THE CHALLENGE OF AUTOMATION FOR LARGE SCALE TOPOGRAPHIC MAPPING OF OIL AND GAS DEPOSITS BASED ON TERRESTRIAL LASER SCANNING DATA

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ABSTRACT:

Terrestrial laser scanning (TLS) is a modern method of spatial data acquisition. The most common application of this method is large scale topographic mapping. Point clouds obtained with laser scanning contain all necessary data for producing topographic maps and plans. One of the territories, where TLS is particularly important, is oil and gas deposits. Built-up areas of oil and gas deposits are represented with complicated industrial objects. On the one hand, introduction of TLS method for surveying of these areas significantly speeds up field surveying works. On the other hand, dense point clouds of built-up areas slow down the process of mapping due to the necessity to filter extra data. To hasten the process of mapping special algorithms of feature extraction from point cloud and techniques of compiling plan and maps are being developed. Nonetheless, majority of developed algorithms can work fine for point clouds of high uniform density where the number of objects is not large. For built-up areas developed algorithms can be not applicable. The basic steps of compiling a topographic plan are described. It is discussed which object types can be automatically extracted and vectorized in built-up areas of oil and gas deposits. The examples of manual point cloud vectorization are given.

1. INTRODUCTION

Topographic mapping is a process of representing a part of the Earth's surface in a two-dimensional coordinate system with reducing in several times. Earth's surface elements are displayed in maps using points, lines, and area symbols (Bettinger et al., 2020). Information about relief is represented in the form of digital elevation models, contours, ground elevations. Depending on a scale topographic maps or plans are produced. Basic scales for topographic maps are 1:25000, 1:50000, 1:100000, 1:200000, 1:500000 and 1:1000000 whereas for topographic plans – 1:10000, 1:5000, 1:2000, 1:1000 and 1:500. For built-up urban territories topographic plans at a scale of 1:1000 and 1:500 are produced (Theotop, 2022). All area objects are mapped in a certain order accordingly to common recommendations (Kent, 2009). The technique of producing topographic maps and plans depends on the size of a surveyed territory, its scale, chosen surveying method, used software for data processing.

One of the most complicated areas for mapping is the territory of oil and gas deposits. These territories include heterogeneous infrastructure: pipelines, buildings, racks, reservoirs located inside certain facilities, such as booster pipeline pumping stations, oil stations, production support bases (Vereschaka, Bakanova, 2019).

The number of individual industrial facilities can be quite large in the territory of any oil and gas deposit. A network of roads is laid between industrial facilities. Not only individual oil and gas facilities, roads, infrastructure around them, but also forests are subject to mapping, as often deforestation is required to improve transport accessibility. The appropriate surveying method is chosen depending on the particularities of territories. Currently, terrestrial, aerial and satellite methods can be used. Methods of terrestrial surveying are based on applying theodolites, electronic total stations, levels, satellite receivers or laser scanners. Aerial surveying is carried out from manned or unmanned aircrafts equipped with digital cameras or laser scanners. Satellite surveying is implemented from space using digital cameras or microwave radars (Cantemir et al., 2016).

Among all surveying methods the most detailed information about territories can be obtained using laser scanners. The technology based on applying this equipment is called laser scanning. The results of laser scanning are presented in the form of point cloud. Point cloud consists of laser points with 3D coordinates. This technology can be applied in such applications as mining, forestry, architecture, crime investigation, civil engineering, for geological purposes, road and railway construction (Gumilar et. al., 2019). The environment can be measured with using this technology statically or kinematically. Aerial surveying applies only kinematic laser scanning whereas terrestrial ones – both types. Kinematic laser scanning from air is called airborne laser scanning (ALS) whereas from ground – mobile laser scanning (MLS). Static type of this technology is called terrestrial laser scanning (TLS).

ALS allows obtaining information about isolated territories, such as swamps and forests. Unlike aerial photography, ALS collects accurate data on the terrain in areas with dense and high vegetation. When analyzing the results of ALS for forests, it is possible to identify tree species based on the measurement of crown shapes (Trier, 2015).

MLS is used for surveys of urban scenes, out-of-town roads and railways, as well as linear extended objects nearby them. At the short period of time, several hundred kilometers of roads with an extremely high degree of detail can be surveyed (Oude Elberink, 2020).

TLS is widely applied for surveying built-up industrial areas. Such territories include, for example, electric substations, oil stations, pumping stations. Individual city objects, small road sections are also surveyed. TLS system is similar to electronic total stations and consists of a laser scanner, a built-up digital camera, control unit, processing software and so on (Ting et al., 2021).

Comparing to ALS and MLS, TLS is capable to provide data with millimeter accuracy. TLS point clouds can be additionally used for monitoring of any constructions. For territories of oil and gas deposits these are protective fencing and walls, oil storage facilities, buildings, supporting structures. TLS can be applied not even outside large constructions but also inside them where other methods of laser scanning are impossible to implement (Dedkova, Komissarov, 2020).

In built-up areas of oil and gas deposits there are a lot of areas with small objects that are difficult to reach using conventional terrestrial surveying methods and MLS. Aerial surveying methods are also not suitable for such areas in most cases due to the fact that many structural elements are not identified from the air and obtained data have lower accuracy. The most optimal method for surveying built-up areas of oil and gas deposits is TLS. Due to providing data through contact-free means and the opportunity to place a laser scanner almost anywhere it is possible to acquire point clouds of the whole built-up area. Within the goal of large scale topographic mapping, any feature elements of oil and gas deposits can be extracted from point clouds and used for creating topographic plans (Ting et al., 2021).

Feature extraction is the most complicated task when processing laser scanning data. Compiling a topographic plan, it is necessary to extract corner points of buildings and constructions, center points of small objects such as poles and supporting structures. Feature extraction is a time-consuming task.

To speed up extraction special techniques and algorithms of automatic processing are being developed. Any algorithm is aimed at identifying a certain object type. Built-up facilities of oil and gas deposits contain a lot of various object types: roads, buildings, pole-like infrastructures, vegetation, small linear objects such as pipelines and electric power lines.

Extracting roads their edges should be detected. It can be carried out based on identification of smooth or planar surfaces and the point cloud classification using elevation and intensity information (Vosselman, G., 2009). For example, Kumar at al., 2013 used gradient vector flow introduced in Xu, Prince, 1997 and balloon parametric active contour models. For detecting road edges, they used information about reflectance, elevation and pulse width. Point clouds with this information were converted into 2D raster images for reducing computational expense. If there is an earlier created map or plan, it can be used for speeding up the process of road edge identification. Boyko, Funkhouser, 2011 presented a method of projecting road edges from an existing 2D map onto a 3D point cloud and checking whether they are parts of a road or not.

A lot of studies are devoted to building extraction from laser scanning data. Concerning the task of producing topographic plans, it is enough to extract only building walls without roofs. Rutzinger et al., 2009 proposed to perform a region growing segmentation for finding planar areas in a point cloud. It can be implemented on the basis of measuring density of laser points. Density of projected building façade points is greater than other object types. Building walls can be extracted on the bases of projection features. They used 3D Hough transform to find seed surfaces. Neighbouring points can be added to these surfaces if they are located within a specified threshold to the plane. Then recalculation of the plane is carried out and new laser points are searched. The results are checked on size, inclination and dimension. In Xia, Wang, 2018 walls were extracted by means of region growing and projected to create a 2D rectangle grid. Chen et al., 2021 proposed to measure density of projected laser points on a polar grid instead of rectangle one.

For detecting pole-like infrastructures different approaches have proposed. Lehtom ̈aki et al., 2010 proposed a method based on point cloud analysis and cylinder fitting. Yu et al., 2015 proposed a shape matching with prototype objects for isolating poles after application of a Euclidian clustering method for the non-ground laser points. Li et al., 2018 proposed a feature-based technique based on the analysis of horizontal slices for the non-ground laser points. To identify the certain type of pole-like infrastructures special geometrics rules are used. Another approach of detection is connected with deep learning techniques on the basis of labelled data (Wu et al., 2017).

Next task is detection of vegetation and individual trees. Detection of tree canopy can be carried out on the basis of methods developed for imagery. Such methods can be implemented after projection of point clouds into planes. Each pixel of an obtained 2D image contains information from the point cloud, such as minimum elevation, maximum elevation, number of echoes (Vega et al., 2014). Crown segments can be extracted with region-growing algorithms (Hyyppa et al., 2001). Yang et al., 2015 proposed to extract tall trees on the bases of the 3D fractal object dimensions.

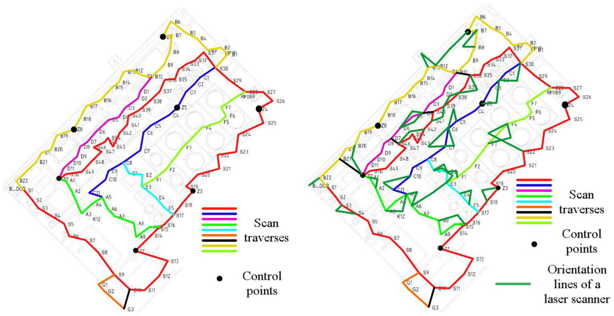
Thus, many object types can be extracted automatically. Nonetheless, objects of oil and gas deposits are usually located with high density. Because of it not all existing algorithms can automatically identify objects with high accuracy. It is necessary to estimate whether the certain algorithm to extract feature points of some object automatically or it is easier to extract them manually. In case of manual extraction, it is necessary to visualize point clouds in the form that simplifies their perception.

After any extraction, objects should be converted to symbols in accordance with a scale of a compiled topographic plan. It can be carried out using classification codes. Unique classification code can be assigned to a certain object type.

The final step of mapping is generation of contours. When displaying relief at topographic plans it is necessary to preliminary recognize ground laser points and extract some of them that represent the main ground forms. It can be automatically implemented with ground classification, breakline extraction and thinning algorithms.

2. DATA ACQUSITION AND PRELIMINARY PROCESSING

To discuss the opportunity of applying automatic object extraction algorithms for the goal of large scale topographic mapping there were used TLS data acquired for the territory of central gathering oil station at Talakan oil and gas deposit. This deposit is located in Yakut region of Russia. It was necessary to produce a topographic plan at a scale of 1:500 with a contour interval of 0.25 m. The area of surveying was 16.7 Ha. It was scanned with Leica ScanStation 2 using the technique of traversing with setting up additional stations oriented with resection method. Laser scanning was carried out from about 160 positions. Previously, geodetic control network from 7 points was created with Trimble R8 satellite receivers. Coordinates of control points were measured from a continuously operating reference station located not far from the oil station. The scheme of creating geodetic control network is shown in Fig. 1.



(a) (b)

Figure 1. The scheme of creating horizontal and vertical control survey network and scan traversing for the territory of the central gathering oil station:
(a) without additional stations; (b) with additional stations.

After field surveying works laser scanning data were preliminary processed to obtain a point cloud of the whole oil station in the external coordinate system based on coordinates of control points. Coordinates were computed in the result of data processing from satellite receivers in Trimble Business Center software. Point cloud registration was carried out automatically in Leica Cyclone software using artificial targets. The results of accuracy estimation using the targets are given in Tab.1.

	X, m	Y, m	Z, m
Mean error	0.002	0.001	0.003
RMS error	0.003	0.002	0.005
Maximum error	0.008	0.009	0.012

Table 1. Accuracy estimation of point cloud registration

Fig. 2 demonstrates the result of point cloud registration displayed by elevation.

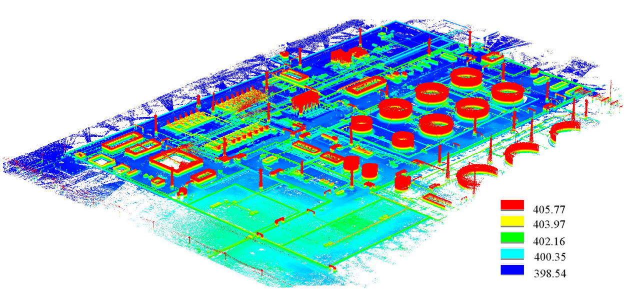


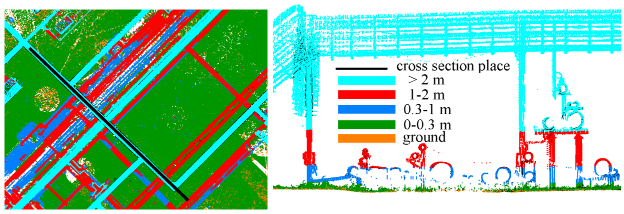
Figure 2. Point cloud displayed by elevation for the territory of central gathering oil station.

To recognize object characteristics in the point cloud, separately obtained digital images were used. Fig. 3 shows an example of the image that assist to recognize types of pipelines.

Figure 3. Digital image of a complicated area with pipelines.

3. PRODUCING TOPOGRAPHIC PLANS BASED ON POINT CLOUDS

The technique of producing topographic plans based on laser scanning data is radically different from the one based on pickets, which are the result of surveying using total stations and satellite receivers. Due to the fact that laser scanning data have extremely high density, the creation of a topographic plan is carried out as a result of manual vectorization of point clouds or automated extraction of feature elements. Regardless of the chosen approach for the convenience of this process it is necessary to first classify the point cloud: detect ground points, and divide the rest by height from them. As the result of visual analysis next height levels were chosen: 0–0.3 м, 0.3–1 м, 1–2 м, > 2 м (Fig. 4). Ground points were identified by the Axelson's algorithm (Axelsson, 2000).

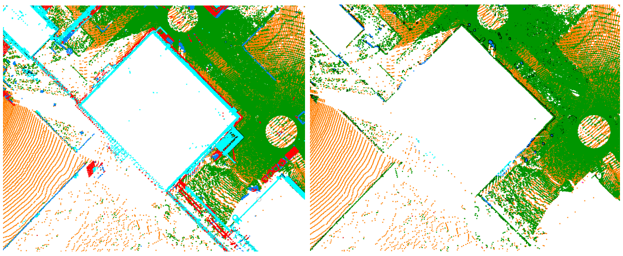


(a) (b)

Figure 4. The result of point cloud classification:
(a) top view; (b) cross section view.

For built-up areas of oil and gas deposits the next order of object vectorization and extraction was offered: buildings and constructions, roads, pipelines and electric power lines, pole-like infrastructures, relief, vegetation.

Extracting buildings, their walls should be vectorized at topographic plans. Vectorization is always carried out at building base. It can be carried out by creating horizontal sections at the ground or displaying the preliminary defined point cloud class corresponding to the first height level above the ground. Fig. 5 shows the example of the point cloud top view for a building and its horizontal section corresponding to the height level 0–0.4 m. Building walls were vectorized manually. Nonetheless, 3 walls of 4 could be exracted automatically by many algorithms specified in section 1. The point cloud density of the fourth wall at the ground is rather low because of presence of fencing, stairs and a platform at the entrance to the building. Fig. 6 shows the result of topographic plan production at this place without letterings. Automatic algorithms could extract the fourth wall only at higher altitude. On the other hand, the necessary wall position would be wrong, as vectorization must be implemented for the lowest height level of buildings.



(a) **(b)**

Figure 5. Creating horizontal sections for building extraction: (a) top view; (b) horizontal cross section 0–0.4 m.

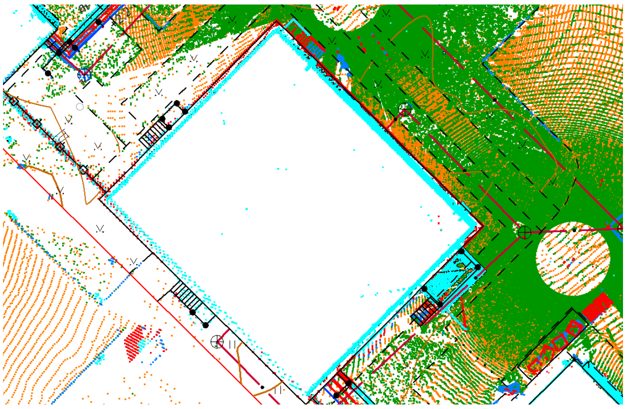
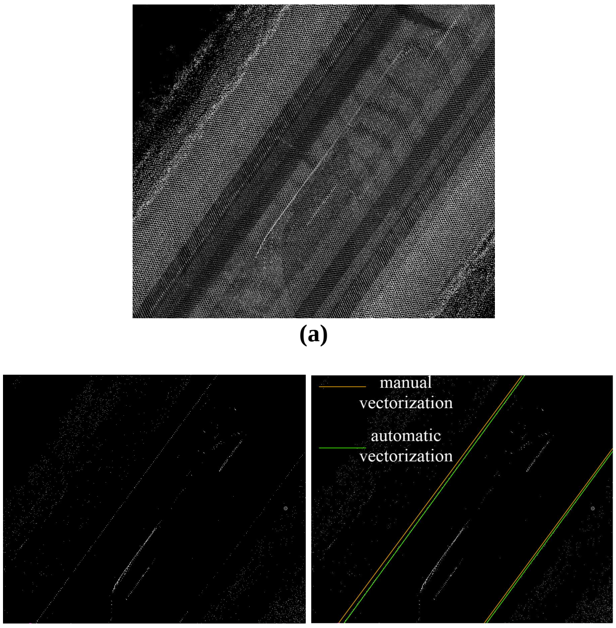


Figure 6. The result of topographic plan production at the place of a building location.

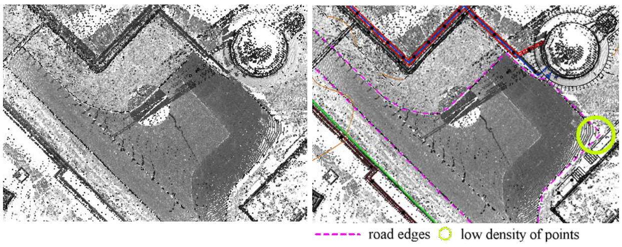
Most of road edges can be extracted automatically. For roads with curbs the extraction is carried out by searching places of changing elevation. For roads without curbs the extraction is carried out by searching places of changing intensity values of laser points at the ground. Depending on the used algorithm, extraction can be done with 3 main approaches: completely automatically by analyzing the whole point cloud, automatic vectorization from a location specified by a user, automatic moving nodes of an approximately drawn polyline. Fig. 7 shows the example of processing point cloud for extracting road edges using the last-mentioned approach (TerraScan User Guide, 2022). Point cloud was classified by intensity values to extract road making points. Lines of road edges were approximately drawn with low accuracy. The position of lines was automatically adjusted by means of their inscribing in the nearest classified points.

For implementing automatic approaches of line extraction by intensity values, point cloud density should be high. Fig. 8 shows another example of road edge extraction in places without curbs. It is the result of manual extraction. In case of applying majority of automatic algorithms the right part of the road in this figure would not be identified correctly due to low point cloud density. The best result of automatic road edges extraction will be in places with the same density. It is mostly typical for MLS data than for TLS.



(b) **(c)**

Figure 7. The process of extracting road edges: (a) top view of the point cloud; (b) the result of extracting points by intensity; (c) the process of extracting road edges.

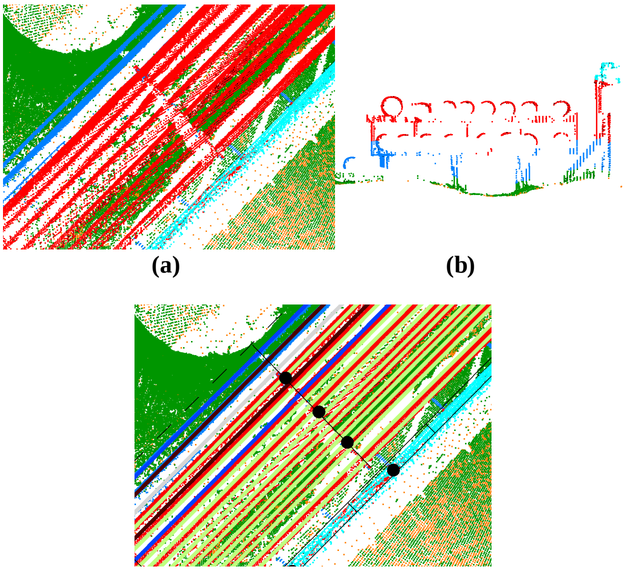


(a) **(b)**

Figure 8. The result of topographic plan production at the place of a road:
(a) top view of the point cloud; (b) top view of the point cloud with extracted elements.

The next objects for extraction are linear elements such as pipelines. Fig. 9 shows point cloud of pipelines with the result of manual vectorization. It is seen from the cross-section view that there are a lot of pipelines within a small area. Density of pipes located inside this area is quite low for any automatic procedures. For built-up territories of oil and gas deposits it is a common situation. It is also related to supporting structures located under pipes.

Supporting structures are a type of pole-like infrastructures. There were also such pole-like infrastructures within the territory of central gathering oil station as road signs and lamp posts. Among all objects of the mapped territory, road signs and lamp posts have the highest probability to be correctly extracted in an automatic mode because of the fact that they are located separately from nearby other objects.



(a) (b)

(c)

Figure 9. Point cloud of pipelines:
(a) top view; (b) cross section view;
(c) top view with vectorized pipelines and supporting structures.

After vectorization of pole-like infrastructures it is necessary to generate contours using thinned ground points and to place ground elevations. Point cloud thinning consisted in identifying a small part of ground points best describing the shape of the relief with a contour interval of 0.25 m. Thinned point clouds allows generating contours more smoothly.

These operations are carried out automatically by many algorithms. Nonetheless, the results of algorithms can differ a lot. Fig. 10 demonstrates the results of contour generation using two different algorithms.

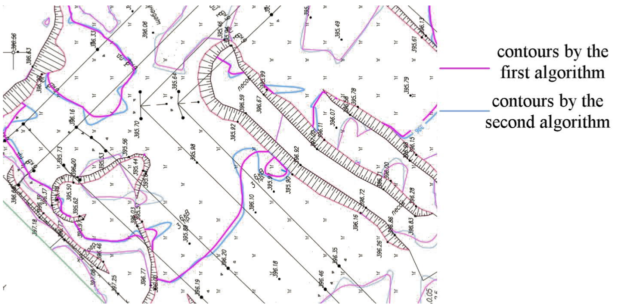
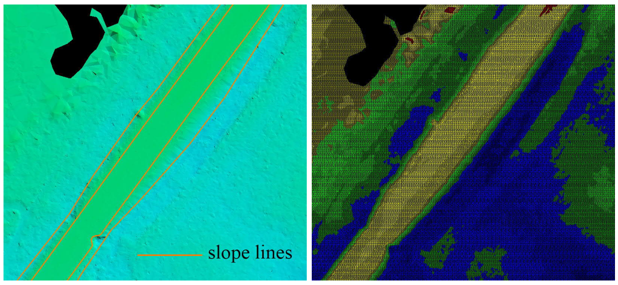


Figure 10. The comparison of generating contours using different algorithm.

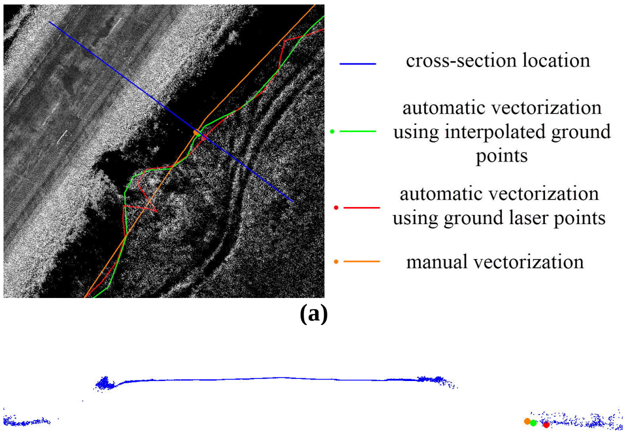
Fig. 10 also shows that contours are interrupted between slope lines. Slope lines are drawn in the result of breakline extraction process using thinned points. As the number of ground laser points for a foot of slope can be rather low when scanning from the road surface, some ground points can be added in the result of interpolation. The approach of automatic moving nodes of an approximately drawn polyline can also be applied. Fig. 11, a shows both the result of generating digital elevation model using thinned points and the approximately drawn slope lines. Next, the thinned point cloud was interpolated to generate a 20 cm grid of points (Fig. 11, b).



(a) (b)

Figure 11. Digital elevation model:
(a) DEM based on ground laser points; (b) ground points interpolated by 20 cm grid.

The grid of points was used for correcting slope line nodes. In case of applying ground laser points obtained by thinning of point cloud instead of interpolated ground points by grid, the position of the foot of the slope would be inaccurate. Fig. 12 demonstrates the results of extracting the foot of the slope using different points.



(a)

(b)

Figure 12. Slope foot detection:
(a) top view; (b) cross-section of the point cloud.

After contour generation ground elevations are placed at the topographic plan. Their locations are chosen so that do not overlap other vectorized elements.

The final step of producing the topographic plan is vectorizing vegetation. It is necessary to place both point symbols of vegetation and borders of area vegetation. At the territory of central gathering oil station this operation can be carried out only manually. Majority of developed algorithms for vegetation extraction are aimed to find individual trees and forest. The oil station had only low vegetation without trees in the form of grass.

4. CONCLUSION

Large scale topographic mapping of built-up industrial territories using TLS data is a complicated process that includes many tasks of object extraction and vectorization. For this purpose, a lot of algorithms have developed. Applying these algorithms, we count on speeding up point cloud processing for the solving the certain task. When producing topographic plans, a lot of various objects are necessary for extraction. The topographic plan of the central gathering oil station at Talakan oil and gas deposit was created using manual procedures except generating contours and extracting slope lines. It was discussed that automatic procedures at dramatically built-up areas can not provide high confidence level that all elements can be correctly extracted from TLS data. In case of applying automatic algorithms, all results should be checked.

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