The role of echosounder measurement in lidar point cloud calibration

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Abstract

The calibration of the lidar point clouds over aquatic environments presents unique challenges compared to terrestrial calibration, primarily due to the refractive and reflective properties of water. This discrepancy arises due to the fact that the majority of the calibrated area is situated in a water body. In instances where a point cloud contains water, alternative methods can be employed. These include the utilization of control points located on the beach or an echosounder with a depth greater than 1m.
The area was subjected to thorough research in the vicinity of Lubiatowo, where a 1.5-kilometre coastal zone was identified, with a depth of approximately 10 meters. This survey was conducted using a lidar point cloud, created in 2018 by the Austrian company Airborne Hydro Mapping (A-M) for Polish company Apeks. The Riegl Vq880g scanner was utilized in the measurement process, which involved the registration of the seabed and the adjacent land near Lubiatowo. In the immediate vicinity, the seabed was subsequently measured using the echosounder Echotrac Cv100 (Odom) of the Polish Academy of Sciences in Gdańsk. All measurements were conducted under calm sea conditions, which minimized surface interference and improved data consistency.
The received data were found to be in a 3D coordinate system UTM\WGS84 ellipsoid, and appeared to be preprocessed lidar point cloud. Therefore, an investigation was made into the relationship to the echosounder measurement. It was determined that the transforms used programs such as Microstation Power Draft with Terrascan, Geokonwerter, and Microsoft Office Excel. Calibration of the lidar point cloud was primarily conducted at a depth greater than 1m, based on echosounder measurements. Initially, the adjustment lidar point cloud size was defined to enhance its accuracy.
Following the calibration process, the lidar point cloud was matched to the echosounder. The point cloud's correction magnitude (average) ranged from -1.14m. It is imperative to measure additional data using an echosounder during the registration of lidar data. This result underscores the necessity of integrating hydroacoustic measurements for accurate registration of lidar data in submerged environments, and reinforces the importance of methodical calibration in the development of reliable coastal and bathymetric models.

1. Introduction

The Lidar is a laser scanner that functions by emitting light in the green or near-infrared spectrum. It represents a sophisticated form of active remote sensing, whereby the impulse of a laser beam is transmitted from a sender, and the receiver detects the time of the return travel impulse upon its arrival at the target.

Bathymetric lidar is a technology that determines water depth by measuring the travel time of two impulse laser waves of different lengths. One of these waves crosses the water surface, while the other is sent into water and is reflected from the seabed depending on the water depth and turbidity (Piel and Populus, 2012).

Elevated sea levels have a detrimental effect on research, given the turbidity growth that occurs in the environment and on the delicate seabed. Such states of the sea also render measurement with an echosounder unfeasible. Lidar research is conducted in sea states 1 and 2, where wave heights are less than 0.6 meters. The conditions that prevail in conditions opposite high sea levels are analogous to "mirrored" (stationary) conditions (Quadros, 2013). The strength of the return signal is determined by the hardness of the seabed for acoustic measurements and by the brightness for lidar measurements. This affect is analogous to the fact that the hard bottom of the rock is as essential for echolocation as the white base is for lidar (Here, 1994). The error be attributable to the alteration of bottom-sea sculptures over time. This is particularly evident in the comparison of lidar and echosounder in shallow water. It may be a laser beam comparison in deep water, as in one area where the seabed exhibits minimal changes. As asserted by Here, alterations in the configuration of the bottom sea invariably result in an augmentation of noise level, irrespective of the specific circumstances (Here, 1994).

Parrish asserts that conventional correction refraction should be predicated on Snell's law. This approach necessitates the procurement of pertinent information, including:

- The localization facts reflected from the bottom sea are manually and automatically analyzed to obtain bottom sea points.
- The reflected points create a water surface model localization information of water.
- The estimated correction coefficient of refraction of light during a pulse travel from air to water.
- The height of the vector showing the photon unit determines the angle of incidence for each laser beam. (Parrish at al., 2019).

The Riegl company provides software for processing bathymetric data, which is designated RiHydro. However, it should be noted that refraction correction at underwater points requires a geometric water surface model (Riegl Development Team, 2018).

A comparison was made between airborne bathymetric lidar data and data collected by an echosounder. The Federal Maritime and Hydrographic Agency (BSH) has been collecting this data for the past 20 years, with measurements being taken over the last few years on ships valid, allowing older echosounder measurements to be used as a reference for approximate accuracy. For subsequent analyses, a digital terrain model (DTM) was generated for grid size of 1 meter using the "nearest neighbor" interpolation method, thereby facilitating the exploration of the historical echosounder data. The comparison of the DTM with lidar point cloud reference points reveals that these techniques yield analogous results, with the majority of laser points exhibiting a discrepancy of 0.5 meters. However, more substantial differences, reaching up to 1 meter, were observed in deeper areas, potentially attributable to alterations in bottom morphology between the two surveys (Niemeyer, 2014).

Accurate depth measurements in coastal and underwater environments are critical for a variety of applications, including but not limited to marine mapping, coastal engineering, and environmental monitoring. However, the collection of lidar data over water bodies is subject to the effects of light refraction, resulting in errors in depth measurement. Although lidar provides high-resolution spatial coverage, it is not as accurate as echosounder measurements in terms of vertical accuracy. This research was necessary to address this discrepancy by utilizing reliable echosounder data to calibrate and correct lidar point clouds, thereby establishing a consistent correction coefficient. This ensures more accurate, reliable depth data, especially in shallow coastal zones where high accuracy is important.

The primary objective of the research endeavor was to ascertain the efficacy of the rule echosounder profile in the calibration of lidar point cloud. This endeavor enabled the allocation of a coefficient that could be utilized for the purpose of rectifying light refraction in water.

2. Materials and Methods

Lidar point clouds were acquired in the 3D coordinate system UTM\WGS84 ellipsoid. The point cloud was unclassified and contained noises, and there was also a trajectory but no information on accuracy. Based on these findings, it was determined that the point cloud was pre-processed. The lidar point cloud was then classified using a cross-section with a 2 m spread in Terrascan. The manual classification tool assigned the layers at the sea's bottom and the terrain to the one class, while points below or above the cross-section were unclassified. The data were collected at an altitude of 400 meters and received as a point cloud with a density of approximately 40 points per square meter. Artificial tie points marked on the beach describe an average error XY of 0.40 meters, Z of 0.25 meters.

The calibration of lidar point clouds, including sea bottom areas, is slightly different than for land. This is due to the fact that almost of the calibrated area is covered by water. In the case of a lidar point cloud area, artificial tie points marked on the beach or an echosounder profile more significant than 1m can be used.

The research area was located in the Lubiatowo region, where a 1,5 km long coastal zone section was recorded, with a depth of 10m (figure 1).

The research was based on the lidar point clouds from 2018, which were executed by the Austrian company Airborne Hydro Mapping Gmbh for the Polish company Apeks. The Riegl scanner Vq 880 g was utilized to measure the seashore and bottom of the sea near Lubiatowo. Concurrently, the Institute of Hydro-Engineering of the Polish Academy of Sciences in Gdańsk initiated a rapid assessment of the seabed. This endeavor entailed the utilization of an echosounder and GPS technology, enabling precise geolocation and topographical analysis.

Furthermore, the system demonstrated its capacity for aerial imaging, as illustrated in Figure 2. This imagery revealed the absence of suitable objects for use in the calibration process at the sea depths.

The echosounder profile measurement was conducted using a single-beam echosounder manufactured by the Odom Company. This product is designated as “Echotrac CV100”, and it was calibrated to measure depth with a precision of 10 centimeters.

The Leica product was utilized for GPS/RTK measurement on the beach and in the water. The system for bathymetric measurement was created using the GS10 model with a CS15 controller and As10 antenna. The measurement was completed with a precision of 10 centimeters.

In this study, a Riegl VQ-880 g scanner was obtained, which is capable of measuring the topographical bottom sea with a narrow green laser beam. The beam is emitted by a powerful laser source and subsequently launched into the water, where it strikes the target. The measurement distance is based on the travel time of a very short laser impulse.

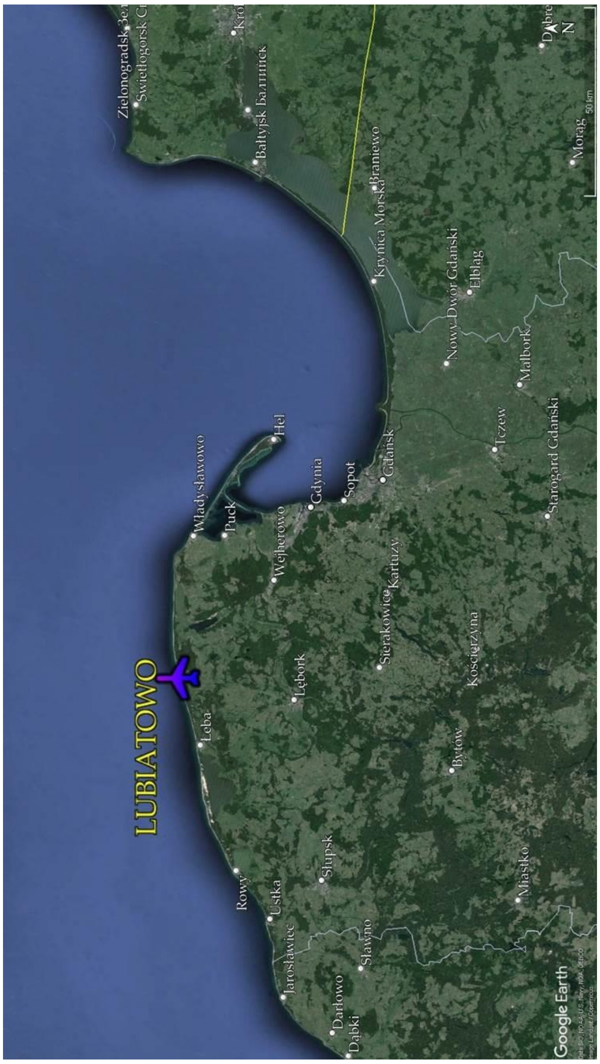

Figure 1. Registration of a section of the Baltic Sea with a beach near the Lubiatowo (Poland) region.
Source: Google Earth.

The laser beam contacts the water's surface at constant scan angle of 20 degrees. The scanner is equipped with an inertial measurement unit (IMU) to facilitate subsequent analyses and enhance instrument localization model (Riegl Development Team, 2018).

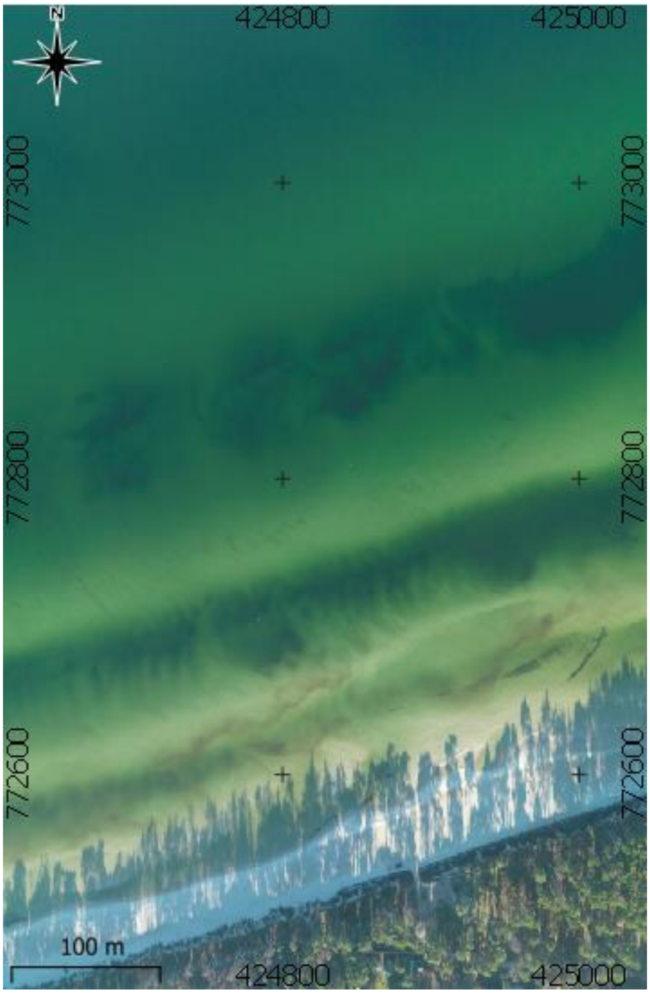

Figure 2. View of the bottom of the sea near Lubiatowo. Source: Aerial imagery from Apeks Company.

3. Results and discussion

As illustrated in Figure 3, eight lidar point strips were performed parallel to the coastal zone, with one line perpendicular to them and integrated.

The echosounder profile is performed perpendicular to the lidar point cloud, commencing at a depth of 1m. Figure 3 illustrates its localization. The measurement was conducted immediately following the completion of lidar point cloud registration. An investigation was conducted into the relationship between lidar point cloud depth and echosounder profile at the location indicated in Figure 3, with the objective of ascertaining their disparities.

The utilization of Microstation Power Draft in conjunction with Terrascan, Geokonwerter, and Microsoft Office Excel software facilitates the generation of the echosounder profile rule within the context of lidar point cloud calibration.

The echosounder profile was configured with points separated by 10-centimeter intervals. The echosounder point XY precise localization did not yield any lidar returns, yet it successfully established a surface area for lidar returns. This guarantees the ability to compare the attributes of the lidar and the echosounder. The development of a model TIN (Triangulated Irregular Network) in software was based on return points. The selection of parameters was informed by three options embedded within Terrascan: maximum slope, maximum triangle, and z tolerance. The maximum slope setting delineates an upper limit for the terrain slope, thereby ensuring that the measured slope, does not exceed the actual slope of the location, thus averting any inadvertent skewing of the measurement (Geocue Development Team, 2017).

The Z tolerance, on the other hand, accounts for the laser points, akin to the intuitive approach one would take when visually fitting a line of best fit to data (Geocue Development Team, 2017).

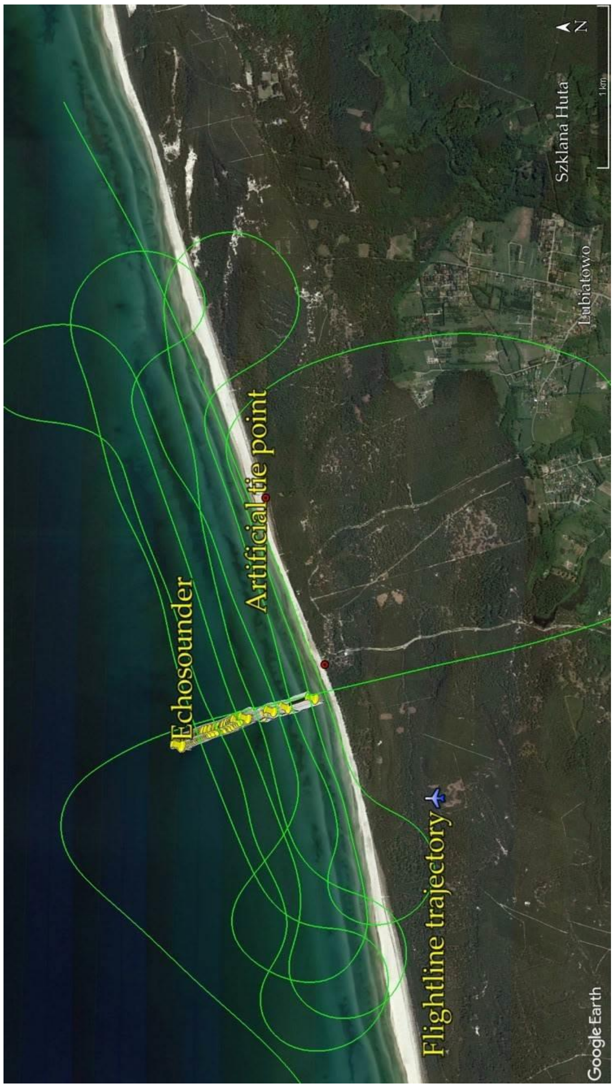

Figure 3. The localization of a partial lidar point cloud for analyses. Source: Apeks on Google Earth

Subsequent to the creation of the surface, a plumb probe will be fabricated from the control point to the surface. The location at which the probe intersects the surface will be designated as the

XYZ location at the conclusion of the comparison (Geocue Development Team, 2017).

As illustrated in Figure 4, the calculation of distance from a given point to the plane surface is achieved through a systematic series of steps. Within the specified radius R(2m), the echosounder and lidar points are identified, and the closest point is determined. Once installed, the plane triangle is managed through the implementation of least squares estimation. The distance from the echosounder point to the plane-fitted surface is denoted as Dz (Geocue Development Team, 2017).

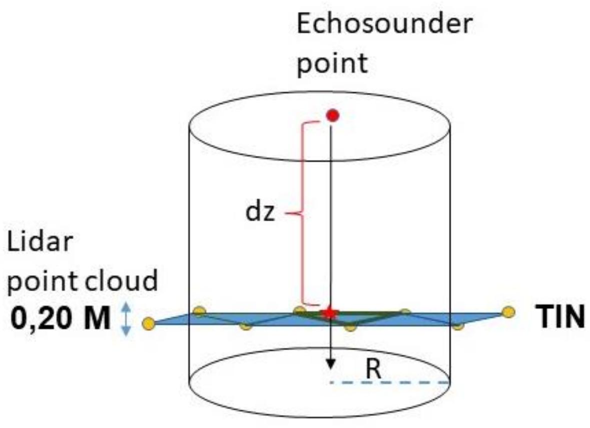

Figure 4. Scheme for determining the lidar height adequate for echosounding.
Source: Own elaboration based on the user guide for Terrascan (Terrasolid and Geocue Development Team, 2017).

The Excel spreadsheet was populated with echosounder and interpolated lidar points. The subsequent steps(see Figure 5) employed the method of calculating depth and height from the lidar point cloud.

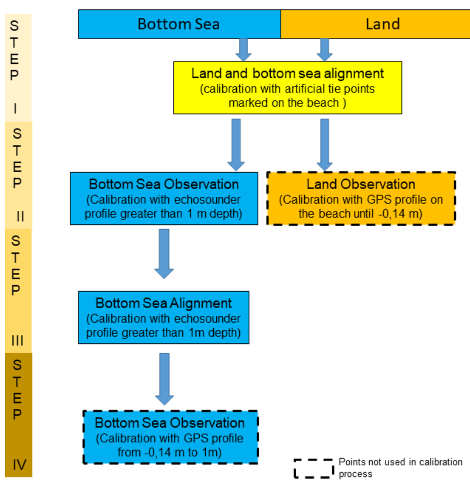

Figure 5. The modification steps of the lidar point cloud.
Source: Own Elaboration

This method was also employed in the calculation of GPS and echosounder points.

The initial step entailed the utilization of first step land and seabed to calibrate lidar point clouds. The initial step entailed verifying the relationship between the echosounder and the preceding lidar points, where the vertical depth of the sea exhibits an average variation of 1.14 meters. The ensure the constant change (0.20) and proportional change (0.76) between the data, a linear function y=0.76x-0.20 was created. The deviation of artificial tie points marked on land and measured by GPS from the pre-processed lidar point cloud was found to be approximately -0,25m. Utilizing the artificial tie points marked on land (see figure 3), the lidar point cloud was vertically shifted using TerraScan's 3D transformation (shift, rotation). This change was observed both on the ground and at sea.

In the second step of the process, the observations made on the beach demonstrated the efficacy of artificial tie points. Following the calibration process, the area of the lidar point cloud was analysed in conjunction with the measured GPS points on the beach (see Figure 6). The analysis revealed an average vertical deviation of -0.04 meters, with a standard deviation of 0.01 meters. In the second step of the process, the observational component of the bottom-sea survey demonstrated the efficacy of artificial tie points. The selected bottom-sea area was subjected to a subsequent analysis employing echosounder profile depths ranging from 1 to 10 meters and interpolated lidar points. Utilizing an Excel spreadsheet, a scatter diagram was constructed to illustrate the relationship between the data points. The resulting equation's trend line was determined to be y=0.76x. This equation revealed residual variations between the lidar and echosounder depths.

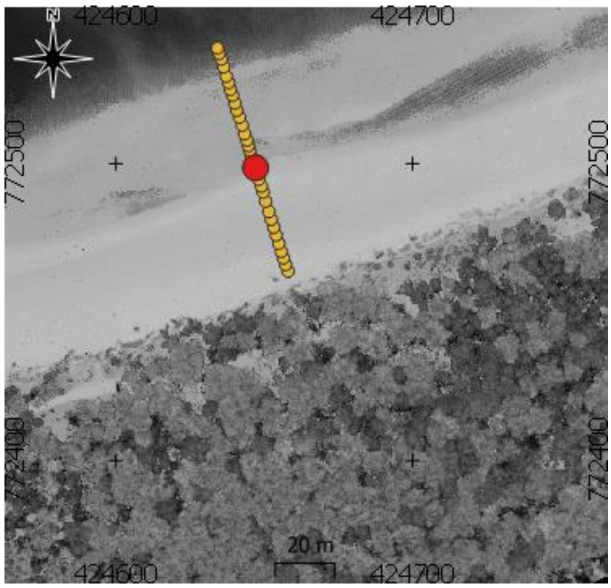

Figure 6. The grayscale of the lidar point cloud with GSP points
Source: Own elaboration

In the third step, the efficacy of the correction coefficient in enhancing depth is examined. To this end, the depths of the original lidar points for the bottom sea were calculated (ranging from -0.14m to 10m) in an Excel spreadsheet. The coefficient 0.76 was employed, and the data differences were refined.

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In the fourth step of the experiment, the observation of a portion of the sea floor revealed a usefulness coefficient of 0.76, ranging from 0.14 meters (sea level) to 1 meter in depth. The lidar point cloud area was examined using a GPS profile and a range of 0.14 to 1 meter. Consequently, only the vertical deviation, equivalent to the standard deviation (0.02 meters), was detected.

The calibration process thus produced a reliable correction function, y=0.76x-0.20, which was used to align lidar point cloud data with echosounder depth measurements. Initial comparisons revealed an average vertical difference of 1.14 meters between raw lidar data and echosounder data. The application of GPS- measured artificial tie points, in conjunction with TerraScan’s 3D transformation, resulted in vertical shift of -0,25 meters, thereby significantly enhancing the alignment process.

Subsequent post-calibration analysis of the beach areas indicated an average vertical deviation of -0.04 meters, with a standard deviation of 0.01 meters, thereby substantiating the accuracy of the adjusted point cloud. In seabed areas, further validation of the 0.76 coefficient across depth ranges (0.14 to 10 meters) maintained accuracy, with minimal vertical deviation of 0.02 meters observed in shallow water.

The outcomes of this study demonstrate the efficacy of the correction coefficient in minimizing vertical error and enhancing the overall accuracy of lidar bathymetric data.

As illustrated in Figure 7, the echosounder profile plays a pivotal role in the calibration of the lidar point cloud. The graph demonstrates a shifted lidar point cloud, derived from the localization of the echosounder profile. The coefficient of 0.76 was derived from the relationship between the two data sets, and its application resulted in a change in the lidar point cloud’s depth. The differences between the data can be primarily explained by the functions y=0.76x to y=1. In the case of calm Baltic Sea water, the coefficient 0.76 can be used for refraction correction.

In this context, the key role of complementary measurements should be emphasized. These measurements provide the basic reference points necessary for the accuracy, correction and alignment of sensor data, which is particularly important in the context of environmental factors such as water collapse.

However, it is important to note that the accuracy of the coefficient is subject to changes under various water conditions, including turbidity and wave dynamics. It is recommended to conduct further studies in different environments to assess the possibility of generalizing the approach and refining the correction model accordingly.

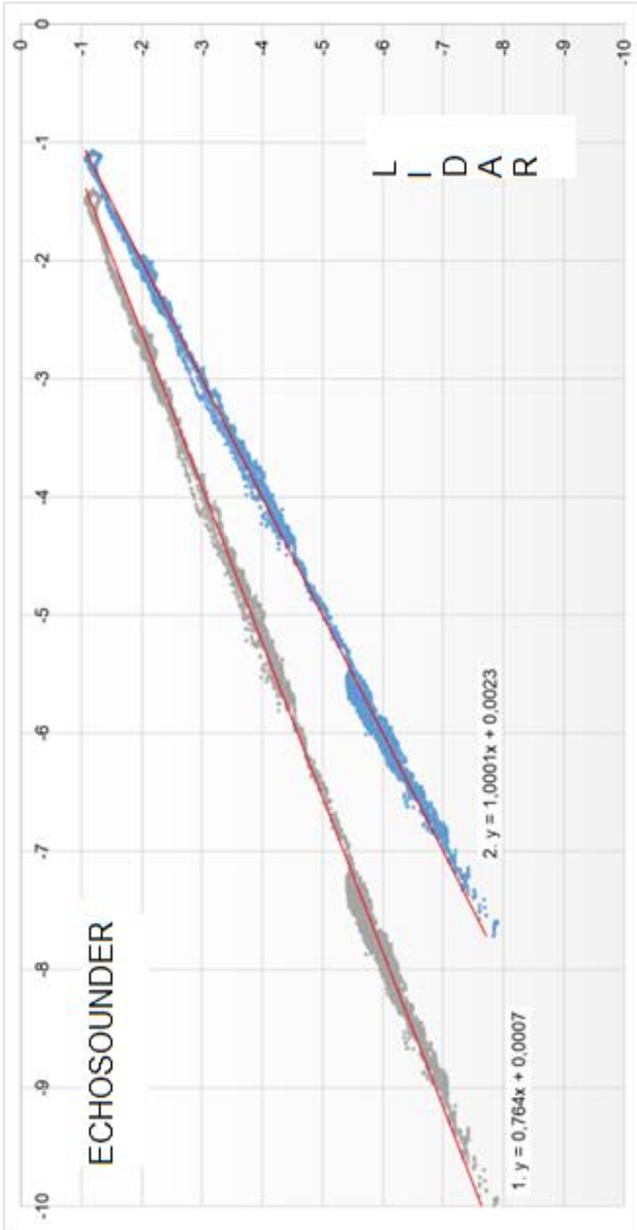

Figure 7. The modification of the lidar point cloud based on the echosounder profile. Source: Own elaboration.

4. Conclusions

The calibration of the lidar point cloud using echosounder data and GPS – measured artificial tie points was found to be a highly effective process. The established correction function, y=0.76x-0.20, has been shown to consistently align lidar and echosounder depths across a range of environments, from terrestrial to shallow and deeper seabed areas. The minimal vertical deviations observed – particularly the 0.02 – meter standard deviations in the final test – demonstrate the reliability of the 0.76 coefficient for accuracy correction in calm Baltic Sea conditions. These results emphasis the necessity of incorporating supplementary ground – truth measurements to guarantee better accuracy, high – quality lidar data calibration in coastal and marine studies.

The echosounder profile enhances the accuracy of the lidar point cloud coefficient (0.76), facilitating the implementation of refraction correction in the stable Baltic Sea.

It is imperative to execute the echosounder profile concurrently with the registration lidar point cloud to ensure the efficacy of the calibration process. This approach enables the calculation of corrections and deviations.

The methodology involves the assessment of the trend in changes in depth between lidar and echosounder profile measurements.

Additionally, GPS points can be utilized for the validation of the lidar point cloud post-modification, with these points situated on land or in water up to a depth of 1m.

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