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MOBILE LASER SCANNING FOR DETAILED DIGITAL TOPOGRAPHIC MAPPING

Abstract

Mobile Laser Scanning (MLS) is a technique characterized by high data acquisition efficiency and level of detail. However, a lot of information contained in the LiDAR point cloud is only implicitly available. Therefore, in order to create a digital topographic map from a large quantity of MLS survey data, it is necessary to define a methodology that requires a combination of various software tools. In general, the applied methodology mainly depends on the final product specifications (data model, accuracy, level of detail, etc.). This paper describes the standard methodology of creating a detailed digital topographic map using data collected by MLS, which proved to be two times faster than the conventional methods (total station or GNSS survey).

Keywords: mobile laser scanning, digital topographic map, point cloud

МОБИЛНО ЛАСЕРСКО СКЕНИРАЊЕ ЗА ДЕТАЉНО ДИГИТАЛНО ТОПОГРАФСКО КАРТИРАЊЕ

Сажетак

Мобилно ласерско скенирање (МЛС) је техника коју карактерише висока ефикасност прикупљања поидатака и висок ниво детаљности. Међутим, велика количина информација садржана у LiDAR облаку тачака је само имплицитно дата. Стога, да би се израдио дигитални топографски план на основу велике количине МЛС података, потребно је да се дефинише методологија која захтева коминацију различитих софтверских алата. Генерално, примењена методологија углавном зависи од спецификација коначног производа (модел података, тачност, ниво детаљности, итд.) У овом раду описана је стандардна методологија израде крупноразмерног дигиталног геодетског плана коришћењем података добијених MLS-ом која се показала дупло бржа од конвенцијалних метода мерења (ГНСС премер или тотална станица).

Кључне ријечи: мобилно ласерско скенирање, дигитални топографски план, облак тачака

1. INTRODUCTION

Advances in technology and surveying techniques make it possible to obtain a large amount of data in a short time. Light Detection and Ranging (LiDAR), also known as laser scanning or 3D scanning, is one of the remote sensing methods with a rapid development and wide applications in the last two decades. The method is based on collecting extremely large amount of spatial data in the form of point clouds, a set of closely spaced three-dimensional points (X, Y, Z). The data collected by laser scanners enable detailed representation of various objects and phenomena, such as terrain, vegetation, transmission lines, buildings, streets, elements of traffic markings and signs, and other objects and surfaces. Depending on the platform it uses, laser scanning method is divided into Airborne Laser Scanning (ALS), Terrestrial Laser Scanning (TLS), and Mobile Laser Scanning (MLS). All three methods have found wide application for collecting spatial data in geodesy, whose products are used in different disciplines. ALS method is usually used for large areas and objects, wherever it is necessary to collect massive data in a short time. This method is mainly used to collect data in cadastre [1, 2], hydrography - bathymetry [3], biology [4, 5], geology [6], weather disasters [7], and various similar areas. Data collected by TLS method have found wide application in engineering geodesy for the needs of: deformation analysis of buildings [8, 9], architecture [10], glaciers [11], forestry [12], mining [13], and other areas. The third method of laser scanning - MLS has been applied for 3D cadastral [14, 15], for road infrastructure monitoring [15, 17] and in various other fields such as forestry [18]. Furthermore, these three methods are applied in combination for some disciplines such as 3D cadastre [19, 20], hydrography [21], indoor laser scanning [22, 23] and many other purposes.

Spatial data is used for the digital representation of the Earth's surface and objects located on it, such as buildings, roads, vegetation, and other human creations. Contemporary topographic maps are made in digital form, i.e. as digital topographic maps. In order to collect necessary spatial data for that purpose, various surveying methods and techniques can be applied, including the conventional terrestrial surveys and photogrammetry, methods of global positioning (RTK - GNSS) and different types of remote sensing methods including MLS.

Papers published in the last several years indicate the increasing number of applications of MLS in the field of urban 3D modeling mainly for creating detailed digital topographic maps and detection and extraction of urban objects [17, 23].

Processing of MLS data, similarly as for the other types of laser scanning data, involves classifying points from the cloud according to the phenomena and objects they relate to. In addition, to create a digital topographic map, it is necessary to create the appropriate content built upon point clouds in the form of vector data: points, lines and surfaces with appropriate geometry, topology and other attributes related to these vector data. Forming the content of a detailed digital topographic map based on point clouds is a complex task, because it demands that information that are implicitly contained in the point cloud are extracted and make explicit. This process involves the use of manual, or preferably automatic procedures supported by the appropriate software tools to make the whole process as efficient as possible, but also to ensure appropriate quality control of the collected data and the process itself. The main goal of this study is to present a methodology for creating detailed digital topographic maps using the data obtained by MLS, using various software tools.

2. OUTLINE OF THE METHODOLOGY

MLS survey is carried out using a scanning system consisting of a vehicle-mounted scanner (or other platform moving on the surface of the earth) that collects data in motion on a predefined path [24, 25]. In general, MLS system configuration usually integrates LiDAR sensors, location and navigation sensors (e.g., Global Navigation Satellite System (GNSS) antenna, an Inertial Measurement Unit (IMU), and a Distance Measurement Indicator (DMI)), advanced digital cameras, and a centralized computing system for data synchronization and management [17, 23]. When the platform is in motion, MLS can efficiently collect three-dimensional measurements of the environment. Today, the standard MLS can collect 1 million points per second, meaning that the system can cover the predefined path and the surrounding surface with a point density of 2000 points per m^2, where the distance between points ranges from a few mm to a few cm, at the vehicle speed from 10 to 100 km/h [25].

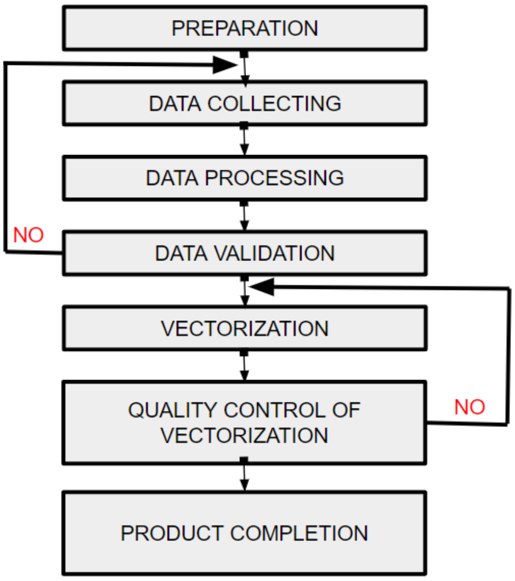

Figure 1. *Flowchart of the applied methodology*

As already mentioned, creating a digital topographic map based on MLS survey data is a very complex task. In general, the applied methodology depends on the MLS system, object and phenomena that are surveyed and the final product specification. The applied methodology is shown on the diagram above on Figure 1. The procedures of the methodology will be explained in the following sections.

Methodology presented in this study is generally used when this type of data is to be used for making digital topographic maps. For some of the procedures, for example vectorization and quality control of vectorization, productivity can be improved by introducing more or less automation, such as machine learning – for automatic feature extraction [1, 4, 18, 19]. Also, methodology could be different if one processes the data obtained by systems that don't have an integrated camera.

Firstly, all the data related to the route of vehicles must be prepared, such as a path plan. Also, marking of ground control points (GCPs) [26] which are to be used later for processing and validation of point clouds has to be finished. The path plan consists of lines representing the streets that need to be surveyed, usually in *.kmz or *.kml format. The locations of the GCPs are selected/chosen according to the project extent. Any method providing sufficient positional accuracy can be used to determine coordinates of GCPs. GCPs must be marked on the ground before mobile laser scanning starts. After data preparation, installed instrument is calibrated before the actual laser scanning takes place. Movement at a certain speed and in certain directions in order to define the domain of all the parameters necessary for surveying.

Before data collection starts, the reference permanent GNSS station must be turned on. The permanent GNSS station works one hour before and after data collection with MLS.

The team for MLS surveying consists of two people, who set up the instrument together on the roof of the car [27]. During surveying, one team member drives a car and the other one works on the PC tablet, where the *.kmz or *.kml file with the path of the car route is loaded, facilitating the survey according to the planned route. Collected data includes the laser scanner data, spherical photography imagery and Inertial Navigation System (INS) and GNSS data.

The first activity within MLS data processing phase is synchronization of the data from the INS unit and RINEX (Receiver INdependent EXchange format files contain raw satellite navigation system data relative to a specified interval of time) files. After synchronization, the obtained data must be processed in relation to the reference GNSS station in order to obtain the positions and orientation angles of the MLS device at every moment during the process of data collection (survey process). After the trajectory is determined, the generation of point clouds and spherical photographs (360^{o} images) can start.

Once the point clouds are created, fine alignment should be done, which ensures high data quality, eliminates anomalies, eliminates dissents in multiple car passages, etc. After alignment, a definite point cloud is available for further processing.

GCP coordinates are determined with classic geodetic surveying method (Global Navigation Satelite System – Real Time Kinematic, GNSS - RTK) during preparation phase. Marked GCPs have to be found in the definitive point cloud and their coordinates have to be calculated. Two sets of coordinates (two locations) for the same GCP that are determined with different methods, can be used in the next step - the validation of the collected data. The GCP coordinates determined by the GNSS - RTK method are treated as reference ones, so these are used to determine the deviations of the point clouds from the reference positions.

After successful data validation, point clouds can be used for vectorization. Various software applications are designed and developed to facilitate this activity (online or desktop versions). The software enables creation of the digital content representing the terrain surface or objects on the terrain. Certain software products provide support for automatic [25, 26] or semi-automatic segmentation, classification and interpretation of the point cloud data.

Procedures for automatic vectorization are based on machine learning techniques and they provide simpler and easier vectorization. However, manual vectorization is still providing the results with better accuracy and precision. Both of these approaches result in errors which must be detected and eliminated. Various controls can be designed and implemented depending on specific projects and product specifications. For example, two such quality controls have been applied within the methodology that will be presented within this paper: Identification of intersection points and Checking the point elevation using contour lines. These controls have proven to be an excellent solution for quality control of vectorization [25].

Final activities are dedicated to cartographic design (layout) of the created topographic map content. Among other things, this assumes application of prescribed map symbol library for spatial features and arrangement of labels (elevations). Sometimes, creation of topology between spatial features could be required. Once again, software tools enabling automatic, semi-automatic or manual data processing can be used. Cartographic design is governed according to rules that are prescribed by relevant rulebooks. In Serbia, these rules are specified by the digital topographic key (DTK) that is defined and published by the Republic Geodetic Authority (RGA). Proper DTK symbol must be assigned to each spatial entity (feature). There are many solutions for labels (elevations) arrangement on the map, so their overlapping is prevented. Of course, the easiest way is to use automatic procedures for this purpose. Sometimes, this also means that certain labels have to be disabled from the displaying.

3. METHODOLOGY VERIFICATION

The methodology outlined in the previous section has been verified within an experiment. In general, the software used for methodology implementation can be commercial, free, or developed in-house. All types of programs were used within this study for methodology verification. Usually, work with laser scanning data requires integration of various software products due to the complexity of the data. Some of the software tools used for methodology verification will be presented in the paper (Figure 2).

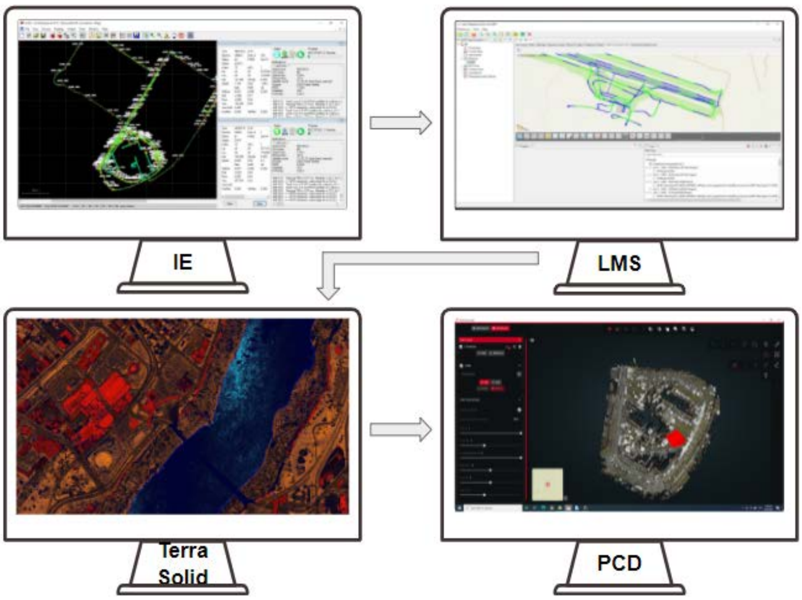

Figure 2. *Major Software tools used for methodology implementation*

3.1. STUDY AREA

The municipality of New Belgrade is one of seventeen that comprise Belgrade, the capital of the Republic of Serbia. New Belgrade is divided into 83 large rectangular residential blocks that are separated by wide boulevards. The study area, residential block - Block 19a, is located on the left bank of the Sava River, and covers an area of approximately 8 ha, of which 6 ha are built-up areas (4.5 ha - buildings and 1.5 ha - roads, sidewalks, green area, parking, etc.) (Figure 3.).

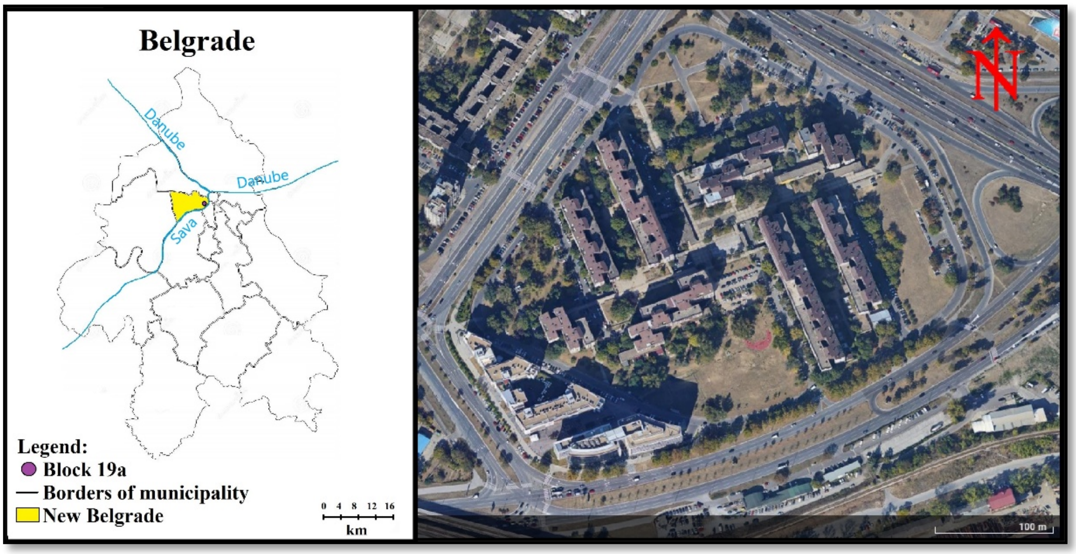

Figure 3. *Study area (New Belgrade - Block 19a)*

3.2. PREPARATION

Firstly, the optimal route, i.e. path plan for MLS system movement has to be defined. Things that have to be taken into consideration are: area/objects that are to be surveyed, street direction, traffic density during the surveying period and other things that affect the movement of the car. Path plan file is provided in *.kml or *.kmz format.

As already stated, another activity within preparation phase is to specify locations for GCPs. This task is very important because location of these points will influence how easy and fast it will be to find them in point clouds during the MLS data vectorization and validation phase. GCP must be marked on terrain before surveying. Precise locations of 10 GCPs were determined by using GNSS - RTK technique (3 x *30 seconds observations*). Locations of these GCPs are given on Figure 4.

Figure 4. *Locations of GCPs*

3.3. DATA COLLECTING

Laser scanning data is collected within reference coordinate system that is related to the GNSS permanent station. The ASCII format (XYZ RGBI) is a basic and the simplest digital format for saving data collected from LiDAR. Depending on the method and instrument used for surveying, in most cases, specialized data collection software is provided by the MLS system provider. In this case, Teledyne Optech Maverick [28] system has been used. The system has its own software application for data collection that can connect on Wi-Fi and it can be used on devices such as PC, tablet or mobile phone.

After the system is installed on the car, the system has to be calibrated driving 35 km/h for 10 minutes. Collection of MLS data is carried out by driving the vehicle and surveying the area of interest according to the prepared path plan.

Total area covered by MLS survey is 12.8 ha (wider area is covered). Total area of interest, that is the area of the city block including streets on the block border, is 8.5 ha. Total number of MLS point cloud points is 280882394. Average point cloud density is 2246 points/m^2.

3.4. DATA PROCESSING

In order to combine the LiDAR data and the INS data together, the NovAtel Inertial Explorer (IE) [29] software is used. The result is provided in Exchange Format file which contains information about the position and orientation of the MLS device in every moment of the survey.

As explained in the methodology, the next steps are to generate raw point clouds and spherical photography imagery, their synchronization and adding texture to points of the point cloud. Lidar Mapping Suite (LMS [29]) is used for this task. The software performs basic synchronization of trajectory data (the result of processing in the NovAtel Inertial Explorer software tool).

After collecting and processing the data, the following step could be fine-leveling processing. This step isn’t necessary, because two previous steps are sufficient for many projects. However, this processing was also done within methodology verification. TerraSolid, the most popular commercial software, is used for this kind of processing [29]. TerraSolid software is comprised of many software products. In this case, TerraScan and TerraMatch products were used for fine processing of point cloud data.

During the process of fine alignment of point clouds obtained from different positions, accuracy of 3 cm has been achieved.

3.5. DATA VALIDATION

For such a large project area, it is necessary to mark 10 GPC points as shown in Figure 4. Data validation phase includes calculation of the differences between coordinates of GCP that have been digitized in the point cloud and the coordinates of the same GPC that have been measured with GNSS. Horizontal and vertical differences for GCP points are given in Table 1. According to these values, it can be stated that achieved accuracy of point cloud georeferencing is in line with the expectations.

Table 1. Horizontal and vertical differences of coorinates at GCPs

Coordinates from GNSS-RTK				Differences at GCP	
Point number	E [m]	N [m]	h [m]	Horizontal differences [m]	Vertical differences [m]
35	454665.83	4961501.20	118.22	0.02	0.03
36	454851.45	4961391.32	117.89	0.01	0.00
37	454953.94	4961418.86	118.17	0.02	0.00
38	455069.11	4961568.87	119.36	0.02	0.00
39	454963.85	4961701.62	117.85	0.04	0.00
41	454899.34	4961681.52	118.21	0.04	0.02
42	454841.41	4961719.37	118.27	0.02	0.00
43	454784.97	4961690.20	120.42	0.02	0.03
44	454722.59	4961595.71	118.66	0.02	0.05
45	454905.56	4961527.34	118.45	0.03	0.03

All coordinate differences are positive values.

3.6. VECTORIZATION

Vectorization can be done in many online or desktop applications, commercial or in-house developed an application. The vectorization aims at presenting real-world features by using certain map features (using adequate feature geometry: point, line and polygon). For each of these features a set of attributes is assigned according to specified data model. According to the requirements of the investor and/or certain regulations or accepted norms from the professional practice, requirements related to spatial features and the relationships between them are followed (for example, proper spacing between adjacent points on linear feature in order to preserve geometry of the curve during it's discretization).

Point Cloud Desktop (PCD, Figure 5a) is a software application for vectorization from point cloud data developed by Geoput d.o.o. This application has been used for the methodology verification. The data structure used by this application consists of 4 parts (types of datasets): point clouds, spherical photography images, templates with defined geometry and a project-related data. The point cloud data are given in universal point cloud format - LAS that is supported by most, if not all, software applications developed for point cloud management. Templates can be added before or after images, during vectorization, and it is also possible to create new ones.

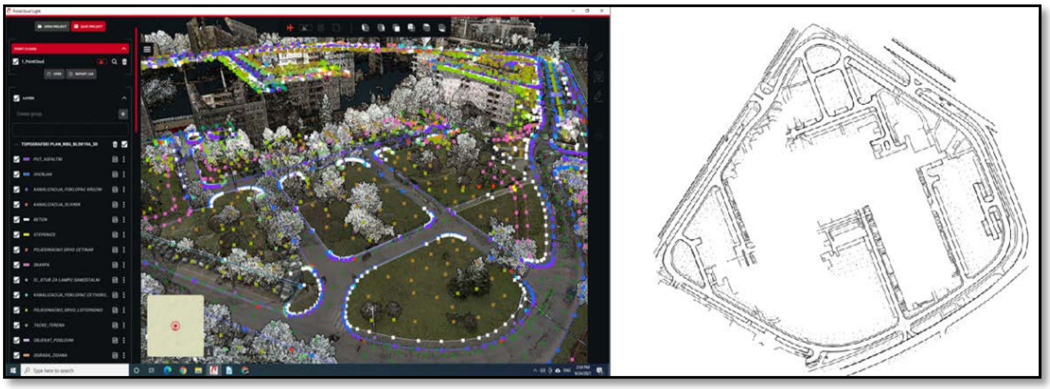

Figure 5. *a) Vectorization area in Point Cloud Desktop application and b) Vectorized data in AutoCAD*

Total number of map points after data vectorization is 6219. 425 of these points are used for terrain surface modelling and 5794 points are used for other map features.

3.7. QUALITY CONTROL OF VECTORIZATION

Vectorization process, especially in case of manual or semi-automatic vectorization, is prone to errors. Therefore, control of the vectorized data has to be provided in terms of geometry and topology of the map features, but also regarding the attributes assigned to these features. For example, every intersection of two lines should have intersection point feature, only terrain points should be used for DTM creation, etc.

Identification of intersection points (Figure 6a) controls if two lines, that are in the same plane, have a point at their intersection. If there isn't one, the software will automatically show an error and the place where it occurred. Only the first step in the control - identification of intersection points is shown (Figure 6a), where it is shown that one line is snapped to the other without the existence of the point of intersection. This error can be fixed by adding the point at the intersection.

Checking the terrain points using contour lines (Figure 6b) controls whether only terrain points are used for DTM creation. If so, contour lines should look naturally. Framed part in the Figure 6b shows a part where contour lines are more concentrated than they should be, and that (peak) point has to be checked visually and corrected, if needed.

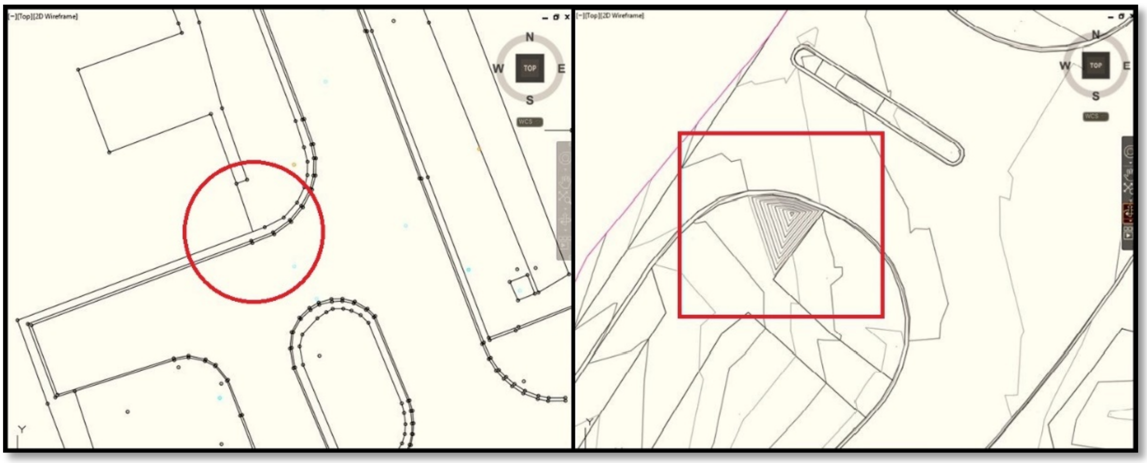

Figure 6. *a) First control - Identification of intersection points and b) second control - Checking the terrain points using contour lines*

3.8. PRODUCT COMPLETION

The next processing phase assume cartographic processing of the verified vectorized data. First of all, DTK symbols have to be assigned to map features. The data are exported from PCD using in GeoJSON format and loaded into software application where cartographic data processing can be done.

There isn't a set of rules that needs to be followed, but it is shown that it is best to start from more simple ones, such as point features. The next ones are lines with their orientations, then hatches for areal features and at the end, labels (text) are added (Figure 5b). Topographic map layout after cartographic processing of the vectorized data is given on Figure 7.

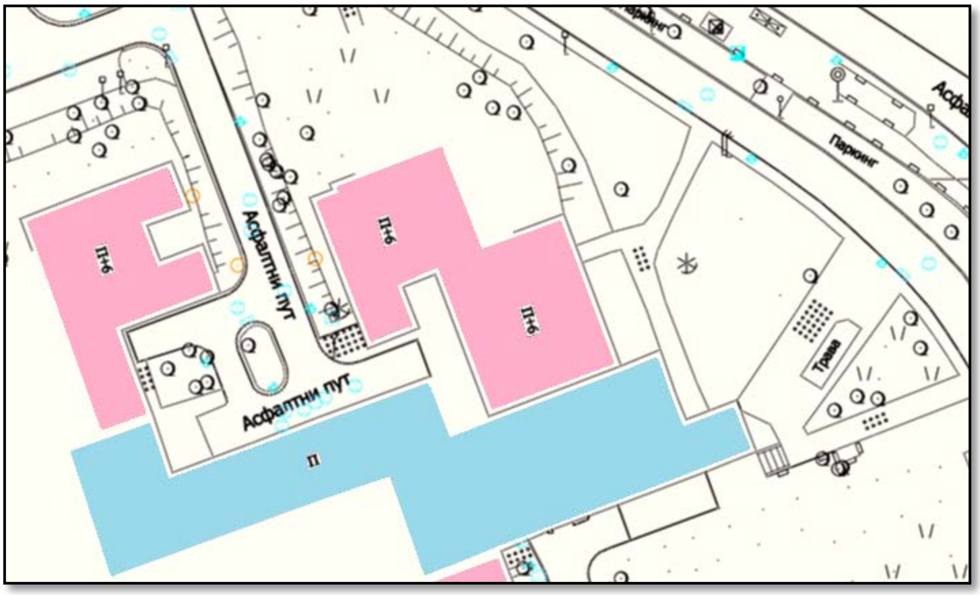

Figure 7. *Cartographic processing of vectorized data*

Also, elevations for some points (usually terrain points) have to be displayed as map labels. This can be done by using GIS or CAD software. As for other labels, elevation labels have to be placed on the map so that they are not overlapping with each other and with other map features. This can be done manually, or more or less automatically by using some software tools.

4. COMPARATIVE ANALYSIS

Different methods can be used for collecting data for creating a detailed topographic map. The choice of methods depends on many factors (equipment and other resources, required accuracy and level of detail, project area, etc.). Comparative analysis was performed between conventional measurement technique (total station survey) and MLS.

Table 2. Comparative analysis between a conventional geodetic survey and MLS

	Total station survey	MLS
Data collection and processing	20 days	9 days
Team size	4 members	4 members
Acquisition of missing data	All team members	One team member
Initial costs for equipment	Low	High

For the presented experiment, the first two phases, Preparation and Survey, lasted 1 day with 2 team members engaged. This was followed by Processing and Validation of the data which lasted 1 day and was done by 1 team member (software processing time lasted for 12 h). Vectorization was done by 4 team members in 6 days. The number of people engaged in the vectorization phase can be higher or lower, but 4 members were chosen so that it could be more easily compared to the total station 4-member team size. The last two phases, Quality Control and Topographic plan, lasted 1 day with 1 team member engaged. Cumulatively, the mentioned phases lasted 9 days, of which the field works lasted 1 day, whereas the conventional total station survey would have taken 10 field days followed by additional 10 days for data processing.

From this comparative analysis it is clear that surveying with MLS is twice as fast. Also, this method does not constantly depend on atmospheric conditions. MLS provides possibilities for easier and faster acquisition of missing details. The disadvantage of the MLS is that initial investment in acquiring and making operational the system is much higher and the surveying can be done only near the road (it is not possible to survey areas inside building blocks), because the surveying is from the car, and it is usually difficult or impossible to enter the off-road area.

5. CONCLUSION

Modern technology speeds up and facilitates the processes of making detailed topographic maps. MLS enables collecting a vast amount of data in a very short time. No time is wasted on placing the instrument from one point to another. Instead of that, the instrument is placed on the vehicle from the beginning to the end of the surveying. This saves time and resources and provides data that can be used for different projects. However, processing of massive quantity of LiDAR data requires adequate procedures and software tools. Extraction of spatial features that constitute the content of topographic map from point cloud data is still time-consuming process. This process can be improved significantly by developing and implementing automatic procedures. The only disadvantage of the MLS technique is that initial investment is much higher and the surveying in urban places is limited to facilities that are near roads (not behind fences or deep inside building blocks). That is why, MLS, is especially useful for the survey of road/street and railway infrastructures. It should be noted that the objective of this study was the methodology for making detailed topographic maps. The reason for this is that many users of spatial data in Serbia still prefer to use spatial data in map format. However, MLS data open-up possibilities for making moor sophisticate products (3D models or spatial databases). Therefore, afford should be made by all stakeholders to unlock these possibilities.

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