DESIGN DOCUMENT

ECE 445- SENIOR DESIGN PROJECT LABORATORY
GROUP 56

Marina Manrique López-Rey (marina3)
Luis Navarro Velasco (luisn2)

Index

1. Introduction

1.1.Title

Data collection, GPS monitoring and power management of pollution measurement system on boat.

1.2. Background

The USGS (U.S Geological Survey) has estimated that each person uses up to 130,000 liters of water every year. A big part of this consumption is for drinking and hygiene. Water companies, consumers and environmental scientists need to know the condition of water resources in order to take action if the pollution levels of water raise unexpectedly, given the importance of drinkable water.

Water pollution is a bigger issue than we think. Actually, it causes more deaths than any war. More and more people die due to water pollution every year. The UN (United Nations) has estimated that 1.8 millions of kids younger than 5 years old die every year due to the consumption of polluted water. This is equal to one death every 20 seconds.

1.3. Objective

The company CERSE (Center for Environment Restoration and Sustainable Energy) has realized that water pollution is a big issue, and want to make sure that the water that is being consumed is safe. That is why they came up with this project: a boat that analyses water in lakes and rivers and sends real time alerts if water is not drinkable.

Our main aim is to shorten the reaction time that is from when the boat measures the water levels to when the team reads the data and can take measurements to control the levels and alert the population. Right now, the system stores the data on the boat, what makes it impossible to retrieve until it comes to shore. With our project, the team could access the data within 15 minutes of it being read and act consequently.

Our duty in this project is to create some of the modules that this boat needs in order to complete its commitment. We want to provide this boat a GPS system, so that we get information on where the boat is located at every instant of time. This is needed in order to know if the boat is in the position where we want to analyze the water. Also, we want to create the module for data transmission system, which is needed to send the data collected by the multiple sensors that the boat is equipped with, and send it to a server so that they can be checked in real time from a laptop or phone. An app will be created to receive this data and get the alerts that the boat sends depending on the water pollution. In addition to this, we are creating the electric system to power the boat, which includes a solar panel so that the boat can stay offshore for a few days, so that it does not have to pause its job to get charged.

1.4. High-Level Requirement List

CERSE’s main requirement for this project are the following:

- Data transmission every 20 minutes for later analysis with desktop application.
- Power the electronics of the boat using solar energy, in order to make this project eco-friendly from an energy point of view.
- Monitoring via GPS with a precision of +/- 2 m in order to track the trajectory of the boat and attach each sensor reading to a set of coordinates.

2. Design

2.1. Modular Block Diagram

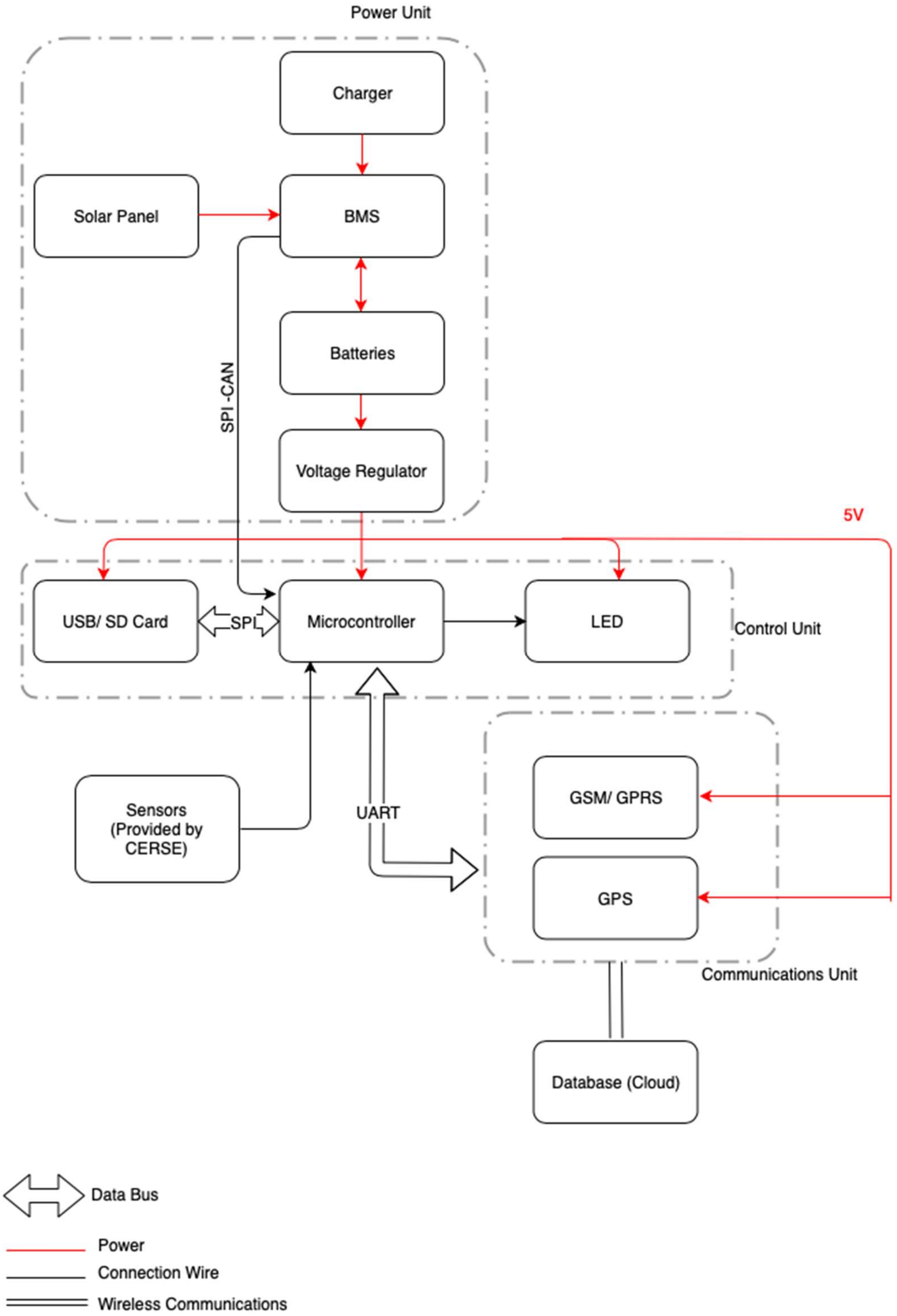


Figure 1: Modular Block Diagram

2.2. Components Descriptions

2.2.1. Power Management Unit

- **Solar panel:** as we want to make this project eco-friendly, we have decided to use renewable energies to power the electronics of the boat. That is why we are installing a solar panel.

- **Batteries:** a set of batteries is needed in order to store the energy received by the sunlight and be able to power the electronics.

    - Lead acid: these batteries are cheap and have a small depth of discharge. Despite that, they are heavy, have a short lifespan and its chemical components can be hazardous.

    - Lithium Ion: they are the most expensive out of the three types, but are lighter and have the largest lifespan. They are not as dangerous as the Lead Acid.

    - Saltwater: these types of batteries are very eco-friendly, which is good for this project in case something happens to the boat, so that it implies no danger to the environment. Despite that, their depth of discharge is the largest of these three types of batteries. Also, their lifespan is not great, and we are not sure if they can be used with a BMS, which is needed for this project.

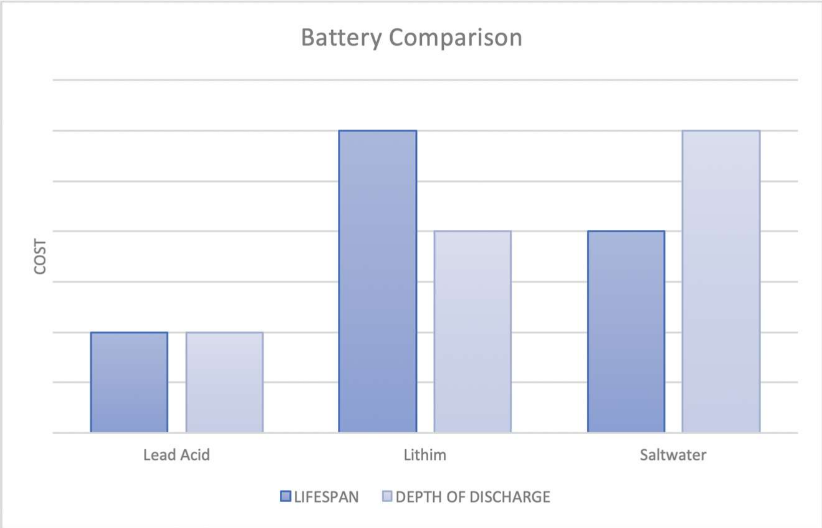


Figure 2: Battery Comparison

After doing research on the internet, we decided to use lithium batteries for this project, as they are a good balance between weight, safeness for the environment and cost.

- **BMS:** Battery Management System to control the state of charge of the batteries and check that all of them are working properly.

2.2.2. Control Unit

The control unit manages every other module of the system. Receives the data from the sensors installed on the boat and prepares the information to be sent over the GSM module, as well as stored in an SD. It also provides feedback or alarms over the LED module.

- **Microcontroller:** The microcontroller handles all the data. First, it collects the data from the sensors via its connection pins. Then it stores the data in the SD/ USB module via SPI connection and sends the data to the GSM module via UART. We will work with ATmega328, a model that must be able to process the great quantity of data that would be generated by the sensors.

- Requirements:
  - Simultaneous UART and SPI.
  - Pins with 3.3V output.
  - High data processing.

- **LED:** We will install LEDs in the protoboard in order to see if the module is transmitting and receiving data correctly or something is wrong with the system.
- **USB/ SD Module:** The SD Card module will be connected to the microcontroller via SPI. This is necessary because given the case were data connection is lost, the GSM module won't be able to send the data, and we need it to be stored in a SD module to avoid losing the data.

2.2.3. Communications Unit

- **GSM/ GPRS:** The GSM/ GPRS module will be in charge of sending data to the cloud in order for it to be accessible to the users from a computer or android device.
  - Requirements
    - 2G/ 3G data connection.
    - Send alarms via SMS to a designed number.
- **GPS:** The GPS module has two main functions. First of all, data must be classified according to the geographical coordinates and the date in order to keep a clean record. Second, in case data connection is lost, an SMS alarm must be sent with the current GPS coordinates of the device.
- **Antenna:** An antenna module is necessary in order to increase precision of the GSM and GPS modules, and increase connectivity as well.

2.3. Risk Analysis

We need to take into account many factors that can influence the performance of our system.

- Climatological conditions can be a factor to take into account given that various components (such as the GPS sensor or the solar panels) can be affected by this. We must guarantee that our system keeps working even on non-favorable conditions.
- Remote location can also affect performance. GPS monitoring and data transfer can be affected if the boat final destination is an isolated point. We must guarantee that the GSM/GPRS system provides either 3G or 2G connectivity in order to transfer the data in real time or with the minimum latency possible.

2.4. Schematics

2.4.1. Option A

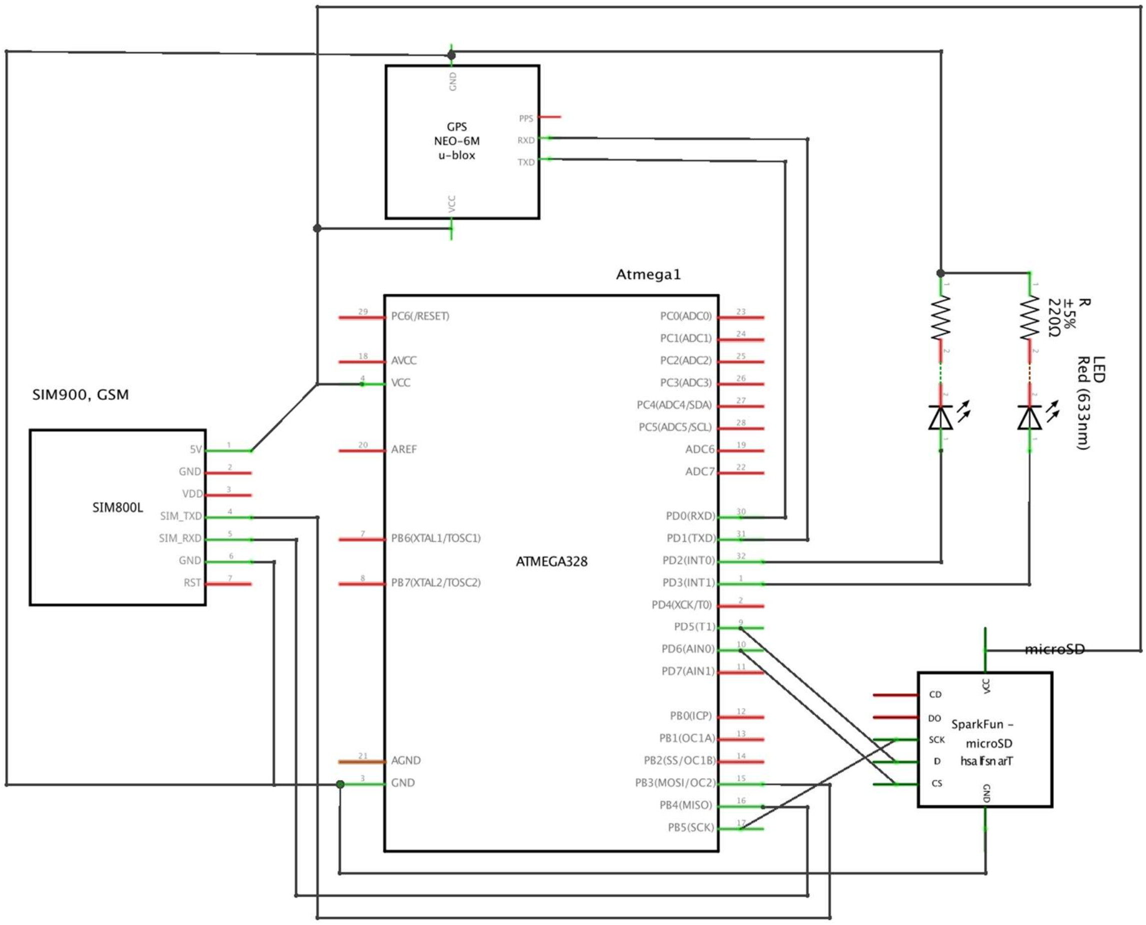


Figure 3: Option A Block Diagram

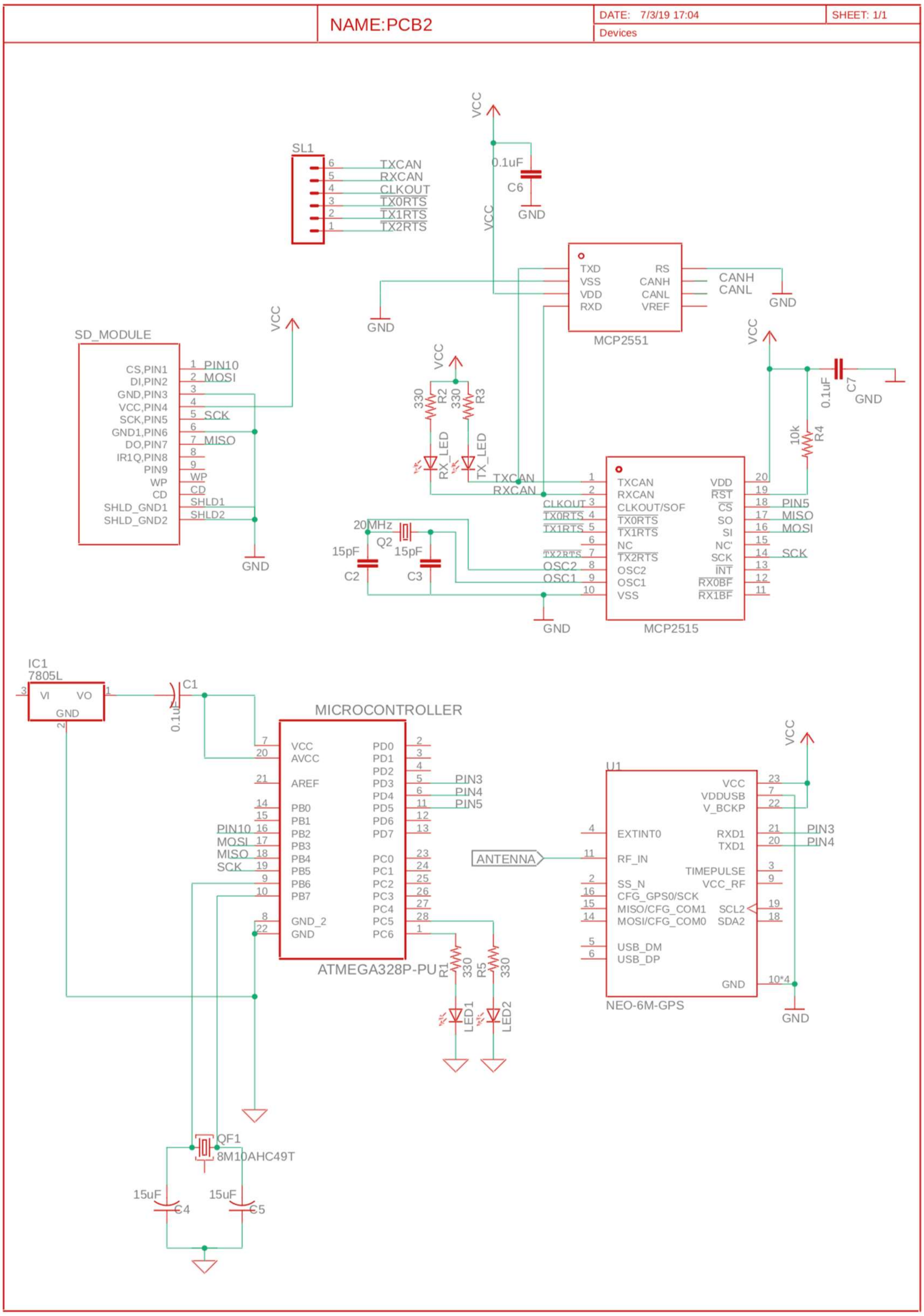


Figure 4: PCB Schematic

2.4.2. Option B

Our initial prototype (Option A) is designed in order to have enough processing capabilities for obtaining one sample from 5 sensors every 15 minutes. Given the case that we needed to increase the number of sensors or add autonomous conduction to the boat, the ATmega328-PU might not have the adequate processing capabilities. Given this case, the option to connect our initial protoboard with a Raspberry Pi microprocessor would be taken into account.

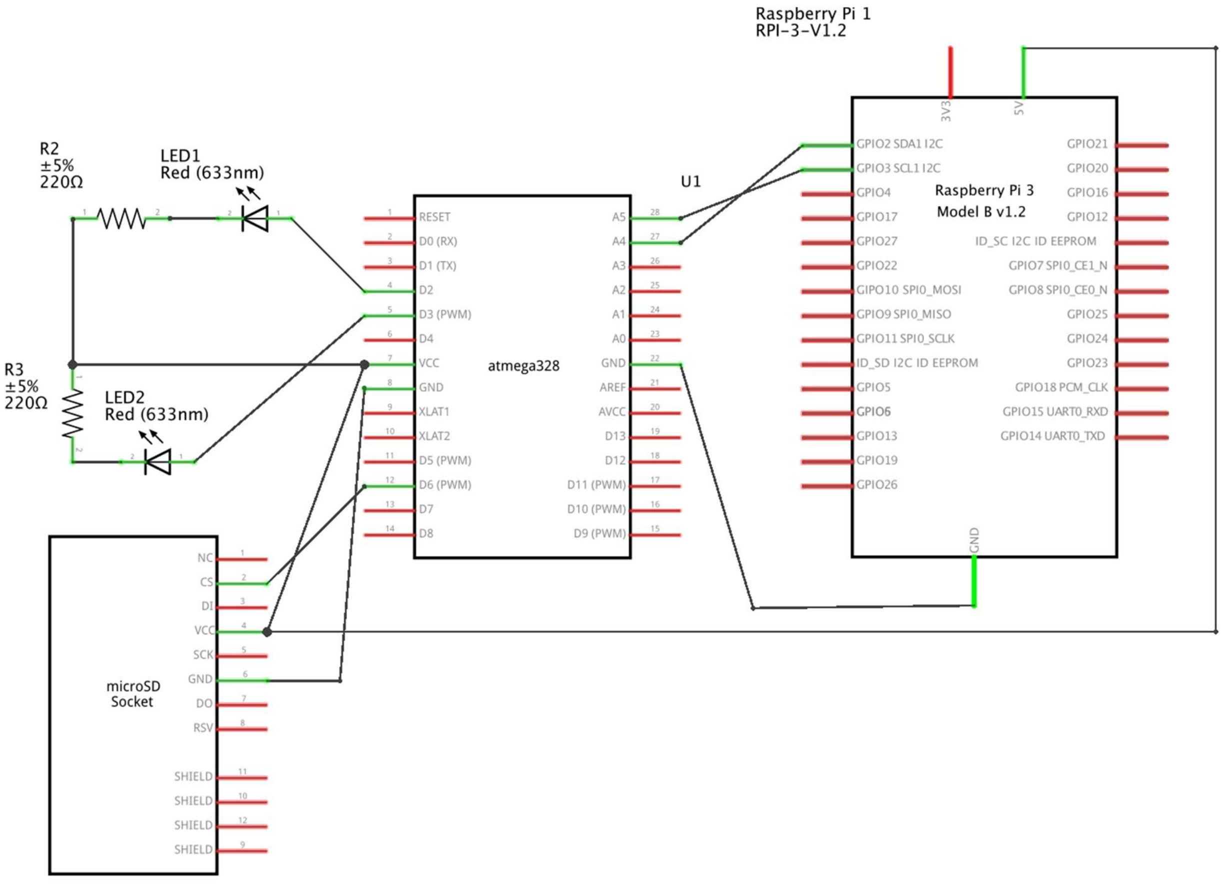


Figure 5: Option B Block Diagram

2.5. Software Flowchart

2.5.1. Flowchart Microcontroller Software

The flowchart shows the actions that the microcontroller must carry out every interval of time determined (in this case every 20 minutes) As it is explained, the ATmega would send the data from the sensors to the GSM module, that would connect to the database cloud server.

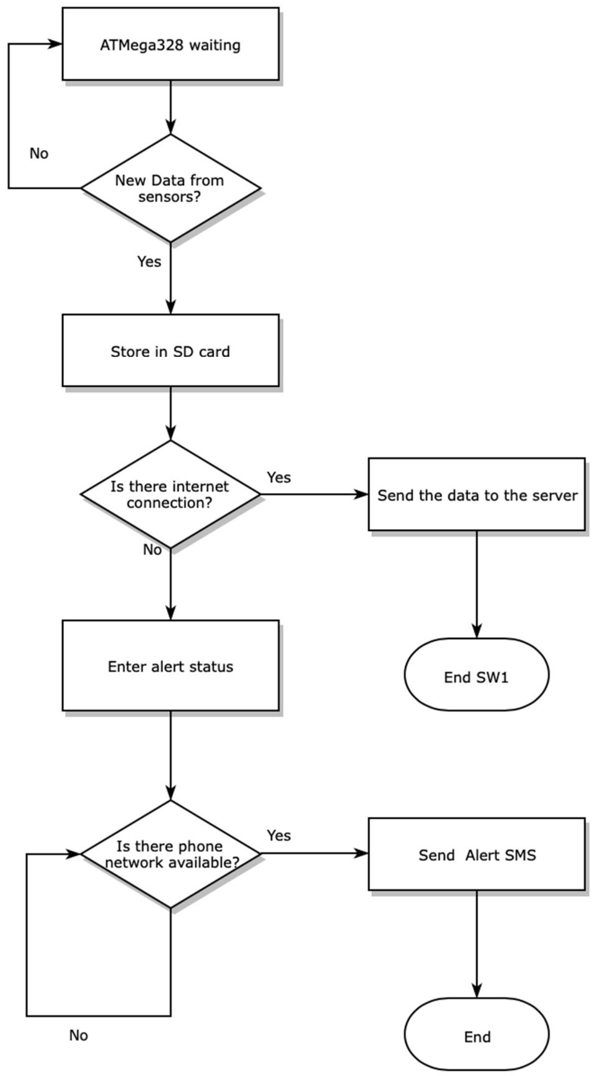


Figure 6: Microcontroller Software Flow

2.5.2. Activity Diagram of Desktop Application

A desktop application to access the data is one of the main requirements of CERSE. The application must be easy to handle as well as efficient, with graphical representation of all the data sent by the microcontroller.

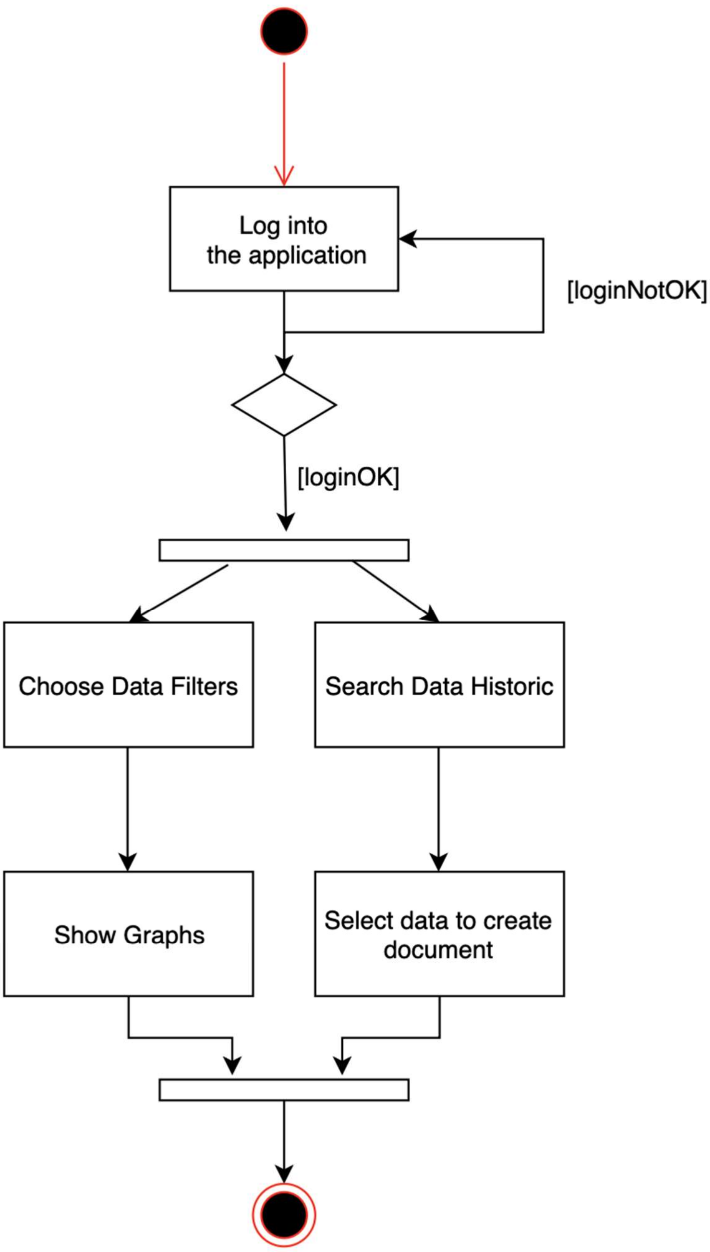


Figure 7: Desktop Application

2.5.3. Network Diagram

The network diagram shows the wireless connections for the data transmission of the project. Full availability is required for every authorised user, and quality of service must be the highest available in order to guarantee the minimum latency (around 15 minutes)

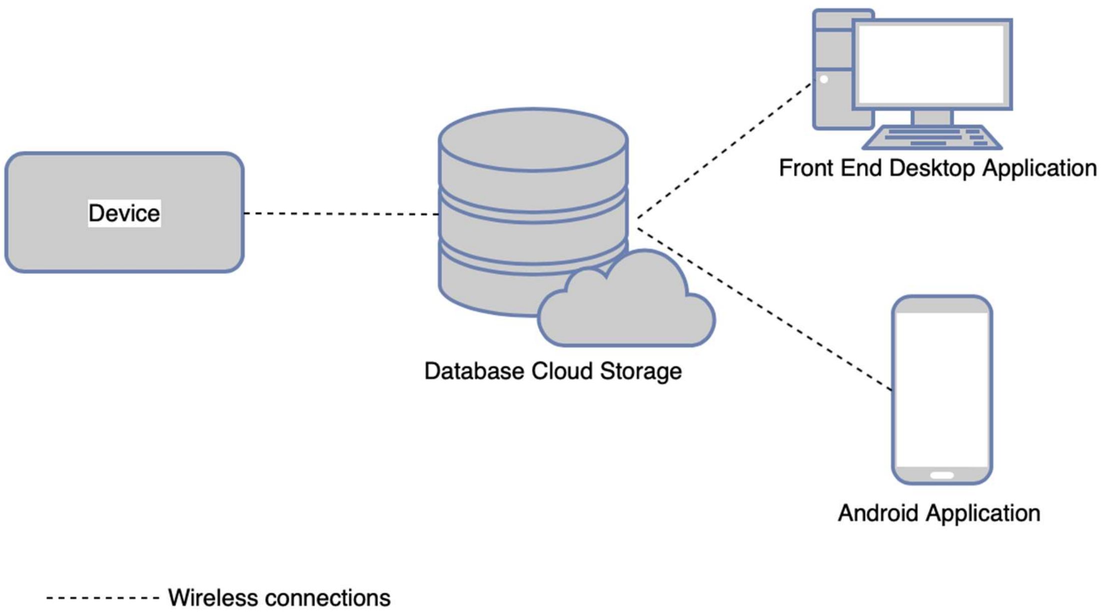


Figure 8: Network diagram

2.6. Calculation and Simulation

On this part of the document, we are going to do some calculations on the power balance of the system.

First, let’s analyze the power consumed by the system. On the next table, we show the estimated power consumption of each component, assuming that they will be continuously turned on:

Table 1

Component	**Current**	**Power**
Microprocessor	1.5mA at 3V	0.0015A*3V*1h = 0.0045 Wh
GSM	1mA at 4V	0.001A*4V*1h = 0.004 Wh
GPS	4mA at 3V	0.004A*3V*1h= 0.012Wh
Bus CAN for BMS	5mA at V	0.005A*5V*1h= 0.025 Wh
LED	30mA at 5V	0.03A*5V*1h=0.15 Wh
Total power per hour		0.1955 Wh

Knowing this, we can say that the total power consumption of our system in a day will be 0.1955*24h= 4.7W.

The batteries used for this project are 12V and 9800mAh. That means, that they can give 12*9.8=117.6W of power. If we divide this number by the total power consumption of our system, we get that the number of hours that our system can run before charging the batteries again is:

$$Time = \frac{117.6}{0.1955} = 601.535\ hours = 25\ days$$

Having this in mind, now we can add the power that the solar panel adds to the system. The solar panel that is going to be used for the project has an output power of 10W.

Assuming that there are 8 hours of sunlight a day and that the power we get from the solar panels are giving one third of the power due to not having a full sunny day and having some lossees:

$$Power\ a\ day = 6h * 3.33W = 20W\ per\ day$$

This means that the number of extra hours of power that the solar panel can give us in average 40W per day, which is enough to fully charge the batteries every day (as the power consumption per day is smaller than this number). This implies that the system in this project can be powered just with solar panels.

3. **Requirements and Verifications**

3.1. GPS

The module we chose for this project is the Ublox NEO-M8N:

1. Reception of up to 3 GNSS (Global Navigation Satellite System): GPS, Galileo, GLONASS, BeiDou.
2. -167dBm navigation sensitivity.
3. Velocity accuracy of 0.05m/s

Table 2

REQUIREMENTS	**VERIFICATION**
A. Location error must not be over 2m B. Must transmit latitude and longitude coordinates of the boat C. Must send data to the micro controller	A. Move the system from a known point to a known destination and measure the distance error. B. Study the data store in the web server. C. Control, via SD card or an auxiliary LCD, if the micro controller is able to receive its location data.

3.2. GSM/GPRS

The specifications for the Ublox SARA G350 module are:

1. Easy migration between 2G,3G and 4G modules.
2. Receiver sensitivity of -109dBm

Table 3

REQUIREMENTS	VERIFICATION
A. Connect to the server and send data. B. Connect to the network with the highest speed (2G/3G/4G) to minimize latency.	A. Log into the server and check that it is receiving the coordinates of the boat. B. Send SMS to designated number to test connectivity 2G and email to test 3G connectivity.

3.3. Microcontroller

ATMEGA328-PU:

1. SPI and UART interface
2. Possibility of adding a CAN module with an Arduino module

Table 4

REQUIREMENTS	VERIFICATION
A. Transmit 100 bytes (corresponding to coordinates and output of one sensor) of data via SPI every 20 minutes to the SD card. B. Show alerts if any of the modules stops working. C. Configure the micro controller and GSM module to connect to the server every 20 minutes and send the sensor data file. D. Receive position coordinates from the GPS sensor and match each sensor reading with its GPS coordinates.	A. Send data of a predetermined size to check if the data sending rate of the micro controller is the appropriate one B. Code by color LEDs to verify the proper performance of the microcontroller. C. External software may be needed to measure the packets that the system is sending to the database system (Wireshark software) D. Check every sensor data on the server is linked to a latitude and a longitude coordinate.

3.4. USB/SD Card

Table 5

REQUIREMENTS	VERIFICATION
A. Receive and log data from the microcontroller.	A. Send a sample.txt file to the micro controller and compare this file with the one saved on the SD card.

3.5. LED

Table 6

REQUIREMENTS	VERIFICATION
A. Be visible with intense sunlight (110,000 lux). B. Flash if the modules are functioning according to plan.	A. Ensure that the LED is visible when flashing an intense light on it. B. Check each LED lights when connecting the PCB to a power source.

3.6. Solar panel

Waterproof solar panel (IP65). 12V 10W

Table 8

REQUIREMENTS	**VERIFICATION**
• Be able to charge the batteries.	A. Fully discharge the batteries and then charge them, making sure that the solar panel is powering them.

3.7. BMS

12V 30A BMS PCB board for Li-ion batteries with charge balance.

Table 9

REQUIREMENTS	**VERIFICATION**
• Communicate with the microcontroller with CAN communication. • Be able to analyze the state of charge of the battery.	A. Check if the microcontroller receives the battery charge data from the BMS. B. Check that the BMS is sending the microcontroller information about the charge in the batteries

3.8. Batteries

12V 9800Ah battery.

Table 10

REQUIREMENTS	VERIFICATION
• Power the electronic components of the project. • Be able to be charged by solar panel	A. Place a load equal to the average power consumption of the whole system and check if the batteries can power this equivalent system. B. Discharge the batteries and connect them to the solar panel. Then check that the battery load has increased by discharging the batteries again.

3.9. Desktop Application

Table 12

REQUIREMENTS	VERIFICATION
A. Retrieve and process data from database or web service B. Graphical representation of the data retrieved from the server C. Filter and search on data tables D. Show data with an actualization delay of at most 15 minutes	A. Compare data from application with data stored in the server. B. Represent sample data in a processing software (MATLAB) and compare the accuracy of the desktop application. C. Check filtering by application and type of sensor by navigating through the application. D. Check real time timestamps of the data from the server.

4. Tolerance Analysis

The critical part of the project is the GSM sensor given that it is the module that connects the system to the user (web application) If GSM sensor is not configured to reach connectivity in the right frequency (1900 MHz in order to be able to work for the main phone companies and for 2G/3G, or 5200 MHz if we wanted to reach 4G, but this is not guaranteed given that the project is aimed at remote locations)

The GSM most used bands change between continents. We would take North and South America as a reference in order to test the error of our sensor. For this location we need to take into consideration the following characteristics:

Table 13: GSM frequency range

Name	Interface	Generation	Range (MHz)
850	GSM, UMTS, LTE	2.5G, 3G, 4G	824.2-893.8
1900 (PCS)	GSM, UMTS, LTE	2.5G, 3G, 4G	1850.2-1989.8

We might encounter the situation in which the antenna inside of the boat doesn't a signal strong enough to establish a connection. This might be caused because the depth of penetration of the signal is not enough for the characteristic impedance and width of the boat material.

The losses in this case would be equal to:

$$L_{dB} = 20log\left(e^{-t\frac{d}{\delta}}\right)$$

Eq. 1

In this case, we might need to design a radome in order to maximize the signal power output and install the GSM sensor on the surface of the boat, given that this minimally attenuates the signal.

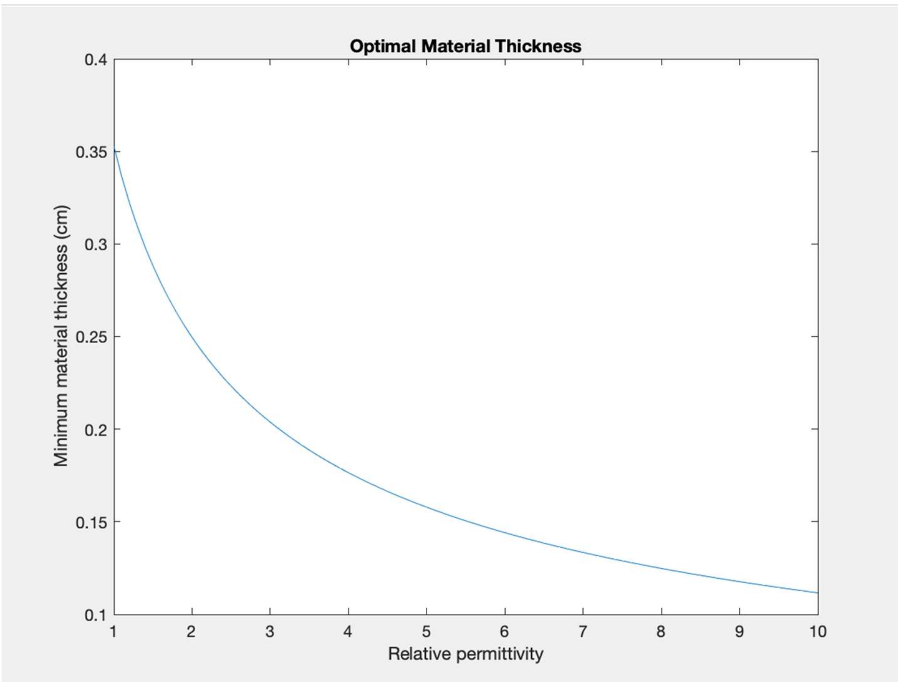
Given a signal of 850MHz and a plastic for the radome of relative permittivity to 3,5 (for this example), the width of the radome (or in its defect the width of the boat material) should follow the following rules, in order not to affect the antenna adaptation.

The wavelength of the medium should be $\lambda/2$, so the input impedance is not displaced. The wavelength of this material would be:

$$\lambda = \frac{c}{f\sqrt{\varepsilon_r}}$$

Eq. 2

The minimum wavelength of the material should be, in this case, 1.33 cm. We should aim to achieve the optimal value for the material of our boat or radome.



Graph 1: Thickness vs permittivity

5. Cost Analysis

Table 14: Component Cost

Component	Model	Cost
GPS (Option 1)	Ublox NEO-M8N	$22.87
GSM/GPRS (Option 1)	Ublox SARA G350	$13.23
GPS (Option 2)	GNSS MIKROE-2760	$41.00
GSM/GPRS (Option 2)	GSM MIKROE-2388	$49.00
Microcontroller	ATMEGA328-PU (2)	$3.24
Communications Hub	Raspberry Pi 3B+	$39.99
Diode		$0.4
LED	(2)	$0.7
SD reader	FPS009-3004	$7.59
Solar Panel	ECO-WORTHY 20W 12V IP65	$33.56
BMS	3S,50A,11.1V/12V/12.6V BMS PCB Li-ion Battery with Balance	$17.29
CAN BUS adapter for Arduino	Makerfocus CAN-BUS Shield V1.2	$17.99
Charger	12V Li-ion Chicago Electric	$14.99
Batteries	Li-ion 12V, 9800mAh	$26.15
Material total		$198

Table 15: Labor Cost

Function	Estimated Hours (h)	Cost ($)
PCB design	25	750
Battery design	20	600
Desktop Application development	25	750
Android Application development	25	750
GPS/GSM calibration and configuration	35	1050
Charger and solar panel study	30	900
Building system	25	750

Table16: Other costs

Service	Cost
PCB manufacturing	$35/h
Database cloud subscription	$20/month
Data Plan (Internet and SMS)	(To be determined)

6. Schedule

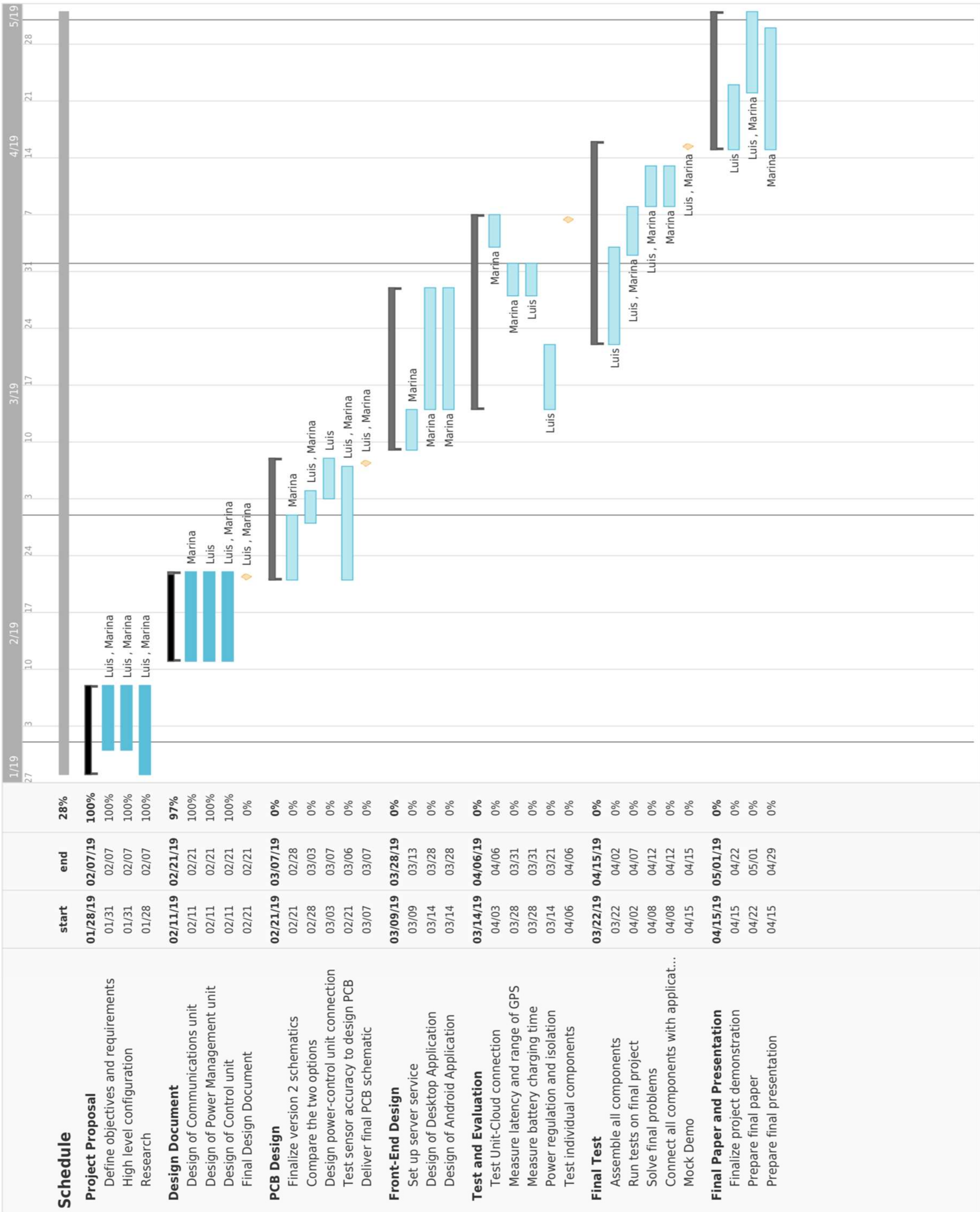


Figure 9: Schedule

7. Ethics and Safety

This system should entail no risk to the environment, or to the animals living in or around the lakes or rivers that are being analysed. Also, if the water being analysed is polluted, the consumers of this water should be alerted instantly.

In addition, when designing this project, we need to keep in mind the environmental impacts that it could have and also guarantee a sustainable system given CERSE's commitment to sustainable practices and its commitment to the environment.

According to the IEEE Code of Ethics, the project we need to agree "to be honest and realistic in stating claims or estimates based on available data". This point has great importance to our project given that the data collected must be analyzed by not biased algorithms and keep people's interests and not companies first, given that drinkable water is a priority in our society. Information should be managed and published in a honest way, always having in mind that people's health is in risk.

The boat should be perfectly sealed, so that no water gets into the electric system and entails no risk. If water gets into the system, there could be a short circuit. This could destroy the electric system and could be dangerous for the animals that live in the water that is being analysed, as they could get an electric shock. This is also a reason for choosing a waterproof solar panel.

It should be ensured that that the electric system is completely isolated from the body of the boat. If there is not a complete isolation, the boat could be electrically charged and could be very dangerous for the living creatures of the lake or river, as they could get an electric shock.

The chosen motor should be an electric motor. These type of motors are the most eco-friendly ones. Using a petrol or gas motor would pollute the water, as oil could get spilled in the water, and also the smoke it produces is dangerous for the environment. Also, this smoke and oil could taint the water samples that the boat collects.

We should have in mind that if there is an issue with the boat and the batteries get into the water, they should be collected immediately. These batteries are made of very polluting and dangerous chemical materials, such as lithium or lead. This is why they should be collected from underwater if the boat sinks, before they damage the water.

8. References

[1] “Adafruit Industries LLC 254”, DigiKey Electronics, February 21 2019 [Online]

https://www.digikey.com/product-detail/en/adafruit-industries-llc/254/1528-1462-ND/5761230&?gclid=EAIaIQobChMI8Ku9kZzM4AIVdB-tBh2BAQ4TEAYYAyABEgKgKfD_BwE

[2] “GNSS 5 click”, MikroElektronika, February 21 2019 [Online]

https://www.mikroe.com/gnss-5-click

[3] “GSM 4 click”, MikroElektronika, February 21 2019 [Online]

https://www.mikroe.com/gsm-4-click

[4] “NEO-M8 Datasheet”, U-blox, August 5 2016 [Online]

https://www.u-blox.com/sites/default/files/NEO-M8-FW3_DataSheet_%28UBX-15031086%29.pdf

[5] “Positive Voltage Regulators”, Texas Instruments, May 2003 [Online]

https://www.sparkfun.com/datasheets/Components/LM7805.pdf

[6] “SARA-G3 series”, U-blox, March 27 2018 [Online]

https://www.u-blox.com/sites/default/files/SARA-G3_DataSheet_%28UBX-13000993%29.pdf

[7] “How to choose the best battery for a solar energy system”, Energysage, January 1 2019 [Online]

https://www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels/

[8] “Lithium-Ion Battery Management Systems and large battery packs”, Li-Ion BMS, [Online]

http://liionbms.com/php/index.php

[9] “Como elegir baterías para paneles solares”, Calefacción solar, February 14 2019 [Online]

http://calefaccion-solar.com/como-elegir-baterias-para-paneles-solares.html