A MULTI-PURPOSE USV PROTOTYPE FOR PHOTOGRAMMETRY APPLICATIONS – CASE STUDY OF A 3D MODEL OF THE GRUNWALDZKI BRIDGE (WROCŁAW, POLAND)

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ABSTRACT: The BATDRON Unmanned Surface Vessel is an original structure developed at Wrocław University of Science and Technology, intended to conduct measurements using a diverse range of sensors. Initially, it was used to measure the geometry of reservoirs and waterways, however, owing to the constant development of the platform, it was possible to use a new sensor – a non-metric camera, and to carry out photogrammetric measurements. The first tests were carried out using a NIKON D800 camera and included measuring the Grunwaldzki Bridge in Wrocław.
The analysis of the trajectory of the BATDRON remotely controlled (RC) vessel demonstrated that it maintains the programmed course (the average value of the distance from the set mission route was -0.04 m), which is of great importance in the case of photogrammetric measurement sessions. Also, the internal quality control (IQC) of data obtained from the non-metric camera in relation to reference data obtained with a Riegl laser scanner showed satisfactory accuracy of photogrammetric data.

1. INTRODUCTION

At the beginning of the 21st century, drones became one of the most dynamically developed transport platforms used in the field of geodesy to carry out field measurements. They are used in many environments and on many levels, including: as walking or driving robots in mining, controlled surface and underwater vessels, or low- and high-altitude unmanned aerial vehicles (Farley et al., 2020). Each of the above-mentioned types of systems is designed for different purposes/tasks, mainly determined by the type and measurement method of the sensor within its equipment (Bonetto, 2015; Liu et al., 2016).
BATDRON is one of such solutions. It is an original unmanned surface vessel (USV) designed and manufactured at Wrocław University of Science and Technology. It has been developed by the employees of the Department of Geodesy and Geoinformatics and students of the Young Surveyors Group Research Club.
Initially, its purpose was to perform bathymetric measurements using a single-beam echosounder. However, the gradual development of the platform (starting in 2019) allowed the installation and testing of additional sensors. The vessel ensures high stability (catamaran structure), good mechanical properties (maneuverability and movement speed) and has a precise satellite positioning system based on a single GNSS antenna. As a result, it is a perfect platform for carrying out photogrammetric missions from the water level (Fig. 1).
This article presents the results of the first test measurements (photogrammetric measurements) performed with the use of the platform. The research object was one of the most famous and characteristic bridges in Wrocław – the Grunwaldzki Bridge.

Figure 1 BATDRON platform with NIKON D800 camera and Reach RS2+ GNSS antenna.

2. METHODOLOGY

The use of USV BATDRON for photogrammetric measurements of bridge structures was dictated primarily by safety reasons. From the operator's point of view, this type of measurement is more convenient and safer in the case of low-hanging structures (Fig. 2), as it allows the elimination of risks threatening a flying drone, e.g. loss of visual contact with the measurement platform or gusts of wind that could lead to its sinking.

2.1 BATDRON boat development and camera integration

The sensor used in the measurement session was a NIKON D800 36 MPix DSLR non-metric camera. The use of this type of cameras is common and widely known in the literature (Al-Hamad and El-Sheimy, 2014; Kowalczyk and Markiewicz 2016). For the purposes of the photogrammetric mission, the NIKON D800 camera was integrated with the Mission Planner autopilot based on the Mavlink communication protocol. The image acquisition was based on the programmed mission plan and the DGNSS WGS84 georeferencing using DROTAG x (2021).

Figure 2 An example image acquired during the photogrammetry mission with the NIKON D800 camera.

2.2 Mission planning and image acquisition

The lens of the NIKON D800 camera has a fixed focal length of 50 mm. The average image overlap for photogrammetric image acquisition was set to 80%.

The planned trajectory of the USV was a straight line approximately 100 m long in the direction parallel to the modeled object, while the average distance of the measurement platform from the object was 40 m (Fig. 3). In this approach, the key element in the 3D modeling of the bridge structure is the camera field of view. By maintaining an identical distance from the object and a straight trajectory, the same image scale can be ensured for the entire mission. Although the purpose of this study was not to 3D model the underside of the bridge, such a model could be generated with the use of the platform.

The mission plan of the BATDRON system was programmed using Mission Planner software (Ardupilot, 2023). Raw GNSS measurements and IMU parameters were recorded locally in the on-board computer of the vessel.

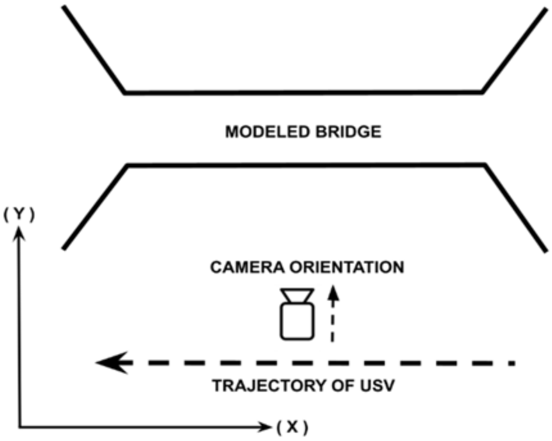

Figure 3 Schematic representation of the USV image acquisition mission.

During the USV photogrammetric mission, the set trajectory was not a precisely straight line (Fig. 4). The correct trajectory of the vessel can be maintained on condition of low water level and relatively weak current in the river. In such conditions, images can be acquired with correct orientation towards and distance from the object, in accordance with the mission plan.

A key element when planning a USV mission is the beginning and end of the survey line. Unlike in the case of photogrammetric flights with the use of Unmanned Aerial Systems (UAS), where the possibility of collisions with obstacles is eliminated by selecting an appropriate Above Ground Level (AGL) flight elevation, in the case of an RC vessel the bank of a body of water is a barrier that must be taken into account when planning a photogrammetry mission. In the case of water objects, the advantage of a RC USV photogrammetric image acquisition mission results from the safety of the sensor located on the floating platform.

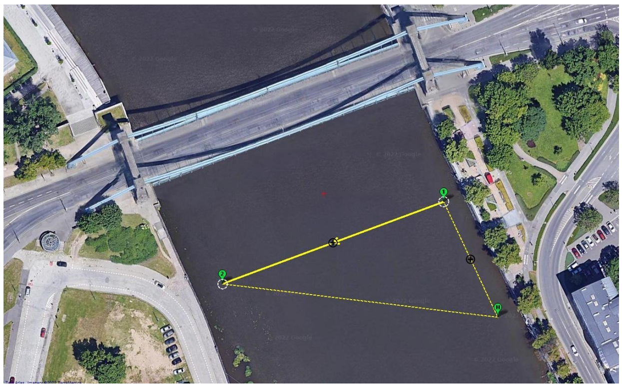

Figure 4 Mission planning in the Ardupilot platform as a straight bold yellow line parallel to the Region Of Interest (ROI)

2.3 SfM photogrammetric image postprocessing

The photogrammetric model was developed by marking ground control points (GCP) measured using an independent geodetic technique with a total station in a certain coordinate system. The reference markers were set on the characteristic objects on the bridge. Locations of example GCPs are shown in Figure 5. The first two GCPs were set on the left pylon, two points on the characteristic signs on the bridge structure and 2 GCPs were located on the right pylon of the bridge (Fig. 6).

The photogrammetric analysis was carried out in Metashape PRO 2.0.2 software (Agisoft LLC, 2023). As the EXIF properties of the photos taken from the USV did not include their external orientation elements, the alignment procedure was based on 5 GCPs located on the bridge (Table 1). Camera alignment was developed with simultaneous autocalibration of the Nikon D800 non-metric sensor (Verykokou and Charalabos, 2018)

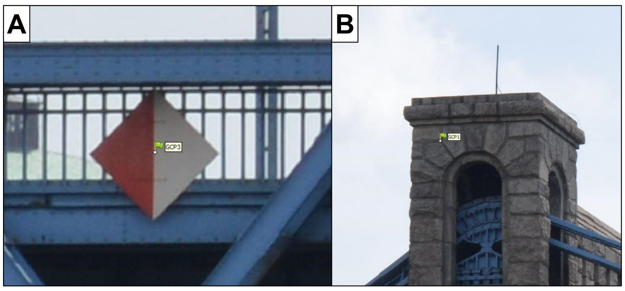

Figure 5 Locations of GCP markers (A) shipping sign on the bridge, (B) corner of the brick on the bridge pylon

Table 1 Photogrammetry point cloud processing RMSE errors

No. of GCP	Total RMSE(X)	Total RMSE(Y)	Total RMSE(Z)	Total RMSE (3D)
6	2.2 cm	1.8 cm	2.3	2.52 cm

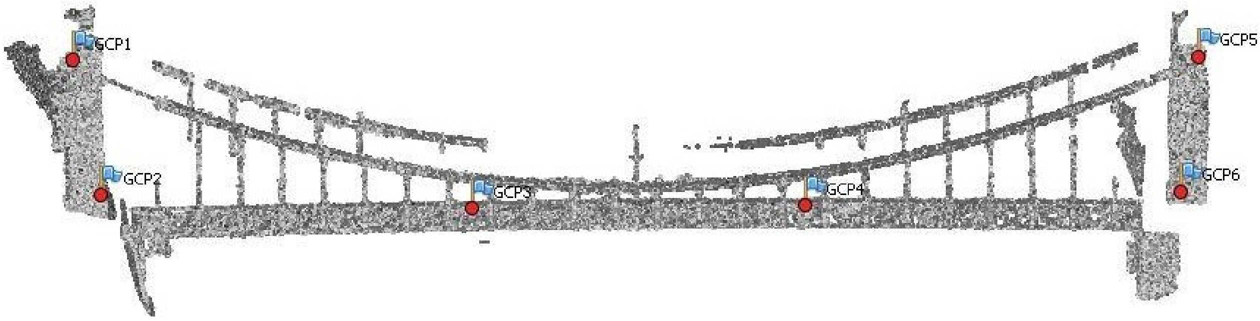

Figure 6 Localizations of 6 GCPs on the Grunwaldzki Bridge, marked as red dots

2.4 Terrestrial laser data acquisition

The reference data were collected using 3D terrestrial laser scanning (TLS) technology. This procedure was performed with the use of the RIEGL VZ400i system (two stations located on opposite banks of the river). The measurement data were processed with multi-station adjustment algorithms (Sterle at al., 2018) in the same reference system as used in the photogrammetric mission (Fig. 7).

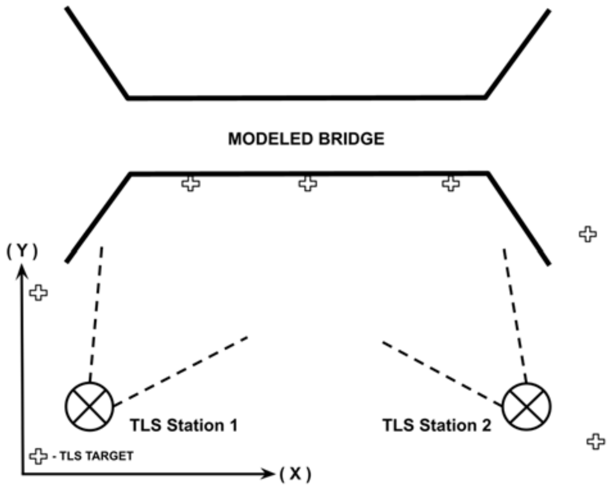

Figure 7 Schematic representation of the TLS data acquisition

The looking angle of the scanner located on the left and right banks provided reliable and complete information for building the 3D model of the bridge (Fig. 8). The scanner positions were related to reference targets measured using the static GNSS technique. The entire study was carried out using the Multi Station Adjustment approach, which takes into account reference targets on the matrix, targets on the object, GNSS observations of the scanner and the orientation of the internal measurement unit.

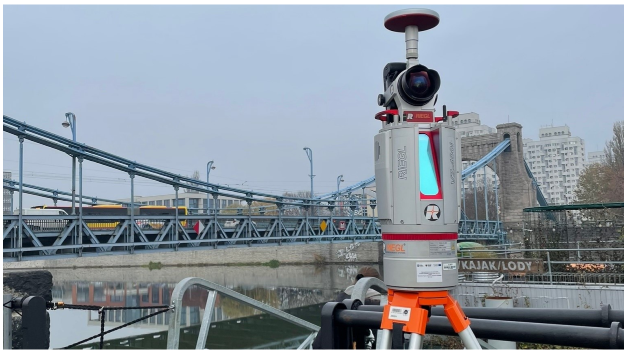

Figure 8 TLS data acquisition using RIEGL VZ400i

3. RESULTS AND DISCUSSION

The data sets acquired using the laser scanner and the RC vessel allowed the construction of a 3D numerical model of the object of interest, as well as trajectory analyzes (for the USV system) and internal quality control for the TLS-USV data.

3.1 USV trajectory analysis

The photogrammetric USV mission was planned as an approximately straight line, ca. 100 m in length, in accordance with the trajectory planned in the Ardupilot application. The pixhawk autopilot paired with the Ublox NEO-M8N (L1) antenna allowed the vessel position to be maintained in a straight line, which was measured every 2.5 m with an independent GNSS receiver Emlid REACH RS+ in the GNSS RTK precision measurement mode based on the ASG EUPOS system of reference stations (Emlid, 2023). The trajectory analysis was performed in the local system (Fig. 9). Changes of horizontal values as normal distances projected onto a straight line were shown as a function of distance after removing the straight-line trend. The values are shown in Fig. 10. The maximum distance from the set straight line was -0.3 m, and its average value was -0.04 m.

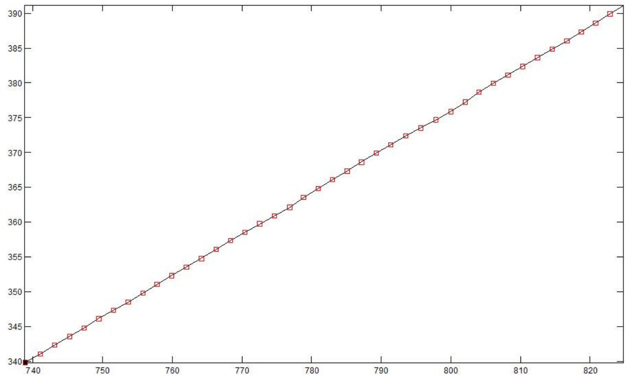

Figure 9 Analyzed trajectory in the local coordinate system. The RTK-fixed position at ca. 2.5 m

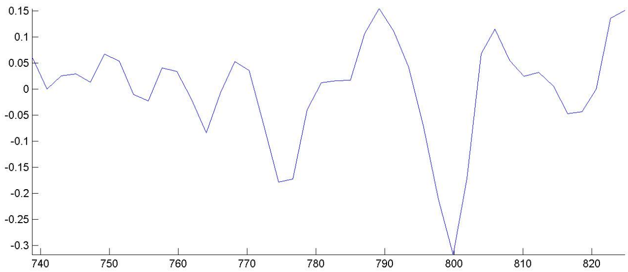

Figure 10 XY changes after Trend Removal in meters

The vessel azimuth for the analyzed sample of the GNSS RTK positioning data was calculated for locations at every 2.5 m. Fig. 11 shows changes in the azimuth value from the set straight trajectory for the vessel.

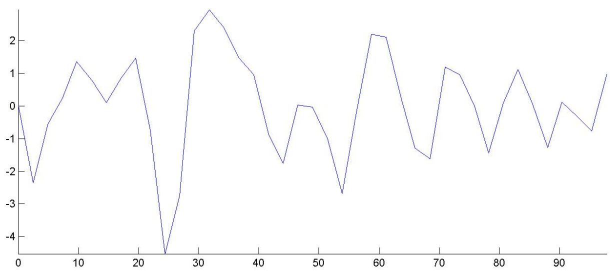

Figure 11 Azimuth of vessel changes in degrees.

Taking into account the accuracy of the GNSS RTK control positioning of the boat, which was recorded by EMLID Reach RS+ 0.01-0.02 cm horizontally and 0.03 cm vertically, the altitude changes as a function of the boat's distance from the starting point are shown in Fig. 12. The effect of altitude changes did not exceed 0.03 m, ensuring vessel stability on the water. The performing of the analyzes based on precise GNSS RTK positioning was possible owing to the open horizon above the vessel. If the horizon is obstructed or the vessel moves under the bridge, the positioning method should be changed to e.g. a total station equipped with a 360° mirror.

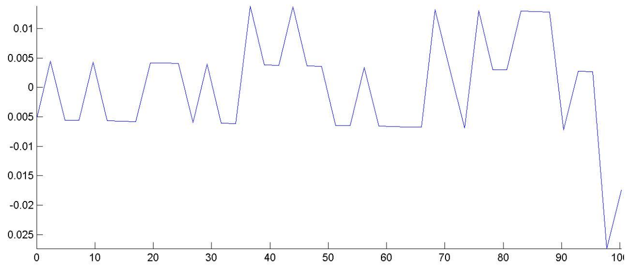

Figure 12 Z (height) changes caused by the rocking of the vessel

3.2 3D photogrammetric point cloud

The processing of the acquired photogrammetric data in the Agisoft Metashape environment resulted in a dense point cloud. The next stage of image post-processing involved manual data filtration and the isolation of points representing the southern side of the Grunwaldzki Bridge (~ 2 million points; Fig. 13).
As the photogrammetric model was constructed in the PL1992 system, the resulting point cloud had full georeferencing and could be used in further differential analyzes based on the reference TLS data.

Figure 13 Isometric view of the processed photogrammetric point cloud

3.3 TLS data processing

The post-processing of the TLS data involved registering the measurement stations into one coherent data set and filtering the constructed point cloud using the reflectance and deviation thresholding parameters. The resulting point cloud also consisted of over 2 million points. For further analyses, the spatial scope of the TLS point cloud was cropped to match the outline of the two pylons (Fig. 14).

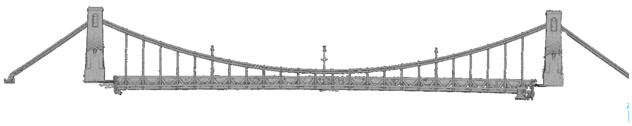

Figure 14 Isometric view of the processed reference TLS point cloud

3.4 IQC analysis

In the last step of the study, an attempt was made to assess the accuracy of the point cloud obtained from photogrammetric measurements. This step was performed using the Cloud-to-Cloud ICP distance method (Ahmad Fuad et al., 2018). Internal quality analysis showed that the point cloud constructed on the basis of data obtained from the floating platform equipped with a Nikon D800 camera with a 50 mm lens allows the reconstruction of the 3D model of the bridge with an average deviation not exceeding 4 cm (Figs. 15 and 16).

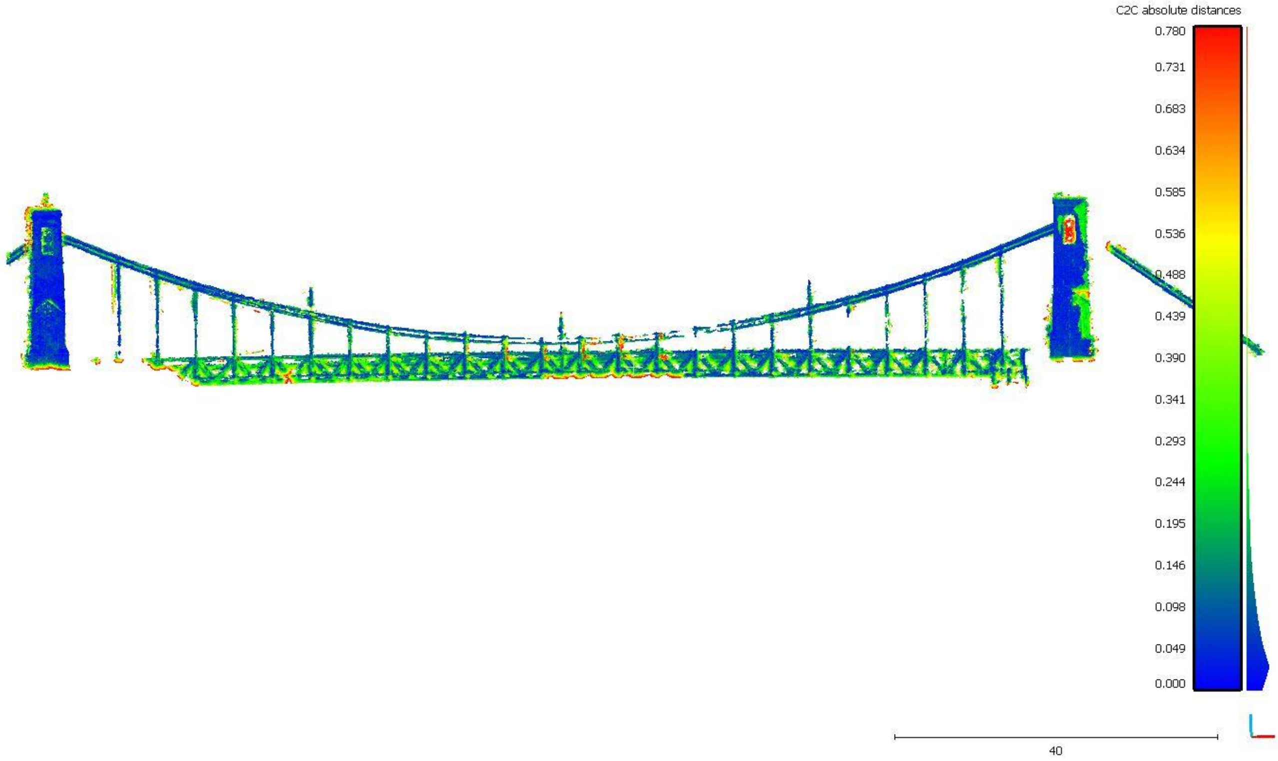

Fig. 15 Results of the Cloud-to-Cloud Iterative Closest Point (ICP) analysis between the 3D photogrammetric data and the reference TLS point cloud data

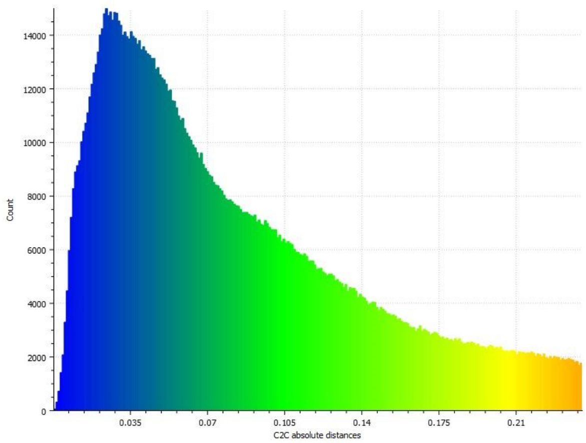

Fig. 16 Histogram of the absolute photogrammetric cloud to TLS cloud 3D distances

The largest values of cloud-to-cloud distances are located in the central part of the model and are up to 25 cm. The reason for such high difference values is most likely the complexed structure of the bridge structure in this part. Outliers on the right pylon (in red) may be due to obscuration by vegetation and a small number of images at the edges of the model.

4. CONCLUSIONS

The USV platform allowed a smart implementation of the photogrammetric mission. The USV BATDRON platform integrated very well with the relatively heavy DSLR sensor. It thus proves advantageous in relation to flying platforms, in which the large weight of the sensor could significantly shorten the mission time and negatively influence the stability and safety of the platform itself. This research demonstrates that images automatically acquired with the use of a RC platform can be an excellent source of information about such engineering objects as bridges.

In order to prepare the 3D model of the Grunwaldzki Bridge, further work should focus on integrating images from UAV photogrammetric flights with this USV photogrammetric study. Additionally, future works on the full bridge model should involve an integration with the LiDAR SLAM.

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