École Nationale Supérieure de Techniques Avancées

Internship Report

Second Year - Engineering Cycle
Autonomous Robotics

Bathymetric Data Acquisition for Micro-AUV State Estimation

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Abstract

This report details the work conducted during a four-month internship at the Lab-STICC, Robex team, focusing on the implementation of a functional bathymetric mapping pipeline for the micro-AUV Yuco (Seaber). To extend the baseline functionality of the AUV, a custom payload section called Yodac was introduced. It provides a dedicated platform for testing state estimation filters, autonomous decision-making algorithms and bathymetric mapping. The resulting system integrates an embedded electronic board, including a single-beam echo sounder.

The core technical contribution involved designing and implementing an embedded ROS software architecture within the Yodac payload, interfacing it with the Yuco AUV via its communication API, and integrating the echo sounder through a custom software library. Finally, the developments were validated through experimental sea trials to evaluate the system's operational behavior. Ultimately, this work serves as a foundational starting point for future research and autonomous implementations on the micro-AUV.

Résumé

Ce rapport détaille les travaux menés lors d'un stage de quatre mois au sein du Lab-STICC (équipe Robex), axés sur l'implémentation d'une chaîne de cartographie bathymétrique fonctionnelle pour le micro-AUV Yuco (Seaber). Afin d'étendre les fonctionnalités de base de l'AUV, un module de charge utile personnalisé, appelé Yodac, a été introduite. Il offre une plateforme dédiée au test de filtres d'estimation d'état, d'algorithmes de prise de décision autonome et de cartographie bathymétrique. Le système qui en résulte intègre une carte électronique embarquée, comprenant un échosondeur monofaisceau.

La principale contribution technique a consisté à concevoir et implémenter une architecture logicielle ROS embarquée au sein de la charge utile Yodac, à l'interfacer avec l'AUV Yuco via son API de communication, et à intégrer l'échosondeur par le biais d'une bibliothèque logicielle sur mesure. Enfin, les développements ont été validés par des essais expérimentaux en mer afin d'évaluer les performances de cartographie et le comportement opérationnel du système. En définitive, ces travaux servent de point de départ fondamental pour de futures recherches et implémentations autonomes sur le micro-AUV.

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Acronyms

Lab-STICC	Laboratoire des Sciences et Techniques de l'Information, de la Communication et de la Connaissance
Robex	ROBotics for EXploration
CNRS	Centre National de la Recherche Scientifique
UMR	Unité Mixte de Recherche
AUV	Autonomous Underwater Vehicle
ROS	Robot Operating System
DVL	Doppler Velocity Log
API	Application Programming Interface
SDK	Software Development Kit
INX	Intuitive Navigation eXperience
IMU	Inertial Measurement Unit
PCB	Printed Circuit Board
USBL	Ultra-Short Baseline
SBES	Single-Beam Echo Sounder
CW	Continuous Wave
I2C	Inter-Integrated Circuit

1 Introduction

1.1 Laboratory

The Laboratoire des Sciences et Techniques de l'Information, de la Communication et de la Connaissance (Lab-STICC) is a French multidisciplinary Unité Mixte de Recherche (UMR) 6285 affiliated with the Centre National de la Recherche Scientifique (CNRS), the principal state research organization and a central institution in the French scientific ecosystem. It is jointly supported by several academic institutions in Brittany, including ENSTA, IMT Atlantique, and the Université de Bretagne Occidentale (UBO). The laboratory is known for its research in fields such as information and communication sciences, embedded electronics, computing, signal processing, and robotics. It applies these competencies primarily to sectors like the maritime environment, defense, and autonomous systems.

Within the ENSTA Brest campus, the ROBotics for EXploration (Robex) team operates as a research group integrated into the Lab-STICC. The team focuses on the development, localization, and control of autonomous marine and underwater vehicles. Its research addresses challenges in subsea operations, including autonomous exploration, trajectory tracking, and mapping in unstructured environments.

1.2 Theme

AUVs are critical assets for subsea observation and bathymetric surveying. However, conventional survey-class vehicles impose severe logistical burdens due to their mass (often exceeding 100 kg), necessitating dedicated support vessels and crane operations (*Daurade* AUV, [2]). To lower operational footprints, micro-AUVs (under 10 kg, single-operator deployable) have emerged as an agile alternative for coastal and shallow-water surveying.

The Robex research team recently acquired a commercial micro-AUV, the *Yuco-Carrier* developed by Seaber, equipped with a Doppler Velocity Log (DVL) Water Linked A50. Although the vehicle offers an integrated navigation via its proprietary software, it operates as a closed, turnkey system. It executes predefined paths without providing native access to internal control loops or supporting real-time perception-driven algorithms required for scientific exploration and mapping. For that reason, the team has developed a custom payload section called Yodac, which is reasponsible for extending the base functionality of the Yuco micro-AUV through the addition of other sensors. Ultimately, this approach aims to enable the testing of state estimation filters, autonomous decision-making algorithms and bathymetric mapping.

The present internship focuses on integrating the recently created Yodac platform in the micro-AUV. The work involves designing and implementing an embedded Robot Operating System (ROS) software architecture, interfacing it with the Yuco AUV via its communication Application Programming Interface (API), and integrating the echo sounder through a custom software library. The developments will be validated through experimental sea trials to evaluate the system's operational behavior.

With the laboratory projecting the acquisition of additional micro-AUVs to deploy multi-agent swarms, the Yodac architecture establishes the baseline hardware and software standard for future autonomous survey fleets. By resolving multi-sensor integration and data synchronization, this internship provides the foundational infrastructure required for further reasearchs.

1.3 Objective

The central objective of this internship is to implement and experimentally validate a data acquisition embedded chain on an instrumented micro-AUV. In other words, the Yodac payload.

The technical scope of this work is articulated around six major tasks:

1. **Integration of the Yodac Section with the AUV:** The Yodac structure and components were priorly designed and manufactured, however not yet fully tested and integrated to the AUV. Therefore, the idea is to ensure that the payload is completely operational from a mechanical, electrical and software standpoint.

2. **Development of a Dedicated Single-Beam Echosounder Library:** Develop a ROS 2 compatible C++ library that enables low-level access to the echosounder data stream.

3. **Interfacing Yuco AUV Telemetry with the Yodac Payload:** The third objective is to establish a communication link between the Yuco AUV and the Yodac payload, enabling the retrieval of vehicle state information (position, orientation, depth, DVL measurements, etc) through the Yuco's API.

4. **Deployment of a ROS 2 Embedded Framework:** Designing a ROS 2 environment to integrate in a single log file all data retrieved from the echosounder, the Yuco AUV and the internal pressure, temperature and humidity sensors.

5. **Mission Preparation and In Situ Experimental Validation:** Formulating pre-dive checklists, mechanical ballast, trim balancing, and mission path definition. The idea is to evaluate the integrated system in real conditions to validate the components and to acquire bathymetric data for post-processing analysis.

6. **Post-Deployment Evaluation:** Evaluating the collected data to check the AUV's performance and behavior during the sea trials. The issues identified during this evaluation will inform further refinements to the Yodac payload and its software architecture.

2 Contextualization

2.1 Yuco-Carrier AUV

2.1.1 System Overview

The Yuco-Carrier is a micro-AUV developed by Seaber and designed for an ease deployment. It is specifically tailored to support custom payloads and sensor integration, making it a suitable platform for coastal and shallow-water research. It provides a built-in support for the Water Linked A50 DVL, bought separately by the laboratory.



Figure 1: Yuco-Carrier AUV (Seaber) with the Yodac payload (white section).

The Yuco-Carrier relies on Seaber's proprietary Intuitive Navigation eXperience (INX) system for precise underwater localization. Because GNSS signals cannot penetrate water, the INX algorithm performs dead-reckoning by tightly coupling data from the vehicle's IMU, depth sensor, and DVL. This continuous sensor fusion allows the AUV to calculate its estimated trajectory and actively compensate for ocean currents.

The AUV provides an Ethernet API to enable the communication with payloads. It allows extracting mission real-time informations and changing Yuco behavior during a mission.

2.1.2 Technical Specifications

Specification	**Details**
Max Depth	300 m
Max Speed	3.0 m/s
Min Turning Radius	15 m
Weight in Air Without Payload (approx.)	7 kg
Typical Endurance	8 h @ 1.5 m/s
Dimensions (L × D)	98 cm × 12 cm
Battery Capacity	42 Ah (Li-Ion)

2.1.3 SEAPLAN Software

SEAPLAN is the proprietary software suite utilized for the complete lifecycle of a Yuco AUV mission. It serves as the primary interface for the operator to interact with the vehicle before and after deployment. Key capabilities include:

- **Mission Planning:** Operators can visually map out mission trajectories on geographic charts, defining precise waypoints, operational depths, altitude from seabed, speed parameters, among other configuration options.
- **Pre-Dive Configuration:** The software allows for pre-dive parameter setting, checking sensor status, calibrating compass and fins positions, and validating overall vehicle health.
- **Data Management:** Post-mission, SEAPLAN is used to download dive logs, telemetry data, and payload sensor recordings for external analysis and mapping.

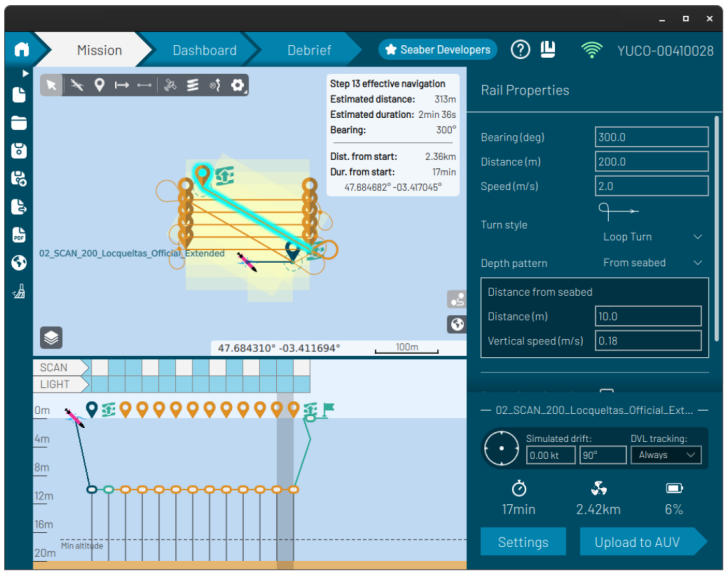


Figure 2: SEAPLAN Software UI displaying AUV status.

2.1.4 SEACOMM Remote Control

The SEACOMM is a remote control unit designed for surface communication and manual operation of the AUV. Its primary purposes are ensuring safe handling during the critical phases of deployment and recovery, as long as providing immediate surface oversight. It utilizes LoRa UHF point-to-point networking with a range of up to 2.5 km.

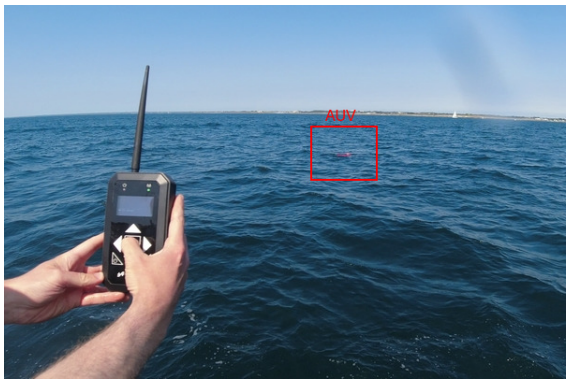


Figure 3: SEACOMM Remote Control Interface.

2.2 Yodac Payload

2.2.1 Mechanical Enclosure

Mechanically, the Yodac payload consists of a cylindrical waterproof section inserted in-line between the vehicle's midsection and the forward nose cone. The internal electronics system is mounted on a rigid longitudinal tray attached to the end-cap bulkhead.

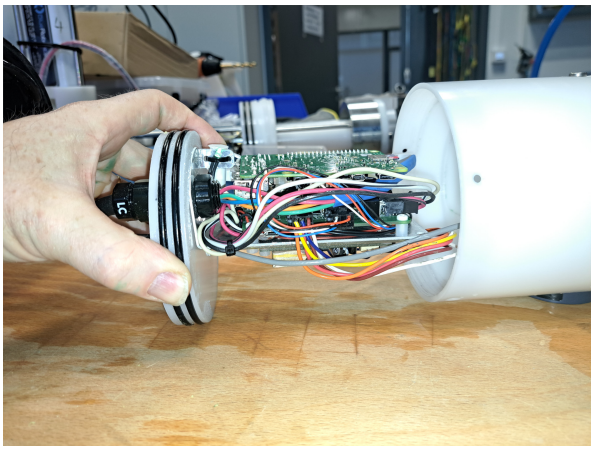


Figure 4: Yodac - Internal view.

To secure seal integrity prior to deployment, the cylindrical hull is equipped with a dedicated purge port sealed by a custom screw fitted with an elastomer O-ring washer. Prior to a subsea campaign, this port is connected to an electric vacuum pump to evacuate air from the enclosure and generate a controlled low-pressure internal environment (approximately 650 to 750 mbar).

This pre-dive vacuum procedure protects the internal electronics from water leaks by adding a constant inward axial compressive force on the end-cap bulkheads. This pre-compresses the O-rings uniformly before hydrostatic forces take over at depth.

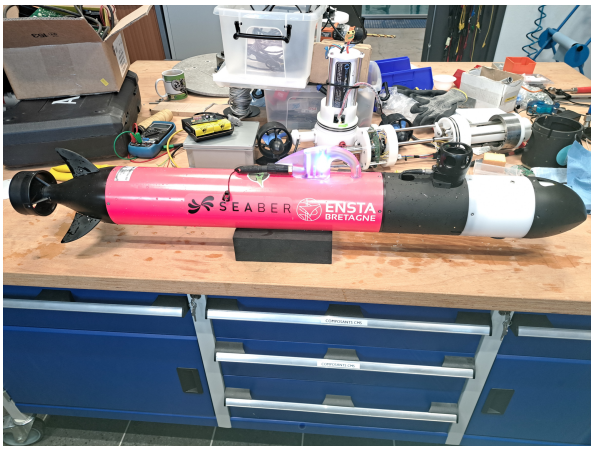


Figure 5: Yodac assembled to the AUV.



Figure 6: Sealing the payload in low-pressure environment using a vacuum pump.

2.2.2 Embedded Electronics

The Yodac system is equipped with a Raspberry Pi 4 Model B attached to a custom Printed Circuit Board (PCB) that centralizes power activation and bus conversion to other sensors. Essentially, the carrier board provides the following functionalities:

- **Non-Invasive Magnetic Switch:** System activation by approaching an external permanent magnet to the hull. No need to unseal the enclosure.
- **Real-Time Clock:** A temperature-compensated real-time clock with dedicated battery backup.
- **Internal Environmental Monitoring Unit (Bosch Sensortec BME280):** Responsible for measuring internal pressure, temperature, and relative humidity.
- **Echosounder interface:** Single-beam Sea Scan® Echo sounder.

- **USBL interface:** SeaTrac X010 Ultra-Short Baseline (USBL) transponder beacon.

Although the system is connected to an USBL sensor, the current work does not explore this capability.

2.3 Acoustic Pinger

In case of a major failure of the AUV, an acoustic pinger was attached to it in order to help locate it. Also known as Underwater Locator Beacon (ULB), it sends one pulse per second at 37kHz. Figure 7 presents the device.



Figure 7: Acoustic pinger (Model ULB-350/37 by RJE International.

Tests showed that the internal buoyancy foams absorbs the pinger signal, therefore it was not possible to place the pinger inside the AUV as can be seen in Figure 8.



Figure 8: Exterior positioning of the acoustic pinger.

2.4 Echo Sounder

To measure the vehicle altitude above the seafloor, the Yodac payload integrates a commercial Single-Beam Echo Sounder (SBES): the *Sea Scan® Echo* developed by Marine Sonic Technology (Atlas North America) (Figure 9). The sensor operates using a single reversible piezoelectric transducer for both acoustic transmission and reception.

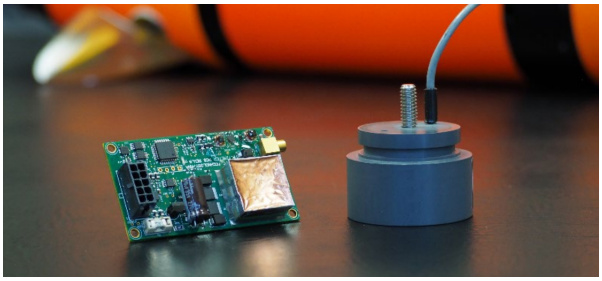


Figure 9: Altimeter - Sea Scan Echo sounder.

The Sea Scan Echo communicates with Yodac's Raspberry Pi over a RS-232 serial link and NMEA 0183 protocol. Table 1 shows the sensor specifications.

Table 1: Sea Scan Echo technical and acoustic specifications.

Parameter	**Nominal Value**
Operating Frequency (f_0)	540 kHz
Pulse Length (τ)	12 μs
Beam Width ($\theta_{-3\text{dB}}$, two-way conical)	6°
Source Level (SL)	$<$ 213 dB ref 1 μPa @ 1 m
Bandwidth (B)	$<$ 200 kHz
Maximum Operating Range ($r_{\max}$)	100 m (listening range configurable to 120 m)
Minimum Operating Range ($r_{\min}$)	0.5 m
Instrument Range Resolution	1.5 cm
Configurable Sound Speed Range	1400 m $\cdot$ s^{-1} to 1600 m $\cdot$ s^{-1}
Internal Filter Length (N_{filter})	1 to 32 pings (moving average, default: 10)
Depth Rating	300 m

3 Activities

3.1 Echo Sounder Library Development

To integrate the Sea Scan® Echo sounder into the Yuco micro-AUV, a low-level library was required to interface directly with the sensor though NMEA0183 protocol over RS-232 serial connection. The manufacturer provides a Windows SDK, which is incompatible with the embedded Linux environment running on the Raspberry Pi 4 (Ubuntu 24.04 LTS). Consequently, a native and modular C++ library was developed from scratch to interface directly with the sensor. The library was later inserted in the ROS 2 environment of Yodac. The software architecture was designed following several principles and good practices in the literature [3].

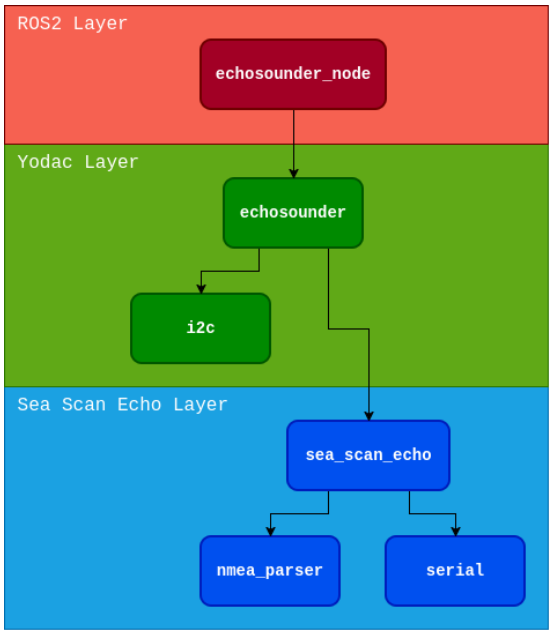


Figure 10: Software abstraction layers of the echo sounder.

As illustrated in Figure 10, the architecture layers consist of:

1. **Sea Scan Echo Abstraction Layer:** The Sea Scan Echo library itself. It manages physical communication bus, sentence tokenization, checksum verification, and device-specific states.

2. **Sensor Abstraction Layer:** An intermediate layer responsible for handling Yodac specific activies like starting up the sensor through I2C communication signals.

3. **ROS 2 Abstraction Layer:** The ROS 2 middleware interface handling node lifecycle, parameter binding, publisher routines, and inter-process synchronization.

3.2 ROS 2 Framework Development

In order to transform the Yodac payload into a real-time processing unit, a ROS 2 middleware was configured. The choice of Jazzy Jalisco distribution running on Ubuntu

24.04 (Noble) was made to ensure native compatibility between the two systems and take advantage of the long-term support provided by both. Figure 11 shows the complete diagram of classes separated by abstraction layers. As another point of view of the system, Figure 12 shows the nodes and topics.

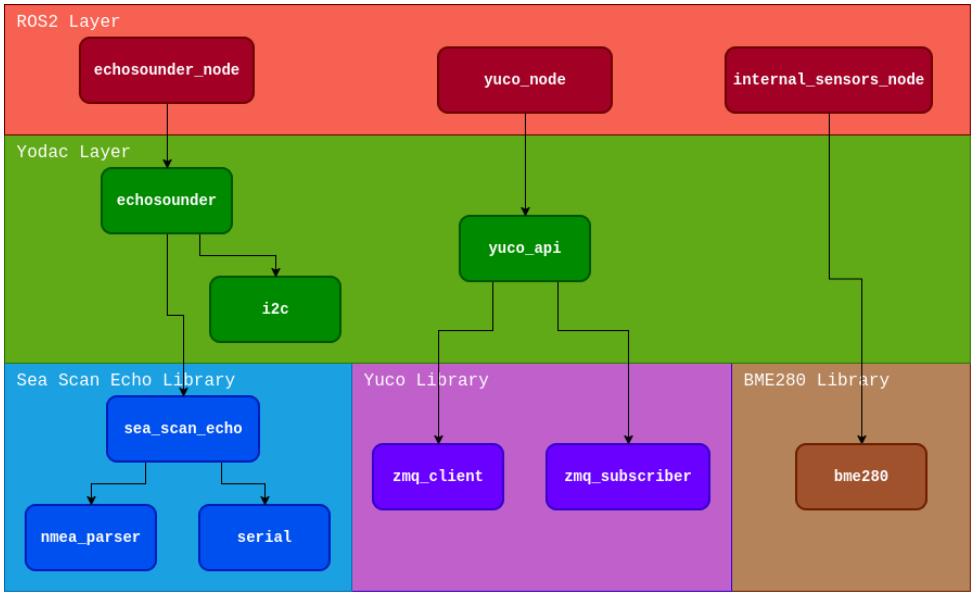


Figure 11: Software abstraction layers of the ROS 2 middleware.

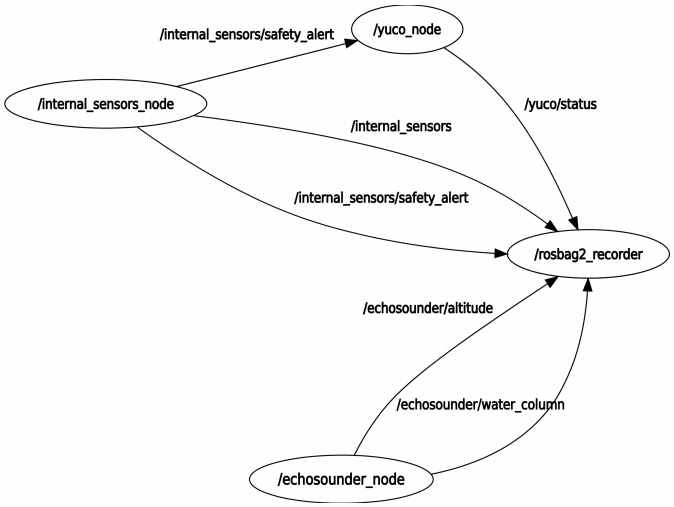


Figure 12: ROS 2 nodes and topics diagram.

1. `yuco_node`: Handles all mission real-time data received via Ethernet and parsed by the proprietary Seaber Yuco API library.
2. `internal_sensors_node`: Handles the temperature, pressure and relative humidity sensor BME280 to monitor Yodac's internal. It triggers safety alerts in case of seal failure, aborting the mission.
3. `echosounder_node`: Explained in Section 3.1.

3.3 Missions

3.3.1 Buoyancy Test and Calibration

Before deployment, hydrostatic balancing and trim calibration must be performed. The micro-AUV is designed to maintain a slight positive net buoyancy as a passive safety mechanism, ensuring that the vehicle autonomously resurfaces in the event of propulsion loss or power shutdown.

In addition to net buoyancy, static longitudinal tilt must be adjusted. Because the vehicle possesses positive buoyancy, initiating descent from the surface solely through hydrodynamic control surfaces requires substantial thrust and can cause surface skimming. To facilitate diving and reduce energy expenditure during immersion transients, the longitudinal positions of the Center of Gravity and the Center of Buoyancy are calibrated using internal ballast trim weights and foams.



Figure 13: Experimental buoyancy calibration.

3.3.2 Results

During the internship, three major mission campaigns were conducted: the first at Lake Guerlédan, and the final two in the Bay of Brest. The results presented in this section reference this final campaign in the bay.

On September 3 in the Bay of Brest (also around the Bay of Roscanvel), the last experiment took place. Two major objectives were involved: test the integration of the echo sounder of *Yodac* payload with the Yuco logs; and generate datasets for post-processing state estimation algorithms. Three distinct mission profiles were designed and executed using the SEAPLAN software (Section 2.1.3).

The primary objective of this experimental campaign was to acquire synchronized time-series of Doppler Velocity Log (DVL) bottom-track velocities, single-beam echosounder (SBES) acoustic ranges, and internal vehicle telemetry across contrasting geometrical trajectories. In post-processing, these datasets combined with the terrain bathymetry serve as ground observations to evaluate position readjustment filters—such as Extended Kalman Filters (EKF) and Particle Filters (PF).

Mission 1: Isobath Baseline and System Functional Validation Mission 1 was configured as a short, low-complexity path designed to run along an isobath contour at

constant depth (Figure 14). Mission time: 15 minutes.

First objective of this mission was to test the sensors integration before avancing to the next ones. Additionally, evaluate the AUV's performance in an isobath navigation regime.

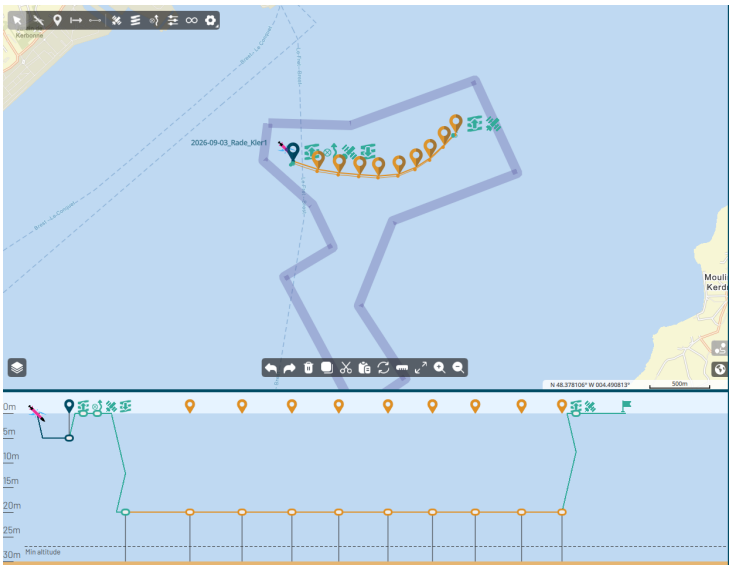


Figure 14: Mission 1 – Bay of Brest: Isobath trajectory.

Mission 2: Re-localization in Map Boundary Mission 2 introduced an intentional constraint of making the AUV leave and re-enter the bathymetric reference map (Figure 15). Mission time: 35 minutes.

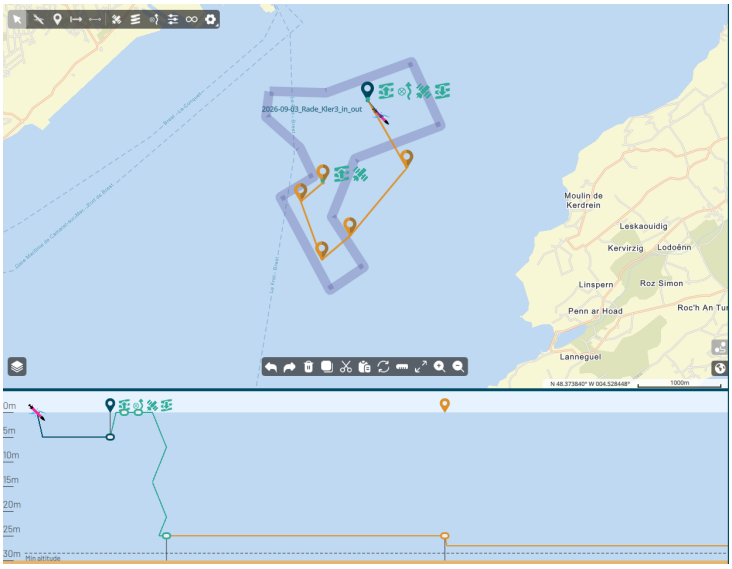


Figure 15: Mission 2 – Bay of Brest: Re-localization in map boundary.

Mission 3: Lawnmower Survey and Filter Stress-Testing Mission 3 is the longest deployment of the campaign, executed in the Bay of Roscanvel. The AUV was programmed

to perform an extended zigzag pattern as shown in Figure 16. This mission accumulates substantial dead-reckoning errors. Mission time: 52 minutes.

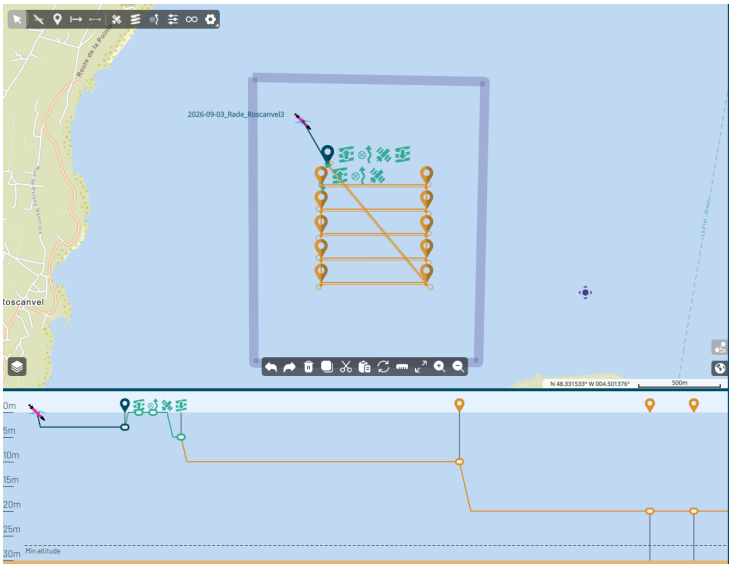


Figure 16: Mission 3 – Bay of Roscanvel: Long zigzag pattern.

3.4 DVL-Based Bathymetry Modeling

3.4.1 Method

Although DVLs are primarily dedicated to velocity estimation for dead-reckoning navigation, their multi-beam acoustic sounding structure can be used to generate local bathymetric data of the seabed[1]. The following calculations explore the DVL as an altimeter by combining the beam's distances into a single vertical bathymetric altitude.

The DVL installed in the Yuco is the Water Linked DVL-A50 DVL with four acoustic beams. Figure 17 shows its coordinated frame mounted on the AUV and Figure 18 shows the side view of the device.

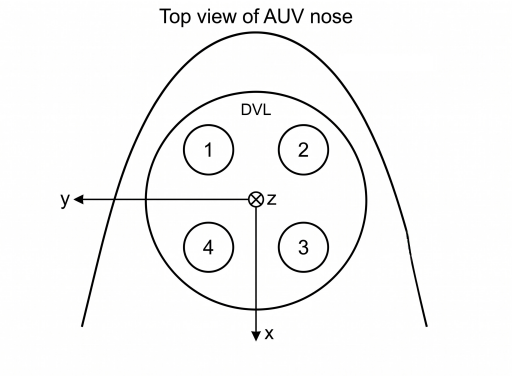


Figure 17: DVL orientation in the AUV.

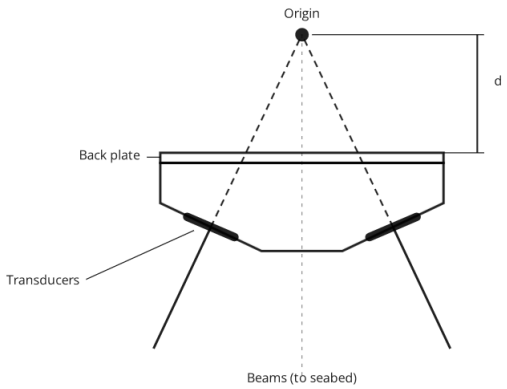


Figure 18: DVL side view.

Looking at the sensor datasheet, it is possible to extract the inclination angle with respect to the vertical z-axis $\gamma = 22.5°$, the distance between the origin and the back plate $d = 28mm$ and the azimuth angle β_j of each each beam $j \in \{1, 2, 3, 4\}$.

$$\beta_1 = 135°, \quad \beta_2 = 225°, \quad \beta_3 = 315°, \quad \beta_4 = 45°. \tag{1}$$

Let d_j denote the acoustic range measured by beam j between the transducers origin and the seafloor reflector. The vertical distance z_j^{DVL} is expressed as:

$$\cos\gamma = \frac{z_j^{\mathrm{DVL}}}{d_j} \iff z_j^{\mathrm{DVL}} = d_j \cos\gamma. \tag{2}$$

The projection of the beam slant range onto the horizontal xy-plane yields:

$$d_j^{\mathrm{proj}} = d_j \sin\gamma. \tag{3}$$

Consequently, the Cartesian coordinates of the seabed impact point $\boldsymbol{P}_j^{\mathrm{DVL}} = \begin{bmatrix} x_j^{\mathrm{DVL}} & y_j^{\mathrm{DVL}} & z_j^{\mathrm{DVL}} \end{bmatrix}^\top$ in the DVL frame are given by:

$$\begin{cases} x_j^{\mathrm{DVL}} = d_j \sin\gamma \cos\beta_j \\ y_j^{\mathrm{DVL}} = d_j \sin\gamma \sin\beta_j \\ z_j^{\mathrm{DVL}} = d_j \cos\gamma. \end{cases} \tag{4}$$

Factoring out the vertical depth component z_j^{DVL}, the beam position vector can be reformulated directly as a function of z_j^{DVL} and the fixed geometric angles:

$$\boldsymbol{P}_j^{\mathrm{DVL}} = \begin{bmatrix} x_j^{\mathrm{DVL}} \\ y_j^{\mathrm{DVL}} \\ z_j^{\mathrm{DVL}} \end{bmatrix} = z_j^{\mathrm{DVL}} \begin{bmatrix} \tan\gamma \cos\beta_j \\ \tan\gamma \sin\beta_j \\ 1 \end{bmatrix}. \tag{5}$$

Assuming that the footprint created by the four beam contact points is locally planar, the seabed profile can be represented by the first-order polynomial:

$$f(x, y) = a + bx + cy, \tag{6}$$

where $\boldsymbol{p} = \begin{bmatrix} a & b & c \end{bmatrix}^\top$ represents the vector of plane parameters.

To compute the optimal fitting plane across the four simultaneous soundings, we formulate an least-squares minimization problem with the linear system:

$$\boldsymbol{M}\boldsymbol{p} = \boldsymbol{y}, \tag{7}$$

where:

$$\boldsymbol{M} = \begin{bmatrix} 1 & x_1^{\text{DVL}} & y_1^{\text{DVL}} \\ 1 & x_2^{\text{DVL}} & y_2^{\text{DVL}} \\ 1 & x_3^{\text{DVL}} & y_3^{\text{DVL}} \\ 1 & x_4^{\text{DVL}} & y_4^{\text{DVL}} \end{bmatrix} \in \mathbb{R}^{4\times 3}, \quad \boldsymbol{p} = \begin{bmatrix} a \\ b \\ c \end{bmatrix} \in \mathbb{R}^{3\times 1}, \quad \boldsymbol{y} = \begin{bmatrix} z_1^{\text{DVL}} \\ z_2^{\text{DVL}} \\ z_3^{\text{DVL}} \\ z_4^{\text{DVL}} \end{bmatrix} \in \mathbb{R}^{4\times 1}. \tag{8}$$

The least-squares parameter estimate $\hat{\boldsymbol{p}}$ is obtained via the Moore-Penrose pseudo-inverse:

$$\hat{\boldsymbol{p}} = \boldsymbol{K}\boldsymbol{y}, \quad \text{with} \quad \boldsymbol{K} = \left(\boldsymbol{M}^\top \boldsymbol{M}\right)^{-1} \boldsymbol{M}^\top. \tag{9}$$

Finally, the estimated vertical distance can be found by replancing $(x, y) = (0, 0)$ in Equation 6:

$$\hat{z}^{\text{DVL}} = a \tag{10}$$

3.4.2 Results

Based on the modeling in Section 3.4.1, Figure 19 shows the comparison between the echo sounder altitude and the DVL-based altitude. Note that the algorithm do not need all four beam distances at every time instant to work. If there are 3 or 4 beams, it uses the least-squares approximation of the plane. However, if only 1 or 2 beams are available at a time instant, simple projections and averages are computed instead. The Figure validates the modeling calculations.

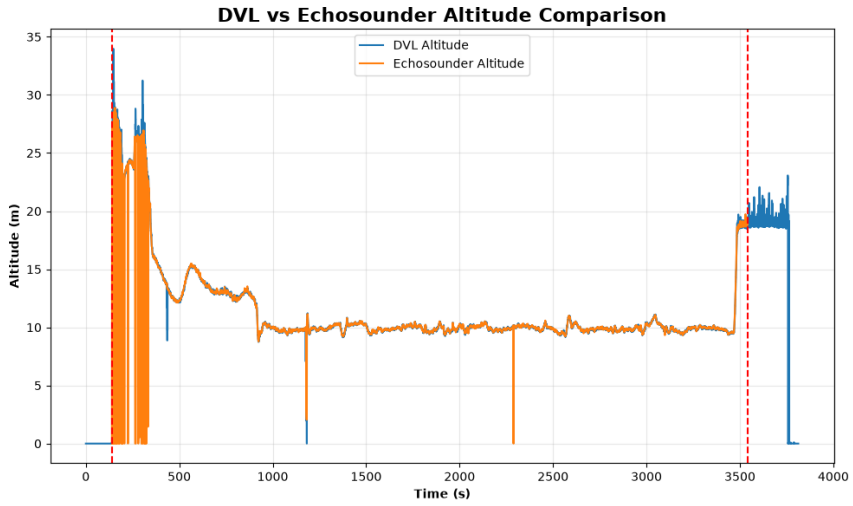


Figure 19: DVL-based altitude versus echosounder altitude (Mission 3).

3.5 Analysis

3.5.1 Sensors Interference

Because multiple active acoustic sensors operate simultaneously within the micro-AUV, it is important to evaluate the possibility of interference between them.

- **Acoustic Pinger:** $f_{\text{pinger}} = 37\,\text{kHz}$;
- **Single-Beam Echo Sounder (SBES):** $f_{\text{SBES}} = 540\,\text{kHz}$ with an acoustic pulse duration $\tau = 12\,\mu\text{s}$ (main-lobe bandwidth $B \approx 1/\tau \approx 83.3\,\text{kHz}$);
- **Doppler Velocity Log (DVL):** $f_{\text{DVL}} = 625\,\text{kHz}$.

Acoustic cross-talk requires that the transmitted acoustic energy of one emitter falls within the receiving passband and sensitivity envelope of another. The frequency separation between the sensors satisfies:

$$\Delta f_{\text{SBES, DVL}} = |f_{\text{DVL}} - f_{\text{SBES}}| = 85\,\text{kHz}. \tag{11}$$

The pinger operates at a low acoustic frequency compared to the other instruments. Its harmonics are also in multiples there are far from the theirs frequencies.

Between the echo sounder and the DVL, the 85 kHz frequency delta protects them from mutual interferences. Consequently, the overall system operates concurrently without measurable interference.

3.5.2 Echo Sounder Acoustic Analysis

Acoustic Operating Principle The Δt between the emission of the acoustic pulse and the detection of the seabed echo determines the one-way slant range r:

$$r = \frac{c \cdot \Delta t}{2} \tag{12}$$

where c is the sound velocity in the water column (nominally $c \approx 1500\ \text{m} \cdot \text{s}^{-1}$).

The transmitted signal is a truncated Continuous Wave (CW) pulse $s(t)$ of carrier frequency $f_0 = 540$ kHz and pulse duration $\tau = 12\ \mu$s:

$$s(t) = \Pi_\tau(t) \cdot A\cos(2\pi f_0 t + \varphi_0) \tag{13}$$

where $\Pi_\tau(t)$ is the rectangular window of duration τ, and A denotes the signal amplitude. The spectral bandwidth B associated with this rectangular pulse envelope is governed by the main lobe of the sinc function:

$$B \approx \frac{1}{\tau} = \frac{1}{12 \times 10^{-6}\ \text{s}} \approx 83.33\ \text{kHz} \tag{14}$$

which is consistent with the instrument's bandwidth constraint ($B < 200$ kHz).

Range Resolution The range resolution δr_{theo} of an unmodulated rectangular pulse represents the minimum separation along the acoustic axis required to distinguish two discrete targets. It can be calculated as:

$$\delta r_{\text{theo}} = \frac{c \cdot \tau}{2} = \frac{1500 \text{ m} \cdot \text{s}^{-1} \times 12 \times 10^{-6} \text{ s}}{2} = 9.0 \times 10^{-3} \text{ m} = 9.0 \text{ mm} \tag{15}$$

However, the manufacturer specifies an effective range resolution of $\delta r = 1.5$ cm. This difference between the theoretical and instrumental resolution is can attributed to the internal signal processing, filtering, and sampling constraints of the sensor.

Acoustic Wavelength and Spatial Transducer Dimension At $f_0 = 540$ kHz, the acoustic wavelength in seawater is:

$$\lambda = \frac{c}{f_0} = \frac{1500 \text{ m} \cdot \text{s}^{-1}}{540 \times 10^3 \text{ Hz}} \approx 2.78 \text{ mm} \tag{16}$$

For a circular planar piston of active diameter D, the theoretical two-way beam directivity function $\mathcal{D}(\theta)$ is given by the square of the Bessel directivity function:

$$\mathcal{D}(\theta) = \left(\frac{2J_1\left(\pi \frac{D}{\lambda} \sin\theta\right)}{\pi \frac{D}{\lambda} \sin\theta} \right)^4 \tag{17}$$

The total two-way beam aperture $\theta_{-3\text{dB}} \approx 6°$ implies an acoustic diameter $D \approx 1.028 \frac{\lambda}{\theta_{-3\text{dB}}} \approx 27.3$ mm, which is consistent with the outer mechanical transducer diameter of 46.7 mm when including potting and shielding.

Seabed Insonification Assuming vertical incidence over a locally horizontal seabed, the acoustic beam insonifies a circular footprint as shown in figure 20. The equivalent solid beam angle Ψ for a narrow conical beam ($\theta = 6°$) is:

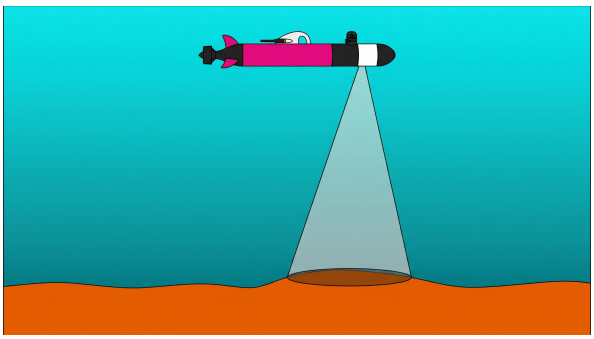


Figure 20: Insonified area illustration of the echo sounder.

$$\Psi \approx \pi \left(\frac{\theta}{2}\right)^2 \approx \pi \left(\frac{0.1047}{2}\right)^2 \approx 8.61 \times 10^{-3} \text{ sr} \quad (10 \log_{10} \Psi \approx -20.65 \text{ dB sr}) \tag{18}$$

At an altitude h above the seafloor, the footprint diameter $d_{\text{footprint}}$ is:

$$d_{\text{footprint}} = 2h \tan\left(\frac{\theta}{2}\right) \approx 2h \tan(3^\circ) \approx 0.1048 \cdot h \tag{19}$$

The corresponding insonified surface area $\mathcal{A}$ in the beam-limited regime is:

$$\mathcal{A} = \pi \left(h \tan\left(\frac{\theta}{2}\right)\right)^2 \approx \Psi \cdot h^2 \tag{20}$$

Table 2 highlights the footprint dimensions and theoretical insonified areas across different operational altitudes of the micro-AUV.

Table 2: Beam footprint diameter and area as a function of AUV altitude ($c = 1500$ m$\cdot$s^{-1}).

Altitude h [m]	**Footprint Diameter** $d_{\text{footprint}}$ [m]	**Insonified Area** $\mathcal{A}$ [m^2]	**Two-Way Time** Δt [ms]
5.0	0.52	0.216	6.67
10.0	1.05	0.863	13.33
15.0	1.57	1.941	20.00
20.0	2.10	3.452	26.67
25.0	2.62	5.393	33.33
30.0	3.14	7.766	40.00
50.0	5.24	21.57	66.67
100.0	10.48	86.29	133.33

Ping Rate Constraint To prevent range ambiguity between two successive pings, the pulse interval must exceed the two-way transit time for the maximum set range $r_{\max}$:

$$T_{\text{ping}} > \frac{2r_{\max}}{c} \implies f_{\text{ping}} < \frac{c}{2r_{\max}} \tag{21}$$

For $r_{\max} = 100$ m, $T_{\text{ping}} > 133.3$ ms ($f_{\text{ping}} < 7.5$ Hz).

3.5.3 Bathymetric Acquisition Chain

The objective of the bathymetric acquisition chain is to transform discrete acoustic range measurements and vehicle telemetry into georeferenced seabed soundings referenced to an absolute vertical datum.

To model the sounding geometry, three primary Cartesian coordinate frames are defined:

1. **Navigation Frame** $\mathcal{F}_n = \{O_n; \mathbf{x}_n, \mathbf{y}_n, \mathbf{z}_n\}$: A local North-East-Down (NED) terrestrial reference frame.

2. **Body Frame** $\mathcal{F}_b = \{O_b; \mathbf{x}_b, \mathbf{y}_b, \mathbf{z}_b\}$: A vehicle-fixed reference frame centered at the AUV's origin O_b.

3. **Sensor Frame** $\mathcal{F}_s = \{O_s; \mathbf{x}_s, \mathbf{y}_s, \mathbf{z}_s\}$: Located at the acoustic center of the altimeter. Not considering the lever-arm offset vector.

The angular attitude of the micro-AUV relative to the navigation frame $\mathcal{F}_n$ is parameterized by the standard aerospace Euler angle sequence Z-Y-X, defined by yaw (ψ), pitch (θ), and roll (ϕ).

The direction cosine matrix $\mathbf{R}_b^n \in \mathcal{SO}(3)$ mapping body-frame vectors into the navigation frame is given by:

$$\mathbf{R}_b^n(\phi, \theta, \psi) = \mathbf{R}_z(\psi)\,\mathbf{R}_y(\theta)\,\mathbf{R}_x(\phi) \tag{22}$$

Expanding this product yields the complete Euler transformation matrix:

$$\mathbf{R}_b^n = \begin{bmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix} \tag{23}$$

Let a denote the acoustic range (altitude) measured by the altimeter along its acoustic axis. In the sensor frame $\mathcal{F}_s$ (and body frame $\mathcal{F}_b$), the vector pointing from the transducer center to the insonified seabed area is expressed as:

$$\mathbf{v}_{\text{beam}}^b = \begin{bmatrix} 0 \\ 0 \\ a \end{bmatrix} \tag{24}$$

Applying the rotation matrix $\mathbf{R}_b^n$, the sounding beam vector in the navigation frame $\mathcal{F}_n$ becomes:

$$\mathbf{v}_{\text{beam}}^n = \mathbf{R}_b^n\,\mathbf{v}_{\text{beam}}^b = a \begin{bmatrix} \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi \\ \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi \\ \cos\phi\cos\theta \end{bmatrix} \tag{25}$$

From Equation (25), the true vertical component Δz_n of the acoustic altitude beneath the transducer is:

$$\Delta z_n = a\cos\phi\cos\theta \tag{26}$$

At any acquisition instant t, by ignoring the the transducer vertical mounting offset, the total instantaneous water column depth $D(t)$ measured can be calculated as:

$$D(t) = z_{\text{depth}}(t) + a(t)\cos\phi(t)\cos\theta(t) \tag{27}$$

To refer the to the chart datum, the tidal reduction $h_{\text{tide}}(t)$ must be applied, formulating the fundamental bathymetry equation as:

$$Z_{\text{bathy}}(t) = z_{\text{depth}}(t) + a(t)\cos\phi(t)\cos\theta(t) - h_{\text{tide}}(t) \tag{28}$$

Finally, it is important to note that the AUV's depth $z_{\text{depth}}(t)$ can be easily measured by its hydrostatic pressure sensor, as well as the altitude $a(t)$, and the pitch (θ) and roll (ϕ) angles (though these may experience some drift over time). The major challenge here is related to the measurement of the tidal reduction $h_{\text{tide}}(t)$. Even when using a tide gauge near the AUV's mission area, combining its GNSS location with the terrain's bathymetry is not a trivial task due to several uncertainties.

4 Conclusion

This internship demonstrated the development of a bathymetric data acquisition chain on the instrumented micro-AUV *Yuco-Carrier* via the custom *Yodac* payload. The experimentations validaded the integration of a dedicated C++ driver library for the echo sounder within the ROS architecture. This enabled synchronized logging of vehicle navigation states, creating the framework for further post-processing analysis and future reasearch.

The experimental trials conducted in the Bay of Brest confirmed the acoustic and operational feasibility of the selected sensor configuration:

- **Echosounder Acquisition Rate:** As detailed in Table 2, the pulse repetition frequency of $f_{\text{ping}} = 1.0\,\text{Hz}$ proves well-dimensioned for the survey operational velocity, satisfiyng the unambiguous echo return threshold ($T_{\text{ping}} > 133.3\,\text{ms}$ for $r_{\max} = 100\,\text{m}$).

- **DVL-Based Bathymetric Modeling:** The mathematical formulation developed in Section 3.4—which models the four slanted acoustic beams of the A50 DVL via a local first-order plane least-squares estimation—was validated against the echo sounder vertical soundings (Figure 19). The close agreement between the estimated vertical altitude $\hat{z}^{\text{DVL}}$ and the echosounder measurements raises a doubt about the echo sounder true necessity. However, this should be studied more carefully in future work before a major decision.

Despite these positive operational outcomes, the experimental campaigns highlighted two constraints that require further refinement:

- **Acoustic Pinger Integration:** The acoustic pinger was affixed externally to the vehicle's hull after tests revealed that internal buoyancy foams heavily attenuated its acoustic transmission (Section 2.3). While functionally operational, this external configuration alters vehicle hydrodynamic performance and presents snagging hazards. Future work must consider a proper enclosure.

- **Tidal Reduction Model $h_{\text{tide}}(t)$:** As formulated in Equation (28) and discussed at the end of Section 3.5.3, computing true chart datum bathymetry $Z_{\text{bathy}}(t)$ requires an accurate tidal reduction $h_{\text{tide}}(t)$. However, relying on distant shore-based tide gauges introduces non-negligible vertical uncertainties caused by spatial phase lags, coastal shoaling effects, leading to discrepancies in the estimated value. Local tide gauges also have several uncertainties that needs to be considered. Implementing an improved approach must be considered in future work.

Ultimately, this work establishes the essential foundation for future studies on state estimation filters like Particle Filter or Extended Kalman Filter.

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