Modern Methods of Processing and Extracting Data From Point Cloud

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Key words: point cloud, matching, extraction, accuracy

SUMMARY

In modern age laser scanning technology has become the most powerful and effective method of collecting large amount of data in relatively short time. Laser scanning is a technology which uses laser beams to measure and capture environments in 3D with speed and accuracy. A laser scanner works by pulsing out a beam of light which is rotated 270 degrees vertically and 360 degrees horizontally. Any surface that the light touches is reflected back and recorded as a data point, which is assigned a color and surface reflectivity. To be useful, the millions or even billions of 3D points generated by laser sensor need to be stored, organized, combined, geo-referenced, measured, analyzed and distributed within organizations or outward. Laser scanning method follows development in areas of computer hardware, software capabilities, sensor technology and memory capabilities. Laser scanning technology provides data of great detail, and hence requires software and hardware components capable for processing these large amount of data. This method is still improving, as well as procedures for its processing and extracting necessary data. This paper presents the most contemporary methods of working with point cloud, i.e. its processing and deriving data of interest. In this paper will be presented procedures of point cloud matching, classification of point cloud, extraction of structural entities from point cloud. In addition, this method has great potential for further development and obtaining even more diverse data as final product. In this way, laser scanning technology will find its way at implementing in different areas of science and application. This is one of the most important trends in further improvement of this technology.

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1. INTRODUCTION

Point cloud, similar to photos, is used to collect information that describe objects and entities in our area. Contrary to photographs, which contain a two-dimensional projection of the scene in the form of a fixed grid, the point cloud is a set of disorganized three-dimensional points in a uniform coordinate system that shows the complete 3D scene (Gil et al 2017).

As with other surveying methods, when scanning the terrain with a laser scanner, various errors occur. One of the possible occurrences is that the laser beam is not reflected from the surrounding obstacle, or different materials in the space have different reflection signatures and therefore the laser sensor needs to be calibrated. The projection of the laser beam on the terrain is not a point, but a surface that can cover even parts of terrain of different heights and materials. Laser beam that is reflected from steep plane can produce error in measured lengths. It should also be noted that the position of the sensor is determined using the *Global Navigation Satellite System* (GNSS), so, accordingly, the accuracy of the point cloud is conditioned by the accuracy of a certain position determined with this sensor (Burman, 2002), (Shouzhi et al 2015).

With mobile laser scanning, the scanner is constantly on the move, which is recorded as a trajectory. Points in the obtained cloud are linked to the trajectory through a time stamp, vector laser scanner-point and vector trajectory-laser scanner. The offset errors and the orientation errors between the overlapping parts of the point clouds can often occur. In order to improve the accuracy of the point cloud, the scans taken from different scan lines are matched. There are several algorithms for matching overlapping parts of scans, but the point is (Bang et al 2009):

- finding connections between overlapping scans, errors and position offset and orientation errors;
- adjustment of the point cloud based on identified offsets and errors.

2. POINT CLOUD MATCHING

The point cloud matching procedure involves determining precise connections between two or more data sets that are collected at different moments of time, from different angles or from different platforms or sensors.

2.1. Problem definition

Matching of point cloud is challenging because it has an enormous amount of points, and the coordinate system can vary in terms of translation, rotation and scale. Point positions generally do not match noise is common due to incomplete scans. Also, some of the data may be missing such as the intensity or point coordinates.

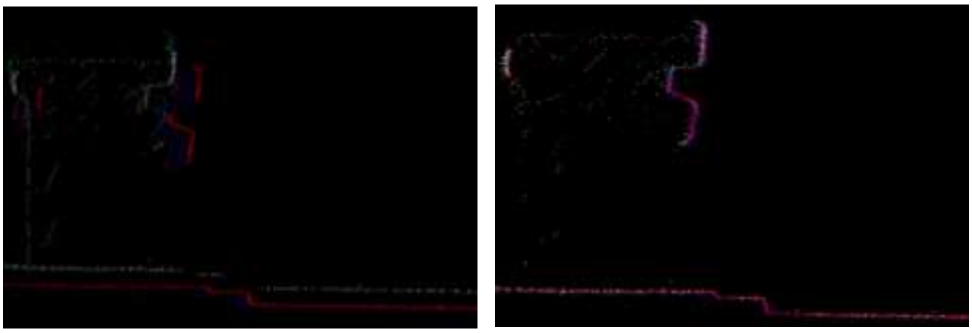
In order to perform matching of point cloud, it is necessary to have multiple scans of the same area between which there is a corresponding overlap. Also, the data must contain clearly defined surfaces - the matching can not be performed if all the recording data represent the forest areas for example.

2.2. Previous research

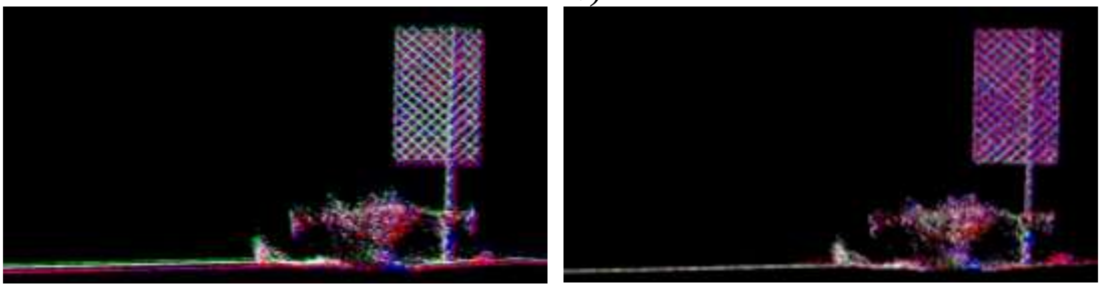
One of the first proposed methods of matching the point cloud is based on the *Gaussian sphere mapping* (Sanchez et al 2017). Later, an ICP (*Iterative Closest Point*) algorithm was developed, in which one scan is defined as fixed, while the second scan is transformed to best suit the reference one. The algorithm iteratively checks the transformation aimed at minimizing the distance between the reference scans and the scans whose fitting is performed. This algorithm is analyzed and implemented in papers (Pomerleau et al 2013), (Pomerleau et al 2015). Due to the different sampling intervals of scans and noise that comes from sensor, the coincidence between points is not entirely correct, so point-to-plane ICP and generalized ICP algorithms dealing with solving these problems are developed (Sanchez et al 2017). In the paper (Huang et al 2012) is presented a method of matching based on finding similarities in 3D space depending on the combination of geometric and photometric information. The matching process is completely automatic and the obtained data show the robustness of the method over 3D data under various transformations and noise.

2.3. Working methodology

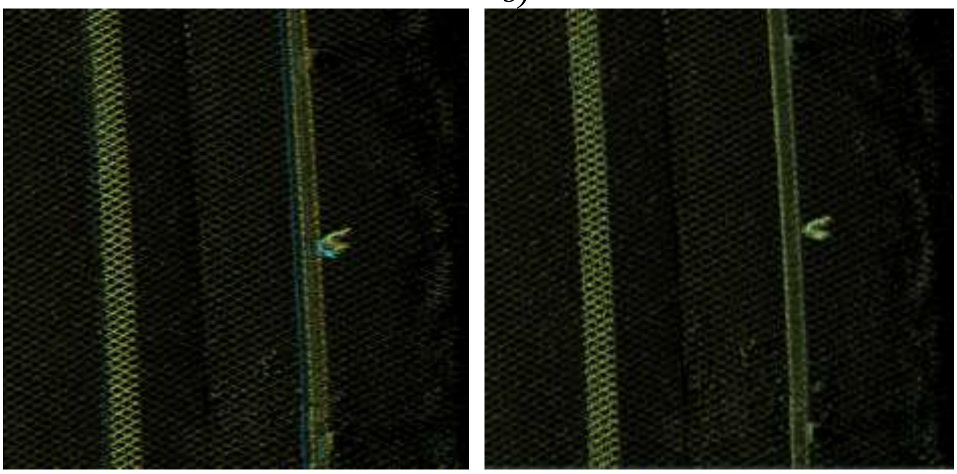
One of the possible ways to match the point cloud is in the *TerraSolid* software solution using the *TerraMatch* toolkit. *TerraMatch* is a tool designed to improve the accuracy and quality of the raw point cloud. It compares laser data from overlapping areas, or overlapping parts of scans taken from different passages in order to calculate xyz location errors. The correction values can be based on the fitting of surfaces or different types of tie lines (Margarita et al 2017). The results of matching point cloud that represent sections of the A7 motorway in Germany conducted in *TerraMatch* are presented in Figure 1a, b and c. In this pictures it is possible to see effects of matching point cloud, mainly regarding the achieved accuracy. Each pair of pictures shows better fitting of scans (colored in different colors) after the matching is performed. Figures 1a and b show results of matching in vertical meaning, while Figure 1c shows obtained results in horizontal meaning.



a)



b)



c)

Figure 1. Point cloud matching results – a) Curb detail; b) Road profile and traffic sign; c) Guardrail fence and white line on the road (top view)

Matching of point cloud takes place through the following phases:

- preparing data for matching and creating a project;
- automatic search for tie lines and addition of control points;
- matching of point cloud;
- quality control and final matching of point cloud;
- separation of problematic parts.

The point cloud matching process is preceded by the processing of raw data collected by the mobile mapping system. First, it is necessary to correct raw trajectories containing data from the GNSS sensor and inertial system based on the data from the network of permanent stations and precise ephemeris. In the next step, point clouds corresponding to individual scanning passes are exported based on the corrected trajectories. The corrected product of the surveying, or the point cloud in the *.las* format, is imported into the project. After importing, a rough classification of point cloud is performed and the definition of the scan lines is defined.

In the second phase automatic search of horizontal and vertical section lines is performed. An automatic search involves identifying the same details in different scan lines. Section lines represent identical lines contained in multiple scans, or point clouds obtained from different scan lines. As this entity can serve lines that represent an identical flat surface or part of the terrain, the vertical edges of the surrounding buildings or columns. The key thing in this step is to select the appropriate parameters in the automatic search of section lines. Defining the parameters is directly conditioned by the method of data collection, the required accuracy, and so on. Also, it is necessary to manually add control points so that the point cloud is georeferenced. If control points in the field are indicated by the appropriate markers, they can be automatically recognized in the point cloud.

The third phase involves matching point cloud. In the first iteration based on control points and section lines (horizontal and vertical), corrections are calculated. The calculated corrections are applied to the point cloud, trajectories and tie lines. In the next iteration, based on the corrected tie lines, new corrections are calculated and applied to the point cloud, trajectories and tie lines from the previous iteration. This process takes place through several iterations.

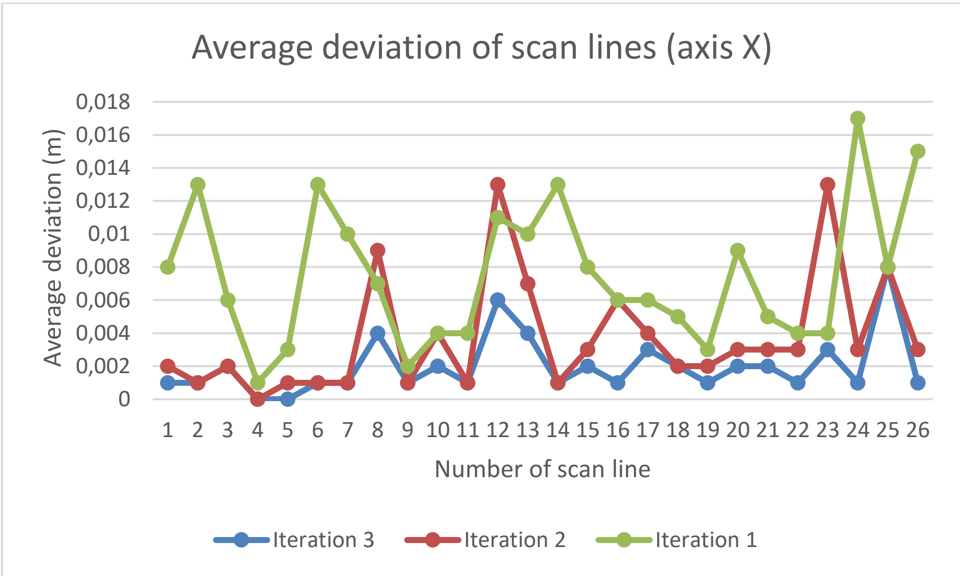
In the fourth phase, the quality of matching of the point cloud is controlled. Quality control also involves manually adding tie lines at places where matching quality is not satisfactory. After quality control based on existing and new tie lines, corrections are calculated and applied to the point cloud, trajectories and tie lines. The process takes place through several iterations.

The fifth phase involves the separation of problematic parts where the quality of matching is not satisfactory and defining a new project. In this step, the second, third and fourth phases are applied.

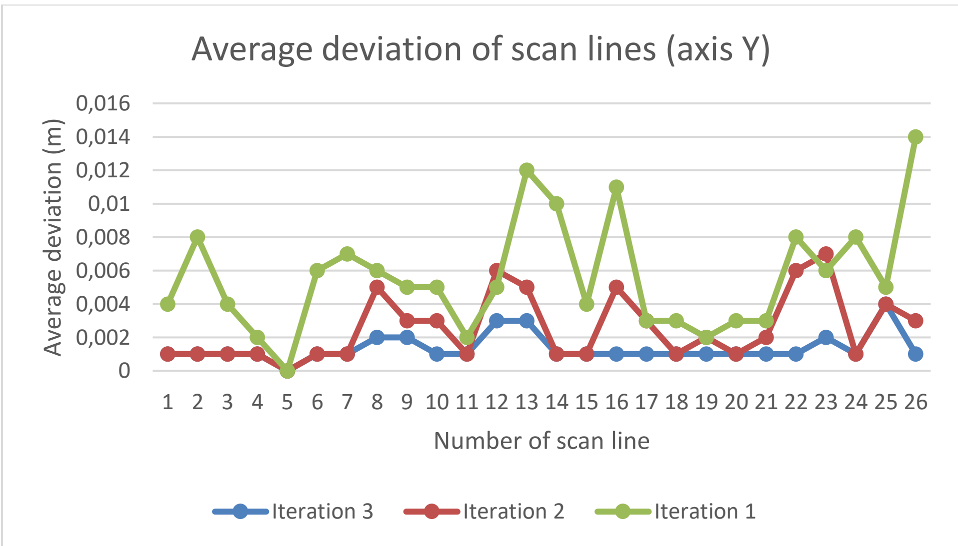
Below are represented the numerical results of matching the point cloud represented in Figure 1. Table 1 gives data related to the used elements in matching the scans obtained from 26 different scanning lines. Three iterations were conducted. In the first iteration, 854642 automatically detected section lines were used. After that, in the second iteration, 1534 XY points were manually added and identified on different scans representing the same area. Certain number of section lines that have a big error has been eliminated. Finally, in the third and final iteration, additional filtering of elements that do not meet the accuracy is performed. Graphs 1, 2, and 3 show the mean deviation values of 26 scanning lines in three iterations by X, Y and Z axes, respectively. From the graphs it can be clearly seen that the deviations are greatest in the first iteration, while in the second iteration there are smaller deviation values. The best results were achieved in the third iteration.

Table 1. Used elements in matching of point cloud – 1st, 2nd and 3rd iteration

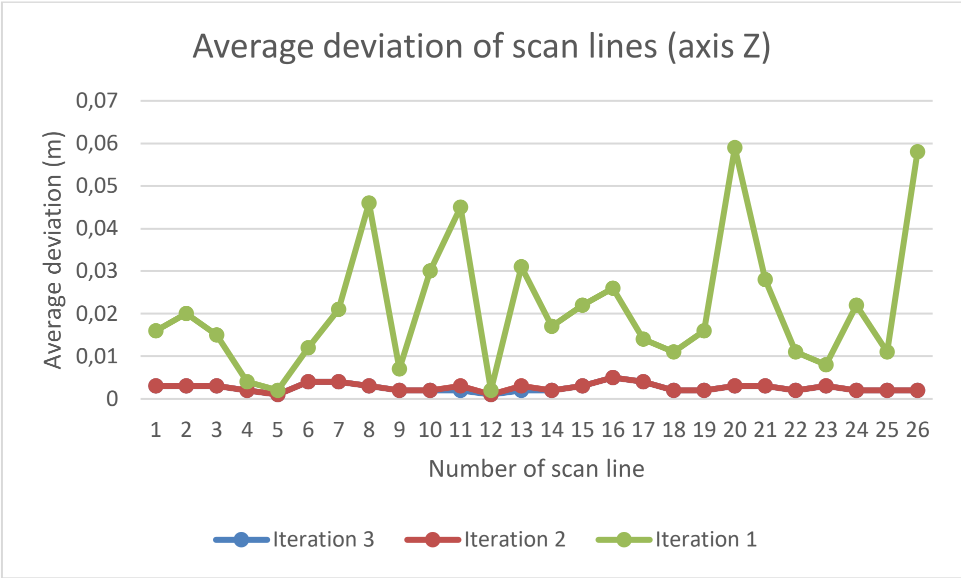
	First iteration	Second iteration	Third iteration
Ground points	-	-	-
XY points	-	1534	1527
Elevation points	-	-	-
Ground lines	-	-	-
Section lines	854642	855149	855072
Roof lines	-	-	-



Graph 1. Average deviation values of scan lines by X axis (1st, 2nd and 3rd iteration)



Graph 2. Average deviation values of scan lines by Y axis (1st, 2nd and 3rd iteration)



Graph 3. Average deviation values of scan lines by Z axis (1st, 2nd and 3rd iteration)

3. FEATURE EXTRACTION

The preparation process of data obtained by laser scanning from the moment of surveying to the final product consists of several phases. After the initial step, ie. phase of the matching of point cloud, it is possible to extract certain elements from the point cloud. This chapter introduces a procedure for extraction of characteristic elements of road infrastructure from the matched point cloud.

3.1. Problem definition

Traditional surveying methods require a lot of time in the process of data collection as well as in the post-processing, especially when it comes to surveying huge or inaccessible areas. Therefore, modern technologies have begun to gain importance and to be applied in different spheres. The great advantage of these technologies is in fast, accurate and high quality post-processing, where It is still working on advancement and automation. The one example of semiautomatised extraction is revised in this paper.

3.2. Previous research

Many papers in recent times deals with the extraction of spatial entities from the point cloud. Thus, in paper (Daniels et al 2007) a robust method that identifies sharp elements in the point cloud by returning a series of smooth curves set along the edges is presented. This extraction is an example of the multiphase precision method that uses the concept of robust moving least squares to locally adjust the surface to the potential elements. Using the Newton method, the points are projected over multiple surface slices and then penetrate into the polylines through the projected cloud. After solving the gap and linking the edges, the algorithm returns a set of complete and smooth curves that define the elements.

Paper (Gumhold et al 2007) shows the method for direct extraction of the lines from the point cloud. There is no need to reconstruct the surface in advance, only computing a neighboring chart that links nearby points. Extraction of characteristic elements is performed in two phases. The first phase consists of assigning a certain weight to each point that showed as a part of a characteristic element and associating this particular weight at the end of the a neighboring graph. The subgraph extraction from the neighboring graph that minimizes certain weights on the joints produces a set of element patterns. The second stage is particularly useful for noise-containing data, and repairs characteristic lines and joints. As the method works only on the local neighbors graph, it quickly and automatically adjusts to the sampling resolution. This makes this approach ideal for the pre-processing step in the network generation.

In the paper (Guy et al 1997) is described a robust algorithm for extracting surfaces, characteristic lines, and joining points from the point clouds containing the noise. They discretized the space around the point cloud into a volume grid and accumulated for each cell surface votes from the data points. From the accumulated votes they defined a saliency function for junctions and a combined scalar and vector valued saliency function for the crease lines. Junctions are simply global maxima of the saliency functions and crease lines are extracted with a modified marching cubes algorithm. One of the objectives of paper was to avoid the discretization into a volume grid in order to allow for efficient handling of non uniformly sampled point clouds.

Sinha and Schunk (Sinha and Shrunk 1992) fit spline patches to depth images and adjusted the spline parameters such that the spline patches could bend sharply around creases

In the paper (Steder et al 2011), the topic of extracting significant elements from the point cloud for recognition and identification of objects was discussed. A new method of extracting key points that is working on range images generated from arbitrary 3D point clouds, which explicitly considers the borders of the objects identified by transitions from foreground to background. It also presents the descriptor of elements that take into account the same information.

3.3. Working methodology

In this paper for the extraction of spatial entities simple tools contained in the *MicroStation* software package has been used. The process of extraction of characteristic elements from the point cloud contains of the following phases:

- preparation of data for extraction;
- extraction of elements in 2D;
- extraction of elements in 3D;
- quality control.

The first phase is introducing with the data formats and the requested level of detail with which extraction should be carried out. Also, it is necessary to create layers regarding to the entities that are the subject of extraction, and in order to speed the work and reduce the possibility of error, layers should be categorized in groups, such as elements that are digitized in 2D, and those that are extracted directly in 3D, or elements which are extracted as points, then a new set of layers for line elements, and a third set for polygon assets.

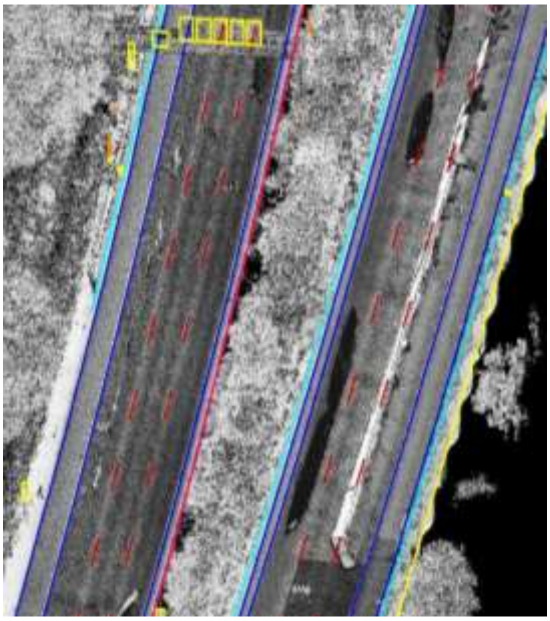
The second phase implies extraction of the required elements. The structural lines of the road infrastructure are the edge and middle lines of the carriageway, the top and bottom edge of the curbs, the edges defining the channels, etc. After that, the extraction of other spatial entities is carried out, such as: the white lines on the road, the pedestrian crossings, cycle paths, objects, poles, traffic signs, trees, fences, borders of different cultures, etc.

Individual elements are assigned only 2D coordinates when drawing, where there are several ways to subsequently join height data. One of them is to directly select elements of interest and set the height. Also, it is possible to create a digital terrain model of points belonging to the ground class. After that, entities that do not have a given height are "dropped" on the created model. Assigning the height values as points have in the environment is another one method.

Drawing of certain entities is done in 3D, ie, beside the X, Y coordinates, they are also assigned the actual height from the space. Drawing is done in profiles, where the option for automatical creation of profile at a certain distance, a certain width and length is used. Also, the automatic extraction of the curb is performed by an tool where, after drawing the line that follows the curb and defining the maximum possible distance of the curb from that line, the automatic extraction of the bottom and top line of the curb is performed.

In the fourth stage, the quality of the extraction of the road infrastructure structural elements is controlled, at first by the visual inspection, and then by the verification of the elements whether they are in the appropriate layers and of the respondent type. Quality control also implies extraction of spatial entities that have been missed out or not digitized appropriately.

Figures 4 and 5 show the extraction of the elements of the road infrastructure, done phase by phase explained above. After the laser scanning of a highway in Germany, the resulting point cloud was matched and then the extraction was carried out. Figure 4 shows two parts of the highway - with and without point cloud, while complete crossroad extraction is shown in Figure 5.



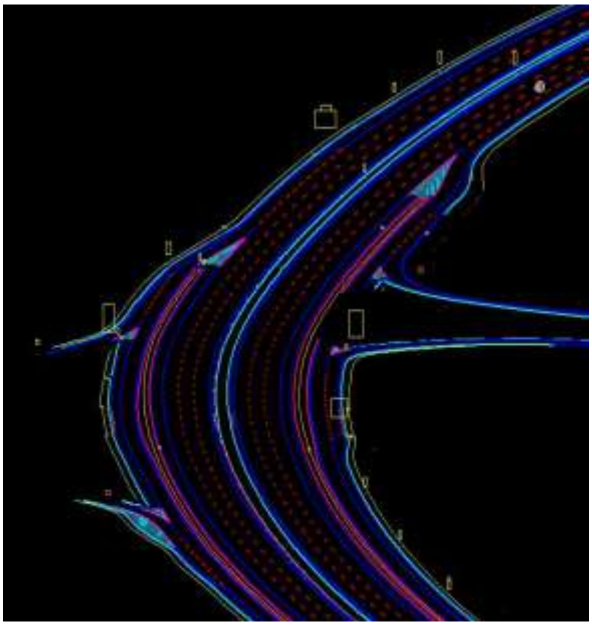


Figure 4. Example of extraction of the road infrastructure – high way

Figure 5. Road infrastructure extraction example - crossroad

4. CONCLUSION

The extraction of the road infrastructure is very important for many scientific disciplines. Architects and civil engineers need this information when designing urban areas or deciding on a location for a new building. In traffic control is necessary to obtain precise information on road infrastructure and traffic regulation by traffic lights and traffic signs in order to avoid the occurrence of traffic jams. Also, the automotive industry's current trends are the development of autonomous cars, where these data are of great importance (Vasić et al 2018).

This paper presents an approach for extraction of characteristic elements from point cloud. The extraction is shown on the example of the road infrastructure elements, where the point cloud is obtained by surveying with a laser scanner. The proposed method is fairly fast, robust and easily adapts to the needs of the project task. The initial step is point cloud matching, and without the quality of this step, all other manipulation over point cloud will result in significant loss in terms of quality.

Note: Project presented in paper is published with kind permission of the contributor. The original data were provided by DataDEV company, Novi Sad, Republic of Serbia.

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BIOGRAPHICAL NOTES

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