: Left: roughness results, middle: width measurement, right: tipping of the fiber tape

Evaluation of the results

The results had been formulated as a feasibility study. There are effectively quite successful outcomes instead of they are gained on fundamental knowledge of previous examinations with identical sensors which are not selected for this purpose [7], [8]. The calibration gauge is used during the calibration procedure for the physical correlation between the intrinsic coordinate system of the cameras of the self-calibrated light-section system and the extrinsic world-coordinates. For former measurement objects it can be used e.g. as a point-plate with known distance and diameter distributed in the measurement square. For better results on objects with large aspect ratios the segmentation, the size and the distance of these points can be varied depending to the measurement range and the surface [8]. The results are principally comparable to validated measurements of e.g. white-light interferometry (WLI) instead of the accuracies are not located in the same magnitude.



White light interferometry
(Talysurf CCI, Taylor Hobson)
Measurement range (lateral): 0.9 x 0.9 mm
Measurement range (vertical): 400 µm
Measurement points: 1024 x 1024
Resolution lateral: 0.88 µm
Resolution vertical: 0.01 nm

direction of selection (below)
only scanning of a small segment possible
No movement of measurement object allowed

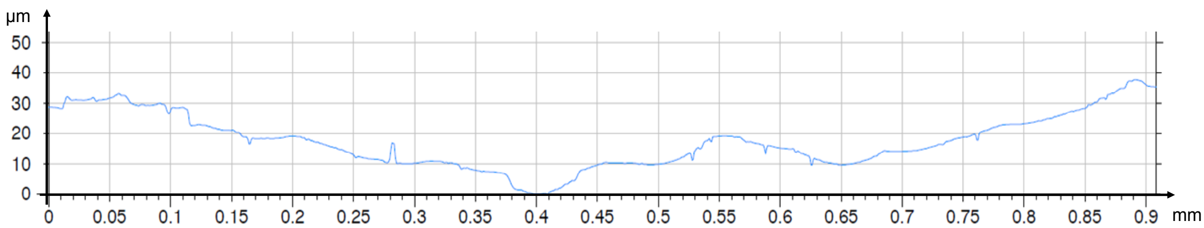


Fig. 5: Measurement with WLI: upper: colour results, bottom: selected area, scanning height

The accuracy of the method depends to the used illumination and mostly to the resolution of the cameras which have not been selected for the here presented contribution. The angle of the measurement object could be examined with standard uncertainties of +/- 0.1°. In combination with the dataset of the shadow system the width can be measured. There are accuracies of 10 µm obtainable what is satisfying for a swinging rough object which is running with speeds of up to 10 m/s. In the here presented measurements on a fiber tape the R_{max} can be measured with better 0.5 µm, R_a with 0.7 µm and R_z with better 1.5 µm. The optical bi-sensor-method can be basically used for the measurement of fast-running fiber tapes on the geometrical characteristics width, angle of the cross-section over ground and the standard roughness parameters R_{max}, R_a, and R_z for the surface of the part.

Conclusion and outlook

The optical bi-sensor-measurement method – consisting of a combined light-section system and a shadow system – is suitable for the in-line measurement of extruding under shop floor conditions. In this contribution the mock-up has been modified for measuring very flat objects successfully. So, the measurement of in-line products like textiles, fiber-tapes or similar semi-finished products is enabled. Therefore the gained measurement uncertainties of this feasibility study can be reduced significantly in further research. The main reason is the limited resolution of the deployed sensors which had not been high enough for the distorted flat field of view in a small measurement range. So, an increased resolution helps to optimize the results for form and surface parameters considerably. The validation of the tilt output in production and impressions of the surface can be increasingly used for proposals concerning the conformity as well in the industrial area of manufacturing innovative textiles and plastics.

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