The terrestrial laser scanning during the industrial object construction results analysis

A A Kuznetsova 1*, M J A Bryn 2

1Limited liability company Trimetari Consulting, 108 A, Torez Ave., Saint-Petersburg, 194017, Russia
2Emperor Alexander I St. Petersburg state transport university, 9, Moskovsky pr., Saint-Petersburg, 190031, Russia

E-mail: anzhelikaalexeevna@gmail.com

Abstract. This paper shows the results of monitoring the construction of industrial facility using terrestrial laser scanning and BIM. The construction object’s monitoring has been carried out for one year, from the moment of the foundations’ installation beginning to the main supporting building structures installation end. During the monitoring period, the geodetic basis for construction controlled, terrestrial laser scanning controlled, laser scanning data processing controlled, the construction of an executive digital information model controlled and the mounted structures deviations identification from their design solutions were performed.

Introduction

When carrying out the construction and installation works at industrial sites, one of the important tasks is the installed structures critical deviations timely detection from the design solution. Stating the high density of industrial buildings, it is necessary to conduct the geodetic monitoring of the mounted structures deviations in a short time. One of the tools to solve this problem may be the joint use of terrestrial laser scanning technologies (TLS) and BIM [1-2]. Technological scheme of the work and analysis of the results are presented in this paper.

Characteristics of the object and conditions of work

The object was a unit for processing straight-run gasoline fractions. The total building area was 33 thousand m². The facility consisted of the technically complex structures with a height of over 90 m. The facilities were open shelves, interdepartmental racks and blocks of columns, saturated with metal structures, equipment and pipelines. NLS on the construction site was carried out for one year, from the start of installation of the foundations to the end of the installation of the main supporting building structures. During this period, 5 periodic cycles consisting of the following stages were performed [3]:

Step 1. Controlled the geodetic basis for construction (GBC);
Step 2. Measurements with terrestrial laser scanning technique;
Step 3. Cloud registration;
Step 4. Create as-built BIM using a point cloud;
Step 5. Identification of deviations of the mounted structures from their design solutions.
Table 1 presents the schedule of cycles.

**Table 1.** Cycle execution schedule

| Climatic conditions, °C | march | june | september | december | march |
|-------------------------|-------|------|-----------|----------|-------|
|                         | -2    | +30  | +7        | -18      | -3    |

**Controlled the geodetic basis for construction**

The construction and equation of the GBC was conducted from the reference baseline at the work site. A detailed description of the technology of building GBC is described in [3]. In total, 62 points were fixed on the construction site, which were evenly distributed throughout the site. The points of the GBC were possible to be installed only on the existing structures due to the characteristics of the object and the limitations in visibility. This precluded the possibility of the measurements from the GBC points. The GBC stability control was performed in each of the 5 cycles. Subsequently, the baseline strongholds were shifted at the construction site. A closed course of polygonometry was laid. The measurements were made at the GBC points to control the location of the points of these items from the stations of the course. The measurements were performed at several points of the GBC from each station. Excess on the sides of the course was determined by the trigonometric leveling. From each station by a single polar approach, the measurements were made of vertical, horizontal angles and distances to points of the GBC. In the CredoDAT software package, the coordinates of the GBC points were taken as the initial ones when the obtained measurements were equalized. Further analysis of the adjustment results was carried out according to the amendments statement. This statement shows the stations from which the measurements were made, the points of the GBC to which the measurements were made, the reduced value of the measurements and the correction to the measurement relative to the coordinates of the reference points. It was stipulated that if the amendment to the measurement of angles, distances or elevations has values higher than permissible according to the network construction requirements presented in Table 2, then such points were considered unstable and were excluded from the reference points. Accordingly, for such points the new coordinates were calculated. In the process of building a closed loop, a measurement log was formed, which took into account the requirements for the construction of a closed loop.

**Table 2. Requirements for building a closed loop**

| Network name | Corners RMSE (sec) | Directions RMSE (sec) | RMSE the lines, m (without ppm) | Directional angles RMSE (sec) | Allowable residual (sec) | RMSE the relative position of the points (m) | Relative error |
|--------------|--------------------|-----------------------|-------------------------------|-------------------------------|-------------------------|---------------------------------------------|---------------|
| 2nd discharge OMC | 2 1,414 | 0,0015 | 3,5 | 5,0 | 0,070 | 1:20000 |           |

As a result of the GBC control in the period from March to December, a shift was detected at three points. In spite of the fact that construction was intensively conducted on the site of the facility, cranes, pile driving machines, etc., worked. The GBC points remained in a stable position. During the period of negative temperatures from December 2018 to February 2019, deformations of eight GBC points were detected. The causes of this situation may be deformations of metal structures due to low temperatures, various fixings of metal structures at the installation sites of the GBC, different component composition of metal structures, as well as soil deformation.
**Terrestrial laser scanning**

TLS was carried out only for the new structures during each periodic cycle. For the reinforced concrete and metal supporting structures (foundations, floors, columns, beams, connections, etc.) their position was controlled. The number of stations in each cycle increased depending on the speed of construction and decreased by the end of construction. The number of stations is shown in Table 4. It was decided to divide the entire area into areas for performing the TLS with equalization of the scan results at these sites separately due to the large area of the construction site. This technology has reduced the accumulation of errors due to the large number of stations in the point cloud.

Ensuring a stable position of the point cloud was an important task for the whole complex of works. Therefore, the results of each subsequent scan cycle were compared with the previous and first cycles. The results of the scan of all cycles (Figure 1) were combined to analyze the differences of each cycle from the original. The results are shown in Table 3.

![Combined TLS results for all cycles](image)

**Table 3. Stability analysis of point clouds between cycles**

| The name of the object in the cloud of points | Section height from ground level, mm | Pipe diameter, mm | Maximum difference axis X, mm | Maximum difference axis Y, mm | Maximum difference axis Z, mm |
|---------------------------------------------|-------------------------------------|------------------|-------------------------------|-----------------------------|-----------------------------|
| Smokestack 60 m                             | 9915                                 | 6536             | 5                             | 9                           | 7                           | 4                           |
| Smokestack 90 m                             | 9739                                 | 8160             | 6                             | 8                           | 3                           | 5                           |

The results of the point cloud mutual and external orientation
The method “cloud-to-cloud” [4-7] was chosen from all the existing types of scans relative orientation for performing the work. This method was the most optimal due to the need to scan an industrial object with very dense buildings and a large saturation of building structures. A mark coordinates catalog was created for the exterior orientation of a point cloud, obtained during the inspection points of geodetic basis for construction. Then it transformed into a cloud of points. The centers of marks in the point cloud were assigned the corresponding coordinates from the catalog, thus the point cloud was oriented relative to the given coordinate system. The technology of mutual and external orientation was the same for all scanning cycles. The results of orientation are presented in Table 4.

Table 4. The results of mutual and external orientation of the point cloud

| Number of cycle | Number of station | Number of constraints | RMSE mutual orientation of scans, m | RMSE external orientation of scans, m |
|-----------------|-------------------|-----------------------|-------------------------------------|-------------------------------------|
| 1               | 205               | 6807                  | 0.0028                              | 0.0013                              |
| 2               | 246               | 4672                  | 0.0020                              | 0.0008                              |
| 3               | 401               | 12006                 | 0.0023                              | 0.0010                              |
| 4               | 138               | 892                   | 0.0021                              | 0.0016                              |
| 5               | 156               | 1321                  | 0.0028                              | 0.0012                              |

BIM Creating and identifying deviations from the project

The resulting cloud of points was transferred to the computer-aided design (CAD) system for analyzing the compliance of the assembled structures with design solutions. For the analysis, an executive BIM was created by adjusting a copy of the elements of the project BIM in accordance with their actual location and dimensions in the point cloud. Further, in CAD a comparison of project and executive BIM was made. This method allowed to analyze a large number of structures using the tools of automated comparison in CAD in a short time. Also, this method allowed to quickly identify potentially dangerous areas of construction due to the visualization of deviations on the three-dimensional information model. Analysis of the identified deviations for all work cycles is presented in Table 5.

Table 5. Analysis of the deviation detected

| Type of structure | Number of mounted structures | Number of structures mounted with deviations of more than 15 mm |
|-------------------|-----------------------------|-------------------------------------------------------------|
|                   |                             | cycle 1                                                      |
| Foundations       | 3230                        | 130                                                         |
| Column            |                             | 124                                                         |
| Beam              |                             | 640                                                         |
| Only              |                             | 894                                                         |
|                   |                             | cycle 2                                                      |
| Foundations       | 2803                        | 125                                                         |
| Column            |                             | 116                                                         |
| Beam              |                             | 528                                                         |
| Only              |                             | 769                                                         |
|                   |                             | cycle 3                                                      |
| Foundations       | 5483                        | 106                                                         |
| Column            |                             | 122                                                         |
| Beam              |                             | 1833                                                        |
Summary
This article describes the results of the combined use of TLS and BIM study in monitoring the construction of industrial facility. The authors proposed a technological scheme of work. The article describes the analysis of the results of geodetic basis for construction, the registration cloud of laser scanning data. Additionally, an analysis was conducted of the points between different cycles cloud position stability. The technology of BIM formation is described and the results of mounted structures deviations detection from the design positions are shown. As a result, it can be concluded that the combined use of TLS and BIM can be used to solve the building monitoring tasks.

References
[1] Smith D K, Tardiff M 2009 Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers, John Wiley and Sons (Inc, New Jersey).
[2] Abdul Shukor S A 2015 3D Terrestrial Laser Scanner for Managing Existing Building (Journal Technology. Sciences and Engineering) 76 (12) 133-139.
[3] Kuznetsova A A 2018 The Use of Laser Scanning to Detect Deviations of Structures from their Design Values (Geodesy and Cartography) 79 (12) 2–7.
[4] Paul J. Besl, Nail D. McKay 1992 A Method for Registration of 3-D Shapes (IEEE Transactions on Pattern Analysis and Machine Intelligence) 14 (2) 239-256.
[5] Makovetskii A Yu, Voronin S M, Tihonikh D V, Alekseev M N 2017 Closed Form Solution of ICP Error Minimization Problem for Affine Transformations (Chelyabinsk Physical and Mathematical Journal) 2 (3) 282-294.
[6] Yang B, Zang Y 2014 Automated Registration of Dense Terrestrial Laser-Scanning Point Clouds Using Curves (ISPRS Journal of Photogrammetry and Remote Sensing) 95 109–121.
[7] Akca D 2003 The Fully Automatic Registration of Laser Scanner Point Clouds (Optical 3-D Measurement Techniques) 5 330-337.