

# Correlation between Incident Angle, Measurement Distance, Object Colour and the Number of Acquired Points at CNC Laser Scanning

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*In this paper the results of research about the influences of the incident angle, the measurement distance and object colour and reflectivity on the number of acquired points while using a laser-triangulation scanner on CNC-machines, are presented. The number of points is an essential parameter of a successful 3D surface reconstruction, although it is rarely considered as a subject of research. In this research we identified the scanning parameters to acquire a sufficient number of points for any surface reconstruction. The causes of the results are also identified and could be considered when creating automatic-measurement strategies for CNC-machines. Finally, the equation for an estimation of the number of acquired points in the optimal area of measuring parameters for the case example is also introduced.*

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## 0 INTRODUCTION

Laser scanning of real object based on the laser triangulation to obtain 3D computer models has gained a lot of attention and popularity due to its price affordability and performance, especially in the field of control and reverse engineering. Therefore, a considerable amount of research has been conducted also on enhancing the quality of measuring results, which is constrained by optical laws and hardware limitations. Laser scanning system can be compared in several different ways, as it has been suggested by different research works and methods for quality evaluation.

Feng [1] and Xi [2] suggested separating the error into its systematic and random component since they have a different origin, and the systematic error is usually much easier to control. To achieve that, they introduced a combination of a flat surface and a ball to estimate the measurement error in their experiments.

Lartigue, Contri and Bourdet observed the quality of digitized point clouds [3] and [4]. They introduced the following four criteria: *density*, *completeness*, *noise* and *accuracy*.

Van Gestel [5] investigated different methods for evaluating the quality of measurement results, based on the scanning of different objects.

He paid special attention to the advantages and disadvantages of different geometries during an estimation of the measurement quality. He exposed the problem of a sphere that does not give stable results when scanned only from one direction. Together with his team, he suggested a method for a rapid evaluation of the scans measured with laser line scanners, based only on measurements of the flat surface. The method consists of the two of the above mentioned valuations: i.e. the random and systematic error component and therefore, gives the information only about the overall error magnitude.

In contrast to the previously mentioned researchers, Vezzetti [6] states that the problem occurs in differences between different measuring systems. Technical specifications of measuring systems given by manufacturers do not provide sufficient information about the accuracy and performance of the equipment. At the same time the knowledge of the users is also insufficient for choosing an appropriate measuring system and for accurate interpretation of measured results. Therefore, Vezzetti suggested a user-oriented procedure to estimate performances of laser 3D measuring system. He exposed the necessity for the information regarding accuracy, repeatability

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and resolution of measuring a system at different measuring conditions.

From the above mentioned research works it can be derived that the number of acquired points and their distribution are some of the major parameters in the evaluation of the performance of a 3D measuring device. They represent the first condition for a successful surface reconstruction based on the point cloud triangulation. Yet, they can be expressed in several different ways: either directly as density and completeness as Lartigue et al. suggested, or indirectly from the resolution as in [6]. Regardless, the sufficient amount of point data is essential for a successful surface reconstruction even if some of the point reduction methods [7] are applied later in the process of reconstruction.

## 1 EXPERIMENT

### 1.1 Measurement System

Laser measurement systems are normally based on the principle of laser optical triangulation. This relies on the geometrical conditions of the light beams, particularly on the information regarding the angle and distance between the light source and the picture of the reflected light on the CCD sensor [8]. When scanning complex or larger shapes, it is often necessary to move the measuring sensor relative to the object. In such cases the information about the sensor's position in space is also needed, and not just the information provided by the laser scanning unit. Therefore, laser measurement equipment needs to be connected to a device that guides the sensor through the space and acquires its position. The 3D non-contact measurement system, therefore, consists of a four-axis milling machine from the Flexmatic company, a CVC-496 servo-motor controlling system from the Isel Automation company, a Zephyr KZ-50 laser triangulation measuring sensor from the Kreon company which is fixed to the CNC machine, and a personal computer for the coordination of the equipment. The layout of this 3D measuring system is shown in Figs. 1 and 2. The X, Y, Z, and A dimension CNC milling machine is driven by AC servo motors, and the encoder for each AC servo motor has a resolution of 2000 pulses per revolution. The

drivers for the AC servo motors are of the voltage control type. Multi-function interface cards, which include four channel encoders and counters were used to read the displacement data of each axis. The information about all three linear coordinates is sent in real time to the laser-sensor control-unit, where the position information is merged with the measured data of the sensor. The fourth, rotational axis is used only for the rotation of the measured object. The table is controlled by a PC controller. According to the manufacturer's information, the accuracy of the measuring table is 0.01 mm for each axis. The PCL-711 interface card has a 12-bit A/D channel to read in the laser displacement data. The manufacturer of the Kreon laser sensor claims that the resolution of the laser sensor is 0.005 mm, and the repeatability is 0.006 mm according to the OSIS workgroup-3 standard [9]. Based on this information and our experience we estimate the sensor accuracy to be about 0.01 mm. The whole measuring system was calibrated by scanning a calibration ball from several viewpoints. The obtained 2 sigma of the whole measuring system was 0.04 mm. The system is controlled by a PC that is used to handle all the I/O data from the controller. For the surface data acquisition, Kreon hardware and Polygonia software are used. The signal achieved through the RS232 serial link from the machine encoders and the signal from the laser sensor unit are simultaneously collected and merged to obtain the proper information about surface geometry.

### 1.2 Measurement Procedure

Coloured 200×150×10 mm flat granite stones were used for measurement due to their good geometric stability. The flat-surface measurements were taken for three different surface colours which were equally distributed across the whole visible light spectrum. This approach was used because surfaces usually reflect broader light spectrum and do not have only narrow monochromatic reflection properties, which was discussed in [10] and [11]. For this reason, it is impossible to fully describe reflective properties of a surface with only one or few parameters.

Therefore, we decided to do three different sets of measurements which gave several

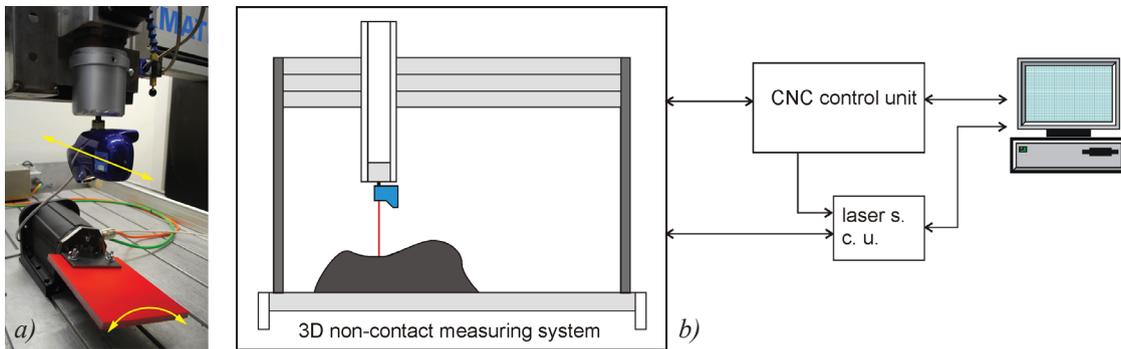


Fig. 1. a) axes of measurement and rotation; b) measurement setup for laser triangulation scanning on the CNC platform

advantages. Due to the sensor's narrow-band filter we were interested in reflectance intensity rate only around 675 nm wavelength, regardless of the colour of the measured surface. Laser light power and sensor exposure time were adapted to each surface according to this intensity rate. The goal was to obtain light intensity which hits the CCD sensor as similar as possible for all different surface colours (Table 1). Referential settings were defined as a perpendicular surface-laser beam position with 130 mm sensor-surface distance. This combination enables measurement over the whole measurement range, for all surface colours and comparability of the results.

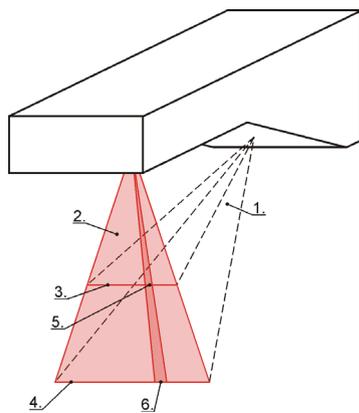


Fig. 2. Geometry of the laser sensor measuring field; (1) camera view-field; (2) laser light plane; width of the measuring field; (3) near; (4) far from the laser source, sampling resolution; (5) near; (6) far from the laser source

Relative reflection rate was determined with the spectral measurement of a light reflection

from different surfaces, which was described in [10]. The value shows the intensity of the light which reflects from some surface, compared to the intensity of the light, which is reflected from the white surface with the ideal Lambertian diffuse reflection.

Table 1. Relative reflection rate of different surface colours for 675 nm laser light and optical settings of the measurement

	Relative reflection rate [-]	Exposure time [s]	Laser power [mW]	Line width [dots]
Red	0.87	1/1000	2.0	6.9
Green	0.23	1/250	2.5	7.1
Blue	0.07	1/125	4.0	7.1

Since measured point clouds cover a different area of surface due to the measurement angle and the distance, only a central part of the point clouds was used. They were trimmed to the width of 15 mm in horizontal direction Y and length of 80 mm in horizontal direction X. The data prepared in this way give possibilities to easily estimate the point density from the number of points, and reduce the influence of distance variation when measuring at higher angles.

The measurements were performed at 7 different measurement distances, beginning at 130 mm and ending at 190 mm from the surface, and 14 different longitudinal measurement angles (i.e. rotation around axis parallel to the sensor movement – Fig. 1a) from 0 to 65 degree with 5-degree increment. Measurements of different distance-angle combinations were done in

random order to minimize the effects of possible systematic error.

## 2 MEASUREMENT RESULTS

### 2.1 Red Surface

Fig. 3 shows the relation between the number of acquired points, the surface-sensor distance and the longitudinal measurement angle for a red surface. The number of points was taken from a  $X \times Y = 80 \times 15$  mm large sample. It can be seen that the highest number of points i.e. 40,000 was obtained at the smallest surface-sensor distance while the number of points decreased with higher distance in a linear manner and reached 30,000 points at the most distant boundary of system's view-field. This effect can be explained by Fig. 2, points (5) and (6) which represent the distance between two adjacent points at the beginning and at the end of system's view-field. It can be seen that the distance between two points rises with the distance from the sensor, which causes lower point density at larger measurement distances.

The number of points did not change significantly with the longitudinal measuring angle across most of the system's measurement range, and deviations began at 60 degrees, but no rule can be derived solely from this measurement. Therefore, it was necessary to investigate the other surface colours as well.

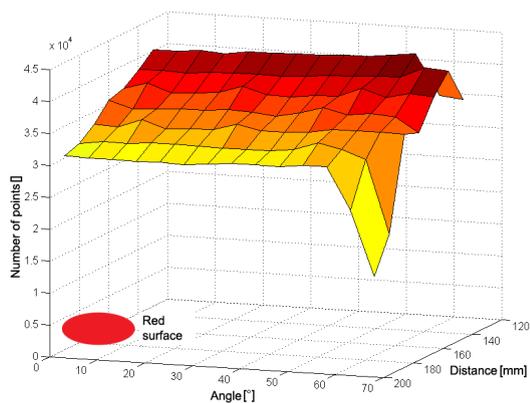


Fig. 3. The number of acquired points on the red surface with horizontal cross-section  $X \times Y = 80 \times 15$  mm, depending on the surface-sensor distance and the longitudinal angle of measurement

### 2.2 Green Surface

The results of the investigation of the green surface are presented by Fig. 4. The maximum number of acquired points in this case was approximately 36,000 at close measurement distances and approximately 28,000 at larger measurement distances.

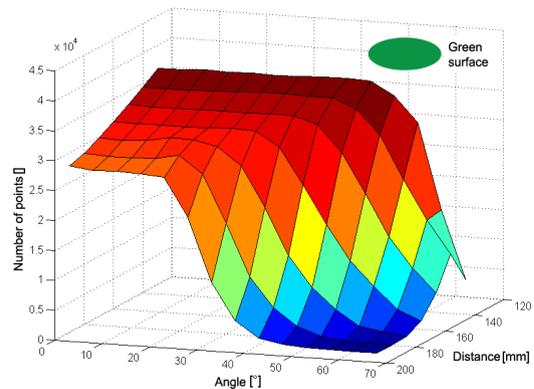


Fig. 4. The number of acquired points on the green surface with horizontal cross section  $X \times Y = 80 \times 15$  mm, depending on the surface-sensor distance and the longitudinal angle of measurement

As in the case of a red surface, the longitudinal measuring angle up to some angles did not have a significant influence on the measured number of points. The fold-down borderline was stretched from 20 degrees for large measurement distances, to 40 degrees when the sensor-surface distances are the smallest. After that line, the number of acquired point dropped drastically. It reached only half of the maximum value already after 5 to 10 degrees from the fold-down line and after 20 degrees from the fold-down line the number of acquired reaches was already less than 1000. The reason for the quick drop of the acquired number of points is found in the decrease of the laser light intensity which returns into the sensor under the threshold value of the measuring sensor.

### 2.3 Blue Surface

If the number of point results from red and green surface is compared the trend for scanning surfaces with lower reflection rates (Table 1) can be predicted. The maximum number of points acquired on a blue surface is therefore,

approximately 4,000 points lower than on a green surface and is around 32,000 points at the smallest measurement distances and approximately 24,000 points when measured at the largest possible measurement distances. The results are graphically shown in Fig. 5.

The fold-down border is very obvious again and this time occurred at even smaller longitudinal angles of measurement. The fold-down border of the largest measurement distances was at approximately 15 degrees and at 25 degrees the number of acquired points was only one tenth of the maximum number of points measured at that distance. At the smallest measurement distances the fold-down border occurred at approximately 25 degrees, but the drop was not that steep, so one tenth of the maximum number of points for that distance was acquired at 55 degrees.

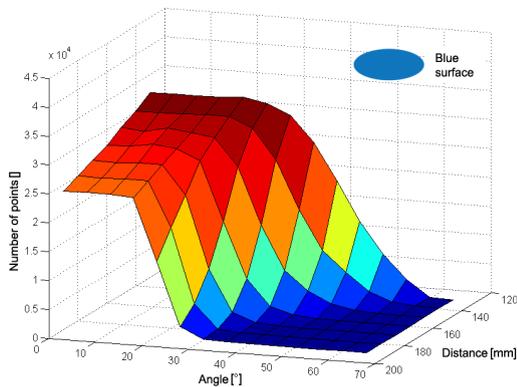


Fig. 5. The number of acquired points on the blue surface with horizontal cross section  $X \times Y = 80 \times 15 \text{ mm}$ , depending on the surface-sensor distance and the longitudinal angle of measurement

### 3 EQUATION

From the results presented in the previous section it can be seen that there are rules to predict the number of acquired points. For that reason, it was necessary to define an equation which would describe the results from the previous section. Since the highest number of points could be obtained only at the angle-distance combinations which are represented with flat regions of diagrams in Figs. 3 to 5, we simplified the problem only to these regions, providing also the threshold line of

acceptable angle-distance combinations.

The approximate equation was obtained statistically with the help of the factorial analysis and the analysis of variance (Anova test). The result is given in Eq. (1), where  $N$  [-] stands for the number of acquired points,  $d$  [mm] stands for the sensor-to-surface distance,  $\alpha$  [°] stands for the longitudinal angle of measurement and  $\rho_{rel}$  [-] stands for relative reflection rate of the measured surface, which is the function of surface colour and of the wavelength of measuring laser.

Obviously linear characteristics of both geometric parameters are reflected in a linear characteristic of the equation, while the relative reflection rate requires the second power to obtain better results of the interpolation.

$$N = 46896.41017 - 132.63109 \cdot d + 48.54960 \cdot \alpha + 36484.59021 \cdot \rho_{rel} - 0.30158 \cdot d \cdot \alpha - 36.97909 \cdot d \cdot \rho_{rel} + 27.01690 \cdot \alpha \cdot \rho_{rel} - 23020.57456 \cdot \rho_{rel}^2 \quad (1)$$

### 4 CONCLUSIONS

This article presents the results of a comprehensive research which was done to investigate the influences of different scanning parameters on the quality of the measurement results. The colour of the measured surface, the distance between the surface and the sensor and the angle of measurement were recognized as the factors which have the greatest impact on the quality of the measurement results. In this paper only the number of points as one of the quality output possibilities has been presented, while other, such as measurement uncertainty, have been covered in other papers and articles.

The results showed that measurement angle has no impact on the acquired number of points up to some value, which starts at extreme 70 degrees for red surfaces and short measurement distances but stretches down to 20 degrees with the poorer surface reflectivity (e.g. blue surface) and longer measurement distances. When crossing this angle boundary, the number of the acquired points decreases drastically.

On the other hand, the relation between the distance and the number of acquired points gave almost ideally linear correlation that originates in

the spreading of the scanner's view-range with the distance.

All the results were gathered in an equation for the estimation of the number of acquired points. The equation could be used as a support for more reliable measuring strategies.

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