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Two-Dimensional Modeling of Aquatic Surfaces Based on Obstacle Detection and Distance Measurement Using Ultrasound

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Abstract

The best tool for acquiring information is research, this is one of the reasons why man is distinguished from other species on planet Earth. In man's desire to understand the nature that surrounds him, various obstacles appeared, one of which is being able to enter places that are difficult to physically access such as canyons or sea caves. It is for this reason that a means is developed by which three-dimensional modeling of the aquatic surface will be carried out based on the detection of obstacles and measurement of distance using ultrasound. This project presents the response to this problem through the use of ultrasound, which is responsible for sending and receiving sound waves for measuring distance on aquatic surfaces and the use of a radar that sends and receives electromagnetic waves with the objective to detect obstacles in the research route. The results of the development of this project are greater access to natural or superficial places with complicated characteristics for human entry, allowing the recognition of the interior of these ecosystems through modeling of the environment in which the environment is located. In short, the progress of this project will be of great contribution to different sectors such as research, construction, social, among others, whose procedure is the prior study of the environment for the development of the work.

Keywords
Investigation, Modeling, Ultrasound, Radar, Recognition.

1. Introduction
Nature has always been defined as a "neutral" and "unpredictable" field because, due to our own works (roads, water houses, bridges, etc.), they come to be destroyed by natural phenomena. That is why we need to have devices capable of performing tasks for which humans are not prepared and thus making work easier (Bellavista 2016). The latter would not be possible if, starting with the Industrial Revolution, science and technology were irreversibly merged (Echo location 2017). Currently, many construction companies or simply related studies on the aquatic surface use technologies or electronic devices to carry out their previous studies in the work area. But in a large part of Peru (specifically in the jungle), not much of this technology is available for the construction of traditional Amazonian houses, since these have as their main piece the piles or pillars that will be the base of the house, which are buried approximately 6 meters deep (Lupiáñez and Sánchez 2019).

In this research, the ultrasonic sensor model HC-SR04 was used as the main component because this is a small radar that will allow us to measure the distance to obstacles. Its operation acts similar to echolocation in bats because they emit sound waves through their mouths or noses; once they hit an object, they produce echoes. Making the echo bounce back to the bat's ears, only in the case of the HC-SR04 does it emit a sound pulse at a non-audible frequency and measure the time it takes for this sound to reach the obstacle, bounce back, and return to the sensor again (Quispe 2014)

1.1 Objectives

In recent years, technology has been advancing, and with natural disasters, these technologies have been of great help to human beings, which is why in this project we will develop an efficient implementation technique for the integration of ultrasonic sensors in oceanic areas, focusing on the optimization of computational and energy resources. To achieve this objective, several aspects must be considered in this study:

1. Explore and evaluate the feasibility of integrating ultrasonic sensors with other technologies to improve the accuracy and reliability of the system.

2. Evaluate and compare different electronic devices that we can use in this project.

3. Investigate and evaluate the influence of the different fluids that the boat will be in contact with during the practical time of the project.

2. Literature Review

The word SONAR (sound navigation and ranging) refers to the method and/or equipment necessary to determine by sound the presence or location of objects in the water. Active sonar is similar to RADAR because it emits a train of acoustic waves with a certain power into the water. If an object is submerged and hits these waves, they will be reflected back to the emitting focus (Illa, 2005, pages 14–15). As already mentioned, there is active sonar, which is similar to the ultrasonic sensor, with the difference that the latter emits ultrasonic waves and receives the reflected wave that returns from the object.

The HC-SR04 ultrasonic sensor can be programmed to send an ultrasonic burst by setting the TRIG pin to HIGH; once sent, the ECHO pin will be set to HIGH. This pin will remain high until the burst hits the sensor again. This sensor calculates the distance to the object by controlling the time in which the ECHO pin remains HIGH; while it remains HIGH, the burst traveled (Morgan, 2014).

According to Vega Huerta, Cortez Vásquez, Melgarejo Solís, Marquera, & Arakaki Namisato (2010), in their article “Intelligent System to Measure Volume of Liquids Using Ultrasound Sensors," they indicate that every sensor is capable of transforming physical quantities into electrical quantities; these physical quantities can be distance, temperature, humidity, or torque. It defines the ultrasonic sensor as the device to calculate distance using a transducer, which emits ultrasound "packets," which contain a series of intermittent sound waves. In turn, ultrasound measurement can be affected by the type of surface on which it is located, the angle that the wave forms with the sensor, and the distance of the sensor from the objective surface.

According to Caballo (page 3), he mentions that with the passage of history, the shape of the cases has been adjusted to the requirements of navigation that have been more or less similar; only the size and speed have varied. The hulls of the ships resemble each other since their fusiform silhouette has solved flotation and displacement since before the formulation of Archimedes' principle. Boats are basically defined by two main measurements. The first is the length (length of the vessel), the second is the beam (the greatest width that corresponds to the central width), and the third is the draft, corresponding to the depth.

3. Method

The robot is very useful for activities that a human being could not be capable of. You must have the following main elements in the project for its proper functioning in measurements:

- HC-SR04 Ultrasonic Sensor.
- Platform.
- Power Unit

These elements are the main and necessary ones for the correct functioning of our present research project. According to the following flow chart, the operation of the main sensor is explained (Figure 1):

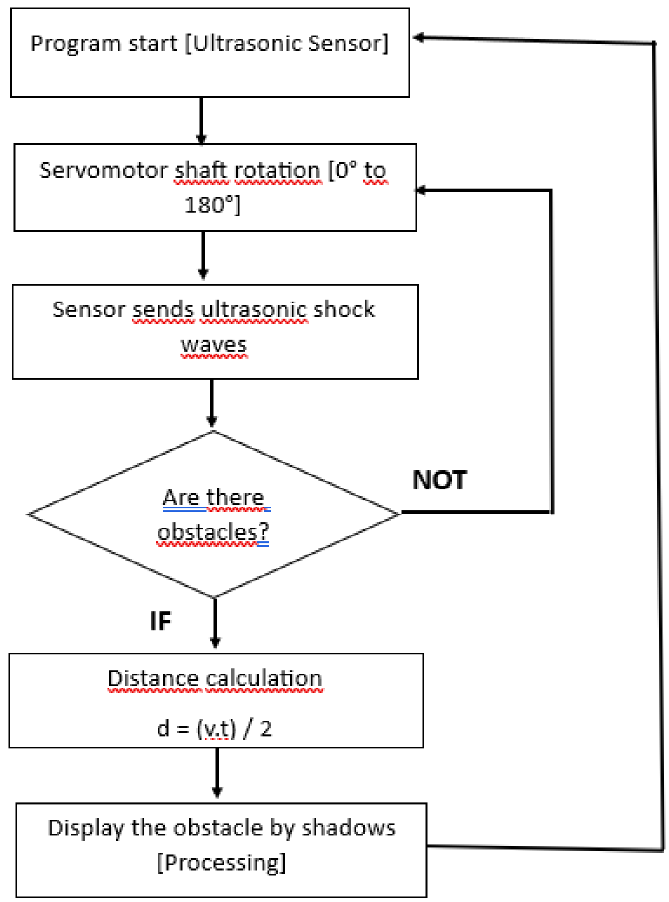

Figure 1. Depth Gauge Boat Operation Flowchart

In order to measure distances to certain obstacles that are in the middle of the path, the HC-SR04 ultrasonic sensor was chosen, which is an ultrasonic distance measuring sensor capable of detecting objects and calculating the distance to the that obstacles are found in a range of 2 to 40 cm. The ultrasonic sensor will be supported by an SG90 servomotor which will rotate from 0° to 180°, this allows for a larger study territory. The HC-SR04 sensor sends ultrasonic waves which will bounce off the obstacle if it is present. Using the programming code that the ARDUINO UNO will execute, the distance between the ultrasonic sensor and the present obstacle will be calculated, displaying this result and the shadow of the object in the Processing program.

Among the main factors taken into account at the time of construction were:
• Buoyancy

We start from Archimedes' principle, which clarifies that "Everybody immersed in a fluid experience a vertical and upward thrust equal to the weight of the displaced fluid". This trust Will be calculated with:

$$\boldsymbol{E = \rho_f . g . V} \qquad (1)$$

Where:
- **E**, the force or push that the body experiences,

- **ρ**, fluid density (for water ρ = 1000kg/m3),
- **g**, gravitational acceleration (g = 9.81 m/s2),
- **V**, volume of displaced fluid.

Everybody has a weight which is calculated.

$$W = m.g \qquad (2)$$

- **m**, is the mass of the body in kg.

Now yes:

- E=W, the body will be in a state of equilibrium with the fluid,
- E > W, the body will be partially submerged,
- E < W, the body will be completely submerged.

• Stability

The stability of floating bodies is very different from that of submerged bodies; because its center of gravity (cg) > center of buoyancy (cb). In part (a), the body is in equilibrium and the center of gravity is above the center of buoyancy. In part (b), the body is slightly rotated, and its center of buoyancy has changed to another position (Figure 2).

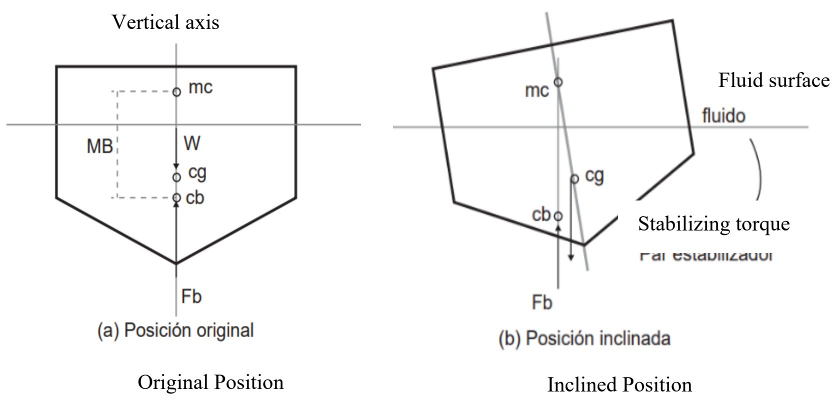

Figure 2. Stability conditions for floating bodies

To define the condition of stability in a floating body, we require a new term, the metacenter (mc), defined as the intersection of the vertical axis of a body when it is in equilibrium and a new vertical line that passes the center of buoyancy and its new position due to slight turning/movement.
The distance from the metacenter to the center of buoyancy (MB) is calculated as:

$$MB = \frac{I}{V_d} \qquad (3)$$

Where:

- V_d, is the displaced volume of the fluid,
- **I**, is the minimum moment of inertia in a horizontal section of the body taken from the surface of the fluid.

If the distance MB occupies the metacenter above the center of gravity, it can be said that the body is considered stable.

• Reliability is the probability that a device, process, and/or system functions and fulfills its function after a certain time or use.

• Low cost This factor was directly related to the development of the project or boat. This cost is based on both the materials, sensors, and/or control systems that the boat will have. In this research project, the cost was kept below the norm since we not only focused on the result that the boat would give us but also wanted to use those materials that were already used and that had the potential for a second use.

On the other hand, during the construction and assembly process of our project, the following components were of great importance:

• Arduino UNO R3 microcontroller board based on the ATmega328P (Electronic Agency 2023), used for its great ease of communication between a computer, another Arduino board, or other microcontrollers (Figure 3).

Figure 3. Arduino UNO R3

- **Sensor Ultrasónico** Sensor HC-SR04 es un sensor que envía una onda ultrasónica la cual llega a un objeto y es reflejado para de ahí calcular la distancia de la siguiente manera (Illa 2005)

$$\boldsymbol{d} = \frac{\boldsymbol{v.t}}{\boldsymbol{2}} \tag{4}$$

- **HC05 Bluetooth Module**

The HC-05 Bluetooth module allows us to connect our Arduino projects to a cell phone or PC wirelessly (Bluetooth) with the ease of operation of a serial port.

- **Relay**

Electromechanical device that acts as a switch controlled by an electrical circuit. They are mainly used to control higher-power electrical loads with lower-power signals, such as those coming from electronic circuits.

After the concise and punctual description of the main electronic components used during the project, we proceed to assemble and connect all the components and sensors according to the logic and nomenclature of inputs and outputs managed by the Arduino program, as can be seen in Figure 4.

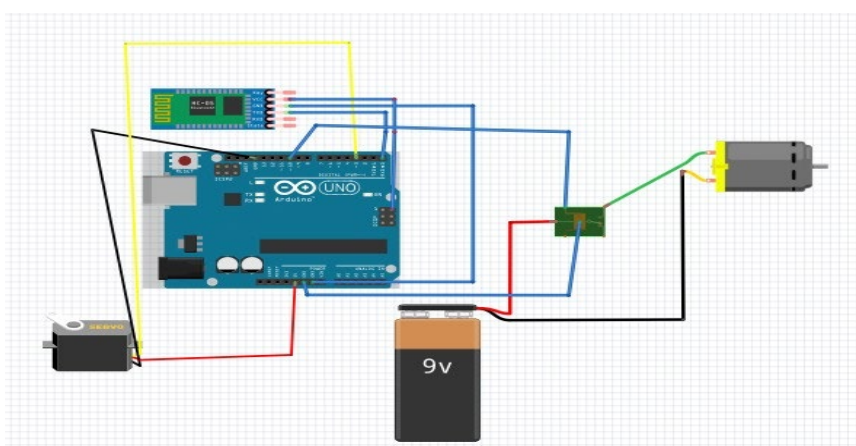

Figure 4. Boat (motor) circuit via Bluetooth connection
Source: self made

Once the prototype had been assembled, tests were carried out with the aim of testing the functionality of the algorithm, obtaining feedback on both sections (algorithm logic and hardware response), and discovering flaws in both software and hardware. This was carried out in a controlled environment, where the main characteristic was being able to verify the functionality of the algorithm in the prototype based on the main variables of the system: measurement and stability.

For the radar transport circuit, different components were used, all of which are connected to the Arduino Uno board. The Bluetooth sensor is powered directly from the Arduino through the ICSP and GND pins, and it will send electrical pulses through the TXD pin of the sensor, which is connected to the RXD pin of the Arduino Uno board. In addition, the SG90 servomotor, which will direct the boat propeller, is powered directly from the Arduino Uno board through its 5V and GND pins and will be controlled through its communication cable. which is connected to analog pin 3 of the Arduino Uno. In order to power the DC motor with a 9V battery, a relay was used, whose coil is powered by the GND and analog pin 10 of the Arduino Uno. The common contact pin of the relay is connected to the positive pole of the battery, the NO pin (normally open) is connected to the positive pole of the DC motor, and finally, the negative pole of the DC motor is connected to the negative pole of the 9V battery (Figure 5).

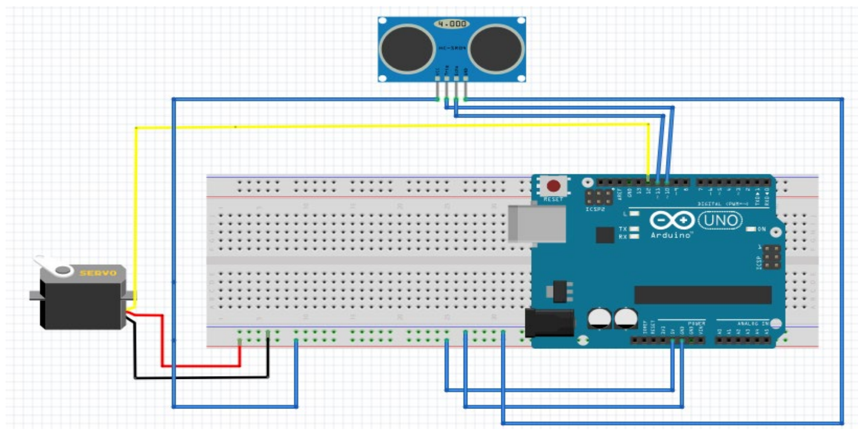

Figure 5. Radar circuitry
Source: self-made

For the implementation of the obstacle detector, radar, and distance meter, electronic components that fulfill different functions were used; however, these complement each other to achieve the proposed task. The main component is the HC-SR04 ultrasonic sensor, which is responsible for emitting and receiving ultrasonic waves to detect obstacles and, through the programming code and the application of formulas, can calculate the distance that the obstacle is with respect to the objects present. For the operation of this sensor, we provide the power supply by connecting its VCC and GND pins to the 5V and GND pins of the Arduino Uno board, respectively, through the breadboard channels. In addition, in order to achieve communication by electrical impulses, the Trig and Echo pins of the sensor must be connected to the analog pins 10 and 11 of the Arduino Uno board, respectively.

The second component is the SG90 servomotor, which is responsible for covering the scanning area of the HC-SR04 ultrasonic sensor. For the correct work of this component, we provide the power supply by connecting its red and brown VCC and GND pins correspondingly to the 5V and GND pins of the Arduino Uno board, respectively, and finally, to achieve communication with the programming code. Implemented on the board, the orange communication pin of the servo motor must be connected to the analog pin 12 of the Arduino Uno board.

4. Data Collection

Measuring distances is an essential procedure when carrying out any design or construction of a building or tool. There are various types of analog and electronic instruments that facilitate this distance measurement task; however, not all these instruments have a considerably low error rate; some distance measurement instruments show a considerably higher error rate compared to others. Taking these data into consideration, a comparative table was made between the precision of these distance-measuring instruments.

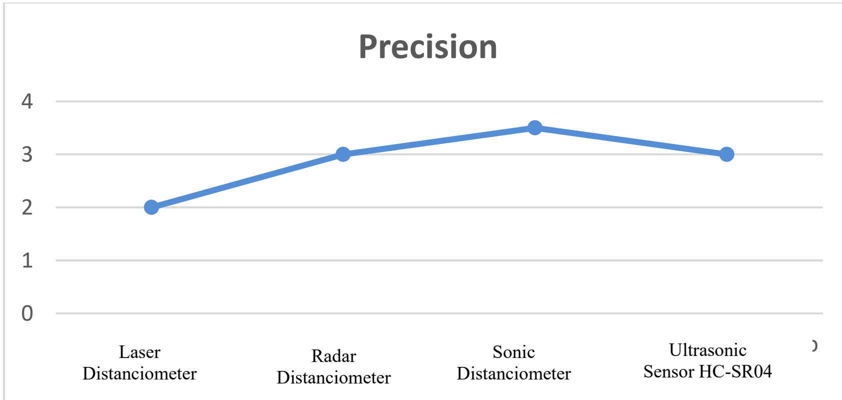

Figure 6. Percent error of the different distance measuring instruments
Source: self-made

Figure 6 shows the precision of four distance measuring instruments, one of which is the laser distance meter. This distance meter works with a visible laser beam that is projected onto the surface to be measured. This tool has a screen that will indicate the distance with an accuracy of ±2 mm. The second is the radar or ultrasound distance meter. This type of distance meter works in the same way as a laser distance meter, but using the element that characterizes it, such as the electromagnetic wave in the first and a warning sound for the second, it counts with an accuracy of ± 3 mm. The third is the sonic distance meter, whose sound waves have a high degree of sensitivity towards the environment, which is why any other factor or natural element that gets in the way of the measurement can alter the value. Finally, the HC-SR04 ultrasonic sensor is located, which emits a sound and counts how long it takes to return. It uses acoustics that consider sound as a vibration. It not only detects the object but also the distance at which it is located. to the sensor with a high precision of ± 3 mm.

In order to carry out two-dimensional modeling of the aquatic surface, in addition to the distance measuring instruments, another instrument is needed that mobilizes these instruments across the entire aquatic surface that can be covered and, in this way, can take different samples. and measurements at immense quantities of points within the aquatic surface to be studied. For this reason, an electric boat was used, which will move through different types of water found in the environment. The aquatic environment has different types of this liquid matter according to the ecosystem in which we are located. However, the stability of the boat is not the same in all these types of water because it depends on its density. Therefore, in Table 1, we will see the different fluids in the ecosystem and the density they have.

Table 1. Density of the different fluids

Fluids	Density (kg/m^3)
Sweet Water	1000
Salt Water	1027
Brackish Water	1025

Fresh water is generally characterized by having low concentrations of dissolved salts and low total dissolved solids; fresh water has a density of 1000 kg/m3. The next is salt water, which has this characteristic due to the concentration of dissolved mineral salts it contains: 3.5%; that is, in each liter of water there are 35 grams of dissolved mineral salts on average. Salt water has a density of 1027 kg/m3. Brackish water is water that has more dissolved salts than fresh water but less than salt water. Technically, brackish water is considered to be water that has between 0.5 and 30 grams of salt per liter. This brackish water has a density of 1025 kg/m3.

The speed of sound is the phase speed of sound waves in a given medium; that is, it is the speed at which a wave front propagates in said medium, depending on the medium in which it is transmitted, due to its variation with the same; as well, it depends on the characteristics of the medium in which said propagation takes place and not on the characteristics of the wave or the force that generates it.

Because the HC-SR04 ultrasonic sensor is going to be used, it works with the emission and reception of sounds to calculate the distance of obstacles that arise. In the experimental process, the speed of sound was calculated using the different types of water to which this project can be applied.

Table 2. Speed of sound in the different experimental fluids

Fluids	**Speed of the sound (m/s)**
Sweet Water	1.480
Salt Water	1.540
Brackish Water	1.515

In Table 2, you can see the comparison of the speed of sound in the context of fresh, salty, and brackish water. It was obtained that the speed at which these sound waves propagate is greater in salt water since it depends on different factors such as the pressure, temperature, and salinity of the water, since saltwater shows a higher percentage of mineral salts compared to fresh water and brackish water. It can be concluded that, in the context of carrying out this experiment in seas, results can be obtained faster compared to if it is carried out in lakes, wetlands, or waters adjacent to the sea.

5. Results

The work of labor on aquatic surfaces is usually quite risky for their health and integrity due to the unexpected and unpredictable behavior of these waters during the long period of work, which is why the construction of this robot was carried out with the objective of supporting the workforce and not exposing their physical and mental integrity to any risk.

This project is based on the detection of obstacles and measurement of distance using the HC-SR04 ultrasonic sensor, which sends and receives ultrasonic waves to recognize obstacles in the study area and calculate the distance from the ultrasonic sensor to the obstacles present. Next, the radar was put under experimentation by placing different solid elements within the work area, and a comparison was made between the distance measurement of the HC-SR04 ultrasonic sensor and the distance measurement through the use of a fluxmeter.

Table 3. Comparison between measurement with a fluxmeter and HC-SR04 ultrasonic sensor

Object	**Measurement with flexometer(cm)**	**Measurement with HC-SR04 (cm)**
Plastic Bottle	15	15
Salt Shaker	12	12
Orange	5	5

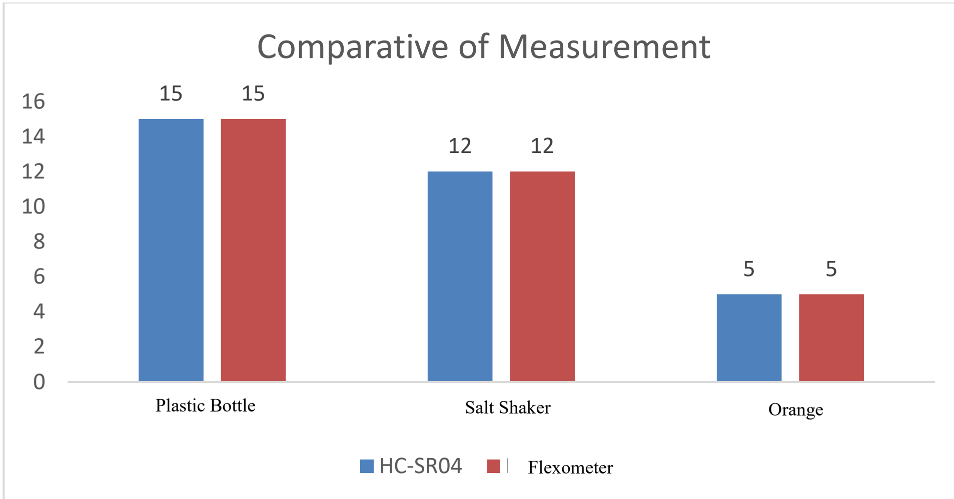

Figure 7. Comparison between measurement with a fluxmeter and HC-SR04 ultrasonic sensor
Source: self made

Three solid objects were placed within the radar work area and a comparison was made with the measurement through a fluxmeter, a measuring instrument that has greater precision. These items placed within the radar work area were a plastic bottle, salt shaker, and an orange. In both Table 3 and Figure 7 it can be seen that the distance measurement with respect to the plastic bottle, the orange and the salt shaker is the same both when using the HC-SR04 ultrasonic sensor and the fluxmeter. This can be translated into the great contribution of the HC-SR04 ultrasonic sensor in distance measurement precision.

To transport the radar across the water surface so that it can carry out the corresponding measurements, a boat that works via a Bluetooth connection is used. To power this Bluetooth boat, a 9-volt battery is used, which is connected to the motor through jumpers and a relay. However, during the working period of the Bluetooth boat, the 9-volt battery suffers certain wear due to the energy that the DC motor needs for its correct operation, which is why there is a record of the battery voltage. after a certain period of work (Table 4).

Table 4. Battery wear after a certain time

Working Time (segundos)	Voltage of Battery (V)
0	9.26
20	7.26
30	7.23
60	6.88
90	6.69
110	6.61
120	6.25

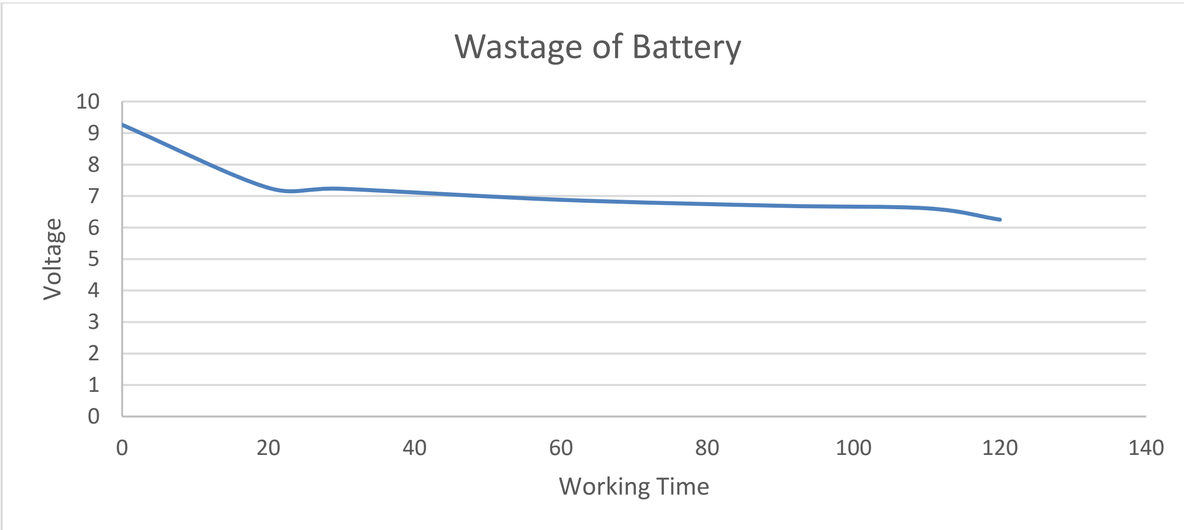

Figure 8. Battery wear versus time of use
Source: self-made

Within the period of time in which the Bluetooth means of transport mobilizes the radar in order to make the corresponding measurements, the 9-volt battery that powers the Bluetooth boat motor suffers wear and tear due to the consumption of the DC motor. In Figure 8, you can see a large voltage consumption at the beginning of operation. This is because the motor starts up in such a short period of time. Subsequently, it can be seen that after the boot interval, moderate battery consumption appears. It should be noted that the motor stops after 110 seconds of continuous work; however, by applying a small force to the motor propeller, it starts spinning again, but at a lower speed than before.

6. Conclusions

From the development of this work, the following conclusions can be obtained:

- A mobile boat was designed and built based on an Arduino platform with an ultrasonic sensor; these sensors allowed responses to be obtained as stipulated in the flow chart. However, the logic in the diagram, mainly in the sensor control code, allowed us to observe a series of improvements and updates on the operation of the robot with the aim of having the highest possible efficiency.
- The use of an ultrasonic sensor to detect obstacles on a water surface was an efficient option since ultrasonic waves can be reflected by objects present in the aquatic environment, providing information about the presence of obstacles. However, it is important to consider factors such as the propagation of ultrasonic waves in water, which can affect accuracy over greater distances.
- Continuous optimization of detection algorithms and data processing techniques is essential to improving the accuracy and reliability of this model. Additionally, this two-dimensional water surface model may need to be integrated with other sensors to address specific limitations or improve the robustness of the system under different conditions.

References

Bellavista, T. I., ULTRASONIC SENSOR, 2016. Retrieved from https://blogsaverroes.juntadeandalucia.es/iesbellavista/files/2016/02/SENSOR-ULTRAS%C3%93NICO.pdf

Echo location., Asu.edu, 2017. https://askabiologist.asu.edu/eco-localizacion

Lupiáñez Bellido, A., & Sánchez Domínguez, I., Design of a security system for a β prototype of an explorer robot in hostile environments through gross control intervention and spatial relocation in a safe area. Mexico, 2019. Retrieved from https://www.redalyc.org/journal/467/46760427007/46760427007.pdf

Quispe, R. S., STABILITY OF FLOATING BODIES. Unamba, 2014. https://www.academia.edu/8076014/ESTABILIDAD_DE_CUERPOS_FLOTANTES

Electronic Agency, HC-SR04 ULTRASONIC DISTANCE SENSOR. Obtained from HC-SR04 ULTRASONIC DISTANCE SENSOR, 2023: https://ageelectronica.lat/pdfs/textos/U/ULTRASONIC-HC-SR04.PDF

Illa, M. A., Depth measurement of reservoirs, rivers and lakes through telemetry to obtain the cross section. Retrieved from Measuring depth of reservoirs, rivers and lakes via telemetry to obtain cross section, 2005. https://core.ac.uk/download/pdf/323345613.pdf

Diaz Gutiérrez, C. E., Segovia de los Ríos, J. A., Garduño Gaffare, M. P., & Tejeda Vega, S., Redalyc. Retrieved from FLOW MEASUREMENT THROUGH THE IMPLEMENTATION OF A WATER VEHICLE, 2012. https://www.redalyc.org/pdf/370/37023172007.pdf

MaxBotix, Ultrasonic Sensors vs. LiDAR: Which One Should You Use?, 2021. Retrieved from https://maxbotix.com/blogs/blog/ultrasonic-sensors-vs-lidar-which-one-should-you-use

Morgan, E., HC-SR04 Ultrasonic Sensor, 2014.

Vega Huerta, H., Cortez Vásquez, A., Melgarejo Solís, R., Marquera, W., & Arakaki Namisato, T., Intelligent System to Measure Liquid Volume using Ultrasound Sensors. Obtained from Intelligent System to Measure Volume of Liquids using Ultrasound Sensors, 2010.https://sisbib.unmsm.edu.pe/bibvirtual/publicaciones/risi/2010_n1/v7n1/a03v7n1.pdf

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