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Technical note

Adjustment recommendations of a conoscopic holography sensor for a reliable scanning of surfaces with roughness grades obtained by different processes

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ABSTRACT

Conoscopic holography (CH) is a non-contact interferometric technique used in surface digitizing. Like other laser techniques it is influenced by different factors such as surface reflectance, material, colour or even speckle noise caused by roughness. In this work, a CH system was used for analysing the influence of roughness on surface digitizing. For this purpose, several digitizing tests were performed on roughness specimens corresponding to EDM, face milling and flat grinding processes. Each roughness grade was digitized under different combinations of the sensor setting parameters (frequency F and power P) which satisfy that the signal acquired by the sensor lies within the quality values recommended by the manufacturer. The results were analysed by using two indicators that show quality of the points captured by the sensor regarding the surface geometrical reconstruction and its metrological reliability. Finally, the study provides a series of recommendations for adjusting the sensor in order to satisfy both indicators simultaneously.

1. Introduction

Industrial use of commercial scanners like non-contact digitizing systems has grown significantly in recent years with a wide range of applications that go from dimensional metrology to reverse engineering [1–3]. Apart from avoiding contact with the object to be measured, the main advantages over contact systems are the ability to capture small geometries and complex shapes as well as the high speed for points acquisition. Additionally, the portability of non-contact systems offers the possibility to be installed on different equipment such as coordinate measuring machines (CMM), coordinate measuring arms, machine tools or production systems, which certainly favours its industrial application.

Despite the above advantages, commercial non-contact scanners are usually less accurate than the traditional contact-type methods, since their accuracy depends strongly on the relative position and orientation of the sensor with regard to the digitized part, the configuration parameters of the sensor, the part geometry, the optical properties of material, the surface roughness, etc.

Currently, there exist numerous non-contact techniques for surface digitizing, such as those based on triangulation laser which are more deeply analysed and disseminated every day [4–8]. However, the performance of other technologies has not been fully described yet. This is the case of conoscopic holography (CH).

CH is an interferometric technique based on the double refractive property of birefringent crystals. It was first described by Sirat and Psaltis [9] and patented by Optimet Optical Metrology LTD. When a polarized monochromatic light ray crosses the crystal, it is divided into two orthogonal polarizations, the ordinary and extraordinary rays, which travel at different speeds through the crystal. The speed of the ordinary ray is constant. However, the speed of the extraordinary ray depends on the angle of incidence. In order to make both rays interfere in the detector plane, two circular polarizers are placed before and after the crystal. The interference pattern obtained in the detector has a radial symmetry, so that all the information is contained in one radius. Therefore, given an appropriate calibration, it is possible to calculate the original distance to the light emitting point from the fundamental frequency of one of the signal rays.

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Malet and Sirat [10] stated that the performance of a conoscopic system can be described by the quartet of precision, depth of field, speed and transverse resolution. Furthermore, many advantages of CH in front of laser triangulation were reported by Sirat et al. [11]: better accuracy and repeatability (up to 10 times for a given depth of field), good behaviour for a wide variety of materials (even for translucent ones) and steep slope surfaces up to 85°. Another practical characteristic is that a single conoscopic sensor can be combined with different lenses to be adapted to various depths of field (0.6 mm up to 120 mm) with accuracy from less than 1 μm up to 60 μm, respectively. Finally, being a collinear system allows for accessing to complex geometries such as holes or narrow cavities, by using simple devices for light redirection. On the other hand, Álvarez et al. [12] presented several examples of industrial applications of CH systems, as well as the main characteristics to improve the results met by these systems in comparison with other scanning technologies, such as those based on triangulation laser.

All the advantages and characteristics aforementioned demonstrate the feasibility of CH systems for being applied to different fields of industry, including quality assessment, reverse engineering or in-process inspection. Nevertheless, CH digitizing quality may be affected by surface optical properties similarly to other optical techniques [13–17]. Lathrop et al. [18] applied CH technology for surface digitizing of biological tissues. In their work, the sensor main configuration parameters, power (P) and frequency (F), were adjusted to provide good quality measurements. Additionally, the signal-to-noise ratio (SNR) parameter, which is automatically provided by the sensor itself for every single measurement, was traditionally used as a quality criterion. Therefore, following recommendations by the manufacturer, a minimum of 50% SNR is demanded for high quality measurements. These authors also considered repeatability as a performance indicator. They found that the nature of surface material (colour, texture) has influence on digitizing quality. Consequently a specific adjustment of tuning parameters must take into account the surface characteristics.

The use of SNR as a quality indicator is well established in different works [19–21]. However, this is an indicator of signal quality, and it is not clear if the best SNR value (the maximum one) for a particular digitizing test provides the best results according to geometrical or dimensional criteria. Therefore, in those cases with high precision requirements, a geometrical type indicator should be used to ensure minimum errors in measurement.

In the present work a commercial-type CH system was used for analysing the influence of surface roughness on scanning quality. Several specimens with different roughness grades corresponding to different manufacturing processes were tested. The results were analysed by using two indicators that show quality of the points captured by the sensor from the point of view of the surface geometrical reconstruction and its metrological reliability. Finally, the study provides a series of recommendations for adjusting the sensor so that both indicators are satisfied simultaneously.

2. Characteristics of the conoscopic holography system

The work described in this study was performed by means of the conoscopic holography (CH) sensor Optimet Conoprobe Mark 10 equipped with a lens of 50 mm focal length and 8 mm of working range. The visible light source is a Class II laser diode which wavelength of 655 nm. This is a point-type sensor, thus each reading provides the value of the distance from the transmitter to the projection of the laser beam on the material surface (spot). Table 1 shows the main characteristics of the sensor [22].

Table 1
Characteristics of the conoscopic sensor Mark 10.

Property (lens 50 mm)	Value
Dimensions ($L \times W \times H$) (mm)	167 × 79 × 57
Weight (g)	720
Measuring frequency, F (Hz)	up to 9000
Power level, P*	0–63
Depth of field, DOF (mm)	8
Stand-off (mm)	44
Laser spot size (μm)	26
Static resolution (μm)	<0.1
Precision (μm)	6
Reproducibility 1σ (μm)	1
Angular coverage (°)	170

* Maximum power level (63) is equivalent to 1 mW.

2.1. Setting parameters of the conoscopic holography system

There are two main setting parameters in a CH sensor Conoprobe Mark 10:

- *Power level* (P) represents the value of the laser beam energy and can be set up in a range from 0 to 63.
- *Working frequency* (F) represents the data acquisition rate and can be set up to a maximum of 9000 Hz.

For a given frequency F, the value of power P has to be adjusted so that a proper amount of energy reaches the sensor. For a low level of P, the amount of light reflected off the surface that reaches the CCD may be insufficient and the quality of the measurement will drop. On the other hand, high values of P may yield a saturated signal, which indicates that the measurement values are not reliable.

Apart from these parameters, the CH systems commonly use two quality indicators:

- SNR (signal-to-noise ratio) for describing the quality of a digitized point-cloud. It is calculated by comparison of the peak power value used for the measurement to the whole signal power, which includes signal noise. SNR may range from 0% to 100% and it is commonly assumed that the higher the SNR, the higher the accuracy of measurement. Reliable values of SNR should be above 50%.
- *Total*, which is proportional to the area limited by the signal envelope and increases as signal intensity does. Acceptable values of *Total* should be between 1200 and 18,000 [22].

2.2. Integration of the conoscopic holography sensor on the CMM

In order to perform accurate sweeps of a surface, a CH sensor was integrated in a DEA Swift Coordinate Measuring Machine (CMM). The Maximum Permissible Linear Measuring Tolerance (MPE_E) and Maximum Permissible Probing Tolerance (MPE_P) of this CMM were certified as:

$$MPE_E = 4 + 4 \times 10^{-3} \times L \quad [\mu m], \quad \text{being } L \text{ in mm} \tag{1}$$

$$MPE_P = 4 \quad [\mu m] \tag{2}$$

This CMM is operated by means of the measurement and control software PC-DMIS. Volumetric reasons have led to install the sensor on the Y-axis of the CMM. This implies that the sensor can be displaced on a plane parallel to the X–Y reference system, but not in Z direction. In this work, only planar surfaces parallel to the X–Y plane were tested, thereby the sensor arrangement in the CMM has not become a constraint for the execution of tests.

Once the CH sensor is mounted in the CMM, it is necessary to perform a calibration procedure in order to know the coordinates of any digitized point with respect to the machine origin. The