

## INFLUENCE OF ATMOSPHERIC CONDITIONS ON THE RANGE DISTANCE AND NUMBER OF RETURNED POINTS IN LEICA SCANSTATION 2 POINT CLOUDS

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### ABSTRACT:

The aim of this research is to analyze experimentally the influence of atmospheric conditions on a series of measurements obtained by a terrestrial laser scanner. The scan series represents a dike covered by containers. These containers are gradually filled with water during the experiment to simulate a controlled dike collapse. From the morning of 25.09.2008 till the afternoon of 27.09.2008 two kinds of measurements were made. The first one assessed the atmospheric condition by measuring variations in radiation, temperature and humidity, which were taken as weather attributes for future analysis. The second measurements were made by the terrestrial laser scanner ScanStation 2 from Leica. During the experiment a total of 159 scans with a resolution of 5 cm on 50 m distance of the dike were made. On the scanned region twelve stable virtual targets were selected based on intensity and range. Three scan attributes were determined for each target at each of the 159 epochs: number of observed points, mean distance between scanner and target, and also standard deviation of these distances. The resulting scan attributes are compared to the 3 atmospheric attributes described above. The results indicate that scans affected by fog can be detected automatically by analyzing independent meteorological data. A weak linear relation of about 2 mm range increment per degree temperature increment at 70 m distance should be further investigated.

### 1. INTRODUCTION

In recent years, the technology of Terrestrial Laser Scanner (TLS) became more and more popular in structural engineering applications. TLS technology enables to acquire fast 3D measurements. However, the measurements are subject to errors due to influencing factors that cannot be eliminated, (Coşarcă et al., 2009; Ingensand, 2006). Few point cloud quality influencing factors are being investigated and can be categorized in four major groups.

The first group concerns the instrumental properties. It includes the scanner mechanism precision, mirror center offset, rotation mechanism aberrations (Zhuang and Roth, 1995), the beam width divergence and angular resolution (Lichti and Jamtsho, 2006) and the detection process of the reflected signal (Pesci and Teza, 2008). The second group deals with the object properties. This factor includes the surface properties (Boehler et al., 2003), i.e. the material (Hoeftle and Pfeifer, 2007) and the shape (Kersten et al., 2005) dependent anisotropy. The third category of influencing factors refers to the scanning geometry (Salo et al., 2008), typically parameterized by the range and the orientation of the object to the scanner, and the local sampling point density (2005, Lichti, 2007). The last factor relates to atmospheric conditions. This factor incorporates error behaviour related to atmospheric turbulences, such as humidity and scanning conditions (i.e. indoors, outdoors) (Borah and Voelz, 2007) and ambient light (Voisin et al., 2007). This paper explores the effects of the latter on the point cloud quality.

Although it is generally accepted that changing environmental conditions have influence on scan quality, little experiments have been conducted. Such experiments are difficult to organize, as many scans acquired under different atmospheric conditions are needed.

The experiment presented in this paper, was not at first designed to assess the environmental influence. It however presented to be as a very suited test case for the assessment of the influence of atmospheric conditions on the point cloud quality. This experiment compromises many outdoor scans, capturing the same object under rapidly changing weather conditions.

### 2. METHODOLOGY

As the methodology presented in this paper strongly depends on the available data, in this section the available meteorological and scanner data are first described, before presenting the quality descriptors used.

#### 2.1 Point Cloud Time Series

The point clouds used in this paper were obtained during an experiment performed to simulate a dike collapse. It consists of an embankment with containers placed on top of it, see Fig. 1. During three days, load on the embankment was gradually increased by filling the containers with water, which eventually resulted in a controlled collapse of the central part of the embankment (Anon, 2009). The process was carefully monitored by a large number of different measurements. In this work we determine the correlation of the meteorological measurements with the large number of scans made, to assess

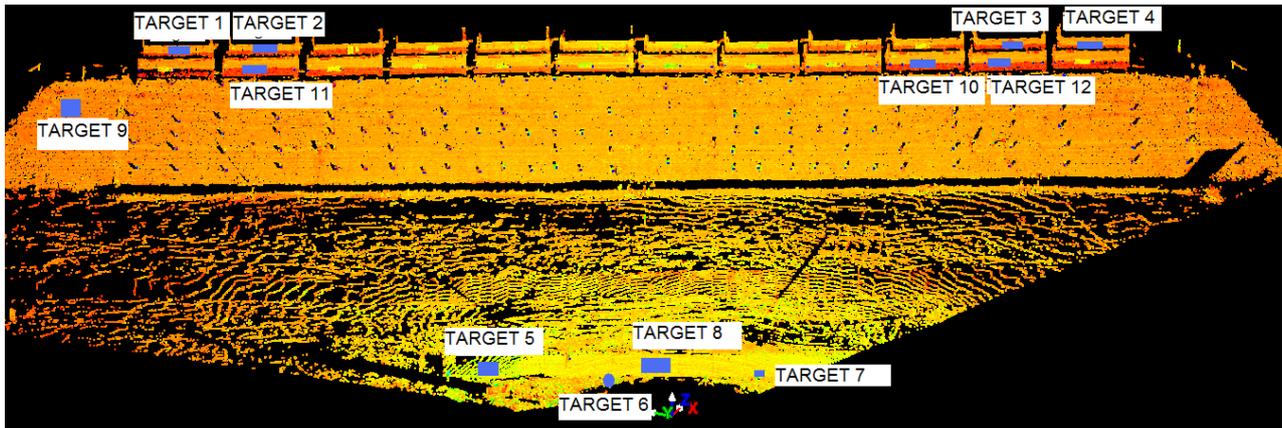


Figure 1: Embankment with the position of selected targets on the containers, on the slope terrain and near the TLS.

the influence of atmospheric conditions on the scan quality. In total, 159 scans were captured, over three days, under various atmospheric conditions.

Although the central part of the embankment faced large deformation, scan points at the far edges are considered stable. As a consequence, time series of range measurements to virtual targets in these stable areas seem suited to compare to corresponding time series of meteorological measurements.

In the stable part of the dike and its surroundings, twelve areas (further referred to as targets) were selected, as depicted in Fig. 1. These locations were selected based on their distance to the scanner, their intensity response and their difference in geometry (on containers, on the ground, on the dike or spherical target). Eight targets, numbered 1 to 4 and 9 to 12 were chosen on the embankment at distances ranging between 60 to 75 m. The other targets were located in front of the embankment at distances ranging between 8 to 21 m. Target No. 7 is situated at approximately 21 m from the scanner. The last three targets (No 5, 8, 6) are situated respectively at 15 m, 12 m and 8 m away from the TLS.

Usually, a point cloud consists of 3D positions expressed in Cartesian coordinates  $(x,y,z)$  and an uncalibrated intensity value. The scans used in this paper were registered to ensure all the scans are expressed in the same system of coordinates. To select the points belonging to each target, the Cartesian coordinates were transformed to spherical coordinates. The boundaries of each targets were on forehand manually selected, using one reference scan to determine a spherical box  $[\theta_1, \theta_2] \times [\varphi_1, \varphi_2]$  for each target. For each of the 159 scans the same spherical box was used for selecting points belonging to the same target

## 2.2 Meteorological Measurements

For the duration of the experiment, the radiation ( $w/m^2$ ), the temperature ( $^{\circ}C$ ) and the humidity (RH) were monitored, as shown in Fig. 2, (Brock and Richardson, 2001). The radiation represents the sum of the direct solar beam and the diffuse component of sky-light. The humidity is the amount of water vapor in the air. In this case, relative humidity is defined as the ratio of the partial pressure of water vapor in a parcel of air. Fig. 2 depicts the correlation between the radiation and the temperature; it is also inversely correlated with humidity. With low radiation and low temperature and more than 95% of humidity, fog appears. It occurred between 5 am and 10 am in both days, as shown in Fig. 2. It is therefore expected that this atmospheric condition will have an influence on the

measurements; especially the laser light may not be able to reach the virtual targets.

During the three days of measurements, precipitation was monitored as well. As almost no precipitation was detected, except for one time, when 0.2 mm was recorded, we decided not to take the precipitation into account. Radiation, temperature and humidity are the three weather condition parameters that are incorporated in the further analysis.

## 2.3 Terrestrial laser scanner data

For the scan measurements, the TLS ScanStation 2 from Leica was used. It is a pulse based, dual axis-compensated instrument with an integrated high resolution digital camera. Leica indicates that the following environmental conditions allow the instrument to work properly: it is fully operational under bright sunlight and complete darkness; it can work during non-condensing humidity (Leica ScanStation 2 Product Specifications, Ingress Protection).

## 2.4 Data Analysis

Two types of analysis of the scan points were performed, global and local. Globally the number of points in each of the 159 scans is considered. Locally, for each of the twelve targets three parameters are determined for each scan: number of points, mean distance and standard deviation. For a given target in given scan, first the points belonging to that target are determined using its fixed spherical box described above. The *number of points* is simply the number of points in the spherical box; the *mean distance* and the *standard deviation* are the mean and the standard deviation resp. of the distances between the points in the box and the scanner.

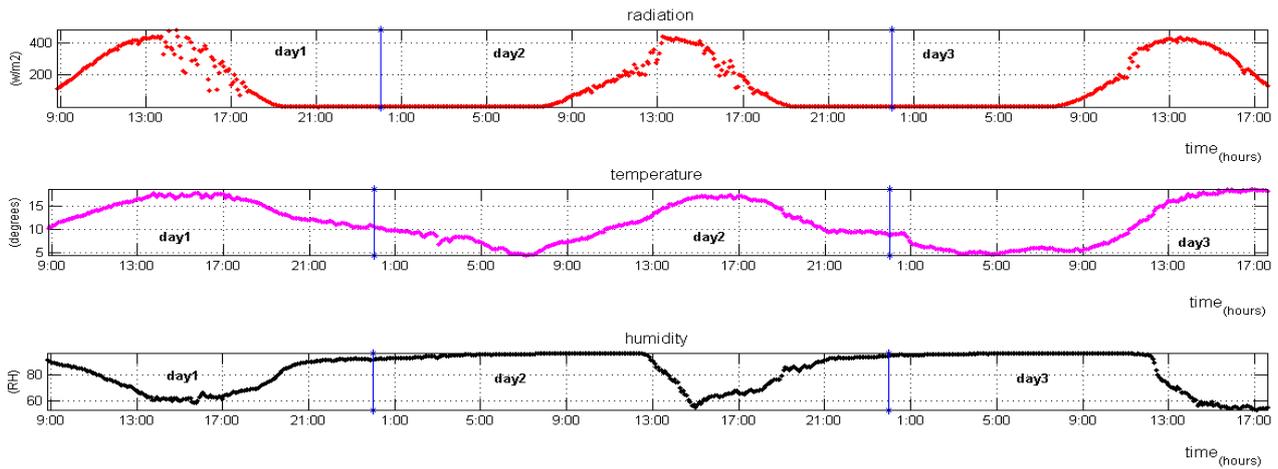


Figure 2: Radiation, temperature and humidity time series over three days.

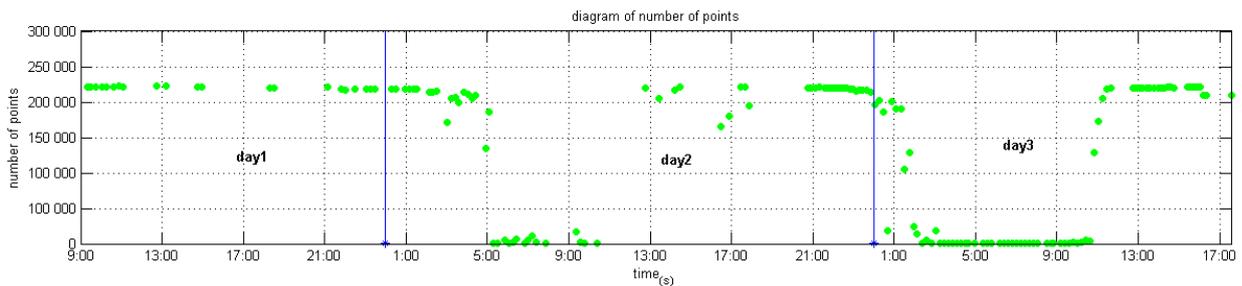


Figure 3 Number of points in each scan as a function of time.

### 3. RESULTS

In the following first the global results, considering the number of points in each scan as a function of time are discussed. Then the results per target are discussed

#### 3.1 The number of points per scan through time

Fig. 3 shows the number of points in each of the 159 scans for the fixed region of interest, corresponding to the scene in Figure 1. In both early mornings (between 5 a.m. and 10 a.m.) the number of points per scan decreases dramatically to a number in the order of 200 points per scan.

Table 1. Statistics of point belonging to each target

Target #	Distance [m]				max #. of points
	min	max	mean	std	
1	68,05	68,33	68,18	0,040	173
2	64,43	64,53	64,50	0,029	112
3	66,70	66,82	66,74	0,035	141
4	71,01	71,26	71,11	0,075	96
5	14,11	16,03	15,21	0,237	968
6	8,52	9,51	8,53	0,078	31
7	21,52	23,66	21,57	0,249	239
8	12,08	12,85	12,37	0,105	2984
9	69,89	71,81	71,29	0,165	260
10	63,19	63,36	63,25	0,035	142
11	63,58	63,78	63,75	0,030	110
12	67,05	67,23	67,10	0,036	141

By relating the results shown in Fig. 2 and Fig. 3, it can be seen that when the temperature and the radiation reach their daily minimal values the humidity is more than 95%. Simultaneously the number of point per scan is decreasing. This results show that the automatically detected fog strongly affects the effective range of the scanner. It is also concluded from Fig. 3 that during non foggy conditions the number of points is stable at the 220 000 points level.

#### 3.2 Statistics of the points belonging to the 12 targets

Table 1 gives for each of the 12 targets the mean, minimal and maximal distance of points to the scanner and also the standard deviation of these distances. Also the maximal number of points per target is given. Note that for the virtual targets close to the scanner the st.dev, is mostly larger than for the far away targets. Fig. 1 indicates that close by targets are often situated on the (horizontal) ground, while the far away targets are mostly situated on vertical structures. Therefore the difference in standard deviation values may be explained by the difference in orientation with respect to the scanner. Note also that the number of points per virtual target ranges from only 31 points for target 6 to almost 3000 points for target 8, which will definitely affect statistics. Still a more detailed local analysis is needed to analyse what points exactly are selected by the virtual target selection procedure in each scan.

### 3.3 Different types of meteorological conditions.

After a first analysis of scatter plots relating scanner parameters to meteorological parameters it was decided to define a few types of meteorological conditions. In this way it is possible to identify and consecutively isolate points affected by e.g. fog. The atmospheric data were divided in the four groups defined in Table 2.

No. group	radiation (w/m <sup>2</sup> )	temperature (°C)	humidity (RH)
1	10-450	10-18	54-92
2	0-10	4-9	95-100
3	0-10	7-10	90-94
4	11-320	5-12	95-100

Table 2 Four different types of meteorological conditions, defined based on specific radiation, temperature and humidity

To the first group belong the scan points that in the following will be plotted in blue, which were obtained during normal daytime meteorological conditions: During the scans it was light, which can be concluded from high radiation and temperature values combined with a low humidity. The second group, the red points, contains scans obtained during atmospheric conditions which indicate the presence of fog: a low radiation combined with a high humidity. The third group contains points (in green) from before and after fog appearance. The last group, gray points, contains morning measurements when sun is up but temperature is still low and humidity is high.

The blue points are the points for which scan conditions are normal. For these points it may make sense to relate changes in scan point statistics to changes in meteorological parameters. In the following the results from target 1 are presented as an example.

### 3.4 Number of points per target over time

A similar behaviour of the number of points according to the atmospheric condition was visible for all targets as for target 1. However for the targets situated close to the scanner the influence of atmosphere was less profound as for the targets situated at a distance of above 60 m. For these four targets (No 5 to 8) the results are similar as for target 1.

In Figures 4 to 6 it can be seen that the atmospheric conditions have significant impact on the number of points representing the target. In many cases 'red' and 'gray' meteorological conditions correspond to a very low number of sampled points. For the observations in blue, the normal day observations, it is visible that when the temperature and radiation is increasing, the number of points is also slightly increasing, together with the humidity

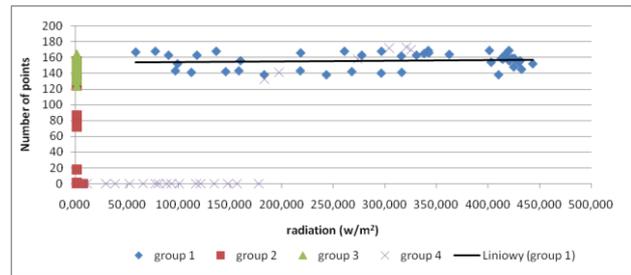


Figure 4: Number of points w.r.t. radiation (target 1)

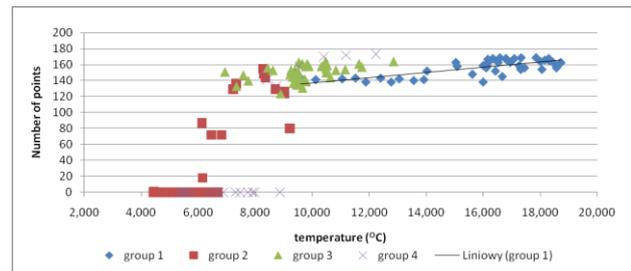


Figure 5: Number of points w.r.t. temperature (target 1)

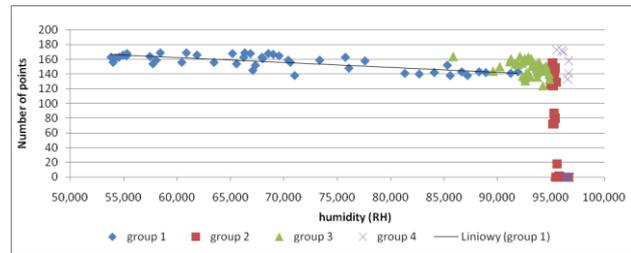


Figure 6: Number of points w.r.t. humidity (target 1)

### 3.5 Distance to target over time

The second test considers the range distances to the twelve targets. The given results were similar for all targets, hence only target no 1 is shown as an example here

Figures 7 to 9 show the relation between the mean distance to target 1 with respect to radiation, temperature and humidity. Figure 8 shows clearly that the group of green, red and gray points all have a relative large variation in mean distance. The blue points seem more stable, but still a small positive linear relation seems to exist between temperature and mean range distance, corresponding to an increase of about 2 mm per degree. It should be investigated further however if this trend represents a bias in the scanner or is actually caused by an expansion of the scanned object due to temperature influences.

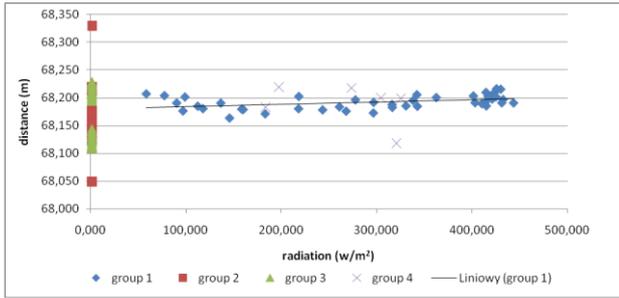


Figure 7: Distance w.r.t. to radiation (target 1)

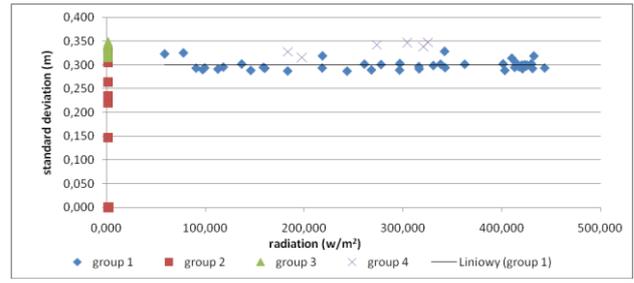


Figure 10: Standard deviation w.r.t. to radiation (target 1)

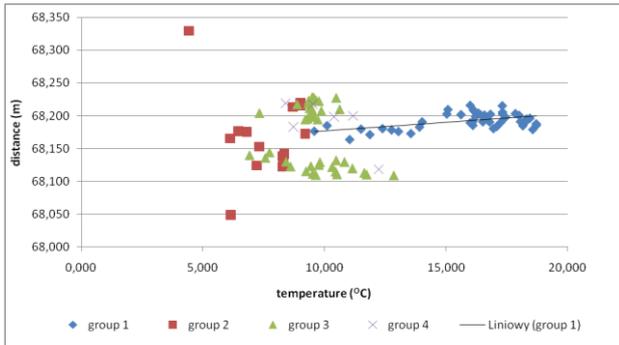


Figure 8: Distance w.r.t. to temperature (target 1)

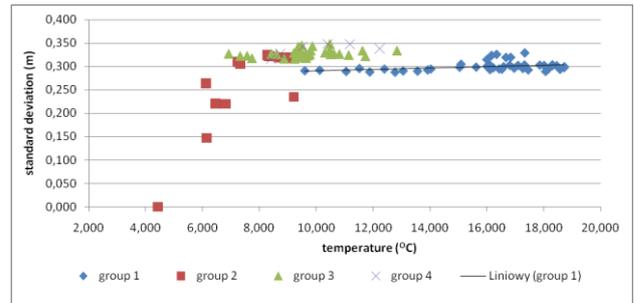


Figure 11: Standard deviation w.r.t. to temperature (target 1)

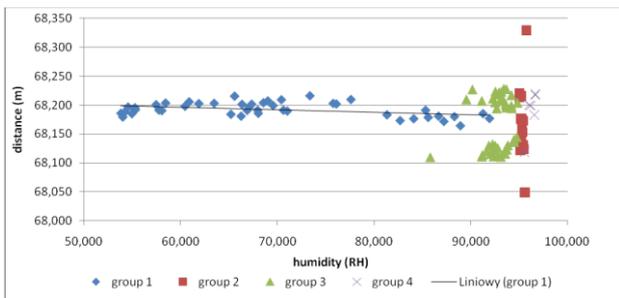


Figure 9: Distance w.r.t. to humidity (target 1)

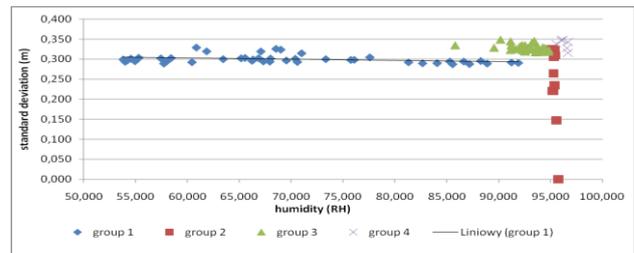


Figure 12: Standard deviation w.r.t. to humidity (target 1)

### 3.6 Distance standard deviation per target over time

In combination with the target distance, the local noise level was determined by considering the standard deviation of the available range values. Fig. 10, 11 and 12 show the standard deviation values related to again, radiation, temperature and humidity. The lower standard deviation values during `red conditions` can be largely explained by the small number of points obtained during fog at 70 m. Meanwhile, during the green and gray transitional conditions the standard deviations are just above 3 cm. During normal, blue, conditions the standard deviation stays at a stable level of 3 cm.

## 4. CONCLUSIONS AND FURTHER STEPS

In this paper, the influence of atmospheric conditions on a time series of measurements made by a terrestrial laser scanner was analyzed. A three days experiment was conducted, where 159 scans were acquired, under changing atmospheric conditions. Statistics of range measurements to virtual targets that are considered stable were linked to meteorological parameters.

As expected, the numbers of points acquired by a terrestrial laser scanner depends on the atmospheric conditions for larger distances, in this case distances between 63-71m. For close by objects, foggy conditions have less impact as the returned energy is still high enough to be detected by the scanner receiver unit. When scanning under fog, no points are returned to the laser at all.

It turned out possible to identify less favourable scan conditions by analysing the meteorological data. This means that for automatic scanning projects, without human operator present, a filter can be constructed to automatically stop the scanning when meteorological data indicates so.

A linear trend between temperature and observed range of about 2 mm per degree was found. This relation should be further investigated to reveal if it is related to a scan bias or to object expansion due to temperature increase. A first step to this goal would be to perform a detailed deformation analysis of the 159 scans, also for the parts that at first look were considered stable.

The current division into meteorological condition types should be further improved. Normal, favourable conditions for scanning at night exist, but where not present in the current analysis.

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## REFERENCES

- Anon. *IJkdijk experiment*, [www.ijkdijk.eu](http://www.ijkdijk.eu), accessed on December 21, 2009.
- W. Boehler, A. Marbs “*Investigating Laser Scanner Accuracy*” In Proceedings XIXth CIPA Symposium, Antalya, Turkey, 30 Sep – 4 Oct, 2003
- Borah, D. K. and Voelz, D. G., 2007. Estimation of Laser beam pointing parameters in the presence of atmospheric turbulence. *Journal of Applied Optics* 46(23), pp. 6010–6018.
- F. V. Brock, Scott J. Richardson; *Meteorological Measurement Systems*, Oxford University Press, Inc, 2001
- C. Coșarcă, A. Jocca, A. Savu “*Analysis of error sources in Terrestrial Laser Scanning*”, In Proceedings International Scientific Symposium GeoCAD’09, Alba Iulia, May 07-09, 2009
- Hoefle, B. and Pfeifer, N., 2007. Correction of Laser Scanning intensity data: Data and model-driven approaches. *International Jnl. of Photogrammetry and Remote Sensing* 62(6), pp. 415–433.
- H. Ingensand “*Metrological aspects in terrestrial laser scanning technology*” In Proceedings 3rd IAG / 12th FIG Symposium, Baden, May 22-24, 2006
- Ingress Protection (IP) Ratings for Electrical Enclosures IEC 60529(ed2.1), clause 4.1
- C. Ioannidis, A. Valani, A. Georgopoulos, E. Tsiligiris “*3D model generation for deformation analysis using laser scanning data of a cool tower*”, In Proceedings 3<sup>rd</sup> IAG/12<sup>th</sup> FIG Symposium, Baden, May 22-24, 2006
- G. Jacobs “*Feature: 3D Laser Scanning An Ultra-fast, High-Definition, Reflectorless Topographic Survey*”, *Professional Surveyor Magazine*, May 2004
- Kersten, T. P., Sternberg, H. and Mechelke, K., 2005. Investigations into the accuracy behaviour of the Terrestrial Laser Scanning system MENS1 GS100. In: Gruen/Kahmen (ed.), *Proc. in the Optical 3D Measurement Techniques*, Vol. I, Vienna, Austria, pp. 122–131.
- Leica ScanStation 2 Product Specifications [http://www.leica-geosystems.nl/nl/HDS-Systemen-Leica-ScanStation-2\\_62189.htm](http://www.leica-geosystems.nl/nl/HDS-Systemen-Leica-ScanStation-2_62189.htm) from 03.02.2010
- Lichti, D. D., 2007. Error modelling, calibration and analysis of an AM CW Terrestrial Laser Scanner system. *International Journal of Photogrammetry and Remote Sensing* 61, pp. 307–324.
- Lichti, D. D. and Jamtsho, S., 2006. Angular resolution of Terrestrial Laser scanners. *The Photogrammetric Record* 21, pp. 141–160.
- Lindenbergh, R., Pfeifer, N. and Rabbani, T., 2005. Accuracy analysis of the Leica HDS3000 and Feasibility of Tunnel Deformation monitoring. In: IAPRS (ed.), *Proc. in the ISPRS Workshop, Laser Scanning 2005*, Vol. XXXVI(3/W3), Enschede, The Netherlands, pp. 24–29.
- Pesci, A. and Teza, G., 2008. Terrestrial Laser Scanner and retroreflective targets: an experiment for anomalous effects investigation. *International Journal of Photogrammetry and Remote Sensing* 29(19), pp. 5749–5765.
- Salo, P., Jokinen, O. and Kukko, A., 2008. On the calibration of the distance measuring component of a Terrestrial Laser Scanner. In: IAPRS (ed.), *Proc. in the XXIIth ISPRS Congress*, Vol. XXXVII - B5, Beijing, China., p. 1067.
- D. Schneider “*Terrestrial laser scanning for area based deformation analysis of tower and water dams*”, In Proceedings 3<sup>rd</sup> IAG/12<sup>th</sup> FIG Symposium, Baden, May 22-24, 2006
- Voisin, S., Foufou, S., Truchetet, F., Page, D. and Abidi, M., 2007. Study of ambient light influence for three-dimensional scanners based on structured light. *Optical Engineering* 46(3), pp. 030502–1 030502–3.
- Zhuang, H. and Roth, Z. S., 1995. Modeling gimbal axis misalignments and mirror center offset in a single-beam Laser tracking measurement system. *The International Journal of Robotics Research* 14(3), pp. 211–224.