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Performance evaluation of optical scanner based on blue LED structured light

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Abstract

Non-contact 3D digitizing scanners based in structured light projection are increasingly more accurate, fastest and affordable. The purpose of this work was to determine the quality, accuracy and traceability of the data provided by new LED technology scanner of structured light Comet L3D (Steinbichler) acquired by the Department. Calibration of the equipment and accuracy analysis was carried out with a calibration plate and a number of gauge blocks of different sizes. The accuracy range of the scanner has been established through multiple digitizations showing the dependence on influential factors such as the characteristics of the object and scanning procedure. Although many factors influence, accuracies announced by manufacturer have been achieved under optimal conditions and it has been noted that the quality of the point clouds (density, noise, dispersion of points) provided by Comet L3D system is higher than that obtained with laser technology devices.

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1. Introduction

Non-contact 3D digitizing techniques constantly evolve and scanners based in laser triangulation or those that use structured light projection are increasingly more accurate, flexible and affordable, letting enlarge its usage in industry. Although they do not still have the accuracy of the coordinates measuring machines (CMM), structured

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light scanners are very fast and accurate, reaching centesimal details under optimal conditions.

Ramos and Santos (2011) or Mahmud et al (2011) have analyzed and compared the methodologies and precisions obtained with non-contact measurement systems showing its high sensitivity to various external factors inherent to the measurement process or the optical characteristics of the object.

However, for the case of non-contact scanning systems and because of the complexity of the evaluation of the errors that occur during the process, there is no reliable standardized method for evaluating the measurement uncertainty as described in the ISO/TS 14253-2: 1999 and ISO/IEC Guide 98-3: 2008.

It is difficult to establish criteria for evaluating the performance of these equipment. ISO 10360-7: 2011, still in development, studies CMM machines with optical heads. However there is currently no specific rule for the case of laser scanners, fringe projection systems or structured light systems.

Non-contact 3D digitizing systems are mostly used in the field of reverse engineering, in which numerical models are reconstructed from clouds of points, as described by Sansoni (2004) or Bradley (2005). They are also used in pattern recognition of machine vision applications, online measurement systems and dimensional control systems. With these systems the coordinates of a large number of points can be obtained in a few seconds, but they require further treatment as they form discrete images of objects.

To use this geometric data, point clouds must be processed using specific applications requiring a reverse engineering process to identify the geometric elements of the parts to be measured. Fig. 1 schematically shows the point clouds processing from the initial stages of the discretization to the generation of the numerical model.

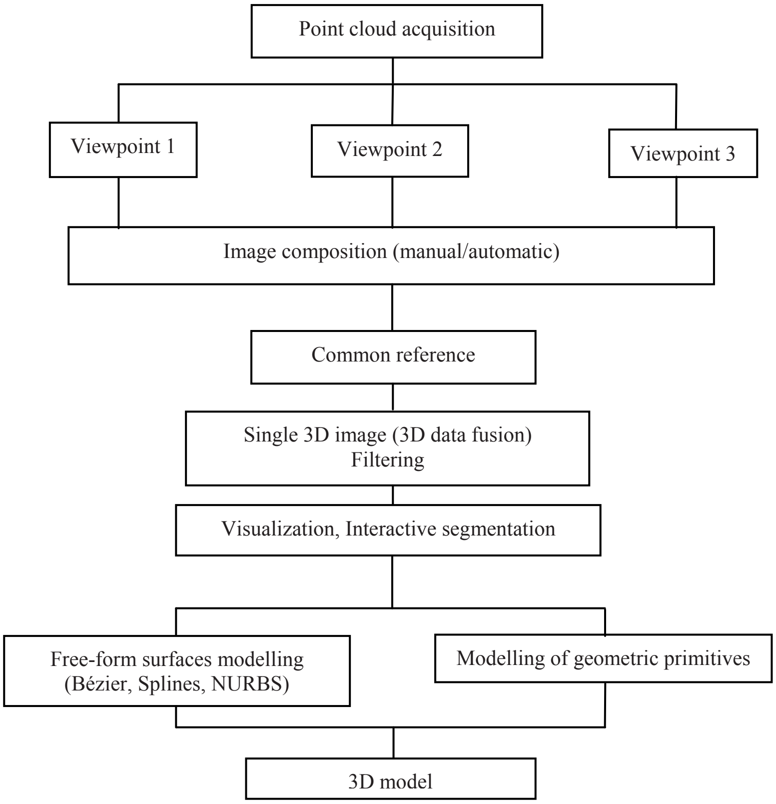


Fig. 1. Synthesis of the point clouds processing

In some cases the points obtained are ordered by parallel planes. However, points obtained by many laser scanners or structured light scanners are disordered (set of n points unrelated) and may describe all or part of the object surface. Depending on the part geometry and direction of the scanning, shaded areas and disconnected regions may be obtained. To get a complete picture of the object it is necessary to change point of view, take a new image and merge the different images into a single data file.

Subsequently filtering operations, structuring or interactive segmentation of the point clouds must be carried out. The last step is to make approximations of the point clouds, either by free-form shapes as complex surfaces or by canonical forms in order to obtain a numerical model of the object.

2. Scanner calibration

In order to assess the accuracy of the scanner Comet L3D (Fig. 2 (a)) a calibration process is performed by digitizing a number of gauge blocks whose uncertainty can be considered negligible compared to uncertainty of the equipment.

The measuring faces of gauge blocks have been modelled from the cloud of points in order to compare the distances between faces with nominal values. To obtain the numerical model, in our case the planes corresponding to the block faces, a series of operations are required as described in Fig. 1. The process has a number of intrinsic measurement errors that arise both in the instrument itself and in the processing of point clouds.

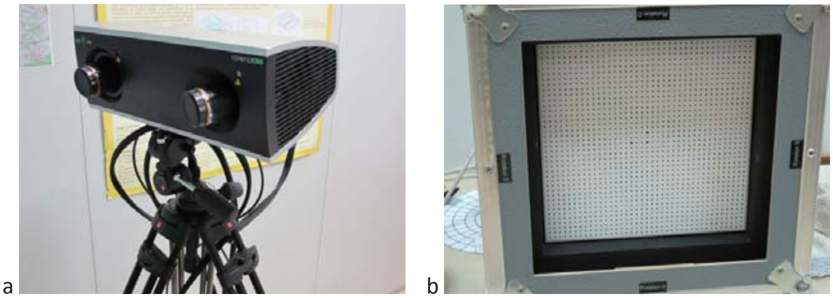


Fig. 2. (a) Comet L3D sensor; (b) calibration plate

2.1. Intrinsic error data acquisition

Initially it is necessary to perform a calibration of the device using a calibration plate supplied by the manufacturer. For this purpose it is necessary to scan at standard conditions, a planar calibrated card with circular targets located in a uniform grid of 5 mm (Fig. 2 (b)). This plate has a calibration certificate, ensuring traceability.

If the measurement of the calibration plate is within the range specified by the manufacturer (< 8µm), it is possible to start working with the Comet L3D scanner. This accuracy value corresponds to the maximum accuracy in data acquisition. However other errors from various sources are introduced during the digitization process. The most common errors are due to:

- The temperature increase during operation of the scanner (light source, internal processor) may alter the measurement due to variation of distance between the transmitter and the CCD sensor affecting the triangulation process.
- Vibrations, specular reflections or optical characteristics of the measured object (color, brightness) can generate erroneous digitized points.

2.2. Errors caused by the composition of images

In most cases, the digitization of an object requires several images from various angles. The merging of images is obtained by overlapping common edges of each digitization. This process is called image composition and is performed defining the relative position of the views with respect to a common origin.

This is done by identifying characteristic features on each image as corners, edges or objects that are matched and calibrated by correspondence, to obtain the rigid transformation (translation + rotation) that permit to switch from one reference to another. Subsequently, data fusion can be performed by grouping all points in a single file. This operation is usually accompanied by a systematic or selective filtering of points depending on the amount of local information (overlapping areas).

Generally, the acquisition of points introduces distortions in the lateral areas of the image, making difficult a good concatenation of the views. To correct this, point acquisition systems optimize geometric transformations to move from one point of view to another, minimizing errors. For this purpose it is defined, for a given displacement (R, T) consisting of a rotation and a translation, the distance between a point X_1 on the S_1 surface and the surface S_2.

This distance should be the minimum distance between X_1 and all the points of S_2, as expressed in Eq.1 :

$$d(X_1, S_2) = \min_{X_2 \in S_2} d(X_1, X_2) \tag{1}$$

After rigid transformation X_1 can be written as ($R\ X_1 + T$). A minimization criterion is expressed by the following expression (Eq. 2):

$$d_{R,T}(X_1, S_2) = \min_{X_2 \in S_2} \left\| RX_1 + T - X_2 \right\| \tag{2}$$

This expression can be minimized by an ICP algorithm (Iterative Closest Point) described by Besl et al (1992) and Greespan (2001). Defining D the set of data points of the surface S_1 and M the set of points of the model or surface S_2, this method establish a matching of D and M points. Thus for each point of D there is a point (the nearest) of the model M. By the correspondence established above, the transformation that minimizes the distance criterion is calculated and applied to the points of the set D and the overall error is calculated using least squares method. An iterative process allows optimal adjustment of the images and the evaluation of the error. In our case, the image composition of 3-4 digitizing views of gauge blocks is done by the software of the Comet L3D with errors varying between 8 and15 μm.

2.3. Approximation of point clouds by geometric primitives

To perform the calibration process using gauge blocks it is necessary to know the distance between the flat faces of the numerical model (measuring faces). The first step is the segmentation of the cloud of points and the extraction of the points corresponding to the flat faces of the block. These points are not strictly contained in a plane due to the inherent errors or the measurement noise, and must be approximated.

With the least squares method it is possible to find the best set of parameters that minimizes the sum of the squares of the errors of the approximation of the plane. In general, the objective function J to minimize can be written by the expression (Eq. 3):

$$J = \sum_{i=1}^{n} \left[\frac{d(X_i, S)}{\sigma_i} \right]^2 \tag{3}$$

where:

S is the approximation surface,

X_i the measuring points,

$d(X_i,S)$ the minimum distance from X_i to S, and

σ_i the standard deviation of measurement noise associated with each point X_i.

When the measurement noise is unknown or difficult to evaluate, it is considered to affect each point with the same intensity and therefore produces the same standard deviation for each measuring point. Putting the term $1/\sigma_i$ in common factor it has no influence on the result of minimization and the above expression can be expressed as (Eq. 4):

$$J = \sum_{i=1}^{n} \left[d(X_i, S) \right]^2 \tag{4}$$

This problem is solved by using Lagrange multipliers under a constrained minimization approach, as detailed by Goulette (1999). With the cloud of points and the resulting approximated plane it is possible to evaluate maximum and minimum deviations and standard deviation of the measured points. Reverse engineering software and specific treatment programs are able to analyze quality of the approximation. CATIA V5 surface reconstruction modules and INSPECT + software of Steinbichler have been used for this work.

3. Methodology

In order to assess the accuracy of the equipment, four steel gauge blocks of 60, 50, 30 and 25 mm adapted to the volume provided by the 100 mm scanner lens with a measuring volume of 75 mm x 60 mm have been digitized. The complete process is considered, covering both data acquisition and subsequent processing. A white opaque adhesive tape of 60 µm thick is applied on the measuring faces in order to eliminate noise during scanning, due to the mirror-finishing of the blocks. Initially, measurements were made by applying a specific white powder spray on the blocks, discarding this method because of the inability to control the thickness and uniformity of the coating layer.

Two gauge blocks (grade 2) of 25 and 30 mm have been measured in a TESA VISIO profile projector with a measurement uncertainty of $L/40$ µm (L in mm) to assess the uncertainty due to the coating of the blocks. The measurements of coated blocks are made in various sections with results shown in Table 1.

Table 1. Measures of the tape over-thickness on 25and 30 mm gauge blocks

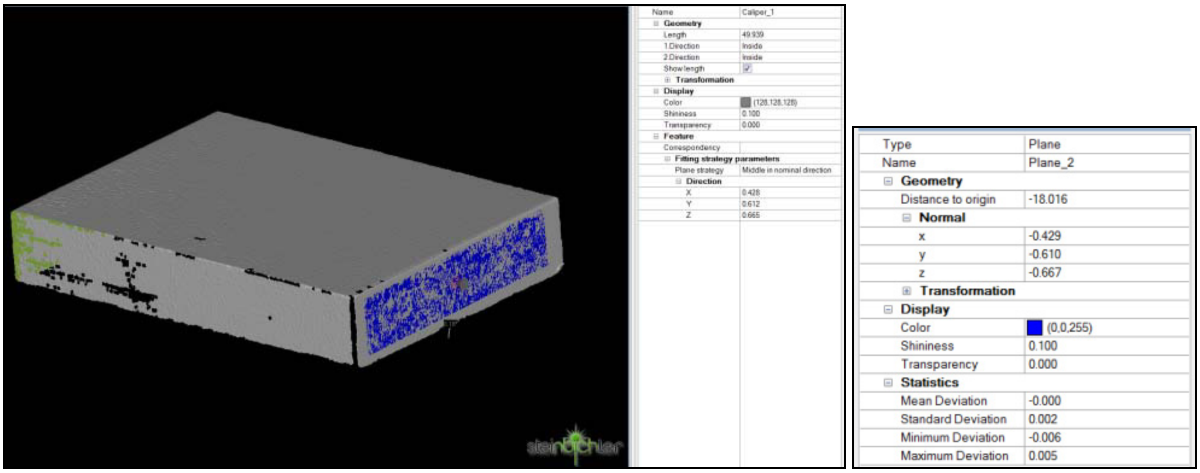
Measure	1	2	3	4	5	6	7	8
Block 25	25,107	25,104	25,116	25,111	25,110	25,108	25,107	25,115
Block 30	30,094	30,113	30,113	30,107	30,103	30,098	30,101	30,106

The measurements obtained show that the average thickness of the tape, once applied, are 54 µm ($\sigma = 0.004$) and 52 µm ($\sigma = 0.006$) for the blocks of 25 and 30 mm respectively. It is considered a value of tape thickness of 53 µm for the measurement of gauge blocks of 60, 50, 30 and 25 mm.

Five complete measurements were made for each gauge block. For each measurement, at least six shots from different viewpoints were required in order to not exceed 15 µm of error in the composition of the images.

Then the point clouds have been approximated by planes to check the nominal dimensions of the blocks. Fig. 3

shows the approximation of the measuring plane and the error and standard deviation calculated by the program of Steinbichler Inspect +.

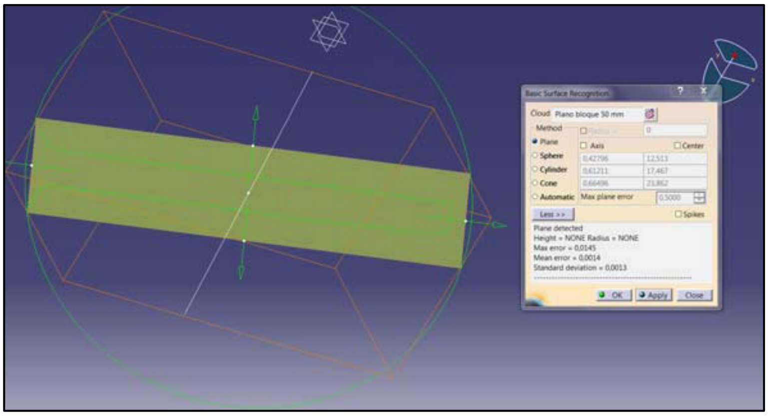


Name	Caliper_1
Geometry	
Length	49.939
1.Direction	Inside
2.Direction	Inside
Show length	☑
Transformation	
Display	
Color	(128,128,128)
Shininess	0.100
Transparency	0.000
Feature	
Correspondency	
Fitting strategy parameters	
Plane strategy	Middle in nominal direction
Direction	
X	0.428
Y	0.612
Z	0.665

Type	Plane
Name	Plane_2
Geometry	
Distance to origin	-18.016
Normal	
x	-0.429
y	-0.610
z	-0.667
Transformation	
Display	
Color	(0,0,255)
Shininess	0.100
Transparency	0.000
Statistics	
Mean Deviation	-0.000
Standard Deviation	0.002
Minimum Deviation	-0.006
Maximum Deviation	0.005

Fig. 3. Plane approximation for measurement of 50 mm gauge block with Inspect+

The 50 mm gauge block was also approximated with Catia V5 and evaluation of the distances between planes was performed, obtaining similar results (Fig. 4).



Cloud: Plano bloque 50 mm

Method: ● Plane ○ Sphere ○ Cylinder ○ Cone ○ Automatic

☐ Axis ☐ Center

0,42796	12,513
0,61211	17,467
0,66496	23,862

Max plane error: 0,5000

☐ Spikes

```
Plane detected
Height = NONE Radius = NONE
Max error = 0,0145
Mean error = 0,0014
Standard deviation = 0,0013
```

Fig. 4. Approximation of planes with Catia V5 (50 mm gauge block)

4. Results

The results of measurements show that point clouds obtained have an average resolution of 80 μm. This resolution corresponds to the average of the minimum distances between points. It is based on the resolution of the camera sensor, which in the case of Comet L3D is $1{,}92.10^6$ pixels (1600 x 1200), being greater than the resolution provided by laser systems. The equipment analyzed provides uniform distances between points allowing obtain good quality meshes.

The nominal size of gauge blocks is increased by 106 μm due to 53 μm thick tape adhered on each side of measurement. It is noteworthy that in all measurements the errors introduced by plane approximation do not exceed 10 µm. However, it has been found that due to the composition of the various images, angular errors produces defects of parallelism between the planes of the measuring faces. The accuracies obtained are consistent with the specifications provided by the equipment manufacturer (50 µm), but there is variability in results, as detailed in the following tables.

Table 2. 60 mm gauge block

	Room T ºC		**Sensor T ºC**		**Number of views**	**Scanner measures**			
	start	**end**	**start**	**end**		**Max.**	**Min.**	**Mean**	**Δ (µm)**
Measure 1	19,6	19,7	27,5	30,0	7	60,146	60,104	60,125	19
Measure 2	19,7	19,9	30,5	31,5	7	60,320	60,230	60,275	169
Measure 3	19,9	20,0	31,5	31,8	7	60,129	60,045	60,087	-19
Measure 4	20,0	20,1	31,8	31,8	8	60,373	60,040	60,207	101
Measure 5	20,1	20,2	31,8	31,8	7	60,163	60,023	60,093	-13
						Mean value		X=60,157	51
						Standard deviation		σ =0,081	

Table 3. 50 mm gauge block

	Room T ºC		**Sensor T ºC**		**Number of views**	**Scanner measures**			
	start	**end**	**start**	**end**		**Max.**	**Min.**	**Mean**	**Δ (µm)**
Measure 1	17,6	18,0	28,3	29,5	7	49,964	49,913	49,939	-167
Measure 2	18,0	18,2	29,5	30,0	7	49,952	49,893	49,922	-184
Measure 3	18,5	18,4	27,5	29,5	7	50,297	44,621	49,959	-147
Measure 4	18,4	18,9	29,5	30,5	7	50,554	50,209	50,382	276
Measure 5	19,0	18,4	30,8	31,3	7	50,694	49,556	50,125	19
						Mean value		X=50,065	-41
						Standard deviation		σ = 0,174	

Table 4. 30 mm gauge block

	Room T ºC		**Sensor T ºC**		**Number of views**	**Scanner measures**			
	start	**end**	**start**	**end**		**Max.**	**Min.**	**Mean**	**Δ (µm)**
Measure 1	21,0	21,1	31,8	32,3	6	30,275	29,997	30,136	30
Measure 2	20,6	21,0	28,2	32,3	7	30,126	30,116	30,121	15
Measure 3	21,0	21,1	27,5	32,3	7	30,124	30,098	30,111	5
Measure 4	21,2	21,2	28,0	32,3	7	30,183	30,137	30,160	54
Measure 5	19,2	19,8	28,0	31,0	7	30,152	30,115	30,134	28
Measure 6	20,0	20,4	27,5	31,8	7	30,281	30,191	30,236	130
Measure 7	20,4	20,7	32,0	32,5	7	30,239	30,095	30,167	61
						Mean value		X=30,152	46
						Standard deviation		σ=0,042	

Table 5. 25 mm gauge block

	Room T ºC		Sensor T ºC		Number of views	Scanner measures			
	start	end	start	end		Max.	Min.	Mean	Δ (μm)
Measure 1	19,1	19,5	29,0	30,8	7	25,251	25,141	25,196	90
Measure 2	19,6	20,0	31,3	31,8	6	25,493	24,751	25,122	16
Measure 3	20,0	20,0	31,8	31,8	7	25,454	25,068	25,261	155
Measure 4	19,0	20,3	27,5	31,8	7	25,169	25,130	25,149	43
Measure 5	20,4	20,4	32,0	32,5	6	25,120	25,086	25,103	-3
						Mean value		X=25,166	60
						Standard deviation		σ =0,063	

5. Conclusions

The non-contact digitizing systems evolve rapidly and become more affordable, allowing the acquisition of a large amount of 3D points of the object geometry in a very short time. However, in most applications, especially in the field of metrology and reverse engineering a subsequent computer processing of the data is required.

The tests performed with the scanner Comet L3D reveal that certain errors are generated at various stages of the measurement process. This explains why, even though the scanner accuracies announced by manufacturer (50 μm) are achieved, there is some variability in results.

The processing errors are due to various factors as the orientation and number of views that influence the quality of the approximation. A reduced number of views decrease the amount of errors but increase image composition distortions at the edges of each image. The filtering processes and the noise reduction of digitized geometries have influence in the subsequent approximations.

Moreover, the optical and geometrical characteristics of the object and environmental conditions influence the results and skills and experience of the operator are important to ensure correct processing of the data captured by the device.

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