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Influence of Ambient Light on the Quality of Laser Digitized Surfaces

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***Abstract*— Laser triangulation systems allow for non-contact, accurate and fast digitizing of surfaces. The quality of the digitized surface depends on many factors. Some, like laser emission wavelength, are characteristics of the system. Other factors, like part surface quality are external to the system. Laser triangulation systems project a laser beam onto the surface of the workpiece, so that an image of this projection is captured in a photo-sensor. This image is processed using triangulation techniques to calculate the spatial position of every point on the projection. The sensor does not only capture the light projected by the laser, but also captures the ambient light emitted in the same wavelength of the laser beam. Since calculation of points positions depends on the image characteristics, ambient light becomes a potential error source. The present work evaluates the influence of ambient light on the results of the scanning process. A methodology for testing different light sources under the same digitizing conditions has been developed. Three different criteria have been used to analyze the quality of the point cloud: the number of captured points, the average dispersion of the test point cloud with respect to a reference point cloud, and the distribution of such geometric dispersion across the whole surface.**

***Index Terms*— Laser triangulation, digitizing, influence of ambient light.**

I. Introduction

Laser triangulation (LT) systems are used for inspection and reverse engineering of surfaces. Their characteristics make them suitable when accurate and fast non-contact scanning is needed.

In most LT systems, the projection of a laser beam onto a surface is captured as an image in a charged coupled device (CCD). Applying image processing techniques and the triangulation principle, 3D coordinates of the surface points are acquired (Fig.1). If the distance between a particular point *P* and the CCD matches exactly the value of the reference distance (stand-off), its image in the CCD will be placed exactly in a reference point *P'*. Otherwise, if the point onto the surface were further away a distance *H* in the direction of the laser beam, its image on the CCD will be placed a distance *h* from the reference point. As the geometry of the laser system is completely known, it is possible to determine the spatial position of every single point from its image position on the sensor [1].

In order to digitize a part, a relative movement between the laser system and the part surface is needed, so that the laser beam projection sweeps the target surface. This results on a set of digitized points (point cloud) that represents the surface of the part. Usually, LT systems are installed on a coordinate measured machine (CMM) that provides precise and controlled displacements along its axes. Using motorized heads on the CMM also allows for rotating the LT system to obtain a suitable orientation for the scanning process.

Accurate calculation of the spatial position for each point of the laser stripe depends on the accurate calculation of the centroid of its light distribution in the sensor [1], [2]. If the intensity of the light distribution captured in the sensor is too weak, the system can not properly calculate the position of the points. Otherwise, if laser intensity is too high, the sensor will turn into saturation, so that the system could not calculate the position of points. For intermediate situations, the light distribution is analysed to determine its centroid position, which corresponds to distance *h* measured from reference point. Consequently, the light distribution affects the accuracy of distance *H* calculation (Fig.1).

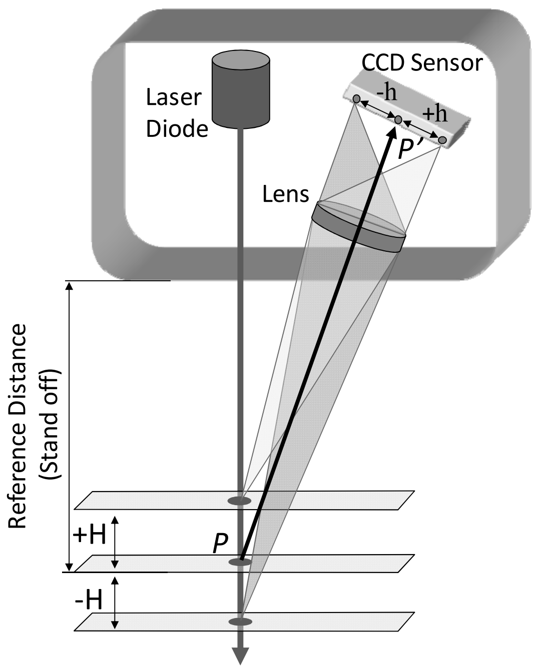

Fig. 1. Scheme of the laser triangulation principle

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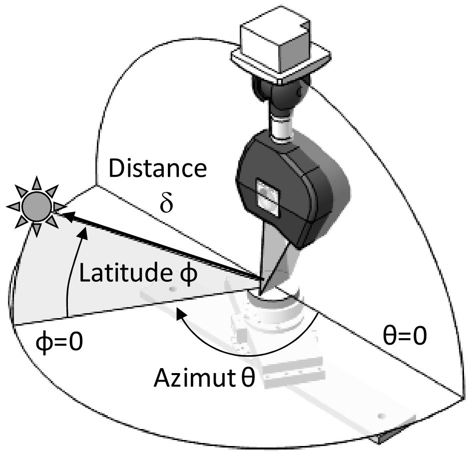

Fig. 2. Spherical coordinate system used to orientate the light source

The result of the scanning process depends on the LT system characteristics, the geometry and quality of the surface [3] and the environmental conditions. These elements determine the shape and contrast of the laser stripe onto the surface and the image captured by the sensor. Since surface quality is an important influence factor, most LT systems allow for adjusting laser intensity according to surface colour and roughness requirements. The objective is to achieve an improvement in the sharpness of the laser beam projection.

The ambient light present at the scanning process is one of the possible environmental influences [4]. Usually, LT systems incorporate optical filters to reduce or eliminate the influence of the ambient light. These filters accept only those wavelengths in the laser emission band. Commercial light sources emit light in a wide spectrum of frequencies. Since ambient light emitted in the laser emission band will not be filtered, it will become part of the information captured by the sensor and will be used in the calculation of point position.

II. Objectives

In this work, ambient light influence on the quality of digitized point clouds is evaluated. Digitizing tests have been carried out to compare results under different ambient light conditions.

Although there is a wide range of commercial light sources, the present work deals with the most commonly used lamps. Tests have been carried out under laboratory conditions, where illumination for each experiment is reduced to a single light source.

For each test configuration, nature and importance of the uncertainty introduced by ambient light have been established. Results for each light source have been afterwards compared to elaborate usage suggestions.

III. Configuration of the Tests

Tests have been carried out using a LT stripe commercial system from *Metris* (model *Metris LC50*) which has been mounted on a *Brown & Sharpe Global* CMM (model *Image*). The *LC50* uses a laser beam emitting in the red visible spectrum with a wavelength emission band between 635 nm and 650 nm. The maximum peak power is 1 mW.

A reflectance standard from *Labsphere* has been used as the surface to be digitized [5]. This surface (a.k.a. *reference surface*) is 99% reflectance certified. This means that its surface is quasi-lambertian, so 99% of the received energy is reflected. This reflexion is ideally diffused, as the energy is reflected in a uniform way in all spatial directions. Orientation of the light source with respect to the reference surface and the LT system has been selected so that the light direction theoretically makes an angle of 45º ($\varphi = 45º$) with the standard surface.

Moreover, theoretical direction of the incident light is orthogonal to the sweep direction. For every point, the system calculates the z coordinate value taking into account distance H (Fig.1) and sensor position and orientation. Therefore, influence of ambient light affects the calculated vertical position of the points.

Fig. 2 shows the spherical coordinate system used for the light sources orientation. The origin of this coordinate system is the centre of the *reference surface*. In order to incorporate the influence of light source intensity to this work, tests have been carried out with two different positions for the light sources: 200 mm ($\delta 1$) or 400 mm ($\delta 2$) from the origin of the coordinate system.

Light sources and *reference surface* are mounted in a test-bench designed *ad hoc*. This test-bench provides a proper position and orientation of the light source according to the spherical coordinate system (Fig. 3). This mounting allows for comparing point clouds obtained under different test conditions. The set formed by the test-bench, the light source and the *reference surface* has been installed on the CMM table.

The light sources used for this work are among the most usual types on a metrological laboratory or a workshop. This way, three types of incandescent lamps (clear, tinted in blue and halogen), a fluorescent lamp, a low pressure sodium lamp and a mercury vapour lamp constitute the final selection.

Although there is a wide variety of light sources for each class that can be tested (attending to power or shape), the selected lamps have similar values for the luminous flux (lumens). This selection criterion is based on finding alternatives that offer the operator a similar visual comfort, when performing long-time running digitizing processes.

Commercial references for the light sources used in this work are in Table I.

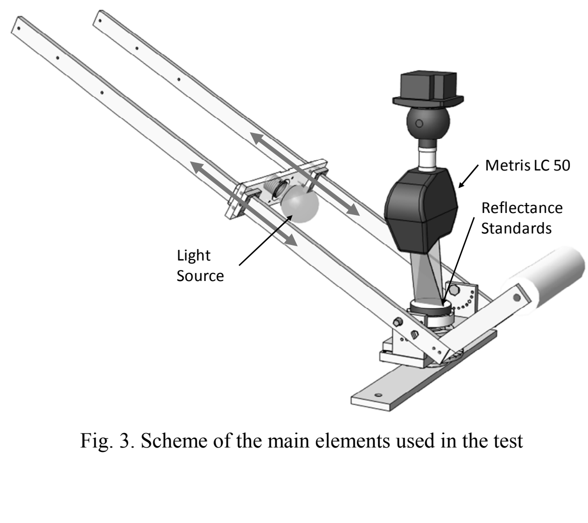

Fig. 3. Scheme of the main elements used in the test

TABLE I. DIFFERENT LAMPS USED IN THE EXPERIMENTS

K	Model	Manufacturer	Lamp Type	lumens
1	CLAS A CL	OSRAM	Clear incandescent	1360
2	DECOR A	OSRAM	Blue incandescent	-
3	64476 BT	OSRAM	Halogen	1600
4	PLE-T	PHILIPS	Fluorescent	1500
5	HQL 50 SDL	OSRAM	Mercury vapour	1600
6	SOX 18	OSRAM	Low pressure sodium	1800

IV. EXPERIMENTAL PROCEDURE

Test where the only illumination comes from the laser itself will not be altered by any external energy. Assuming this, a point cloud that has been digitized in the absence of light will suffer no distortions. Hence, digitizing in the dark appears to be the most appropriated way for scanning surfaces, although working in the absence of light is an unapproachable situation for human operators. Nevertheless, a point cloud obtained in the absence of light can be used as a reference when evaluating the quality of point clouds digitized under normal ambient lighting.

Experimental procedure used in this work allows for comparing the results obtained when digitizing under particular light sources with the results obtained in the absence of ambient light.

Although a single reference point cloud for all test may seem a suitable option, in practice, this approach is not recommended. Sensitivity of the internal geometry of the sensor to thermal variations (related to the time the laser remains switched on) must be taken into account. The fact that the manufacturer of the sensor recommends a minimum 40 minutes warm-up period since switching on the laser until a proper stability is reached, confirms the importance of this effect. Therefore, instead of using a single reference cloud for all tests, specific reference clouds have been used in each test comparison. These reference clouds must be digitized immediately after the capture of each single test cloud. This procedure will minimize the possible alteration of the sensor internal geometry due to thermal drift.

Thus, the first cloud $N^{k\delta}$ is obtained by digitizing the reference surface under a particular type of light source (*k*), placed at a given distance from the origin of the coordinate system (δ). Immediately after the first one, a second point cloud, known as reference point cloud $P^{k\delta}$, is obtained by digitizing the same surface in the absence of ambient light.

Comparison between these two clouds requires each point in the test cloud to have its equivalent in the reference cloud. To ensure this relationship, a computer application has been implemented, capable of selecting and classifying a group of 400 points (20 x 20) in the central area of the *reference surface*. Matrix constructed in this way allows for the comparison between each point and its equivalent.

LT system test parameters (as laser light intensity) have been adjusted to avoid loos of points due to saturation in the reference cloud. Distance between digitized points has been set to be 1.5 mm in both X and Y directions of the CMM coordinate system.

V. ANALYSIS CRITERIA

Three criteria have been used for comparing the quality of point clouds obtained under different sources of light.

The first criterion evaluates the influence of lighting on the number of points captured in the test cloud. As discussed previously, an excessive input of light energy turns the sensor to saturation. Therefore, it becomes impossible to calculate a proper value for the *z* coordinate of the saturated points.

The saturated points are not included in the cloud $N^{k\delta}$ as the system rejects them. The parameter used to characterize this criterion is the number of valid points ($n^{k\delta}$) on the cloud.

The second criterion evaluates the influence of lighting in the proper calculation of *z* coordinate value for each point. Improper values will cause the points of the test cloud to appear in a higher or lower place than they really are.

The absolute difference between the *z* values for each equivalent pair of valid points in both the test cloud $N^{k\delta}$ and its reference cloud $P^{k\delta}$ is calculated (1).

$$\left|d_i^{k\delta}\right| = \left|z_i^{Nk\delta} - z_i^{Pk\delta}\right| \tag{1}$$

The standard deviation $\sigma^{k\delta}$ of the calculated differences $d_i^{k\delta}$ has been used as the characteristic parameter for this second criterion (3).

$$\mu^{k\delta} = \frac{1}{n}\sum_{i=1}^{n} d_i^{k\delta} \tag{2}$$

$$\sigma^{k\delta} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(d_i^{k\delta} - \mu^{k\delta}\right)^2} \tag{3}$$

The last criterion used in this work is qualitative. It consists on a graphical representation of deviations $d_i^{k\delta}$ for each digitized point cloud. This representation shows how the ambient light modifies the position of each single point. It allows for determining whether light influence is equal across the whole surface or not.

VI. RESULTS DISCUSSION

Attending to first criterion ($n^{k\delta}$), the results of the tests in Table II, illustrate how certain types of light sources cause a high percentage of points to become saturated.

Thus, in three of the tests (N^{11}, N^{12}y N^{31}), no point has been captured due to saturation caused by the great amount of energy in the laser wavelength band. The sensor can not obtain properly the *z* coordinate value of these points, therefore the point cloud is empty.

A partial loose of points has only occurred in one case (test N^{21}). However, the same light source placed on a further position (test N^{22}) provides a complete point cloud. The rest of the tests provide complete point clouds, so that proper information from surface geometry can be easily obtained.

An order of preference between different light sources can be established by using the second criterion (explained in previous section) referring to the standard deviation ($\sigma^{k\delta}$).

From these tests it can be concluded that the best results for both testing positions are obtained for the low pressure sodium lamp. This light source causes a lower distortion for the test cloud over the reference cloud. Comparison between pairs of clouds, all obtained in the absence of light, provides a medium value of 1.2 µm as the systematic error [6] attributable to the system itself. Then, the result obtained for the sodium lamp and the furthest position ($\sigma^{k\delta}$ =1.13 µm) indicates a moderate influence of this light source on points positions.

TABLE II. RESULTS OF THE TESTS FOR THE NUMBER OF VALID POINTS AND THEIR STANDARD DEVIATION WITH RESPECT TO THE REFERENCE CLOUD

K	δ	$N^{K\delta}$	$n^{K\delta}$	$\sigma^{K\delta}$ [μm]	$d_{i\,min}$ [μm]	$d_{i\,max}$ [μm]
1	1	N^{11}	0	-	-	-
	2	N^{12}	0	-	-	-
2	1	N^{21}	44	8.36	-29.24	17.33
	2	N^{22}	400	4.64	-21.49	21.12
3	1	N^{31}	0	-	-	-
	2	N^{32}	400	4.83	-19.4	25.15
4	1	N^{41}	400	4.33	-7.33	21.97
	2	N^{42}	400	2.14	-8.97	9.89
5	1	N^{51}	400	2.15	-10.75	9.21
	2	N^{52}	400	1.88	-7.75	9.89
6	1	N^{61}	400	1.99	-18.19	13.79
	2	N^{62}	400	1.13	-5.92	5.07

The behaviour of the fluorescent lamp is clearly worse than the mercury vapour one for the closest position, while for the furthest one the difference is not so evident.

For the tinted blue incandescent lamp and the furthest position, the standard deviation is approximately 4.1 times greater than the value calculated for the sodium lamp. For the closest position, its standard deviation is extremely high, but it must be remarked that this value has been calculated considering a small number of valid points, as most of the theoretical points in the cloud have not been captured due to saturation.

In the case of the halogen lamp, the results for deviation $\sigma^{k\delta}$ are the worst of all. At the furthest position, the deviation is the maximal observed, approximately 4.3 times greater than the sodium lamp. This result was predictable as this lamp causes all the points to become saturated for the distance of 200 mm.

Finally, the third criterion (graphic representation of the parameter $d_i^{k\delta}$ along the whole area) shows how the distribution of these values depends on the type of light source and is clearly non-uniform (Fig. 4 and Fig. 5).

Thus, when testing the blue incandescent lamp at a distance of 200 mm from the origin of the coordinate system (Fig.4), the graph shows how the lack of points due to saturation is produced in points of the *reference surface* that are close to the light source.

On the other hand, valid points are only registered in a narrow strip placed in the area where the points of the surface are further from the light source. In certain areas of each test cloud, some of the points are located in an upper vertical position from their equivalent ones in the reference cloud, whereas points in other areas are located in a lower position.

However, this distortion in the test clouds does not seem to be related to the proximity of points to the light source, even when such a relationship can be established for the saturation of points.

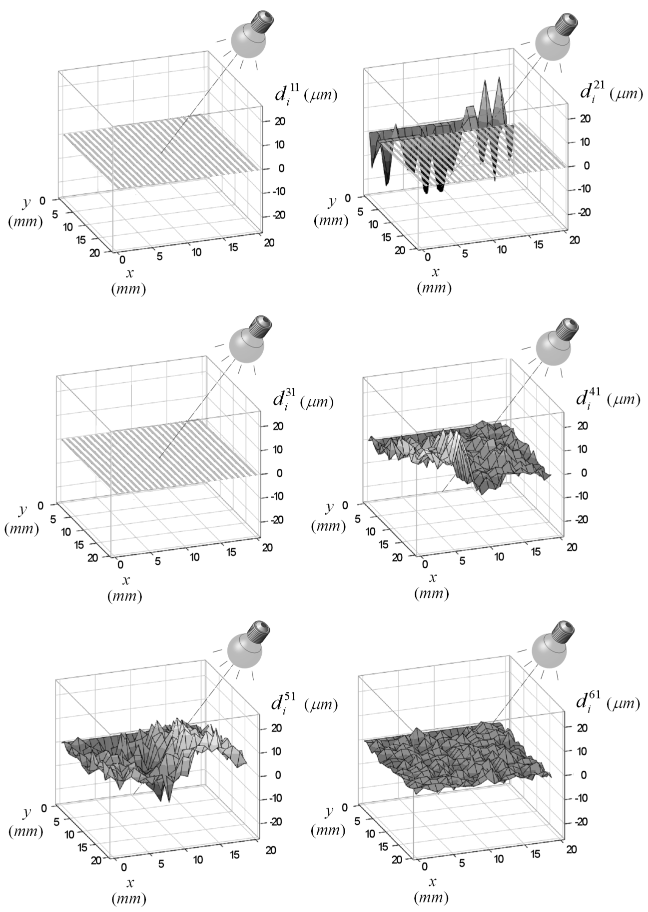

Fig. 4. Distribution of $d_i^{k\delta}$ for a distance δ = 200 mm

By contrast, the distribution of peaks and valleys in Fig. 4 and Fig. 5 shows a parallel orientation to the laser stripe projection onto the surface.

This result does not fit with any of the previous assumptions. The effect may be related to local irregularities on the reference surface properties. This should be confirmed by later work.

The appearance of the differences plotted in Fig. 4 confirms the conclusions obtained for the second criterion. Since sodium lamp generates less distortion in the cloud, it provides the best performance among the tested lamps.

This distortion is increased for mercury lamp and for fluorescent lamp. On the other hand, the blue incandescent lamp causes a huge distortion effect.

When testing the lights on the furthest position (δ = 400 mm), five completely-full clouds have been obtained (Fig. 5). As it was set for the closest distance, distribution of $d_i^{k\delta}$ shows a non-uniform behaviour. Furthermore, the parallelism between the preferential direction of peaks and valleys in the graphs and the orientation of the laser stripe can be noticed as in previous Fig.4.

Moreover, the result in terms of the level of distortion for the test clouds follows the same previously established pattern according to the type of light source.

The sodium lamp is again the source that has a lower influence in the distortion introduced in the test cloud. For this position, the distortion introduced by mercury and fluorescent lamps is very similar, when a better behaviour of the mercury one has been established for the closest distance.

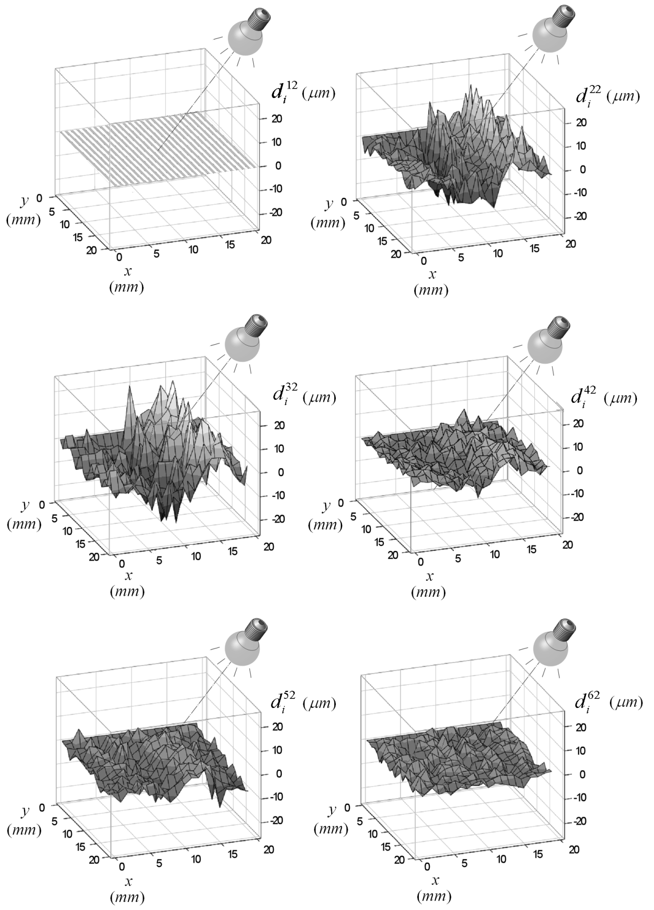

Fig. 5. Distribution of $d_i^{k\delta}$ for a distance δ = 400 mm

The results for the incandescent lamps (both the blue one and the halogen) are the worst among the tested lamps. The differences (both positive and negative) are significantly higher than for the rest of lamps. This result matches previous conclusions.

Specific test has been carried out to clarify the causes of the non-uniform distribution of peaks and valleys. The new tests provide three clouds digitized using the blue incandescent lamp in position *δ2*.

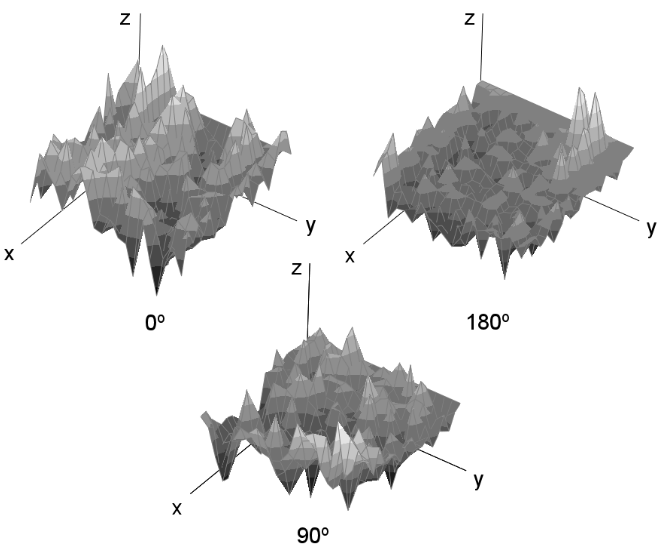

Fig. 6. Point clouds obtained under the same conditions when rotating the reference surface

Each test is carried out after rotating the *reference surface* 90º clockwise around its geometric centre. In second test, the surface has been rotated 90º clockwise. In third test the rotation reaches 180º. Fig. 6 shows the results of these three tests and how irregularities in the form of peaks and valleys rotate with the surface, even when the rest of the elements of the test have remained unchanged. Therefore, it can be concluded that the assumption of a lack of uniformity in terms of the *reference surface* properties is true.

VII. Conclusion

This work has established the influence of ambient light on the quality of laser triangulation digitized surfaces. Results of the tests show how the influence of the light sources affects the digitizing in different ways.

Sources that introduce a huge amount of energy on the laser wavelength band will cause some of the points to saturate. In severe cases this affects the whole point cloud and no information will be obtained.

It has been also demonstrated that different types of sources cause different results when calculating vertical position for every point of the cloud.

In addition, it has been verified that this influence is not uniform. Thus, depending on the type of light source used, some of the points of the test cloud are located in an upper vertical position from their equivalent points in the reference cloud, whereas other points on the same test cloud are located in a lower position. This effect is more evident for sources that apparently have a greater influence on clouds, such as the incandescent ones.

The experimentation carried out confirms that laser digitizing of surfaces in complete absence of external sources of light provides the best results. In the usual case that this requirement can not be satisfied, results lead to recommend using those sources of light that cause less distortion of the point cloud.

According to this, the recommended sources shall be the low pressure sodium lamp and the mercury vapour lamp. Sodium lamps emit in the orange range (589 nm) of the visible spectrum, which is especially annoying when working for long time periods, as it disables the operator for distinguishing different colors. This leads to recommend mercury vapour lamps as the most appropriate election.

Future work will deal with the evaluation of the influence of light source orientation upon the quality of the digitized point clouds.

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