TECTONIC

TEchnological **C**onsortium **TO** develop sustai**N**abl**I**ity of underwater **C**ultural heritage

Reporting the activities of the secondments 39ESR & 40ESR

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25/8/2023

TECTONIC project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 873132

General information

IDs	39ESR & 40ESR
WP	4. Open technologies for the robotic inspection, monitoring and documentation of UCH
Task	4.3 Customization of the software for ROV/AUV remote control
Objectives	• Testing the solutions generated (communication protocols, electronic architecture, etc.) by H2O colleagues and previous TECTONIC secondees. • Working on integrating functionalities (acoustic ToF, LoRa, WiFi, GPS, etc.) in the prototype buoy system. • Integrating global positioning system (GPS) functionality in each of the buoys to obtain the absolute reference points concerning the target underwater unit. • Solution testing in a controlled environment. • Contribution to deliverable D4.3 Report on the customisation of the Mission Planner.
Period	26/6/2023 – 25/8/2023
Sending institution	USAL
Hosting institution	H2O ROBOTICS

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1. Executive summary

This document describes the development of an Underwater Buoy System for underwater locations in the framework of **WP4. Open technologies for the robotic inspection, monitoring and documentation of UCH**, which main objective is to design, develop and implement a highly innovative buoy system that allows the precise location of remotely operated submersible vehicles (underwater ROV) to obtain the exact position where the vehicle is located by obtaining data (video, marine parameters, etc.).

The **Underwater Buoy System** will provide advanced positioning and tracking capabilities. Using open-source technologies, the system will be equipped with high-precision sensors and reliable communication to detect and transmit vital information about an underwater object's location and surrounding conditions. This work is based on the work carried out by previous TECTONIC secondees and colleagues from H2O Robotics.

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2. The Underwater Bouy System

The proposed system includes the following elements (Figure 1):

- **Underwater Acoustic Unit.** An underwater object of which the absolute position is intended to be obtained. This object is the ROUV, but it can be any object incorporating an acoustic transceiver compatible with the system (divers, scanner, sensors, etc.).
- **Master Buoy.** A buoy that orchestrates the distance measurement between each buoy and the Underwater Unit. To do so, it creates a WiFi access point to which the other buoys connect and, using the MQTT messaging protocol, exchange information with each other. The Master Buoy acts as an MQTT broker. It has a LoRa module to transmit messages over long distances (up to 10 km) with the Offshore Unit, sharing the GPS location of each buoy (latitude, longitude and error) and the distance between each buoy and the Underwater Unit. The Master Buoy executes the range measurement sequence when requested by the Offshore Unit, to which it responds with the data obtained by each buoy.
- **Slave Buoys.** Two buoys connected to the WiFi access point created by the Master Buoy and acting as MQTT clients. They initiate the distance measurement with the Underwater Unit when requested by the Master Buoy. Once the distance and GPS location data are taken from the device itself, the information is published to a specific MQTT topic.
- **Offshore Unit.** Located on the shore or in a catamaran, it consists of a modem with LoRa (Long Range) technology, and a computer connected via USB.

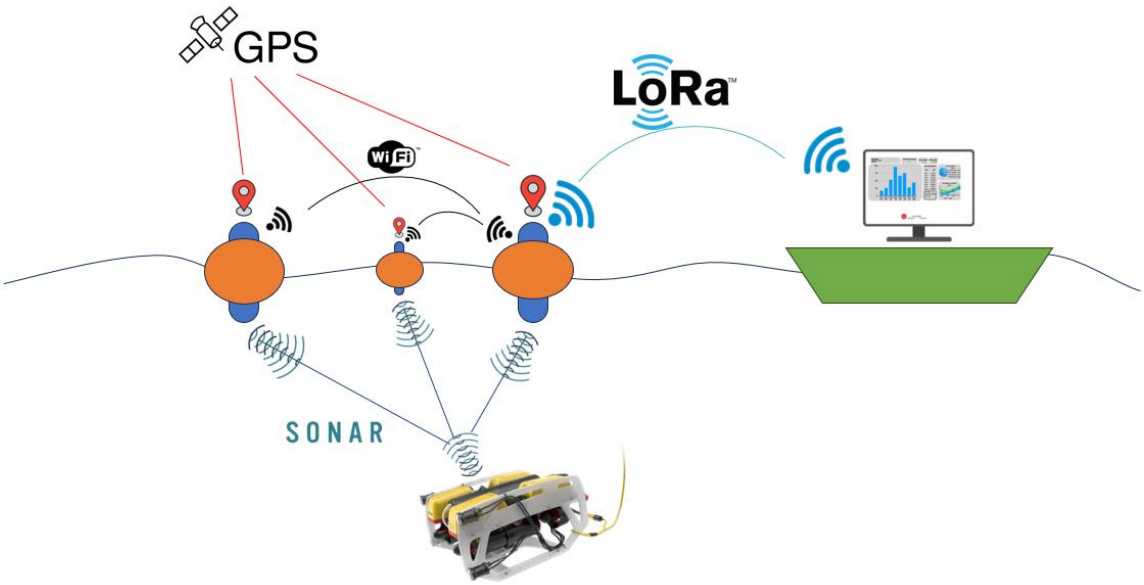

Figure 1. Graphical abstract of the Underwater Buoy System.

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3. Network and software architecture

The network architecture (Figure 2) of the proposed system is divided into two distinct parts. The first part is the surface communication between the Offshore Unit, the Master Buoy and the Slave Buoys. The second part is the underwater communication between the three buoys and the Underwater Acoustic Unit.

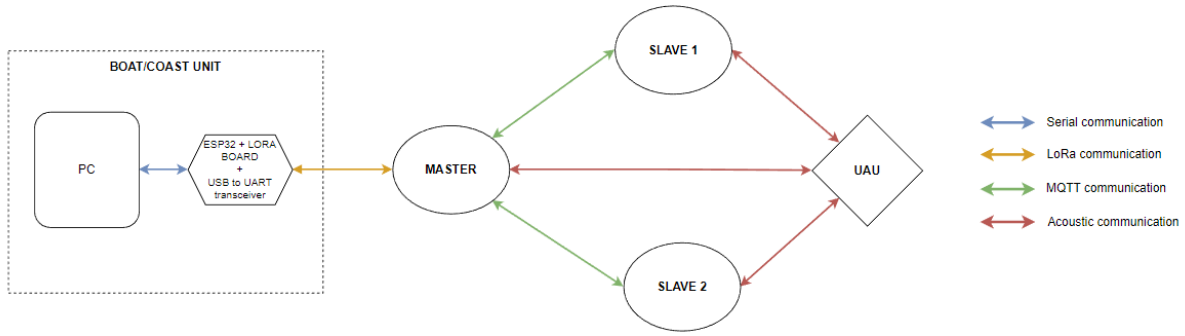

Figure 2. Network architecture of the Underwater Buoy System.

3.1. Offshore Unit – Master Buoy communication

From the computer, via the serial port, a message of the form "$G,<NUM>, RNG", where <NUM> corresponds to the three-digit identifier of the target underwater unit, is transmitted to the ESP32 board. This message is referred to as a ping request. The ESP32 + LoRa board, acting as the Gateway, picks up such a message and sends it to the Master Buoy via LoRa wireless communication. The LoRa message carries an identifier of the receiver to which the message is addressed and an identifier of the sender. Thus, if the device receiving the message does not have the identifier indicated in the message, it is ignored. The same process is performed from the Master Buoy to the Offshore Unit.

When the Master Buoy receives the range data between each buoy and the Underwater Acoustic Unit and the GPS position of each buoy, the message with all the information is formed and sent via LoRa to the Offshore Unit. When the message is received, the ESP32 microcontroller adds the time of receipt and redirects it to the computer via serial. The message, when it arrives at the PC, has the following form:

<date> <time> [RNG] B1, RNG, <range>, <lat>, <lon>, <GPS_error>
<date> <time> [RNG] B2, RNG, <range>, <lat>, <lon>, <GPS_error>
<date> <time> [RNG] B3, RNG, <range>, <lat>, <lon>, <GPS_error>
<date> <time> [RNG] T, <time_to_get_range>

Where,

- <date>: date in the format dd/mm/yyyyy
- <time>: time in the format hh:mm:ss
- [RNG]: data type contained in the message. In this case, it is the range request response. If this field is [CU] the message displays internal ESP32 information.
- B#: buoy to which the message belongs (B1: Master, B2: Slave 1, B3: Slave 2)

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- RNG: range calculated correctly. Otherwise it shows LOG.

- <range>: distance in meters between the buoy and the Underwater Acoustic Unit.
- <lat>: latitude in decimal degrees.
- <lon>: longitude in decimal degrees.
- >GPS_error>: error in centimetres.
- T: indicates that the information below is related to the range acquisition time by all buoys.
- <time_to_get_all_ranges>: range acquisition time in milliseconds from the time it is initiated by the Master Buoy until the range is received from the Slave 2.

3.2. Master – Slaves buoys communication

The Master Buoy acts as a transfer node through which all information is passed between the Offshore Unit and the buoys. The Master Buoy creates a WiFi access point to which the Slave Buoys connect. Once the Master Buoy has received the ping request, the process is executed sequentially:

1. The Master Buoy pings the underwater unit.
2. If communication is achieved and it calculates the range, Slave Buoy 1 is requested to ping.
3. When the range calculated by Slave Buoy 1 is received, Slave Buoy 2 is requested to ping.
4. Once the Master Buoy receives the last range, the messages are packaged and sent to the Offshore Unit.

The communication between the buoys is accomplished using the MQTT messaging protocol, as shown in the figure below.

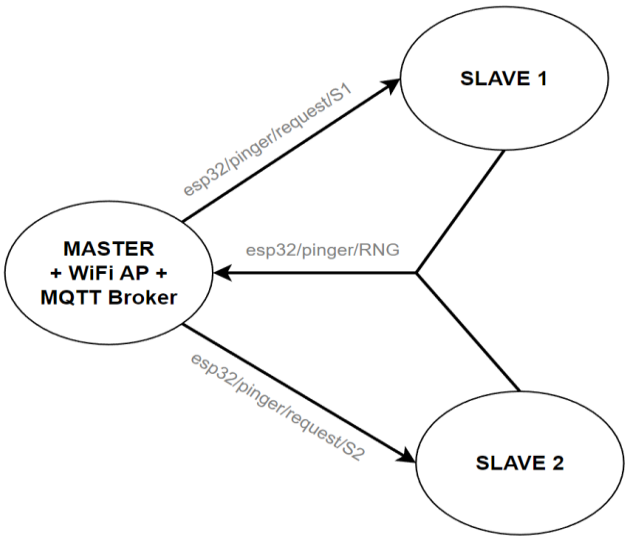

Figure 3. Communication protocol between the buoys.

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The communication via MQTT is accomplished by posting on different topics.

- esp32/pinger/request/S1: topic in which the Master Bouy posts the request for the start of range measurement of Slave 1.
- esp32/pinger/request/S2: topic in which the Master Bouy publishes the request for the start of the range measurement of Slave 2.
- esp32/pinger/RNG: topic in which each Slave Buoy publishes its range calculation.

4. Electronic architecture

The electronic architecture of each of the elements of the proposed system is described below.

4.1. Underwater Acoustic Unit

The electronic architecture of the Underwater Acoustic Unit used for the development of the functional tests of the system is displayed below (Figure 4).

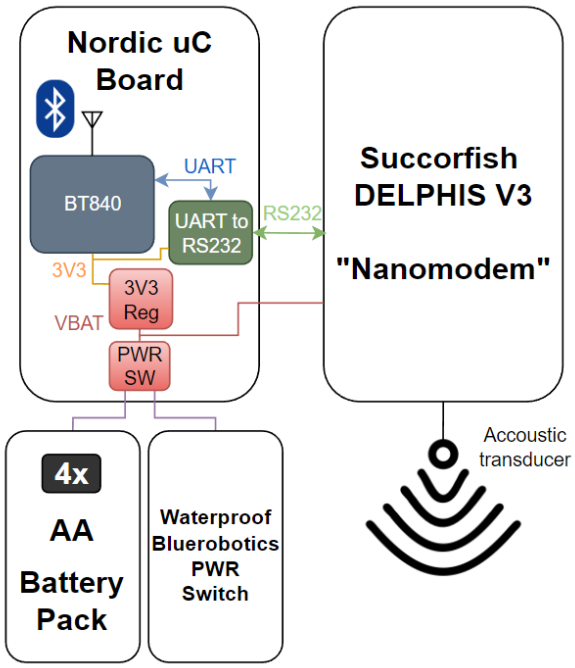

Figure 4. Electronic architecture of the Underwater Acoustic Unit.

The unit comprises:

- **Underwater acoustic transducer**. A component that transforms electrical signals into sound waves, and vice versa, in the aquatic environment for communication and data transmission. It is used to transmit and receive information in marine environments, such as oceans, lakes and rivers.
- **Nanomodem** (Succorfish Delphis V3). An electronic circuit that allows underwater acoustic communication using an acoustic transducer. It has the necessary electronic components to

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generate the electrical signals, which will later be transformed into acoustic signals, and to analyse the signals received. The product datasheet shows a series of commands for communication between the product and an external device. This communication is established through an RS232 interface, which allows for maintaining the integrity of the data against noise.

- **Nordic uC Board**. Printed Circuit Board (PCB) developed by the Labust Research Group. It has the BT840 module, based on the Nordic nRF52840 microcontroller, which integrates a Bluetooth module. It is responsible for transmitting data between the nanomodem and the ESP32 + LoRa board and regulating the voltage required for the correct operation of the electronic components.
- **Power switch** (Blue Robotics Power switch). Waterproof power switch from Blue Robotics. It allows control of the on/off of the circuit without the need to open the housing. This ensures the waterproofness of the device.
- **Pack of 4 AA batteries**. Pack of 4 AA batteries to power the circuit.
- **Encapsulation**. Set of plastic parts that enclose the electronic components and make them watertight.

The unit used during the development and validation of the prototype is shown in the figure below (Figure 5):

Figure 5. Underwater Acoustic Unit used.

4.2. Master Buoy

The electronic architecture of the Master Buoy used for the development of the functional tests of the system is displayed below (Figure 6).

The unit comprises:

- **Underwater acoustic transducer.** A component that transforms electrical signals into sound waves, and vice versa, in the aquatic environment for communication and data transmission. It is used to transmit and receive information in marine environments, such as oceans, lakes and rivers.
- **Nanomodem** (Succorfish Delphis V3). An electronic circuit that allows underwater acoustic communication using an acoustic transducer. It has the necessary electronic components to generate the electrical signals, which will later be transformed into acoustic signals, and to analyse the signals received. The product datasheet shows a series of commands for communication between the product and an external device. This communication is established through an RS232 interface, which allows for maintaining the integrity of the data against noise.

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- **Power switch** (Blue Robotics Power switch). Waterproof power switch from Blue Robotics. It allows control of the on/off of the circuit without the need to open the housing. This ensures the waterproofness of the device.
- **Three battery pack**. 3.7V 2500 mAh Li-Ion 18650 batteries connected in parallel for a total capacity of 7500 mAh.
- **Encapsulation**. Set of plastic parts that enclose the electronic components and make them watertight.
- **ESP32 + LoRa Board.** Electronic board developed by the manufacturer e-radionica.com (now Soldered Electronics). It has an ESP32-WROOM-32D microcontroller, which integrates WiFi and Bluetooth wireless communications technologies, and a LoRa module for data transmission over long distances. The ESP32 microcontroller communicates with the "Nordic uC Board" and the GPS module via 2 UART serial buses and with the LoRa module via the SPI serial bus. Although the board has a USB connector, it is only used to power the board. To program the ESP32, a USB to UART transceiver must be used and compatible with the microcontroller.
- **GPS module** (Adafruit Ultimate GPS): high-precision and high-performance GPS module developed by Adafruit Industries. It offers real-time satellite tracking, providing location, speed and time data. It communicates with the ESP32 microcontroller through the UART serial bus. Once it receives a given command from the ESP32, it starts the position calculation process and returns the information to the microcontroller for interpretation.

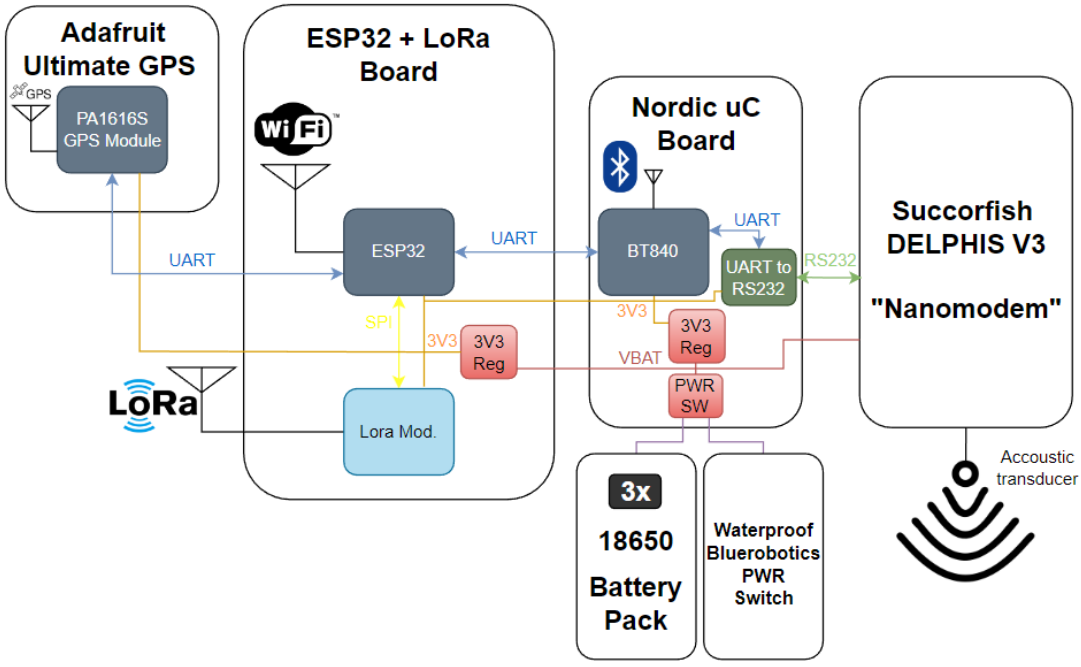

Figure 6. Electronic architecture of the Master Buoy.

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The encapsulated electronic device used for the Master and Slave Buoys during the prototype development and validation is shown in Figure 7.

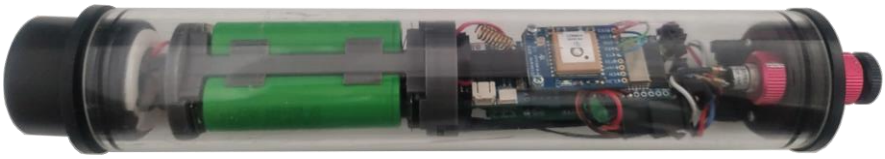

Figure 7 Encapsulated electronic device used for the Master and Slave Buoys.

Figure 8 displays the electronic device inside the buoy, which allows its buoyancy and the permanent immersion of the acoustic transducer in the water.

Figure 8. Electronic device inside the buoy.

4.3. Slave Buoys

The electronic architecture of the Slave Buoys used for the development of the functional tests of the system is displayed below (Figure 9). The electronic architecture of these devices is similar to the Master Buoy; the only difference is the absence of the LoRa antenna.

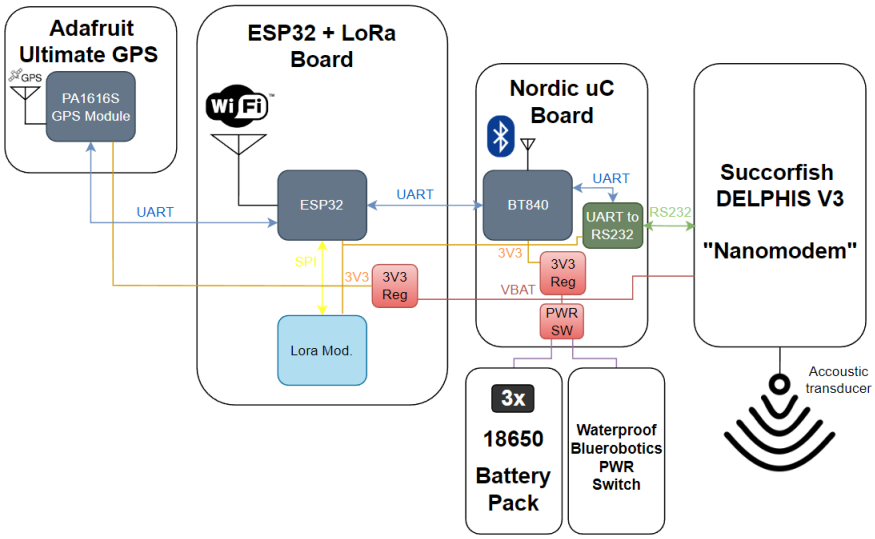

Figure 9. Electronic architecture of the Slave Buoys.

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4.4. Offshore Unit

The electronic architecture of the Offshore Unit used for the development of the functional tests of the system is displayed below (Figure 10).

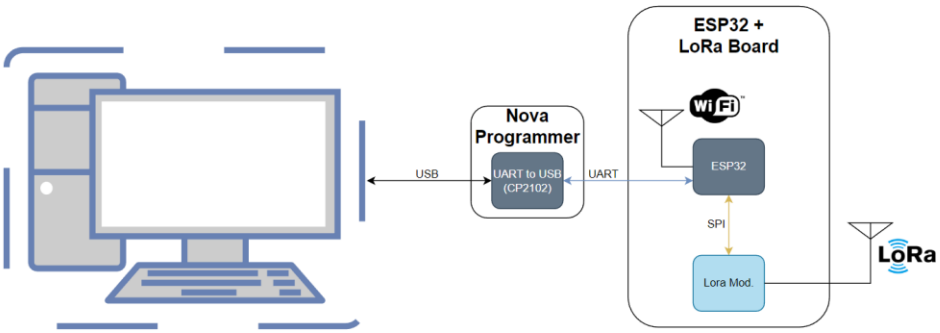

Figure 10. Electronic architecture of the Offshore Unit.

This unit comprises the following elements:

- **ESP32 + LoRa Board**. Here, the board works as a gateway to transforming the information from the computer (via UART) into a LoRa wireless communication, and vice versa.
- **ESP32 Programmer** (Nova Programmer). This device provides a USB interface to connect the ESP32 board to a computer. This programmer, compatible with the microcontroller, allows not only to transmit information between the two devices but also to save new program codes in the internal memory of the microcontroller.
- **Computer.** This equipment is used as an interface for the use of the system. It transmits and receives information through the serial port to which the microcontroller is connected. By sending certain codes, the system starts the position measurement sequence, after which the information is sent back to the computer, where it will be further processed.

The electronic components used for data reception/transmission between the computer and the buoy system via long-range wireless communication "LoRa" are shown in Figure 11.

Figure 11. Electronic components of the Offshore Unit used for data reception/transmission.

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5. Firmware

This section describes the firmware designed for the development of the system, as well as the environments and libraries used. The code generated is shown as a general data flow diagram for a better understanding. The function of each symbol is displayed below:

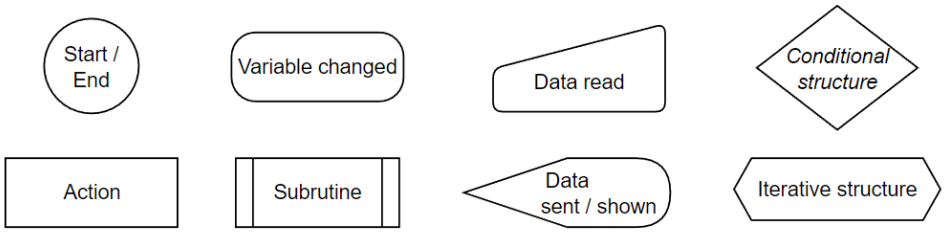

Figure 12. Function of each symbol used in the data flow diagram.

5.1. Development environment

This project has been developed in C++ programming language. The Arduino IDE has been used for the development of the ESP32 code of each of the devices. The version of the IDE on which the developed code has been compiled and uploaded is Arduino IDE 2.1.1.

To compile the code compatible with the ESP32 microcontroller, it is necessary to download and install the ESP32 board package. To do this, the following link is added in the *File > Preferences > Additional boards manager* URLs menu:
https://raw.githubusercontent.com/espressif/arduino-esp32/gh-pages/package_esp32_index.json

Subsequently, open the board browser under *Tools > Board > Board manager…* and install the **ESP32** by **Espressif Systems package**. The system has been programmed with version 2.0.11. The board selected to compile and save the code correctly is "ESP32-WROOM-DA Module".

To compile the project codes, the following libraries must be downloaded from *Sketch > Library Manager:*

- **LoRa** by Sandeep Mistry (0.8.0), from the IDE library manager.
- **SafeString** by PowerBroker2 (4.1.27), from GitHub.
- **PubSubClient** by Nick O'Leary (2.8), from the IDE library manager.
- **sMQTTBroker** by Vyacheslav Shiryaev (0.1.6), from the IDE library manager.
- **ArduinoHttpClient** by Arduino (0.4.0), from the IDE library manager.
- **ArduinoJson** by Benoît Blanchon (6.21.2), from the IDE library manager.
- **ESP32Time** by fbiego (2.0.0), from the IDE library manager.
- **TinyGPS** by Mikal Hart (13.0.0), from the IDE library manager.

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5.2. Programming interface

Figure 13 displays the connection mode of the ESP32 + LoRa board with the Nova programmer. Any other compatible programmer can be used.

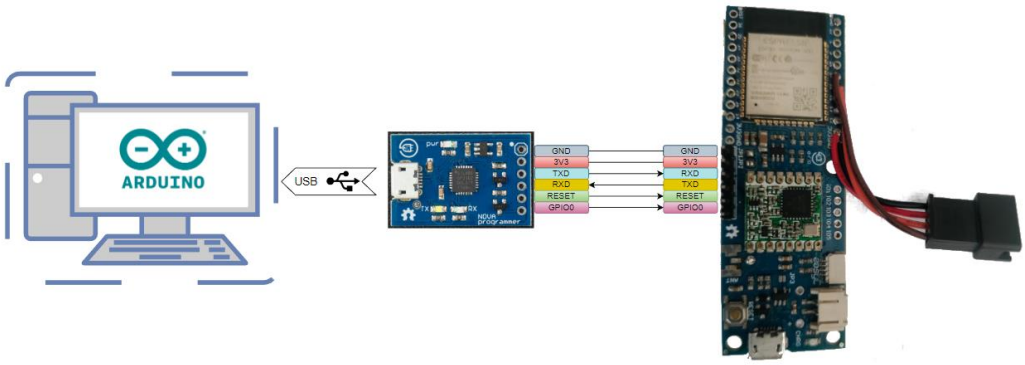

Figure 13. Connection mode of the ESP32 + LoRa board with the Nova programmer.

5.3. Data flow diagram of the Master Bouy

Figure 14 displays the data flow diagram of the Master Bouy, showing the programmed behaviour of the device. Once the initial configurations are executed, the code run on the two cores of the ESP32 microcontroller: using one core for the initialisation and management task of the MQTT broker and the other one for the main program task.

The main task consists of an infinite loop in which the MQTT connection and the arrival of data from the Offshore Unit are managed via LoRa. Once a correct message is received for the initialisation of the measurements, the device executes the sequential measurement, first calculating its distance to the Underwater Acoustic Unit and its GPS location; and then requesting the Slave Buoys (in order). The Slave Buoys share the requested data through an MQTT topic, to which the Master Buoy has previously subscribed.

If the data are collected within a time limit, they are sent back to the Offshore Unit via LoRa. Otherwise, a "Timeout" message is sent, which means that the measurement has not been successfully completed by all buoys.

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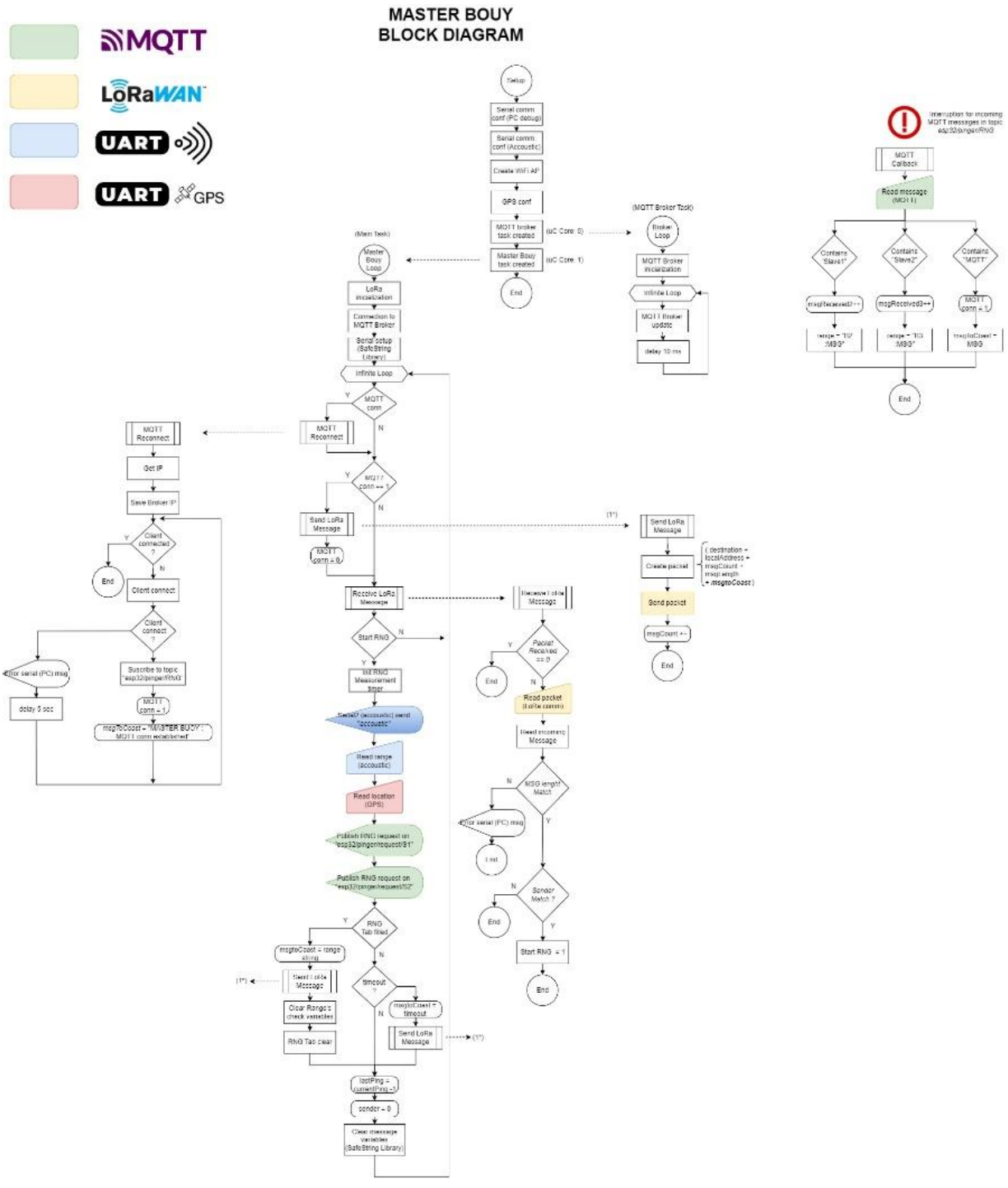

Figure 14. Data flow diagram of the Master Bouy.

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5.4. Data flow diagram of the Slave Bouys

Figure 15 displays the data flow diagram of the Slave Bouys.

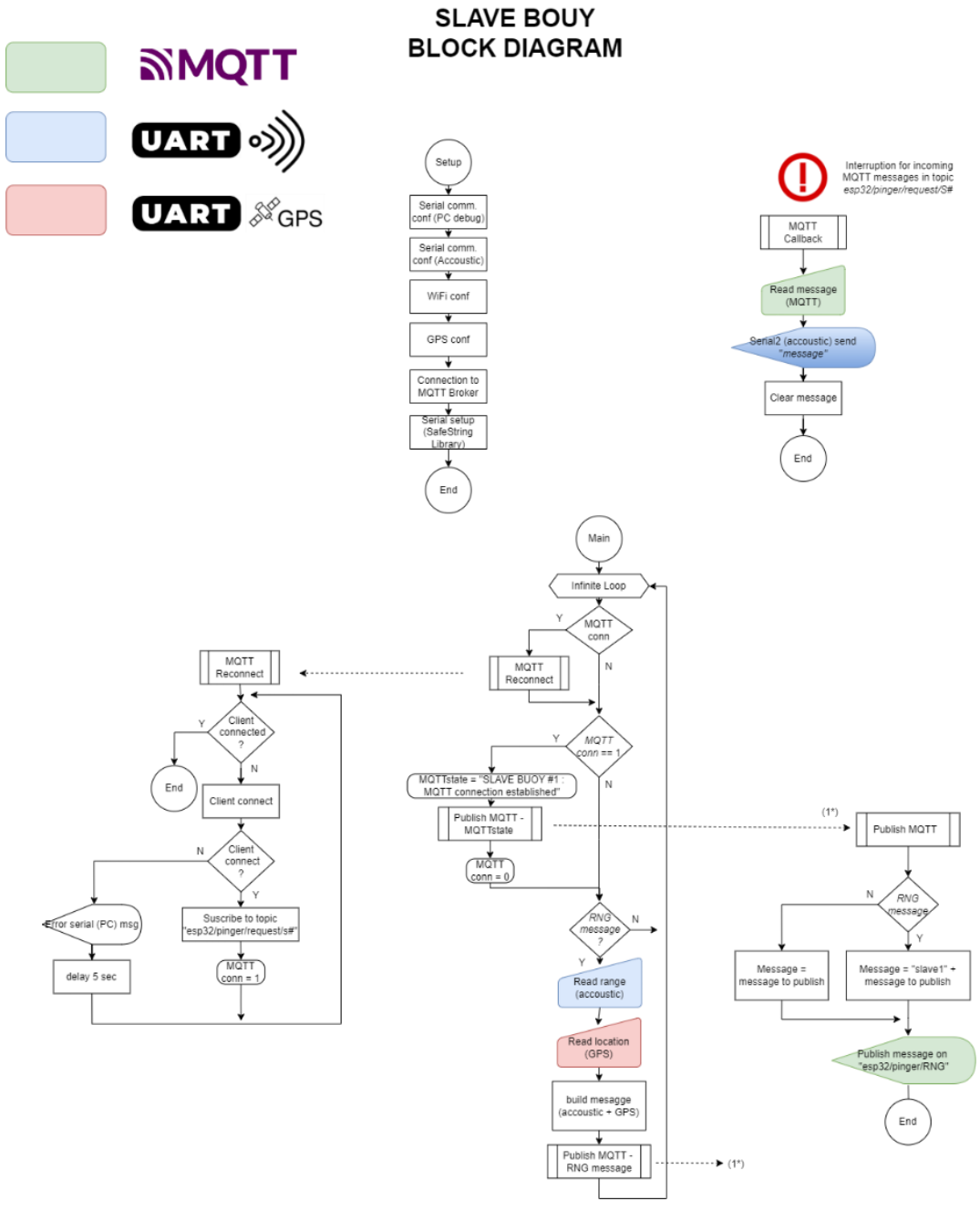

Figure 15. Data flow diagram of the Slave Bouy.

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First of all, the internal configurations and peripherals necessary for the correct operation of the device are executed. Once the initial configurations are completed, the device enters the loop that defines the main program. In this loop, the WiFi connection to the access point created by the Master Buoy is managed, as well as the MQTT connection with the broker, subscribing to the topic through which the Master Buoy will send the information.

Once the Master Buoy requests to start the measurements, the device initiates the communication with the "nanomodem" to obtain the distance calculation between the unit itself and the Underwater Acoustic Unit, obtaining the GPS location data.

These data are grouped and posted in the MQTT topic so that the information is shared with the Master Bouy.

5.5. Data flow diagram of the Offshore Unit

Figure 16 displays the data flow diagram of the Offshore Unit device. It acts as a gateway, taking information via UART from the computer and transmitting it via LoRa, and vice versa. Initially, connecting to a WiFi network synchronises its internal clock with an NTP (Network Time Protocol) server so that the messages it receives via LoRa are marked with a timestamp before being redirected to the PC.

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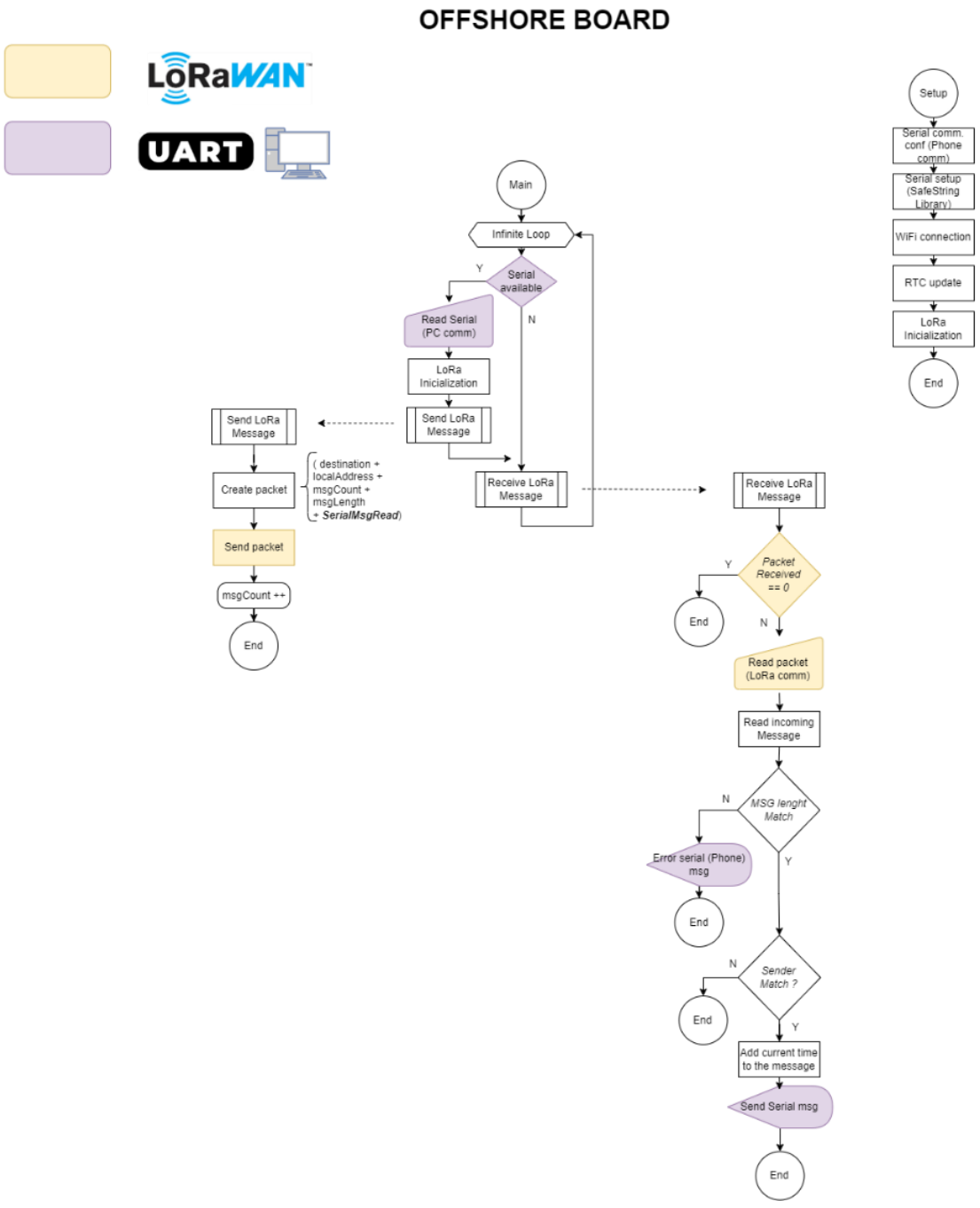

Figure 16. Data flow diagram of the Offshore Unit.

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6. Mechanical design

A series of plastic parts have been designed and printed to avoid short circuits due to the contact between cables and plates and to optimise the space inside the encapsulation. Figure 17 is the 3D design with the set of elements that make up the encapsulation of the buoys, which have been designed with the software Autodesk Inventor 2023.

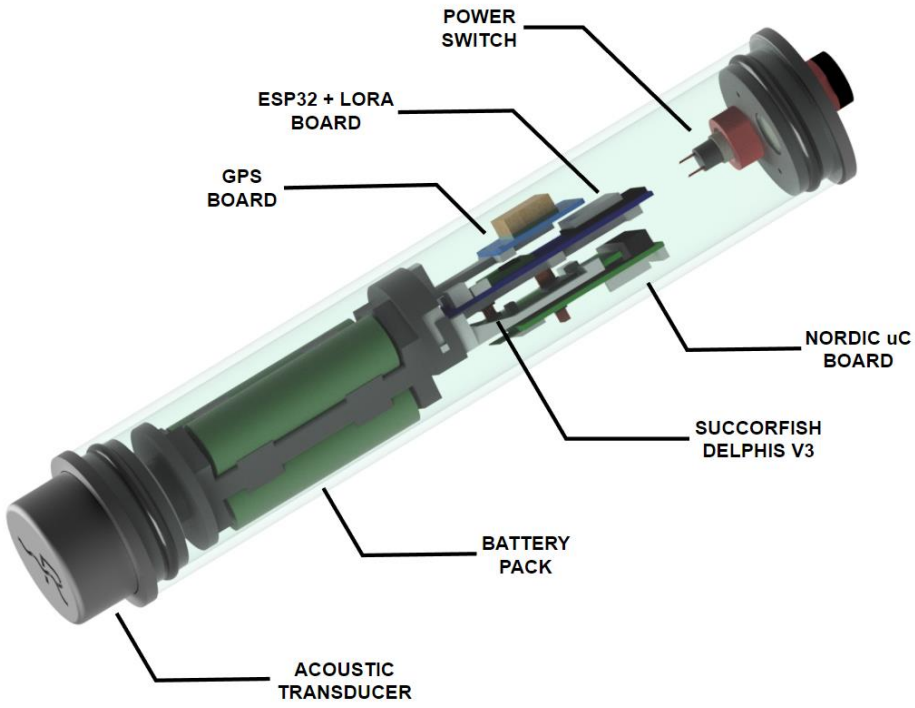

Figure 17. 3D design of the set of elements that make up the encapsulation of the buoys.

7. Serial interface

The serial interface from the PC to the Offshore Unit has the following features:

- Baudrate: 9600 baud
- Data bits: 8
- Stop bits: 1
- Parity: none
- Flow control: Xon/Xoff

Some of the software used during the tests for reading the serial port were:

- MobaXterm
- Putty
- Docklight
- Arduino Serial Monitor

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The code that initialises the range and location measurements is:

$G,<NUM>,RNG

Where <NUM> is the 3-digit identifier of the Underwater Acoustic Unit. For example, the range measurement with a unit with ID = 7 would be:

$G,007,RNG

Care must be taken not to enter any spaces in the string.

8. User guide

1. Program each of the system units. When programming the Slave Buoys, the macro defined in line 11 "BUOY_NUM", corresponding to the number identifying each Slave Buoy, must be changed.
2. Connect the Offshore Unit to a computer via USB and open a serial port that allows bidirectional communication (e.g., Arduino IDE).
3. Power the circuits of each buoy by manually closing the power switch mechanism. No matter the order in which the buoys are turned on, once the Master Buoy is started and creates the access point to which the Slave Buoys are connected.
4. Initiate the range measurement process by sending, manually or automatically (using some programmed script), the initialisation code through the computer's serial port.
5. The data obtained by each buoy will be sent back and displayed through the computer's serial port.

9. Field tests and validation

On the 24th of August 2023, field tests were carried out at Lake Jarun (Zagreb). The data collected is displayed below.

[CU] COAST BOARD
[CU] Attempting to connect.....[SETUP] Connected to WiFi network: JorgeWiFi
[CU] Getting RTC...
[CU] LoRa init succeeded!
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:16:18 [RNG] B1,RNG,1.83,45.779357910156246,15.936900138854981,81
24/08/2023 12:16:18 [RNG] B2,RNG,6.33,45.779346466064456,15.936886787414550,81
24/08/2023 12:16:18 [RNG] B3,RNG,3.00,45.779373168945314,15.936898231506346,81
24/08/2023 12:16:18 [RNG] T,3005
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:16:34 [RNG] B1,RNG,2.34,45.779357910156246,15.936898231506346,81

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24/08/2023 12:16:34 [RNG] B2,RNG,6.94,45.779346466064456,15.936886787414550,81
24/08/2023 12:16:34 [RNG] B3,RNG,2.39,45.779373168945314,15.936898231506346,81
24/08/2023 12:16:34 [RNG] T,3504
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:16:48 [RNG] B1,RNG,3.05,45.779357910156246,15.936897277832031,81
24/08/2023 12:16:48 [RNG] B2,RNG,7.59,45.779346466064456,15.936886787414550,81
24/08/2023 12:16:48 [RNG] B3,RNG,2.58,45.779373168945314,15.936900138854981,81
24/08/2023 12:16:48 [RNG] T,3187
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:17:07 [RNG] B1,RNG,3.23,45.779357910156246,15.936895370483399,81
24/08/2023 12:17:07 [RNG] B2,LOG,Timeout,45.779346466064456,15.936886787414550,81
24/08/2023 12:17:07 [RNG] B3,RNG,3.66,45.779365539550784,15.936902046203613,81
24/08/2023 12:17:07 [RNG] T,6766
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:17:30 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:17:35 [MQTT] SLAVE BUOY #2 : MQTT connection established
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:17:51 [RNG] B1,RNG,2.48,45.779357910156246,15.936889648437500,81
24/08/2023 12:17:51 [RNG] B3,LOG,Timeout,45.779354095458986,15.936878204345703,81
24/08/2023 12:17:51 [RNG] B2,LOG,Timeout,45.779338836669918,15.936884880065917,81
24/08/2023 12:17:51 [RNG] T,6162
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:18:15 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:18
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:18:34 [RNG] B1,RNG,3.42,45.779357910156246,15.936886787414550,81
24/08/2023 12:18:34 [RNG] B2,RNG,6.33,45.779338836669918,15.936882019042968,81
24/08/2023 12:18:34 [RNG] B3,RNG,4.50,45.779338836669918,15.936900138854981,81
24/08/2023 12:18:34 [RNG] T,3771
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:19:00 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:19:01 [MQTT] SLAVE BUOY #2 : MQTT connection established
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:19:27 [RNG] B1,RNG,4.69,45.779354095458986,15.936882019042968,81
24/08/2023 12:19:27 [RNG] B2,LOG,Timeout,45.779338836669918,15.936815261840820,81
24/08/2023 12:19:27 [RNG] B3,LOG,Timeout,45.779373168945314,15.936841964721679,90
24/08/2023 12:19:27 [RNG] T,12040
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:19:42 [RNG] B1,LOG,Timeout,45.779354095458986,15.936880111694335,81
24/08/2023 12:19:42 [RNG] B2,LOG,Timeout,45.779335021972658,15.936812400817870,81

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24/08/2023 12:19:42 [RNG] B3,RNG,4.45,45.779365539550784,15.936818122863769,81
24/08/2023 12:19:42 [RNG] T,11648
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:19:57 [RNG] B1,RNG,3.19,45.779354095458986,15.936877250671386,81
24/08/2023 12:19:57 [RNG] B2,LOG,Timeout,45.779327392578128,15.936804771423340,81
24/08/2023 12:19:57 [RNG] B3,LOG,Timeout,45.779354095458986,15.936806678771972,81
24/08/2023 12:19:57 [RNG] T,12142
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:20:08 [RNG] B1,RNG,3.61,45.779350280761716,15.936875343322753,81
24/08/2023 12:20:08 [RNG] B2,LOG,Timeout,45.779319763183590,15.936800003051758,81
24/08/2023 12:20:08 [RNG] B3,RNG,3.38,45.779346466064456,15.936802864074706,81
24/08/2023 12:20:08 [RNG] T,7774
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:20:30 [FAIL] RNG Measurement Timeout: 3
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:20:53 [RNG] B1,RNG,2.91,45.779350280761716,15.936866760253907,81
24/08/2023 12:20:53 [RNG] B2,RNG,5.91,45.779289245605472,15.936779975891113,81
24/08/2023 12:20:53 [RNG] B3,LOG,Timeout,45.779342651367187,15.936802864074706,81
24/08/2023 12:20:53 [RNG] T,7709
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:21:04 [RNG] B1,RNG,4.92,45.779346466064456,15.936862945556640,81
24/08/2023 12:21:04 [RNG] B2,RNG,4.08,45.779281616210933,15.936772346496582,81
24/08/2023 12:21:04 [RNG] B3,RNG,6.61,45.779342651367187,15.936801910400390,81
24/08/2023 12:21:04 [RNG] T,4252
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:21:23 [RNG] B1,RNG,5.53,45.779346466064456,15.936860084533690,81
24/08/2023 12:21:23 [RNG] B2,LOG,Timeout,45.779289245605472,15.936750411987303,81
24/08/2023 12:21:23 [RNG] B3,RNG,3.75,45.779342651367187,15.936801910400390,81
24/08/2023 12:21:23 [RNG] T,7854
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:21:39 [RNG] B1,RNG,5.53,45.779346466064456,15.936858177185058,81
24/08/2023 12:21:39 [RNG] B2,RNG,5.67,45.779289245605472,15.936744689941406,81
24/08/2023 12:21:39 [RNG] B3,LOG,Timeout,45.779342651367187,15.936800003051758,81
24/08/2023 12:21:39 [RNG] T,8455
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:21:57 [RNG] B1,LOG,Timeout,45.779346466064456,15.936855316162108,81
24/08/2023 12:21:57 [RNG] B2,RNG,5.48,45.779281616210933,15.936739921569824,81
24/08/2023 12:21:57 [RNG] B3,LOG,Timeout,45.779342651367187,15.936798095703124,81
24/08/2023 12:21:57 [RNG] T,11977
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:22:08 [RNG] B1,RNG,3.19,45.779346466064456,15.936852455139161,81
24/08/2023 12:22:08 [RNG] B2,RNG,6.19,45.779273986816404,15.936735153198242,81

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24/08/2023 12:22:08 [RNG] B3,LOG,Timeout,45.779342651367187,15.936797142028808,81

24/08/2023 12:22:08 [RNG] T,7508

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:22:23 [RNG] B1,RNG,2.72,45.779342651367187,15.936847686767579,81

24/08/2023 12:22:23 [RNG] B2,LOG,Timeout,45.779262542724605,15.936724662780761,81

24/08/2023 12:22:23 [RNG] B3,RNG,3.14,45.779342651367187,15.936795234680176,81

24/08/2023 12:22:23 [RNG] T,8076

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:22:38 [RNG] B1,RNG,3.47,45.779342651367187,15.936844825744628,81

24/08/2023 12:22:38 [RNG] B2,RNG,10.0,45.779251098632816,15.936717987060546,81

24/08/2023 12:22:38 [RNG] B3,LOG,Timeout,45.779342651367187,15.936795234680176,81

24/08/2023 12:22:38 [RNG] T,7629

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:22:53 [RNG] B1,LOG,Timeout,45.779342651367187,15.936842918395996,81

24/08/2023 12:22:53 [RNG] B2,RNG,11.3,45.779243469238277,15.936715126037597,81

24/08/2023 12:22:53 [RNG] B3,RNG,2.91,45.779338836669918,15.936792373657226,81

24/08/2023 12:22:53 [RNG] T,8230

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:23:08 [RNG] B1,RNG,4.50,45.779338836669918,15.936841964721679,81

24/08/2023 12:23:08 [RNG] B2,LOG,Timeout,45.779239654541017,15.936713218688964,81

24/08/2023 12:23:08 [RNG] B3,RNG,1.92,45.779338836669918,15.936790466308594,81

24/08/2023 12:23:08 [RNG] T,7748

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:23:19 [RNG] B1,RNG,4.22,45.779338836669918,15.936838150024414,81

24/08/2023 12:23:19 [RNG] B2,RNG,10.1,45.779228210449218,15.936708450317382,81

24/08/2023 12:23:19 [RNG] B3,RNG,1.88,45.779338836669918,15.936790466308594,81

24/08/2023 12:23:19 [RNG] T,3366

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:23:34 [RNG] B1,RNG,3.28,45.779338836669918,15.936835289001464,81

24/08/2023 12:23:34 [RNG] B2,RNG,7.59,45.779220581054689,15.936699867248536,81

24/08/2023 12:23:34 [RNG] B3,RNG,4.17,45.779338836669918,15.936787605285644,81

24/08/2023 12:23:34 [RNG] T,4022

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:23:53 [RNG] B1,RNG,3.09,45.779335021972658,15.936832427978515,81

24/08/2023 12:23:53 [RNG] B2,LOG,Timeout,45.779209136962890,15.936692237854003,81

24/08/2023 12:23:53 [RNG] B3,RNG,6.00,45.779338836669918,15.936786651611328,81

24/08/2023 12:23:53 [RNG] T,7693

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:24:03 [RNG] B1,RNG,4.27,45.779335021972658,15.936829566955566,81

24/08/2023 12:24:03 [RNG] B2,RNG,6.47,45.779201507568361,15.936684608459472,81

24/08/2023 12:24:03 [RNG] B3,RNG,7.69,45.779338836669918,15.936784744262695,81

24/08/2023 12:24:03 [RNG] T,3232

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

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24/08/2023 12:24:19 [RNG] B1,RNG,5.44,45.779331207275388,15.936826705932616,81

24/08/2023 12:24:19 [RNG] B2,RNG,6.28,45.779193878173831,15.936676979064941,81

24/08/2023 12:24:19 [RNG] B3,RNG,8.95,45.779335021972658,15.936782836914062,81

24/08/2023 12:24:19 [RNG] T,3824

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:24:45 [FAIL] RNG Measurement Timeout: 3

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:25:04 [RNG] B1,RNG,4.88,45.779331207275388,15.936820030212402,81

24/08/2023 12:25:04 [RNG] B2,RNG,9.14,45.779190063476562,15.936675071716308,81

24/08/2023 12:25:04 [RNG] B3,RNG,6.28,45.779273986816404,15.936692237854003,81

24/08/2023 12:25:04 [RNG] T,4389

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:25:30 [FAIL] RNG Measurement Timeout: 3

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:25:49 [RNG] B1,RNG,8.48,45.779327392578128,15.936812400817870,81

24/08/2023 12:25:49 [RNG] B2,RNG,9.47,45.779186248779293,15.936673164367675,81

24/08/2023 12:25:49 [RNG] B3,RNG,4.97,45.779258728027345,15.936687469482421,81

24/08/2023 12:25:49 [RNG] T,4122

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:26:15 [FAIL] RNG Measurement Timeout: 2

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:26:45 [FAIL] RNG Measurement Timeout: 2

24/08/2023 12:26

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:27:04 [RNG] B1,RNG,10.0,45.779323577880859,15.936800003051758,81

24/08/2023 12:27:04 [RNG] B2,RNG,13.8,45.779182434082033,15.936668395996093,81

24/08/2023 12:27:04 [RNG] B3,RNG,3.80,45.779235839843748,15.936637878417969,81

24/08/2023 12:27:04 [RNG] T,3760

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:27:30 [FAIL] RNG Measurement Timeout: 3

24/08/2023 12:27

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:27:57 [RNG] B1,RNG,11.0,45.779308319091800,15.936782836914062,81

24/08/2023 12:27:57 [RNG] B2,LOG,Timeout,45.779159545898435,15.936636924743652,81

24/08/2023 12:27:57 [RNG] B3,LOG,Timeout,45.779201507568361,15.936633110046387,81

24/08/2023 12:27:57 [RNG] T,11833

[CU] Sending automatically '$G,007,RNG' to Master Bouy...

24/08/2023 12:28:04 [RNG] B1,RNG,11.4,45.779304504394531,15.936779975891113,81

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24/08/2023 12:28:04 [RNG] B2,RNG,18.5,45.779151916503906,15.936628341674805,81
24/08/2023 12:28:04 [RNG] B3,RNG,5.11,45.779201507568361,15.936632156372070,81
24/08/2023 12:28:04 [RNG] T,3423
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:28:19 [RNG] B1,RNG,10.2,45.779304504394531,15.936778068542480,81
24/08/2023 12:28:19 [RNG] B2,RNG,17.9,45.779144287109376,15.936622619628906,81
24/08/2023 12:28:19 [RNG] B3,RNG,3.61,45.779201507568361,15.936630249023437,81
24/08/2023 12:28:19 [RNG] T,4029
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:28:38 [RNG] B1,RNG,6.80,45.779300689697262,15.936777114868164,81
24/08/2023 12:28:38 [RNG] B2,RNG,15.8,45.779140472412107,15.936622619628906,81
24/08/2023 12:28:38 [RNG] B3,LOG,Timeout,45.779201507568361,15.936636924743652,81
24/08/2023 12:28:38 [RNG] T,7654
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:28:49 [RNG] B1,RNG,4.69,45.779300689697262,15.936775207519531,81
24/08/2023 12:28:49 [RNG] B2,RNG,16.8,45.779140472412107,15.936622619628906,81
24/08/2023 12:28:49 [RNG] B3,RNG,3.80,45.779205322265621,15.936617851257324,81
24/08/2023 12:28:49 [RNG] T,4296
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:29:15 [FAIL] RNG Measurement Timeout: 3
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:29:33 [RNG] B1,RNG,2.39,45.779220581054689,15.936715126037597,81
24/08/2023 12:29:33 [RNG] B2,RNG,9.98,45.779136657714847,15.936622619628906,81
24/08/2023 12:29:33 [RNG] B3,RNG,8.67,45.779201507568361,15.936614990234375,81
24/08/2023 12:29:33 [RNG] T,2690
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:30:00 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:30:06 [MQTT] SLAVE BUOY #2 : MQTT connection established
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:30:22 [RNG] B1,LOG,Timeout,45.779212951660159,15.936726570129393,86
24/08/2023 12:30:22 [RNG] B2,RNG,3.61,45.779136657714847,15.936602592468260,86
24/08/2023 12:30:22 [RNG] B3,RNG,14.4,45.779216766357420,15.936585426330567,86
24/08/2023 12:30:22 [RNG] T,7131
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:30:34 [RNG] B1,RNG,4.36,45.779205322265621,15.936735153198242,86
24/08/2023 12:30:34 [RNG] B2,RNG,5.77,45.779136657714847,15.936602592468260,86
24/08/2023 12:30:34 [RNG] B3,RNG,12.0,45.779216766357420,15.936585426330567,86
24/08/2023 12:30:34 [RNG] T,3677
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:30:48 [RNG] B1,RNG,2.58,45.779209136962890,15.936712265014647,86
24/08/2023 12:30:48 [RNG] B2,RNG,5.48,45.779136657714847,15.936602592468260,86

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24/08/2023 12:30:48 [RNG] B3,RNG,12.0,45.779216766357420,15.936585426330567,86
24/08/2023 12:30:48 [RNG] T,3286
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:31:07 [RNG] B1,RNG,2.86,45.779212951660159,15.936684608459472,86
24/08/2023 12:31:07 [RNG] B2,RNG,6.09,45.779136657714847,15.936605453491210,86
24/08/2023 12:31:07 [RNG] B3,LOG,Timeout,45.779216766357420,15.936585426330567,86
24/08/2023 12:31:07 [RNG] T,6763
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:31:23 [RNG] B1,RNG,3.52,45.779216766357420,15.936675071716308,86
24/08/2023 12:31:23 [RNG] B2,RNG,9.94,45.779136657714847,15.936607360839842,86
24/08/2023 12:31:23 [RNG] B3,LOG,Timeout,45.779216766357420,15.936582565307617,86
24/08/2023 12:31:23 [RNG] T,7451
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:31:34 [RNG] B1,RNG,2.67,45.779216766357420,15.936687469482421,86
24/08/2023 12:31:34 [RNG] B2,RNG,9.52,45.779136657714847,15.936608314514160,86
24/08/2023 12:31:34 [RNG] B3,RNG,7.41,45.779216766357420,15.936582565307617,86
24/08/2023 12:31:34 [RNG] T,3982
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:31:49 [RNG] B1,RNG,6.38,45.779216766357420,15.936695098876954,86
24/08/2023 12:31:49 [RNG] B2,RNG,13.3,45.779136657714847,15.936610221862792,86
24/08/2023 12:31:49 [RNG] B3,RNG,4.17,45.779216766357420,15.936582565307617,86
24/08/2023 12:31:49 [RNG] T,3505
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:32:13 [RNG] B1,RNG,523.,45.779216766357420,15.936693191528319,86
24/08/2023 12:32:13 [RNG] B2,LOG,Timeout,45.779136657714847,15.936610221862792,86
24/08/2023 12:32:13 [RNG] B3,LOG,Timeout,45.779209136962890,15.936576843261718,86
24/08/2023 12:32:13 [RNG] T,12526
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:32:19 [RNG] B1,RNG,6.66,45.779224395751949,15.936695098876954,86
24/08/2023 12:32:19 [RNG] B2,RNG,12.0,45.779148101806637,15.936612129211424,86
24/08/2023 12:32:19 [RNG] B3,RNG,3.05,45.779201507568361,15.936557769775390,86
24/08/2023 12:32:19 [RNG] T,4154
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:32:39 [RNG] B1,RNG,5.58,45.779228210449218,15.936693191528319,86
24/08/2023 12:32:39 [RNG] B2,RNG,9.14,45.779148101806637,15.936612129211424,86
24/08/2023 12:32:39 [RNG] B3,LOG,Timeout,45.779197692871091,15.936534881591796,86
24/08/2023 12:32:39 [RNG] T,8426
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:32:48 [RNG] B1,RNG,3.52,45.779228210449218,15.936692237854003,86
24/08/2023 12:32:48 [RNG] B2,RNG,9.00,45.779148101806637,15.936612129211424,86
24/08/2023 12:32:48 [RNG] B3,RNG,6.84,45.779193878173831,15.936519622802734,86
24/08/2023 12:32:48 [RNG] T,3009
[CU] Sending automatically '$G,007,RNG' to Master Bouy...

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24/08/2023 12:33:08 [RNG] B1,RNG,5.91,45.779228210449218,15.936692237854003,86
24/08/2023 12:33:08 [RNG] B2,LOG,Timeout,45.779148101806637,15.936612129211424,86
24/08/2023 12:33:08 [RNG] B3,RNG,8.86,45.779197692871091,15.936517715454101,86
24/08/2023 12:33:08 [RNG] T,7635
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:33:22 [RNG] B1,RNG,7.50,45.779228210449218,15.936692237854003,86
24/08/2023 12:33:22 [RNG] B2,RNG,4.12,45.779148101806637,15.936612129211424,86
24/08/2023 12:33:22 [RNG] B3,LOG,Timeout,45.779197692871091,15.936519622802734,86
24/08/2023 12:33:22 [RNG] T,7155
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:33:45 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:33:46 [MQTT] SLAVE BUOY #2 : MQTT connection established
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:34:15 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:34:27 [MQTT] SLAVE BUOY #2 : MQTT connection established
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:34:37 [RNG] B1,RNG,7.78,45.779243469238277,15.936682701110839,86
24/08/2023 12:34:37 [RNG] B2,RNG,6.42,45.779148101806637,15.936610221862792,86
24/08/2023 12:34:37 [RNG] B3,LOG,Timeout,45.779243469238277,15.936532974243164,86
24/08/2023 12:34:37 [RNG] T,7003
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:34:49 [RNG] B1,RNG,8.67,45.779243469238277,15.936677932739257,86
24/08/2023 12:34:49 [RNG] B2,RNG,6.42,45.779148101806637,15.936608314514160,86
24/08/2023 12:34:49 [RNG] B3,RNG,14.3,45.779262542724605,15.936528205871582,86
24/08/2023 12:34:49 [RNG] T,3645
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:35:03 [RNG] B1,RNG,9.14,45.779251098632816,15.936677932739257,86
24/08/2023 12:35:03 [RNG] B2,RNG,5.91,45.779148101806637,15.936608314514160,86
24/08/2023 12:35:03 [RNG] B3,RNG,15.1,45.779273986816404,15.936530113220214,86
24/08/2023 12:35:03 [RNG] T,3260
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:35:30 [FAIL] RNG Measurement Timeout: 3
24/08/2023 12:35
[CU] Sending automatically '$G,007,RNG' to Master Bouy...
24/08/2023 12:35:49 [RNG] B1,RNG,9.47,45.779277801513673,15.936693191528319,86
24/08/2023 12:35:49 [RNG] B2,RNG,4.88,45.779148101806637,15.936608314514160,86
24/08/2023 12:35:49 [RNG] B3,RNG,18.4,45.779308319091800,15.936572074890136,86
24/08/2023 12:35:49 [RNG] T,3606
[CU] Sending automatically '$G,007,RNG' to Master Bouy...

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This data corresponds to the information received by a PC through the serial port and stored by the MobaXterm software. Eighty periodic attempts (every 20 seconds) of range measurement initiation are identified.

- 26 measurements were performed correctly. The following fragment extracted from the data collected shows an example of a successful measurement:

  24/08/2023 12:23:19 [RNG] B1,RNG,4.22,45.779338836669918,15.936838150024414,81
  24/08/2023 12:23:19 [RNG] B2,RNG,10.1,45.779228210449218,15.936708450317382,81
  24/08/2023 12:23:19 [RNG] B3,RNG,1.88,45.779338836669918,15.936790466308594,81
  24/08/2023 12:23:19 [RNG] T,3366

- 25 measurements were executed with partial success because some range measurements between some of the buoys and the Underwater Acoustic Unit failed. The following fragment extracted from the data obtained identified how the range measurement of Buoy 2 has not been performed successfully:

  24/08/2023 12:33:08 [RNG] B1,RNG,5.91,45.779228210449218,15.936692237854003,86
  *24/08/2023 12:33:08 [RNG] B2,**LOG,Timeout**,45.779148101806637,15.936612129211424,86*
  24/08/2023 12:33:08 [RNG] B3,RNG,8.86,45.779197692871091,15.936517715454101,86

- 14 measurement attempts were not executed due to a time limit overrun, probably due to problems in the MQTT communication between buoys. Message type: *[FAIL] RNG Measurement Timeout: X*

- 15 measurement requests have had no response from the Master Buoy, probably due to problems in the LoRa communication between the Offshore Unit and the Master Buoy.

The file with the data obtained during the field tests is provided below:

Data_Obtained_24-08-2023.txt

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