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MOBILE TWO-DIMENSIONAL LASER SCANNER USED FOR CLASSIFICATION OF OBJECTS IN THE URBAN AREA

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Abstract: The paper deals with classification of objects in the urban area, particularly road surface, facades of buildings and pole-like objects. The attention is paid to processing of three-dimensional models generated and reconstructed on the base of two-dimensional mobile laser scanning. There are different methods available to classify scanned objects; however, various shortcomings and limitations are usually identified in relation to their practical usage. Most classification methods applied to the three-dimensional models are based on range data processing. We present our three-stage classification algorithm that has been proposed and implemented with motivation to explore how range and reflectivity data could be used separately or in fusion to classify certain objects. The paper shows results of practical experiments based on real data recordings and proving usability of the proposed algorithm.
Keywords: Laser, scanning, 3D model, algorithm, classification

INTRODUCTION

Generation and reconstruction of three-dimensional (3D) models is a hot research topic in many application areas. Data collection is the first and most important step in every approach since improper selection of the measurement method can impair the whole process or make it quite impossible due to unrealizable requirements (e.g. accuracy, distance). The ideas presented in this paper are based on data collected by mobile two-dimensional (2D) laser scanning in the form of point clouds that contain information about positions of scanned points; however, nothing is known about which of the points represent and belong to particular objects. Therefore various classification approaches are being proposed and tested. Membership of the same object may be expressed in different ways, e.g. by adding a color aspect, unique signs or through points separation into the specific file. Our intention has been to propose, implement and test classification algorithms capable of identifying and extracting road infrastructure objects such as road surface, trees like objects and facades of buildings. The class of potential applications where 3D models might be used is quite wide – from a transport domain (autonomous steering, intelligent transport systems, navigation, etc.) to visualization of various environments like factories, office buildings, airport areas, critical infrastructures, etc.

State-of-Art Survey

Generation and reconstruction of 3D models of various scenes from point clouds has made a considerable progress in the recent decade. Unlike terrestrial laser scanning (characterized by high accuracy and a static way of measurement) and airborne laser scanning (characterized by a mobile way of measurement and ability to scan large land areas but with lower accuracy), the mobile laser scanning process proposes dynamic measurements with average accuracy. Differences among existing solutions result from different models uses. 2D laser scanners are usually based on a time-of-fly measurement method. The important factor influencing total velocity of mobile measurement system movements is scanning frequency and a total number of implemented scanners. Measurement systems usually combine equipment for dynamic collection of information with positioning systems. Combination of laser scanners and cameras is often motivated by intention to get as true representation of the scene as possible. An example of low-cost and portable solution to road mapping with removable sensors can be found in [1]. Combining information from a camera, scanner, digital maps and data characterizing vehicle dynamics may ensure selection of lines and road shaping (curving) [2]. The approach [3] brings laser-based detection of road edges while search for the lines is based on camera image processing. Laser scanners are also very often combined with the Global Positioning System (GPS), Inertial Navigation System (INS) and/or other devices recording moved distances (e.g. odometers). A state of the system may be estimated from measurements containing accidental errors with the help of a Kalman filter [4]. Combination of the 2D laser scanner and the GPS is also employed in accurate navigation tasks in urban environments where the satellite signal may temporarily be lost due to high buildings [5]. A 2D laser scanner, GPS-based positioning and the INS may be operated together to monitor vehicle movements and subsequently re-construct its trajectory [6]. If synchronization of multiple autonomously working devices is needed, time stamps are added to any information coming from each device [7]. Our attention is paid to classification of selected objects of the road infrastructure such as road surface, facades of buildings, pole-like objects and vegetation. Most existing approaches have the same initial step: a physical location of used components and configuration. In [8] data about movement of the mobile platform are provided by the odometer. The segmentation algorithm utilizes knowledge of properties of objects found in the scene like horizontal character of road surface, vertical character of facades of buildings or a variable shape of tree-tops and bushes (classified as scattered points). One of the very important factors used in classification may be reflectivity [9], with success rate about 95% cases. A special problem seems to be classification of pole-like objects, especially trees. An approach integrating classification data from multi-spectral image and a point cloud may use a normalized Digital Surface Model [10]. High vegetation could be detected using air-borne laser scanning [11]. Object surface properties are also considered when using a scanner with continuous waveform modulation [12]. The approach [13] consists of three steps: trees detection, simplification of a point cloud and trees modeling. Determination of height and diameter of trees may apply physical and statistic functions and data from air-borne laser scanning [14]. Extraction of pole-like objects from laser scanning data is a mature task. The method [15] is applicable only to vertical objects without an additional structure - traffic signs and trees are unrecognizable. The approach [16] proposes 4 steps to recognize objects in urban environment: localization, segmentation, extraction of contour and clusters classification, together with several alternative procedures considered for each step. Declared detection accuracy is about 65%. The algorithm [17], successful in 77% cases, expects capture of at least three parts (ovals) belonging to a detected object. Recognition of pole-like objects based on Laplace smoothing may have detection success 64% cases [18]. The approach [19], also consisting of four phases (segmentation, multiple filtering, implementation of the 2D closed circle algorithm and the classification itself), is successful in 70-79% of cases depending on a kind of detected objects. Similar methods calculating with radius of points in profiles may be found in [20]. Information about position of scanned points for classification of 'basic' objects [21] may be sufficient if fundamental object features are considered, e.g. horizontal character of road surface. A bigger problem usually comes with classification of smaller objects situated close to a road in surrounding environments (traffic signs, street lamps, billboards, tree trunks, etc.). There is no 'absolutely' reliable method for classification of pole-like objects. Every approach has its specific limitations and needs certain improvements. Table 1 shows some of typical limitations for selected methods classifying pole-like objects.

Table 1. Limits of selected methods classifying pole-like objects

Method	Limitations	Detection
[15]	Focused on rods only without associated structure	unknown
[16]	Does not work reliably if different types of objects are to be detected	65%
[17]	Requires a scanning trace in a point cloud	77%
[18]	Requires correctly segmented points	64%
[20]	Requires more than one method and needs additional information for points classification	unknown
[22]	Does not work well for thick objects such as trees	82%

The Measurement Platform

Data processed in our research have been collected by the mobile measurement platform self-developed at the home university. It is equipped with two 2D Sick laser range scanners operating at the wavelength 905 nm. One of them is the Sick LD-OEM 1000 type, which generates data processed by the proposed classification algorithm. It features a 360° field-of-view, max. adjustable angular resolution is 0.125 and a head rotational frequency is 5 Hz up to 15 Hz selectable in 1 Hz steps. For verification of measurement principles the scanning frequency is sufficient; however, for practical commercial scanning tasks a faster 2D scanner should be employed. Accuracy of the 3D model depends on precise localization of the mobile platform. It is ensured by the NOVATEL SPAN-CPT equipment, combining data from the GPS with data from the INS. Data are recorded by the server FUJITSU Primergy RX300 with 6.4TB memory capacity. Since most sensors installed at the mobile measurement platform communicate via Ethernet, the powerful CISCO switch is also needed. Visual information is obtained via 6 IP cameras that cover the whole range of the profile scanned by laser scanners. The whole system is powered by a gas generator and the backup source UPS Eaton

2200. Since all mentioned devices work autonomously and without synchronization, a special approach to data processing is needed to enable data collection and fusion. The concept is depicted in Figure 1. A point cloud is processed off-line in a personal computer due to high demands on computing power. The chosen coordinate system respects default setting of axes Z (up), Y (forward) and X (left side in relation to Y). To calculate position of a point in the coordinate system it is necessary to extract: an initial angle of scanning, final angle of scanning, angle resolution and a distance of the point measured (calculated) by the laser scanner. Individual packets are stored together with time data on packet receipt/sending; CPU time is used as a reference time. The procedure applied for data processing according to the block diagram in Fig. 1 is summarized in Figure 2 together with steps needed for data visualization.

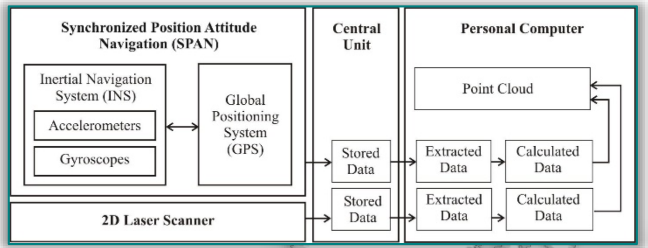

Figure 1. The block diagram of the mobile measurement platform

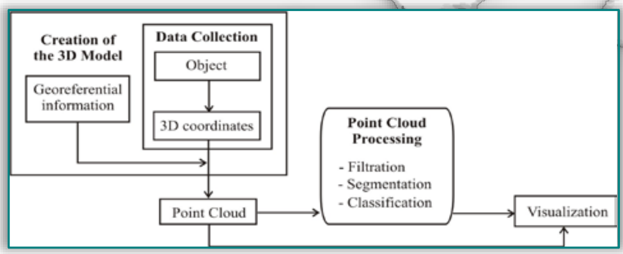

Figure 2. The principal scheme of data processing.

At the beginning raw data are available representing the measured reality. Within the following steps some operations are needed to:

- Remove unnecessary or faulty data;
- Distribute points into groups based on their membership to the same objects;
- Classify objects on the base of their position in the space (according to spatial coordinates);
- Interpret a point cloud in a graphical form.

THE CLASSIFICATION ALGORITHM

Mobile laser scanning achieves average accuracy if compared with methods of air-borne and terrestrial laser scanning. Differences exist in a way of points processing. A point cloud may be processed as a whole or in parts. The minimum item to be processed is one scanned profile or its quadrant. Sequential processing of the profile (one after another) is more advantageous since one may use information about position of points in the profile which may be unworkable in processing of a final point cloud. In some cases it may be profitable to combine or entirely substitute information about coordinates of each scanned point with information about intensity of reflected laser beam (reflectivity). There are multiple factors that influence the final reflectivity values: distance, incidence angle, structure of the surface, color, atmospheric conditions, etc. All these individual factors act at the same time but definition of their mutual dependency is rather difficult or impossible. Therefore, for practical reasons we have decided to apply only those of them whose effects were proved to be unambiguous enough and whose occurrence may be assumed, tested and understood for constant levels of other effects. Getting a value of reflectivity of the particular point while effects of other factors are ignored is for the classification purpose meaningless. Thanks to information about position of each scanned point attenuation caused by distance can be corrected and theoretically one could assume what an incidence angle is. Unfortunately, information about other factors such as object color and/or surface structure is not available despite it may significantly change the final value of reflectivity. Therefore it has no sense to observe reflectivity values only in one scanned profile. Our experiments showed us that a series of consecutive values of reflectivity obtained within several adjacent profiles can provide an added value. Thus our classification method uses intensity of reflected laser beam as additional source of information. Certain types of objects are classified sequentially, with the objects being represented by the most points first. The final algorithm we have created and present in this paper has three stages as shown in Figure 3.

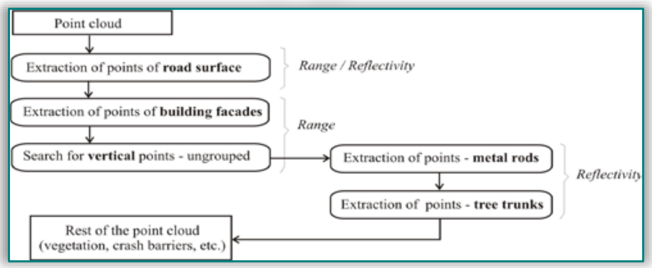

Figure 3. A concept of the three-stage classification algorithm

The principle applied in every stage results from the idea that the points that have already been processed and assigned to a certain object are not used any more. They are removed and saved to a separate file. This step brings a significant decrease of further demands on computing power and processing time. The method processes measured points in one profile after another but in several cases more profiles are being processed at once.

Road Surface

Generally, road surface could be identified based on range data, i.e. data representing measured distance from a laser head to scanned points. Unlike most other objects, road surface has typically a horizontal character.

This fact might be applied to histogram of the scanned profile where Y-axis represents frequency (number of occurrences) of the points. The spike part of the histogram then corresponds to amount of points lying in the plane representing road surface. Then one may segment all the points that are adjacent to the spike of the histogram. However, this approach fails at the moment when road surface is not spatially bounded (by road curbs, ditches, etc.) and smoothly goes to a lawn, pavement or parking area as shown in Figure 4. In those cases road edges create only slight surface irregularities (1-2 cm) which are hardly recognizable by the time-of-flight method.

Figure 4. Undistinguished spatial ends of road surface in the point cloud and the real scene (taken from a different view).

Measured points do not clearly indicate where the end of road surface is and where the parking area starts. Unlike range data processing, changes in surface material, its structure and/or color may result in changes of surface reflectivity. Considering this principle we have designed a method for extraction and classification of points belonging to road surface. When recording data the scanner head is located approximately 1.2 m above road surface. It is reasonable to take location of road surface points into considerations before reflectivity analysis is performed. The only relevant and meaningful sectors are quadrants I and IV. Processing of data from other quadrants would uselessly load the computing power. The same structure of surface will be manifested by expected reflectivity values (Figures 5 and 6). Any change of reflectivity will bring change of span and measured values.

Contrast between dark road surface and white reflex color may be used to detect an edge of the road or to extract points of horizontal traffic markings (Figure 7). Significantly visible line at the road border is easy detectable within one profile representation - see it in the marked area of Figure 8. Our classification algorithm preferably uses reflectivity values. If no striking change of line representation is detected, the way of classification is as follows (Figure 9).

Processing of points located in the quadrant I:

- The initial value (for normal incidence of the beam) and other values are used to calculate an average value of reflectivity;
- We observe an increment of the value of reflectivity for gradual increase of angle of the scanner head. Thus information about consecutive points is available;
- Change of the road surface structure is characterized by changes of reflectivity values of the whole group of points. In that place a limit angle is being determined;
- Points being below the limit angle are grouped to the ’road object’ and removed, others will be kept for further processing.

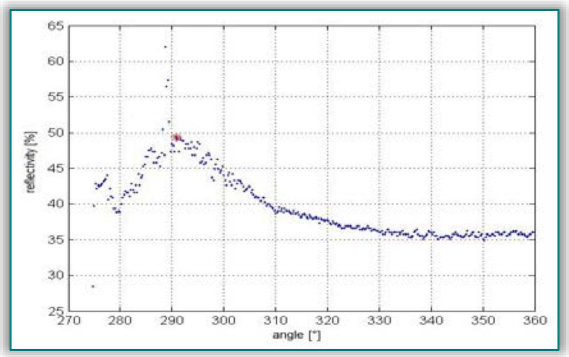

Figure 5. Reflectivity values measured in the quadrant I.

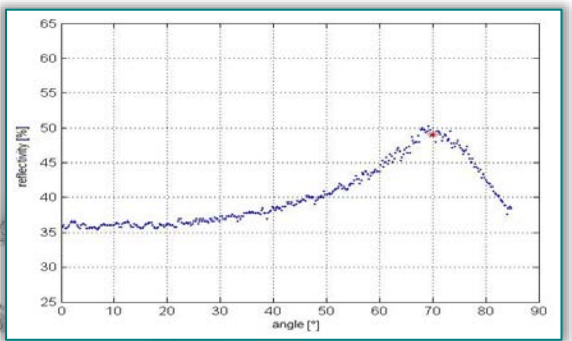

Figure 6. Reflectivity values measured in the quadrant IV.

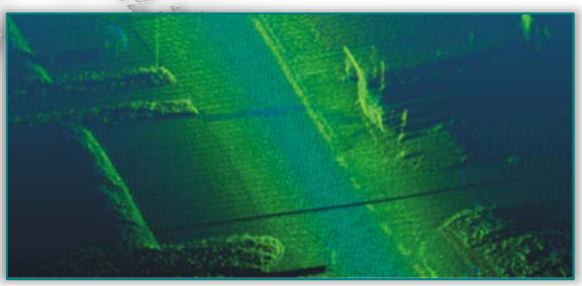

Figure 7. A point cloud with color-distinguished reflectivity.

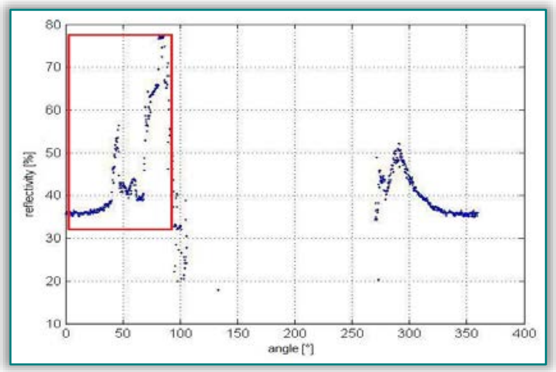

Figure 8. Reflectivity values in the profile

Processing of points located in the quadrant IV: unlike the procedure applied in the quadrant I, points with the greater angle are extracted as road surface points, others will be processed in next steps of the classification algorithm. Finally, all points belonging to road surface are removed and extracted to a separate file.

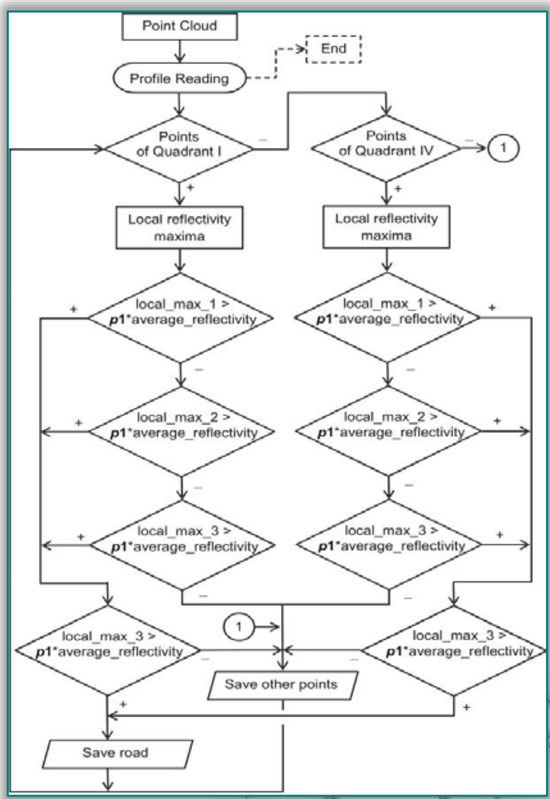

Figure 9. Algorithm for extraction of points representing road surface

Facades of Buildings

In the analyzed environment we may find a lot of vertical objects such as facades of buildings, lamp poles, vertical traffic signs or tree trunks. Facades of buildings have typically greater surface in Z-axis. We propose creation of the histogram that shows frequency of X-coordinates in the given profile (Figures 10 and 11). Vertical objects have typically a lot of values contained in a short interval. To avoid extraction of points belonging to different objects, it is necessary to consider several consecutive profiles.

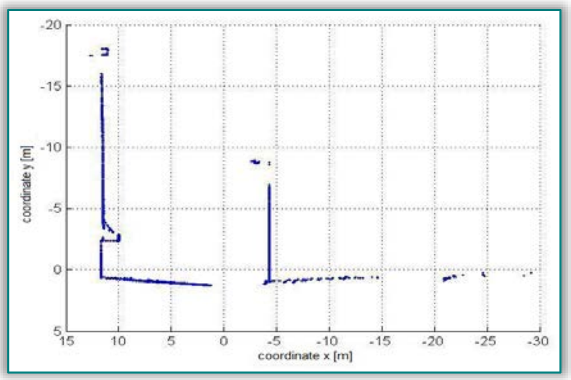

Figure 10. 2D-view at 5 scanned profiles of the building surface.

Classification of facades is based on range data since facades are very often rugged, with a various structure and different colors. Thus reflectivity is very accidental and does not create any assumable structures.

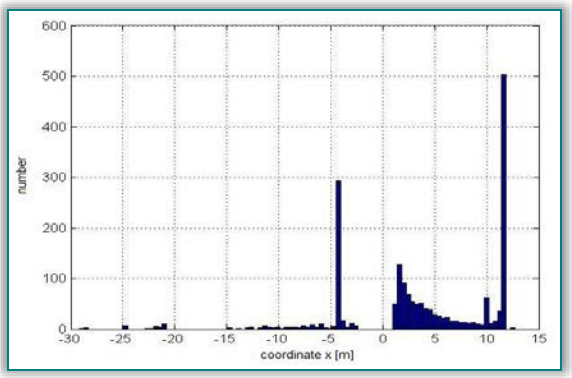

Figure 11. The histogram of coordinates occurrence.

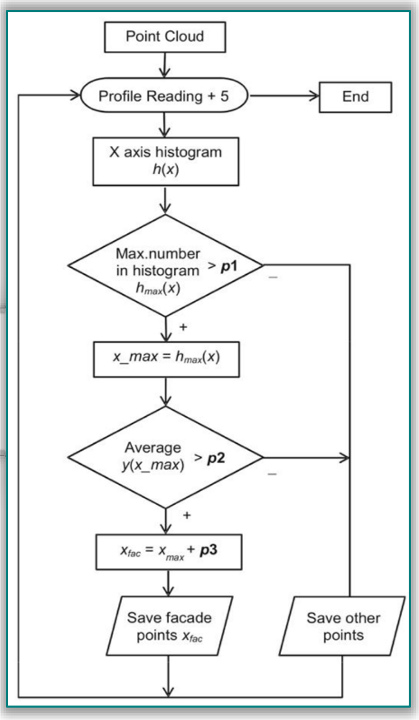

Figure 12. Algorithm for extraction of building facades

The proposed classification procedure (Figure 12) consists of several steps:

» Creation of the histogram of X-coordinates and determination of the coordinate having the maximum number of points;
» If the maximum number corresponds to the minimum required value of the number p1, the average value Y (height) at the value X may be determined;
» If the average value Y fulfills condition of the minimum value p2, points found inside the surrounding area defined by p3 are extracted and saved as points belonging to the building facade.

To get the best results we must define constants p1, p2 and p3 and make decision on how the histogram is to be divided (for how many values) and how many profiles should be processed together when classifying one profile. In our case all these settings have been done experimentally.

Pole-like Objects

The third stage of the proposed algorithm enables processing of the rest of points and search for pole-like objects. Figure 13 illustrates what kinds of objects may be included - tree-tops, tree trunks, a lamp, benches or car profiles. The significant landmarks are objects that probably represent the poles of street lighting and objects representing tree trunks. Considering accuracy of time-of-flight method, we are not able to rely only on range data to distinguish between tree trunks and traffic signs situated inside vegetation. Using reflectivity values, it is possible to identify objects having the same surface characteristics. Rods of traffic signs or street lamps are made of metal, with flat surface and the same structure. On the other side, structure of tree trunks is variable, containing various cracks and irregularities causing accidental reflection. Several consecutive reflectivity values do not create any dependency. To illustrate the situation Figure 13 shows two adjacent objects being close to each other (marked inside the picture). If we compare scanned profiles from the viewpoint of range data (Figures 14 and 15), there is no chance to distinguish between a tree trunk and rod.

Figure 13. Example of the point cloud after extraction of road surface and building facades

Combining information on vertical character and reflectivity of a group of points we can identify objects with the same surface structure. These most probably represent rods of traffic signs or street lamps. The same profiles processed on the base of reflectivity values (Figures 16 and 17) show that points representing rods are mutually located in a relatively narrow range of values while points representing tree trunks are distributed accidentally.

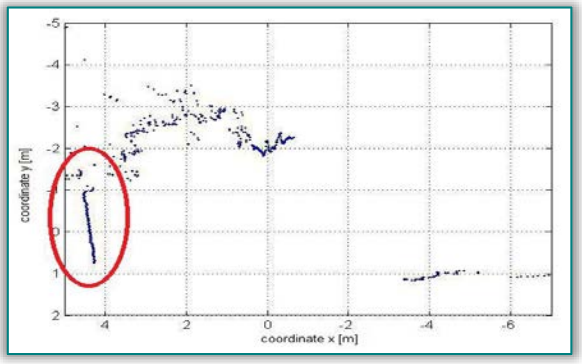

Figure 14. Scanned profiles with a marked tree-trunk

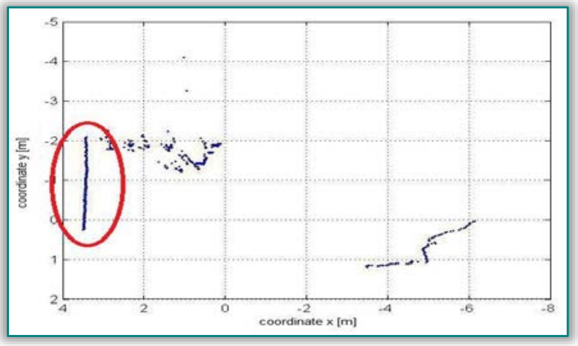

Figure 15. Scanned profiles with a marked metal rod

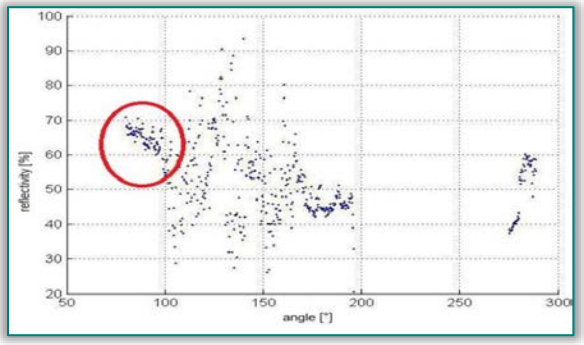

Figure 16. Reflectivity of points representing a tree trunk

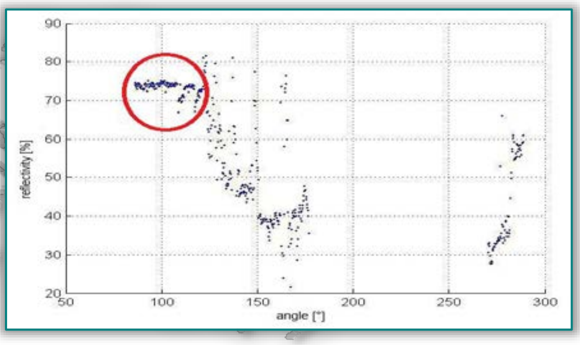

Figure 17. Reflectivity of points representing a rod

The classified tree trunk has been several times wider than the rod but considering an average distance between scanned profiles (ca 20 cm) it has been captured in one pro-file only. Based on deeper analysis of curves obtained from reflectivity measurements we have defined the basic classification between tall pole objects (poles of street lamps, poles of trolley-lines) and short ones (rods of traffic signs). A tall object is captured during one scan standardly along the whole length which gives a sufficient number of points for processing (Figures 19 and 20). Smaller and thinner objects are captured as if diagonally distributed which creates a specific shape. At the edge most of the laser beam is reflected to surrounding environment, in the middle the maximum value is obtained. This feature may be used for classification, too. Points in the profile are approximated to a curve. The result is a second-degree polynomial evaluated for the constant en-try. For a lack of sufficient data samples this approach is still under our development.

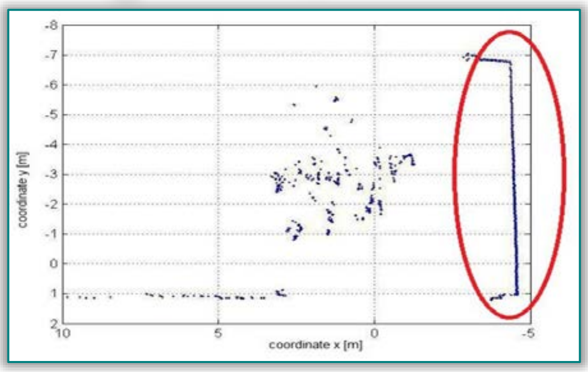

Figure 18. The profile representing grass, tree-top and a lamp

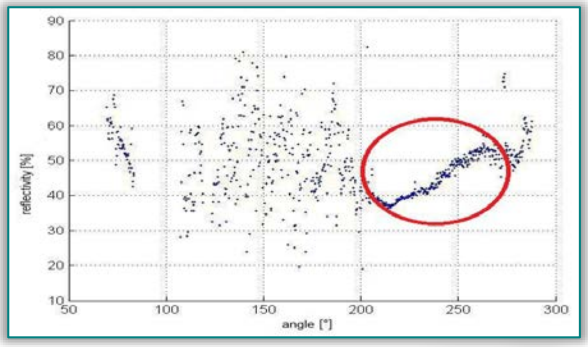

Figure 19. Reflectivity values with marked points belonging to the lamp pole

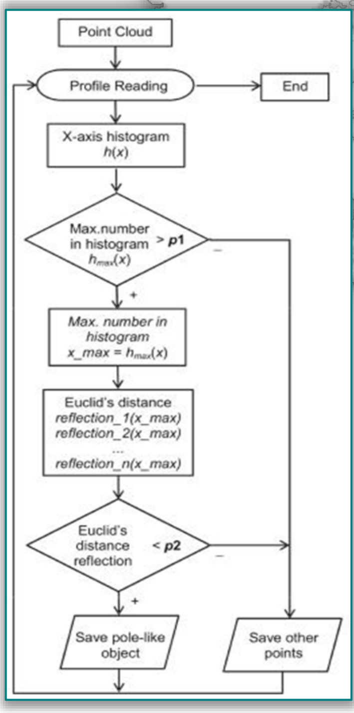

Figure 20. The procedure for extraction of pole-like objects

The classification procedure (Figure 20) is focused on taller pole-like objects:

- Creation of the histogram of X-coordinates and determination of coordinates having a maximum number of points;
- If the maximum number corresponds to the minimum required number p1, determination of the average value Y (height) for the X value;
- Gradual computation of Euclidean distance of reflectivity values expressed in dependency on the angle for vertical points;
- Classification of points having a lower mutual distance than p1 as pole objects.

Next steps focused on classification of other identifiable objects (tree-tops, bushes, vegetation) are not presented here. They may be based on analysis of range data, quadrants II and III, followed by analysis of diffuseness of reflectivity data caused by various positions of leaves. Finding clusters with expected features may result in identification of tree-tops.

CLASSIFICATION ALGORITHM TESTING

The proposed algorithms have been tested using real data obtained by the mobile measurement platform. To maximally eliminate inaccuracy of the final model classification is performed before integration of other data considering all axial inclinations and the altitude. As a representative example we can show a point cloud of a part of the university campus (Fig. 21). At the parking area we can see poles of street lamps, some parts of traffic signs and other objects (cars, waste containers). The route of the mobile platform movement is recognizable through the highest density of the scanned points. Before classification itself the points were filtered from a distance-based point of view. The higher distance of scanned points is, the higher inaccuracy occurs due to vibrations. Therefore, despite the fact that the scanner is ranged up to 200 m, all points located in a distance greater than 30 m from the scanner head have been filtered out.

Classification of Road Surface

Comparing a distance of the scanner head to road surface with distances to other objects, it is clear that just points of road surface are the most represented points in the obtained cloud. They represent more than half of all scanned points. From the quantitative point of view sequential analysis of profiles and points contained in them is most demanding computing power among all proposed sub-algorithms. The model presented here has contained fewer than 630 000 points (size of the text file 24 MB) and its processing lasted about 1 hour (DELL studio, CPU: i7 Q720 1.6 GHz, RAM 4GB, MS Windows 7). As mentioned earlier, road surface is identified through significant changes of reflectivity caused by changes of the surface structure. The first change found near road edge may be caused by presence of the white line as a part of the road traffic marking. It is detectable very well. In comparison with the black asphalt significant increase of reflectivity can be observed. If the white line is missing, surface of a different material (in our case grass and paving) causes changes of reflectivity (decrease, increase, or scattering). The edge may not be defined strictly. Sometimes places with undetectable transition may appear in the analyzed scene. Then the algorithm also classifies those points as not belonging to road surface (Fig. 22).

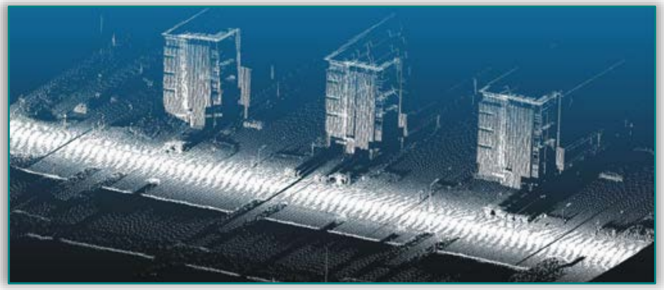

Figure 21. A cloud of non-classified filtered points.

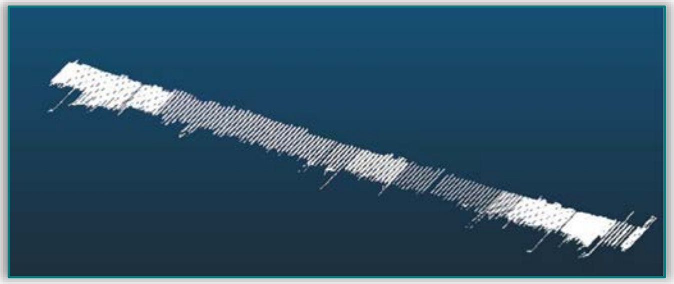

Figure 22. Extracted points representing road surface.

Classification of Building Facades

A new point cloud (Figure 23) is significantly smaller. Thanks to that its off-line processing is faster (for the given example ca 20 minutes). As described earlier, classification is based on range data processing. As far as the constants are concerned their values have been experimentally set to the following values:

- p1 - the best results have been obtained for the limit value 700 (to avoid interchange of trees and lamps);
- p2 - an average height of the object was set to 4 m (to eliminate close and densely covered objects);
- p3 - a range around the maximum X coordinate is 1 m; this value considers various juts (windows, window sills).

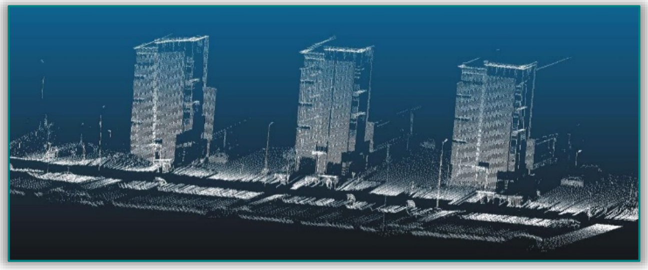

Figure 23. A cloud of points after road surface removal

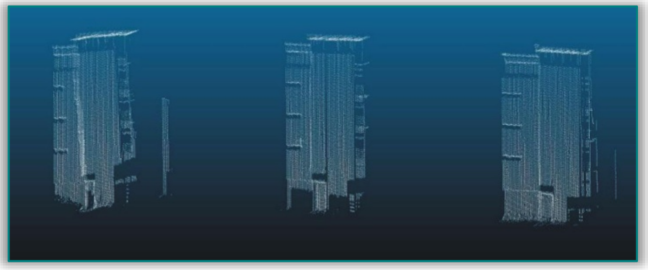

Figure 24. Extracted points representing building facades

For large and relatively flat surfaces the algorithm works reliably. Most of the points belonging to building facades is correctly identified and extracted (Figure 24). The applied approach defines one potential coordinate with facade appearance (using a group of profiles) per one profile. In the case of two buildings standing against each other only that one with a larger number of points contained in a plane would be detected. The procedure for multilevel processing has not been included yet. The points situated at edges of a detected building or outside the tolerance interval of the determined X-coordinate do not fulfill condition for assignment to building facades and will be put into the file for further processing (Figure 25).

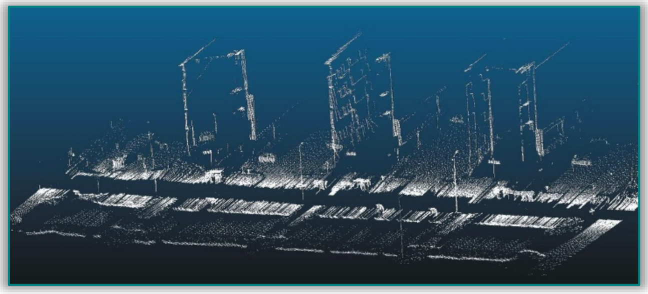

Figure 25. A cloud of points after facades extraction

Classification of Pole-like Objects

After removal of building facades the cloud contains points representing mostly smaller objects (Figure 25). Through internal setting (histogram range, Euclidean distance) the algorithm has been adapted to identify and classify taller objects that are captured in a sufficient range. Narrow rods of traffic signs have been during the test captured only partially. Therefore information about their position and reflectivity is incomplete what makes their classification under considered conditions impossible.

Close to the trajectory of the mobile laser scanner there are three poles and at the next row of parking places another two ones. Focusing on wider objects the algorithm has been able to extract three of them. Relevant points have been automatically saved to a separate file (Figure 26). Two poles situated in a distance slightly lower than 30 m have not been classified. Point coverage has not been sufficient to fulfill conditions for extraction. It results from algorithm parameters settings.

Figure 26. Extracted points representing poles of street lamps

CONCLUSIONS

The proposed classification algorithms have been developed within the research project and tested on multiple 3D models generated for different road infrastructure environments. The main advantages of the proposed approach as mentioned in the paper are preferential use of range data or reflectivity data or both for different classification tasks. The main disadvantage results from the fact that if a set of points representing the given object is not sufficient, the object is not classified. This problem is typical for classification methods based on range data processing. Static test measurements of pole-like objects provide excellent results also for smaller objects (e.g. rods of traffic signs). Problems have been identified only if surface has been damaged or color has been varying. Classification of facades works perfectly for large plane surfaces. However, rather bad results appear if the building with a complicated structure has been obliquely oriented. Our future research will be oriented to fuse point clouds with visual information - images obtained from cameras integrated in our mobile measurement platform.

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References

[1.] Z. Huijing, Ch. Yuzhong, S. Ryosuke, An efficient extrinsic calibration of a multiple laser scanners and cameras' sensor system on a mobile platform. In Proceedings of the IEEE Intelligent Vehicles Symposium. Istanbul (Turkey), 2007, p. 422–427.

[2.] M. Tsogas, N. Floudas, P. Lytrivis, et al. Combined lane and road attributes extraction by fusing data from digital map, laser scanner and camera. Information Fusion, 2011, vol. 12, issue 1, p. 28–36. ISSN: 1566-2535.

[3.] A. Huang, D. Moore, M. Antone, et al. Finding multiple lanes in urban road networks with vision and lidar. Auton Robot, 2009, vol. 26, issue 2-3, p. 103–122. ISSN: 0929-5593. DOI: 10.1007/s10514-009-9113-3

[4.] G. Welch, G. Bishop An introduction to the Kalman filter. 2006, TR95-041, 16 pages. [Online] Cited 2015-03-30. Available at: http://www.cs.unc.edu/welch/media/pdf/kalman intro.pdf

[5.] J. Peng, El Najjar M.E., C. Cappelle A novel geolocalisation method using GPS, 3D-GIS and laser scanner for intelligent vehicle navigation in urban area. In Proceedings of the International Conference on Advanced Robotics ICAR, Munich (Germany), 2009, p. 1–6. ISBN: 978-1-4244-4855-5.

[6.] M. Joerger, B. Pervan, Range-domain integration of GPS and laser-scanner measurements for outdoor navigation. In 19th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2006), Fort Worth, TX (USA), 2006, p. 1115–1123.

[7.] A. Soloviev Tight coupling of GPS, laser scanner, and inertial measurements for navigation in urban environments. In Proceedings of the Position, Location and Navigation Symposium IEEE/ION, Monterey (Canada), 2008, p. 511–525, eISBN: 978-1-4244-1537-3, print ISBN: 978-1-4244-1536-6. DOI: 10.1109/PLANS.2008.4570059

[8.] I. Abuhadrous, S. Ammoun, F. Nashashibi, et al. Digitizing and 3D modeling of urban environments and roads using vehicle-borne laser scanner system. In IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), 2004, vol. 1, p. 76–81. DOI: 10.1109/IROS.2004.1389332

[9.] J.X. Hang, X.G. Lin Object-based classification of urban airborne lidar point clouds with multiple echoes using svm. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2012, vol. I-3, p. 135–140. ISSN: 1682-1750.

[10.] N. Haala, C. Brenner Extraction of buildings and trees in urban environments. ISPRS Annals of the Photogrammetry & Remote Sensing, 1999, vol. 54, no. 2-3, p. 130–137.

[11.] M. Rutzinger, N. Pfeifer Detection of high urban vegetation with airborne laser scanning data. In Proceedings of ForestSat'07, 2007, Montpelier (France), 2007, 5 p. on CD.

[12.] A.T. Darmawati Utilization of multiple echo information for classification of airborne laser scanning data. MSc Thesis, Enschede (the Netherlands): International Institute for Geo-Information Science and Earth Observation (ITC), 2008, 77 p.

[13.] M. Rutzinger, A.K. Pratihast, O.S. Elberink, et al. Detection and modelling of 3D trees from mobile laser scanning data. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2010, vol. 38, part 5, p. 520–525.

[14.] X. Yu, J. Hyyppa, M. Vastaranta, et al. Predicting individual tree attributes from airborne laser point clouds based on the random forests technique. ISPRS Journal of Photogrammetry and Remote Sensing, 2011, vol. 66, issue 1, p. 28–37. DOI: 10.1016/j.isprsjprs.2010.08.003

[15.] C. Brener Advances in GIScience. Lecture Notes in Geoinformation and Cartography (Extraction of features from mobile laser scanning data for future driver assistance system). Berlin-Heidelberg (Germany): Springer-Verlag, 2009, p. 25-42. ISBN: 978-3-642-00317-2. DOI: 10.1007/978-3-642-00318-9-2

[16.] A. Golovinski, V. Kim, T. Funkhouser Shape-based recognition of 3D point clouds in urban environment. In 12th International IEEE Conference on Computer Vision, 2009, p. 2154–2161. ISBN: 978-1-4244-4420-5. DOI: 10.1109/ICCV.2009.5459471

[17.] M. Lehtomaki, A. Jaakkola, Hyyppä, et al. Detection of vertical pole-like objects in a road environment using vehicle-based laser scanning data. Remote Sensing, 2010, vol. 2, no. 3, p. 641–664. ISSN: 2072-4292. DOI:10.3390/rs2030641

[18.] H. Yokoyama, H. Date, S. Kanai, et al. Pole-like objects recognition from mobile laser scanning data using smoothing and principal component analysis. ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2011, vol. XXXVIII-5/W12, p. 115–120. DOI: 10.5194/isprsarchives-XXXVIII-5-W12-115-2011

[19.] M. Vakautawale Information Extraction from Mobile Laser Scanner for Inventory Application. MSc Thesis, Enschede (the Netherlands): University of Twente Faculty of Geo-Information and Earth Observation (ITC), 2010, 63 p.

[20.] S.I. Ee-Halawany, D.D. Lichti, Detection of road poles from mobile terrestrial laser scanner point cloud. In International Workshop on Multi-Platform/Multi-Sensor Remote Sensing and Mapping (M2RSM). Xiamen (China), 2011, p. 1–6. ISBN: 978-1-4244-9402-6. DOI: 10.1109/M2RSM.2011.5697364

[21.] I. Stamos, O. Hadjiliadis, Z. Hongzhong, et al. Online algorithms for classification of urban objects in 3D point clouds. In 2nd International Conference 3D Imaging, Modeling, Processing, Visualization and Transmission (3DIMPVT). Zurich (Switzerland), 2012, p. 332–339.

[22.] S. Pu. Advances in 3D Geoinformation Systems (Automatic building modeling from terrestrial laser scanning). Berlin (Germany): Springer-Verlag, 2008, p. 147-160. ISBN: 978-3-540-72134-5. DOI: 10.1007/978-3-540-72135-2 9

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