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MOBILE LASER SCANNING CALIBRATION ON A MARINE PLATFORM

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ABSTRACT

The article describes the method of calibration of the Riegl VMZ-400 mobile scanning system on a floating platform and an experiment aimed at conducting measurements from a previously calibrated instrument. The issue of factors affecting the quality of measurements was discussed.
Mobile laser scanning is an increasingly popular measurement solution, but it is still innovative on a European scale. The use of a floating platform is unique on a national scale. The presented solution is the result of the work of the Gdańsk University of Technology team on the development of the measurement procedure for scanning land from the sea and the river.

Keywords: mobile laser scanning, marine laser scanning, scanning of a boat, calibration of laser scanning, sea measurements, MarLS

INTRODUCTION

Mobile laser scanning is a modern, more and more widely used measuring solution. Scanning from a floating platform, including scanning from the sea, is still an innovative solution on a European scale. The principle of the system operation can be reduced to impulse measurement of the time of the laser beam passing to the object and back. The latest measurement solutions are able to collect up to one million points per second with three-dimensional coordinates while taking digital photos of the area. A fact on a national scale is the use the system on a watercraft and carrying out a measurement mission from such a calibrated instrument [1-2]. Such solutions have already appeared in Europe [3], but due to the location of the measurement mission on the southern coast of the Baltic Sea and obtaining results with accuracy better than 10 cm is an innovation on a European scale.

The authors took part in earlier studies aimed at scanning from the sea (2014). In relation to previous measurement results, the presented study introduced new solutions. Qualitative verification has been performed and limitations of the measurement method were indicated. The authors took into account the vessel selection factor and meteorological factors affecting the measurement to clearly state under which conditions the marine mobile scanning gives the possibility of achieving accuracy of 10 cm, based on the current worldwide knowledge of increasing the accuracy of these data [4].

The continuous development of measurement solutions gives the opportunity for faster, more accurate data acquisition, thus achieving the possibility of using this type of solution, for example for:

- cliff edge monitoring [5] (including cliff stability analysis [6-7]) to obtain measurement results comparable with stationary laser scanning [8-10],
- assessment of the condition of port and quay infrastructure on the basis of analysis of data collected in close proximity to waterways and ports [11],

- creating an inventory of bridges, plate wharves, on piles or with a supporting grid from the water side,
- obtaining data for inventory and promotional purposes of objects that are within the range of the scanner's work during the measurement experiment.

In the measurement experiment described in the article, the Riegl VMZ-400 mobile scanner was used during the implementation of the voucher for innovations "Implementation of the 3D laser scanning measurement procedure from a floating platform" whose main purpose was to obtain a mobile scanning procedure, where the platform is located on the vessel. The project was carried out in cooperation of the Gdańsk University of Technology with the company ZUI Apeks Sp. z o.o. Figures 1 and 2 show a fully operational system during a measurement mission using laser scanning from the sea.

Fig. 1 A mobile platform on a vessel during a measurement mission.

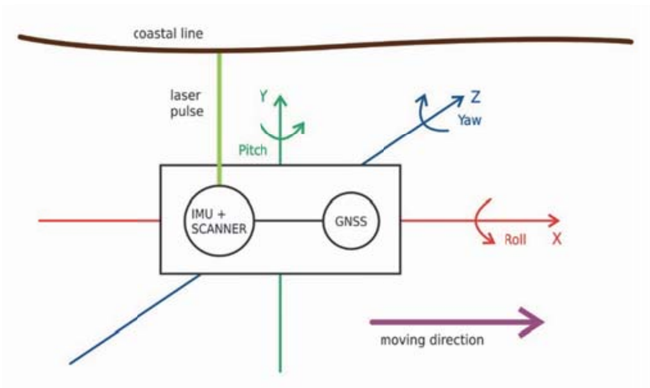

Fig. 2 Diagram of the system during laser scanning from the sea

PLANNING OF THE MEASUREMENT MISSION

When planning a measurement mission - apart from the type of scanning system, the quality of the IMU (Inertial Measurement Unit) and the GNSS receiver (Global Navigation Satellite System) - the following are of particular importance for the measurement results:

1. selection of a vessel,
2. meteorological conditions,
3. geometrical conditions of GNSS signal availability.

In the case of selecting a vessel, special attention should be paid to:

- relatively low immersion depth (up to approx. 1.5 m),
- optimization of the relationship between maneuverability and directional stability,
- the possibility of taking a 2 person measuring team on board (except for the crew of the vessel),
- the possibility of mounting a mobile platform on board.

In the case of immersion depth, the main determining factor is the depth of water at which the platform will move. The range of the scanner is about 400 meters, so it is the maximum distance from this type of scanner to the scanned object. Due to the variability of bottom depth in the coastal zone of the sea, it is difficult to scan the edge with a unit with a large immersion. Therefore, for projects related to scanning from the sea, it is recommended to select a unit with a low immersion depth. At the same time, one should pay attention to its stability, which is associated with the safety of use. Optimization of the relationship between maneuverability and directional stability is important due to the dynamic initialization of the system on the vessel and maintaining the appropriate accuracy of the determined angles of rotation by the IMU. Typically, units do not achieve the speed of movement, such as cars used in standard terrestrial mobile scanning, they cannot accelerate and slow down as rapidly, and therefore optimization is extremely important to achieve the intended purpose, i.e. to properly initiate the system and maintain the appropriate angular values determined by IMU.

The quality of data is influenced by factors related to GNSS positioning and meteorological conditions [13-15]. For meteorological factors, it should be noted that they determine safety, which is related to the stability of the platform, and which can only move under certain weather conditions [9]. It is recommended to scan from the sea in the period from April to November, because during this period there are smaller storm surges, the day is relatively longer, and the sun appears over 20 degrees above the horizon for most of the day (this property favors taking photos, which supplement information on the coordinates of points registered by the scanner). Additionally, when planning the measurement, make sure that there is no slurry or objects preventing the vessel from moving (e.g. an iceberg) and that the wind does not exceed 2-3 degrees on the Beaufort scale, when the unit flows against the wave and 6 degrees, when the unit scans flowing with a wave. At this stage, it should be mentioned that waving occurs not only under the influence of wind, therefore the final decision regarding the measurement must be made by the equipment operator. In addition, the measurement should be carried out in favorable weather such as no precipitation. Cloud cover is important when the purpose of measurements is additionally taking photos from the platform. The temperature range in which this particular measuring set can work is from -10 ° C to + 50 ° C.

In the case of GNSS satellites availability, before the measurements are made, attention should be paid to the signal quality forecast. Due to the fact that the quality of the trajectory is decisive in the final product, it must have sufficient conditions to obtain the appropriate accuracy. An unquestionable advantage of using a measuring solution with a scanning platform on a vessel over a traditional mobile solution is the possibility of full monitoring of coast changes in hard-to-reach places and building spatial models for the reconstruction of the Baltic coast, in particular seaports.

CALIBRATION OF THE MEASUREMENT SYSTEM

The mobile system Riegl VMZ-400 mounted on the watercraft is formed of components corresponding to the numbers in Figure 3 which are:

Fig. 3 Components of the Riegl VMZ-400 system on a vessel 1. Riegl VZ-400 laser scanner. 2. IMU. Connection cables between the scanner, 4. IMU, power source and laptop.5. GNSS antenna.6. Aluminum frame on which individual components are mounted.7. Aluminum clamps securing the platform to the elements of the vessel.8. Straps that fasten the platform to better stabilize the entire platform

Platform calibration refers to calculating the distance from the IMU center to the center of individual components, determining the rotation of the platform relative to the direction of travel and connecting the system to the laptop using the TCP/IP protocol. The view of the operating laptop system is shown in Figure 4.

Fig. 4 View of the laptop that operates the system.

INITIALIZATION OF THE SYSTEM AND TAKING MEASUREMENTS

In order to ensure proper quality, precision and accuracy of data, a measuring network should be designed in order to establish the final product to the global coordinate system. The most suitable solution is to measure planes in order to establish XY and Z scans. The software used to establish the point cloud has been made available by ZUI Apeks Sp. z o.o. In the software, the planes are created in the following scheme, shown below, in which the format specifying the coordinate system and the points P1 - P7, which show the individual coordinates, are marked accordingly.

The plane creation scheme:

TYPE=PlaneObj<CR><LF>
NAME=Plane001<CR><LF>
FORMAT=ECEF_CARTESIAN<CR><LF>
COUNT=7<CR><LF>
P1=0.000 0.000 0.000<CR><LF>
P2=1.000 0.000 0.000<CR><LF>
P3=1.000 0.500 0.000<CR><LF>
P4=2.000 0.000 0.000<CR><LF>
P5=3.000 0.000 0.000<CR><LF>
P6=3.000 1.000 0.000<CR><LF>
P7=0.000 1.000 0.000<CR><LF>

The device initialization itself consists of static and dynamic initialization. Static initialization consists of a 5-minute collection of data on the position of the device based on GNSS measurements. Dynamic initialization is used to stabilize the angles roll, pitch and yaw, recorded by the IMU. The second stage on the vessel is very difficult to implement due to the limited possibility of accelerating and slowing down the device, which is why the maneuverability parameter plays a key role here. Sudden turning of the platform in motion can provide sufficient accuracy of the measured rotation angles of the platform to obtain a suitably accurate spatial model.

The corresponding values measured by the IMU unit are shown in Figure 5.

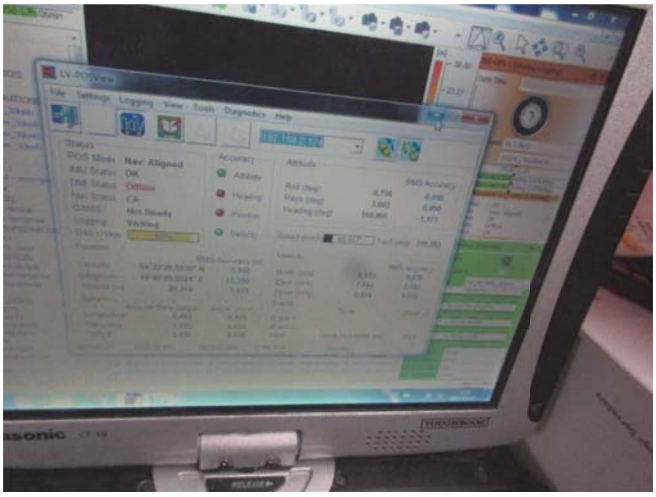

Fig. 5 Display of values measured by the IMU in real time.

IMPLEMENTATION OF THE MISSION AND THE ACQUIRED DATA ALIGNMENT ACCURACY

The measurement mission was carried out in the Władysławowo Sea Port and the sea shore in the section from this port to the vicinity of the North Star located in Jastrzębia Góra. The place of measurement is shown in Figure 6 inside the red polygon.

Fig. 6 Location of measurements on the seacoast inside the red polygon [source: Google Earth TM]

The trajectory alignment results are shown in Figures 7-9 showing the mean square error on each axis.

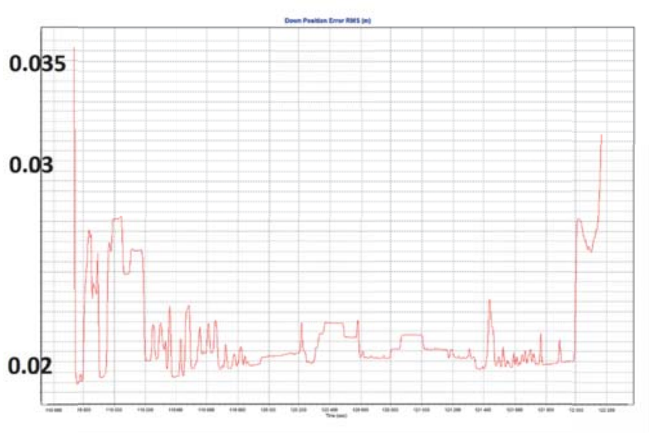

Fig. 7 Trajectory to height alignment mean square error.

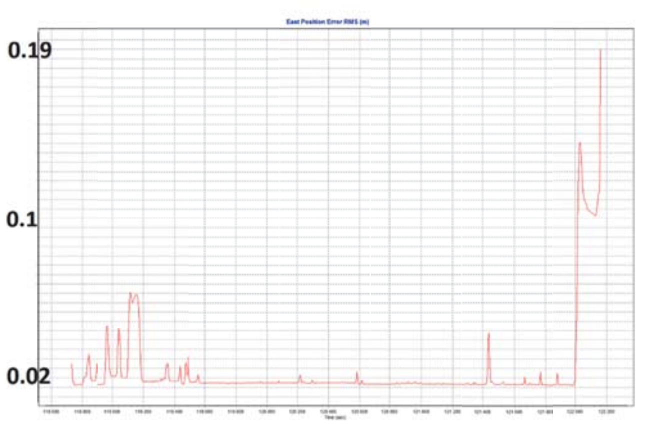

Fig. 8 Trajectory alignment of the Y-axis mean square error

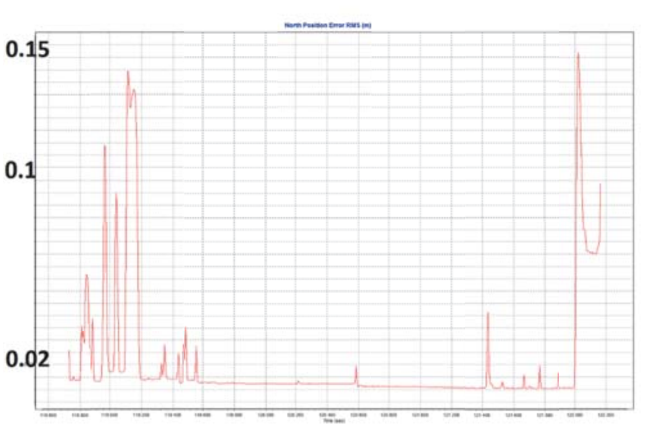

Fig. 9 Trajectory alignment of the Y-axis mean square error

The analysis of diagrams (Fig. 7-9) allows to indicate the moment of commencement of the measurement mission (the place where the error on the X and Y axes did not exceed 2 cm). At the same time, it can be stated that the accuracy of the data obtained has the greatest error at height, while the average error on each axis does not exceed 5 cm, so there is a real chance to obtain data with accuracy not worse than 10 cm. The result of establishing data on control points is shown in Figures 10 and 11 in the form of a report for all records and a histogram of residues from the planes used.

Calculation results

Number of free parameters: 24

Number of observations: 782

Error (Std. deviation) [m]: 0.0620

Fig. 10 Standard deviation of the alignment of individual records.

Formula for standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X-\bar{X})^2}{N}}$$

In order to transform the database, the 7- parameter transformation of Helmert is used.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{Target} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} Source + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \begin{bmatrix} D & -R_z & R_y \\ R_z & D & -R_x \\ -R_y & R_x & D \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

XYZ source- XYZ coordinates of the source data
XYZ target – XYZ coordinates of the target data
Tx, Ty, Tz – translation factors
Rx, Ry, Rz- rotation factors
D – scale factor.

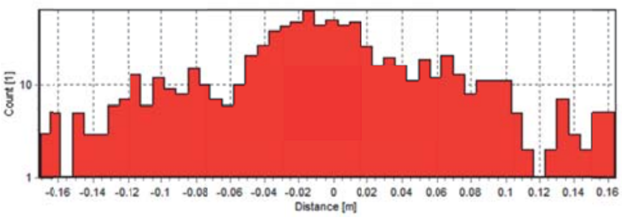

Fig. 11 Histogram of Residues of used planes

The last step in checking the accuracy of the data was to determine the coordinate differences between the control points measured with traditional methods, not used in the alignment and the point corresponding to this point on the scan (3D model). The results are presented in Table 1. The obtained result in the form of a point cloud is shown in Figure 12.

Table 1 Difference of distance in 3D space from points measured by classical methods to scanned details.

Object number	Difference in the distance between the detail and the scan
149	0.071 m
141	0.092 m
135	0.106 m
119	0.082 m
146	0.063 m

In reference to Table 1, an average result of 8.28 cm was obtained, and the numerical analysis showed an accuracy better than 10 cm.

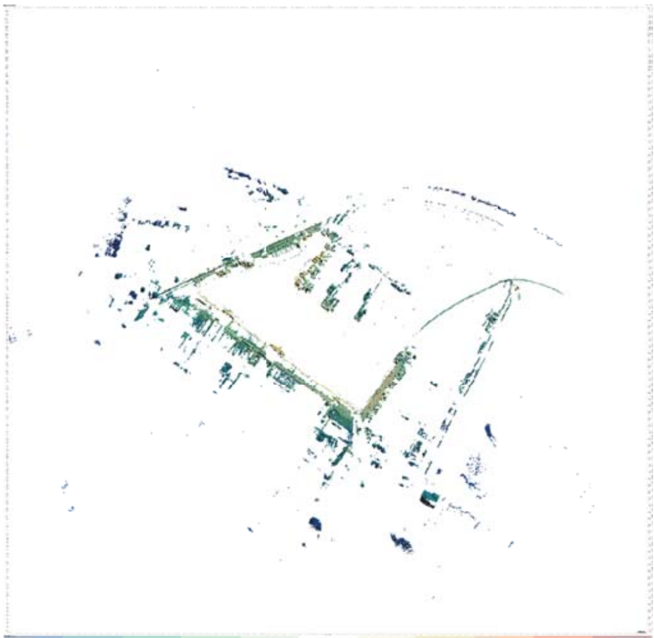

Fig. 12 Cloud of points showing the Port of Władysławowo, originating from scanning from the sea.

CONCLUSIONS

As a new measurement solution, mobile scanning using a watercraft may have a wide range of applications such as: sea coast monitoring, assessment of durability of seaports or obtaining data for inventory of buildings in close proximity to the scanner's range or above the water level. On the market, stationary laser scanners are used more and more often. However, through continuous development of data acquisition methods, methods employing their use are slowly becoming time-consuming and ineffective compared to mobile scanning of longer sections exceeding several hundred meters. This opens up new possibilities, constituting competition with traditional solutions and as a supplement for other types of laser scanning, increasing the possibilities of data analysis on real estate markets and creating hazard maps for infrastructure objects and people in the near degradation impact zone [16-18]. In addition, solutions used by the authors may be used in other areas not related to the marine environment, e.g. to monitor and assess the condition of the structure [19-28], also in combination with imaging methods and photogrammetry using UAV [29-31]. The use of proprietary algorithms in the field of laser scanning [32-34] allows to increase the accuracy and analysis of the geometry of objects based on MarLS (marine laser scanning) and MLS (mobile laser scanning) made from inland and port waterways.

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