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Influence of 3D Scanning Data Scattering to Volume Measurement of Horizontal Fuel Tanks

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***Abstract*—Calibration of the fuel tanks must be made once in a 5 years. For calibration of the fuel tank 3D laser scanning and data processing method can be used. This article describes the influence of 3D laser scanning data scattering to volume measurement of horizontal fuel tank by means of relative error. It describes how to eliminate data scattering effects using filtering.**

***Index Terms*—3D laser scanning, fuel tank calibration.**

I. INTRODUCTION

Calibration of the fuel tanks must be made once in a 5 years. For the tank calibration geometric and volumetric methods can be used [1], [2]. Last few years authors were working with calibration of various fuel tanks using 3D laser scanning method. In previous papers [3], [4] authors presented a new approach to the calibration of horizontal and vertical fuel tanks which is based on the 3D laser scanning technique. The main idea was that the tank can be scanned using an accurate laser and volume of the tank can be calculated using 3D point clouds.

The main advantages of the 3D laser scanning method are:

1. Time saving and water waste problems;
2. Lower measurement temperature limit;
3. Only 1 person is needed for calibration.

Experimental verification of the algorithms which was performed with different types of fuel tanks showed that for all fuel tanks relational error stays around 0,3 %–0,4 %. This can be explained by scattering of the data merged from different scans.

In this article we will analyse the influence of data scattering effect to fuel tanks volume measurements and explain the method for data scattering effect decreasing.

II. CREATION OF THE CLOUD OF POINTS FROM 3D LASER SCANNING

Calibration of horizontal or vertical fuel tanks is followed by these steps [3], [4]:

– inspection of the fuel tank,
– preparation of measurement gear and fuel tank for verification,
– fuel tank scanning (2–3 scans for vertical and 1–2 scans for horizontal fuel tank),
– preparation of data for processing (merging, filtering etc.),
– calculation of tanks volume,
– preparation of graduation table.

From inside the fuel tank must be scanned at least 2–3 times from different scanner positions. The best way to scan the horizontal fuel tank is to put a scanner at different sides of the tank. The main problem to make a full scan of the horizontal fuel tank is that most tanks have only one hatch. If you want to put scanner at the end of the tank you have to get inside the tank and move the scanner. But this solution is not acceptable. So, 3D scanner can be placed only near hatches. This can be solved by putting a scanner at different heights and merging scanned data or by creating z plane from points around it (upper, downer z planes).

Figure 1 shows z plane of the fuel tank scanned from one position – scanner was placed at the bottom of the tank. As it can be seen, only half of z plane is "normally" filled with points (-4÷1 on x axis). This can be explained by the scanner position near the hatch which is on the right side of the tank.

Figure 2 shows the same z plane (merged data) of the horizontal fuel tank scanned from two different scanner height positions. The first scanner position was on the bottom of the tank and the second position was near the top of the tank.

As it can be seen the left part of the tank still has big breaks between points. These breaks influence volume calculations.

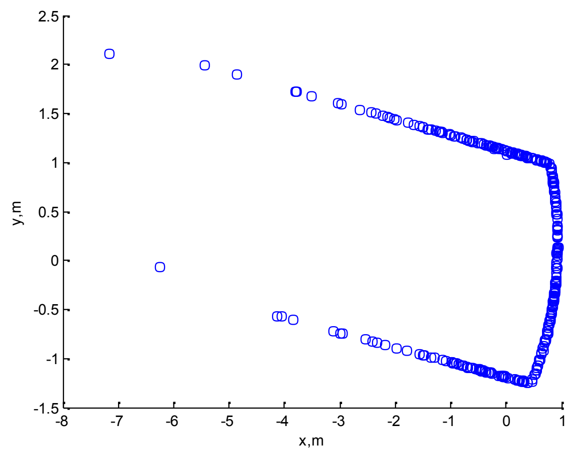

Fig. 1. 3D scan of the fuel tank (1 scan).

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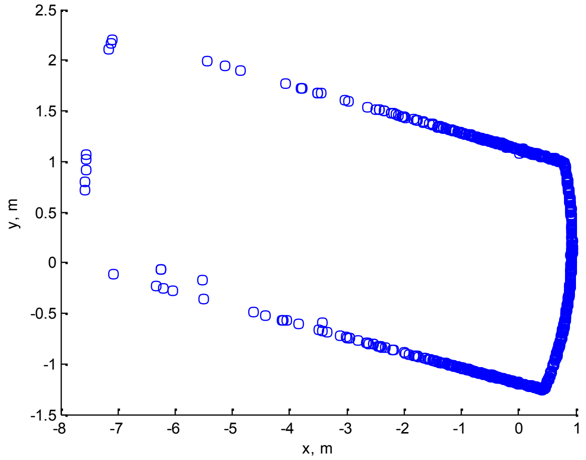

Fig. 2. 3D scan of the fuel tank (2 scans bottom and top merged).

A volume calculation of the scanned fuel tank was described in previous author's publications [3]. The main formulas are

$$A_j = \frac{1}{2}\sum_{i=0}^{N-1}(x_{i,j}y_{i+1,j} - x_{i+1,j}y_{i,j}), \quad [\mathrm{m}^2], \tag{1}$$

where A_j –area of j layer, $j = 1,\ldots H_{\max}/\Delta h$, $H = 1,\ldots H_{\max}$ [cm] fuel tanks filling level, $H_{\max}$ - maximal filling level, Δh - scanning step [mm], x_i and y_i – point coordinates [m], N - point number;

$$V_H = V_{H-1} + \sum_{j=(H-1)\cdot M+1}^{H\cdot M} A_j \cdot \Delta h + \Sigma K_H, \quad [\mathrm{dm}^3], \tag{2}$$

$$M = \frac{10}{\Delta h}, \tag{3}$$

where M – number of layers in 1 cm; ΣK_H – sum of volumes of all inside construction elements.

Algorithm of the calculations can be described as follows: calculations of the area from point cloud of z plane must be made using (1) and volume can be calculated as sum of all areas using (2). Figure 3 shows calculations of z plane area when 2 scans (laser at different heights) were used. It is clear that at the left side we have area cut offs.

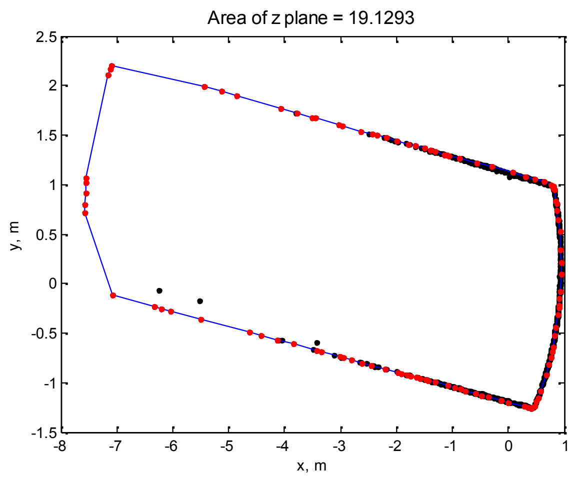

Fig. 3. Calculations of z plane area (2 scans bottom and top merged).

Another method for getting "full" scan of z plane is data merging from upper and downer z planes. After some inspection of scanned data of different sizes horizontal fuel tanks we found out that some z planes has more points on one part and some on another. By merging scanned points in these planes we can receive z plane without big "breaks" between points in the point cloud. Figure 4 illustrates z plane created from its neighbors *z-0,5* cm and *z+0,5* cm with step of *0,1 cm*. 10 *z* planes were merged into 1. Calculations of area of this *z* plane gives results (Fig. 5) close to the real ones measured using liquid fill method (19,64 liters) which is described in [3].

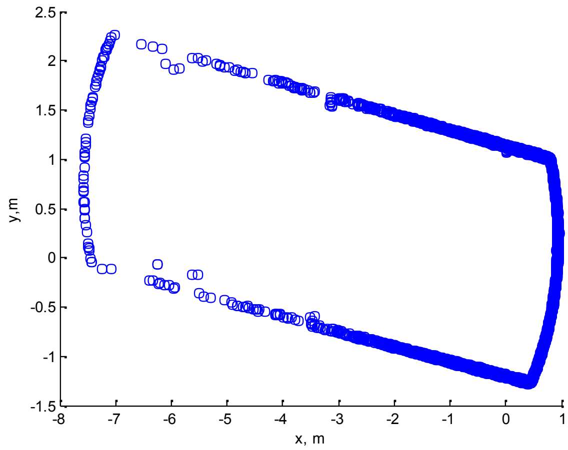

Fig. 4. 3D scan of the fuel tank (1 scan different z plane layers merged).

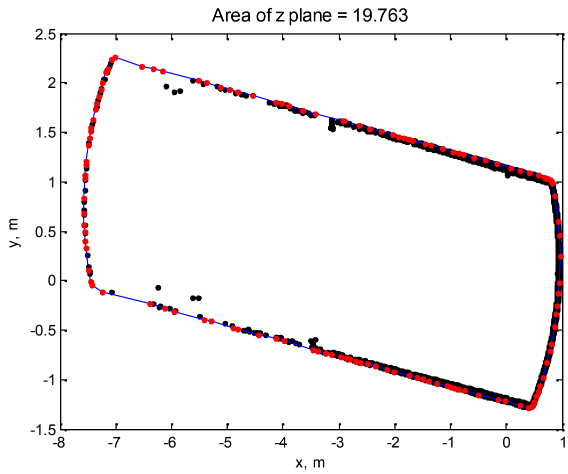

Fig. 5. Calculations of z plane area (1 scan different z plane layers merged).

TABLE I. DEPENDENCIES OF RELATIVE ERROR FROM DIFFERENT DATA MERGING METHODS.

	z plane area (2 scans bottom and top merged) liters	**z plane area (1 scan different z plane layers merged) liters**	**z plane area (liquid fill method) liters**
1 mm	19,12	19,76	19,64
Relative error %	-2,7	+0,6	-
1 cm	191,3	197,6	196,52
Relative error %	-2,6	+0,62	-
10 cm			
Relative error %	-2,6	+0,8	-
Full volume (240 cm)	22653,35	23530,45	23401,68
Relative error %	-2,63	+1,02	-

Differences between methods used for creation of point cloud (*z* plane) can be analysed by relative error. Table I illustrates how relative error changes when calculating fuel tanks volume at different heights. For illustrations only one horizontal fuel tank was used, but our analysis of different size horizontal fuel tanks shows that the same behaviour occurs in all volume measurements. As it can be seen relative error when using 2 scans (bottom and top merged) stays at "–" zone. This means that using this point merging method we always get lower volume. This can be explained, as mentioned earlier (Fig. 3), by breaks between points.

On the other hand, when creating point cloud from 1 scan and merging points from neighbouring layers always gives a little bit increased volume (1 %–1,2 %). This can be explained by data scattering. Normally relative error must stay around ±0,3 % [5].

III. Influence of the Data Scattering To Volume Measurements

Data scattering appears after merging different *z* planes. This happens because of natural cylindrical horizontal fuel tanks shape. After inspection of 50–60 3D scans of different fuel tanks we found out that the best *z* planes merging result is received when 10 planes is merged (*z-0,5* cm and *z+0,5* cm). The main criteria to receive best result were to decrease breaks between points. Data merging gives side effect – data scattering. Figure 6 shows zoomed section of the fuel tank z plane which was used for volume calculations.

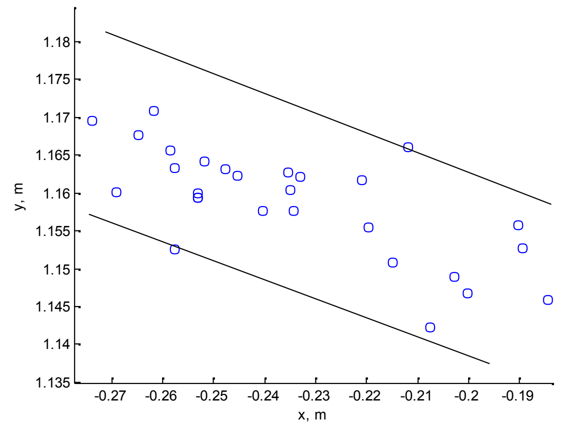

Fig. 6. Data scattering of merged layers.

For better understanding of how data scattering influences volume calculations and for finding the acceptable limit of scanned data scattering mathematical model of horizontal fuel tank was created. We adopted model to real sizes of the fuel tank and created the possibility of imitation of data scattering. The model creates the array of coordinates (x, y, z) of points which form cloud of points. For data scattering imitation for each coordinate random number from determined interval (for example from -0,5 cm to 0,5 cm) is generated and the point is moved from its ideal position. Algorithm for ideal fuel tanks mathematical model was created in MATLAB language.

For experiments with ideal fuel tank model 4 data sets were created:

– No data scattering;
– Data scattering with boundary -1 mm to 1mm;
– Data scattering with boundary -2,5 mm to 2,5 mm;
– Data scattering with boundary -5 mm to 5 mm.

Bigger boundary levels were not analysed because the influence to final volume value and the relative error is too big. Relative error was calculated at 4 different levels. Starting in the middle of the fuel tank (1,20 m) with the $\Delta h = 1$ mm (2):

– Volume of 1 mm;
– Volume of 1 cm;
– Volume of 10 cm;
– Full volume 240 cm.

TABLE II. DEPENDENCIES OF RELATIVE ERROR FROM DATA SCATTERING.

Measured fuel tanks height	Volume (scattering from -1mm to 1mm) l	Volume (scattering -2.5mm to 2.5mm) l	Volume (scattering -5mm to 5mm) l	Volume (no data scattering) l
1 mm	16,35	16,37	16,51	16,31
Relative error %	0,25	0,4	1,2	-
1 cm	163,84	164,15	165,7	163,42
Relative error %	0,26	0,45	1,4	-
10 cm	1687,78	1693,04	1709,82	1682,9
Relative error %	0,29	0,6	1,6	-
Full volume	37333,67	37501,09	37761,52	37203,46
Relative error %	0,35	0,8	1,5	-

As it can be seen from Table II data scattering with boundary of -1 mm to 1mm gives acceptable results; relative error stays around *0,3* %. But at increased boundaries (-2,5 mm to 2,5 mm or -5 mm to 5 mm) relative error increases to *0,9* %– *1,5* %. Figure 7 illustrates how different data scattering boundary levels effect volume calculation going through all the fuel tank from bottom to top (50÷240 cm). First curve from the top represents relative error when data scattering boundary is -1 mm to 1 mm, second – -2,5 mm to 2,5 mm, and third -5 mm to 5 mm.

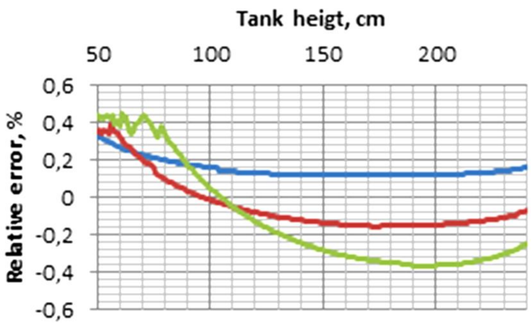

Fig. 7. Dep1endencies of relative error from data scattering.

This data scattering after merging problems can be solved using data filtering methods.

IV. Method of Elimination of 3D Laser Scanned Data Scattering After Merging – Experimental Results

Effect of data scattering can be minimized using data filtering. As can be seen from Fig. 4–Fig. 5, the biggest data scattering can be found on the fuel tank side where the scanner was placed. For data scattering filtering we used algorithm based on regression, which creates boundary levels calculated by equations for each point coordinate:

$$x_i = \left(x(i+n) + x(i+n-1) + \ldots + x(i-n)\right) / S_n, \text{[m]}, \quad (4)$$

$$y_i = \left(y(i+n) + y(i+n-1) + \ldots + y(i-n)\right) / S_n, \text{[m]}, \quad (5)$$

where x_i, y_i – coordinates of i point, n –number of points taken from one and other *i-th* point side, S_n – a span equal to

$$S_n = \frac{1}{2n+1}. \quad (6)$$

Procedure of filtering can be described as follows:

– Creation of *z* plane data points array (Fig. 4);
– Calculation of boundary levels;
– Filtering point which are outside boundary;
– Creation of new filtered *z* plane.

We calculate how many points *n* to use from the size of z plane data array. This algorithm didn’t remove all data scattering effect, but it decreased it to acceptable level.

Figure 8 illustrates how relative error changes after decreasing data scattering. As expected, changes of relative error when data scattering has boundary -1 mm to 1mm is unnoticeable (dot line), but when boundary increases to ±2,5 mm (dash line) or ±5 mm (full line) relative error stays around desired 0,3 % level.

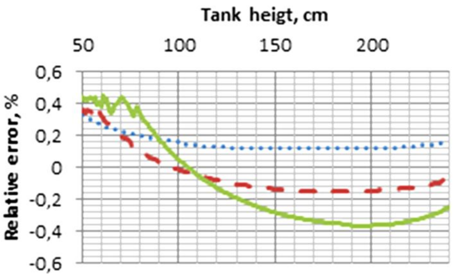

Fig. 8. Dependencies of relative error from data scattering after data filtering.

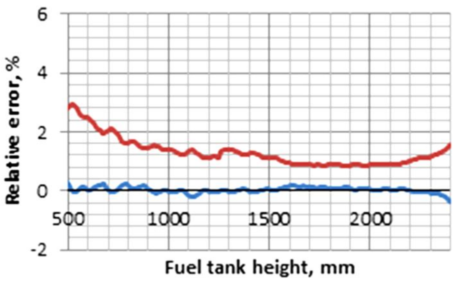

Fig. 9. Dependencies of relative error from data scattering after data filtering using real scanned data.

For experiments with real scanned data we ported scattered data filtering algorithm to LABWINDOWS CVI environment which is based on ANSI C language for faster performance. Cloud of points was formed using only one 1 scan using data merging and scattered data filtering algorithm. Experimental verification of the algorithm was performed with different fuel tanks of various sizes. Figure 9–Fig. 10 represent dependency of relative error from data scattering after data filtering using real scanned fuel tank data. As it can be seen from figures, filtering all unnecessary data improves relative error and helps to keep it in satisfactory ranges ±0.3 % [5] (bottom curve).

The experimental results of 3D scanned data scattering elimination method can be compared with works presented by W. Jintao [6], [7]. Researchers received measured relative error around 0,4 % for horizontal and 0,6 % for vertical fuel tanks. Using our data scattering elimination method we managed to decrease relative error to 0,3 %.

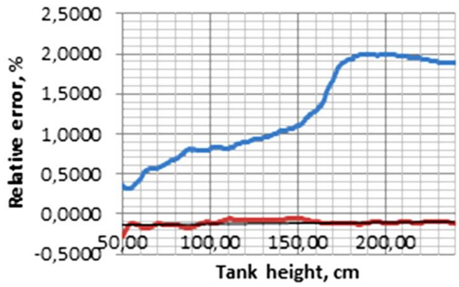

Fig. 10. Dependencies of relative error from data scattering after data filtering using real scanned data.

This article describes the influence of 3D laser scanning data scattering to volume measurement of horizontal fuel tank by means of relative error. Authors present the method for elimination of data scattering effects.

V. CONCLUSIONS

1. Analysis of the different fuel tank scanning methods showed that the best result is received when the fuel tank is scanned from one point and data merging is used. Data merging method forms a side effect – data scattering.
2. Experiments with mathematical model of the fuel tank showed that scattering with boundary of -1 mm to 1 mm gives still acceptable results by means of relative error (stays around 0,3 %), but bigger boundary levels gives unacceptable results.
3. Experiments with ideal fuel tank model showed that the influence of data scattering can be minimized to acceptable level of relative error using data filtering algorithm.
4. Experiments with real scanned data proved that filtering of all unnecessary data improves relative error and helps to keep it in satisfactory ranges ±0,3 %.

REFERENCES

[1] V. V. Nosach, B. M. Belyaev, “The calibration of large vertical cylindrical tanks by a geometrical method”, *Measurement Techniques*, Vol. 45, No. 11, 2002 [Online]. Available: http://dx.doi.org/10.1023/A:1022062532494
[2] V. V. Nosach, B. M. Belyaev, “Salient features of procedures for geometric calibration of large vertical cylindrical tanks”, *Measurement Techniques*, Vol. 46, No. 1, 2003 [Online]. Available: http://dx.doi.org/10.1023/A:1023413606206
[3] V. Knyva, M. Knyva, “New method for calibration of horizontal fuel tanks”, *Elektronika ir Elektrotechnika*, vol. 18, no. 9, pp. 91–94, 2012. [Online]. Available: http://dx.doi.org/10.5755/j01.eee.18.9.2816.
[4] V. Knyva, M. Knyva, “New method for calibration of vertical fuel tanks”, *Elektronika ir Elektrotechnika*, vol. 19, no. 8, pp. 37–40, 2013. [Online]. Available: http://dx.doi.org/10.5755/j01.eee19.8.5391
[5] “Skystų produktų talpyklų patikra 3d lazerinio skenavimo metodu“ BPM 300637345-01:2013. – Lithuania: KTU Metrology institute, 2013. (in Lithuanian).
[6] W. Jintao, L. Zhang, L. Guo, X. Bao, L. Tong, „Precise measurement of liquid petroleum tank volume based on data cloud analysis“, in *Proc. Sixth International Symposium on Precision Engineering Measurements and Instrumentation*, China, 2010
[7] W. Jintao, L. Zhang, L. Guo, X. Bao, L. Tong, „Research on 3D laser scanning method for tank volume metrology and its comparison experiment analysis“, *Chinese Journal of Scientific Instrument*, China, 2010.