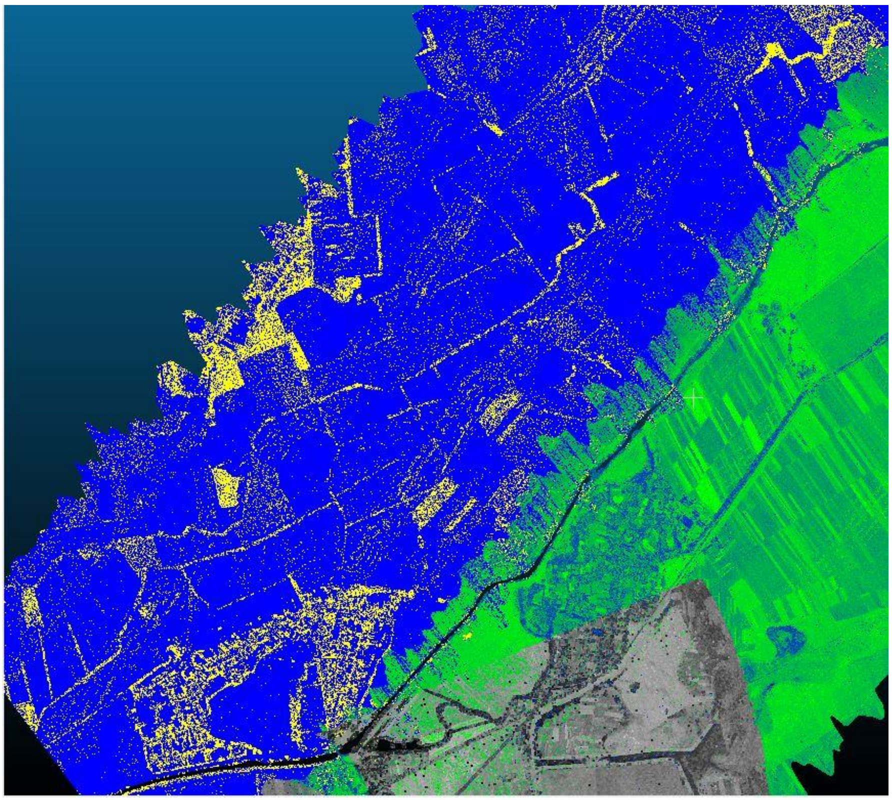

RIGOROUS STRIP ADJUSTMENT OF AIRBORNE LASER SCANNING DATA

Second Researcher Report - 2020

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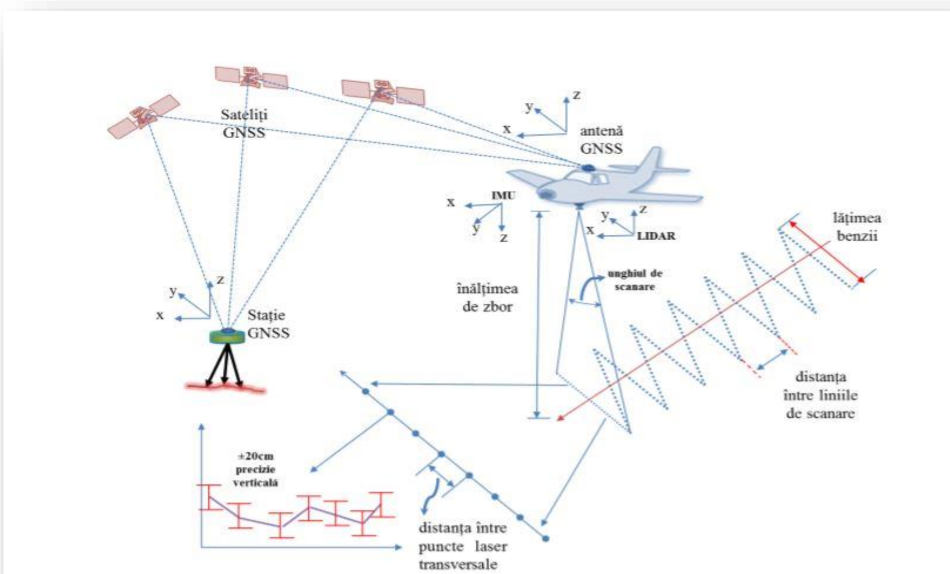
CONTENTS

I. Introduction

The Airborne laser Scanner – ALS, how is also known as LiDAR system, is an active remote sensing system used in a wide variety of fields (topography, hydrography, architecture, archeology, oil exploitation, mining or forestry) for over a decade. The most known application of data got with LiDAR technology in urban areas is the creation of 3D city models. One advantage of the Airborne Laser Scanner (ALS) compared to aerial photogrammetry or high-resolution satellite data is the acacquire of three-dimensional (3D) data with high precision, by the method of polar coordinates (angles and inclined distances) to get the surface geometry . The system consists of a LiDAR device (LIght Detection and Ranging) and high-precision navigation sensors mounted on an aircraft (fig.1). An IMU (inertial unit of measurement) system and a GNSS (global satellite navigation system, egg GPS, Global Positioning System) receiver are used as a navigation sensor, which are operated synchronously with the LiDAR scanning mechanism (Hebel et al. al. 2010). Range values are got from measuring the flight time of a single laser pulse, and it performs scanning by one or more deflection mirrors combine with the moving aircraft. Navigation sensors are used to get 3D points associated with laser pulse and time interval measurements, resulting in a georeferenced point cloud. During the acquisition of ALS data, it transfers the laser beam measurements to the geographical coordinates regarding the current position / orientation of the laser scanner and the angle of the deflection mirrors. Airborne laser scanning is performed, like classical photogrammetry, in the nadir position. Available laser scanners can gain full wave data of reflected pulses, thus allowing alternative methods of analysis (Jutzi et al., 2006; Wagner et al. 2006; Stilla et al. 2008).

Figure 1. ALS System (Iordan, 2014)



Over the past two decades, the acquisition of point clouds and the calibration of laser scanning systems have been explored by various scientists to determine errors and correct them with high data accuracy. Following a quality control of the data delivered from a procurement project with airborne laser scanning, we highlighted large systematic discrepancies (up to over 60 cm) in the overlap of neighboring lanes, which led to the erroneous generation of final products: cloud of misclassified points, and an erroneous Digital Terrain Model (DTM) and a Digital Surface Model (DSM). For this reason, it was necessary to improve the data by aligning the bands by the two methods highlighted in this report. I will compare the methods in order to observe the differences between them and to discover of which method is in line with the project mention above. All the errors that appeared (fig.2) following the actual flight and the steps taken in order to obtain a precise last product will be specified.

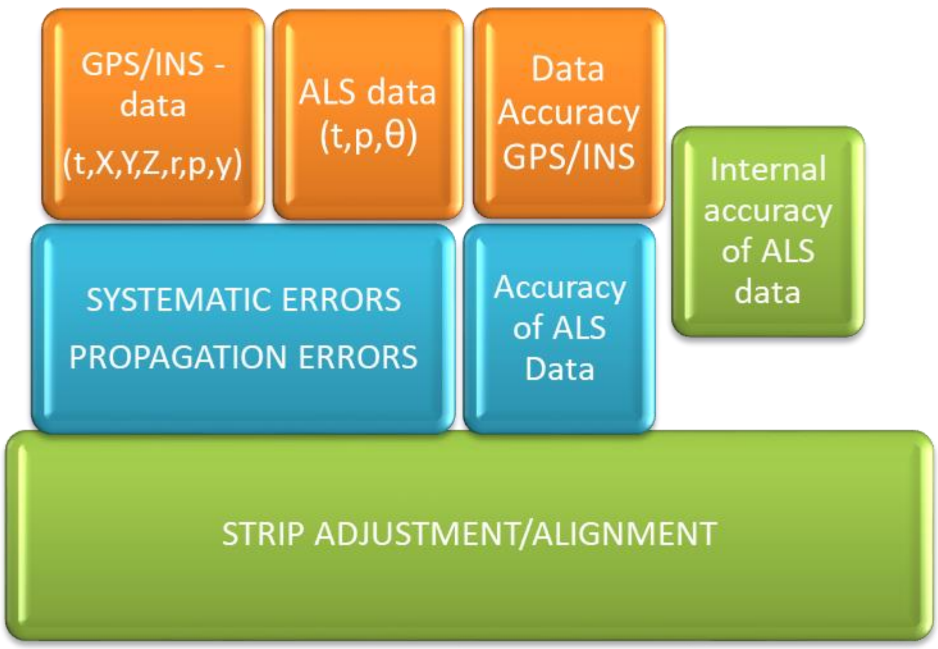


Figure 2. Georeferencing ALS data

Airborne laser scanning, unlike terrestrial laser scanning (TLS), generates the coordinates of the point cloud in the preprocessing stage, after performing the actual flight. Laser data is merged with the flight path (GNSS data) in a process called "direct georeferencing". For 3D data got with greater accuracy, trajectory estimation requires the integration of inertial observations and those from satellite, rover and one or more basic receivers (Skaloud, 2010). Basic receiver data are only available after flight and therefore carrier phase differential positioning integrity (CP-DGPS) can only be achieved then. If the positioning quality is insufficient for periods longer than 10 to 30 s, there is a high probability that the quality of the integrated GPS / INS path will also be insufficient during this interval. Sometimes, the resulting positioning error has a constant influence during the flight line (fig.3).

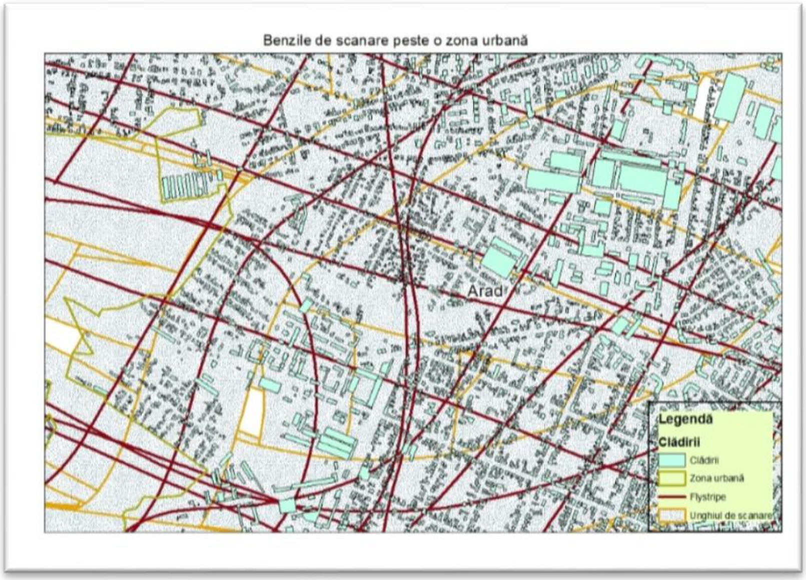


Figure 3. ALS data over an urban area

Direct georeferencing has various errors, such as the fact that external orientation parameters are affected by a certain instability over time (by the rotation between the IMU and the laser system). The values of these parameters during a flight will differ from the last known values (for example, determined during a calibration). It cannot correct these parameters during GNSS / IMU processing, as laser scanner measurements do not take place there. Despite accurate assembly of the sensor system, georeferencing typically leads to considerable displacement in the strip overlap area. We find sources of error in the accuracy of GNSS data, sensor synchronization or scan mirror control. Even the synchronization between GNSS / IMU data and laser measurements can be wrong. For these reasons (even after an error-free GNSS / IMU processing), direct georeferencing will use the wrong transformation parameters, which will lead to wrong coordinates of the points on the measured area. In the final product got, such as the Digital Terrain Model (DTM) this can lead to sudden jumps along the edges of the strip. To improve the accuracy of the points, we must make a correct alignment, a rigorous compensation of the points on the overlapping area, similar to the adjustmet of the photogrammetric block (fig.4) (Ressl et. al., 2011).

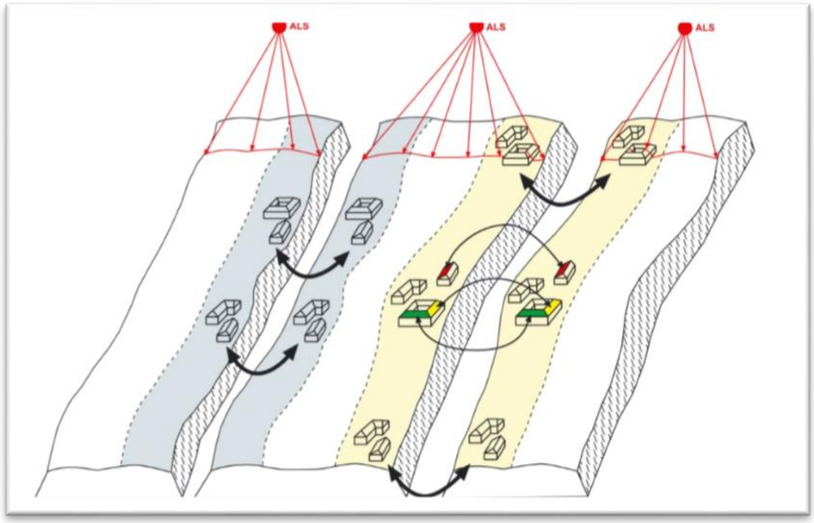


Figure 4. Block georeferencing of ALS data

Rigorous compensation solutions of strips adjustment use original methods that depends on the input data used, such as the estimated parameters and their correspondences, but they must derive from the primary components of the ALS system. The most solutions used methods focus on estimating errors between the scanner and the inertial system (Hebeland Stilla, 2012; Toth, 2002). Correspondences are generated based on the initial point cloud or on a derivative of it (for example, interpolated grids or triangulations). Most methods use planes as geometric elements, they can be fixed or variable in size found by segmentation (for example, on roofs). In other specialized articles that have researched these methods, they highlighted and showed the use of higher order primitives as a correspondence parameter. (Kersting et. al. 2012).

The GNSS and INS measurements are used to estimate the trajectory of the aircraft, meaning its position (three coordinates) and its orientation (three angles). Using the trajectory, mounting, calibration parameters (describing the position and rotation between the scanner and the GNSS / INS systems) and scanner measurements (range and angle), 3D surface coordinates can be determined. Systematic errors in any of these input data lead to a systematic, usually nonlinear, deformation of the collected point clouds. We can recognize these errors in two forms: as discrepancies between overlapping bands and as discrepancies between bands and data about the reality on the ground, for example, ground checkpoints. Using rigorous strip alignment, the quality of ALS point clouds can be improved by minimizing these discrepancies.
There are two types of ALS strip adjustment solutions:

- the direct, which use the trajectory and sometimes they also use the leveling measured in the field as input data (Ressl et. al., 2011);
- the rigorous, which use the original data of the scanner, and the GPS and inertial measurements of the trajectory.

II. Strip adjustment solutions of ALS data

In this report, we focus on adjusting ALS data through the two solutions highlighted above, meaning aligning the laser scanner to the navigation sensors using the software and methods presented below. They have reported it that in order to be able to reconstruct the flight trajectory, the data got from the GNSS or INS systems are required depending on the chosen alignment solution. GNSS data are processed by differential GNSS methods to get accurate information for flight positions over the entire flight duration (Iordan, 2014). Therefore, for example, a flight speed of 70 m/s and a result of the GNSS recording rate of 2 Hz result in a spacing of 35m at which the positions are available. For the rigorous adjustment solution, where both trajectory estimation systems are used (GNSS and INS measurements), the notion of "smoothed best estimated trajectory" (SBET) is defined, which represents the best estimated plane trajectory. As an example, if the data for the altitude and the position have been interpolated at 800 Hz, position and orientation are available at intervals of 0.09 m (at an aircraft speed of 70 m/s). Using standard GNSS / IMU processing, the platform coordinates can be reconstructed with an accuracy of 10 cm. The gap of these data can be eliminated during data processing by adjust the strips based on the ground control points, points from the control surfaces used at the calibration process (Beraldin, 2010).

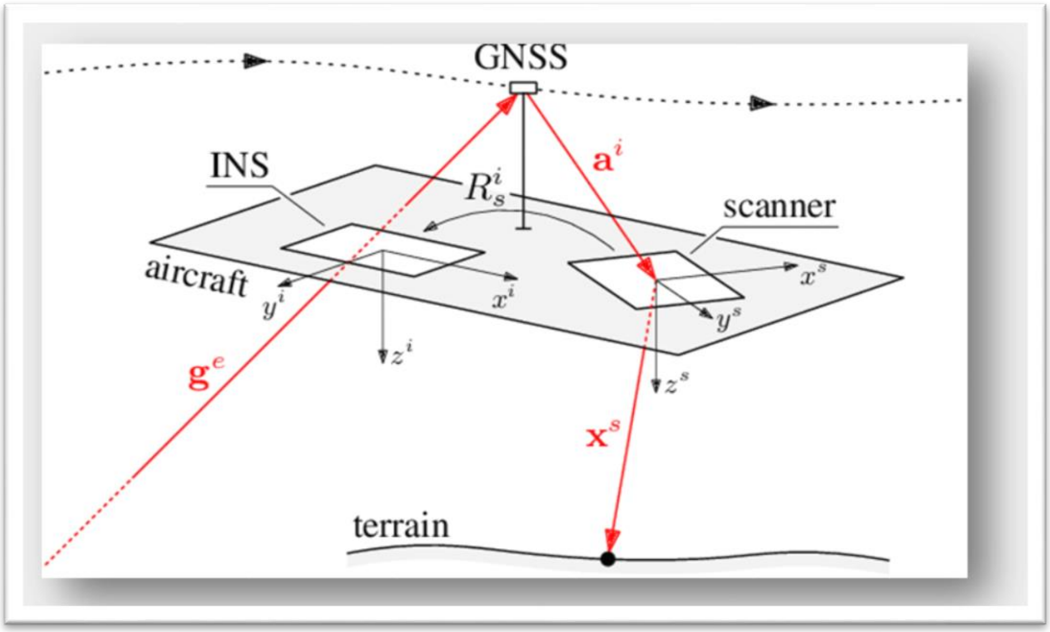
The ALS system is affected by many sources of error, contaminating data with random and systematic errors. Proper analysis and modeling of these errors in data processing is a major problem, as retrieved data is a recognized and used way to generate high-accuracy DTM. A approaches to reduce these systematic errors have already been implemented in the software packages known and used (Burman, 2002). The approaches are complex, either non-automated or limited to small data samples, which creates problems for offsetting extensive amounts of data, such as being able to collect modern 25 or 50 kHz AR-type scanning systems (Kornus, 2003).

A. The Direct Solution of Strip adjustment.

The direct solution of strips adjustment of ALS data requires three types of input data: flight path, scanner measurements and calibration parameters, meaning the control surfaces as optional data (Skaloud et al., 2006; Hebel et al., 2012) (Figure 5). Combining all these measurements, the coordinates of the point at time t are given by the following mathematical equation:

$$x^e(t) = g^e(t) + R_n^e(t)R_i^n(t)\left(a^i + R_s^i x^s(t)\right) \quad \textbf{(1)}$$

Figure 5. The direct solutions of strip adjustment (Gliraa et. al., 2015)



From this equation (1) you can observe the coordinate system in which the laser point measurement is defined in “t” time, while the notation is used to designate a transformation from a source coordinate system to an aim (target) coordinate system, known as the georeferencing, this process which for ALS data is performed after the actual flight in the preprocessing stage.

Consequently, four coordinate systems appear in Equation (1):

- s-system - the coordinate system of the scanner;
- i-system - the INS coordinate system;
- n-system - the navigation coordinate system, equal to a local coordinate system;
- e-system - Earth-centered, fixed-to-Earth (ECEF) coordinate system.

The strip adjustment presented in the case study, by the direct solution method is performed in the e system, the data are georeference in the preprocess stage. Only after that, the points got by equation (1) are projected from the e system to an arbitrary map coordinate system (m-system), the national reference system of Romania – the Stereographic 1970 and the Black Sea 85 altitude system.

To eliminate the systematic errors of the input data, which cause a nonlinear deformation of the ALS band, we must enter the following parameters the mathematical equation of the georeference process. These parameters can be divided into three groups (fig.6):

- **the calibration parameters** of the scanner adjust the systematic errors of the ALS scanner. The estimation of these parameters in the adjustment is referred to the calibration process at the time of flight and scan. The specific choice of parameters depends on the type of construction of the ALS scanner. For example, the parameters required for proper modeling of scanner errors that reflect the laser beam only in one direction (linear scanners) differ from those that reflect the laser beam in a circular pattern (conical scanners). No general recommendation was found, but equation (1) was defined as a function of the polar coordinates ρ, α and **β**:

$$x^s(t) = \begin{bmatrix} \rho(t)\cos\alpha(t)\sin\beta(t) \\ \rho(t)\ \sin\alpha(t) \\ \rho(t)\cos\alpha(t)\cos\beta(t) \end{bmatrix}^s \quad \textbf{(2)}$$

Note: Linear scanners do not influence the laser beam in a single direction (usually along the flight line), so α can be interpreted as the deflection angle of the beam, while β is zero, so the parameters associated with β , meaning Δβ and εβ, can be omitted in this case. The remaining parameters compensate for a distance error (∆ρ), a sphere scale error (ερ), an angle encoder zero point error (∆α), and an angle encoder scale error (εα). However, these parameters may compensate for other related (and unknown) effects. For example, the parameter εα not only serves to correct an error on an angular scale, but also minimizes the influence of atmospheric refraction.

- **the trajectory correction parameters.** The trajectory of the aircraft, meaning its orientation and position is estimated by GNSS and INS measurements in a Kalman filter. These measurements are affected by external influences and therefore their accuracy is not constant. Systematic trajectory errors can vary within a single laser scanning line and I recommend it to estimate the correction parameters as a function of time for each strip. However, the estimation of these errors depends on the geometry of the terrain. Therefore, for each band we have a set of 3 trajectory correction parameters: 3 coordinate corrections, and with rigorous solutions these correction parameters are 6 in number, adding the 3 angle corrections.

- **the mounting parameters at the time of calibration.** In most cases we already know these mounting parameters, for example, from a previous calibration project or from the technical planes of the scanning system. However, these values may be inaccurate or exceeded. Thus, it is recommended to re-estimate the mounting calibration by aligning the strips. Improper alignment can cause large point shifts, as the effect of angular errors is proportional to the distance from the scanner to the scanned object. For this reason, many methods of strip adjustment focus on estimating its value, neglecting other parameters (Toth, 2002; Hebel et. al., 2012), although these parameters are already included in equation (1).

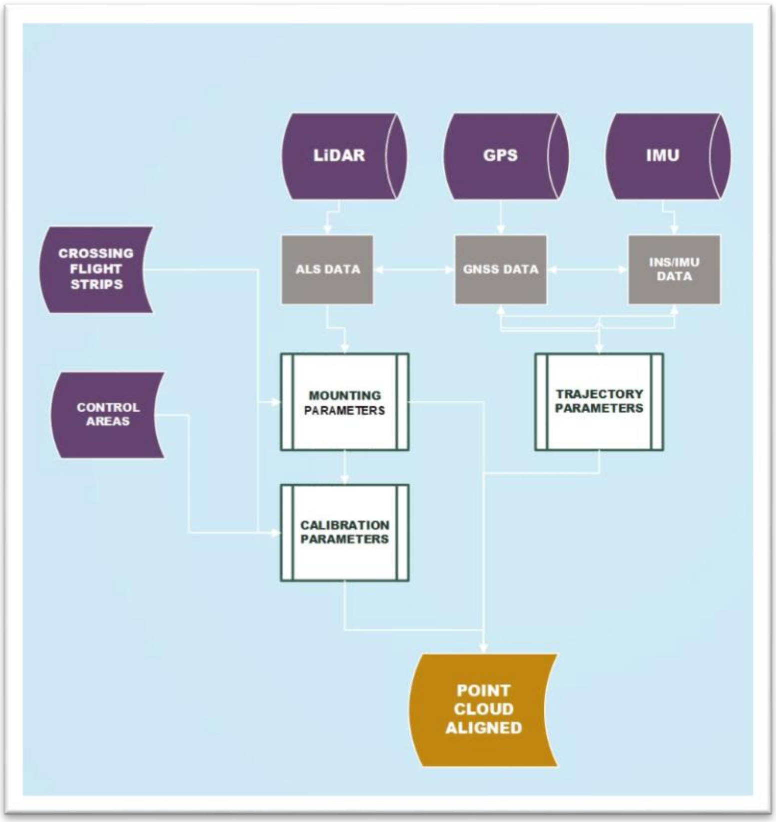


Figure 6. Parameters use in the strip adjustment

In the direct solution of the strip adjustment of ALS data, as with classical photogrammetry, it is assumed that the height is constant on each band separately. In the block adjustment of the scanning strips we have as input data the following three observation groups in order to be able to generate the digital terrain model:

- height differences between data from the scanning bands and the crossing flight strips;
- height differences between scanned data and control surfaces;
- pseudo-observations for the heights of the control points within the surfaces.

For generating the DTM from the first group of observations, first, the locations of the crossing flight strips are detected using the GNSS system and calculates a DTM in a regular grid system from the laser points for each strip and each crossing strip separately. The height differences between the grid points are statistically analyzed, the inappropriate values are eliminated and the average height difference is calculated.

In the second's case group of observations, a DTM is generated and the average difference between the heights of all control points and the heights of the MDT interpolated in the control surfaces is calculated.

In the third's case group of observations, they generate a precise DTM for extensive areas in a reasonable time. It is the simplest method of generating a DTM, being almost automatic. This approach involves a special block design and also requires a well-calibrated LIDAR system. Additional control surfaces and crossing flight strips are used as input data. Each scan strip must be covered with at least one crossing strip, meaning for an ordinary block with all parallel flight strips, a crossing strip and a control surface are sufficient, while with more complicated block shapes they may be more cross strips are required.

The football pitches are usually selected as the control surface, which are flat and thus a horizontal error at a laser point would not affect its vertical component. The design of the block, from the LAKI II project, from which we extracted the data to be adjust is presented in figure 7. The figure presented a small part of the project surface which contains a control area of 5x5 m with 50 points measured on the field and scanning strips that overlap the urban area Săcuieni, and the cross strips.

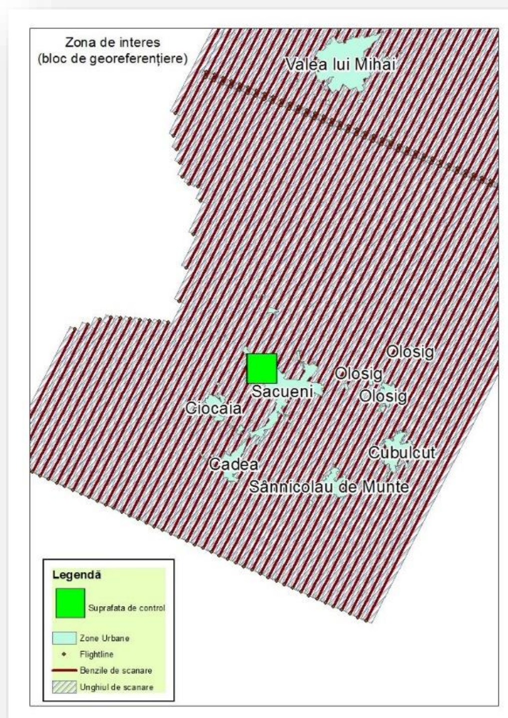


Figure 7. ALS strips and control surface in a small area of the LAKI II project

B. The Rigorous Solutions using Iterative Closest Point algorithm (ICP)

ICP is an algorithm used to minimize the difference between two point clouds and is often used to reconstruct 2D or 3D surfaces from different scans (Besl et. al. 1992). Nowadays, the term ICP does not refer to the algorithm presented in the original publications, but to a group of algorithms for matching the scanned surface that have in common the following aspects:

- I: correspondences are established itteratively;
- C: the nearest point or in general, the corresponding point is used as a correspondence parameter;
- P: correspondences are established punctually (Glira et al., 2015).

To be able to adjust the raw data of the scanner, it requires the following information (Skaloud et. al., 2006):

- **Position and orientation of the acquisition platform**. These are measured by the system consisting of the GNSS and the INS data;
- **Mounting parameters at the time of calibration**. Relative orientation parameters comprising a rotation and a translation;
- **Time**. Synchronization time between scanner and the navigation system;
- **Internal scanner parameters**. Like for example, zero point, scan angle, and scan interval.

The general concept of the algorithm is to improve the alignment of two or more point clouds by minimizing discrepancies in the overlapping area of these point clouds. Alignment is optimized by iteratively transforming the point cloud chosen as the target, while the position of the other point cloud remains fixed, this being the source point cloud. The geometric transformation applied in the ICP algorithm is usually a rigid plane transformation (Skaloud et. al., 2006). However, the biggest problem is that of correspondence. After a thorough research in the literature, it was found that it introduced the initial ICP algorithm with a five-step taxonomy (Rusinkiewicz et. al. 2001). It is necessary to know the initial data of the relative orientation of the points in order to be fulfilled, the fundamental requirement in ALS (Toth, 2008).

They base the ICP algorithm on 5 steps to follow in order to achieve adjustment:

1. **Selection.** This stage means to select a set of points from the point cloud chosen as the source in the overlap area. There are 4 types selection strategies used, the difference between them being the type of input data and the information used as input for point selection:
   - **<u>Random sampling (RS).</u>** This is the fastest strategy since the points are simply randomly selected, regardless of the normal coordinates or vectors of the points. (Masuda & Yokoya, 1995);
   - **<u>Uniform Sampling (US).</u>** This strategy selects points in the object space as possible. This leads to a homogeneous distribution of the selected points. This

option was implemented by dividing the overlap area into a voxel structure and selecting the nearest point at each voxel center. The edge length of a single voxel can be interpreted as the average sampling distance along each direction;

- **Normal space sampling (NSS).** This strategy selects points so that the distribution of heights in the angular space is as uniform as possible (Rusinkiewicz et. al., 2001). For this, the angular space (slope vs. aspect) is divided into classes (for example, 2.5 ° x 10 °), and the points are randomly sampled within these classes. This strategy does not take into account the position of the points;

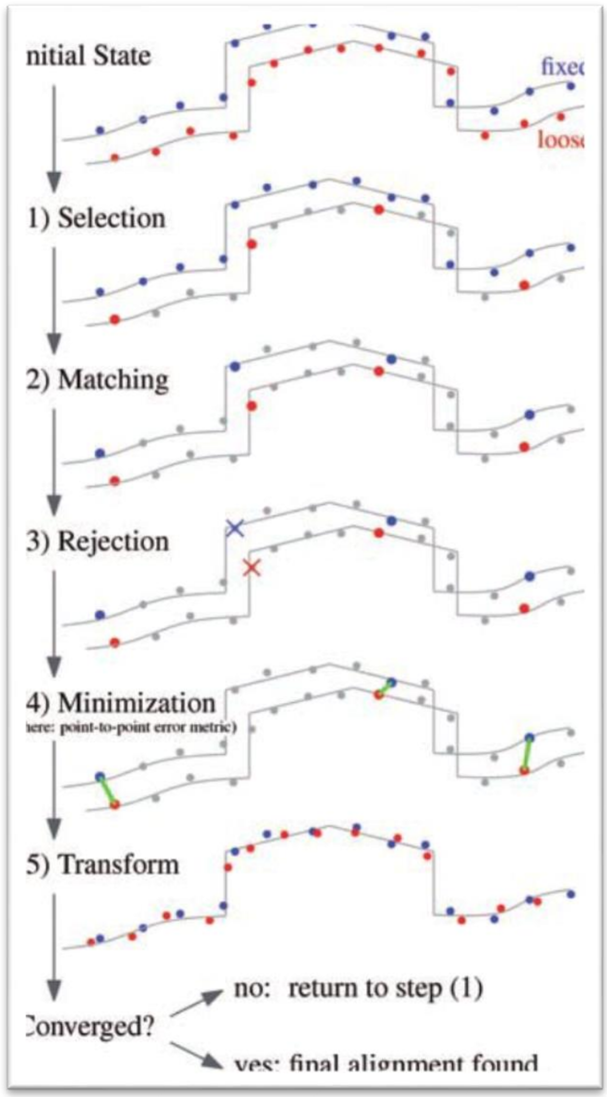


Figure 8. The five basic steps of the ICP algorithm for two overlapping bands (blue = fixed band, red = free band, green = correspondence) (Glira et. al., 2015)

- **Maximum leverage sampling (MLS).** This strategy selects those points, which are best suited for estimating parameters. This strategy takes into account the normal coordinates and vectors of the points.

2. **Matching.** In this step you find the points corresponding to those selected in the data set of the source point cloud, in another point cloud, another strip. This step establishes the correspondences between the points, meaning each point selected from the previous step is associated with its nearest neighbor (the closest point) of the overlapping strip (Chen & Medioni, 1991). Point-to-plane distance compensation is minimized for each match, and two associated points do not have to be identical in object space, but they must belong to the same initial data set (e.g., the flat surface of the terrain), (Blais & Levine, 1995). Because of a good initial orientation and the density of the point cloud, this requirement is met. The nearest neighbor search can be performed using K-D trees (Sharp et. al., 2002).
3. **Rejection**. False matches (outliers) are rejected based on point compatibility. This step identifies errors and reject unsafe or false correspondence (Hampel, 1974). I tests each correspondence for three criteria, these are:
   - **Rejection based on the roughness of the plane corresponding to the points**. I must ensure the reliability of normal vectors to minimize the distance from the point to the plane. This condition is not met if the scanned object may not be modeled properly, e.g. with vegetation;
   - **Rejection based on the angle between the normal point vectors and their correspondence**. To ensure that the two corresponding points belong to the same plane, the angle between the normal vectors of these points must not exceed an upper part. Usually a maximum value of 5 degres is set.
   - **Rejection based on the point-plane distance between the corresponding points**. Apart from a few false correspondences, it is assumed that the point-plane distances are normally distributed for each pair of overlapping bands.
4. **Minimization**. Estimation of transformation parameters by minimizing the distances between the corresponding points. They frequently use two types of distances are frequently.
   - **Euclidean distance (unassigned)** between the corresponding points - it is also called metric error. We could avoid this measurement error in ALS data, because of the different ground sampling of two strips, there are no real point-to-point correspondences, and the convergence rate is slow (RuSinkiewicz & levoy 2001). If an affine transformation is applied, there is a closed (constant) solution for this metric error (Horn et al, 1998).
   - **The perpendicular distance (assigned)** of one point to the tangent plane of the other point, which is called the metric error "point to plane" (Chen & Medioni, 1991). In this measurement error it is unnecessary that the correspondence between points be identical. The only requirement is that the corresponding points belong to the same plane in the object space, e.g. the roof. There is a closed-form solution for affine transformation only after linearization of the rotation matrix, i.e. for small rotations (Chen & Medioni, 1991).

5. **Transformation**. Point cloud transformation using the estimated parameters, the 6 rotation and translation parameters, using the affine transformation to improve the relative and absolute orientation of the strips. However, it is important to use a 12-parameter affine transformation to reduce the effects of an incorrect mounting calibration without taking into account GNSS-INS trajectory data (Ressl et. al. 2009).

Finally, an appropriate convergence criterion is tested. If not met, the process restarts from step 1 or step 2 if point selection is not repeated iteratively (Glira et. al., 2015). It can be seen that the development of the stages is in logical form and that there are two iteration loops: in the external iteration loop the correspondences are restored after each run, and in the internal iteration loop it is necessary to solve the system of nonlinear equations within the adjustment *(fig. 9)*.

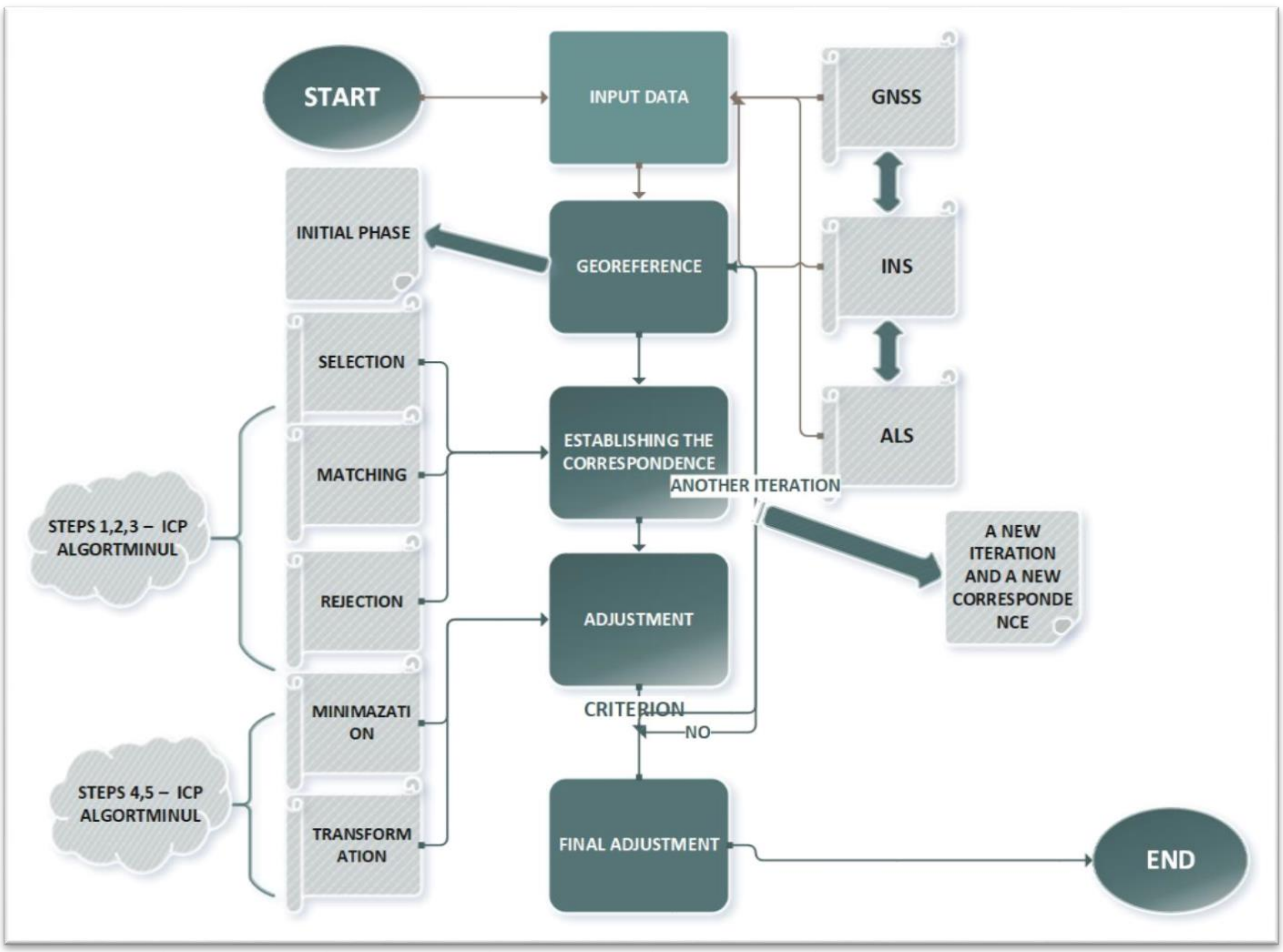


Figure 9. ICP algorithm

The result got by alignment of the strips is impressed by the correspondences used. The ICP algorithm aims to choose correspondences based on the original ALS points and the main reasons are: exploitation of the highest level of data resolution, no time-consuming preprocessing is required (in contrast to correspondences found by segmentation and / or interpolation) and no restrictions are imposed on the object space. A point and its normal vector define a tangent plane, a correspondence represents a correspondence space.

In the context of correcting ALS data, the major disadvantages of ICP-based recording methods are:

- the absolute accuracy remains uncertain, because a data set is kept unchanged - the band chosen as target and the other point clouds are aligned after it;
- the application of the ICP algorithm implies an affine transformation to be sufficient in solving the problem of 3D data acquisition (Hebel et. al., 2012).

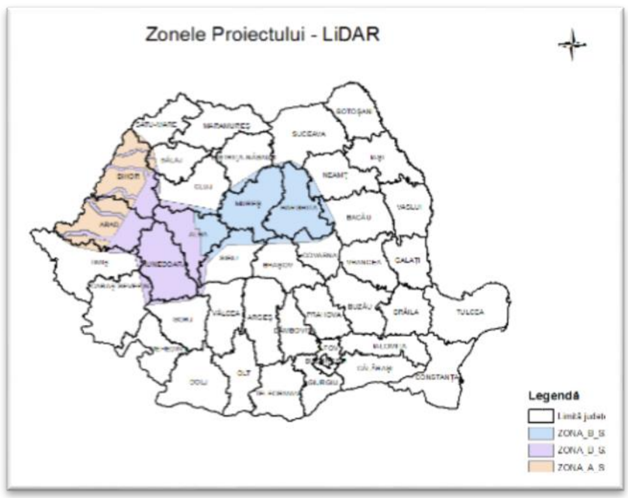
III. Study case

A. Description of input data

Description of the LAKI II project

In 2014, the National Agency for Cadaster and Land Registration, as project promoter organized in Bucharest the launching conference of the project "Geographic Information for Environment, Climate Change and EU Integration (LAKI II)" funded within the EEA Grants 2009-2014 thru the programmer RO03 " Environmental Monitoring and Integrated Planning and Control".The primary activities of the project comprise the production of a detailed terrain model through scanning by LIDAR system, new maps and orthophotos for 50.000 kmp of Romania's surface area.

Figure 10. Project area of LAKI II - LiDAR



Aerial laser scanning obtained the data used for the study case with LiDAR technology. The input data are:

- ALS data - represents the technical details of the scanner used to gain the data. They performed the LiDAR flight with the DA42 MPP aircraft, with a RIEGL Q780 scanner mounted. The ALS data have a point cloud density of 8 points / sqm for the border area:
  - Full waveform scanning;
  - Scanning angle 600;
  - Scanning mode: parallel lines;
  - Diagnosis of laser radiation <0.25 rad;
  - Laser pulse repetition rate:> 400 kHz;
  - Effective measurement rate:> 266 kHz;

- GNSS data - the technical details of the navigation system with was equipped the aircraft, this system is auxiliary. The GNSS model used is of the NOVATEL OEM4 / OEMV type. GPS time is satellite time - standard GPS - minus 1x10ˆ9.
- IMU data - the technical details of the inertial system with which they equipped the aircraft, this system is also an auxiliary one. The INS model used is class D, IGI type, with 256 Hz.

During the project, control surfaces were used to calibrate the device, dispersed throughout the area. Precision leveling measurements for the control points were done starting from 3rd or 4th order leveling points.

Description of the software used for each method

For the direct solution of the strip adjustment is used the point cloud processing software called VRMesh edition 11.1, Demo version, the measurement extension, called VRMesh Survey. VRMesh is an advanced solution for automatic point cloud classification and feature extraction. This software helps to classify vegetation, building roofs and ground points from LiDAR data or UAV images. Detects construction footprints, power lines, poles, tree crowns, curbs and railways. But the fundamental purpose / object in VRMesh Survey is to detect vegetation.

In the second part of the case study in this report, i used for the rigorous solution the OPALS software, how has implemented the ICP algorithm. OPALS is a system of modular programs comprising modules grouped in packages. The purpose of OPALS is to provide a complete processing workflow for ALS data (waveform decomposition, quality control, georeferencing, structure line extraction, point cloud classification, DTM generation). They are uses it in several application areas such as forestry, hydrography, city modeling and power lines. Researchers in the field of photogrammetry and remote sensing at the University of Vienna, Department of Geodesy and Geoinformatics developed this software.

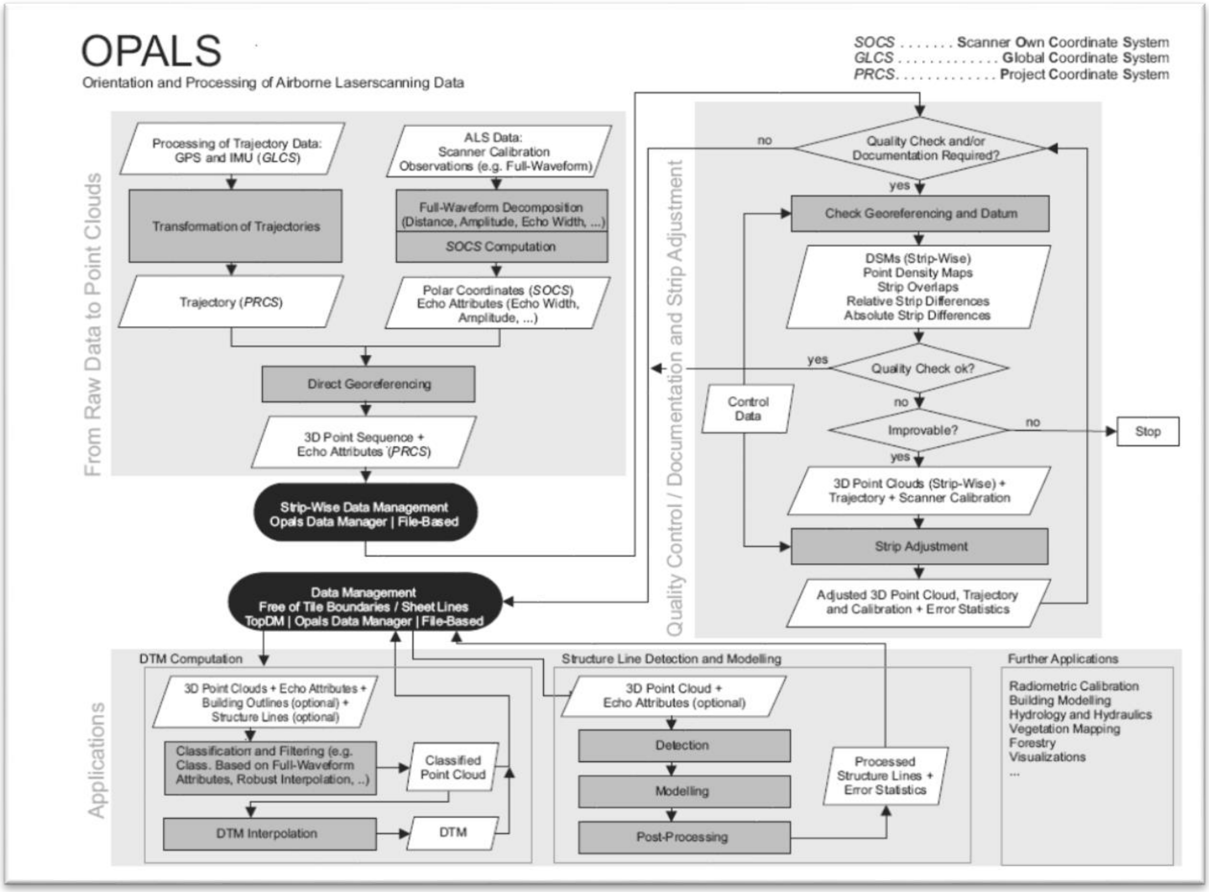


Figure 11. The workflow of OPALS software
(https://opals.geo.tuwien.ac.at/html/stable/usr_sw_concept.html)

B. The direct solution of strip adjustment

VRMesh demo version 11.1 software was used for this method of strip adjustment, having as input data the trajectory, and the original files in *las format with point clouds.

For testing were selected as input data, information from the LAKI II project - Flight LiDAR area A-S1 (border area - with an average density of 8 pt./sqm). I used unprocessed original files extracted from the scanner in *las format.

Flight day is 02.02.2017 - meaning February 2017. Any * las file contains over 150 million points, which represents an enormous volume of data, therefore not all 4 flight strips can be accessed in an open source software, such as Cloud Compare.

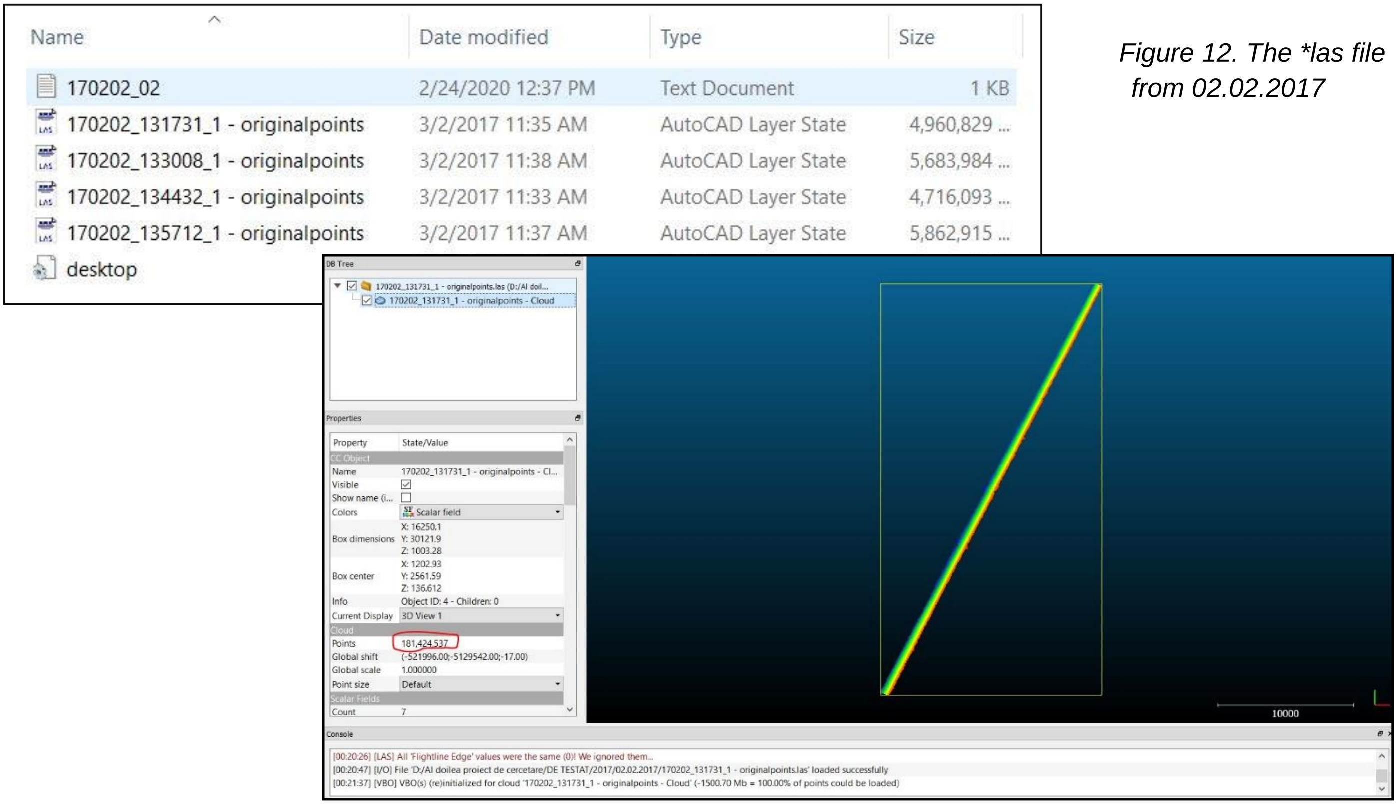


*Figure 12. The *las file from 02.02.2017*

For the testing area using this direct solution, the enormous amount of information in the ALS strips must be reduced. This can be done by cutting the strips on a specific area with the help of VRMesh software. The trajectory file used is in * txt format and contains the 6 parameters of an external orientation, as with classical photogrammetry, the 3 coordinates and the 3 angles, Roll, Pitch and Yaw. This file contains the following details:

- Parameter 1: GPS Time - Accuracy = 10 Accuracy = 5 Units = Seconds-Week
- Parameter 2: Latitude / Datum-WGS84 - Accuracy = 9 Accuracy = 10 Units = Degrees (DD.ddd)
- Parameter 3: Longitude / Datum-WGS8 - Accuracy = 10 Accuracy = 10 Units = Degrees (DD.ddd)
- Parameter 4: Ellipsoidal Altitude / Datum-WGS84 - Accuracy = 6 Accuracy = 3 Units = Meters
- Parameter 6: Roll Angle - Accuracy = 6 Accuracy = 5 Units = Degrees (DD.ddd)
- Parameter 7: Pitch Angle - Accuracy = 6 Accuracy = 5 Units = Degrees (DD.ddd)
- Parameter 8: Yaw Angle - Accuracy = 6 Accuracy = 5 Units = Degrees (DD.ddd)

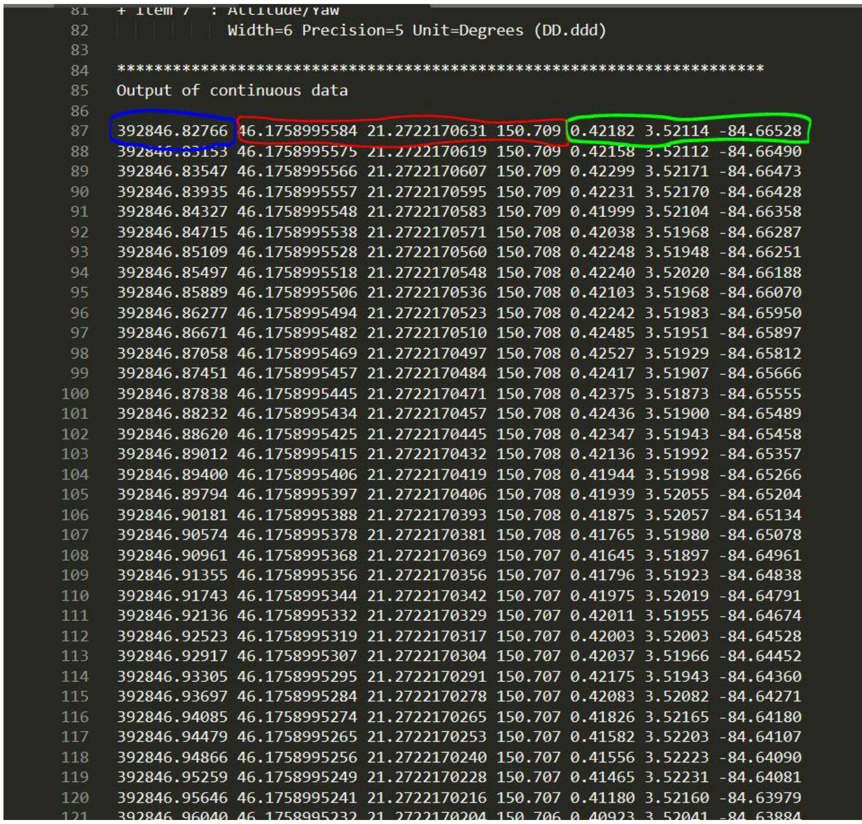
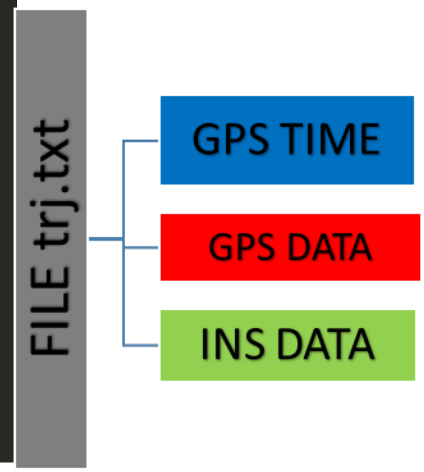


Figure 13. The trajectory file



I have uploaded flight trajectory data to the VRMesh software with the ***Separate LiDAR Strips*** command - this command loads the trajectory, cuts out the strips for a small area and separates them into * las files.

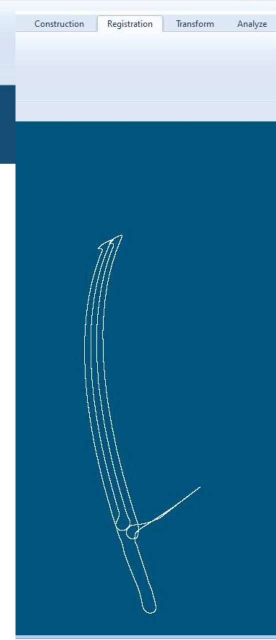


Figure 14. The trajectory from 02.02.2017

The tested area was chosen to allow the * las files to be cut and the four bands of the scanner to be aligned. The selected area is between the points highlighted on the trajectory path.

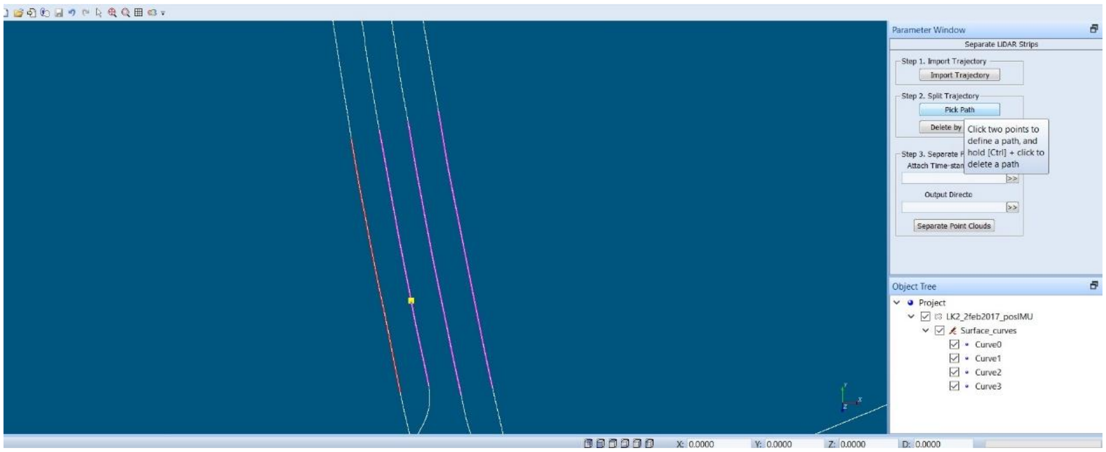


*Figure 15. Selecting the testing area and cutting the *las files on this area*

Because of I use the demo versions of the software the las file were save as indexes. ***Create INDEX file*** – is the command that allows us to upload the *las files created us an index file and to view the information for the four ALS strips had on the trajectory. For each *las file for the four strips y highlighted the number of points and the number of blocks according to table no. 1:

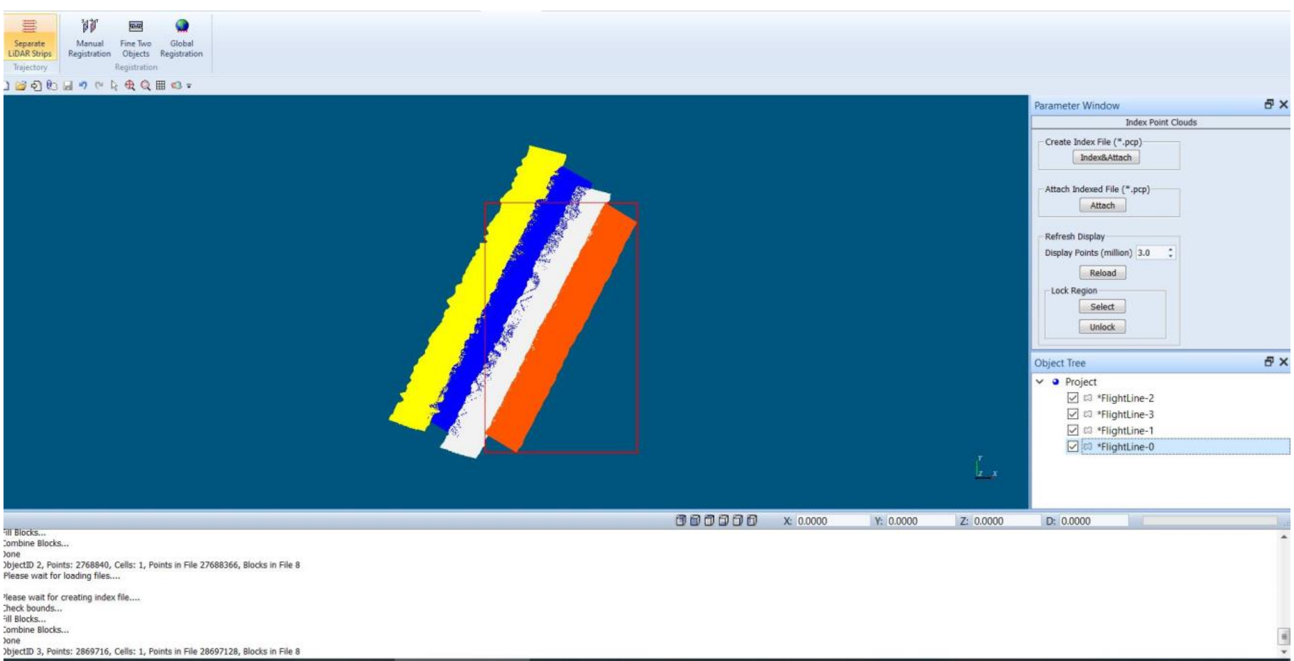


*Figure 16. The testing area-the *las file cut -02.02.2017*

No. crt.	File Name	Number of points	Number of overlapping blocks
1	The filghtstrip 2(blue color)	319026026	16
2	The filghtstrip 3(white color)	26752282	8
3	The filghtstrip 1(yellow color)	27688366	8
4	The filghtstrip 0(red color)	28697128	8

To eliminates minor discrepancies between the four strips in the testing area y use the command: ***Global Registration***. This solution of strip adjustment, based on the trajectory parameters, referees to all the bands visible. This is possible by looking for the overlapping regions of each surface pair and their alignment by the least squares method. An affine transformation is used to align the strips with each other, to eliminate a minimal discrepancy between the overlapping areas. The parameter for this command is the initial overlap distance. The initial value will be adjusted automatically during the registration procedure. We set the overlap distance to zero to allow the program to assign an initial value to find the overlapping area.

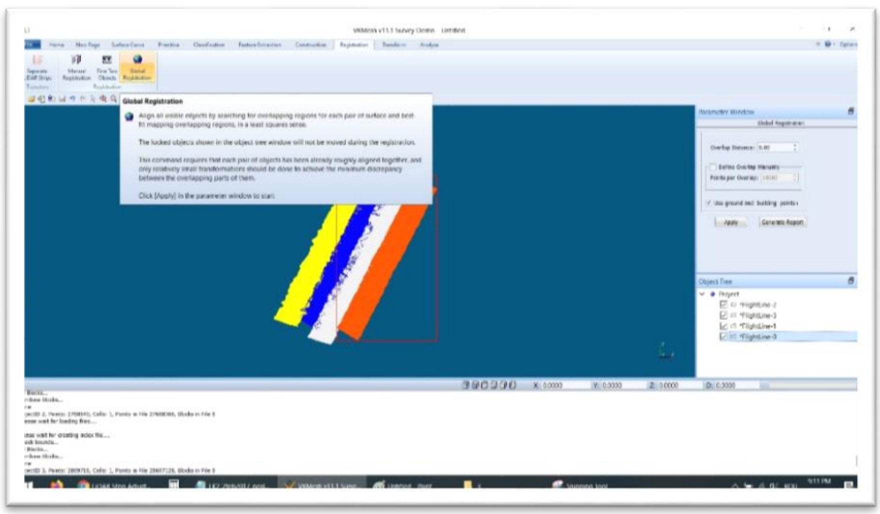


Figure 17. The command use to aligned the strips

Y calculated and got the total number of overlapping regions between the ALS strips. For the tested area in this report the value is equal to 14511, and for each band there are common regions starting from the first band to the last.

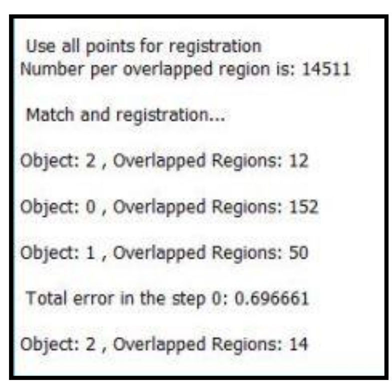


Figure 18. The overlapping areas for the four strips in the testing area

The result got is four *las file aligned and a report generated based on the following formulas highlighted in table no. 2:

No.	Parameters	Equations
1	Mean	$\bar{A} = \sum A_i / N$
2	Deviation	$D = \sqrt{\left(\sum (A_I - \bar{A})^2 / N\right)}$
3	Variation	$V = D/\bar{A} * 100\%$
4	Improvement	$I = (Old - New)/Old * 100\%$

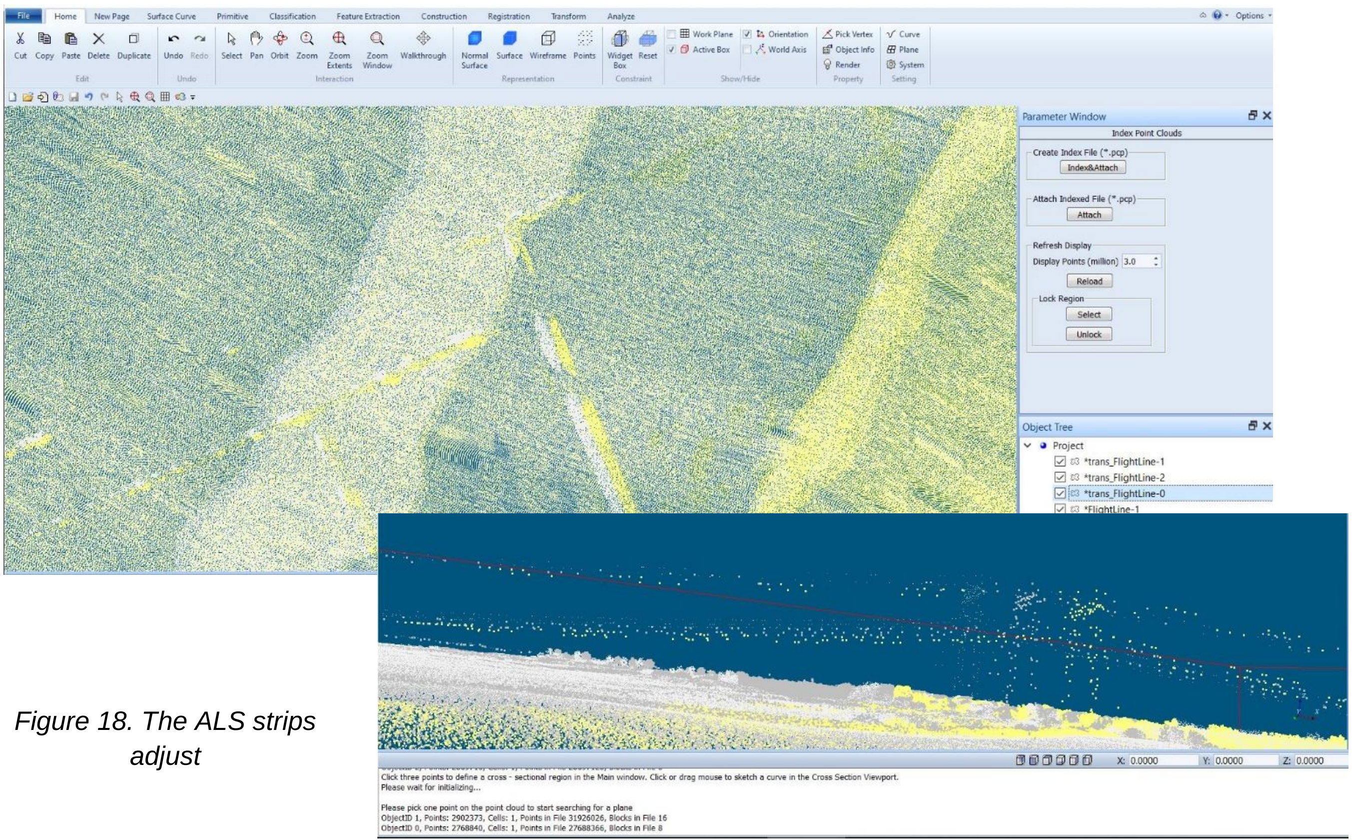


Figure 18. The ALS strips adjust

VRMesh

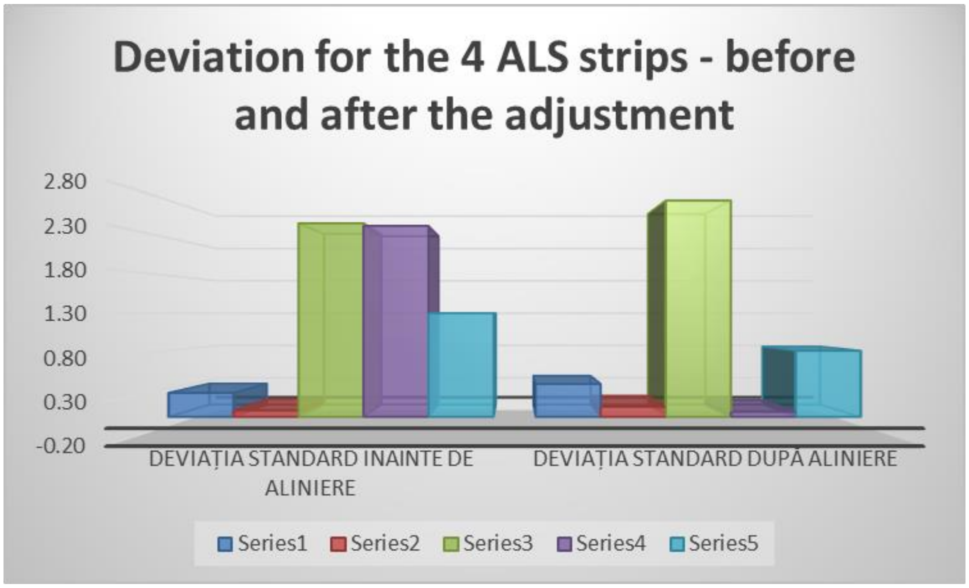
Registration Report

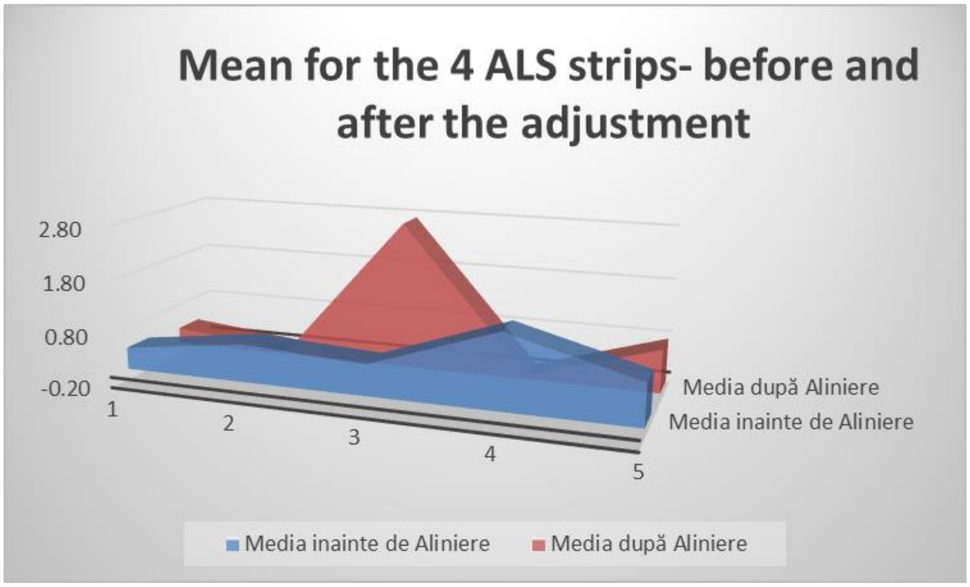
Object		Before Registration			After Registration			Improvement	
ID	Overlaps	Mean	Deviation	Variation%	Mean	Deviation	Variation%	Mean%	Deviation%
0	149	0.4135	0.3006	72.6776	0.3091	0.4114	133.1030	25.2617	-36.8773
1	55	0.7153	0.0800	11.1895	0.0731	0.1262	172.6540	89.7785	-57.7190
2	11	0.5888	2.4271	412.1750	2.7602	2.7116	98.2391	-368.7410	-11.7212
3	8	1.4113	2.3949	169.7020	0.0879	0.0642	73.0145	93.7702	97.3196
Total Average:		*0.7822*	*1.3007*		*0.8076*	*0.8283*		*-3.2379*	*36.3130*

Figure 19. Final report

I have saved the report in pdf format, but because of demo versions of the software *las files cannot be exported or saved for later use in a classification and digital terrain model generation.

Figure 20. Adjustment results in graphs





C. The rigorous solution of strip adjustment.

This ALS alignment method used as input data - the original scanner files in Synopsys Design Constraints File (SDC) format, which is an ASCII text file (with the extension *sdc) that contains design restrictions and assignments, calendar in standard format. The input file was also used in the trajectory file in *txt format, and in the * pof format which is a binary format - a programmer object file (POF) containing an enormous volume of data (over 3 million records).

The data was purchased on September 7, 2017 and the software used in this method is Opals software version 2.3.2. In the Opals software there is a module designed for rigorous alignment of ALS strips. This Module is called Strip Adjust. To be able to use this module I also installed the MATLAB Runtime writing scripts. The Strip Adjust module uses the sexagesimal gradation (full circle = 360°) as a unit of measurement of angles. Angular values are reported, and exported to output files in degrees. However, according to the general rule of OPALS, the angles are stored in radians. Therefore, for readable angles in the file (image paths and external orientations), the radian conversion factor must be provided in the OPALS format definition file.

The workflow for this module is:

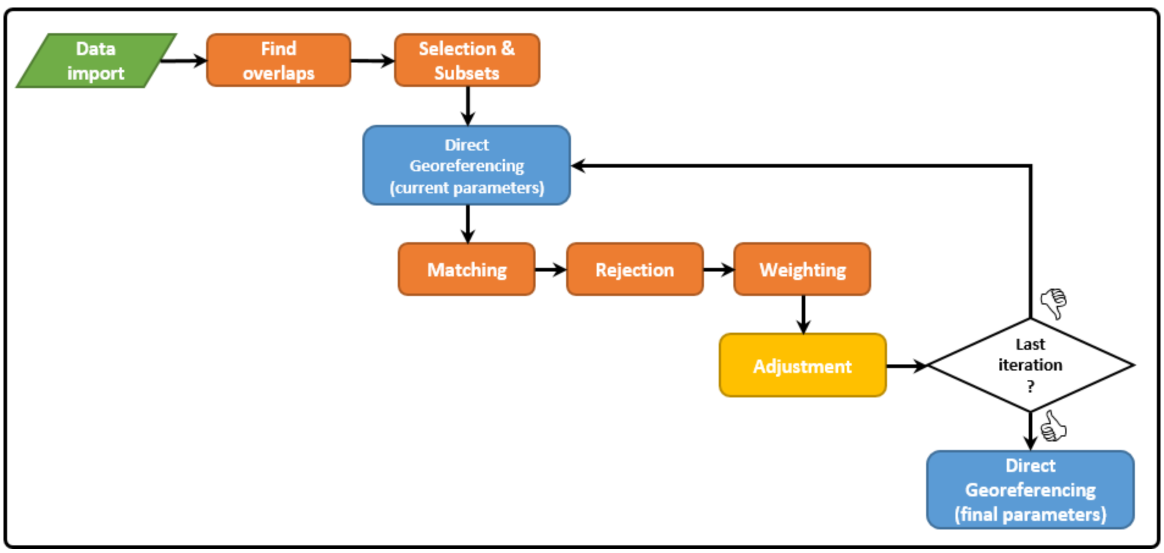


*Figure 20. The workflow of **Strip Adjust***
*(*https://opals.geo.tuwien.ac.at/html/stable/ModuleStripAdjust.html)

Testing began by creating the configuration file; It defines the parameters used in the adjustment, the parameters of the ICP algorithm and the location and name of the input data, the *sdc files and the trajectory file. The trajectory next to the *txt file must also have an *xml file defined, which is part of the source code.

The parameters used and the input data are:

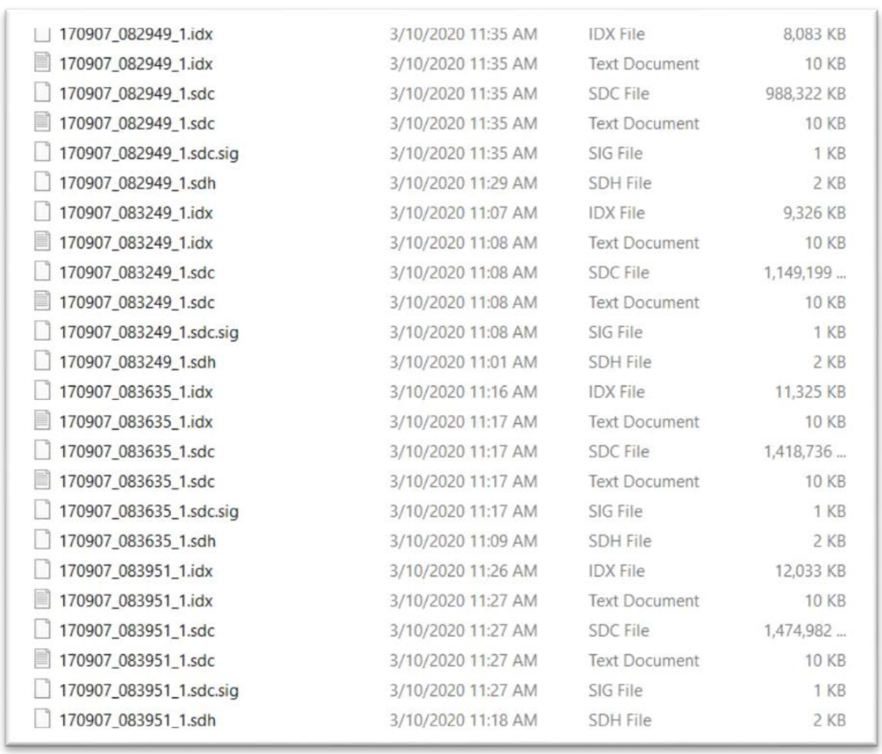
The general input data

- The ALS file in.sdc format (fig. 21)
- The trajectory file in txt and also in xml format (fig. 22)
- The configuration file of the software in txt format (fig. 24)
- The trajectory parameters defined by 3 options

Parametres use in the adjustment method

- The projection informations
- The length of the voxel used to find overlaps between point clouds in the object space
- Maximum number of iterations
- Orientation of the scanner during mounting on the aerial platform
- Search radius for determining the plan by estimating the norms made with another software module and the number of neighbors
- Offset parameters between GNSS antenna and scanner
- Correspondence parameters used to overlap ALS bands
- Selection parameters - the module uses uniform dissection
- Criteria for rejecting correspondence

The data set consists of 4 ALS strips - to be able to create pairs, see the overlap between them and their rigorous alignment. SDC files have an enormous volume of data, which is observed in the space they hold and in the number of several adjacent files.



170907_082949_1.idx	3/10/2020 11:35 AM	IDX File	8,083 KB
170907_082949_1.idx	3/10/2020 11:35 AM	Text Document	10 KB
170907_082949_1.sdc	3/10/2020 11:35 AM	SDC File	988,322 KB
170907_082949_1.sdc	3/10/2020 11:35 AM	Text Document	10 KB
170907_082949_1.sdc.sig	3/10/2020 11:35 AM	SIG File	1 KB
170907_082949_1.sdh	3/10/2020 11:29 AM	SDH File	2 KB
170907_083249_1.idx	3/10/2020 11:07 AM	IDX File	9,326 KB
170907_083249_1.idx	3/10/2020 11:08 AM	Text Document	10 KB
170907_083249_1.sdc	3/10/2020 11:08 AM	SDC File	1,149,199 ...
170907_083249_1.sdc	3/10/2020 11:08 AM	Text Document	10 KB
170907_083249_1.sdc.sig	3/10/2020 11:08 AM	SIG File	1 KB
170907_083249_1.sdh	3/10/2020 11:01 AM	SDH File	2 KB
170907_083635_1.idx	3/10/2020 11:16 AM	IDX File	11,325 KB
170907_083635_1.idx	3/10/2020 11:17 AM	Text Document	10 KB
170907_083635_1.sdc	3/10/2020 11:17 AM	SDC File	1,418,736 ...
170907_083635_1.sdc	3/10/2020 11:17 AM	Text Document	10 KB
170907_083635_1.sdc.sig	3/10/2020 11:17 AM	SIG File	1 KB
170907_083635_1.sdh	3/10/2020 11:09 AM	SDH File	2 KB
170907_083951_1.idx	3/10/2020 11:26 AM	IDX File	12,033 KB
170907_083951_1.idx	3/10/2020 11:27 AM	Text Document	10 KB
170907_083951_1.sdc	3/10/2020 11:27 AM	SDC File	1,474,982 ...
170907_083951_1.sdc	3/10/2020 11:27 AM	Text Document	10 KB
170907_083951_1.sdc.sig	3/10/2020 11:27 AM	SIG File	1 KB
170907_083951_1.sdh	3/10/2020 11:18 AM	SDH File	2 KB

Figure 21. The ALS file in SDC format

The trajectory file contains the 3 coordinates, the 3 angles of the plane (Roll, Pitch and Yaw) and the GPS Time for at least 3 million observations purchased on 07.09.2017. To use this file, it was necessary to change the xml file of the trajectory and the source code of the software, because they programmed it for a file with geocentric Cartesian coordinates, and the trajectory file contained geographical coordinates. Also notices that their order in the xml file wasn't like the one in the source code. At a certain point in the test it forced me to transform the geographic coordinates of the trajectory into geocentric Cartesian coordinates. Y did this task with an external software called PCTrans version 5.0, for all 3 million observations.

```
?xml version="1.0" encoding="ISO-8859-1" ?>
?xml-stylesheet type="text/xsl" href="opalsFormatDefinitionStyle.xsl" ?>

!-- OPALS Format Definition Section -->
opalsFormatDefinition>
 <description>Trajectory ASCII Format</description>
 <!-- Trajectory format x y z time roll pitch yaw -->
 <ascii>
      <commentInitiator val="#" />
   <header>
     <text val="# Trajectory format: Latitudine[deg] Longitudine[deg] Elevation[m] Time[s] Roll[deg] Pitch[deg] Yaw[deg]" />
   </header>
   <data>
     <entry val="x" />
     <entry val="y" />
     <entry val="z" />
     <entry val="GPSTime" />
     <entry val="RollAngle"  toInternal="x*pi/180"  toExternal="x/pi*180" />
     <entry val="PitchAngle" toInternal="x*pi/180"  toExternal="x/pi*180" />
     <entry val="YawAngle"   toInternal="x*pi/180"  toExternal="x/pi*180" />
   </data>
 </ascii>
/opalsFormatDefinition>
```

a) . xml

```
Infos from the postprocessing logfile:
\EROoffice V5.4.50 2015-12-15 .
)ongle-ID: 2-1999962 .
)9/09/2017 08:39:43 .
Header of imported GNSS File .
 .
'roject:     LK2_traiectorii_7septembrie_m1 .
'rogram:     GrafNav Version 8.60.6717 .
'rofile:     IGI AEROCTRL .
;ource:      GNSS Epochs(GNSS Combined) .
'rocessInfo: Run (1) by primer on 09/09/2017 at 08:35:43 .
 .
)atum:       ETRS89, (processing datum) .
laster 1:    Name DEVA, Status ENABLED .
             Antenna height 0.000 m, to L1PC [LEIAT504(LEIS)] .
             Position 45 52 42.29505, 22 54 48.71898, 246.602 m (ETRS89, Ellipsoidal hgt
laster 2:    Name BAIA, Status ENABLED .
             Antenna height 0.000 m, to L1PC [LEIAT504(LEIS)] .
             Position 47 39 06.42476, 23 33 27.76011, 270.818 m (ETRS89, Ellipsoidal hgt
laster 3:    Name OROS, Status ENABLED .
             Antenna height 0.000 m, to L1PC [LEIAT504GG(LEIS)] .
             Position 46 33 18.80168, 20 40 16.84376, 146.024 m (ETRS89, Ellipsoidal hgt
Remote:      Antenna height 0.000 m, to L1PC [Generic(NONE)] .
;D Scaling Settings: .
 Position: 1.0000 .
 Velocity: 1.0000 .
 .
(sec),,,(deg),(deg),(m),(m/s),(m/s),(m/s),(m),(m),(m),(m/s),(m/s),(m/s) .
;PS-Leverarm: 0.604m 0.272m -1.364m .
Mount-Center-Leverarm: 0.000m 0.000m 0.000m .
375901.00607 47.0085906701 22.0446620042 987.463 1.30748 -2.50910 -37.24992
375901.00997 47.0085925794 22.0446605266 987.451 1.30608 -2.50363 -37.24692
375901.01387 47.0085944887 22.0446590490 987.438 1.30094 -2.50458 -37.24474
375901.01778 47.0085963980 22.0446575714 987.425 1.29528 -2.50347 -37.24324
375901.02168 47.0085983074 22.0446560939 987.412 1.29423 -2.49623 -37.24188
375901.02559 47.0086002169 22.0446546164 987.399 1.29194 -2.49322 -37.24141
375901.02949 47.0086021264 22.0446531389 987.386 1.28563 -2.51359 -37.24030
375901.03339 47.0086040358 22.0446516616 987.374 1.27825 -2.51681 -37.23780
375901.03730 47.0086059452 22.0446501842 987.361 1.27354 -2.49928 -37.23503
375901.04120 47.0086078548 22.0446487068 987.348 1.27114 -2.51089 -37.23446
375901.04511 47.0086097643 22.0446472296 987.335 1.26631 -2.51953 -37.23492
375901.04901 47.0086116738 22.0446457524 987.323 1.25909 -2.50293 -37.23384
```

Figure 22. The trajectory file in both format

b) txt

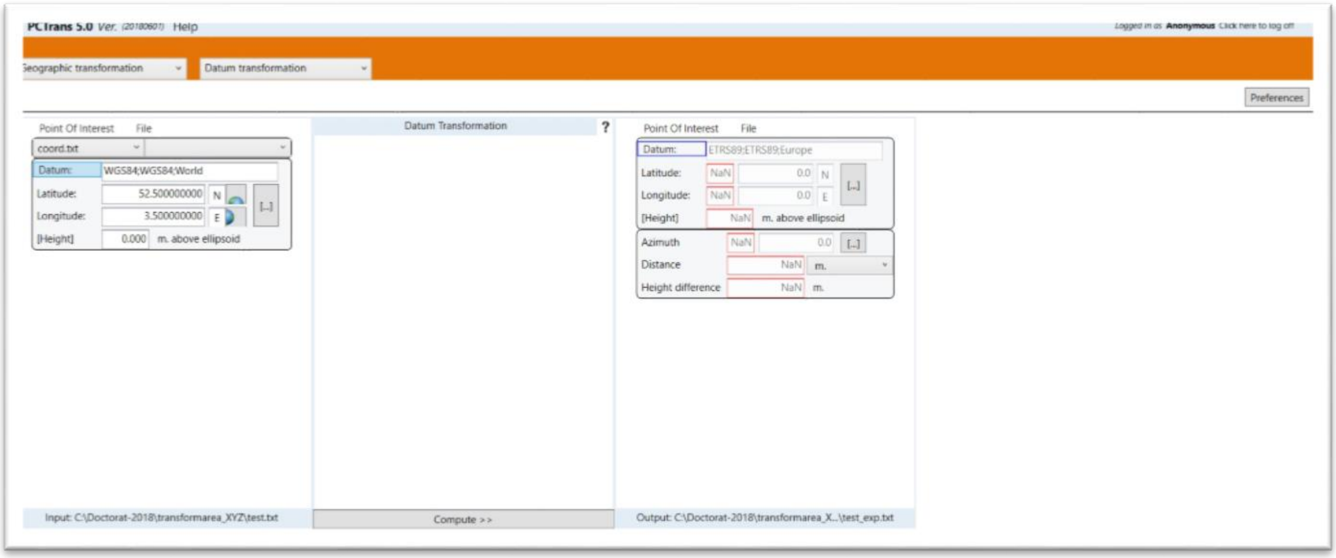


Figure 23. The PcTrans software – the transformation of the coordinates

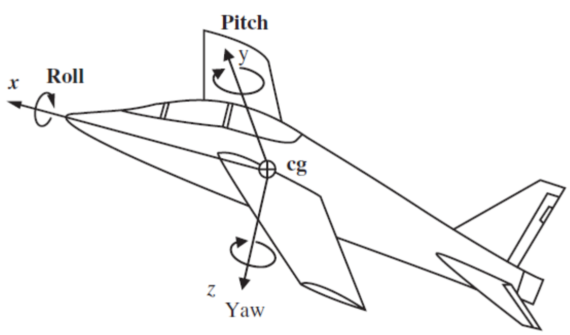
I present The configuration file with the cfg extension below by entering the values of the parameters necessary to align the ALS bands.

Figure 24. The cfg file

```
[opalsStripAdjust]
utm.zone = 32
utm.hemisphere = north
adjustment.voxelSize = ....
adjustment.maxIter = ....
strips.strips.all.iFormat = sdc
strips.strips.all.oFormat = odm
strips.strips.all.scannerOrientation = frd
strips.strips.all.trajectory.correctionModel = bias
strips.strips[0].inFile = 170907_082949_1.sdc
strips.strips[1].inFile = 170907_083249_1.sdc
strips.strips[2].inFile = 170907_083635_1.sdc
strips.strips[3].inFile = 170907_083951_1.sdc
strips.strips[1].trajectory.dX.sigmaApriori = 0
strips.strips[1].trajectory.dY.sigmaApriori = 0
strips.strips[1].trajectory.dZ.sigmaApriori = 0
strips.strips[1].trajectory.dRoll.sigmaApriori = 0
strips.strips[1].trajectory.dPitch.sigmaApriori = 0
strips.strips[1].trajectory.dYaw.sigmaApriori = 0
strips.normals.searchRadius = ......
sessions[0].trajectory.inFile = LK2_Traiectorii_7septembrie2017.txt
sessions[0].trajectory.iFormat = trajectory.xml
sessions[0].trajectory.timeLag = 0.0004
correspondences.strip2strip.overlap = .....
correspondences.strip2strip.selection.samplingDist = ......
correspondences.strip2strip.rejection.maxDist = ........
```

Because of the lack of information about the input data, y performed various tests parameter in order to achieve rigorous alignment of the ALS strips. The first parameter for which I did not know the true value is the orientation of the scanner when mounting on the platform.

Nr. cart	The type of orientation	Definition	No. of test	Observations
1	**FRD**	Bottom / front / right	tested 2 times	gave the error of not overlapping the strips
2	**DFR**	Bottom / back / left	tested once	gave error of no overlapping strips
3	**DBL**	Top / left / back	once tested	failed to overlap the bands
4	**ULB**	Top / right / front	once tested	failed to overlap the strips
5	**URF**	Right / down / front	once tested	failed to overlap the strips
6	**RDF**	Left / down / back	tested once	gave error of non-overlapping strips
7	**LDB**	Bottom / front / right	tested 2 times	gave the error of not overlapping the strips



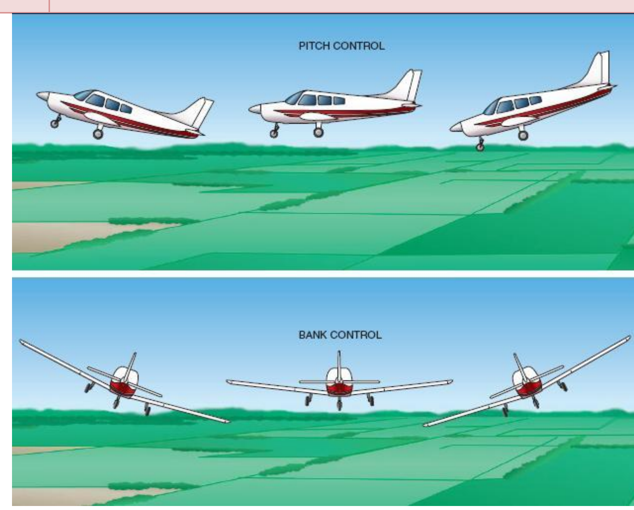


Figure 25. Scanner orientation
(https://en.wikiversity.org/wiki/Aircraft piloting/)

The software allows the use of different epochs of data acquisition by grouping them starting from indexing from 0, assigning to each trajectory a session and the orientation of the specific scanner. To correct the path there is a parameter that must be defined when executing the alignment program. These options are:

- BIAS
- LINEAR
- SPLINE

This parameter defines the model used to correct the trajectory. I tested two values of this parameter: BIAS and LINEAR. In the correct alignment of the ALS bands this parameter had the value **BIAS**. When introducing the ground control points, the value of the parameter will become LINEAR, because a scaling of the trajectory data will be performed.

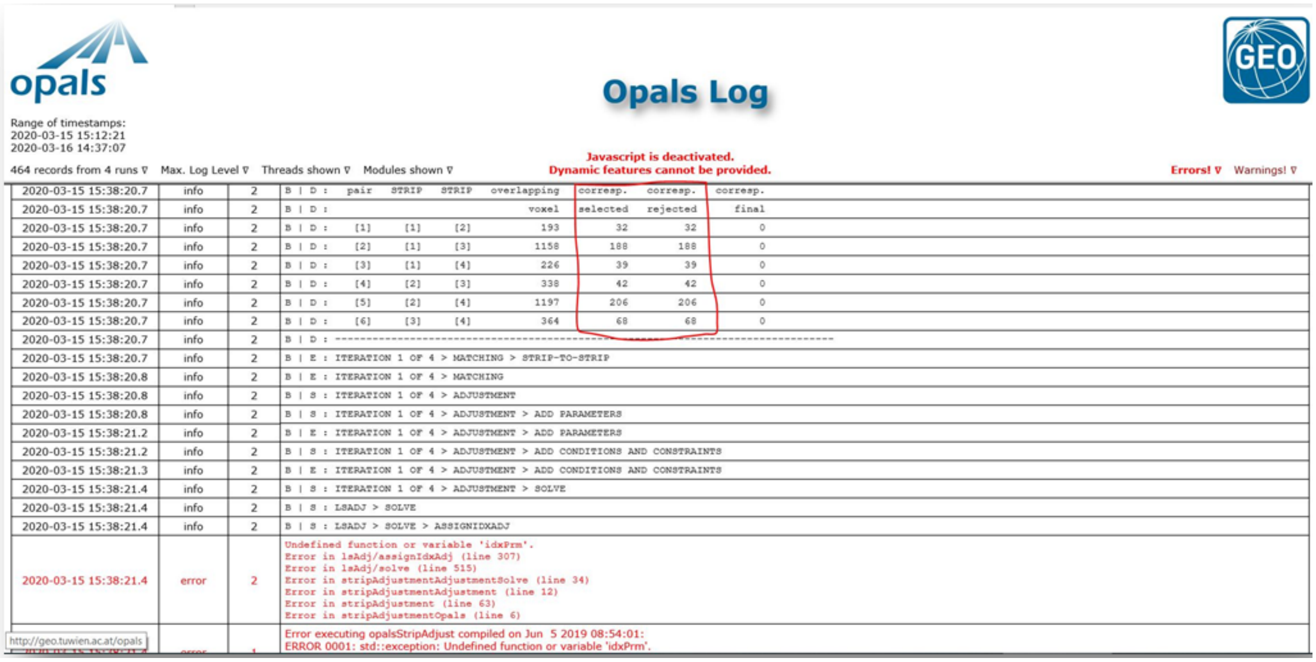
In order to find the overlaps between the ALS strips, i must define the voxel length for each point cloud. This structure is built from voxel centers that contain points in sdc files. If the number of common voxels between two point clouds is greater than the value defined in the configuration file (-correspondences. {Strip2strip, control2strip, image2strip} .overlap), It assumes point clouds to overlap. The length of each voxel used must be an integer value (100, x) == 0. Different values have been tested for this parameter, they are highlighted in the tables with no. 4 and with no. 5:

Nr. cart.	Parameters value	The results and the observations
1	1	This value gives us 90% of the exact number of overlapping blocks between the ALS strips entered as input data. Testing with this value failed, although most overlapping blocks were highlighted.
2	5	They highlighted this value in the example given by the software. It can be used but the number of overlapping blocks is small, and in the next step of selecting the correspondence failed.
3	10	This is the DEFAULT value. I used this value with the best results.
4	20	I tested these 2 values in order to understand how to define this parameter. The software could not process because of Excessive values error / down / back - tested once - gave error of non-overlapping strips.
5	50	

Number of pairs	The Pairs	The value of voxel cell =1	The value of voxel cell =5	The value of voxel cell =10
1	1-2	9896	560	193
2	1-3	173772	4984	1158
3	1-4	9937	601	226
4	2-3	14890	1073	338
5	2-4	190610	5439	1197
6	3-4	15451	1063	364

The number of iterations chosen varied between **values 2 and 4**, because of the long processing time and the various errors encountered during aligning the ALS strips. Because the initial relative orientation of point clouds in the ALS is usually good, only a few iterations (<5) are needed to reach the global minimum of the error function by gross errors.

The parameter for the search radius for mounting the plane, is used to estimate the normal vector at a point. All adjacent points in the search radius are used to match a plan. I need the resulting normal vector to calculate point-to-plane distances. In addition, it is used to reject false correspondence. The number of neighbors corresponding to the imposed value of 1.5 is 8 neighbors. I think this parameter influenced the input data, rejecting all matches found and leading to the error got in almost all tests performed.


Opals Log

Range of timestamps:
2020-03-15 15:12:21
2020-03-16 14:37:07

464 records from 4 runs ∇ Max. Log Level ∇ Threads shown ∇ Modules shown ∇

Javascript is deactivated.
Dynamic features cannot be provided.

Errors! ∇ Warnings! ∇

2020-03-15 15:38:20.7	info	2	B | D : pair STRIP STRIP overlapping corresp. corresp. corresp.
2020-03-15 15:38:20.7	info	2	B | D : voxel selected rejected final
2020-03-15 15:38:20.7	info	2	B | D : [1] [1] [2] 193 32 32 0
2020-03-15 15:38:20.7	info	2	B | D : [2] [1] [3] 1158 188 188 0
2020-03-15 15:38:20.7	info	2	B | D : [3] [1] [4] 226 39 39 0
2020-03-15 15:38:20.7	info	2	B | D : [4] [2] [3] 338 42 42 0
2020-03-15 15:38:20.7	info	2	B | D : [5] [2] [4] 1197 206 206 0
2020-03-15 15:38:20.7	info	2	B | D : [6] [3] [4] 364 68 68 0
2020-03-15 15:38:20.7	info	2	B | D : --
2020-03-15 15:38:20.7	info	2	B | E : ITERATION 1 OF 4 > MATCHING > STRIP-TO-STRIP
2020-03-15 15:38:20.8	info	2	B | E : ITERATION 1 OF 4 > MATCHING
2020-03-15 15:38:20.8	info	2	B | S : ITERATION 1 OF 4 > ADJUSTMENT
2020-03-15 15:38:20.8	info	2	B | S : ITERATION 1 OF 4 > ADJUSTMENT > ADD PARAMETERS
2020-03-15 15:38:21.2	info	2	B | E : ITERATION 1 OF 4 > ADJUSTMENT > ADD PARAMETERS
2020-03-15 15:38:21.2	info	2	B | S : ITERATION 1 OF 4 > ADJUSTMENT > ADD CONDITIONS AND CONSTRAINTS
2020-03-15 15:38:21.3	info	2	B | E : ITERATION 1 OF 4 > ADJUSTMENT > ADD CONDITIONS AND CONSTRAINTS
2020-03-15 15:38:21.4	info	2	B | S : ITERATION 1 OF 4 > ADJUSTMENT > SOLVE
2020-03-15 15:38:21.4	info	2	B | S : LSADJ > SOLVE
2020-03-15 15:38:21.4	info	2	B | S : LSADJ > SOLVE > ASSIGNIDXADJ
2020-03-15 15:38:21.4	error	2	Undefined function or variable 'idxPrm'. Error in lsAdj/assignIdxAdj (line 307) Error in lsAdj/solve (line 515) Error in stripAdjustmentAdjustmentSolve (line 34) Error in stripAdjustmentAdjustment (line 12) Error in stripAdjustment (line 63) Error in stripAdjustmentOpals (line 6)
	error	1	Error executing opalsStripAdjust compiled on Jun 5 2019 08:54:01: ERROR 0001: std::exception: Undefined function or variable 'idxPrm'.

http://geo.tuwien.ac.at/opals

Figure 26. The most common error in the test performed

For the final test - used to align the ALS strips, I used the value **1 with only 4 neighbors**. Correspondences are established between different unique types of point clouds in the object space and within the software have different parameters that lead to a correct setting necessary for a rigorous adjustment.

Overlap - this parameter usually has the same value as the voxel length. ALS strips are overlapped only if the number of overlapping voxels is greater than or equal to this value. A large number has been set to avoid that pairs of ALS bands with minor overlaps are taken into account because they contain extensive correspondences. The last value for this parameter is equal to the parameter set for voxel cells of **10**.

Selection - this parameter is determined by the selection methods listed above in the theoretical part of this report. This software makes a selection by usising the uniform sampling strategy- and is proportional to the overlapping parameters used. It is a percentage that starts from zero and reaches 100. In me case the default value of **5 percent** was used.

Rejection - this parameter determines the criteria for rejecting correspondence. As shown in the theory part, not all point-to-point correspondences found in the matching step are also valid band-alignment correspondences. So it is necessary to eliminate potentially wrong correspondence. Wrong correspondence is given if the two points are not on the same surface or if a reliable normal estimate is not because of high roughness. This parameter is influenced by the parameter entered, the search radius parameter, causing all correspondence to be rejected. The value set for the final test in ALS band alignment was **1**.

After all the tests performed and getting the correct values of the parameters mentioned above corresponding to my data set, i aligned the ALS strips with the help of Opals software. I entered all data both in the configuration file and in the command line. We can see it how the 4 ALS strips were imported on the trajectory data (fig. 27).

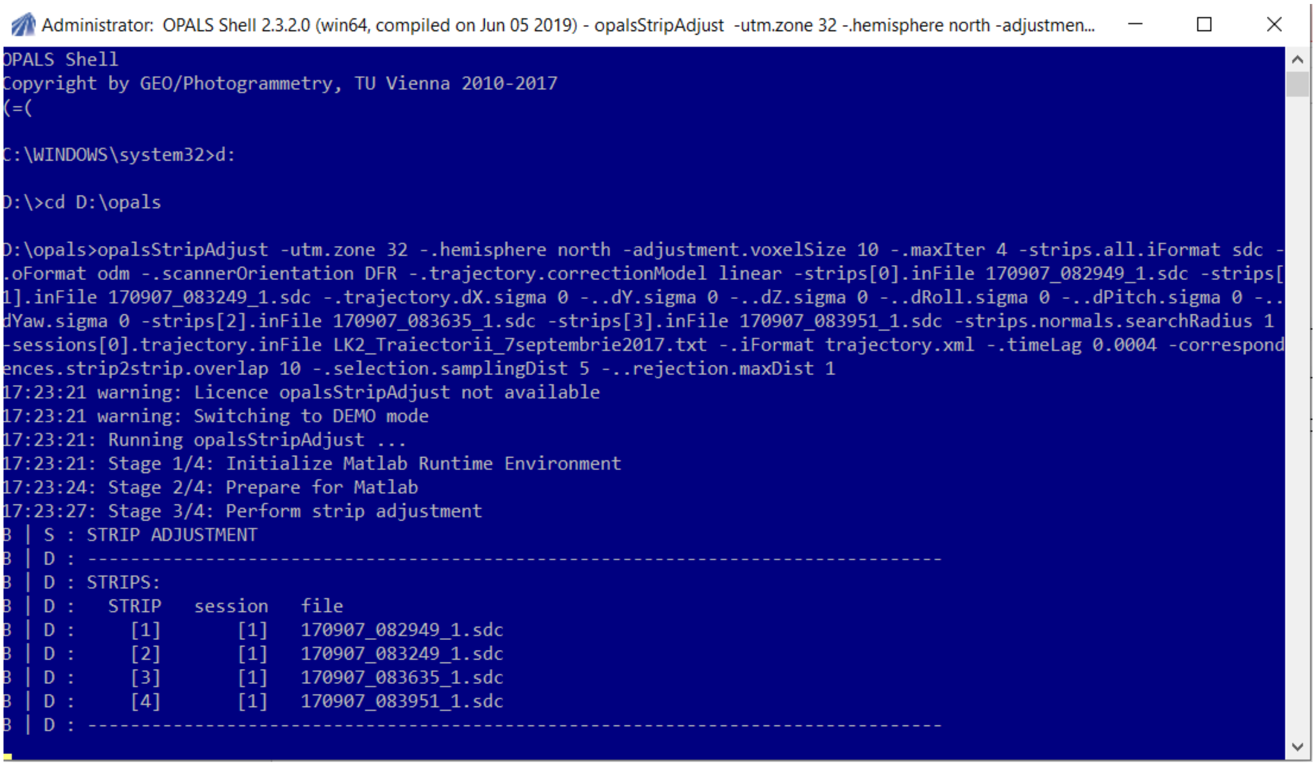


Figure 27. The command line and the ALS strips imported

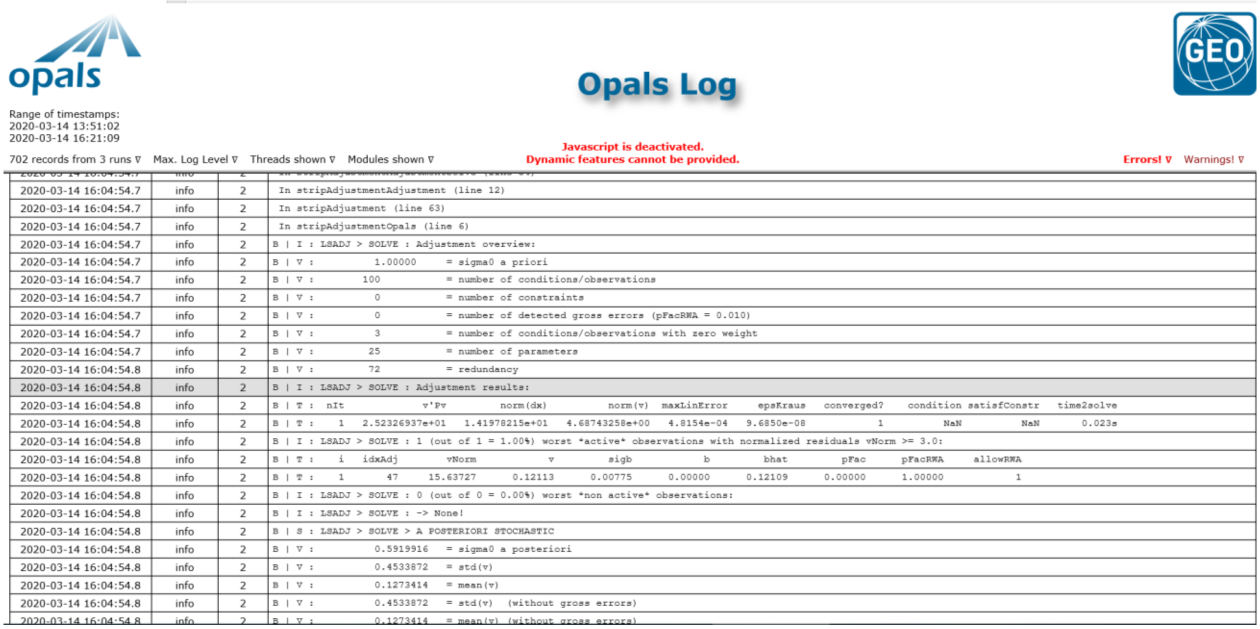
After importing, the 6 pairs of strips were created, the overlapping voxel blocks were determined, after which the correspondence was selected - strip by strip - starting from the first strip, because of the entered parameter used in this stage it was displayed on the screen the number of matches found in the overlap area. The matching step is created for the 6 pairs and a direct georeferencing is made, taking into account the GPS data, for each iteration, highlighting the number of rejected matches, the number of final matches, the standard deviation and the mean value for the distance from point to plan. I show the results after the first iteration in table no. 6:

Number of pairs	No of strip	The voxel	The number of the selected cores.	The number of the rejected cores.	The no of the final cores.	Standard deviation	Mean
1	1-2	193	6019	6019	0		
2	1-3	1158	37686	37639	47	0.522	-0.280
3	1-4	226	6897	6897	2	0.007	-0.652
4	2-3	338	10568	10568	0		
5	2-4	1197	40054	40001	53	0.567	0.203
6	3-4	364	11916	11916	0		

Y proceeded to the strip-by-strip alignment, adding the constraints and conditions, the number of observations and everything necessary for a rigorous alignment of the data entered respecting the required number of iterations and getting values after each iteration. I show the results of the last iteration in Table 7:

'STR2STR point-to-plane observations'

The number of observations = 96
Std(v)= 0.4483404
Mean(v)= 0.1229541
Stdmad(v)= 0.4662228
Median(v)= 0.0757106
Number of gross errors detected = 0
Std(v) (without gross errors)= 0.4483404
Mean(v) (without gross errors)= 0.1229541
Std_mad(v) (without gross errors)= 0.4662228
Median(v) (without gross errors)= 0.0757106



2020-03-14 16:04:54.7	info	2	In stripAdjustmentAdjustment (line 12)
2020-03-14 16:04:54.7	info	2	In stripAdjustment (line 63)
2020-03-14 16:04:54.7	info	2	In stripAdjustmentOpals (line 6)
2020-03-14 16:04:54.7	info	2	B | I : LSADJ > SOLVE : Adjustment overview:
2020-03-14 16:04:54.7	info	2	B | V : 1.00000 = sigma0 a priori
2020-03-14 16:04:54.7	info	2	B | V : 100 = number of conditions/observations
2020-03-14 16:04:54.7	info	2	B | V : 0 = number of constraints
2020-03-14 16:04:54.7	info	2	B | V : 0 = number of detected gross errors (pFacRWA = 0.010)
2020-03-14 16:04:54.7	info	2	B | V : 3 = number of conditions/observations with zero weight
2020-03-14 16:04:54.7	info	2	B | V : 25 = number of parameters
2020-03-14 16:04:54.8	info	2	B | V : 72 = redundancy
2020-03-14 16:04:54.8	info	2	B | I : LSADJ > SOLVE : Adjustment results:
2020-03-14 16:04:54.8	info	2	B | T : nIt v'Pv norm(dx) norm(v) maxLinError epsKraus converged? condition satisfConstr time2solve
2020-03-14 16:04:54.8	info	2	B | T : 1 2.52326937e+01 1.41978215e+01 4.68743258e+00 4.8154e-04 9.6850e-08 1 NaN NaN 0.023s
2020-03-14 16:04:54.8	info	2	B | I : LSADJ > SOLVE : 1 (out of 1 = 1.00%) worst *active* observations with normalized residuals vNorm >= 3.0:
2020-03-14 16:04:54.8	info	2	B | T : i idxAdj vNorm v sigb b bhat pFac pFacRWA allowRWA
2020-03-14 16:04:54.8	info	2	B | T : 1 47 15.63727 0.12113 0.00775 0.00000 0.12109 0.00000 1.00000 1
2020-03-14 16:04:54.8	info	2	B | I : LSADJ > SOLVE : 0 (out of 0 = 0.00%) worst *non active* observations:
2020-03-14 16:04:54.8	info	2	B | I : LSADJ > SOLVE : -> None!
2020-03-14 16:04:54.8	info	2	B | S : LSADJ > SOLVE > A POSTERIORI STOCHASTIC
2020-03-14 16:04:54.8	info	2	B | V : 0.5919916 = sigma0 a posteriori
2020-03-14 16:04:54.8	info	2	B | V : 0.4533872 = std(v)
2020-03-14 16:04:54.8	info	2	B | V : 0.1273414 = mean(v)
2020-03-14 16:04:54.8	info	2	B | V : 0.4533872 = std(v) (without gross errors)
2020-03-14 16:04:54.8	info	2	B | V : 0.1273414 = mean(v) (without gross errors)

Figure 28. The software log.

The final parameters are highlighted in the table no. 8, and it created a result file for each input date. The offset *sdc files containing the point cloud aligned for each band were saved as *odm file (*las format for Opals software). The trajectory has been corrected and its last version has been saved in *trj format (* ASCII format) for each strip. The correspondences between each pair of bands at each iteration were also saved. We can see it from the final parameters that the rigorous alignment of the strips is of an accuracy and precision superior to a direct alignment. It can work with an enormous volume of input data gained even in different GPS eras. The only disadvantage of this method and the use of this software is the incorrect information about the input data.

The final parameters	
[0].trajectory.dX.value	**-8.09987332924755**
[0].trajectory.dY.value	**3.54174730559599**
[0].trajectory.dZ.value	**1.36078337285548**
[0].trajectory.dRoll.value	**-0.114582141319452**
[0].trajectory.dPitch.value	**0.286610553168481**
[3].trajectory.dY.value	**0**
[3].trajectory.dZ.value	**0**
[3].trajectory.dRoll.value	**0**
[3].trajectory.dPitch.value	**0**
[3].trajectory.dYaw.value	**0**
scanner.range.offset.value	**0**

[0].trajectory.dYaw.value	**0.083462493872385**
[1].trajectory.dX.value	**0**
[1].trajectory.dY.value	**0**
[1].trajectory.dZ.value	**0**
[1].trajectory.dRoll.value	**0**
[1].trajectory.dPitch.value	**0**
[1].trajectory.dYaw.value	**0**
[2].trajectory.dX.value	**-8.06207731023042**
[2].trajectory.dY.value	**0.616141532095415**
[2].trajectory.dZ.value	**0**
Sesiunea [2].trajectory.dRoll.value	**0**
[2].trajectory.dPitch.value	**0**
[2].trajectory.dYaw.value	**0**
[3].trajectory.dX.value	**0**

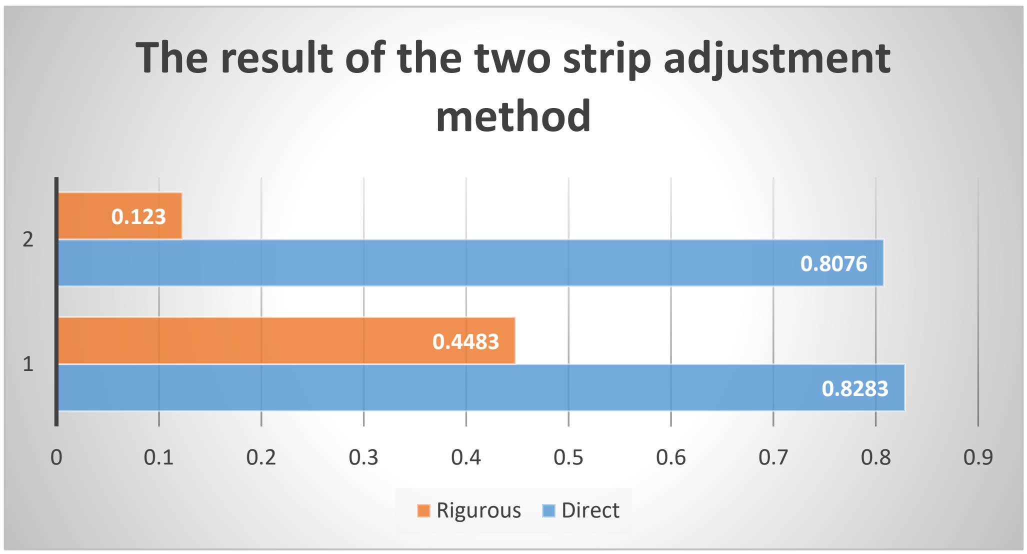
scanner.range.scale.value	**1**
scanner.scanAngle.offset.value	**0**
scanner.scanAngle.scale.value	**1**
scanner.tiltAngle.offset.value	**0**
scanner.tiltAngle.scale.value	**1**
datum.dX.value	**0**
datum.dY.value	**0**
datum.dZ.value	**0**

To view the last files of the adjust point cloud, use the Iview mode within the Opals software through a simple command line. It highlights the number of points for each odm file at the time of impressions. Table with no. 9 contains the number of 3D points in the compensated ALS files

The name of the ALS strip	Number of points in each strip
170907_082949_1	22489657
170907_083249_1	26150494
170907_083635_1	32283953
170907_083951_1	32694968

D. Comparison of methods

The solution used	The result after the strip adjustment		
	Number of overlapping observations	Standard deviation	Mean
Direct	149	0.8283	0.8076
Rigorous	96	0.4483	0.1230



It can be seen that although the number of observations in overlapping areas is higher in the direct method, the accuracy of the rigorous adjustment method is higher. Both the standard deviation value and the mean got from the adjustments are equal in the direct adjustment method and are twice and six times lower in the rigorous method.

Another advantage of the rigorous adjustment method is the ability to align ALS strips that contain an enormous volume of data. And the widespread elimination of systematic discrepancies for a enormous block of ALS strips - as was the area tested.

Conclusions

- For a large scan area I recommend it to use crossing strips in order to increase the redundancy and confidence of the adjustment, I recommend it that the control surfaces be covered by a cross strip and the longer data strips be crossed by several crossing strips;
- For the direct solution of adjustment we only need the trajectory given by the two GPS and INS systems and the original *las files, and the results are satisfactory if the scanning area is not a large one with an enormous volume of data;
- The larger the overlap area, the better the alignment of the ALS strips is;
- The direct solution of adjustment process does not require a high-performance computer, if the data set does not have a large volume of information or if it is pre-cut on different areas, the whole process can take from 10 minutes for a small area cut up to a maximum of 1 time for a larger volume of information. As with the tested data, the 4 bands from February 2, 2017;
- To improve these georeferencing methods, the points measured in the field can also determine the control surface, used in the calibration process;
- For rigorous solution of adjustment I recommend it to use ground control points, for an accurate assessment of accuracy. We define the parameters of these ground control points according to the software requirements;
- Because of the lack of various information required in performing the rigorous adjustment of the ALS strips, such as the exact orientation of the scanner during mounting on the airborne platform, various tests were required by replacing the required parameter;
- The entered parameters are related to the input data, and the inaccuracy of the input data leads to the testing of the parameters to find the exact solution in achieving the alignment of the ALS strips;
- Correspondences must be established, as they have a large effect on the final alignment of the ALS bands. There are no real correspondences in terms of points in the ALS data. We must take this into account, by minimizing the distances between the points and their tangent plane (instead of minimizing the point-to-point distances);
- Rigorous alignment is much more accurate than direct alignment, although the number of observations in the area of overlapping ALS bands is higher in the direct method;
- The software allows the use of different epochs of data acquisition by grouping them starting from indexing from 0, assigning to each trajectory a session;
- The software allows the use of an enormous volume of data and the alignment of some ALS bands in a quick time and with a high precision;
- It is highlighted in this report that taking into account the need and accuracy of the final product resulting from the point cloud - such as DTM - any of these 2 methods can be used. The type of input data must also be taken into account.

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