DOI 10.5162/sensor2015/A8.1

Areal optical surface measurement – how to get reliable topography data

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Abstract:
The change of requirements of technical surfaces and the demand to act expeditiously leads to a change in surface metrology – from 2D tactile profilometry to 3D optical areal measurements. As a result a wide range of systems with sensors based on different physical principles have been developed – all with system inherent disadvantages regarding the measurement uncertainty.

In order to assess the quality of surface datasets, three points have to be considered, the lack of knowledge regarding system setup and parameter adjusting, the restraints of optical measurement systems, e.g. the restricted dynamic range of camera sensors and the ignorance regarding the uncertainty of single points in datasets. To optimize the datasets, an assistance system to guide the operator through the measurement process was developed, measurements to optimize the number of valuable points in datasets and considerations about quality indicators for single data points have been carried out.

Key words: 3D optical areal measurements, assistance system, number of valuable points, quality indicators, measurement uncertainty

Surface Measuring

Nowadays surface measurement especially in mass production mostly consists of tactile profile measurements. Due to higher requirements regarding the surface topography of functional elements, isolated 2D profiles are no longer sufficient for an increasing number of measuring tasks to describe the surface adequate. Thus 3D surface measurement procedures with optical systems (white light interferometer [1], confocal microscopes [2], focus variation systems [3]) have been introduced. The great advantage of optical systems for 3D measuring of surfaces is their contactless principle of operation. But also some disadvantages accompany with this. One point is that the standardization of these procedures is still ongoing and not yet finished. Principle inherent restraints like the restricted acceptance angle, problems with inhomogeneous reflectivity of surfaces due to the limited dynamic range of camera sensors represent another point of handicaps. The worst problem with optical gained surface datasets is the lack of knowledge regarding the quality of the individual topography data points of a surface dataset. This may lead to uncertain or wrong results of surfaces and may cause major issues within the production process or the customer-supplier relationship.

In relation to the optical surface topography measurements, three main problems have been identified, first the huge amount of setup variations and adjustment possibilities which represent a labyrinth for the operators of optical surface measurement systems, especially if different kind of surfaces have to be measured, second the extremely different measurable inhomogeneous surfaces and third the resulting datasets whose information content or quality could not be estimated.

User Assistance

Up to now, the tactile profile surface measurement is state of the art (also within standardization) within mass production of e.g. automotive components. Due to higher requirements in relation to the surfaces and micro contours, only profile measurement is no longer sufficient. Therefore areal optical systems are more and more used, nowadays more likely in measuring rooms than direct for quality control in mass production. The variety of sensors, working with different principles and the linked to these enormous possibilities for settings is the biggest disadvantage. This leads to huge uncertainties of the measurements because of different and in the worst case, wrong settings. To avoid these, two possibilities can be chosen, either training of every operator,

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or to develop an assistance system which guides the operator through the labyrinth of settings.

To overcome problem one, a specially adapted user guidance is necessary, to lead the operator through the amount of different variations within setup decision process for the several sensors. The best way to guide the user is a combination out of active and passive guidance which means, that the user is on the one hand actively lead to the right settings and on the other hand a large variety of additional information regarding optical surface measurement and its standardization is provided. To implement these help for the operators, first the state of the knowledge for typical users and their main problems had to be identified by a survey.

With the generated data, the following four main categories with problems have been identified, the interpretation of drawing specifications and definition of the measuring strategy, the preparation and realization of the measurements, the evaluation and interpretation of the measuring data and last but not least the acceptance tests and system calibration.

Out of this information two fundamental areas of responsibility for the assistance system could be identified. The first one is to guide the user to measurements which comply with the standardization, the second one is the contribution, with additional knowledge, to get more reproducible results by providing e.g. physical contexts for sensors.

The prototypical implementation of these relevant points has been done within a software package which supports measurement planning with confocal and white light interferometry microscopes. It consists out of measurement planning, calibration, evaluation and the database. Within these four categories, the data about the measuring object and the planned measurements including the parameters which should be evaluated. Based on them, the tool suggests the necessary calibration steps. The database module is used as storage for data about the available measuring systems and objectives with their assignment, last but not least for the standards for calibrating the systems. Within these four modules the operator is guided through the measurement planning and calibration process by leading him with questions about mandatory input. The decisions within the algorithms are felt based on physical correlations and the existing standards.

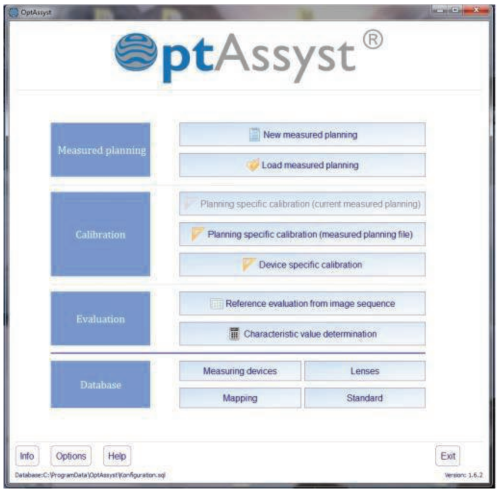

Fig. 1 Start Screen of protoypical software package

The result of the planning part is a suggestion for the system-objective combination and the necessary calibration steps for the measurement. Within the parameter evaluation tool, based on existing standards, the filter settings are suggested.

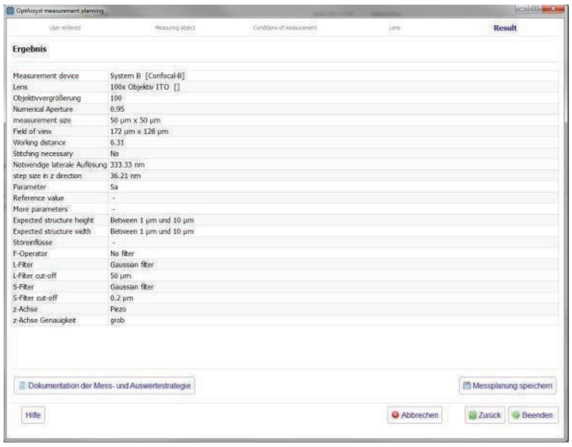

Fig. 2 Result of the measurement planning

As a passive assistance the demonstrator includes an extensive "Help"-part built up like the well-known help-files from e.g. office packages, so that it is easy to use for the operator. It contains information about how to use the system, why which inputs are necessary and hints to existing and relevant standards for surface measurements.

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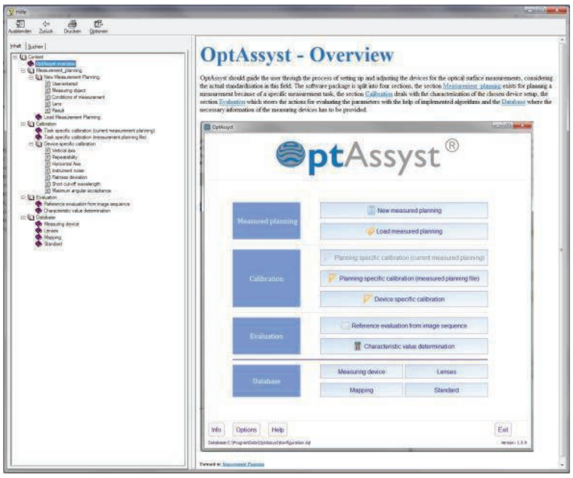

Fig. 3 Help-File structure of the prototypical software package

Exposure time

Another impact on the measuring value, which is not yet implemented in the prototypical software package, is the choice of the optimal exposure setting, which is necessary for getting the maximum of information about the measured surface. For getting the best information about the surface topography, it is ideally necessary to get from every point of the surface the perfect amount of light intensity in order to be able to generate a topography point. The perfect amount means, enough light to be able to detect it via CCD-Chip after it passed the optical path and not so much that the system gets an overexposure, the range of the detectable amount of light is limited by the dynamic range of the camera system and the used CCD-Chip.

For e.g. white light interferometry the adjustment of the light settings is easy for smooth and homogenous surfaces like mirrors or silicon chips. With rough inhomogeneous surfaces different difficulties accompany. First, different materials own various reflectivities. Second, rough surfaces contain areas with diverse inclination angles. Both issues lead to a wide range of reflected intensity, possibly broader than the dynamic range of the camera chip. Metallic surfaces rectangular to the optical path reflect very well, light from tilted surfaces is depending on the numerical aperture and the slope angle of the surface more or worse reflected into the optical path.

The result of this behaviour is an incomplete data set with areas where no surface points can be generated. This means a lack of information. Figure 4 shows such a dataset, measuring surface was a nail file out of diamond embedded in a nickel matrix. The metallic matrix reflects the light very well while the reflection of the rough diamond particles with steep flanks is very poor.

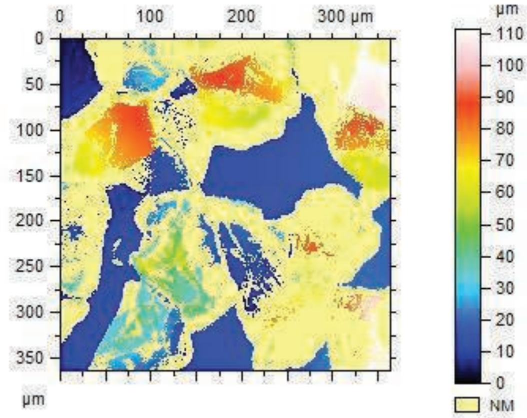

Fig. 4 Incomplete surface dataset of a nail fail with about 56 % not measured points (NM)

In order to gain information from surface areas with different reflectivities, wider than the dynamic range of the camera system, different shots with different light settings need to be done and merged to one common dataset [4]. Figure 5 shows a dataset which is merged with a commercial software package out of five single measurements. Nowadays commercial software already offers the merging of single datasets but they do not yet offer a possibility to use single point quality as a parameter during the merging process.

In order to get datasets with a high quality of the single points it is necessary to use only the points with best quality in the merged topography dataset. A procedure for qualifying and choosing the best points for the merged dataset, if z-height information exists in more than one single measurement, has to be developed.

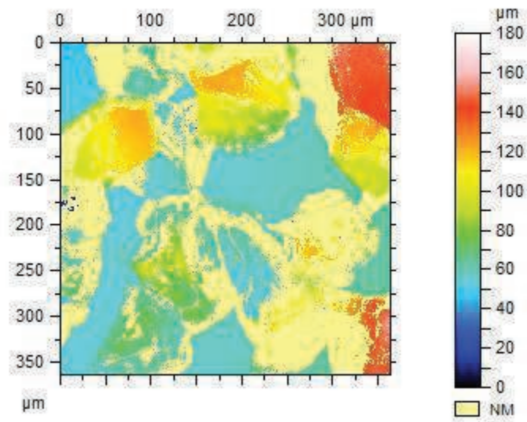

Fig. 5 Merged data set out of five different light settings with about 45 % not measured points

Figure 6 shows exemplarily the run of measured points for different settings. It shows

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for the used surface that it is more efficient to begin with a high exposure and to reduce it step by step for the different measurements. Otherwise a higher amount of measurements is needed to get the same result regarding the number of measured points.

The maximum possible benefit of information with this procedure depends on the characteristic of the surface which should be measured. But a benefit of about 30 % related to the maximum number of points for one shot is possible. Still problematic are steep mirroring flanks which reflect the light in different directions which may extend the acceptance angle of the used objective.

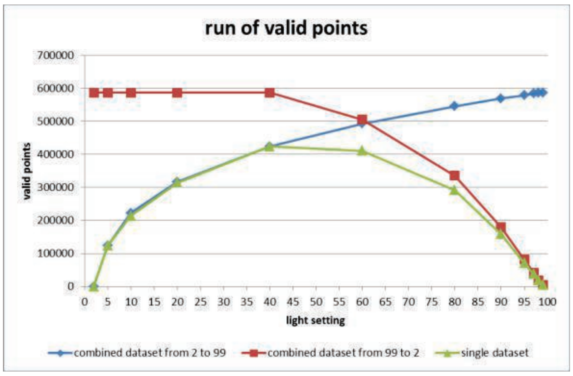

Fig. 6 Diagram run of valid points for a combined measurement out of measurements with different light settings

Single point quality

With the merged datasets, the number of captured points is increased, but the operator still does not know anything about the reliability of the single points within the dataset. The interaction of specimen and measuring system is at optical measurements more distinctive than at tactile surface measurements. To reach the goal of evaluating the uncertainty of each single point of areal optical surface measurements, the generation of the single topography point has to be investigated. The single point quality has to be divided into a lateral and a vertical quality component. The lateral component can be detected and corrected more easily than the vertical one. The lateral uncertainty component depends on the detector array, the objective and the calibration procedure. For white light interferometry, the correlation diagrams for the single pixels are built out of single pictures with interference pattern (fig. 7) which are recorded during the vertical scan of a surface.

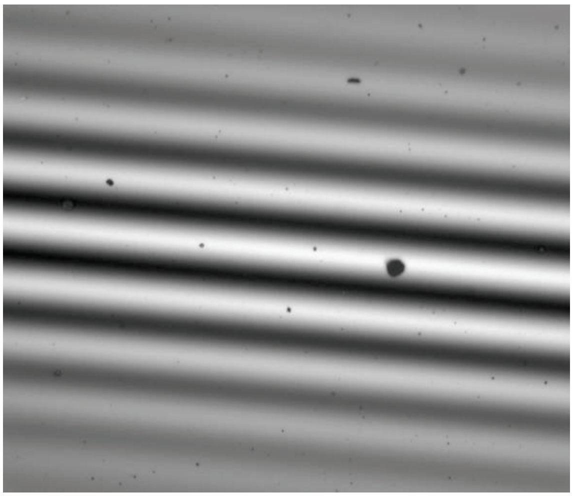

Fig. 7 Detected picture as part of an image stack with an interference pattern (specimen: mirror with little defects)

For evaluating the z-coordinate of the surface point out of the correlation diagram, different methods are well known [5]. These respond with different sensitivity to the shape of the diagrams. For rough surfaces, because of the unknown phase of the signal, the envelope is the best way to evaluate the height of the surface point.

Due to the cooperativeness of the local surface area, the correlation diagram is more or worse ideally shaped. Mirroring surfaces rectangular to the optical path generate nearly ideal diagrams (Fig. 8), however areas with steep diffuse reflecting behaviour (like the dark points in Fig. 7) lead to distorted diagrams (Fig. 9).

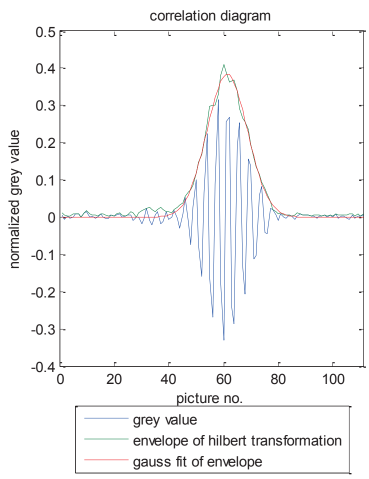

Fig. 8 Well shaped correlation diagram

This performance can be used for a first dividing of different qualities of surface points by checking the shape of each pixel's correlation diagram. To generate the z-value of the pixels for the correlation diagrams in figure 8 and 9 first the envelope of the signal has been built via Hilbert-transformation, for this envelope a Gaussian fit has been done.

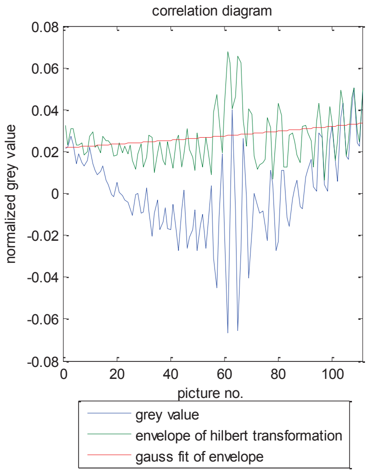

Fig. 9 Bad shaped correlation diagram

According to the quality of the raw signal it works better or worse, so that the parameters of the gauss fit, amplitude (related to the contrast) mean value (which is directly responsible for the z-value by pointing to a certain picture) and standard deviation (characterizing the width of the gauss fit). Higher amplitudes are indicators for higher quality. Mean values are only allowed within the range of the number of pictures, taken during the measurement. Standard deviation values far away from the half of the coherence length identify also bad values.

Summary and outlook

On the way to reliable areal optical surface measurements, three main points, regarding the quality of surface data sets have been processed. The knowledge base of the operators and its deficiencies has been evaluated and the structure of an active assistance system has been developed. Within this system, the passive operator assistance in terms of the help structure has been generated. The lack of information due to missing surface data points has been reduced by merging of several shots with different exposures. Different exposures were used to capture regions with various reflectivities. First studies for the evaluation of the z-value quality of topography points, which show, that there exist differences have been done.

Further work is needed to deepen the knowledge about the behaviour regarding the measurement uncertainty to be able to estimate the single point z-value uncertainty based on the quality studies.

Acknowledgement

The works in relation to the user assistance system have been carried out within the project OptAssyst, which was funded by the German Federal Ministry of Education and Research and hosted by the VDI-TZ (FKZ: 13N10384).

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