RELATIVE ADJUSTMENT OF MOBILE LASER SCANNING DATA IN DIFFERENT SCENES

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ABSTRACT:

Adjustment is a final step in the post-processing of mobile laser scanning (MLS) data. This stage improves the accuracy of point cloud and trajectory registration in the global coordinate system. Cutting-edge software bundled with the corresponding survey complex is capable of performing the majority of MLS data registration steps in an automatic mode for territories with a varied type of development. With the sufficient number of vertical or inclined flat surfaces software algorithms ensure high accuracy of relative adjustment that constitutes calculating and applying corrections to MLS data obtained during multiple passes. The accuracy of automated relative adjustment can be significantly reduced when there are almost no flat surfaces. In this case, pole-like infrastructures can be used. The task of detecting pole-like infrastructures is mainly solved with high accuracy in urban scenes. In out-of-town scenes this task is becoming more complicated due to vegetation along roads. A comprehensive technique for MLS data relative adjustment, which is capable of utilizing the information about pole-like infrastructure location where there are not enough flat surfaces is proposed. The technique allows detecting pole-like infrastructure among vegetation. Analysis of accuracy estimation results demonstrated that only minimum manual correction of tie point locations is required.

1. INTRODUCTION

Mobile laser scanning is one of the cutting-edge surveying methods. A vehicle with mobile scanning system onboard records data about the surroundings on the go. Laser scanners, satellite antennas, digital cameras and inertial measurement unit (IMU) are installed on a vehicle. An odometer is fixed on a wheel. All these devices are controlled with a control unit usually located inside the vehicle. Data are recorded onto the hard drives installed inside the control unit. An operator turns on and off the recording, monitors the process via a laptop or a tablet (Wang et al., 2019). The results of integrated processing of information obtained using the MLS equipment are trajectory path, digital images, and point clouds. MLS can be employed to solve various production problems related to terrestrial surveying. Based on those data, topographic plans, 3D-models of buildings and structures, longitudinal and transverse road profiles are made, and defects of roadways and other objects are exposed. MLS is characterized by high accuracy and speed of data gathering with adequate processing automation (Li et al., 2020, Li et al., 2018).

To obtain sufficient amount of MLS data, in most cases multiple scanning of the same terrain by several passes is necessary. Additional scanning increases data density, which has a positive effect upon the final product but it can cause mismatching of point clouds in the overlapping zones. Relative adjustment of point clouds should be carried out. Mismatching of point clouds in the overlapping zones depends on the quality of satellite signal, weather conditions and features of a surveying system. Another factor is the distance reached by a surveying system from the base station during scanning (Rylskiy, 2020).

In addition, it should be considered that data mismatching can also emerge in a single pass MLS because relative orientation elements of laser scanners can be calculated with poor accuracy. Since an MLS system typically has two laser scanners, mismatching emerges between point clouds produced by them. Accurate values of relative orientation elements of laser scanners are typically obtained calibrating an MLS system as a result of test passes (Gao et al., 2015, Schaer, Vallet, 2016). In surveying systems, where laser scanners are tightly connected to each with special fixing, elements of relative orientation do not change with another MLS system mounting on a vehicle. One-time calibration is usually performed at the manufacturing plant. If scanners are not tightly connected, calibration should be done again every time with new mounting. An example of a technique for estimating calibration parameters is given in Li et al., 2020.

Apart from an increased density, additional scanning can improve absolute data accuracy, because it is possible to calculate the average position among all overlapping point clouds acquired from multiple passes. With many additional passes, relative registration of laser scanning data enhances the accuracy of point cloud position in the external coordinate system (Hussnain et al., 2018).

Increasing the degree of automation is currently the main objective of all studies concerning relative registration of MLS data.

Relative registration of point clouds is one of the major steps in post-processing of MLS data. The following stages of post-processing should be performed before point cloud registration (Medvediev et al., 2014): calculating trajectories recorded with GNSS receivers of a MLS system, relative to the reference stations; trajectory thickening when a set of intermediate points is added to a calculated trajectory; generating point clouds through integrated processing of the calculated trajectory and distance measurements carried out with laser scanners.

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These steps of post-processing are performed in specialized bundled software (BS), supplied with an MLS system. The algorithms embedded in such BS calculate trajectories in a fully automated mode and generate point clouds.

Automating registration of the generated point clouds is more complex and can be done in different ways. Most BS from laser scanner manufacturers perform automated relative registration by searching corresponding flat surfaces in overlapping point clouds by iterative closest point (ICP) algorithm or its modifications (Li et al., 2020). This algorithm minimizes differences among overlapping point clouds. Vertical position is adjusted by horizontal planes, and horizontal position – by vertical ones. Horizontal planes are typically inscribed in the ground surface points, and there are no difficulties for relative adjustment of vertical position in any areas. In its turn, automated adjustment of horizontal position is possible in BS with high accuracy only for surveying areas with flat vertical surfaces. For the maximum accuracy of automated relative registration, it is recommended to scan in different directions, moving along buildings and constructions (Kukko, 2013). Registration methods in BS from manufacturers of laser scanners are similar to those described in Ding et al., 2007, Levinson et al., 2007 and Zhao, 2011.

To improve the accuracy of automated point cloud registration performed in BS from laser scanner manufacturers, additional program modules and special data processing techniques are frequently developed. An example is given in Li et al., 2018: preliminary separation of raw data in the form of trajectories and point clouds, obtained with Riegl MLS systems, on short sections with longitudinal overlap using a special program module. MLS data are duplicated in overlapping zones. The prepared data sections are imported and adjusted in Riprocess software included in the MLS system package (Riegl – Riprocess, 2022). Preliminary data separation allows carrying out more accurate relative registration of MLS data. The described adjustment technique provides an opportunity to compete with even more expensive special software such as TerraSolid. Using TerraSolid implies additional data adjustment after their standard processing in Riprocess or any similar software.

Disadvantages of using software packages from laser scanner manufacturers are a closed program code and relatively limited set of tools. It is not always possible to achieve the maximum accuracy of automated relative registration with the tools offered in case of complicated external scanning conditions. For instance, if flat vertical surfaces are practically absent in point clouds, which is typical for out-of-town areas, or surveying was carried out only rectilinearly, the accuracy of relative registration in horizontal position can be poor. Then manual placement of tie points should be performed using separate pole-like infrastructures such as supports, traffic lights, road signs, etc. Road marking can also be used for tie point identification (Kukko, 2013, Guan et al., 2014).

Adjustment algorithms have been recently developed that automatically identify pole-like infrastructures. Such algorithms are developed using different programming languages in the form of separate program modules. TerraSolid is a set of such modules started from MicroStation software. TerraSolid comprises a lot of tools, which parameters can be flexibly adjusted to solve a particular problem.

One of the automated adjustment methods is given in Hu et al., 2019, which is based on identifying road infrastructure facilities, supports and road markings. The method was tested on the basis of MLS data for urban scenes. At the first step, all pole-like infrastructures are identified. Then they are divided into small groups. It is necessary to separate groups of pole-like infrastructures from vegetation, which heterogeneous structure has a negative impact on the accuracy of identifying man-made objects. The need to use aerial data from manned or unmanned aircrafts for automated classification of pole-like infrastructures by groups is a shortcoming. Otherwise, most identified groups can be recognized only interactively.

To automatically classify groups of pole-like infrastructures without aerial survey data, supervised classification can be used. This method is implemented in many software for processing remote sensing data. It is also used in TerraSolid (TerraScan User Guide, 2022). According to this method of classification, point cloud is divided into separate groups by particular features. Then training samples are formed comprising various groups of objects from a scanned territory. A library of samples is formed, where a separate class is assigned to each group. Finally, the samples are compared with all the unidentified object groups in a point cloud. Each point cloud group is assigned the closest sample class. A disadvantage is the classification results strongly depend on the point cloud density, the number of MLS passes as well as the identified object side, from which scanning was performed. Also, sample library creation is a lengthy process (Scherzinger and Hutton, 2022).

Therefore, many techniques of automated MLS data relative registration and adjustment have already been developed. However, to achieve high accuracy several preliminary processing steps are required to implement before the adjustment. Normally, the suggested techniques are adapted for a certain type of area. The accuracy of automated adjustment may be quite good for high-rise areas, but it can decrease sharply for the terrain sectors with the minimum number of various objects and constructions. In this case, the goals of laser scanning and requirements to the accuracy of the final products should be taken into account. New techniques of relative adjustment should be developed based on a comprehensive approach enabling to consider most specific characteristics of the surveyed area and the given scanning parameters.

A proposed technique of MLS data relative adjustment takes into account many factors. This technique is applicable to MLS data of all territories. Its main advantage is the opportunity to automatically filter most of the high vegetation located along roads. This is especially important in out-of-town scenes where there are almost no vertical flat surfaces for identifying tie lines among multiple MLS passes and pole-like infrastructures have to be used for identifying tie points. It is no need to create training samples or use aerial imagery for detecting pole-like infrastructures. Identification of tie points is carried out on the basis of detecting point cloud groups in overlapping point clouds after filtering vegetation in the certain height interval where pole-like infrastructure elements are mostly presented. To filter vegetation information about the number of reflections per pulse, some calculations and algorithms are used. Ground classification by the Axelson’s algorithm, analyzing tree crowns by watershed algorithm, dividing a point cloud into levels by height, calculating normals, Euclidean distances between neighboring laser points and point cloud density in a limited area is carried out. These processes are separately implemented for multiple MLS passes. Next, ICP-like algorithm in TerraSolid is used for identifying tie points using detected group of laser points. To reduce impact of wrongly identified tie points to MLS data adjustment accuracy, a one-dimensional

Gaussian filter is used when calculating local corrections to overlapping point cloud positions.

2. METHODS

The first step of post-processing is the MLS data registration in BS by automatic means. Point clouds, obtained with MLS, comprise a set of scanlines. Each scanline has its own elements of exterior orientation. The registration algorithms in BS allows calculating corrections to angular exterior orientation elements of each scanline with high accuracy based on point cloud overlaps. The estimated accuracy of linear elements will depend on the original data quality and the number of vertical flat objects along the trajectory. Based on accuracy estimation of MLS data registration it is necessary to make a decision on necessity of MLS data adjustment. For improving relative and global accuracy of registration results, MLS data are imported to additional software such as TerraSolid. Next standard steps took place before adjustment: fragmenting trajectories in accordance with the movement direction, assigning a trajectory fragment number to each point in the cloud, removing excessive points obtained when movements stop, classification of points obtained during turns (Kukko, 2013). Then filtration of low and air points is made by the algorithms described in TerraScan User Guide, 2022.

To adjust MLS data, the following technique was developed, each step of which is performed automatically and separately for each trajectory fragment:

1. Defining the boundaries of searching corrections to linear exterior orientation elements of scanlines. To define errors in vertical position, an inner zone is used between MLS trajectories of forward and backward directions, and in horizontal position – zones between the trajectories and external boundaries. The external boundary is set by parallel copying of a trajectory for a particular distance, selected based on the location of various road infrastructure objects, their number and presence of vegetation. The contours of the external boundary are edited depending on the object presence.
2. Classifying the ground points with use of the Axelson's algorithm (Axelsson, 2000).
3. Moving the ground points located between trajectory lines of opposite passes into the road surface class.
4. Automated searching tie lines, inscribed in the road surface points of the opposite laser scanning passes every 10 m along the traffic direction.
5. Calculating local corrections to the vertical position of trajectories and point clouds using a one-dimensional Gaussian filter:

$$G(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{x^2}{2\sigma^2}}, \qquad (1)$$

where x = is a distance along the scanning trajectory within which smoothing is carried out
σ = standard deviation in Gaussian distribution

It was determined that to adjust the vertical position of MLS data, x = 50 m should be set.

6. Application of local corrections to the vertical position of trajectories and point clouds.
7. Calculating the height from ground for each laser point.
8. Dividing the entire point cloud into two levels by height from ground: 0–1 m, > 1 m.
9. Classifying all laser points where the number of reflections per pulse exceeds 1 to a temporary class.
10. Calculating normals in each point cloud, analyzing positions of neighboring points (Hoppe et al., 1992). Normals are necessary in further described algorithms for searching groups of points and trees.
11. Classifying groups of points at the level "> 1 m" to the class of small vertical objects based on calculating distances between neighboring points. Groups are formed from the nearest points. The minimum number of points for a group is set to 20 (TerraScan User Guide, 2022).
12. Classifying groups of points that are in the zone between trajectories and external boundaries, into a separate class of pole-like infrastructures that are scanned only from the same side not depending on the direction of vehicle movement along a road.
13. Classifying groups of points from the class of small vertical objects to the vegetation class using a TerraSolid algorithm for tree classification that analyses tree crowns. This is a watershed algorithm (Holmgren, Lindberg, 1992). The minimum height of groups above the ground and their minimum diameter are specified in the algorithm. To analyze whether all points in the class of vertical objects represent vegetation, any value of the minimum height lower 1 m and a small diameter value are set. As a result, 0.2 m values were set for both parameters.
14. Classifying groups of points, for which the maximum height value is less than 2.1 m, from the class of vertical objects to the vegetation one. 2.1 m was chosen because the minimum height of road signs and poles around the road is higher.
15. Classifying groups of points, for which the maximum height value is over 13 m, from the class of vertical objects to the vegetation one. The value was chosen based on the maximum height of supports. Thus, groups of points with the maximum height in the range 2.1–13 m remain in the class of vertical objects.
16. Calculating paired Euclidean distances on XY plane for each laser point in the vertical objects class to each point in the vegetation class. If the distance is less than the threshold value, the point is classifying to the vegetation class. The criterion for changing the class of a point may be written as:

$$\sqrt{\left(X_i - X_j\right)^2 + (Y_i - Y_j)^2} \leq D, \qquad (2)$$

where D = a threshold value of Euclidian distance between points of the vertical object class and the vegetation class
$X_i Y_i$ = coordinates of a point from the vertical object class
$X_j Y_j$ = coordinates of a point from the vegetation class

17. Classifying points from the vertical objects class to the vegetation class provided that one or two points of the vertical object class are within a point cloud of 0.512 m^3.
18. Classifying points with more than 6 m height above the ground from the vertical object class to a temporary class. It excludes high-altitude parts of objects from further processing. For example, wires of power lines can be excluded since in most cases they are found in the same group with support (poles) and introduce major errors in the results of searching tie points.
19. Automated search of tie lines by flat vertical objects of all point cloud classes with the following parameters: line length – 0.3 m; section depth – 0.1 m; the maximum angle of line inclination – 10°. Tie lines enable relative adjusting point clouds when there are a lot of building walls. If there are no such objects in the survey area, tie lines can be found on large road

signs; however, the accuracy of relative adjustment by only automatically found tie lines will be low.
20. Automated search of tie points in laser points of the vertical object class among multiple laser scanning passes.
21. Manual analyzing the results of searching tie points on the segments with their low density – less than 3 laser points in 100 m. Removing wrongly identified tie points.
22. Calculating local corrections to the horizontal position of trajectories and point clouds using a one-dimensional Gaussian filter. It was determined that to adjust the horizontal position of MLS data, x = 100 m should be set.
23. Application of local corrections to the horizontal position of trajectories and point clouds.

Axelson's algorithm used for ground classification is based on triangular irregular networks (TIN). A sparse TIN is generated from seed points which ale selected within a grid. The grid size is specified by a user as well as initial values of next threshold parameters: distance to the TIN facets and angles to the nodes. The choice of the grid size is usually connected with the size of the largest structures such as buildings. In the results of iterative process, the initial sparse TIN is densified. One points in each TIN facet is added at each iteration if it meets the criteria on the basis of computed threshold parameters. Threshold parameters are calculated at each iteration from data. Densification of TIN continues until all points are classified as ground.

Proposed MLS data adjustment technique based on overlapping point clouds allows improving relative local accuracy by mean of data corrections with automatic extraction of tie points in the MLS dataset. Automatically extracted tie points allow speeding up data post-processing and reduce its cost. Local correction of overlapping point clouds passes also improves global accuracy of data. The more MLS passes are made, the higher global accuracy will be. Final adjustment for improving global accuracy is conducted with measuring ground control points (GCP)

3. STUDY AREA AND DATA

To test a technique for relative adjusting, MLS data of three areas were used: Talakan – Vitim road, 160 km; 1 km segment of Dzerzhinsky Prospekt, in Novosibirsk; 1 km segment of Stantsionnay street, in Novosibirsk.

The three areas have different development types. There were practically no buildings around the road, and it was surrounded by high vegetation in majority of segments. This is out-of-town area. Pole-like infrastructures occurred regularly. Density of pole-like infrastructures differs in different segments of the road. Most of poles and traffic signs were surrounded by vegetation. High grass and shrub vegetation grew on edges of the road. The average distance from the road to trees was around 20 m and their height did not exceed 30 m. Due to the large length it was possible to check the accuracy of MLS data adjustment technique in conditions of changing density of vegetation and pole-like infrastructures. Density of point clouds changed proportionally to slowing or speeding-up a vehicle with mounted MLS system.

The short second and the third areas were scanned for checking accuracy of MLS data adjustment technique in urban scenes. The second area had high-rise buildings and plenty of various city infrastructure objects without vegetation. The third area had poles along the street where there were no buildings and minimum amount of vegetation.

Scanning of the first and the second areas was performed with Riegl VMX-250 system, whereas the third one – with Lynx Mobile Mapper M1.

Before scanning of the motor road, there were chosen locations for reference stations. (Fig. 1). The coordinates of points for placing reference stations called NGDU and DNS were known. Continuously operating reference stations (CORS) were there. The coordinates of reference station points called B1–B3, D20 were preliminary measured from the state geodetic network points through satellite observations.

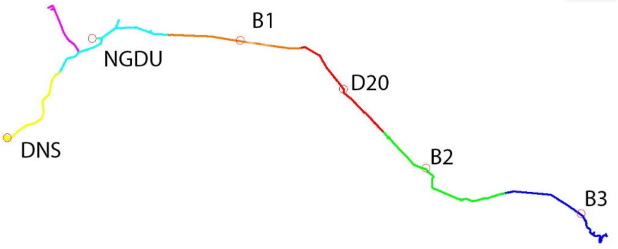
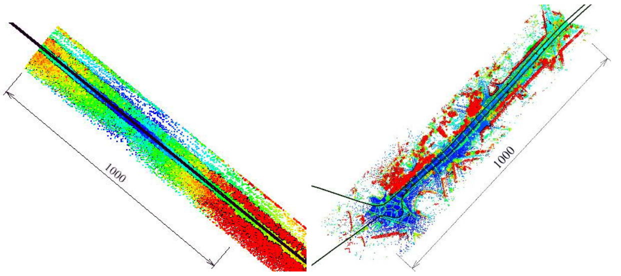


Figure 1. Segments of the Talakan – Vitim road.

Scanning was performed in forward and backward directions successively by segments around a single reference station. Speed of scanning vehicle did not exceed 40 km/h. During each segment survey, GNSS data collection was launched only at the reference station located at the segment center. The effective measurement rate was set at 300 kHz for each laser scanner, and frequency of scanning – 100 Hz. The maximum distance from a reference station did not exceed 15 km, which is half the permissible distance stated in Scherzinger and Hutton, 2022 for MLS systems with Applanix inertial measurement units when surveying from one station. Each survey segment is marked with a separate color in Fig. 1. First, segments from CORS were scanned. Next, the segment around B1 reference station was surveyed. Then a satellite receiver was moved in turns to D20, B2 and B3 points. Compared to the GNNS network technique, surveying by segments shortened the time spent to install satellite receivers on reference stations and decreased the number of receivers to one. Establishing a network of reference stations requires a lot of staff as data should be collected on stations simultaneously during laser scanning. It increases the preparation time considerably and reduces safety for surveyors when scanning low-populated remote territories. The base stations method is of highest relevance when scanning can be done in one day. Fig. 2a shows a fragment of the survey displaying point cloud by elevation from top view.

MLS of Novosibirsk streets was performed from a single CORS called NSKW. Fig. 2b gives a fragment of the street survey result, length – 1 km. The scanning trajectories are shown in black. Speed of scanning vehicle did not exceed 40 km/h as well.



(a) **(b)**

Figure 2. MLS point clouds acquired with Riegl VMX-250: (a) A segment of Talakan – Vitim road; (b) A segment of Dzerzhinsky Prospekt.

MLS of Stantsionnaya street was performed from the same reference station as MLS of Dzerzhinsky Prospekt (Fig. 3). Average speed of scanning vehicle was more for this area than for the first and the second ones. It did not exceed 60 km/h. The effective measurement rate was set at 250 kHz for each laser scanner and frequency of scanning – 200 Hz.

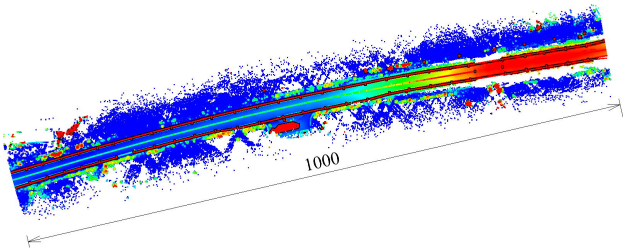


Figure 3. MLS point cloud acquired with Lynx Mobile Mapper M1 for Stantsionnaya street.

4. RESULTS

Initially all MLS data acquired with Riegl VMX-250 system were automatically processed and registered in software POSPac MMS and Riprocess. POSPac MMS is software from Applanix company for direct georeferencing of MLS sensors (Applanix : POSPac MMS, 2022). POSPac carries out calculating MLS trajectories. Since reference stations at each segment of the motor road were not launched simultaneously, trajectories of every road segment were calculated independently. The calculated trajectories and raw data from laser scanners were loaded in Riprocess software, where point cloud coordinates were computed. Then point clouds were relatively registered automatically, separately for each survey segment.

MLS data acquired with Lynx Mobile Mapper M1 system were automatically processed and registered in software POSPac MMS and Lidar mapping suite (LMS). LMS is software from Optech company that has similar functionality to Riprocess (LMS Pro, 2022).

Point clouds, obtained with MLS, are represented as scanlines. Points of each scanline have their own exterior orientation elements. The adjusting algorithm in Riprocess and LMS allows calculating corrections to angular exterior orientation elements of each scanline with high accuracy based on point cloud overlaps. The estimated accuracy of linear elements will depend only on the original data quality and the number of vertical flat surfaces around the MLS trajectory.

To estimate the registration accuracy of MLS data from all the survey segments conjointly and perform additional adjustment, point clouds and trajectories were imported to TerraSolid. Such standard steps were implemented before adjustment as fragmenting trajectories in accordance with the movement direction, assigning a trajectory fragment number to each point in the cloud, removing excessive points obtained when movements stop, classification of points obtained during turns (Kukko, 2013). Then filtration was made by the algorithms described in Hu et al., 2019: low and air points were removed. Next, steps of the proposed technique were carried out.

4.1 Results of MLS data relative adjustment for Talakan – Vitim road

The proposed technique was used for MLS data relative adjustment of the whole Talakan – Vitim road area.

Fig. 4 gives a fragment of the results of searching for 2 m lines with top view. For tie line identification only inner zone between opposite trajectories was used. This zone is cross-hatched and represents a road surface.

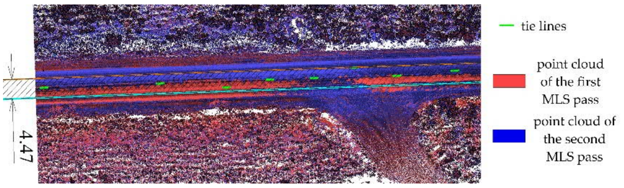


Figure 4. An example of identified tie lines.

Fig. 5 gives an example of searching tie points on a road segment, and Fig. 6 – a cross-section of the segment. The outer search boundary for the Talakan – Vitim road area shifted for 10 m from MLS trajectories due to abundant vegetation and also because all road signs were in the designated zone. In the road segments with a parallel power line, the zone shifted but for no more than 45 m from the power line. It was found when scanning with Riegl VMX-250 with the earlier given survey parameters, the density of MLS data at large distances from the trajectory is insufficient to identify tie points in the overlapping zones. The search distance may be increased if the speed of an MLS system movement decreases.

The tie points identified on pole-like infrastructures practically always correctly represent errors of point cloud relative orientation. Those on vegetation can only partly represent the correct errors. Large orange circles mark 3 tie points found on the tops of shrub vegetation. One of the three tie points identified on shrub vegetation shows a wrong error of relative positioning. Alternatively, tie points were not identified on 2 support poles of the electric power line. It could happen due to a significant inclination of the poles.

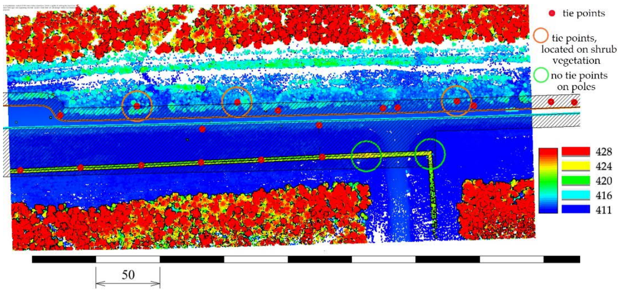


Figure 5. An example of identified tie points on pole-like infrastructures and vegetation.

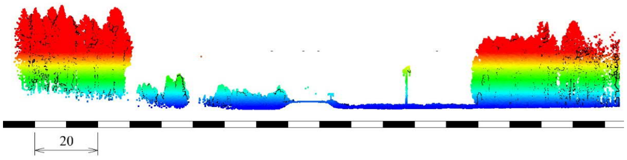


Figure 6. Cross-section of MLS data.

Fig. 7 depicts another example of tie point identification. They were found on all vertical support poles of the power line, on shrubs between the power line and the road, as well as on road signs. All points identified on shrubs are circled in black polygons, many points are identified with low accuracy.

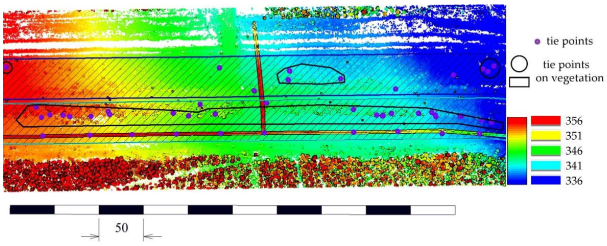
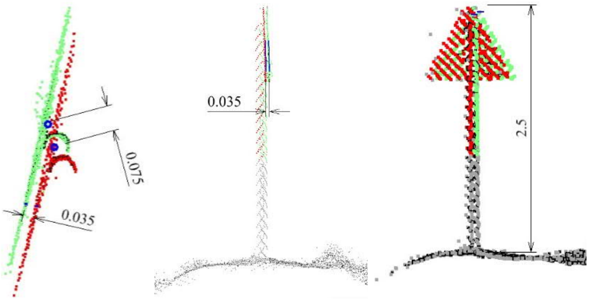


Figure 7. The second example of identified tie points on pole-like infrastructures and vegetation.

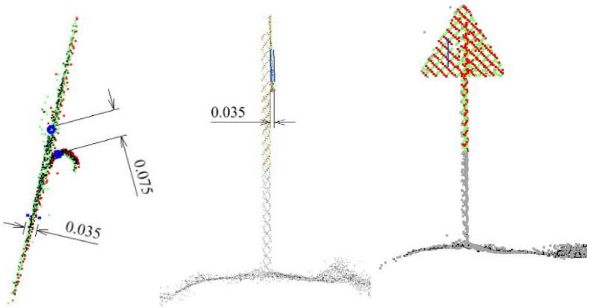
Fig. 8 gives an example of searching tie points and lines on a road sign. The error of relative positioning point cloud by tie points was 0.075 m and by tie lines – 0.035 m. Using only tie lines do not fully eliminate the error of relative positioning, because they define the error only in a single plane. Also, tie lines are not identified on small road signs such as pickets, and on supports



(a) **(b)** **(c)**

Figure 8. Road sign before adjustment: (a) top view; (b) left view; (c) front view.

Fig. 9 depicts an example of applying local corrections. Data mismatching was eliminated. The position of tie points and lines remains the same.



(a) **(b)** **(c)**

Figure 9. Road sign after adjustment: (a) top view; (b) left view; (c) front view.

Tab. 1 summarizes the horizontal and vertical positional errors for the entire area of the Talakan – Vitim motor road, calculated on the differences of tie points and tie lines in the overlapping point cloud.

Accuracy estimation of MLS data relative adjustment is given in Tab. 2.

Error	X, m	Y, m	Z, m
Mean error	0.038	0.049	0.023
RMS error	0.046	0.056	0.048
Maximum error	0.068	0.084	0.297

Table 1. Estimating accuracy of MLS data prior to relative adjustment.

Error	X, m	Y, m	Z, m
Mean error	0.009	0.005	0.003
RMS error	0.013	0.008	0.010
Maximum error	0.033	0.025	0.046

Table 2. Estimating accuracy of MLS data relative adjustment.

Positional errors presented in Tab. 1 and 2 can demonstrate true values only when tie point and tie lines are correctly identified in overlapping MLS point clouds. As tie lines are only identified between opposite trajectory lines on the road surface within automatically classified ground points, calculated vertical positional accuracy tends to correspond to real values.
On the other hand, the values of calculated horizontal positional errors are challengeable. When pole-like infrastructures are located among vegetation, a lot of tie point are identified on such vegetation. It was shown, that some of tie points located on vegetation result in calculating wrong horizontal positional errors. The one-dimensional Gaussian filter allows reducing influence of wrongly identified tie points on horizontal positional errors by smoothing values of local corrections. To choose an appropriate value of a variable x, MLS data adjustment was implemented several times with different values of this variable.

Fig. 10 displays the dependence of a relative point cloud positional error after adjustment from the values of variable x for road signs shown in the fragment of Fig. 7.

The distance between tie points of the road sign and the nearest wrongly identified shrub points was 18 m. As local corrections are not separately calculated for each laser point in the point cloud, longitudinal distance along the laser scanning direction should be factored in for laser points of each scanline. The distance was 14 m.

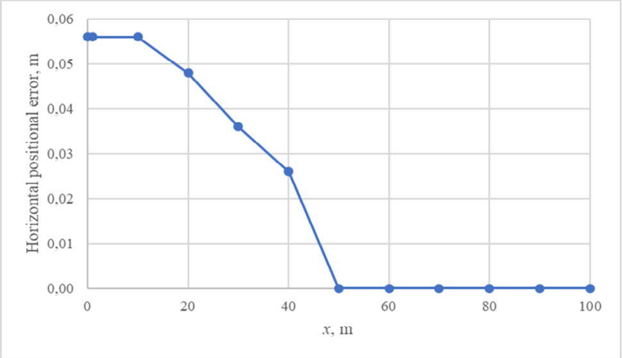


Figure 10. An example of the dependence between a horizontal positional error on a road sign and x value when there is vegetation among many pole-like infrastructures.

According to Fig. 10 if x > 50 m point cloud mismatching for the road sign is fully eliminated.

Fig. 11 gives an example of adjusting point cloud position where another road sign is located. The distance between its tie points and the nearest wrongly identified shrub points was 51 m, and the longitudinal distance – 3 m. Point cloud mismatching for the road sign is eliminated completely when x > 60 m.

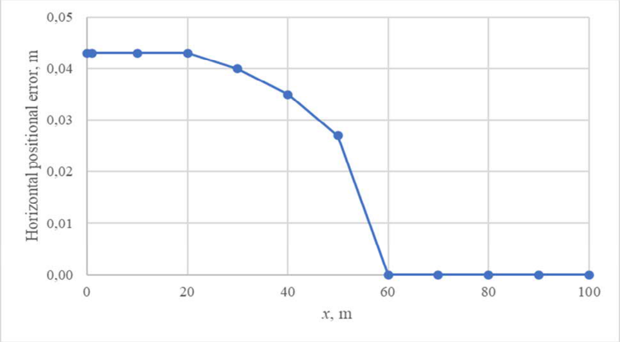


Figure 11. The second example of the dependence between a horizontal positional error on a road sign and x value when there is vegetation among many pole-like infrastructures.

The x = 100 defined as the optimal as the result of analyzing several other fragments of the area, where linear extended objects with support poles, such as power lines, ground pipelines and other industrial facilities were near the road. In this case, wrongly identified tie points practically do not reduce the accuracy of relative adjustment.

Next, a situation when there are only vegetation and a small number of road signs along a motor road should be considered (Fig. 12). Only 7 tie points were identified in the fragment, of which 4 – on road signs and 3 – on shrubs.

Fig. 13 demonstrates a part of the last fragment, zoomed from the right. Tie points on shrubs in the fragment are identified with a major horizontal positional error – 0.150 m. The actual error in this place is only 0.017 m, measured manually by laser points of a road sign.

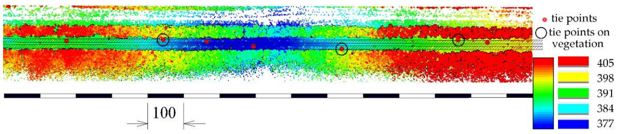


Figure 12. The third example of MLS data with the results of searching tie points.

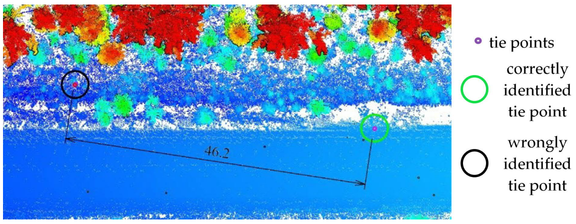


Figure 13. Relative position of correctly and wrongly identified tie points.

Fig. 14 shows dependence between the error of a relative point cloud positional error for the road sign after adjustment and x value, used for smoothing local corrections. The graph is the direct opposite of the above-analyzed situation. Point cloud mismatching on the road sign is fully eliminated at x < 40 m. Due to the low density of tie points, the value of the error on the marked point on shrubs stops affecting correctly identified tie points if the distance between points exceeds the x value.

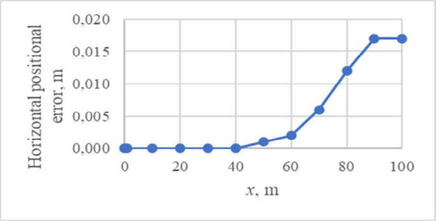


Figure 14. The example of dependence between a horizontal positional error on a road sign and x value when density of tie points is low and there is vegetation

Having analyzed Fig. 14, one may see that the minimum point cloud mismatching on pole-like infrastructures at low density of tie points can be achieved without smoothing filters or with minimum smoothing. Then, however, the largest errors will be observed near all wrongly identified points, for example, point cloud mismatching of the asphalt surfacing edges – where tie points cannot be identified. I.e., a point cloud will be most corrupted after adjustment. Such corruption can be avoided with use of a smoothing one-dimensional Gaussian filter with x = 100 m in the course of adjustment.

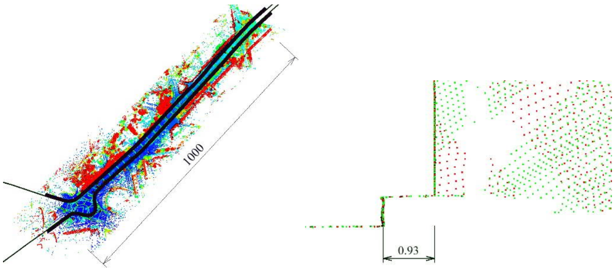
Thus, a conclusion may be reached that tie points identified on vegetation should only be removed manually both when the number of pole-like infrastructures is low and their search distance is limited to 10 m away from the MLS trajectories. The short distance value is chosen due to the absence of any other infrastructures apart from road signs at large distances from the road. If there are other linear-extended objects close to the road at the distance no more than 45 m, the search distance increases and wrongly identified points on vegetation are not removed.

4.2 Results of MLS data relative adjustment for Dzerzhinsky Prospekt

The technique of MLS data relative adjustment is applicable to any types of terrain developments. When adjusting MLS data of urban scenes, a lot of tie lines will be identified on flat vertical surfaces, and for searching tie points if an MLS system moves along right lanes, setting the minimum 10 m zone will suffice to identify most of road signs.

It was mentioned earlier that Riprocess allows adjusting MLS data fully automatically in segments with a lot of flat vertical surfaces. Therefore, export of MLS data for urban streets into additional software for the purposes of further adjustment is not expedient in most cases. Otherwise, using the technique of relative adjustment in TerraSolid will increase the processing time considerably. Figure 15a gives an example of MLS data for a segment of an urban street with the zone for identifying tie points marked in black, and Figure 15b – cross-section of a building corner. The maximum error of relative adjustment did not exceed 0.01 m.

Thus, it is recommended to use the relative adjustment technique for out-of-town scenes without flat vertical surfaces. When scanning both urban and out-of-town scenes should be done in one day, it is necessary to stop and re-launch data collection, i.e. divide a trajectory into fragments.

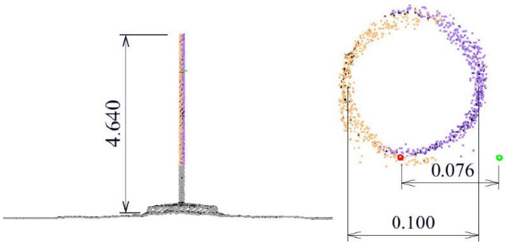


(a) (b)

Figure 15. MLS results: (a) top view with a search zone for tie points; (b) cross-section of a building wall.

Dividing a trajectory into segments may not be expedient when short-term entrance to urban scenes in case of surveying out-of-town areas. In this case, all data are processed using the proposed technique. A lot of pole-like infrastructures help maintain high accuracy of automated relative adjustment in Riprocess.

The specifics of searching tie points are the necessity of scanning pole-like infrastructures from the same side when moving in opposite directions. It always happens for all infrastructures out of the road bounds. If some objects are in the zone between opposite traffic flows, they are scanned from the opposite sides. Laser points of such infrastructure, obtained when scanning in one direction, will differ from laser points obtained in the opposite direction. Fig. 16 gives an example of tie points wrongly positioned on a 0.10 m diameter pole in the zone between the opposite traffic lanes. An actual error of relative point cloud positioning in this place does not exceed 0.01 m, although the error calculated on the basis of automatically identified tie points is 0.076 m. Therefore, the developed technique does not consider the central zone of roads between opposite traffic flows.



(a) (b)

Figure 16. An example of an erroneous result for identified tie points on a pole (a) cross-section; (b) top view.

4.3 Results of MLS data relative adjustment for Stantsionnay street

The technique of relative adjustment was tested for MLS data acquired in the urban street without buildings and other constructions having flat vertical surfaces. Similar streets are usually located at town borders and a small amount of vegetation. Stantsionnay street includes poles located close to the road. Vegetation is situated further from the road edges. Fig. 17 demonstrates results of tie point identification where all tie points were correctly detected on poles. The proposed technique developed on the basis of VMX-250 data allowed adjusting MLS data acquired with Lynx Mobile Mapper M1. It was possible because density of Lynx point cloud was not lower than VMX-250 one.

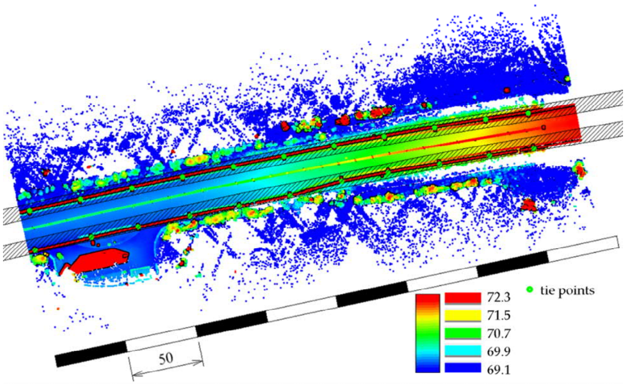


Figure 17. The example of identified tie points on pole-like infrastructures along the street

4.4 Overall accuracy calculation of MLS data adjustment

To estimate how wrongly identified tie points influence on MLS data relative adjustment accuracy a law of total probability was used (Schervish, 1995). All identified tie points were manually checked. At first, it was evaluated how many tie points were identified on pole-like infrastructures and how many of them were detected on other places, mainly on vegetation. As Talakan – Vitim road area consisted pole-like infrastructures and vegetation with different density, it was decided to divide this out-of-town area into 3 zones of in accordance with changing their density. MLS data of urban scenes corresponded to 2 more zones. As a result, 5 next zones were separated for calculating total probability of pole-like infrastructure detection and the overall accuracy:

1. Out-of-town scenes with high density of pole-like infrastructures and low density of vegetation in a searching zone (as data of Fig. 5).
2. Out-of-town scenes with high density of both pole-like infrastructures and vegetation (as data of Fig. 7).
3. Out-of-town scenes with low density of pole-like infrastructures and some amount of vegetation (as data of Fig. 12).
4. Urban scenes with buildings and pole-like infrastructures (as data of Fig. 15).
5. Urban scenes without buildings and with pole-like infrastructures (as data of Fig. 17).

The total probability of pole-like infrastructure detection based on data of these 5 zones can be calculated as:

$$\begin{aligned} P(A) &= P(A|B_1)\cdot P(B_1) + P(A|B_2)\cdot P(B_2) + \\ &+ P(A|B_3)\cdot P(B_3) + P(A|B_4)\cdot P(B_4) + P(A|B_5)\cdot P(B_5) \end{aligned} \tag{3}$$

where $P(A)$ = is the total probability of pole-like infrastructure detection
$P(B_1)$ = $P(B_2) = P(B_3)$ = $P(B_4) = P(B_5)$ = 20% = the probabilities that area of the certain zone will be scanned

$P(A|B_1)$, $P(A|B_2)$, $P(A|B_3)$, $P(A|B_4)$,
$P(A|B_5)$ = the probabilities of pole-like infrastructure detection in the corresponding zone

Tab. 3 demonstrates the calculating results for the total probability of pole-like infrastructure detection. It is seen that a lot of tie point were identified on other places. Mainly, such points were detected on vegetation.

Zone number (n)	The number of tie point identified on poles	The number of tie point identified on other places	$P(B_n)$	$P(A\|B_n)$	$P(A)$
1	1450	136	20%	91.4%	79.3%
2	1268	964	20%	56.8%	
3	826	564	20%	59.4%	
4	121	13	20%	90.2%	
5	68	1	20%	98.6%	

Table 3. Calculation results for the total probability of pole-like infrastructure detection.

To evaluate negative effect of tie points identified on other places to the overall accuracy of tie point identification, the point cloud mismatching in places of pole-like infrastructure locations was manually measured. The value of 2 cm for mismatching was decided to be taken as a criterion that the point cloud had been correctly adjusted in the places of pole-like infrastructure locations. If mismatching between laser points of overlapping point clouds in a pole-like infrastructure location was greater than the criterion value, the point cloud was considered as wrongly adjusted. Tab. 4 presents the calculating results for the overall accuracy of MLS data adjustment based on the probability of pole-like infrastructure detection. In other words, this table demonstrates how wrongly identified tie points, usually detected on vegetation, influence on real point cloud mismatching in places where this mismatching can be manually measured, i.e. in pole-like infrastructure locations.

Zone number (n)	The number of tie point without point cloud mismatching	The number of tie point with point cloud mismatching	$P(B_n)$	$P(A\|B_n)$	$P(A)$
1	1446	4	20%	99.7%	91.2%
2	1254	16	20%	98.9%	
3	475	351	20%	57.5%	
4	121	0	20%	100%	
5	68	0	20%	100%	

Table 4. Overall accuracy of MLS data adjustment based on the probability of pole-like infrastructure detection.

5. DISCUSSION

The technique was developed for adjusting MLS data acquired for the out-of-town scenes. The studied data were a road passing mainly among trees. A lot of grass and shrub vegetation were located close to the road. There were no buildings and other constructions having flat vertical surfaces. This fact dramatically reduces accuracy of relative registration in BS from laser scanner manufacturers whose algorithms search for corresponding points or surfaces among overlapping point clouds. It forces to develop new methods and techniques for adjusting data processed in BS.

A lot of studies have already carried out concerning MLS data adjustment. Many researches use road marking and pole-like infrastructures as a source of tie points and control points. Such objects allow reliably improving registration accuracy. To detect pole-like infrastructures among other man-made and natural objects they often apply aerial imagery.

Most of studies are also done for urban scenes for the goal of increasing absolute accuracy of MLS data. In urban scenes MLS data have usually high relative accuracy and unknown value of absolute one due to a poor GNNS signal.

In out-of-town scenes where there are no buildings for searching flat surfaces, MLS data relative adjustment becomes challengeable. The proposed technique allows identifying tie points on pole-like infrastructures. It can filter most of vegetation prior to identification process without application of any aerial imagery. The influence of wrongly identified tie point on MLS data relative adjustment results is reduced due to smoothing local corrections by the one-dimensional Gaussian filter.

The proposed technique was also applied for data of other test areas. It was checked for urban scenes with building and without them. It was determined that steps of the technique were applicable to any areas. The robustness of defined parameters is confirmed with calculating overall accuracy of MLS data adjustment. All datasets were processed with the same parameters specified in the proposed technique. The technique allows automatically adjusting relative accuracy for areas where the number of pole-like infrastructures is large not depending on amount of vegetation. In places with low density of pole-like infrastructures with high density of vegetation the manual process of checking tie points is required. Despite this fact, the proposed technique improves the performance of registration in out-of-town scenes. Accordingly to Tab. 3 and 4, the number of tie points can be very large. Manual placing all tie points on pole-like infrastructure for large areas can take a lot of time. It is faster to check automatic tie point placement results than to place them manually.

The technique was tested for data of 2 different MLS systems. It was shown that adjustment results do not depend on the model of MLS systems. It depends on received point cloud density. The technique is applicable to data which density not lower than obtained with next minimum survey parameters: the effective measurement rate is 300 kHz, frequency of scanning – 100 Hz, maximum speed of vehicle movement is 40 km/h. If speed of vehicle movement is higher, it can be compensated with increasing frequency of scanning.

6. CONCLUSION

The proposed technique of MLS data relative adjustment considerably accelerates post-processing of the raw data. It can be applied both for urban and out-of-town areas. The relative adjustment technique practically fully automates the searching local corrections to linear relative orientation elements of scanlines in overlapping zones by filtering point cloud from vegetation affecting accuracy of searching tie points on pole-like infrastructures. The chosen values of the algorithm parameters used in relative adjustment technique serve for any point clouds with density no lower than the one of the analyzed data. These values of parameters fit for various areas. The technique takes in account the specific conditions of scanned areas. Relative adjustment on the basis of the proposed technique is also capable to improve absolute positional accuracy due to averaging overlapping point clouds. However, this statement should be studied in future researches when GCPs are used. In future researches the proposed technique also should be improved concerning elimination of the step for manual analyzing the results of searching tie points. In this case the degree of automation can be increased.

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