# AN OPEN-SOURCE, DATA-LOGGING DEVICE FOR MARINE-BASED SURVEYS

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**Commission II WG II/7**

**KEYWORDS**: Data logging, Open-source, Portability, Marine surveys,

**ABSTRACT:**

Observation, monitoring, and understanding of the marine environment, particularly seafloor mapping, have gained global attention. Underwater photogrammetry is a valuable technique for creating accurate seafloor orthomosaics and digital elevation models (DEMs). However, achieving accurate georeferencing in photogrammetry surveys is challenging in marine environments. To address this, a low-cost and open-source data collection device was developed for underwater photogrammetry projects. The device is affordable, flexible, lightweight, and capable of logging position, motion, and utilizing a laser for seafloor feature identification. This paper presents the validation and assessment of the system, focusing on the performance of the position and laser sensors. The study advances underwater photogrammetry and provides insights into the device's capabilities for marine research and mapping applications. The results show that the Post Processed Kinematic (PPK) technique achieves high accuracy, with RMSE values of 0.294 m (distance), 0.267 m (X-coordinate), and 0.12 3m (Y-coordinate) at the Fremantle car park and 0.278 m (distance), 0.16 8m (X-coordinate), and 0.222 m (Y-coordinate) at the Fremantle near boat ramp. PPP exhibits acceptable accuracy, while GPS shows relatively lower accuracy. Echosounder measurements correlate well with bathymetric lidar and RTK Rover reference data, with RMSE values of 45 cm and 28 cm, respectively. The laser distance measurer provides accurate measurements between 25 and 60 cm, showing a good correlation with the echosounder (R = 0.77). After correction for offset and refraction, the laser measurements have an RMSE of 1.8 cm compared to the echosounder. This study further demonstrated the feasibility and effectiveness of low-cost and open-source platforms, like Raspberry Pi, for marine research and mapping applications. Further work will investigate integrating this data into photogrammetry surveys.

## 1. INTRODUCTION

Observation, monitoring, and understanding of the marine environment, particularly seafloor mapping, are central topics of marine research that have received worldwide attention recently (Yuan et al., 2022). Underwater photogrammetry has been shown to be an effective method for creating orthomosaics and digital elevation models (DEMs) of the seafloor (Urbina-Barreto et al., 2021). To be able to create accurately georeferenced mosaics and DEMs, photogrammetry surveys require images to be tagged with position and motion data, and a number of Ground Control Points (James, Robson, & Smith, 2017); however, collecting data in the marine environment is technically and economically challenging.

Accurate data collection in the marine environment is crucial for better understanding and quantification of the seafloor (Yuan *et al.*, 2022). However, several challenges hinder the acquisition of reliable seafloor maps, including limited existing data and difficulties in data collection. These challenges arise from various factors, such as the remoteness and hazards that make it unsafe for ships to survey shallow areas (Iscar & Johnson-Roberson, 2015). Alternative systems like Autonomous Surface Vehicles (ASVs) or Remote Operation Vehicles (ROVs) offer safer options for data collection, but these systems can be expensive, time-consuming, and require specialized expertise to use effectively (Suhari, Karim, Gunawan, & Purwanto, 2017).
This study's aim was to develop a low-cost, open-source, data collection device to support underwater photogrammetry projects, with the following criteria:

- Low cost.
- Open source, to allow flexibility.
- Lightweight so that it could be operated by a snorkeller, swimmer, kayaker or an Autonomous Surface Vessel (ASV).
- Simultaneously log position (X, Y, Z) – both depth down from the water surface and altitude above the seafloor, and motion (heading, pitch and roll). That could be tagged to images collected.[1]
- A laser to identify the location of features in imagery on the seafloor.

This paper presents the validation and assessment of the system, particularly the performance of the position, the echosounder, and laser sensors. The paper is structured as follows an

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introduction section that sets the context and outlines the objectives, followed by a comprehensive literature review to establish the theoretical background. The next section provides a detailed description of the system, highlighting its key features. The validation and assessment process are then presented, discussing the methodology, experimental setup, and obtained results. Finally, the paper concludes with a summary of the key insights, implications of the study, and suggestions for future research directions.

## 2. RELATED WORKS

While there are several examples of commercial devices capable of simultaneously collecting data for depth and position, some of these were either too expensive and/or not adaptable enough to meet all the needs for the current study. For instance, Suhari *et al*. (2018) developed small ROV boats equipped with remote sensing technology, GNSS, echo sounder, and navigational engine for bathymetry surveys in Malaysia. However, both platforms could not be adapted to meet the study’s criteria. However, there were examples of open-source platforms developed for similar applications. Gogendeau (2022), who created an open-source ASV solution for tracking slow-moving marine animals. It uses a short baseline (SBL) acoustic system with a 100 m range. The ASV also collects environmental data and is designed to be low-cost and adaptable for adding other sensors.

Karegar *et al.* (2022) designed a unit to measure water levels, the Raspberry Pi Reflector (RPR) prototype incorporates a low-cost, low-maintenance GPS module and navigation antenna connected to a Raspberry Pi microcomputer. Operating successfully since March 2020 near the Rhine River in Wesel, Germany, it retrieves sub-daily and daily water levels through spectral analysis of reflection data.

Thapliyal & Kumar (2016) have designed a unit to monitor critical parameters and motion detection in restricted compartments onboard, the integrated proof of concept Data Acquisition Console (DAC) prototype utilizes various sensors interfaced with a Raspberry Pi board. The objectives of the study by Thapliyal & Kumar (2016) the project, includes: real-time monitoring of temperature, humidity, and access to restricted compartments, remote access through a web-based site on the ship's LAN, data logging for analysis, and the addition of a pressure sensor for validation and altitude calculation.

Wootton (2020) designed an ASV for marine magnetic and bathymetric surveying. Equipped with Raspberry Pi 2 and Raspberry Pi 3B+ modules, along with a single frequency echo sounder and a magnetometer, the ASV collected data. A Python script synchronized bathymetric and GPS location data, creating a central data collection system. This system received data from the magnetometer, echo sounder, and single point positioning system, resulting in a synchronized geospatial dataset stored within the Raspberry Pi. The survey vessel configuration underwent testing in three Canadian lakes.

Guo & Bräunl (2020) designed a unit using Raspberry Pi 3B for measuring and logging key parameters. The system logs water temperature, pressure, battery level, current speed, GPS coordinates, pitch, yaw, and roll. Data transmission allows communication between various sensors. Additionally, a telemetry method enables remote data storage in a database, real-time monitoring of position and key parameters, and an IoT application for LAN communication and data display on dashboards accessible by multiple devices.

In conclusion, this study explored various examples of commercial and open-source devices for data collection in-depth and position-related applications. The evaluation revealed that while some commercial devices were expensive or lacked adaptability, open-source platforms provided promising solutions. Notable examples included platforms for georeferenced underwater photogrammetric mapping and an autonomous surface vessel (ASV) for marine tracking. Hence, this study was inspired by these related works to be based on an open-source devices. Based on the available options at the time, the Raspberry Pi was determined to be the most suitable device for the study's objectives. Several studies highlighted the successful integration of Raspberry Pi with various sensors for measuring water levels, monitoring critical parameters, controlling environmental factors, and conducting marine surveys. These examples provided valuable insights and inspiration for the current study, showcasing the versatility and cost-effectiveness of open-source devices in data collection applications.

## 3. PROPOSED DEVICE

A schematic diagram, and a photo of the data logging device, are shown in Figures 1 and 2, respectively. A list of the main components and their cost is detailed in Table 1. The data logging device was built around a Raspberry Pi, as these are low-cost, low-power consumption, small-sized computer with open-source software and a Python application for controlling, collecting, and storing sensor data simultaneously. The open-source nature of Raspberry Pi, which enables the development of study-specific analysis, is a key advantage (Addona et al., 2022).

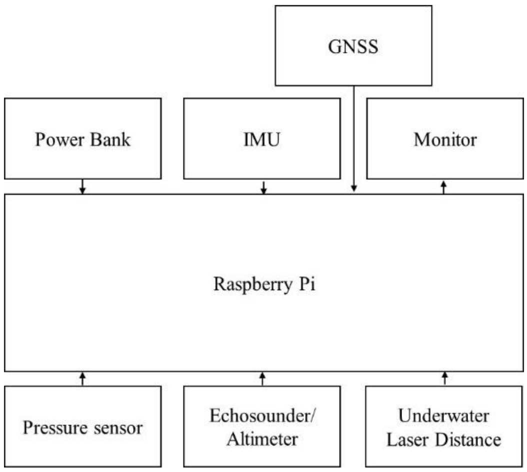


**Figure 1.** A schematic of the data logging device and the sensors integrated.

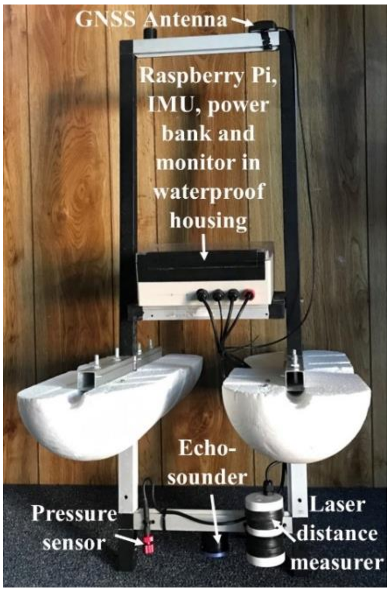


**Figure 2.** Photo of the data logging device and sensors mounted on a frame.

| Component | Role | Price (US$) |
|---|---|---|
| Raspberry Pi 4 | The Raspberry Pi 4 is the main unit that collects and saves the data. | 123 |
| Pressure Sensor | Used for measuring the depth down from the sea surface. Accuracy is 2 mm. | 85 |
| GNSS Antenna | Used to find the location of the vehicle. RTK compatible. | 42 |
| Echosounder/ Altimeter | Uses sound to get the altitude from the seafloor to the sensor. Resolution is 0.5% of range. | 312 |
| IMU | An Inertial Measurement Unit (IMU) chip to measure motion. Including gyroscope and accelerometer. | 53 |
| Laser distance measurer | Uses green light to get the altitude from the seafloor to the sensor. Accuracy is +/- 3mm. | 70 |
| Power bank | To supply the power to the Raspberry Pi and Monitor. | 54 |
| Monitor | Used to show the data from the Raspberry Pi 4 | 79 |
| Styrene floats | Used to keep the vehicle floating on the sea surface | 2 X 35 |
| Total cost | | US$ 888 |

**Table 1.** Components used in the data logging device and their cost (US$).

Integrated into the Raspberry Pi were a RTK compatible GNSS (the SparkFun GPS-RTK Board - NEO-M8P-2 Receiver), an echo-sounder/altimeter (Blue Robotics Ping Sonar), a pressure sensor (Blue Robotics Bar30), a green laser distance measurer (JRT), and a monitor (Figure 1 and Figure 2, Table 1). This was all powered by a 2600mA power bank, which was able to power it for at least 3 hours (Figure 1). The Raspberry Pi, IMU, and power bank were enclosed in a waterproof housing. The waterproof housing was attached in the middle of a rectangle rigid, metal frame. The GNSS antenna was attached to the top of the frame and positioning directly above the echosounder and laser distance measurer, with the pressure sensor located adjacent, attached to the bottom of the frame (Figure 2). Styrene floats were added for floatation and to provide a stable platform (Figure 2). A program was written in Python to log the sensor data and time stamp with the GNSS every second.

## 4. VALIDATION

Tests were carried out to assess the accuracy of the device's:

1) Positioning solution provided by the GNSS receiver both in real-time and post-processed.
2) Depth measurements using the echosounder.
3) Depth measurements of the laser distance measurer.

### 4.1 Datasets

To assess the positioning solution of the GNSS receiver, in-air data collection was conducted twice at Fremantle Sailing Club in Perth, Western Australia. The first test was in the car park (S-32.07033961, E115.7496281 WGS 84) and the second test was near the boat ramp (S-32.07014067, E115.750357 WGS 84). To assess the accuracy of the GNSS receiver and the Post Processed Kinematic (PPK) and Precise Point Positioning (PPP) solutions, the main objective of this study was to compare their position solutions with a Trimble RTK Rover survey that collected discrete points. Two techniques, namely Post Processed Kinematic (PPK) and Precise Point Positioning (PPP), were employed to refine the accuracy of the raw GPS data through error correction and improved positioning results. This study provides valuable insights into the performance of GNSS positioning techniques in real-world scenarios, demonstrating the accuracy, reliability, and effectiveness of raw GPS, PPP and PPK. The comparison with the reference RTK data facilitated the determination of the superior method based on the evaluation of Root-Mean-Squared Error (RMSE) values.

To assess the depth measurements from the echosounder and laser distance measurer, data was collected with the device over a boat ramp at Fremantle Sailing Club, Western Australia (Figure 3, Figure 4, and Figure 5). Echosounder data collected with the Raspberry Pi were corrected for physical offsets, sound velocity and measured tide from Fremantle Fishing Harbour, then converted to Australian Height Datum (AHD) using the Australian Coastal Vertical Datum Transformation Tool (CRCSI, 2016). This data was compared with historic bathymetry LiDAR data (Fugro, 2009), and a Trimble RTK Rover survey that collected discrete points over the boat ramp area, which were both re AHD (Figure 4), to enable a comparison over all of the survey area. As the historic bathymetric lidar data was gridded at 5 m (with a projection of MGA Zone 50), data from the echosounder and RTK Rover surveys were (mean) gridded to the same grid nodes as the bathymetric lidar data, where data was present, to allow a direct comparison. Gridded data were compared by calculating Pearson's correlation coefficient, least-means-squared linear regression and root-mean squared error (RMSE).

The laser distance measurer was an off-the-shelf in-air sensor that was sealed in an underwater housing. The green light produced by the laser can be seen over an underwater target placed in the harbour in Figure 5. As the measurements outputted by the device assume it is in-air, the water index was calculated as per standard formulations (IAPWS, 1997), to correct the distances logged for change in the speed of light. The laser distance measurer was compared with the echosounder data using Pearson's correlation coefficient and least-means-squared linear regression. The intercept (c) of the linear regression (y = mx +c), was used to establish the: fixed height offset between the acoustic centre of the echosounder and the optical centre of the laser distance measurer. The slope (m) of the linear regression was compared to the water index of (green) light (m) as an empirical estimate of the effect of refraction. The distances outputted by the laser were corrected for the height offset and water index and were then filtered using +/- 10% of the echosounder depth for the same measurement. The RMSE was calculated between the corrected laser and the echosounder measurements.

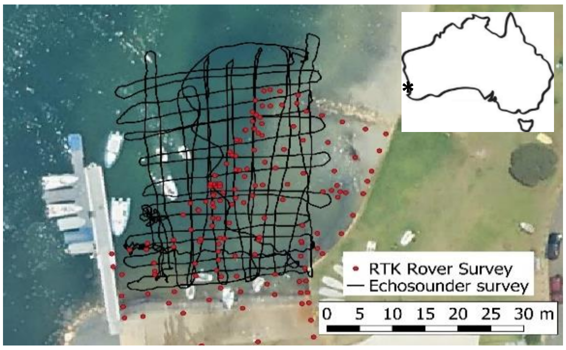


**Figure 3.** Data collection in Fremantle Sailing Club (FSC): (top) the track of device collecting echosounder data as a black line, the Trimble R12 Rover positions as red circles, over an aerial photograph, and location of FSC (*) in Australia (insert).

**Figure 4.** the Trimble R12 Rover data being collected.

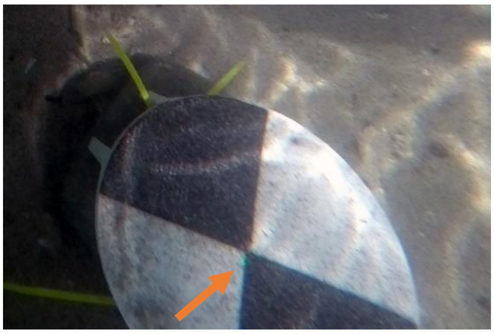

**Figure 5.** Green laser (arrow) on an underwater target.

## 4.2 Evaluation of GNSS

The tracks of the GNSS validation test of GPS, PPP, and PPK techniques in the FSC car park area are shown in Figure 4. It can be seen in Figure 6, and the resulting RMSE values in Table 2, that PPK was the closest of the three positioning solutions to the RTK data. For instance, PPK had the lowest RMSE values in all three categories: distance of 0.294 m, X-coordinate of 0.267 m, and Y-coordinate of 0.123 m. GPS exhibits relatively higher RMSE values, with distances of 2.740 m, X-coordinate of 1.927 m, and Y-coordinate of 1.948 m. PPP shows higher RMSE values compared to PPK, with distances of 2.068 m, X-coordinate of 1.806 meters, and Y-coordinate of 1.007 m. A similar result was found for the boat ramp test, as seen in the track plot in Figure 7, and the RMSE values in Table 3. Where PPK again had the lowest RMSE values in comparison to RTK, in the distance, X and Y directions. Again, GPS and PPP exhibited higher RMSE values in all three categories (Table 3).

In conclusion, the GNSS validation test comparing the GPS, PPP, and PPK techniques in the Fremantle car park area and boat ramp area revealed distinct performance variations. The results demonstrated that PPK was the closest to the reference RTK data, with the lowest overall error. In contrast, GPS and PPP exhibited higher levels of error in all three categories. These results are constant with other studies and confirm PPK as the best solution available for this system.

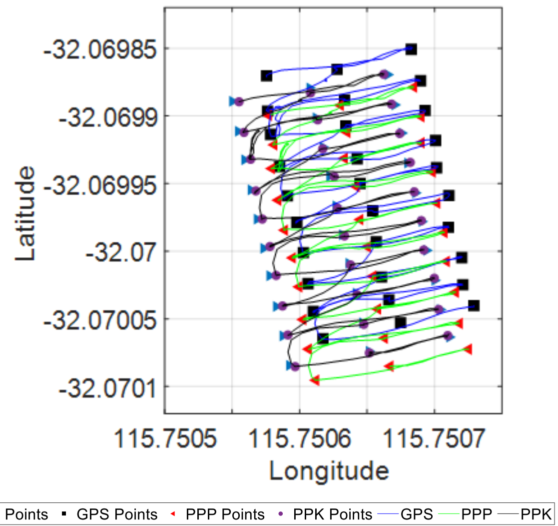


**Figure 6.** Position data results for GPS, PPK and PPP compared with RTK in Fremantle Car Park.

| RMSE (m) | GPS | PPP | PPK |
|---|---|---|---|
| Distance | 2.740 | 2.068 | 0.294 |
| X | 1.927 | 1.806 | 0.267 |
| Y | 1.948 | 1.007 | 0.123 |

**Table 2.** Position data results for GPS, PPK and PPP compared with RTK RMS

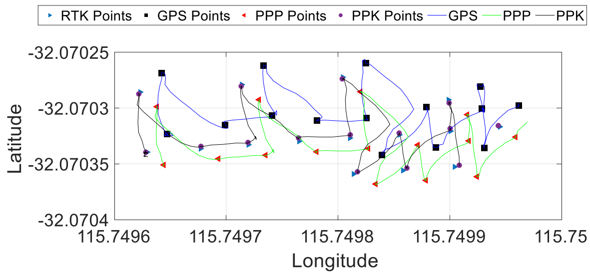


**Figure 7.** Position data (collected in-air) results for GPS, PPK and PPP compared with RTK in Fremantle near boat ramp.

| RMSE (m) | GPS | PPP | PPK |
|---|---|---|---|
| Distance | 2.971 | 1.954 | 0.278 |
| X | 2.094 | 1.582 | 0.168 |
| Y | 2.108 | 1.147 | 0.222 |

**Table 3.** Position data (collected in-air) results for GPS, PPK and PPP compared with RTK RMS.

### 4.3 Evaluation of the echosounder

Depth derived from the echosounder logged by the low-cost device, is compared against bathymetric lidar data, and the RTK Rover survey, in Figure 8. The echosounder data were highly correlated with both the LiDAR data (R = 0.92) and RTK survey (R = 0.89) (Table 3). Linear regression analysis showed the echosounder data had a similar rate of change to the reference data, but slightly deeper depths (12 and 34 cm). The echosounder data had an RMSE of 45 cm with the lidar data, and 28 cm with the RTK Rover survey (Table 4).

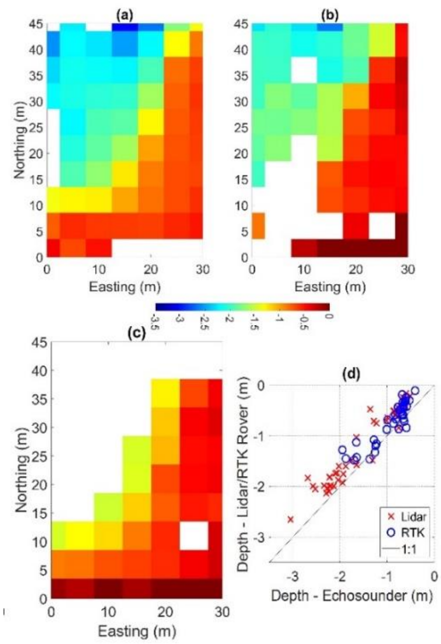


**Figure 8.** Depth data (re AHD) from Fremantle Sailing Club boat ramp: (a) gridded data from echosounder collected using the low-cost device; (b) gridded historic bathymetric LiDAR; (c) gridded RTK Rover survey; and (d) a Cartesian plot comparing depth data.

| Reference data | Pearson's correlation coefficient | Linear regression coefficients | RMS (m) |
|---|---|---|---|
| Bathymetric lidar | 0.92 | y = 1x + 0.34 | 0.45 |
| RTK Rover | 0.89 | y = 0.91x + 0.12 | 0.28 |

**Table 4.** Comparison of the Echosounder data with bathymetric lidar and RTK Rover reference data.

The echosounder results were comparable to the LiDAR and RTK measurements. The small differences between the depth measurements from the different platforms appear to be a constant error (12-34 cm), such as possibly from inadequate physical offset correction or the datum transformation from LAT to AHD, rather than a variable error.

### 4.4 Evaluation of the laser distance measurer

The laser distance measurer collected measurements between 25 and 60 cm Figure 9. Beyond 60 cm, the light was sometimes still visible but reliable measurements were not returned. Typically, lighter (close to white) surfaces appeared to be the most reliable for seeing the green light. The measurements between 25 and 60 cm correlated well with the echosounder (R = 0.77). The water index was calculated: theoretically as 1.34, and from the slope of the regression as 1.32. The laser distance measurements corrected for the physical offset and refraction, and filtered, had a RMSE of 1.8 cm with the equivalent echosounder measurements.

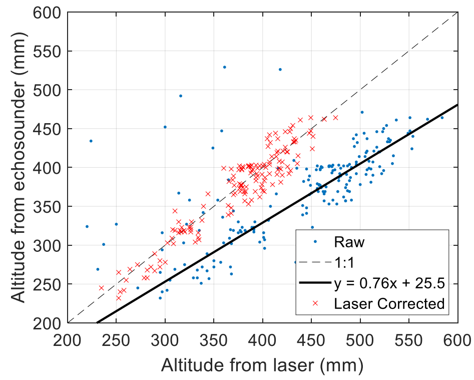


**Figure 9.** Altitude recorded by the laser vs echosounder: showing raw values from both devices (blue dots), and corrected laser distance values (red crosses). The black dashed line is the 1:1 ratio, and the solid black line is the best fit result from linear regression on the raw values.

The laser distance measurer during this study provided raw measurements, between 25 and 60 cm, that correlated well with the echosounder measurements. Laser measurements from longer distances might be possible, through using targets that are more optically reflective, and/or increasing the output power of laser. Nevertheless, having the laser visible on simultaneously acquired images, without a reliable distance measurement, still might be useful in locating the position of targets. However, effects of refraction would need to be adequately accounted. This study found that the effects of refraction could be corrected using either a theoretical or empirically derived index of water.

## 5 CONCLUSION AND FURTHER WORK

This study presented a low-cost and open-source data collection device designed to address the challenges of accurate georeferencing in underwater photogrammetry surveys. The device successfully collected accurate X, Y, Z positions, providing valuable data for photogrammetry work. The results showed that the Post Processed Kinematic (PPK) technique achieved the highest accuracy, while the Precise Point Positioning (PPP) technique exhibited acceptable accuracy. The Global Positioning System (GPS) showed relatively lower accuracy. Additionally, the device incorporated a laser for seafloor feature identification, which proved to be effective within a range of 25 to 60 cm.

This study further demonstrated the feasibility and effectiveness of low-cost and open-source platforms, like Raspberry Pi, for marine research and mapping applications. In addition, it provided an assessment of the sensor's capabilities and performance. Further work will investigate integrating this data into photogrammetry surveys.

## ACKNOWLEDGMENT

The authors would like to thank King Abdulaziz University for funding Alaa Mufti's PhD study, and Mr Malcolm Perry and Mr Ming Lim from Curtin University for technical support.

## REFERENCES

CRCSI,. 2016. AusCoastVDT version 1.20 User Manual. 27.

Fugro,. 2009. Western Australia Two Rocks to Cape Naturaliste Bathymetry and Seabed Survey LiDAR April/May 2009: Report of Survey. 168pp.

Gogendeau, P,. 2022. A Smart multi-sensor system for marine animals with embedded geolocation. *Université de Montpellier*.

Guo, J., & Bräunl, T,. 2020. Elfoil Data Logging, Transmission and Visualisation.

Iscar, E., & Johnson-Roberson, M,. 2015. Autonomous surface vehicle 3D seafloor reconstruction from monocular images and sonar data. *Paper presented at the OCEANS 2015-MTS/IEEE Washington.*

James, M. R., Robson, S., & Smith, M. W,. 2017. 3-D uncertainty-based topographic change detection with structure-from-motion photogrammetry: precision maps for ground control and directly georeferenced surveys. *Earth Surface Processes and Landforms, 42*(12), 1769-1788.

Karegar, M. A., Kusche, J., Geremia-Nievinski, F., & Larson, K. M,. 2022. Raspberry Pi Reflector (RPR): A Low-Cost Water-Level Monitoring System Based on GNSS Interferometric Reflectometry. *Water Resources Research,* 58(12), e2021WR031713.

Suhari, K. T., Karim, H., Gunawan, P. H., & Purwanto, H,. 2017. Small rov marine boat for bathymetry surveys of shallow waters–potential implementation in malaysia. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 42, 201-208.

Thapliyal, A., & Kumar, C,. 2016. Development of data acquisition console and web server using Raspberry Pi for marine platforms. *International Journal of Information Technology and Computer Science,* 8, 46-53.

IAPWS,. 1997 http://www.iapws.org

Urbina-Barreto, I., Garnier, R., Elise, S., Pinel, R., Dumas, P., Mahamadaly, V., Facon, M., Bureau, S., Peignon, C., & Quod, J.-P,. 2021. Which method for which purpose? A comparison of line intercept transect and underwater photogrammetry methods for coral reef surveys. *Frontiers in Marine Science,* 8, 636902.

Wootton, M. R,. 2020. Autonomous Bathymetric and Magnetic Surveying for Canadian Lakes (Doctoral dissertation, Queen's University (Canada)).

Yuan, S., Li, Y., Bao, F., Xu, H., Yang, Y., Yan, Q., Zhong, S., Yin, H., Xu, J., & Huang, Z,. 2022. Marine environmental monitoring with unmanned vehicle platforms: Present applications and future prospects. *Science of The Total Environment*, 159741.