GEODESY AND CARTOGRAPHY
Vol. 67, No. 2, 2018, pp. 193–206

DOI: https://doi.org/10.24425/118709

Original research paper

Three dimensional modeling and geometric properties of oil plant equipment from terrestrial laser scanner observations

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Received: 1 September 2018 / Accepted: 10 October 2018

Abstract: Terrestrial laser scanner (TLS) is a new class of survey instruments to capture spatial data developed rapidly. A perfect facility in the oil industry does not exist. As facilities age, oil and gas companies often need to revamp their plants to make sure the facilities still meet their specifications. Due to the complexity of an oil plant site, there are difficulties in revamping, having all dimensions and geometric properties, getting through narrow spaces between pipes and having the description label of each object within a facility site. So it is needed to develop an accurate observations technique to overcome these difficulties. TLS could be an unconventional solution as it accurately measures the coordinates identifying the position of each object within the oil plant and provide highly detailed 3D models. This paper investigates creating 3D model for Ras Gharib oil plant in Egypt and determining the geometric properties of oil plant equipment (tank, vessels, pipes ...etc.) using TLS observations and modeling by CADWORX program. The modeling involves an analysis of several scans of the oil plant. All the processes to convert the observed points cloud into a 3D model are described. The geometric properties for tanks, vessels and pipes (radius, center coordinates, height and consequently oil volume) are also calculated and presented. The results provide a significant improvement in observing and modeling of an oil plant and prove that the TLS is the most effective choice for generating a representative 3D model required for oil plant revamping.

Keywords: oil plant, terrestrial laser scanner, point cloud, 3d modeling, revamping

1. Introduction

Recently, a lot of mechanisms, techniques and new instruments have emerged in civil engineering specifically in surveying. Terrestrial laser scanning, which has a lot of applications in different fields of engineering, is a relatively new and revolutionary surveying technique. The scans from TLS produce a digital data that called a "point cloud" which is dense in a way that every point of this cloud is shown in 3D space as a three dimensional coordinate. TLS can also represent a panorama picture of the objects. The most important advantage of using TLS is that a very high point density which can be achieved within 1 minute with 5 to 10 mm resolution, but increasing density of the points and resolution affect time of scan that may be increase and reach 7 minutes (Yelda et al., 2016).

Laser scanner technology works by sending light and detecting the reflection of the light to determine the distance to the reflected object accurately. TLS has advantages over other conventional instruments in saving significant time, efforts and money. Rather than making a single measurement as in Total Station, TLS has rotating mirrors (or the entire unit rotates) that allow millions of measurements and take a scene in few seconds depending on the type of the scanner (Pareja et al., 2013).

Terrestrial laser scanners have two types: phase shift scanners (short range) and time of flight scanners (long range). Time of flight laser scanner is usually used for long distances and can also measure short distance; however, phase shift laser scanner is used only for short distances, when there is a need of generating an accurate and precise model of a given facility (Ebrahim, 2015).

1.1. Point coordinates determination and its accuracy from TLS

The coordinates (X, Y and Z) of any observed point (i) from terrestrial laser scanner basic measurements can be determined as following (Beshr, 2012):

$$\left.\begin{aligned} X_i &= S\cos\gamma\sin\alpha \\ Y_i &= S\cos\gamma\cos\alpha \\ Z_i &= S\sin\gamma \end{aligned}\right\}, \tag{1}$$

where: γ, α, S – the vertical, horizontal angles and inclined distance respectively.

There are three observations and no redundancy of observations in eq. (1), and consequently there is a unique solution so the multivariate propagation technique (Jacobean method) is used to determine the accuracy of point coordinates.

$$\underset{(3,3)}{C_X} = \underset{(3,3)}{J} \cdot \underset{(3,3)}{C_L} \cdot \underset{(3,3)}{J^T}, \tag{2}$$

where:

C_X – variance–covariance matrix of unknowns,

J – coefficients matrix (Jacobean coefficient),

C_L – variance–covariance matrix of unknowns.

By differentiate equations (1) and substitute in equation (2), the following formulae can be deduced:

$$\left.\begin{aligned} m_X^2 &= \left(\frac{X}{\sqrt{X^2+Y^2+Z^2}}\right)^2 m_S^2 + (Y)^2 m_\alpha^2 + \left(\frac{ZX}{\sqrt{X^2+Y^2}}\right)^2 m_\gamma^2 \\ m_Y^2 &= \left(\frac{Y}{\sqrt{X^2+Y^2+Z^2}}\right)^2 m_S^2 + (X)^2 m_\alpha^2 + \left(\frac{ZY}{\sqrt{X^2+Y^2}}\right)^2 m_\gamma^2 \\ m_Z^2 &= \left(\frac{Z}{\sqrt{X^2+Y^2+Z^2}}\right)^2 m_S^2 + \left(\sqrt{X^2+Y^2}\right)^2 m_\gamma^2 \end{aligned}\right\}, \tag{3}$$

where: m_S, m_α, m_γ – standard deviation (accuracy) of inclined distance, vertical and horizontal angles of the used instrument respectively.

The values m_S, m_α, m_γ can be taken from the specifications of the instrument or experimental tests. In structural deformation monitoring, it is recommended that these values must be calculated experimentally.

1.1.1. Study the range accuracy of terrestrial laser scanner

Range of scans is a function of the laser intensity and reflectivity of the object scanned. The ranging capability of a laser scanner is more important than it first seems. In some cases, the lack of ranging ability will completely eliminate the ability to do certain projects. Ranging errors can be observed when known distances in range direction are measured with the scanner (Beshr, 2012). If scanners are not equipped with a defined reference point (such as forced centering), it is only possible to determine the range accuracy of laser scanner by comparing the accuracy of the calculated distance between reflective marks resulted from laser scanner and the calculated distance from other accurate instrument (for example total station).

The length of side, from its end coordinates, can be calculated by:

$$S = \sqrt{(X_j - X_i)^2 + (Y_j - Y_i)^2 + (Z_j - Z_i)^2}\,. \tag{4}$$

By differentiation equation (4) using propagation law, the accuracy of the side length between two points can be determined by using the following formula:

$$\begin{aligned} m_S^2 = &\left(\frac{X_j - X_i}{D}\right)^2 m_{X_j}^2 + \left(\frac{X_i - X_j}{D}\right)^2 m_{X_i}^2 + \left(\frac{Y_j - Y_i}{D}\right)^2 m_{Y_j}^2 + \left(\frac{Y_i - Y_j}{D}\right)^2 m_{Y_i}^2 + \\ &+ \left(\frac{Z_j - Z_i}{D}\right)^2 m_{Z_j}^2 + \left(\frac{Z_i - Z_j}{D}\right)^2 m_{Z_i}^2\,. \end{aligned} \tag{5}$$

If the coordinates of laser scanner position equal (0, 0, 0) at any scan, then the length of side from any scanned point to the laser scanner position will be expressed in the form:

$$S_i = \sqrt{X_i^2 + Y_i^2 + Z_i^2}\,. \tag{6}$$

So, accuracy of the length of side from any mark to the laser scanner by applying equation (5) can be calculated using the error propagation as:

$$m_S^2 = \frac{X^2}{X_i^2 + Y_i^2 + Z_i^2} m_{X_i}^2 + \frac{Y^2}{X_i^2 + Y_i^2 + Z_i^2} m_{Y_i}^2 + \frac{Z^2}{X_i^2 + Y_i^2 + Z_i^2} m_{Z_i}^2 . \tag{7}$$

1.1.2. Study the angular precision of laser scanner

The laser pulse is deflected by a small rotating device (mirror, prism) and sent from there to the object. The second angle, perpendicular to the first, may be changed using a mechanical axis or another rotating optical device. The readings for these angles are used for the computation of the 3D point coordinates. Any errors caused by the axes (bearings) or angular reading devices will result in errors perpendicular to the propagation path. Since the positions of single points are hard to be verified, few investigations of this problem are known. Errors can be detected by measuring short horizontal and vertical distances between objects (e.g. spheres) which are located at the same distance from the scanner and comparing those to measurements derived from more accurate surveying methods.

1.1.3. Horizontal angles (horizontal plane)

As shown in Figure 1, the horizontal angle α_{AB} can be calculated from the geometry of horizontal triangle $OA'B'$ as following:

$$\cos \alpha_{AB} = \frac{OA'^2 + OB'^2 - A'B'^2}{2OAOB} . \tag{8}$$

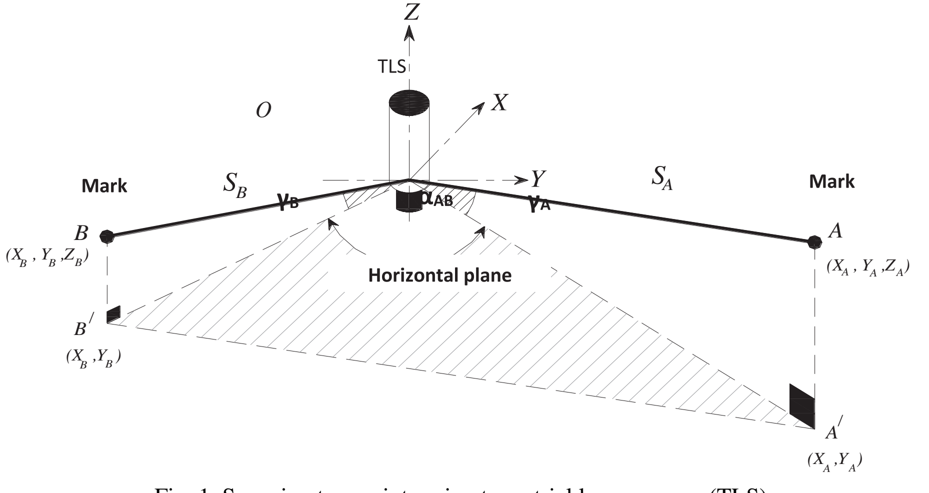

Fig. 1. Scanning two points using terrestrial laser scanner (TLS)

If the coordinates of laser scanner position equal (0, 0, 0) at any scan, the equation (8) can be reconstructed by using the points coordinates as following:

$$\cos\alpha_{AB} = \frac{X_A X_B + Y_A Y_B}{\sqrt{X_A^2 + Y_A^2} \cdot \sqrt{X_B^2 + Y_B^2}}. \tag{9}$$

So, the accuracy of horizontal angle has the form:

$$m_{\alpha_{AB}}^2 = \left(\frac{\partial\alpha_{AB}}{\partial X_A}\right)^2 m_{X_A}^2 + \left(\frac{\partial\alpha_{AB}}{\partial Y_A}\right)^2 m_{Y_A}^2 + \left(\frac{\partial\alpha_{AB}}{\partial X_B}\right)^2 m_{X_B}^2 + \left(\frac{\partial\alpha_{AB}}{\partial Y_B}\right)^2 m_{Y_B}^2. \tag{10}$$

1.1.4. Vertical angles (vertical plane)

From each point in the scanned object it is possible to determine the vertical angle to the laser scanner. If the coordinates of occupied laser scanner station is (0, 0, 0) then the vertical angle from point A (for example), as shown in Figure 1, can be determined as following:

$$\gamma_A = \tan^{-1}\left(\frac{Z_A}{\sqrt{X_A^2 + Y_A^2}}\right). \tag{11}$$

By using the law of propagation, the accuracy of vertical angle can be determined as following:

$$m_\gamma^2 = \frac{\left(X_A^2 Z_A^2\right) m_{X_A}^2 + \left(Y_A^2 Z_A^2\right) m_{Y_A}^2 + \left(X_A^4 + 2X_A^2 Y_A^2 + Y_A^4\right) m_{Z_A}^2}{\left(X_A^2 + Y_A^2\right) \cdot \left(X_A^2 + Y_A^2 + Z_A^2\right)^2}. \tag{12}$$

Manual or automatic image measurements have been used to be measured by close range photogrammetry. It needs spending more time at site, dealing with transparent or reflective surfaces are caused errors, the scan clarity over long distances is kept constant using the camera lenses scale limitations and the user errors may be avoided by depending more on full automated processes and operator experience is very important as it largely affecting in results. However, nowadays in many application areas, three dimensional laser scanners are becoming a standard source for 3D modeling input data (Fabio, 2017). In order to analyse the character and shape of the scanned surfaces, it is necessary to convert irregularly distributed point data into 3D surface information using a surface reconstruction program with no need to go back to the site, where a virtual version can then be created, visualized and interpreted in the office (Slob and Hack, 2004; Hodgetts, 2013 and Hack et al., 2014).

Major environmental disasters such as the Texas City refinery explosion have cast a negative effect on the refinery that occurs in killing 15 workers, injuring more than 180 others and severely damaging. Any disorder occurs might result in many catastrophic failures, so observing and monitoring of this operation is very important. However, the oil and gas industry is still extraordinarily successful and still experiences massive growth (Sabová and Jakub, 2007; Bahadori, 2017). When planning a revamp to an existing oil and gas facility, it is necessary to have a complete and accurate understanding of the currently existing facility objects. TLS provides accurate 3D facility models which make the decisions about objects need to be revamped easier by its ability to take exact measurements. Having a 3D model of the facility supports this capability by providing an easy source of accurate information about the facility. These models are created using 3D laser scanning technology, which bounce thousands of laser points off the facility (Smith, 2015).

Therefore, this paper investigates a geodetic observation technique for detecting oil plant equipment (Tanks, vessel, pump, motor, compressor, dryer and etc...), small pipes and the rest of site for creating 3D modeling by processing and analysis of terrestrial laser scanner observation.

2. Study area and instruments used

The study site, Ras Gharib oil plant, is one of the 17 holding areas of General Petroleum Company (GPC). GPC is the first national oil company in the Middle East and Africa engaged in exploration, production and development of hydrocarbons. GPC was established in September 2nd 1957; the total area of sites is 17719 km^2. The date of exploration of Ras Gharib holding area is 1937; its total area is 100 km^2 and having 278 wells.

Ras Gharib oil plant is one of the GPC five crude oil processing stations in the Eastern Desert (Ras El Behar – Um El Yusr – Ras Gharib – El Hamd – Bakr) as shown in Figure 2 with a total capacity of 1027795 barrels, in addition to Abu Sennan processing station with a capacity of 39060 barrels. GPC erected a major shipping port in Ras Gharib with a storage capacity of 1.543 million barrels (General Petroleum Co., http://www.gpc.com.eg).

Fig. 2. Egypt MAP showing GPC concessions

Ras Gharib oil plant was visited at December 2016 for the first time to explore and photograph the site as shown in Figure 3 to select the suitable type of scanner to be used in the investigation and identify the scanning spots. The site was inspected to identify obstacles and barriers that might limit the use of the geodetic instruments as well as determining the suggested positions of the laser scanner.

Fig. 3. Ras Gharib oil Plant

The terrestrial laser scanner was used in detecting the oil field at Ras Gharib Plant. Optech Long Range as shown in Figure 4 and Faro Short Range laser scanner were used.

Fig. 4. Optech laser scanner (long range)

3. Field work and data acquisition

The point clouds of the studied area were obtained from the processing of several overlapping scans using both the Long and Short Range of TLS. The average time of each scan was 6:7 minutes due to high density of points and high resolution of scan, 8 scans were taken by Optech as shown in Figure 5 and the total number of scans per day by Faro was 20 scans which took in total 3.5 hours without taking into consideration the time of battery change and instruments transportation.

Fig. 5. Yellow spots indicate the occupied instrument positions

Each scan, which had its own coordinate system, must be aligned into one common coordinate system using a registration process. Point clouds were composed of a number of data files including some noise components that were derived from surface quality and laser dispersion. Noise removal and smoothing were performed after registration, and then the data was processed by JRC 3D Reconstructor. The first step was importing the scans and then chose a subsample to compress the scans and to reduce the huge number of points, start to doing preprocess to cleaning the scans from mist or if there were some water in the scanned site that will distort the scans. After that doing preregistration that to connect between scans and merge the modeled object into the original scene, finally, choose the un-structure to division the all area into a small one that easy to draw it, Choose the unstructure and right click then choose export in JRC to las format file, which was specially created to providing 3D modelling.

4. Surface reconstruction and modeling

The generation of surfaces of oil plant and its construction from point clouds produced with laser scanner is described as following:

Modeling by CADWORX:

Modeling Work flow using

- Cyclone Programm;
- CADWORX Plant I;
- CADWORX Field Pipe;
- CADWORX Equipment.

First: Create a spec catalog for the data that took from the oil and gas company using CADWORX specification Editor.

Second: import the point cloud to CADWORX field pipe by using cyclone program.

Third: import the points cloud to CADWORX then start to draw on the points cloud by picking each item in the oil plant as shown in Figure 6.

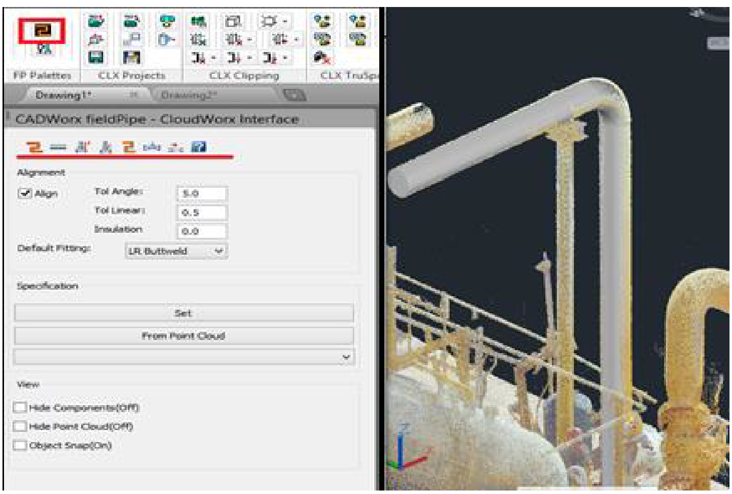

Fig. 6. Drawing the pipeline by picking on the pipe on loaded point cloud

5. Visualization and result

At the available 3D modeling software like Naviswork, AutoCAD plant 3D, Autodesk inventor or EdgeWise 3D, the data of point cloud cannot be properly visualized and the points appear with unknown dimensions limiting the 3D model accuracy (Reeves, 1983; Pfister et al., 2000). The visualization of a 3D model is often the only outcome of interest for the oil and gas companies and remains the only possible contact with the model. However, drawing on CADWORX gives good results and provide realistic visualization (Streilein and Beyer, 1991).

Results of this research confirm the realistic and accurate visualization of the observed point cloud as shown in Figure 7. Description lapel of the drawing item appears when clicking on it that shown in Figure 8.

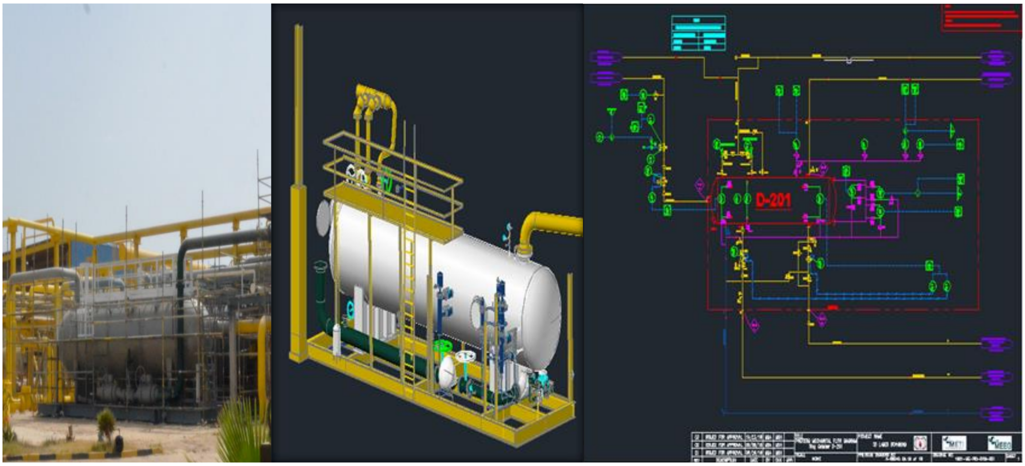

Fig. 7. 3D modeling confirmed the reality and P&ID drawing

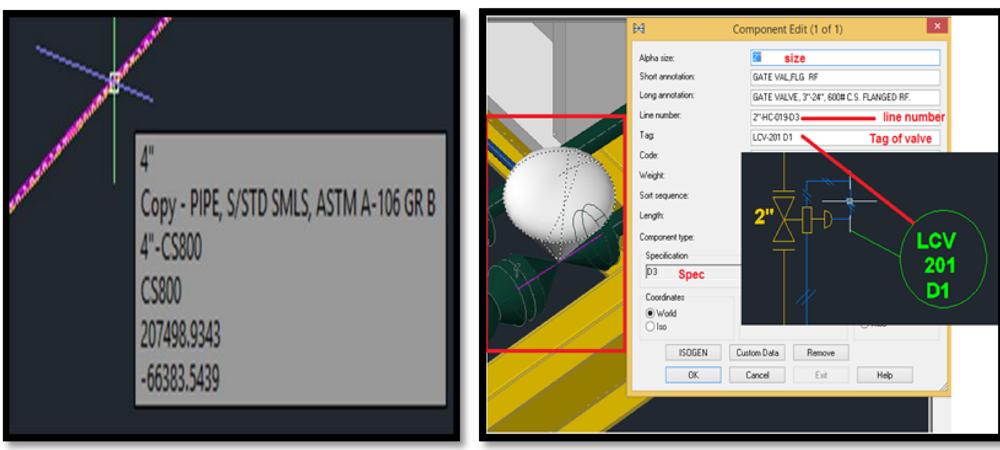

Fig. 8. Lapel of description in pipeline and valves

6. Geometric Properties of oil equipment and pipes from TLS observations

One of the main objectives of this paper is finding the geometric properties of oil plant equipment (tank radius and height, vessels diameter and length, pipe line diameter etc.). In this section, the calculation for tank radius, vessels radius and pipes radius and lengths are done.

The radius r of circular structure from the coordinates of n points (more than three points) coordinates of center (X_C, Y_C) can be determined as following using least square technique.

Any point on the circular section of tank surface (X_i, Y_i) must satisfy the equation of a circle:

$$(\hat{x}_i - \hat{x}_c)^2 + (\hat{y}_i - \hat{y}_c)^2 - \hat{r}^2 = 0. \tag{13}$$

In which X_C, Y_C, and r are the unknown coordinates and radius respectively, of the circular cross section. Since the observables and parameters are not separable in Equations (13), the general combined method of least squares adjustment must be used. For this case, the general linear form of Equations (13) for n points take the form:

$$\underset{(n,u)}{A} \cdot \underset{(u,1)}{X} + \underset{(n,m)}{B} \cdot \underset{(m,1)}{V} + \underset{(n,1)}{L} = \underset{(n,1)}{0}, \tag{14}$$

in which:

n – number of equations; in this case n equals the number of monitoring points;
u – number of unknowns; in this case $u = 3$; radius r and coordinates X_C, Y_C;
m – number of observations; $m = 2n$ for this case;
A – matrix of partial differentials of Equations (13) with respect to (X_C, Y_C, r);
B – matrix of partial differentials of Equations (13) with respect to $(X_1, Y_1, X_2, Y_2, \ldots, X_n, Y_n)$;
L – column matrix of constant terms associated with each of Equations (13);
V – vector of residuals $(V_1, V_2, \ldots, V_n)$ of the observed coordinates.

For applying the least squares adjustment technique, approximate values of the unknowns (radius r^0 and coordinates of center (X^0, Y^0) must be assumed or calculated. Then, the steps of combined least square method must be done to find the corrected values of radius, coordinates of center and their associated accuracies.

MATLAB program using least square method as mentioned was designed to find the geometric properties using n points on the outer surface of tank, pipe and vessel. The tank was divided into sections to determine the radius and center coordinates for each section. The results are shown in Tables 1 and 2.

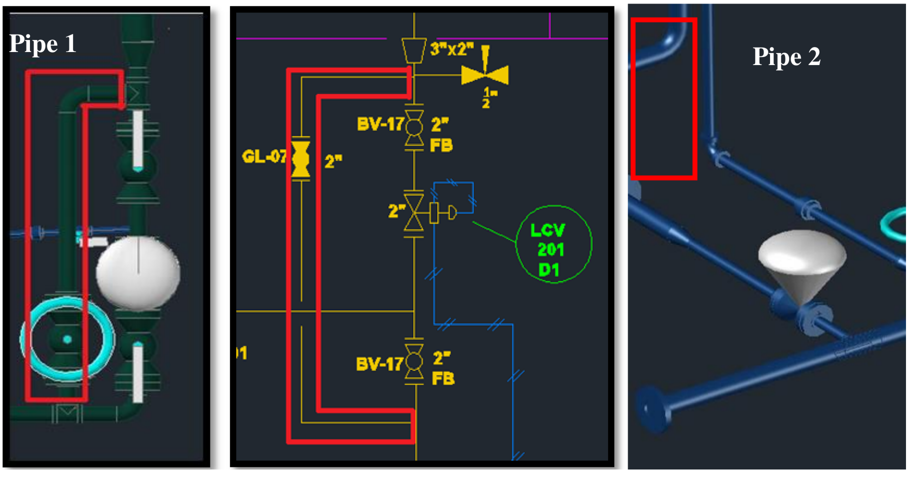

Fig. 9. Pipe 1 and pipe 2

Table 1. Geometric parameters of circular steel oil Tank using TLS observations and least square technique

Tank 1						
Section from – to	r, m	$\sigma\, r$, m	X, m	$\sigma\, x$, m	Y, m	$\sigma\, y$, m
1 m : 5 m	Concrete skirt					
5 m : 6 m	2.9394	0.00124	–229.816	0.00139	0.9716	0.00182
6 m : 7 m	2.9738	0.00091	–227.899	0.0046	2.9416	0.00194
7 m : 8 m	2.9913	0.00219	–227.807	0.0032	–0.9109	0.000911
8 m : 9 m	2.9114	0.0031	–227.844	0.0011	–0.8025	0.0022
9 m : 10 m	2.8906	0.0011	–227.896	0.0013	–0.8705	0.0019
10 m : 11 m	2.932	0.0039	–227.328	0.0011	–0.9003	0.0013
11 m : 12 m	3.0027	0.00476	–227.816	0.00175	–0.9164	0.000912
12 m : 13 m	3.0372	0.00137	–227.943	0.00381	–0.9143	0.00278
13 m : 14 m	2.998	0.00313	–227.853	0.00311	–0.983	0.00283
14 m : 15 m	3.002	0.00242	–227.889	0.00324	–0.995	0.0017
15 m : 16 m	2.986	0.00215	–227.873	0.00271	–0.901	0.00093

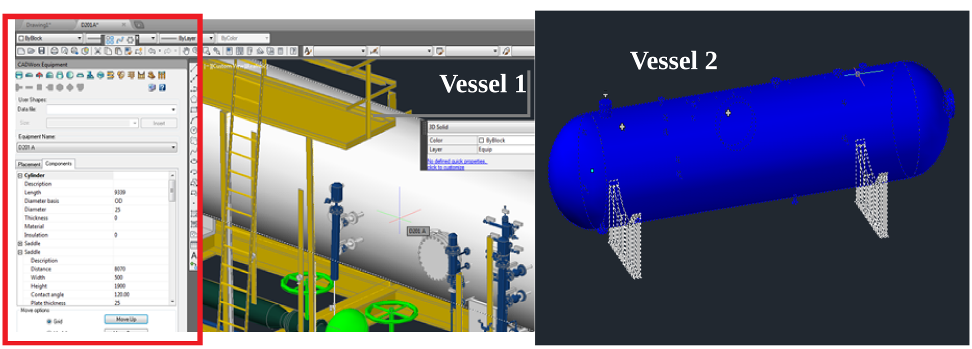

Fig. 10. Pressure vessel 1 and vessel 2

Table 2. Geometric parameters of Pipes and Vessels using TLS observations and least square technique

	r, m	$\sigma\, r$, m	Length, m
Pipe 1	0.250013	0.0013	2.0072
Pipe 2	0.112579	0.000532	4.0171
Vessel 1	12.49768	0.00432	9.9871
Vessel 2	10.00213	0.00331	8.0041

7. Conclusion

This research introduces 3D data acquisition, processing, modeling and visualization using Terrestrial Laser Scanner observations for oil plant at Ras Gharib in Egypt that needed for revamping. Based on the results of field work, data analysis and processing, the following conclusions can be summarized:

1. The results provide a significant improvement in observing and modeling of oil plant equipment and prove that terrestrial laser scanner is the most effective choice for generating a representative 3D model for oil plant revamping because of its speed of data capture and reducing observations time.
2. Accuracy of laser scanner observations depends mainly on the accuracy of the used scanner basic measurements (accuracy of measured slope distance, accuracy of horizontal and vertical angles) and also on the required resolution of creating 3D model besides the position of scanner according to the scanned object.
3. The applied technique for processing scanner observations using Cyclone program is effective and can be applied for any scanner observations. CADWORX is also considered the best software dealing with point cloud which can be properly visualized and appeared with known dimensions.
4. The designed MATLAB program using least squares adjustment technique is very appropriate for adjusting the geodetic TLS observations and can be used for determining the radius and center coordinates of any circular section (circular tank, pipes, vessels, circular building . . . etc.) and its accuracy.

Acknowledgement

The authors want to thank all members and staff of MEEG (Micro Engineering Egypt) company for helping in the field observations collection. The data for this work was supported by this company.

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