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The Research Application of 3D Laser Scanning Technology in the Deformation Detection of Large Cylindrical Oil Tank

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Abstract: In order to ensure the safety in using a large cylindrical storage tank, it is necessary to regularly detect its deformation. The traditional total station method has high accuracy in determining the deformation, however, it has a low measurement efficiency. Long-term observation means, there are more risks in the petrochemical plant, therefore, this paper proposes the usage of the 3D laser scanner, replacing the traditional total station to determine the deformation of a large cylindrical storage tank. The Matlab program, is compiled to calculate the point cloud data, while the tank deformation is analyzed from two different points which are, the local concave convex degree and the ovality degree. It is concluded that, the difference between the data obtained by 3D laser scanning, and total station is within the range of oil tank deformation limit, therefore, 3D laser scanner can be used for oil tank deformation detection.

Keywords: 3D laser scanning technologies; Large cylindrical oil tank; Locally concavo convex; Ellipticity

1. Introduction

Oil is an important energy for the sustainable development of the society. To ensure the safety of the oil, the oil reserve system has been established in China and in other countries. Large cylindrical oil storage tanks are used to store the oil, because it has some advantages, such as, saving the material, need small land to store the tank, and also it is easy to manage, therefore, large cylindrical oil tanks have become the main equipment for storing the oil [1].

The oil storage tank deformation, such as, the loose of sealing ring of the floating roof storage tank, leading to mixture of a high concentration of oil and gas, which can cause fire is something due to happen in the long-term usage of the tank due to many external factors [2,3], therefore, it is important to frequently test the deformation of the oil storage tank based on the local concavity and ovality to avoid any accident which may cost heavy lost [4]. The place for storing the tank, and to transport the oil products is very complex, and it is known as oil depot.

In the traditional detection method, the data regarding deformation are collected inside the oil tank by total station. The collect data is very accurate, however, it is time consuming and inefficient, additionally, due to the special measurement, the environment in the petrochemical plant might be dangerous due to oil and gas leakage, which may have a big potential of safety hazard in the long-term measurement. Compared with the total station method, the three-dimensional (3D) laser scanner can obtain the deformation measurement data more quickly, efficiently and safely [5-8]. Therefore, in this paper, we propose the use 3D laser scanning technology to measure the deformation of the oil storage tank.

2. 3D laser scanning

To confirm that, the 3D laser scanner is correctly reflecting the deformation of the large cylindrical oil tank in the term of geometric dimensioning, two different methods which are Leica 1202r3 total station, and German Z + F 5010 three-dimensional laser scanner was used to collect the deformation data from the same oil tank, and under the same conditions, further the data that is obtained from both the methods were processed and compared [5].

There are two techniques used to collect the point cloud data of the tank body by using the 3D laser scanner, which are the outer method and the inner method [9]. For the outer method, at least three targets around the tank body were selected, and scanned through multiple scanning to obtain the complete data of each station. In the areas with the external insulation layer of the oil tank, it is impossible to measure the oil tank on the outside or on the body, therefore, the internal scanning method was used by directly placed the scanner at the bottom center of the tank to obtain the measurement data at one time.

The original point cloud data, cannot be used directly to represent the information on the deformation of the oil tank, due the influence of the external environment and multiple stations, therefore, the data is preprocessed to exclude the noise and thinning (M25) as mentioned below [10].

(1) Denoising: 3 dreshaper software is used to visualize the point cloud data, and the software was used for internal deletion of the useless preliminarily data, followed by denoising.

(2) Thinning: due to the large amount of 3D laser scanning data and to facilitate the subsequent calculation work, the point cloud data are sparse processed, and the point cloud spacing is changed to 2 meters by using 3 dreshaper software.

3. Data processing

Matlab program is written to adjust the pretreated point cloud data [11], to obtain the center coordinates and radius at the fixed height, further the concavity and ovality of the height through the center coordinates, and radius were calculated. The overall deformation degree of the tank is determined by counting the concave convex degree, and ovality at each height of the tank body.

3.1. Extract center coordinates and radius

The tank center coordinate is located on the central axis, and the theoretical position of the central axis is on the plumb line is the point where the center point is located. However, the tank central axis is usually not in a vertical position, therefore, the tilt parameter correction [12] of the tank body should be considered when calculating the center coordinate and radius. As shown in **Figure 1**, xyz-0 is the coordinates system in the observation coordinate system, $uvh-o$ is the origin in the coordinate system coincides with the coordinate system of the observation point and h is the axis that is parallel to the central axis of the tank body. According to the principle of coordinate transformation, $uvh-o$ is assumed to coordinate the system around u axis in clockwise rotation, with angle α and then around v axis in a clockwise rotation and angle β after the xyz-0 Coordinate system.

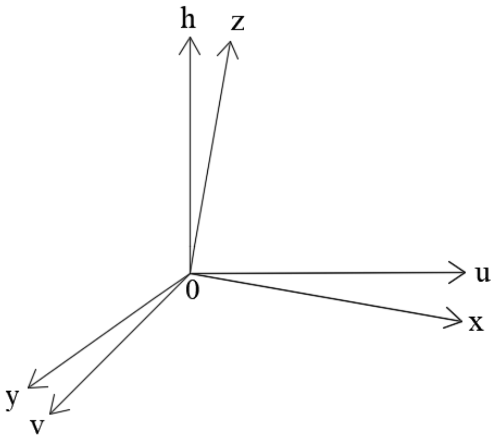

Figure 1. Diagram of observation coordinates

The center coordinates of the tank, is set to the bottom at xyz-0. The coordinates in the coordinate system are $(x_0, y_0, 0)$ existing h_i Any observation point at altitude i (x_i, y_i, z_i). According to the geometric properties of the oil tank cylinder, the formula of coordinate increment is given

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ 0 \end{bmatrix} + R_v(\beta) \cdot R_u(\alpha) \begin{bmatrix} r\cos\theta_i \\ r\sin\theta_i \\ h_i \end{bmatrix} \qquad (1)$$

In equation (1), r Design the radius of the tank, θ_i As point, i The azimuth angle relative to the center point of the tank bottom, $R_u(\alpha)$, $R_v(\beta)$ They are winding u Shaft and v Rotation matrix of the axis. The following error equations are listed:

$$\begin{bmatrix} v_{x_i} + x_i \\ v_{y_i} + y_i \\ v_{z_i} + z_i \end{bmatrix} = \begin{bmatrix} dx_0 + x_0 \\ dy_0 + y_0 \\ 0 \end{bmatrix} + R_v(\beta + d\beta) \cdot R_u(\alpha + d\alpha) \begin{bmatrix} (r + dr)\cos\theta_i \\ (r + dr)\sin\theta_i \\ h_i \end{bmatrix} \qquad (2)$$

Since the purpose of this detection is the size of the shape variable, and has nothing to do with the height, in order to improve the efficiency z Remove the value. The unknown parameters are proposed and simplified.

$$\begin{bmatrix} v_{x_i} \\ v_{y_i} \end{bmatrix} = B \begin{bmatrix} dx_0 \\ dx_0 \\ d\alpha \\ d\beta \\ dr \end{bmatrix} + l \qquad (2)$$

Among B Is the coefficient matrix, l Is a constant vector. List according to this method n All of the observation points, 2n individual, $V = B\hat{x} + l$ Error equation of form. By applying $V^T PV = \min$ The correction and radius of the center point are obtained, $X = -(B^T B)^{-1} B^T l$ Set the initial approximate value of each parameter, where the rotation angle α_0, β_0 The initial value is 0, (x_0, y_0). Take the average value and radius of each observation point r Take the design value. After the adjustment value [13] is obtained, the adjustment value is substituted into the original formula as the next approximate value to increase the accuracy of the result until the correction number is close to 0, and the optimal center point coordinate value and radius value are obtained.

3.2. Calculation of concave convex degree of tank body

Concavity and convexity are defined as the difference between the distance between the observation point and the central axis and the design radius $\Delta i = r_i - r$. Firstly, the distance between the coordinates of each observation point, and the center coordinates at a fixed height is calculated r_i . Next, the concavity and convexity of each observation point at the same height can be obtained by subtracting the design radius. If $\Delta i_i > 0$, then the point is convex outward, otherwise it is concave inward.

3.3. Calculation of tank wall ovality

The central coordinates and radius are also used to calculate the ovality. Ovality [14], is defined as the difference between the maximum and the minimum diameter at the same height of the tank wall with either α_i in this direction, the distance from the observation point to the center coordinate is the radius R ,and $\alpha_i + \pi$ direction radius R' add to get the diameter in this direction.

The irregular distribution of observation points will result in the absence of observation points in some directions at a certain height. At this stage, the direction of interpolation processing, through the interpolation of adjacent points to achieve the completion of observation points take R_i is the value range of interpolation points, for example, $(\alpha_i \pm R_i)$. Each observation point is identified by the program, and the points that meet the regional conditions are included in the interpolation calculation. To avoid the leakage point caused by the angle equal to 0, the judgment interval is divided into two sub-intervals which are:

$(downlimit,\ midlimit1)$ and $(midlimit2,\ uplimit)$ .When $\alpha_i + R_i > 2\pi$ or $\alpha_i - R_i < 0$ When, $midlimit1 = 2\pi$, $midlimit2 = 0$, otherwise $midlimit1 = midlimit2 = \alpha_i$ 。

Take the 0 azimuth as the starting direction, search the observation points at 1 interval, and sample the point by point until all azimuth points are collected. According to the above method, the diameters are obtained of all the directions, screen, and their maximum and minimum values are recorded, and the ovality at this height were calculated.

4. Comparison of experimental data

Under the same conditions, the data measured by the method, the total station and the 3D laser scanner for several oil tanks were compared, to prove the reliability, and the accuracy of the data obtained by 3D laser scanner.

The radius of the oil tank measured by the three-dimensional laser scanner is 39.981m, and the central axis incline for 216 seconds at the clockwise position of 173 degrees due east, with a deviation of 13mm from the highest and lowest points of the central axis. Meanwhile, the radius of the oil tank measured by the total station is 39.986m, and the central axis are inclined for 111 seconds at in a clockwise position of 172 degrees due east, with a 7mm offset from the highest and lowest points of the central axis.

Taking the height range from 1.5m to 13.5m as an example, the maximum concavo-convex degree and ovality measured is calculated by different methods, and the comparison chart is drawn with the Matlab program as follows. From the observation of **Figure 2**, it can be seen that the curve fits well, indicating that the two sets of the data are very close, and the three-position laser scanner can correctly reflect the deformation information on the oil tank.

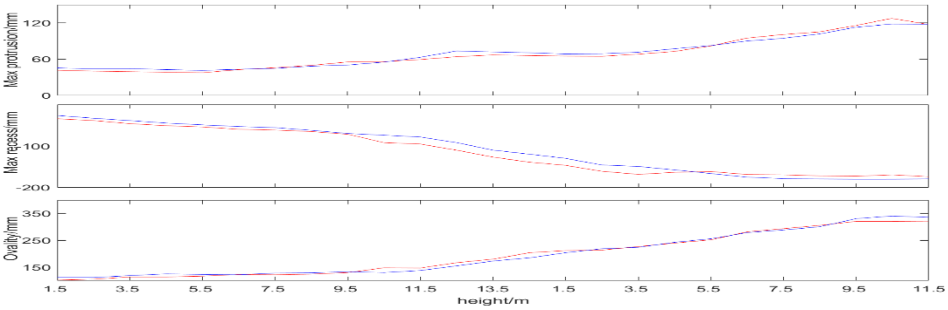

Figure 2. Comparison curve of two measurement results

— 3d laser； — Total station；

Table 1. Comparison of two measurement results

Height/mm	Maximum protrusion/mm		Difference value /mm	Maximum concave/mm		Difference value /mm	Ellipticity/mm		Difference value /mm
	Total station	3d laser		Total station	3d laser		Total station	3d laser	
1.5	41.7	45.4	-3.7	-34.3	-26.5	-7.8	102	112	-10
2	40.2	43.8	-3.6	-38.5	-33.1	-5.4	105	112	-7
2.5	39.4	44.2	-4.8	-46.3	-38.6	-7.7	114	119	-5
3	38.5	42.6	-4.1	-51	-44.8	-6.2	114	125	-11
3.5	37.6	41.4	-3.8	-53.9	-49.1	-4.8	117	123	-6
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
11.5	100.6	94.5	6.1	-169.2	-175.1	5.9	294	289	5
12	105.1	101.6	3.5	-171.7	-179.4	7.7	306	301	5
12.5	115.5	112.6	2.9	-172.6	-180.2	7.6	321	331	-10
13	127.5	118.2	9.3	-169.2	-180.1	10.9	321	341	-20
13.5	117.5	117.8	-0.3	-173.9	-179.2	5.3	322	336	-14

Analysis of the **Table 1**, showed that, the difference of the maximum bulge value is 9.5mm at 7m and -0.3mm at 13.5m, the difference of the maximum concave value is -19.4mm at 8m and -2mm at 5.5m, while, the ovality difference is 20mm at 13 meters and 1mm at 4 meters.

Table 2. Median comparison of absolute value of difference

Median of absolute value of maximum protrusion difference/mm	Median of absolute value of maximum concave progress difference/mm	Mean value of absolute value of ellipticity difference/mm
3.3	6.2	3

It can be seen from **Table 1** that the differences of various indicators are unevenly distributed, and is affected by extreme values. Therefore, instead of using the average, using median can reflect the overall level of data more truly. According to GB 50128-2014 Code for Construction of Vertical Cylindrical Steel Welded Storage Tank, the local bump detection tolerance is ±25mm, and ovality tolerance is ±19mm. From **Table 2**, the median absolute value of the difference between the maximum concave and convex is 3.3mm, 6.2mm and 3mm, respectively, and the values are far less than, the tolerance value. Combined with **Figure2**, the fitting degree of the two kinds of data is shown more intuitively. The comprehensive results show that, the concave-convex value, and ovality reflected by the test data are mainly the deformation information of the oil tank, and the error caused by the measurement can be neglected. Therefore, the three-dimensional laser scanning data can be used to accurately reflect the deformation information of the oil tanks.

5. Conclusion

In this paper, to solve the problems of time-consuming, and high risk in the inspection of large oil tanks, a method of fast and safe data acquisition using a 3D laser scanner instead of traditional total station is proposed. Through the comparative analysis of the deformation data collected by these two instruments, the curve of for deformation value changing with height is very close. Then the difference of deformation data obtained by the two instruments is extracted, and it is found that, it is far less than the specified tolerance of oil tank deformation. It is proved that the accuracy of data collected by 3D laser scanner can meet the requirements of oil tank deformation information detection, and can accurately reflect the deformation degree of oil tank.

With the development of the 3D laser scanning technology, the data acquisition process becomes more efficient and safer. Three-dimensional laser scanner, can describe the deformation of the oil tank with detailed structure and more accurately [15-16], compared to the traditional method. However, the point cloud data have a large amount of data, high processing cost, and high requirements for software. Optimizing software, compressing data, and saving cost are the next directions of the research.

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Disclosure statement

The authors declare no conflict of interest.

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