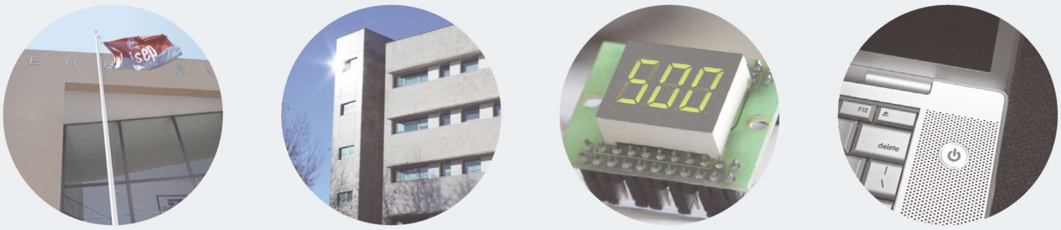
INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO
MESTRADO EM ENGENHARIA ELECTROTÉCNICA E DE COMPUTADORES



Mapeamento 3D com sistemas LiDAR e GNSS

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POLITÉCNICO
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Project Erasmus: 3D mapping with LiDAR and GNSS systems

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Abstract

The project begun by collecting all the information connected with geodesy, map projections and Global Navigation Systems. In the same time theoretical part covers also manuals and specification of further used tools like FARO Laser an GNSS Receiver.

After get to know about theoretical part the next step was to work with outdoor devices. Before do all surveys it has to be known all rules connected with health and safety. Then it has to be done leveling of the FARO Lasers holder. Afterwards on the top it was put GNSS Receiver. It was working for a few minutes to collect as much information as necessary to know the position. Next step was to start the scanning of laser and do the photos. The same was done with the second position on the campus. When the outdoor work was done all parts had been taken to a magazine for further users.

After the outdoor work the time comes to desk work. Before this task it has to be known computer programs that will be used in the project. To do a post-processing it was chosen the RTKLIB program. For the map projecting the best option was CloudCompare. With help from manuals and tutorials the work on a map can go ahead. At least after all tasks the final map was ready for the further use.

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Introduction

1.1 General Outline of Project

This project addresses the subject of 3D mapping with Light Detection and Ranging (LiDAR) and Global Navigation Satellite System (GNSS), to produce an accurate model to be used as a reference for sensor calibration of airborne mobile LiDAR system. This project applies concepts from geodesy, cartography, GNSS data processing and point cloud registration, that were combined to achieve an accurate mapping solution.

Data collection was accomplished by taking several LiDAR scans from different fixed positions. By collecting also GNSS data, the global coordinates of each scanning spot, were determined with centimeter level accuracy. This information, along with point cloud matching techniques, allow all individual scans to be combined, in order to obtain a unified coherent model of the scene. Building a large scale model in this way provides several advantages, namely, the possibility to record geometric information from an area that exceeds the maximum sensor range. Also, by carefully choosing the scanning positions, occlusion situations can be mitigated. Further, since mapping resolution decreases proportionally with range, collecting data from different spots along the interest area may help to improve the resolution of the final model.

1.2 Objectives and Activities

First of all steps was deepening new knowledge at the field of Geodesy, Mapping, Global Navigation System, Post-Processing, Creating the maps and converting the coordinates. After that, outdoor field work focused on the data acquisition aspects, including the operation of the sensor devices including a FARO Laser Scanner and a GNSS Receiver. After completing the surveying work, activities turn to the data processing side, applying state of the art applications for GNSS data processing and point cloud registration.

1.3 Report Presentation

A. Chapter one – presents the framework and the main objectives
B. Chapter two – presents main concepts
C. Chapter three – presents specification of all indoor and outdoor tools
D. Chapter four - presents how everything must be done to prepare to outdoor work and did the measurements
E. Chapter five – presents how to work with computer programs to do a post-processing, converting the coordinates and preparing a map
F. Chapter six – presents a summary about all the did work

1.4 Results of the project

In the geodesy context, modern sensor devices and data processing applications were investigated, as an efficient way of building highly detailed and accurate models of large scale environments. Apart from the group of satellites, integrating the state segment of the GNSS system, it is possible for the general user to access complementary ground networks, as the Portuguese Network of Permanent Base Stations (ReNEP), to improve the positioning accuracy. Thanks that, the accuracy is on high level, compared to theodolite which had a huge error from the human site. Through opensource software applications, all data was combined to achieve a georeferenced, realistic and accurate dense map of the ISEP campus. The produced model will be used in the future as ground truth reference for evaluating self-calibration procedures of airborne LiDAR mapping systems.

Main Geodesy Concepts

2.1 GNSS (Global Navigation Satellite System)

It is a satellite system that is used to pinpoint the geographic location of a receiver anywhere in the world. Five GNSS systems are currently in operation: the United States' Global Positioning System (GPS), the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS), Europe's Galileo, Chinese Satellite System named BeiDou and Japanese one QZSS. Each of the GNSS systems employs a constellation of orbiting satellites working in conjunction with a network of ground stations. Satellite-based navigation systems use a version of triangulation to locate the user, through calculations involving information from a number of satellites. Each satellite transmits coded signals at precise intervals. The receiver converts signal information into position, velocity, time estimates and corrections for calculations. Using this information, any receiver on the earth's surface can calculate the exact position of the transmitting satellite and the distance between it and the receiver. Coordinating current signal data from four or more satellites enables the receiver to determine its position.

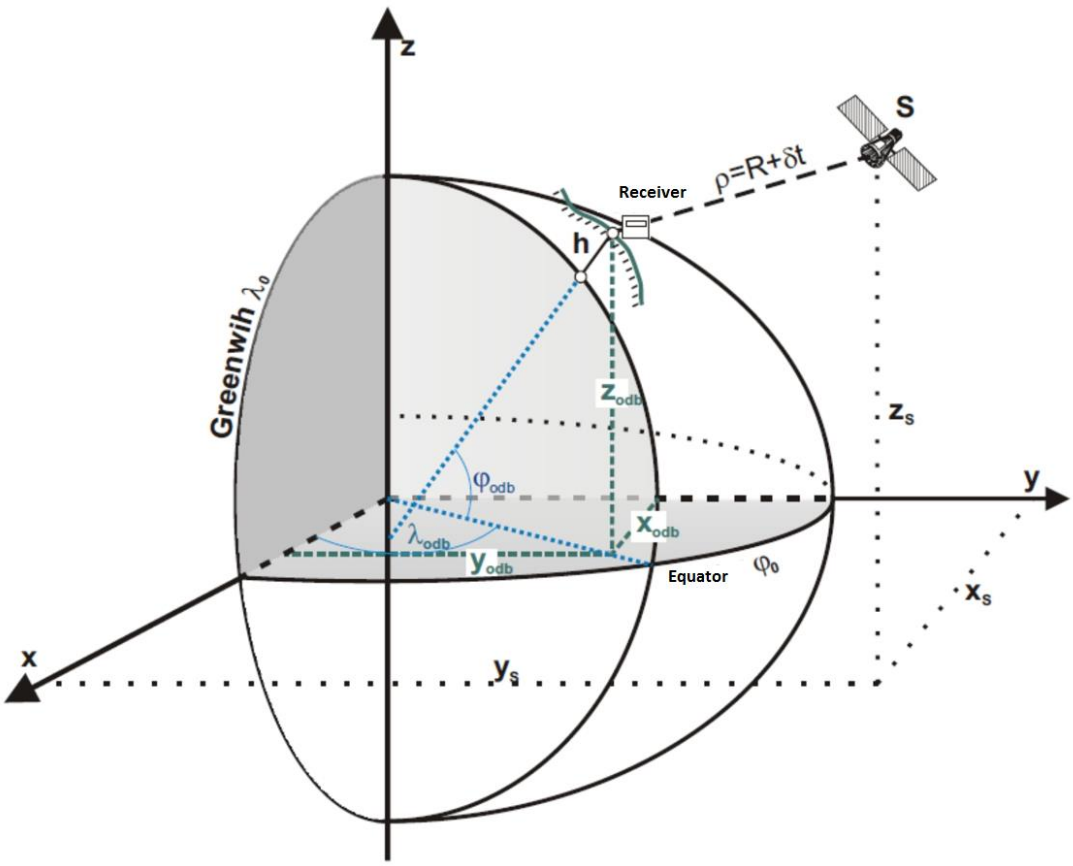

Figure 1 Shows satellite and GNSS receiver in cooperative with Cartesian Coordinate System

Rules for setting position of GNSS receiver:

$$\rho = \sqrt{(x_{sat} - x_{rec})^2 + (y_{sat} - y_{rec})^2 + (z_{sat} - z_{rec})^2} + c \times \delta t$$

Equation 1 Shows how to calculate quasi-distance

In this equation there are three unknown coordinates x_{rec}, y_{rec}, z_{rec}, corresponding to the global receiver position, and an error term related to time synchronization δt. A minimum set of four satellites is necessary to determine those four unknowns. Thanks this method it can be calculated approximate value of position on earth. Additional measures may be adopted to improve the positioning result, up to centimeter level accuracy. Most effective techniques make use of differential observations, provided by an additional base station receiver. Differential observations are combined with the information from the user's receiver, to compute correction of errors affecting the GNSS measurements and also apply alternative precision positioning techniques.. Including differential techniques, other strategies may be employed to obtain more accurate positioning results:

- **Static Survey** executes the continuous collection of data GNSS at a designated point for a long period of time. Using a postprocessing application, all measurements are combined to obtain determine a single position. When combined with differential techniques, static measurements provide the highest accuracy of GNSS. They are used in the establishment and control of geodetic and geodynamic studies.
- **Fast Static Survey** is a variation of previous method, which, instead of collecting data for long periods, consists on working with data collected over a shorter period of time of around 5 to 20 minutes. It demands for good sky visibility conditions and resorts to differential corrections to achieve position accuracies of few centimeters.
- **Real Time Kinematic (RTK)** is a high accuracy differential positioning technique that tracks the phase of the signal's carrier. It requires differential data from a near base station and at least 5 visible satellites. Usually, RTK fixes take less than a minute to acquire, with a multi-frequency receiver, and characterize by centimeter level accuracy.
- **Differential GNSS (DGNSS)** is a differential positioning technique, which in term of accuracy stands in between single receiver positioning and RTK positioning. It tracks the codes transmitted by the satellites, so it requires a minimum of four visible satellites. Positioning accuracy decreases inversely with the distance to the base station. Sub-metric positioning is possible for base stations in a radios up to 10 kilometers. This method is used in touristic navigation with single frequency receivers.

2.2 Geodesy

It is the science of accurately measuring and understanding the Earth's geometric shape, orientation in space and gravity field. The definition is divided on a lot of smaller objects:

- **Low Geodesy** the science of measurements performed on small surfaces with a radius of not more than 15 km or 750 km^2, without taking into account the sphericity of the Earth
- **High Geodesy** the science of measurements performed on big surfaces, more than 750 km^2, with taking into account the sphericity of the Earth
- **Astronomic Geodesy** it studies the theory and methods of determining the latitude ϕ and the longitude λ of a place as well as the azimuth (a) of the direction to a terrestrial object and the local sidereal time (s) from astronomical observations made during geodetic and cartographic work
- **Photogrammetry** field of science and technology dedicated to the reproduction of shapes, sizes and relative positions of objects in the field on the basis of photogrammetric images
- **Remote Sensing** is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on-site observation
- **Satellite Geodesy** the measurement of the form and dimensions of Earth, the location of objects on its surface and the figure of the Earth's gravity field by means of artificial satellite techniques
- **Physical Geodesy** is the study about the physical properties of the gravity field of the Earth, the geopotential, with a view to their application in geodesy
- **Gravimetry Geodesy** is the measurement of the strength of a gravitational field. Gravimetry may be used when either the magnitude of gravitational field or the properties of matter responsible for its creation are of interest.
- **Mapping** is the study and practice of making maps. Combining science, aesthetics, and technique, cartography builds on the premise that reality can be modeled in ways that communicate spatial information effectively
- **Adjustment Calculations** is the study about improvement calculations and minimalize mistakes
- **Topography** in a narrow sense involves the recording of relief or terrain, the three-dimensional quality of the surface, and the identification of specific landforms [1]

2.3 Map projection

It is a mathematically described technique of how to represent the Earth's curved surface on a flat map. In the process of map making ellipsoidal or spherical surfaces are used to represent the surface of the Earth. Which shows the drawing below:

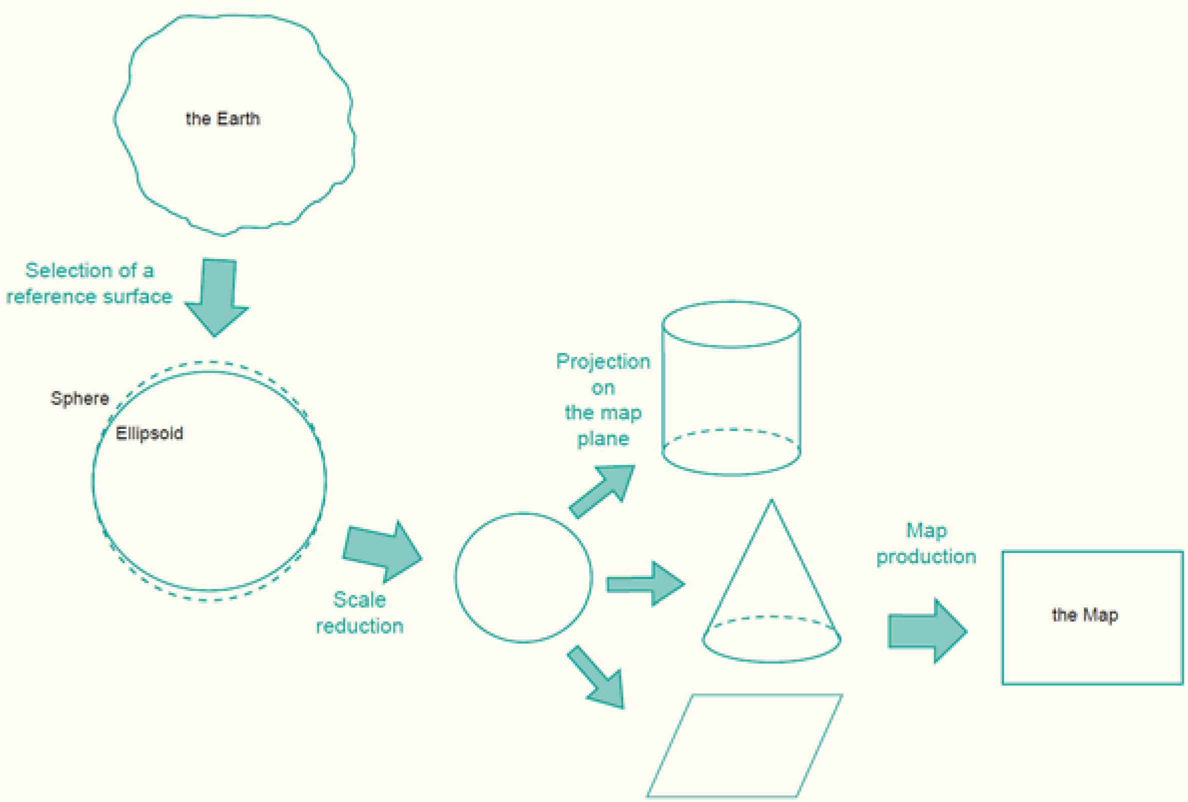

Figure 2 Shows the process of representing the Earth on a flat map

- **Reference surfaces**: Two main reference surfaces are used to approximate the shape of the Earth. One is called the ellipsoid, the other is the Geoid. The Geoid is the equipotential surface at mean sea level and is used for measuring heights represented on maps. The starting point for measuring these heights are mean sea level points established at coastal places. These points represent an approximation to the Geoid. There are several realizations of local mean sea levels in the world. These are called local vertical datums or height datums. The ellipsoid provides a relatively simple mathematical figure of the Earth. It is used to measure locations, the latitude (*f*) and longitude (*l*), of points of interest. These locations on the ellipsoid are then projected onto a mapping plane. The Surface of the Earth is anything but uniform. The oceans, can be treated as reasonably uniform, but the surface or topography of the land masses exhibits large vertical variations between mountains and valleys. These variations make it impossible to approximate the shape of the Earth with any reasonably simple mathematical model. Consequently, two main reference surfaces have been established to approximate the shape of the Earth.

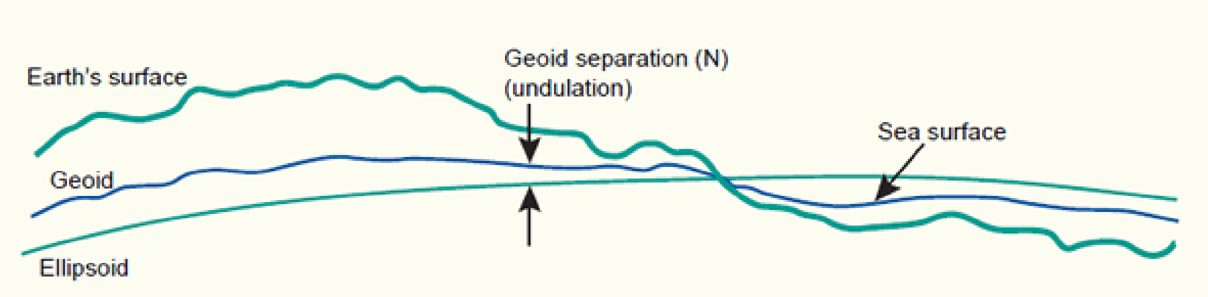

Figure 3 Shows The Earth's surface, and two reference surfaces used to approximate it: the Geoid, and a reference ellipsoid. The deviation between the Geoid and a reference ellipsoid is called geoid separation

- **Figures of mapping**: To represent parts of the surface of the Earth on a flat paper map or on a computer screen, the curved horizontal reference surface must be mapped onto the 2D mapping plane. The reference surface for large-scale mapping is usually an oblate ellipsoid, and for small-scale mapping, a sphere. Mapping onto a 2D mapping plane means transforming each point on the reference surface with geographic coordinates to a set of Cartesian coordinates representing positions on the map plane. The three classes of map projections are cylindrical**,** conical and azimuthal. The Earth's reference surface projected on a map wrapped around the globe as a cylinder produces a cylindrical map projection. Projected on a map formed into a cone gives a conical map projection. When projected directly onto the mapping plane it produces an azimuthal map projection. The figure below shows the surfaces involved in these three classes of projections:

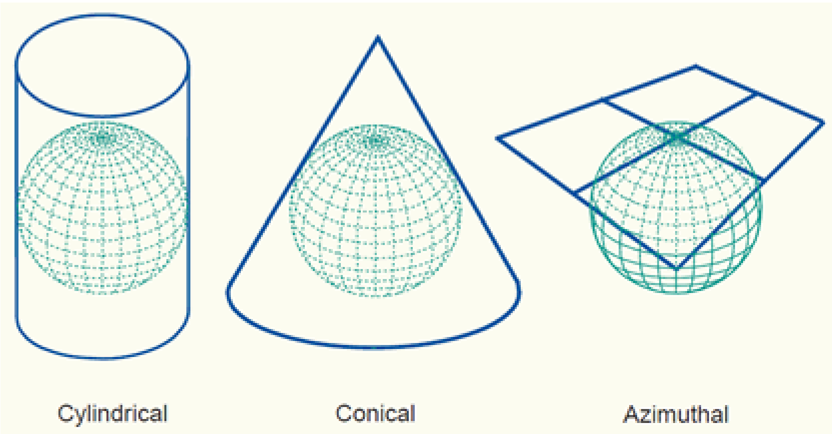

Figure 4 Shows three classes of map projections

- **Scale**: A map projection without distortions would correctly represent shapes, angles, areas, distances and directions, everywhere on the map. Any map projection is associated with scale distortions. There is no way to flatten out a piece of ellipsoidal or spherical surface without stretching some parts of the surface more than others. The amount and which kind of distortions a map will have depends largely - next to size of the area being mapped - on the type of the map projection that has been selected. Since there is no map projection that maintains correct scale all over the map, it may be important to know the extent to which the scale varies on a map. On a world map, the scale variations are evident where landmasses are wrongly sized or out of shape and the meridians and parallels do not intersect at right angles or are not spaced uniformly. These maps may have a scale reduction diagram to indicate the map scale at different locations, helping the map-reader to become aware of the distortions. On maps at larger scales, maps of countries or even city maps, the distortions are not evident to the eye. However, the map user should be aware of the distortions if he or she computes distances, areas or angles on the basis of measurements taken from these maps.

- **UTM**: The most famous projection in use is Universal Transverse Mercator (UTM). This projection uses a transverse cylinder, secant to the reference surface. It is recommended for topographic mapping. The UTM divides the world into 60 narrow longitudinal zones of 6 degrees, numbered from 1 to 60
- **Globalization of Geodesy:** is leading to the establishment of global 3D coordinate systems. These spatial reference systems can be realized thanks to advances in satellite-based positioning. The most important standard 3D system for the GIS (Geographic Information System) community is the International Terrestrial Reference System (ITRS).
- **3D geographic coordinates** (ϕ, λ, h) are obtained by introducing the ellipsoidal height to the system. The ellipsoidal height (h) of a point is the vertical distance of the point in question above the ellipsoid. It is measured in distance units along the ellipsoidal normal from the point to the ellipsoid surface. 3D geographic coordinates can be used to define a position on the surface of the Earth

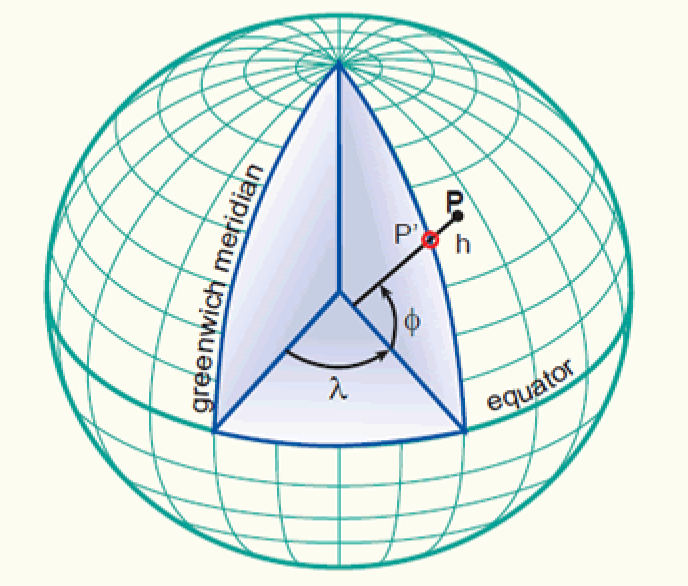

Figure 5 Shows the latitude (φ) and longitude (λ) angles and the ellipsoidal height (h) represent the 3D geographic coordinate system.

- **Changing Map Projections**: Forward and inverse mapping equations are generally used to transform data from one map projection to another. The inverse equation of the source projection is used first to transform source projection coordinates (x,y) to geographic coordinates (ϕ, λ). Next, the forward equation of the target projection is used to transform the geographic coordinates to target projection coordinates (x',y'). The first equation put a projection A into geographic coordinates. The second put geographic coordinates (ϕ, λ) to another map projection B.

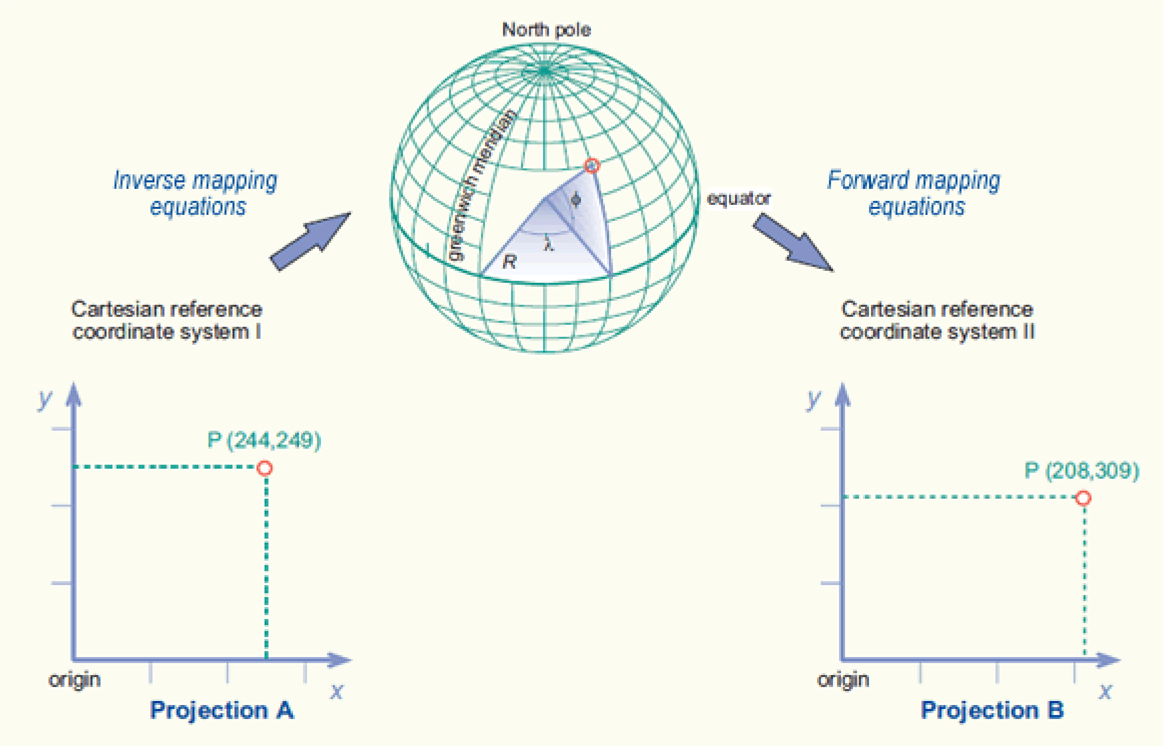

Figure 6 Shows The principle of changing from one into another projection using the mapping equations

- **Datum Transformations**: A change of map projection may also include a change of the horizontal datum . This is the case when the source projection is based upon a different horizontal datum than the target projection. If the difference in horizontal datums is ignored, there will be no perfect match between adjacent maps of neighbors countries or between overlaid maps originating from different projections. It may result in up to several hundred meters difference in the resulting coordinates. Therefore, spatial data with different underlying horizontal datums need transformation. Datum transformations are changing from a 3D coordinate system into another 3D one. [2]

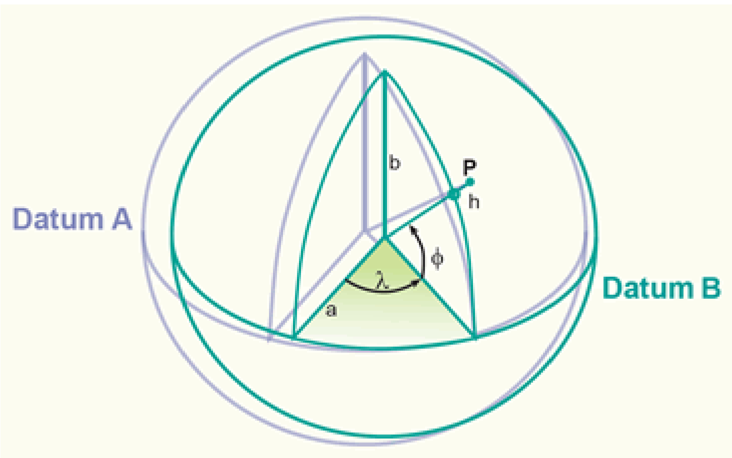

Figure 7 Shows datum shift between two geodetic datums.

Specification of used tools

3.1 Field work tools

A) **FARO Laser Scanner Focus** is enable to capture fast, straight forward and accurate measurements of complex objects and buildings. To measure the distance, the machine uses phase shift technology, where constant waves of infrared light of varying length are projected outward from the scanner. Upon contact with an object, they are reflected back to the scanner. The distance from the scanner to the object is accurately determined by measuring the phase shifts in the waves of the infrared light.

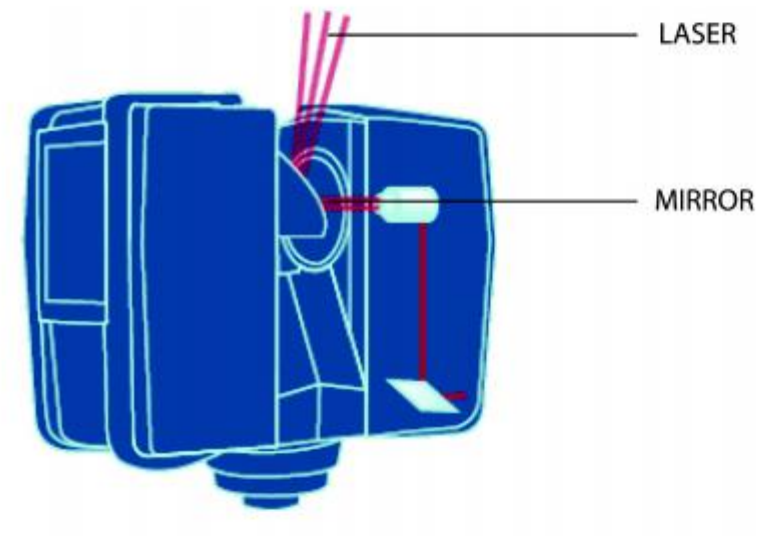

Figure 8 Shows FARO laser while working

The x, y, z coordinates of each point are then calculated by using angle encoders to measure the mirror rotation and the horizontal rotation of the Focus. These angles are encoded simultaneously with the distance measurement. Distance, vertical angle and horizontal angle make up a polar coordinate (δ, α, β), which is then transformed to a Cartesian coordinate (x, y, z). The scanner covers a 360° x 305° field of view.

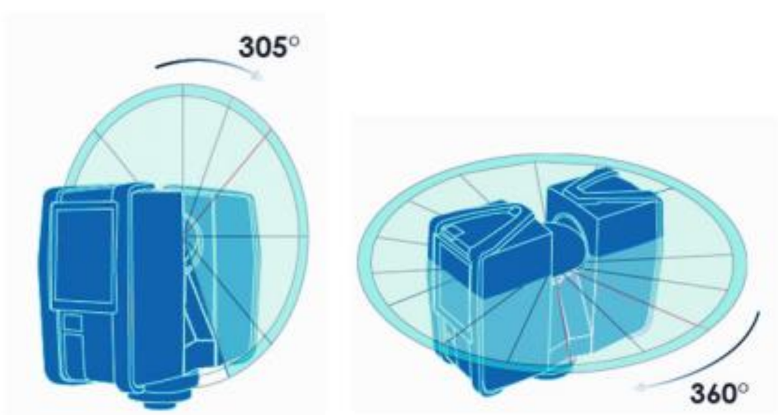

Figure 9 Shows horizontal and vertical angle of FARO Laser

The result of the measurements is a Point Cloud, a three-dimensional dataset of the scanner's environment. Depending on the selected resolution each point cloud consists of millions of scan points. The laser has ±2mm of the range resolution. The laser scans are recorded to the removable SD memory card, enabling easy and secure transfer to the special program. This scanner can be in work by four and a half of hour on the open air in bad weather conditions. The installed camera can take a photos in HDR quality even in the bad lighting conditions. HDR means high dynamic range and is a technique to capture images with multiple exposure times and merging them into a single HDR image layer. These HDR images will be mapped onto the point cloud data generated by the laser scanner. In the machine is a touch screen with an easy software where can be changed all the settings. These settings have an influence for the time of measurements. FARO Laser has got few other machines which differentiate by distance of taking points. The one with the longest distance is with name ending 350, next is 150 and especially to indoor surveys 70. [3]

B) **T300 GNSS Receiver** is a good option to know correct localization of the point that must be in use. By using special algorithm technology, it can function with all the GNSS constellations. The strong anti-interference ability of the receiver makes it possible to work in any environment.

Figure 10 Shows appearance of GNSS Receiver

Thanks to power supply type “hot-swap” T300 can work in terrain without any break for changing accumulators. In the case there are two tough batteries, but when receiver is working it is using only one of them. After discharge of the first one, device automatically change to the second accumulator without break in work. In the same time operator can pull battery out and put it to the charger. The device can work with 256 track signals like GPS, BeiDou and GLONASS. The measurement accuracy in RTK mode reaches ±2,5mm. [4]

3.2 Computer Programs

A) **RTKLIB** is an open source program package for standard and precise positioning with GNSS. RTKLIB consists of a portable program library and several application programs utilizing the library. Program supports standard and precise positioning algorithms with GPS, GLONASS, Galileo, BeiDou, QZSS and SBAS. It make available various positioning modes with GNSS for both real-time and post-processing like: Single, Kinematic, Static, Moving-Baseline and so on. It includes the following functions: Launcher, Real-Time Positioning, Communication Server, Post-Processing Analysis, RINEX Converter, Plot Solutions and Observation Data, Downloader of GNSS Data, NTRIP Browser. [5]

Figure 11 Shows The main launcher of RTKLIB Program

B) **CloudCompare** is a 3D point cloud editing and processing software. The program has meant to deal with huge point clouds. CloudCompare had followed a lot of processing algorithms like registration, resampling, color or normal, vectors or scalar fields management, statistics computation, sensor management, interactive or automatic segmentation. Thanks to very clear user screen it can be specify the main objects like: menu, main toolbar, scalar fields toolbar, plugins toolbar, view toolbar, database tree, properties view, default 3D view and so on. Thanks these functions user can do many thing with point clouds. [6]

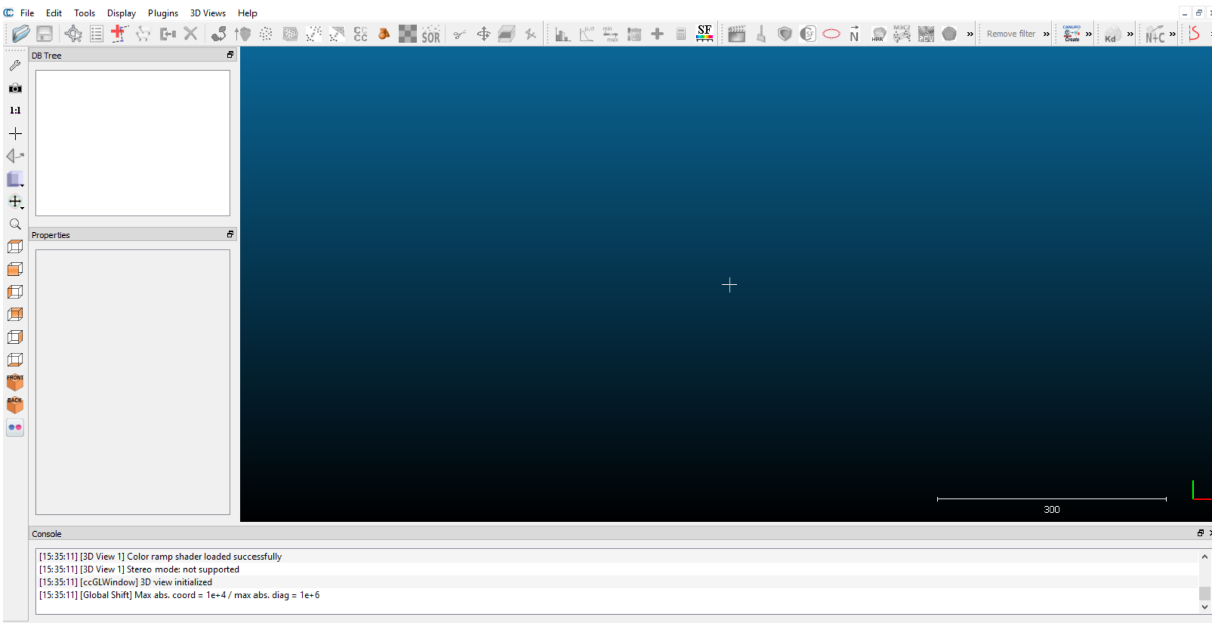

Figure 12 Shows The main Screen of CloudCompare

Outdoor data acquisition

The data acquisition task took place at Campus ISEP on 04-05-2017. In this field experiment, both the Faro laser scanner and the T300 GNSS receiver were used to collect information from different static positions. The methodology used to perform the data acquisition experiment is described below.

4.1 Arrangements to field work

To do the measurements at the beginning operator have to become acquainted with manuals of both devices. To do this kind of work everybody who comes and have contact with machines must know occupational safety and health. To do the surveys operators must have work outfit which will be visual from the long distance. To protect eyes from the laser beam operator must wear special oculars. He needs to check that everything is included with a device – chargers, cables, holders, batteries, protect equipment and memory cards.

4.2 Spacing FARO Laser

At the beginning operator must find a good place to take all measurements. The best way is to find a ground where the holder can stick deeply in the soil. After choose the right place it must be stacked in one leg of rack and trying to put the bubble of air in the center of circle spirit level. When the bubble had roughly the center, it can be dig two more holders legs into the ground. If the bubble will get out from the center after these shakes user can use snaps on the legs. These snaps controlling the length of the holder. When it is really close to the center finally operator can use the adjusting screws. When operators have got confidence that the bubble is in the center they can put on the holder FARO Laser Scanner. To be sure that Scanner will not fall down operators need to tighten lock screw which connect scanner and the holder. Before turn on the device user must be sure that battery is at one hundred percent charge and is inside. After that he must put memory card to the machine.

4.3 Spacing GNSS Receiver

When operator is ready to use the scanner he need to use the GNSS receiver to take right position of the scanning. To do that user do not need to use another special holder to the receiver, just put the device at the top of the scanner.

4.4 Turn on GNSS Receiver

After turn on the machine at the front panel will show five LEDs flashes. On the end left and end right are two flashes which show the charge level of the battery. When the light is long bright it means that in accumulator is enough energy. If the light is flashing, it means the battery is low. Second LED flashes once per second when transmit differential data and flashes still when getting differential data from Base station or Network. The middle LED shows how many satellites locked by the receiver. The blue LED flashes when receiver is connected by Bluetooth with controller or PC. Under the LEDs are two buttons responsible for data logging and turn on/off the device. The power button has got only one usage. If user wants to turn on or off the machine just press the button. The data logging flashes only in three situations:

- ✓ In the static mode - shows the sample interval of collecting data

- ✓ RTK Mode - the receiver is connecting to Controller or PC and receiving commands
- ✓ Internal memory is run out

After turn on the receiver and program all the necessary data user must wait some time for accurate location.

Figure 13 Shows the work of the receiver which is set on the FARO Laser

4.5 Turn on and change settings of FARO Laser

After all preparation operator can turn on the Scanner. After while on the touch screen will appear five icons. The first one on the top right is help. When it was clicked onto, the screen will be shown an article with help by the device. The second one is the biggest button on the center. Thanks this users can start scanning. But before that it must be needed to choose the setting on the third button with name of “Parameters”. After clicked on this, on touch screen will be some more options to choose. To choose a predefined scan profile operator must take the first option “Selected Profile” where it can be choose that scan will be indoor or outdoor. Also part of the day and wheatear. It shows too the name of the selected scan profile. Click to select a scan profile. If the scanning parameters are different from the selected profile, altered is appended to its name. Selecting a scan profile overwrites the scanning parameters with the settings of this scan profile. After choose these kind of settings the next step is to change some things in the second option in the “Parameters” – Resolution and Quantity. It affects the quality of the scan and the scanning time at constant scan resolutions. It allows the user to balance the needs of quality and speed with one simple slider. Moving the slider up increases the scan quality which result is an increased scanning time. Moving the slider down reduces the scanning time but decrease the efficiency of the scan project. The Quality slider sets quality levels either via diverse measurement rates or by applying additional noise compression. To change resolution of the scan operator must use the slider on the left. In the next variable operator can change scan range in the vertical and horizontal area. The name of these variables is "Setting the Scan Range". After these settings operator can change used sensors like inclinometer, compass and altimeter.

- The inclinometer switch has impact on enable or disable the automatic use of the inclination measurement of the built-in dual axis compensator for the scan registration.
- The compass switch has impact enable or disable the automatic use of the data of the built-in compass for the scan registration.
- The altimeter switch has impact on enable or disable the automatic use of the altimeter data for the scan registration

The next button is named "Advanced Settings" which change to on or off clear contour and clear sky. The first one enables the dynamic contour filter. While scanning, this hardware filter will remove incorrect measurements at the edges of objects. It removes scan points resulting from hitting two objects with the laser spot which mainly happens at the edges of objects. The second one enables the dynamic sky filter. While scanning, this hardware filter will remove scan points resulting from hitting no objects at all which mainly happens when scanning the sky. The last switch have can change pictures from the camera to color or black and white. After change all the switches in "Parameters" operator can choose the right bottom switch with name "Manage" where user can change settings like:

- choose the language,
- set the date and time and theirs format,
- set the units of length and temperature,
- see all scanner information.

The last button on the start screen is "View scans" which allows to see all scans that were before.

Figure 14 Shows the main screen of the FARO Laser after turn it on

4.6 Start Scanning

After change all the setting operator can click on the button “Start scan”. After that all people whose near the device must go about 5 meters from machine and put the specially glasses to don’t be liable on laser beam. When the scanner is in work on the touch screen is shown a loading bar with percentage of how much work was already done. While work the laser beam is all the time turn on and the mirror from the opposite site is spinning. Thanks that scanner is sending laser ray to the different locations to measure all near points. Thanks that the scanner is turning around own axis, allows laser to check all the recesses. At the end camera on the faro is taking pictures to put colors on the point cloud.

Figure 15 Shows the scanning of the FARO Laser

Processing Data

5.1 Collect all data needed to post-process in RTKLIB

To do this kind of task at the beginning it must be known all data from GNSS receiver and the nearest base station. After measurements, all the files from receiver must be rip on the computer desktop. The same situation must be with base station, but all the data must be download from files which are shared on the official website “dgterritorio” [7]. It is a website where all the base stations in Portugal are sending the localization to the main site. To search these data users of the receiver must know in what year, month and time they did measurements. The time can be found in the receiver files.

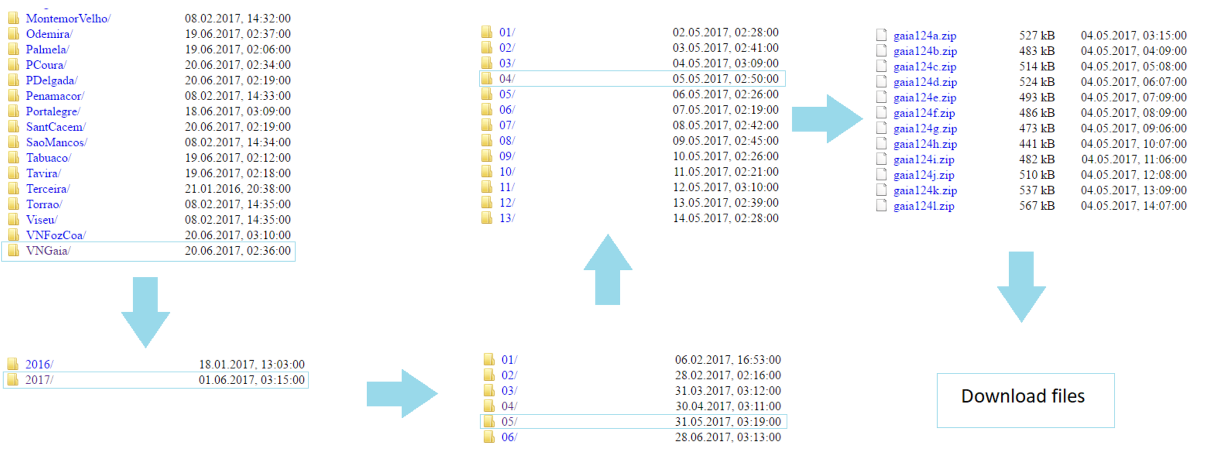

Figure 16 Shows how to download files from the base station website

When users know the time of surveys and the name of the nearest base stations it can be downloaded like that:

- Chose the name of the base station
- Chose the year
- Chose the month
- Chose the day
- Chose the hour
- Download data

5.2 Post-Processing in RTKLIB program

When on the computer are all files and data necessary to work, user can enter all of them into the program. To do that it must be in run RTKLIB launcher. When on the screen will be shown all programs included in it, user must choose RTKPOST.

Figure 17 Shows which program have to be chosen and how RTKLIB Launcher looks like

After click on the right program on the screen will be shown small window with a lot of variables that can be change. Before put all the data on the options user must change some of the variables. At first which type of satellite navigation system had participate in the surveys. Also at the top is the information how the program must do the post-processing. There user can change from single positioning mode to the kinetic positioning mode. Thanks that program can use data from base station.

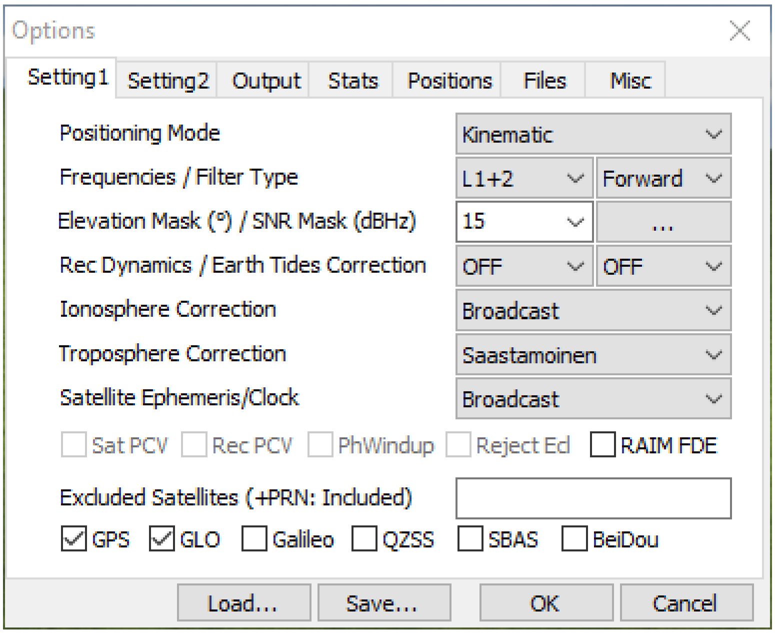

Figure 18 Shows options window in the RTKPOST program

After all changes in the empty fields must be written files paths. At the top is the field named RINEX which means "Receiver Independent Exchange Format". There must be file where are all information like atmospheric conditions, time of measurements, position, speed and other related physical quantities. Below it is a field where must be file path to downloaded base station data with correct time. Below this it must be written the path to a file with information about what type of satellite navigation system was used in the surveys. When everything is ready at the top bottom is a button with name "Execute". User must click on it to do a post-processing.

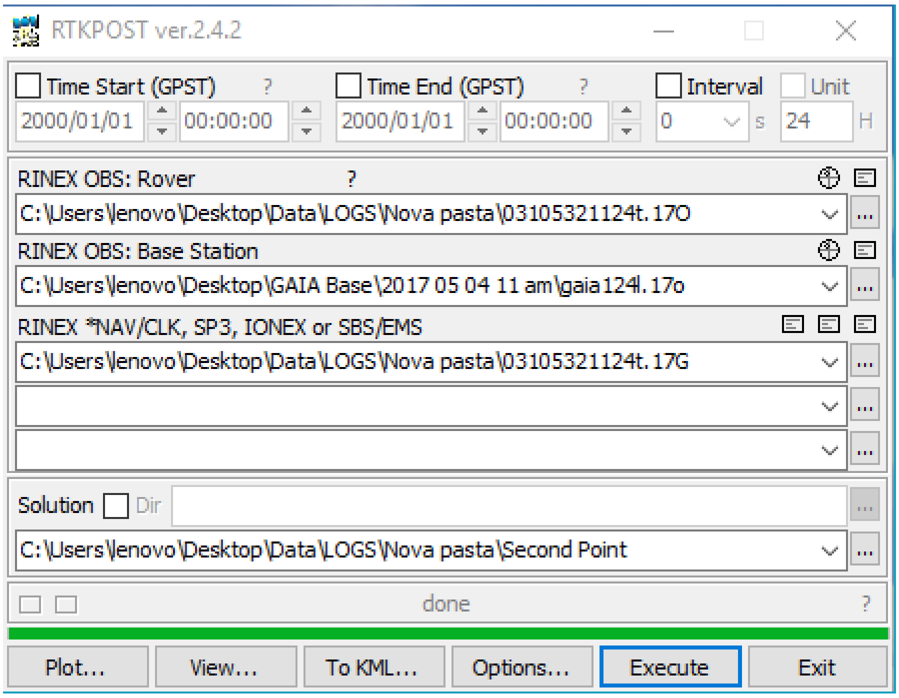

Figure 19 Shows the main screen of RTKPOST

5.3 Collecting the data from post-processing

When the post-processing is done the user must take all information which are connected with quality 1. If the quality has lower number, the surveys are better. When all data with the best quality are noticed user must do an average of them and this is the final result. In the post-processing that user gets a new file with that kind of information:

- Time when all the measurements were done
- Latitude
- Longitude
- Height
- Quality
- Number of satellites
- Measurements errors

2017/05/04 11:04:40.200	41.178976900	-8.607457314	162.9034	2	12	0.6844	0.7029	1.1336	-0.5732	0.5582	-0.5168	0.20	2.6
2017/05/04 11:04:40.400	41.178977811	-8.607459074	162.8469	2	12	0.6844	0.7029	1.1336	-0.5732	0.5582	-0.5168	0.40	2.5
2017/05/04 11:04:40.600	41.178977547	-8.607457602	162.8991	2	12	0.6845	0.7029	1.1336	-0.5732	0.5582	-0.5168	0.60	1.7
2017/05/04 11:04:40.800	41.178978105	-8.607459610	162.9036	2	12	0.6845	0.7029	1.1336	-0.5732	0.5582	-0.5168	0.80	2.4
2017/05/04 11:04:41.000	41.178975513	-8.607456252	162.9914	1	12	0.0094	0.0091	0.0120	-0.0079	0.0057	-0.0053	1.00	4.7
2017/05/04 11:04:41.200	41.178975512	-8.607456264	162.9889	1	12	0.0095	0.0091	0.0121	-0.0079	0.0057	-0.0053	1.20	8.2
2017/05/04 11:04:41.400	41.178975527	-8.607456263	162.9875	1	12	0.0096	0.0092	0.0122	-0.0080	0.0057	-0.0053	1.40	11.8
2017/05/04 11:04:41.600	41.178975494	-8.607456280	162.9853	1	12	0.0097	0.0093	0.0123	-0.0081	0.0058	-0.0053	1.60	9.3
2017/05/04 11:04:41.800	41.178975515	-8.607456242	162.9846	1	12	0.0098	0.0094	0.0124	-0.0082	0.0058	-0.0054	1.80	6.4
2017/05/04 11:04:42.000	41.178975491	-8.607456214	162.9868	1	12	0.0099	0.0095	0.0125	-0.0083	0.0059	-0.0054	2.00	7.5
2017/05/04 11:04:42.200	41.178975474	-8.607456211	162.9900	1	12	0.0100	0.0096	0.0127	-0.0084	0.0059	-0.0054	2.20	6.5
2017/05/04 11:04:42.400	41.178975459	-8.607456211	162.9841	1	12	0.0102	0.0098	0.0129	-0.0085	0.0060	-0.0054	2.40	3.7
2017/05/04 11:04:42.600	41.178975477	-8.607456255	162.9757	1	12	0.0104	0.0099	0.0130	-0.0087	0.0061	-0.0055	2.60	5.8
2017/05/04 11:04:42.800	41.178975463	-8.607456203	162.9815	1	12	0.0105	0.0101	0.0132	-0.0088	0.0061	-0.0055	2.80	4.6
2017/05/04 11:04:43.000	41.178984997	-8.607463409	161.1383	2	12	0.6658	0.7006	1.0589	-0.5654	0.5373	-0.4502	3.00	2.5
2017/05/04 11:04:43.200	41.178982929	-8.607462735	161.1548	2	12	0.6658	0.7006	1.0589	-0.5654	0.5373	-0.4502	3.20	2.6
2017/05/04 11:04:43.400	41.178982193	-8.607462503	161.1826	2	12	0.6658	0.7006	1.0589	-0.5654	0.5373	-0.4502	3.40	2.8
2017/05/04 11:04:43.600	41.178985578	-8.607467306	161.1065	2	12	0.6659	0.7007	1.0589	-0.5654	0.5373	-0.4502	3.60	2.4
2017/05/04 11:04:43.800	41.178985338	-8.607467751	161.3150	2	12	0.6659	0.7007	1.0589	-0.5655	0.5373	-0.4502	3.80	2.3
2017/05/04 11:04:44.000	41.178983920	-8.607466071	161.4598	2	12	0.6659	0.7007	1.0589	-0.5655	0.5373	-0.4502	4.00	2.5
2017/05/04 11:04:44.200	41.178987332	-8.607466346	161.8643	2	12	0.6659	0.7007	1.0589	-0.5655	0.5373	-0.4502	4.20	2.5
2017/05/04 11:04:44.400	41.178986924	-8.607467490	161.9750	2	12	0.6659	0.7007	1.0589	-0.5655	0.5373	-0.4502	4.40	2.9
2017/05/04 11:04:44.600	41.178987737	-8.607465916	162.1391	2	12	0.6659	0.7007	1.0589	-0.5655	0.5373	-0.4502	4.60	2.4
2017/05/04 11:04:44.800	41.178988960	-8.607464680	162.2136	2	12	0.6659	0.7007	1.0589	-0.5655	0.5372	-0.4502	4.80	1.7

Figure 20 Shows file with obtain data

To check in the map what distance is between all points user can choose a button with name "plot". Thanks that the program shows the scale of the map and different color of points. Color is depended by quality. When quality is 1, the color is green, second level of quality shows the orange color. More than number 2, points are red. When receiver is not in cooperation with a base station the map shows inaccurate co-ordinates and they are in a big distance between them. The better option is to cooperate with base which results shows picture below:

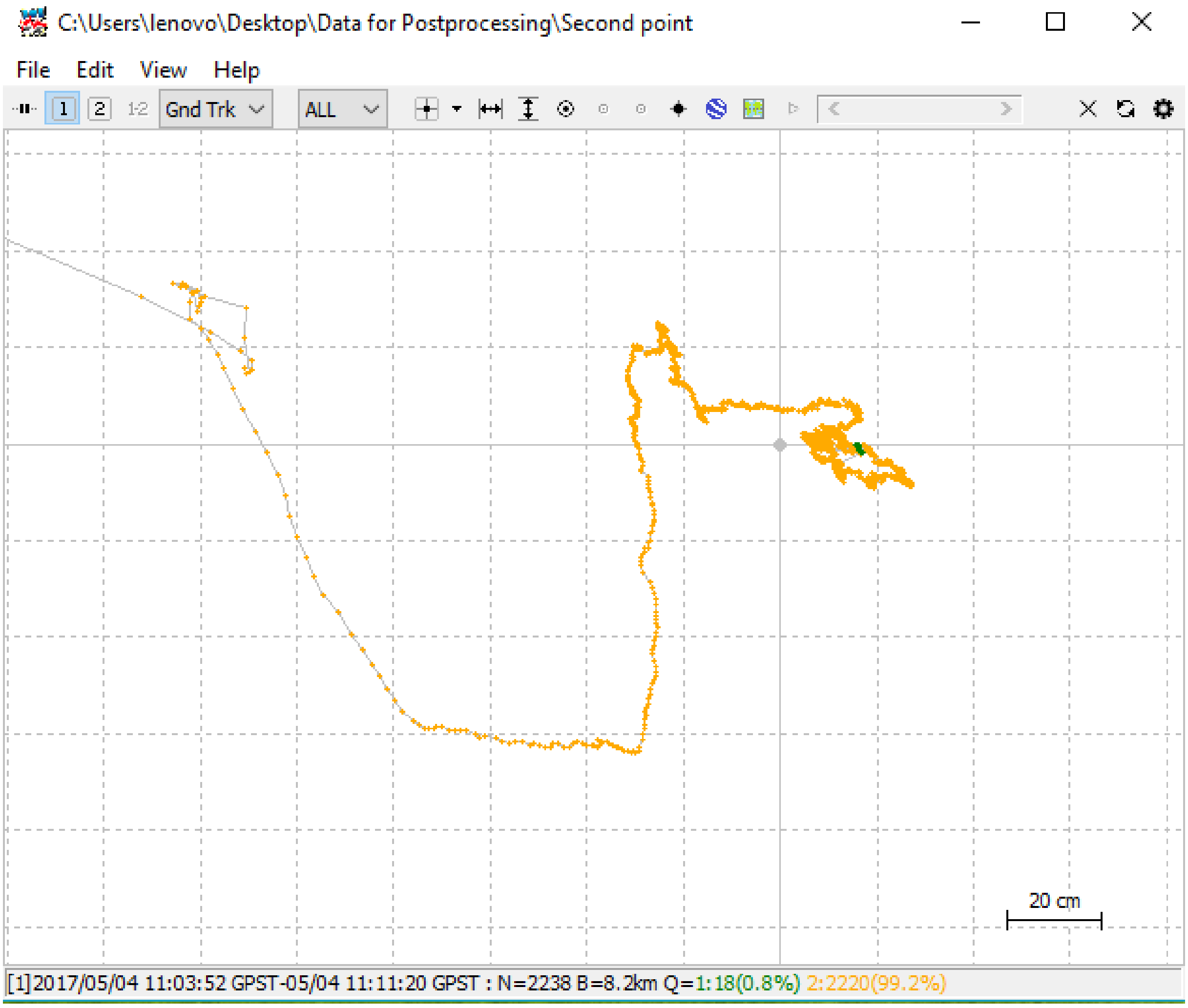

Figure 21 Shows the quality map of received points

After check if everything is in a good quality and prepare average of all of the points user can put all the information in a file to prepare them to further calculations. In picture below are all data collected for the process. From the beginning are latitude and longitude in degrees, after them are latitude and longitude in radians. After theses information are shown height above the ellipsoid and height above the mean sea level. In the received data at first point was a big error connected with height so in the next calculations there are taken results of high from the second point because measurements were at the same level of ground.

```
Project:      P1

Latitude  (+/-D M S)  Longitude  (+/-D M S)Latitude(rad)
Longitude(rad)  H-Ell(m)H-MSL(m)

  41 10 43.78750   -8 36 27.27642
0.7187061632  -0.1502305555      159.151      103.528

Project:      P2

Latitude  (+/-D M S)  Longitude  (+/-D M S)Latitude(rad)
Longitude(rad)  H-Ell(m)H-MSL(m)

  41 10 44.32998   -8 36 26.82455
0.7187087932  -0.1502283648      163.124      107.501
```

Figure 22 Shows Results of post processing

5.4 Converting the coordinates

To put the highest accuracy in mapping at program CloudCompare user must know the matrix with the local data of ENU (Cartesian Coordinate System named EastNorthUp). To do that user must put results of the post processing from WGS84 (World Geodetic System) and convert them into ECEF (Earth Centered, Earth Fixed). To do these calculations it must be used pattern, which is shown below:

WGS84 to ECEF

$$\begin{bmatrix} X_{ECEF} \\ Y_{ECEF} \\ Z_{ECEF} \end{bmatrix} = \begin{bmatrix} (N_e + h)\cos(\varphi)\cos(\lambda) \\ (N_e + h)\cos(\varphi)\sin(\lambda) \\ (N_e(1-e^2) + h)\sin(\varphi) \end{bmatrix}$$

Where:

- φ=latitude (rad)
- λ=longitude (rad)
- h=height above the ellipsoid (m)
- N_e (prime vertical radius of curvature) $= \dfrac{R_{EA}}{\sqrt{1-e^2\sin^2(\varphi)}}$
- R_{EA} (semi-major axis) = 6378137 (m)
- e (first eccentricity of the ellipsoid) $= \dfrac{\sqrt{R_{EA}^2 - R_{EB}^2}}{R_{EA}}$
- R_{EB} (semi-minor axis) = 6356752 (m)

Equation 2 Shows conversion coordinates from WGS84 to ECEF

The process of conversion:

$$e = \frac{\sqrt{6378137^2 - 6356752^2}}{6378137} = 0{,}08181979$$

› For the first point:

$$N_{e_1} = \frac{6378137}{\sqrt{1 - 0{,}08181979^2 sin^2(0{,}7187061632)}} = 6387412{,}168$$

$$\begin{bmatrix} (6387412{,}168 + 163{,}124)\cos(0{,}7187061632)\cos(-0{,}1502305555) \\ (6387412{,}168 + 163{,}124)\cos(0{,}7187061632)\sin(-0{,}1502305555) \\ (6387412{,}168(1 - 0{,}08181979^2) + 163{,}124)\sin(0{,}7187061632)) \end{bmatrix} = \begin{bmatrix} 4753507{,}472 \\ -719543{,}408 \\ 4177498{,}503 \end{bmatrix}$$

The results of the ECEF for first point are:

X= 475307,472m

Y= -719543,408m

Z= 4177498,503m

› For the second point

$$N_{e_1} = \frac{6378137}{\sqrt{1 - 0{,}08181979^2 sin^2(0{,}7187087932)}} = 6387412{,}224$$

$$\begin{bmatrix} (6387412{,}224 + 163{,}124)\cos(0{,}7187087932)\cos(-0{,}1502283648) \\ (6387412{,}224 + 163{,}124)\cos(0{,}7187087932)\sin(-0{,}1502283648) \\ (6387412{,}224(1 - 0{,}08181979^2) + 163{,}124)\sin(0{,}7187087932)) \end{bmatrix} = \begin{bmatrix} 4753501{,}110 \\ -719531{,}793 \\ 4177511{,}099 \end{bmatrix}$$

The results of the ECEF for the second point are:

X= 4753501,110m

Y= -719531,793m

Z= 4177511,099m

Thanks to know the position of the points in the ECEF it must be used the ENU system. To do that the coordinate system must be established in one of the points. For the start of this system it was chosen the point number two. The next step was to calculate the distance between these points in the local coordinate system by x,y and z. To have an result it was taken the latitude and longitude of the origin frame from the second point. After that it has to be done implementation of the coordinate from the first point. The results of the distance between points:

X= 16,735m

Y= 10,532m

Z= 0m

5.5 Preparing map projection in CloudCompare

After collect all data needed to do a 3D map it must be turned on the cloudcompare program. When the main screen is opened the user must pick up two files with the point clouds. In the case of this project it was taken map no. 293 and no. 294. Theses maps have got less point than the two more but they were at similar level of quality. The maps on the screen below are in the different direction to each other because of surveys. They were taken from two different places.

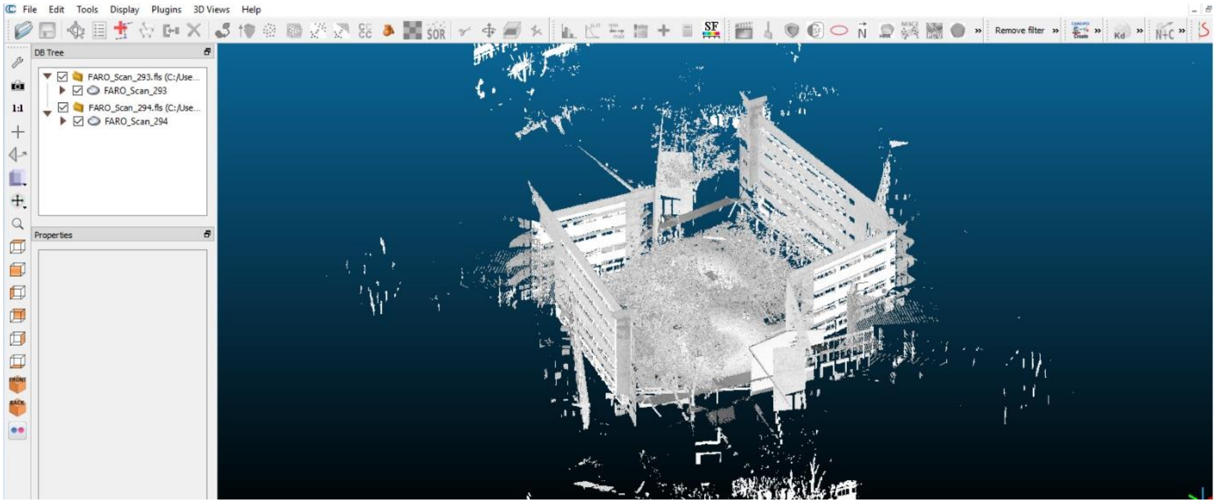

Figure 23 Shows two maps chosen to prepper the map

When all the points from these two files were on the main screen at first the user must subsample them. It is necessary, because one point cloud had more than ten millions of points and they were in color. To do the sampling it was taken one and after that second file and use a tool named "subsample of point cloud".

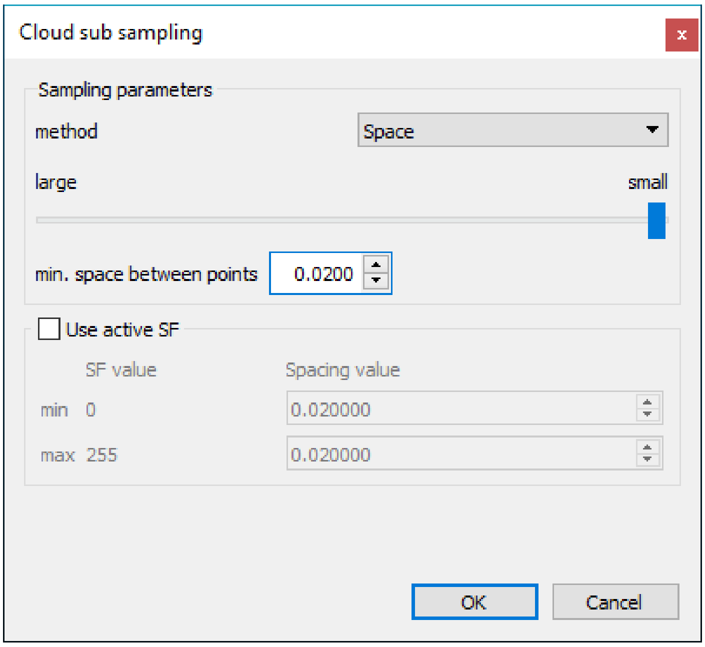

Figure 24 Shows the window of the sub sampling tool

Thanks to these tool the points are not so close to each other that gives better comfortable with rationing maps. If the next map will be still so hard to move it and rotate it this tool can be used one more time to delate more points. When user decided to not delate other points to do not lose more quality a good option is to remove colors and put the map into a grey one. When both maps were working good in cloudcompare the next step was to connect them into one projection. Map two was the point cloud with origins coordinates so the middle was at the 0. To do the connection it was taken the numbers of coordinate distance between points and locate them into the projection matrix of second map. Thanks that these point clouds were really near each other, but to full connection it was missing some details. With this problem user can manage by other helpful tool in the program with name “aligns two point clouds”. After clicked on it a small window appeared on the screen. To put together these maps it must be taken more than three similar points from point clouds.

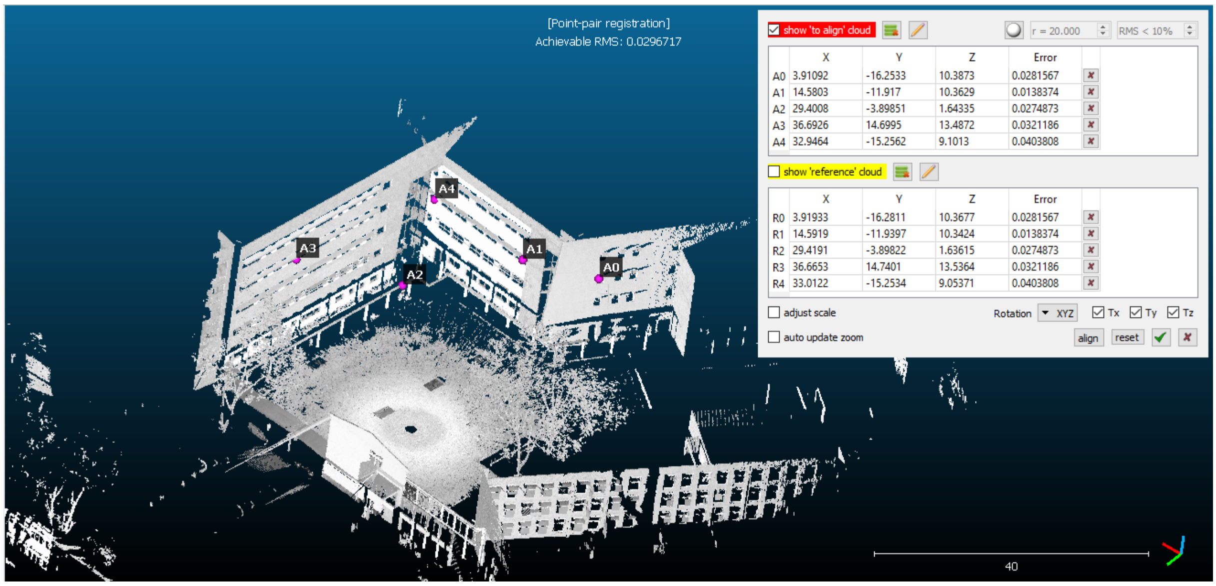

Figure 25 Shows the tool to align the points in CloudCompare

When user takes more the quality of connecting is bigger. To do that user can just click on the one point from the first map, after that turn off it and turn on the second map and choose the nearest point from it which is compatible. After chose the points user must push the button “align” and after that these point cloud will be really near to each other. The next picture below shows how more detailed can be map when the tool in cloudcompare align them together:

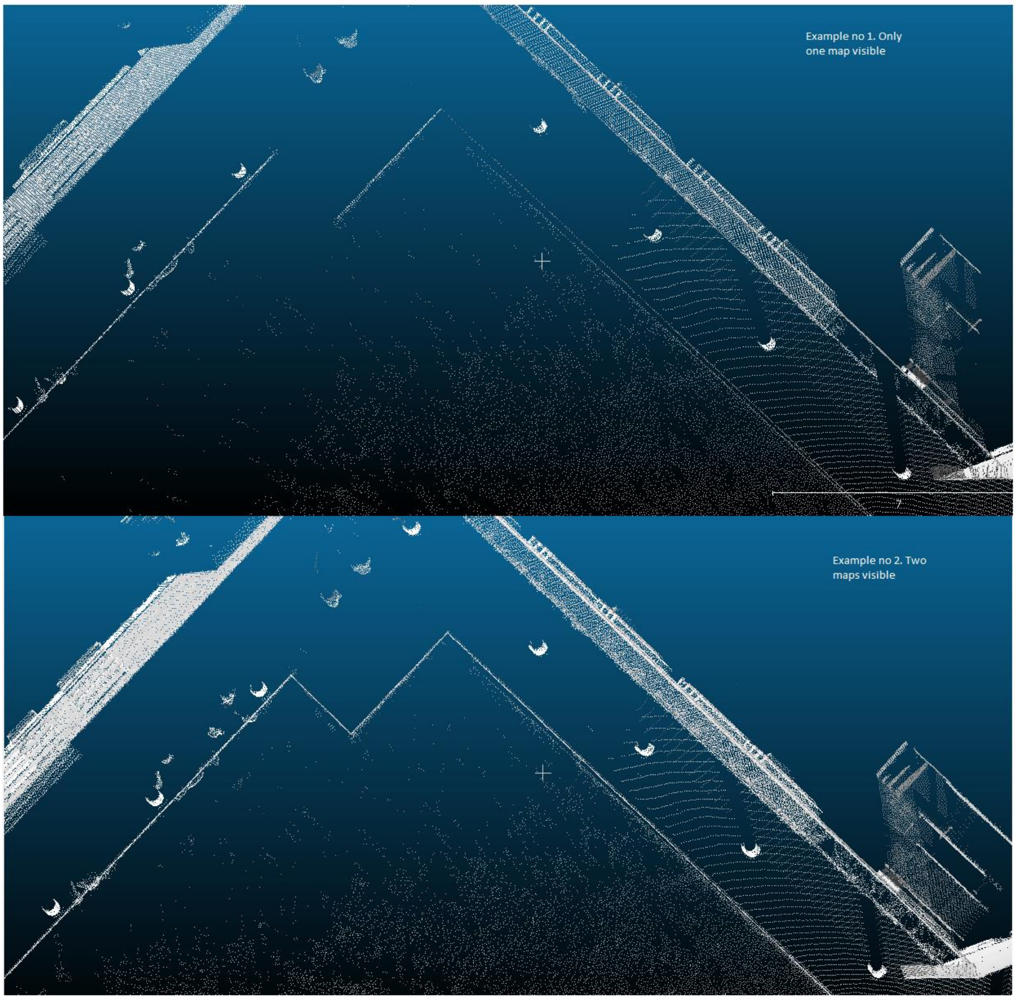

Figure 26 Shows comparison between one map projection and two aligned

Conclusion

After all these steps and used tools the final map is ready to use. Thanks that the field-work drone for measurements can be calibrated and ready to do rest of the surveys in the right way. Thanks to the modern programs and machines connected with geodesy it is more comfortable for users to do these kind of works. Specially compare to the old versions of tools the accuracy is on a better level.

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