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Measurement procedure for application of white light scanner in the automotive sector

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Abstract

Advanced optical metrology systems are continuously being developed to cope with the challenges arising from large-scale, high-quality production, especially in the automotive sector. Therefore, these measuring devices are relatively new and they are ruled by very general standards. The main goal of this work is to develop a specific procedure for a white light fringe projection optical measurement equipment from a general measurement system analysis procedure used in the automotive sector (MSA-4 Reference Manual) considering the recent international regulations for the verification of this type of equipments: Technical Recommendation VDI/VDE 2634 and ISO 10360-8: 2013. Only the tests applicable to the equipment used to validate the proposed procedure, a 3D white light structured scanner SIDIO Pro from Nub3d, were analyzed.

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Keywords: White-light optical equiment; measurement procedure

1. Introduction

The challenges arising from large-scale production and with high quality, the requirements of more advanced systems for the measurement of errors and the optical metrology systems, including those laser based, photography and white light fringe projection systems, are issues of great importance for industry nowadays. The scanning of

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three-dimensional objects has become a quality control procedure commonly used in industry, especially in the automotive sector, due to the high levels of precision and speed of capture needed.

Being such relatively new measuring equipments, users sure face with very general standards, which leads to discrepancies among evaluations of equipment from different manufacturers, given that it is possible that different interpretations are presented when defining which tests to perform for a particular equipment. On the other hand, the combination of different measurement equipments has unclear specific procedures.

For these reasons, the present paper will study one of the main documents related to the subject in the automotive sector, MSA-4 Reference Manual [1], and analyze possible correlations with other two much more specific documents: Technical Recommendation VDI/VDE 2634 [2] and ISO 10360-8:2013 [3], that could be applied to a 3D white light structured scanner SIDIO Pro from Nub3d. The main idea is to provide the automotive sector with a procedure that complies with the MSA-4 Reference manual and in turn the data obtained from the proposed tests can be used to comply with the international regulations after the data processing indicated in each of them. Although there are several published studies related to the research on the best way to evaluate this type of measurement instruments [4], we analyze the application of these standards and not their quality.

The SIDIO Pro equipment consists of a projector located in the central part of the equipment and a camera that is located to one side of the projector in an extensible part. This system, like all equipments on the SIDIO line, is equipped with TRIPLE software [5]. This software is designed with a simple user interface, which includes the most important functions for data capture and sensor control. In addition, it is compatible with different point cloud management and inspection programs such as Polyworks or Geomagic Qualify. See Fig. 1.

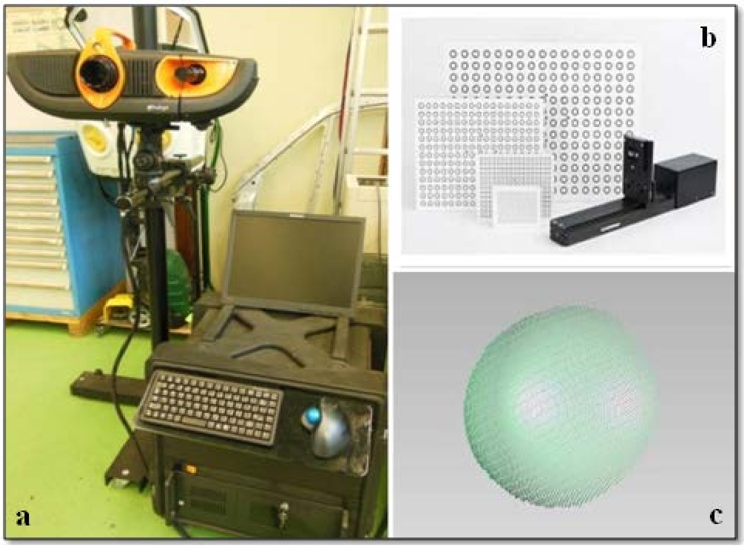

Fig. 1. (a) Photography of SIDIO Pro equipment; (b) Camera calibration equipment; (c) Point cloud example.

2. Normative analysis

This paper analyzes the following three documents in order to find the possible correlation between them, considering as base the first one, for a specific equipment:

- MSA-4 Reference Manual
- Technical Recommendation VDI/VDE 2634
- ISO 10360-8: 2013

The first one, MSA-4 Reference manual, was developed by the Measurement Systems Analysis Working Group (MSA), consisting of Chrysler Group LLC, Ford Motor Company and General Motors Corporation. Under the auspices of the Automotive Industry Shareholder Group (AIAG). Its purpose is to evaluate the quality of a measurement system where readings of each part can be replicated. Other available international reference manuals are the ISO 22514-7 [6] and the VDA 5 [7].

The procedures explained in the manual are very general so they can be used as a reference for very different environments to any measuring instrument, although its main objective is to be used in the industrial world.

The overall set of statistical procedures used for the above-mentioned evaluation is divided into four groups:

- Determination of stability
- Determination of bias
- Determination of linearity
- Determination of repeatability and reproducibility

Each one of these groups is used to determine a specific characteristic that allows an evaluation of one aspect of the quality of the measurement system.

It is important to mention that all procedures established by the MSA-4 Reference Manual are validated against the variability of the production process to be controlled, so that it is possible to ensure an adequate probability of detection of defective parts.

The other two documents share and represent a very different and specific point of view based on the metrological characterization of some optical devices.

The second one, technical recommendation VDI/VDE 2634, was developed by the technical committee of 3D measurement of the society of measurement and automatic control VDI/VDE and by the German association of photogrammetry and remote capture. Defines the parameters for the acceptance and re-verification tests of point-to-point measurements and surface measurements.

For that purpose, the technical recommendation VDI/VDE 2634 was divided into the following three parts:

- Part 1. Point-to-point measurement systems.
- Part 2. Optical systems based on scanning area.
- Part 3. Multiple vision systems based on scanning area.

In each of these parts, the concept "mode of operation" is defined as operation under certain external conditions and configuration. Such external adjustments and factors depend on the type of system being studied. In general some of the adjustments are the luminosity, measurement volume, type and number of sensors used. And some of the external factors are temperature, humidity, vibrations and dust.

In our case, the procedures applicable to the measurement equipment, corresponding to the second and third parts will be performed.

The second part takes into account a series of factors, digitizing errors, mechanical phase errors, pixel errors or coordinates, to proceed with the measurement. While the third part, in addition to the factors mentioned above, takes into account if the system is capable of transforming several captured images independently, in a common system of coordinates. The test error will be affected by two independent errors, firstly the error of the simple measurement in the volume of measurement, and secondly, the error due to the transformation of simple measures.

And the last one, ISO 10360-8: 2013, is applicable to Cartesian MMC (Machines and Coordinate Measurement) with an image probing system of any type, operating in the discrete point probing mode.

First, this standard establishes the operating conditions. Some environmental aspects are defined as well as operational conditions that influence the measurements at a time:

- Temperature
- Air humidity
- Cycles of ignition and heating of machine
- Cleaning procedures
- Qualification of the probing system before calibration

- Thermal stability of the probing system before calibration
- Lighting and environmental lighting system
- Location, type and number of thermal sensors
- Configuration of the probe by image and amplification
- Image Processing Filters and Algorithms

This part of ISO 10360 specifies the acceptance tests for verification of the MMC when measuring lengths indicated by the manufacturer. Verification tests are also specified to allow the user to periodically check the operation of the MMC.

The acceptance tests are executed according to the manufacturer's specifications and the verification tests according to those of the manufacturer and user, in our case, no restriction is imposed on the acceptance values, since the objective of this study is to analyze the standard, not the validity or not of the results of the measurements.

Then in *Table 1* we can see the summary of errors analyzed by VDI/VDE 2634 and ISO 10360-8: 2013 as well as the number of measurements required.

Table 1. Summary errors analyzed.

	VDI/VDE 2634-2	**VDI/VDE 2634-3**	**ISO 10360-8:2013**
	Spheres		
Errors evaluated	Diameter error	Form error Size error	Form error Scatter error Size error Global size error
Number of measurements required	10	15	1
	Lengths		
Errors evaluated	Space gap error	Space gap error Distance error quality parameter E	Length error
Number of measurements required	7	7	105
	Planes		
Errors evaluated	Flatness error	N/A	Flatness error
Number of measurements required	6	N/A	2

3. Proposed procedure

The procedure proposed in this paper is based on Manual MSA.4, which is a general document, but considering the recent international regulations for optical equipment of white light projection. It is important to emphasize that the main idea is to provide the automotive sector with a procedure that complies with the MSA-4 Reference manual and in turn the data obtained from the proposed tests can be used to comply with the international regulations after the data processing indicated in each of them.

The overall set of statistical procedures used in the MSA-4 Reference Manual is divided into four groups:

- Determination of stability: Control graphs
- Determination of bias: Independent sample method
- Determination of repeatability and reproducibility: ANOVA method
- Determination of linearity: Linearity graph

Each one of them determines a specific characteristic that allows to evaluate an aspect of the quality of the measurement system.

In all of them, the suggested method [1] was performed and the three main types of errors that deal with international standards, spheres, planes and lengths were analyzed, with the reference objects and orientations specified therein [2-3]. In other words, the proposed procedure follows the data processing indicated in the manual [1] and in order to comply with international regulations, it follows the indicated parameters (reference objects and orientations) in international regulations [2-3] for obtain the data.

Regarding the measurement error in spheres, the data will be related to the radius of the same. In the case of lengths errors will be referred to the distance between the centers of two spheres. And the one of planes is referred to the distance between the farthest point and the best adjusted plane of the cloud of points.

Determination of stability

In the three types of measurement errors analyzed, the corresponding reference object should be measured 12 times and the measurements should be represented in control charts. In the control chart X-bar (Averages), the 12 values are plotted. In the control chart R (Ranges), the 12 measurements will be divided into 4 subgroups and calculated the range of them so only 4 values are plotted.

Determination of bias

In the three types of measurement errors analyzed, the corresponding standard should be measured 10 times.

Determination of repeatability and reproducibility

The measurements made in the determination of the bias were used and afterwards repeated by another evaluator, obtaining the values of n=5 orientations, k=2 evaluators and r=2positions in the measurement area where it will be measured each orientation.

Determination of linearity

This test evaluates the difference in bias over the measuring range and that concept is only related with the length error measurement evaluated by ISO 10360-8:2013. For it, the reference object specified above was used and the ten measurements should be performed according to the orientations specified in the standard, plus three arbitrary ones.

4. Results

According to the main idea, to provide the automotive sector with a procedure that complies with the MSA-4 Reference manual and in turn the data obtained from the proposed tests can be also used to comply with the international regulations after the data processing indicated in each of them, the results of this proposed procedure, based on MSA-4 Reference manual, will be presented below.

It is important to remember that regarding the measurement error in spheres, data will be related to the radius. In the case of lengths, data will be referring to the distance between the centers of two spheres. And the one of planes is referred to the distance between the farthest point and the best adjusted plane of the cloud of points.

Determination of stability

According to MSA-4 Reference manual, in all three cases the measures are within the limits of control, therefore we can say that the measurement system is stable in this type of measures. *See Fig. 2, 3 and 4.*

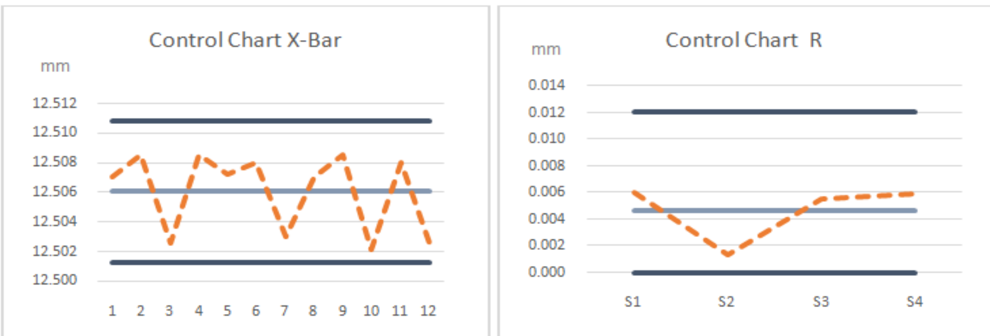

Fig. 2. Control Charts corresponding to spheres.

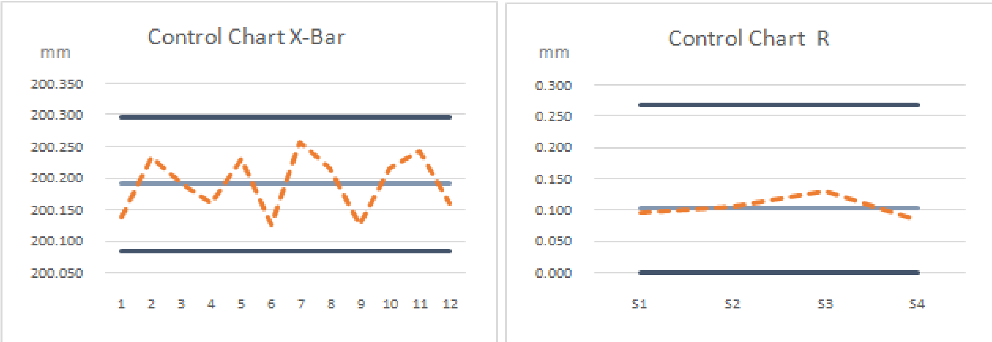

Fig. 3. Control Charts corresponding to lengths.

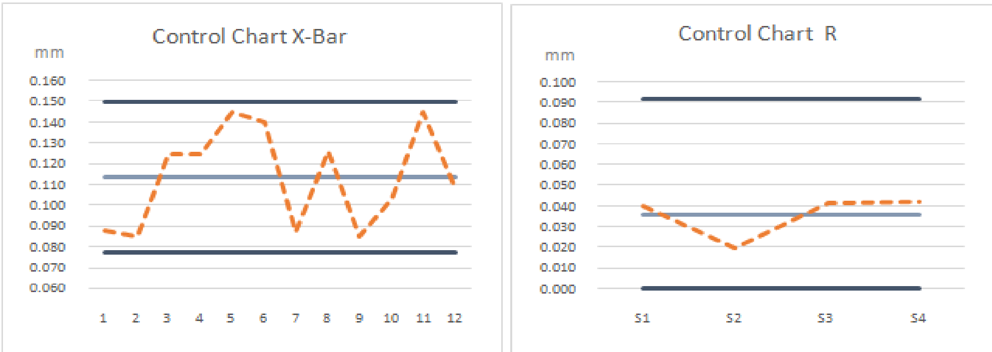

Fig. 4. Control Charts corresponding to planes.

At the same time, when using the standards and orientations set out in the regulations, this data and point cloud capture can be used for the calculation of ball measurement error established in VDI/VDE 2634-2 and ISO 10360-8: 2013, length measurement error set in VDI/VDE 2634-2 and VDI/VDE 2634-3, distance error quality E parameter set in VDI/VDE 2634-3 and flatness measurement error set in VDI/VDE 2634- 2 and ISO 10360-8: 2013. It should be taken into account that they must go through the data processing flow established in each document.

<u>Determination of bias</u>

For the evaluation of this parameter the same data as the determination of stability were used, ten of them. According to the MSA-4 manual, a bias value can be accepted if, when performing the verification calculation (contrast test of null bias hypothesis), the value zero is within the calculated range. As it is possible to appreciate in the test tables, only in the case of the spheres we can say that the presented bias is acceptable. *See Table 2, 3 and 4.*

Table 2. Testing table for the determination of bias corresponding to spheres

Testing		
-0.0044	< 0 <	0.0070

Table 3. Testing table for the determination of bias corresponding to lengths

Testing		
0.0856	< 0 <	0.1311

Table 4. Testing table for the determination of bias corresponding to planes

Testing		
0.0856	< 0 <	0.1311

Determination of repeatability and reproducibility

For this parameter the same data are used as the determination of the bias and then the same measurements were repeated by another evaluator, obtaining the values of n=5 orientations, k=2 evaluators and r=2 spaces in the measurement area where each orientation was measured.

And as indicated in the MSA-4 reference manual, it is possible to appreciate in the three graphs that the lines corresponding to the measurements of the two evaluators are relatively parallel, so we can conclude that the interaction is not significant. See Fig. 5, 6 and 7.

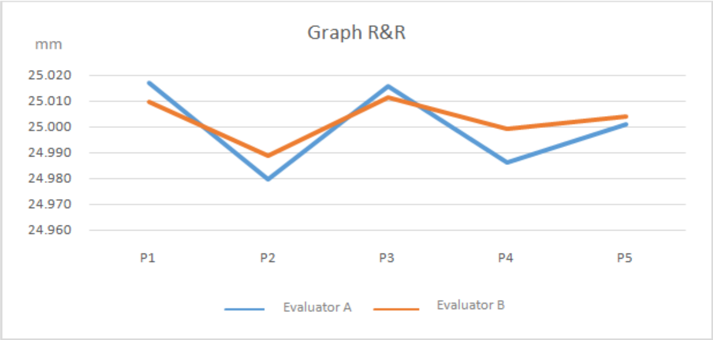

Fig. 5. Repeatability and reproducibility chart corresponding to spheres.

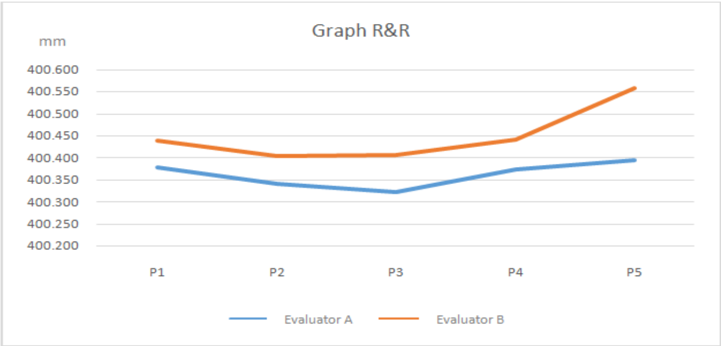

Fig. 6. Repeatability and reproducibility chart corresponding to lengths.

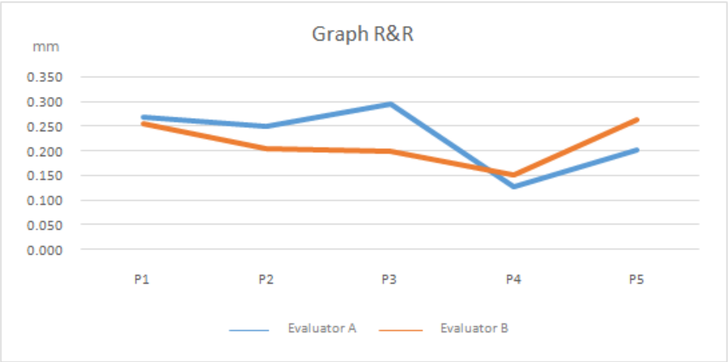

Fig. 7. Repeatability and reproducibility chart corresponding to planes

Determination of linearity

As indicated in the MSA-4 reference manual, the adjusted graph is very similar to the "Bias 0" line, so we can conclude that the equipment complies with linearity in this type of measurements. *See Fig. 8.*

Evaluating the linearity according to MSA-4 but considering the standards and orientations established in ISO 10360-8: 2013, it is also possible to use the same data for the calculation of the length error.

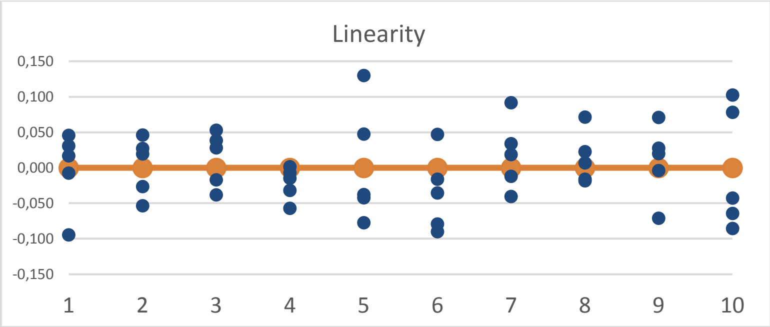

Fig. 8. Linearity graph for lengths.

5. Conclusions

In the results we could observe an example of the application of the proposed procedure based on the MSA-4 reference manual having also taken into account the parameters indicated in the international regulations (VDI/VDE 2634 and ISO 10360-8:2013) for the obtaining of the data. It may be concluded that it is possible to use the same data to comply the standards to a great extent.

It is also possible to conclude that when applying the proposed procedure, the technical recommendation VDI/VDE 2634-2 is fully complied with. In the case of VDI/VDE 2634-3 is only necessary to carry out the additional measurements corresponding to the sphere error measurement. Conversely, when we have the data of the tests carried out according to the technical recommendation VDI/VDE 2634-2, it is necessary to include additional measures, three in the case of lengths and five for the planes, to evaluate stability and bias according to MSA-4.

In the case of ISO 10360-8:2013, enough data are available to perform the data processing corresponding to the error related to spheres and planes. In turn, if two repetitions of the proposed procedure in the determination of linearity are made, sufficient data would be available to calculate the error related to lengths and thus fully comply with the ISO norm. Conversely, having the calibration report based on the ISO standard would only provide sufficient data to perform the linearity determination.

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