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Accuracy evaluation of an optical 3D profiler integrated on a machine tool adapted for laser micro-processing

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Abstract

The characterization of parts manufactured by laser technologies is usually carried out in lab conditions where traceability aspects are established and assured. Part conformity assessment is guaranteed by high accuracy non-contact coordinate measuring machines (CMM) that enable to measure geometric characteristics of produced samples with known uncertainties.

Although parts are commonly checked under controlled environments, more and more on machine/in-situ measuring requirements are being demanded by industry, to avoid the inefficiency of having to move the part from the machine to the laboratories and backwards. Therefore, similar measuring solutions for in-process characterization are meant to be more and more common, aiming to cover these new inspections and measuring needs. However, obtained results are far from traceable values because of a lack of standard procedures for uncertainty assessment in workshop conditions.

In order to analyze and cover this gap between lab and workshop environments, an optical 3D profiler has been integrated on a medium size machine tool adapted for laser micro-processing and developed a software to enable in-situ measurements. This software manages machine tool volumetric displacement, and optical measuring head movements which allows to easily characterize large parts through a simple graphical interface. Employing this functionality, the study is targeting to assess the accuracy of an on-machine based measuring solution for texturized parts. Aiming to quantitatively determine how accurate the manufacturing process is, calibrated artifacts from NPL will be used as well as other texturized surfaces characterized by offline means.

The difficulties arise from many tasks that have to be solved, such as measuring head mechanical and electrical integration, measuring head leveling, communication and synchronization between different systems, isolation of mechanical vibrations, etc. Preliminary results based on large areas are promising from the point of view of 3D surface composition and data continuity. In terms of accuracy, uncertainties of few µm are present in XY axis whereas Z-axis accuracy is in the nanometer range.

Accuracy, automation, calibration, in-process measurement

1. Introduction

The characterization of microparts manufactured by laser technologies is usually carried out in lab conditions where traceability aspects are established and assured. Part conformity assessment [1] is guaranteed by certified coordinate measuring machines (CMM) that enable to measure geometric characteristics of produced samples with known uncertainties. However, neither these devices are next to production machines nor in the same harsh environmental working conditions, which reduces manufacturing process efficiency in terms of cost and cycle time.

Nowadays a general trend is to bring measuring technologies to production lines and adding new measuring functionalities to specific processes and machine tools. This requires not only the physical integration of the measuring device but also an overall and simultaneous management of this device and machine tool controls. Therefore, external software libraries and applications are developed to deal with this goal. Apart from that, other challenges have to be overcome in order to obtain reliable data from this integration, such as sensor alignment, communication between systems, data handling, and processing, achievement of readable information, etc.

Although there exist multiple technologies [2] (confocal chromatic, interferometry, laser-triangulation, structured light, etc..) that cover different measuring needs, each technology has its proper performance and limitations that are not determined for workshop working environments. Therefore, this research targets to fill this gap based on imaging confocal measuring technique and to understand the barriers of this technology for in-situ measuring tasks. ISO-based artifacts and guides [3] will be used as a reference within this aim.

The following paper describes an in-situ hardware integration and software development of a 3D optical profiler on a laser manufacturing machine tool and its testing targeting to assess measuring uncertainty [4] on workshop environment.

2. Material & methods

The measuring sensor itself, called SMART©, is an independent measuring head managed by Sensoscan© software (core). This solution only covers the field of view (FOV) determined by each objective magnification which strongly limits measurable part dimensions and characteristics. Therefore, this measuring capability is combined with machine tool planar movement (in X & Y axes) so as to increase measurable range and enable to verify larger part geometries. The challenge arises from the point of view of system synchronization and data handling as two independent systems are required to be controlled. This goal is carried out by creating a custom application that controls both the SensoSCAN SMART© and the Machine tool simultaneously. The sensor is controlled through a Software Development Kit (SDK) provided by SensoSCAN, and the machine tool is commanded through an internally developed library which uses the Heidenhain DNC library to communicate with the machine automatically and remotely. The application, called "SensoDeckel" (see Figure 1) offers also a customized Graphical User Interface (GUI) to simplify the operation (see Figure 3).

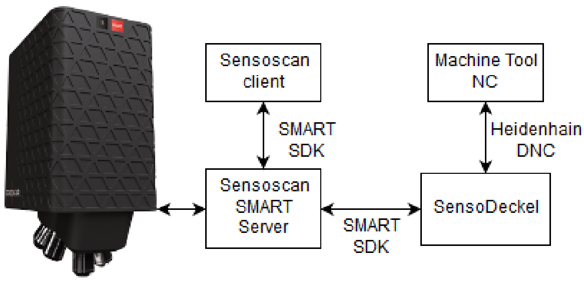


Figure 1. Employed software architecture (SensoDeckel)

The objective of our own application is to manage and launch the measurements, running and controlling XY displacement on the machine tool while handling the capture process on the SMART© sensor. For data visualization, analysis, objective calibration and measuring recipe preparation we still use the SensoSCAN integrated GUI.

2.1. Sensor integration

Sensor integration refers to both mechanical and electrical measuring head adaptation to work on a machine tool (see Figure 2). On the one hand, a fixture has been designed and manufactured to attach the sensor to the machine tool's head with leveling and alignment adjustments. On the other hand, a specific working cabinet has been designed and prepared to safely operate and connect the machine tool with the in-situ measuring system. The operation of the overall system is handled by our application (see Figure3). Moreover, after all the measurements have been carried out, the software determines an extended topography that represents the real surface topography. The 3D representation is shown in a 3D viewer with data analysis capabilities where geometric dimensions can be extracted.

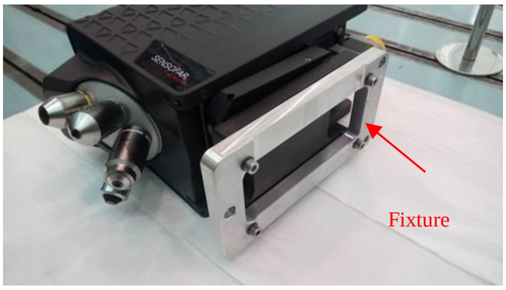


Figure 2. Mechanical fixture to mount and adjust the measuring head on the machine tool

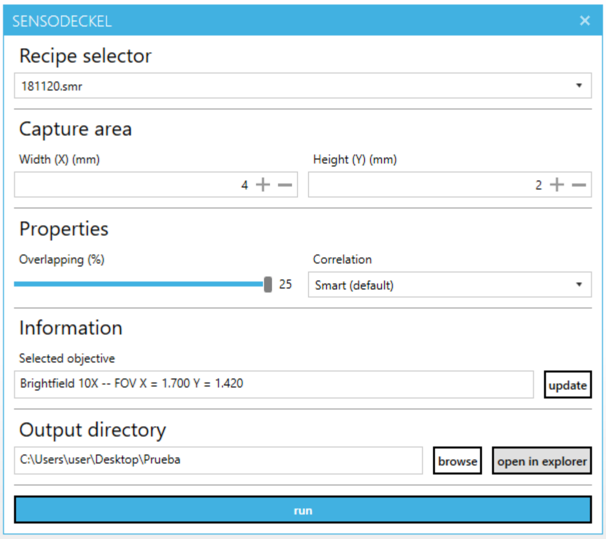


Figure 3. Proprietary Sensodeckel GUI for in-situ measuring management

2.2. Solution set-up

Once the sensor has been totally integrated and GUI's main functionalities have been tested, the in-situ measuring solution has been setup in terms of leveling and measuring parametrization which is directly related to measurand's material and dimensional properties. Although the measuring head offers several measuring techniques [5,6,7] (confocal, interferometry, focus-variation), the confocal technique is the most flexible one, considering the diversity of samples and surface finish. Therefore is has been the one tested and assessed from the point of view of accuracy performance.

Sensor leveling in relation to the working table where the part is positioned has been checked by a reference flat optical mirror assuring that the whole field of view is focused for different machine tool positions (see figure 4). Interferometry is meant to be more precise for this aim, but mechanical vibrations of the workshop have rendered this alternative unfeasible. Other alignment methods, based on image data, are also available, but the mentioned one has been considered good enough for solution testing and uncertainty assessment.

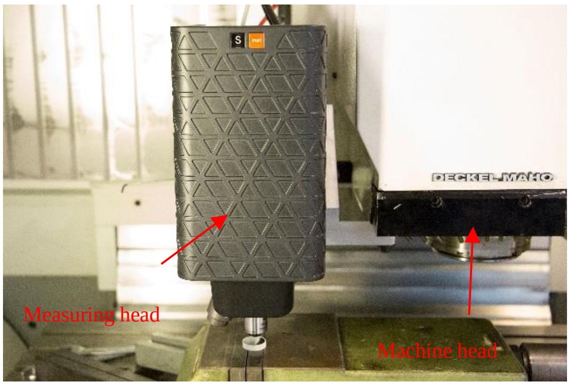


Figure 4. SMART sensor integrated on a Deckel machine tool

The measurement of each part depends on the initial fitting of measuring parameters and conditions, which are saved as an absolute measuring recipe. This procedure is executed afterward by the GUI which controls each partial measurement corresponding to objective's FOV and machine tool required positions to scan the defined surface area.

Machine operation also requires automatic moving protocols and communication to run autonomously all programs estimated for the whole measuring area.

3. Experimental testing

The characterization and system performance analysis has been established by means of Bentobox Areal Standards from NPL, which offer the possibility to determine quantitatively error sources of a topographic surface measurement.

These artifacts (see Figure5) allow users to calibrate the metrological characteristics of areal surface topography measuring instruments such as confocal or interferometric optical profilers. Moreover, they enable the adoption of good measurement practice guides from ISO standards for the determination of 3-D surface texture. Although these guides are thought to be applied in lab conditions, they can also be adapted and applied to workshop conditions.

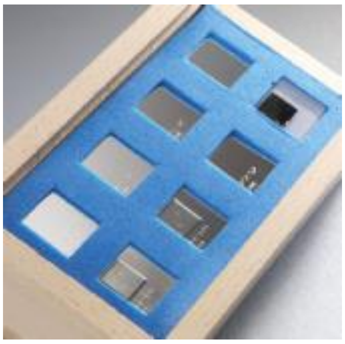


Figure 5. 3D areal calibration specimens

As a preliminary test for overall validation, a sample with a printed name (IK4-TEKNIKER) has been measured in order to check that the main functionalities of the solution run properly, and that the partial data stitching is feasible. After this preliminary test, some others based on known and calibrated geometries have been performed.

Initially, Areal Cross Grating (ACG) artifacts have been employed as they are calibrated for all axis, which enables to determine the accuracy for XYZ machine coordinates. In case of XY coordinates the pitch among some protrusions is known, whereas Z coordinate accuracy is defined by the depth of these geometries for the central motif. These artifacts depict structures with a 100µm pitch and 160µm pitch.

Table 1 summarizes the preliminary tests that have been carried out in order to assess achievable accuracy based on this integration.

Table 1 (note: larger tables can be set over 2 text columns)

Component		**Artifact**
Affecting accuracy for XYZ points	Uncertainty for X-axis (Ux)	ACG1.2 (100 µm pitch)
	Uncertainty for Y-axis (Uy)	ACG1.2 (100 µm pitch)
	Uncertainty for Z axis (Uz)	ACG 0.5/1.2/2.1 (160µm pitch)

The different structures of these artifacts have been measured 3 times to estimate the repeatability of the measurements (standard deviation) and mean values are used to estimate correction values in relation to calibrated reference values. Whereas XY uncertainty is extracted from extended topographies (2154x1650.55 µm), Z uncertainty assessment does not require machine tool multiple positioning. The measured field of view, in this case, is 877.20 x 660.48 µm. Uncertainty will be established by means of these result analysis and error propagation methods. The testing has been repeated for suitable magnifications and calibrated ranges in order to define the applicability of different lenses on machine metrology.

4. Results

The results are directly conditioned by sensor head alignment and leveling with machine tool head and table. Thus, this step is critical to assure a high accuracy performance of the developed measuring solution. Apart from sensor leveling that is controlled by focusing a surface with a low magnification objective, rotation of measuring head around its optical axis is critical. This rotation defines the parallelism of measuring head XY axis and machine tool ones. If this step is not properly set-up, subsequent measuring tests might be conditioned by this fitting.

As a preliminary test, a part with a printed name has been measured, the dimensions of which are bigger than the FOV provided by a 10x magnification objective. In fact, 12 partial measurements were carried out to measure and reach all the range corresponding to the desired surface. Preliminary results are promising from de point of view of data fusion (see figure6).

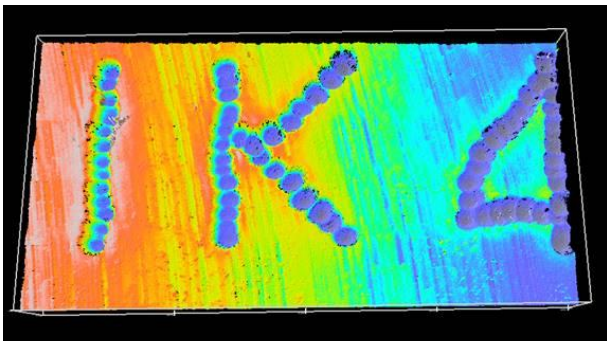


Figure 6. Name grabbed on the surface and measured by extended topography

The quantitative results for NPL artifacts are presented in Table 1 where corrections and repeatability for different control points and axis are presented. Data processing of measured structures (see Figure 7) has been carried out by means of SENSOSCAN© software and statistic analysis among calibrated values and measured ones.

The results show that the accuracy for XY axis is better than ±2.0 µm whereas Z axis is about tens on nanometers for 20X magnification lens. This lens offers a suitable compromise between measuring FOV and spatial resolution.

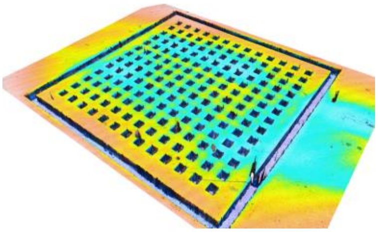
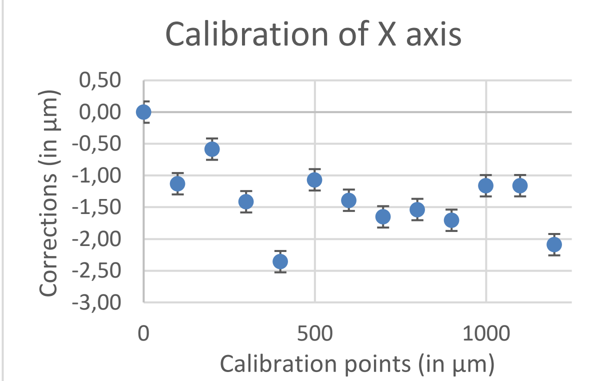


Figure 7. 3D areal calibration specimen topography



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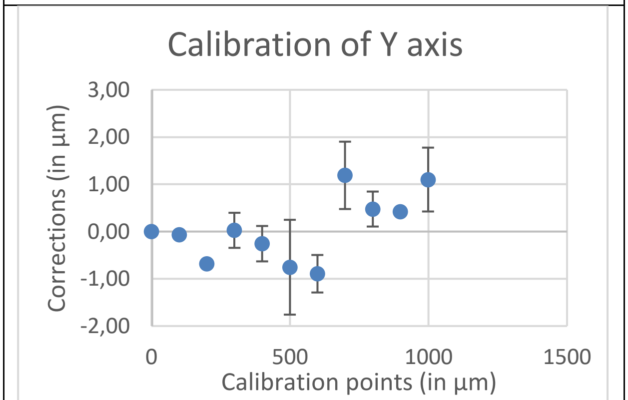

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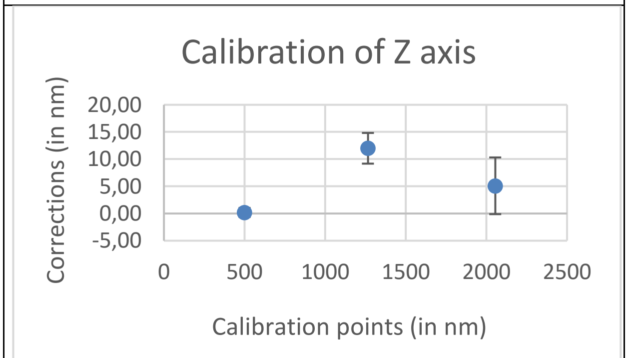

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Table 1. Calibration results for 20X magnification lens and ACG1.2 artifact

Apart from 20X magnification lens, a high magnification lens (150x) has been tested. However, in this case, measurements are not feasible due to mechanical perturbations of the workshop environment on the machine. In fact, this lens is very sensitive to mechanical vibrations and machine tool control loop (Z axis) instabilities. Therefore, is not suitable to workshop working conditions.

5. Conclusions

The paper describes an in-situ measuring solution for areal surface characteristic determination by means of an optical 3D profiler integrated on a laser-based machine tool.

The difficulties arise from many challenges that have to be solved, such as the mechanical and electrical integration of the measuring head, measuring head leveling and alignment, communication and synchronization between different systems, isolation of mechanical vibrations, definition of measuring procedures and recipes, etc.

Preliminary results based on large areas have shown promising from the point of view of 3D surface composition and data continuity. In relation to uncertainty assessment, the accuracy of 20X magnification lens has been characterized with ACG artifacts. The accuracy has been studied separately for each axis achieving deviations of few µm for XY directions and nanometric deviations for vertical (Z direction) axis. This characterization has been conducted by areal calibration artifacts which are recommended for lab equipment calibration.

References

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