DESIGN DOCUMENT

ECE 445- SENIOR DESIGN PROJECT LABORATORY
GROUP 56

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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 analysis every 20 minutes with desktop and android applications to access the data.
- The boat should be able to be charged both by solar panels and a wall plug. The solar panel should increase the autonomy of the boat in at least 2h, and charging the boat by plug should take less than 6hours.
- Monitoring via GPS of the boat with a precision of +/- 2 m

2. Design

2.1. Modular Block Diagram

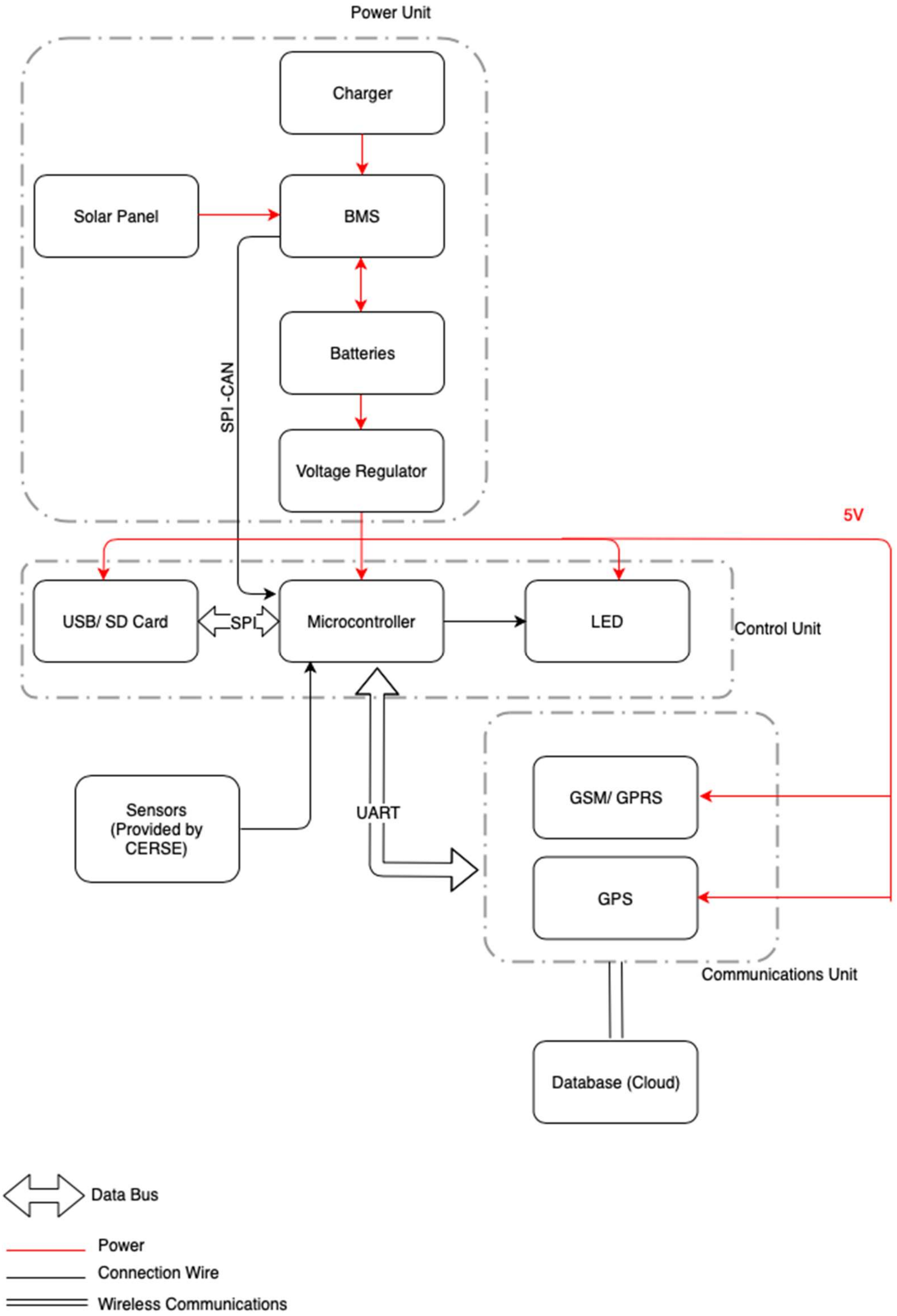


Figure 1: Modular Block Diagram

2.2. Components Descriptions

2.2.1. Power Management Unit

- **Solar panel:** a solar panel is required in order to give the boat the sufficient power to stay in a desired position in a lake or river during various days. The power requirement is yet to be specified by the company.

  The calculation of the solar panel depends on the boat size (still to be specified) and the power needed to power the motor and all the electronics in the boat.

- **Batteries:** a set of batteries is needed in order to store the energy received by the sunlight, and be able to power the boat. Total power needed is still to be specified by the company.

  The calculation of the batteries needed depends on the total energy needed to power the boat, and the amount of days the boat needs to be offshore. Despite that, we have done some research about the batteries that best suit the project. The most common batteries used with solar panels are:

  - 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.

- **Charger:** a charger wants to be implemented in the boat, so that it can be charged faster than with the solar panels when the boat is just about to be deployed. **(**The charger calculations depend on the batteries used, so it is still to be specified.)
- **BMS:** Battery Management System to control the state of charge of the batteries and check that all of them are working properly. Also to start/stop getting energy from the solar panels depending on the battery charge.

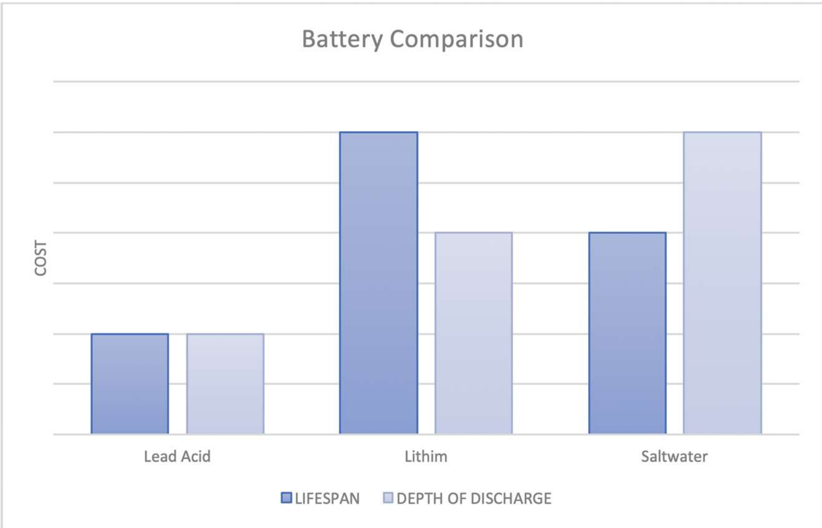


Figure 2: Battery Comparison

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

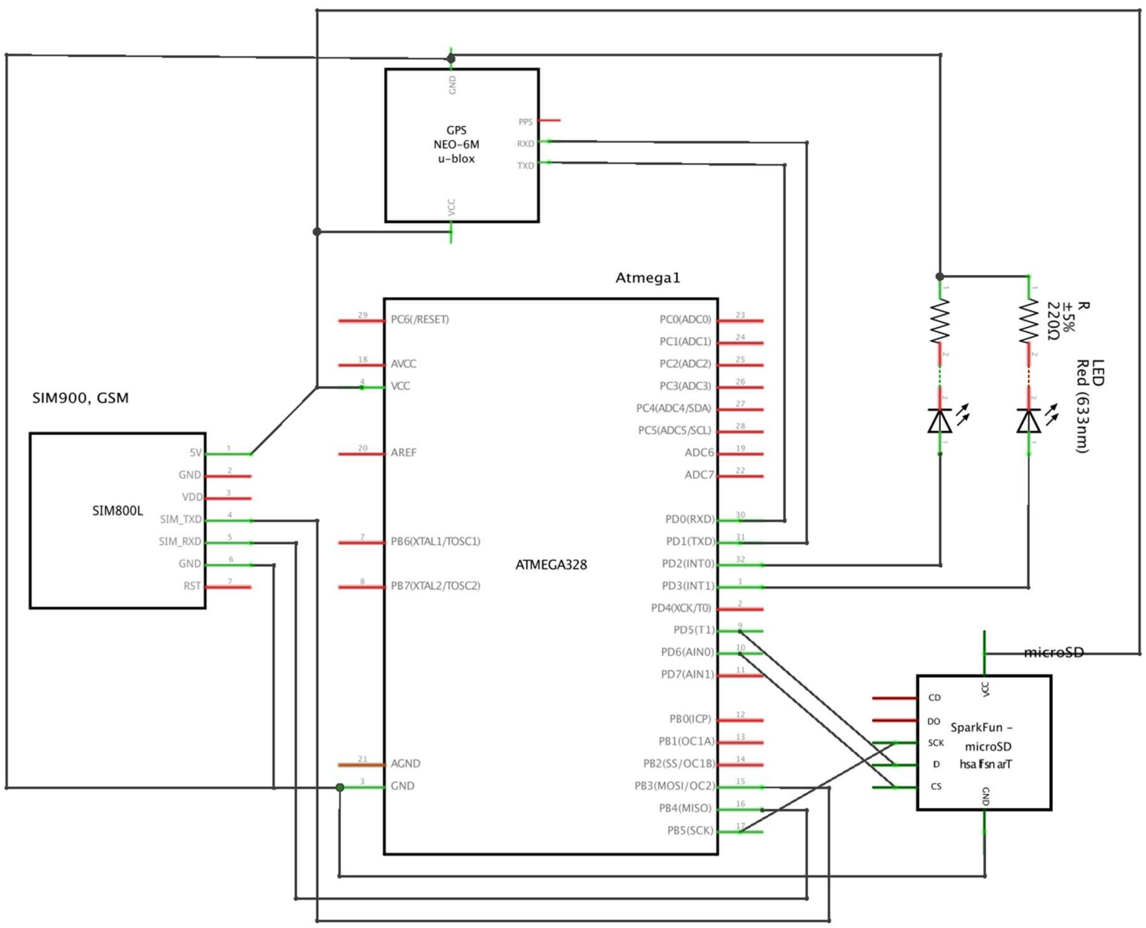


Figure 3: Option A Block Diagram

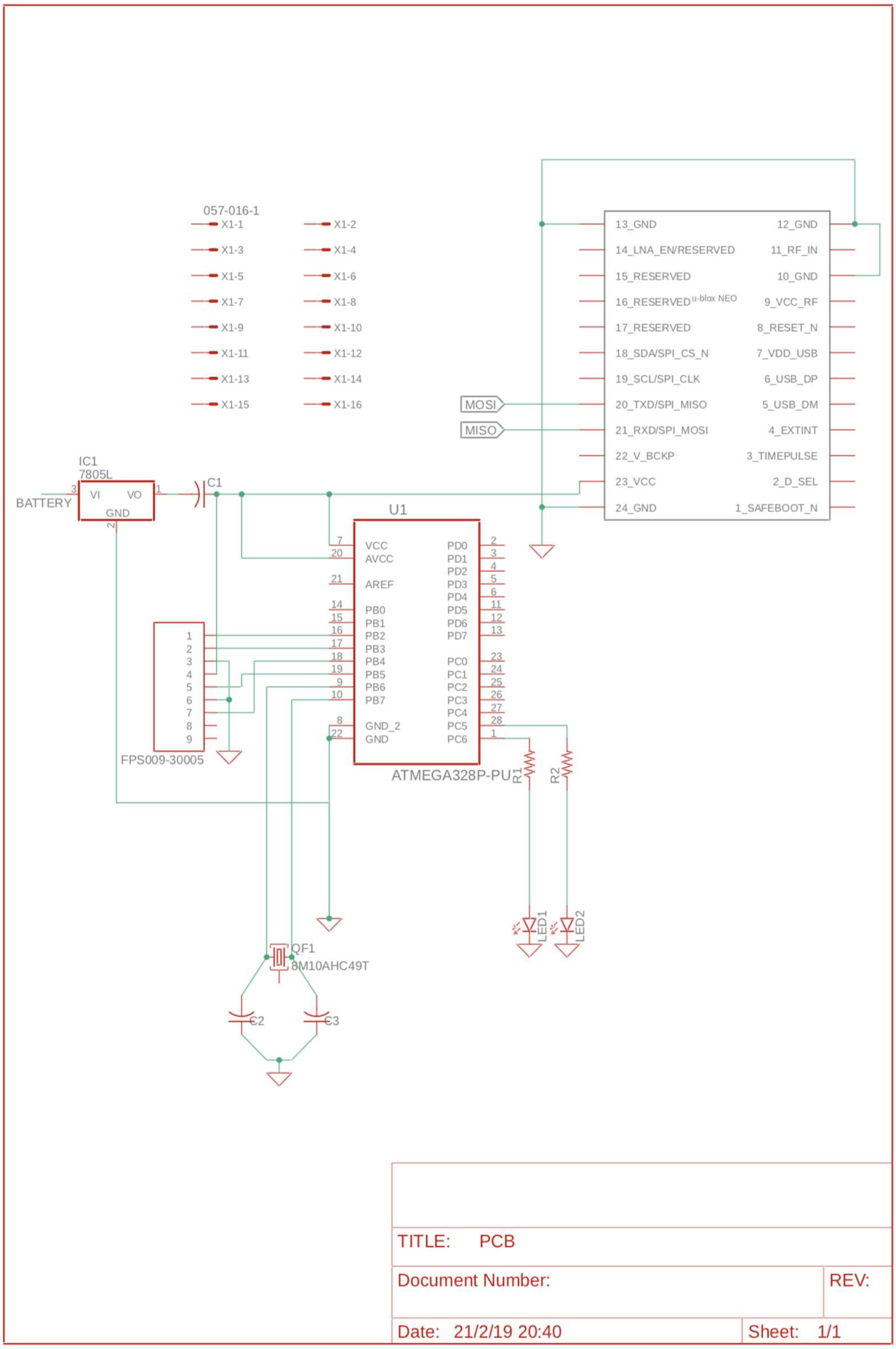


Figure 4: PCB Schematic

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.

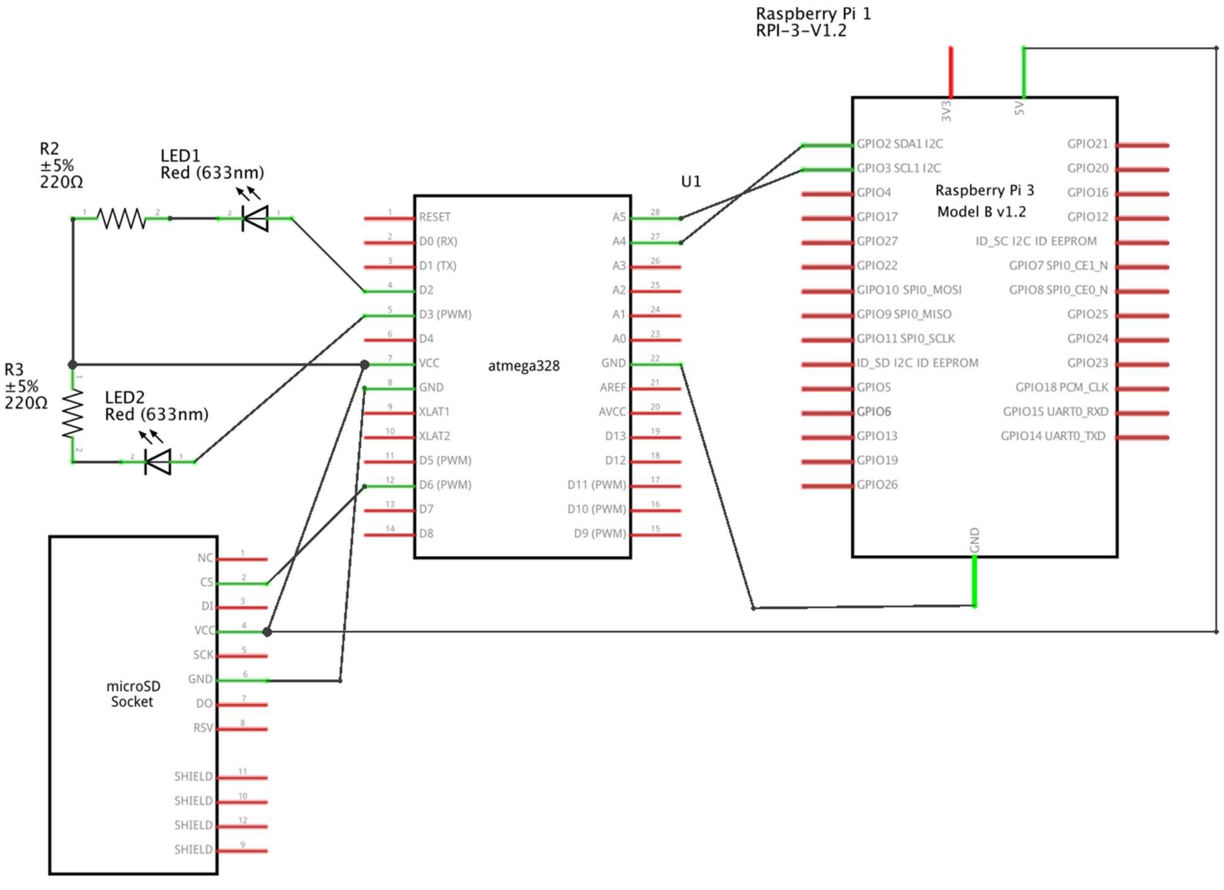


Figure 5: Option B Block Diagram

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.

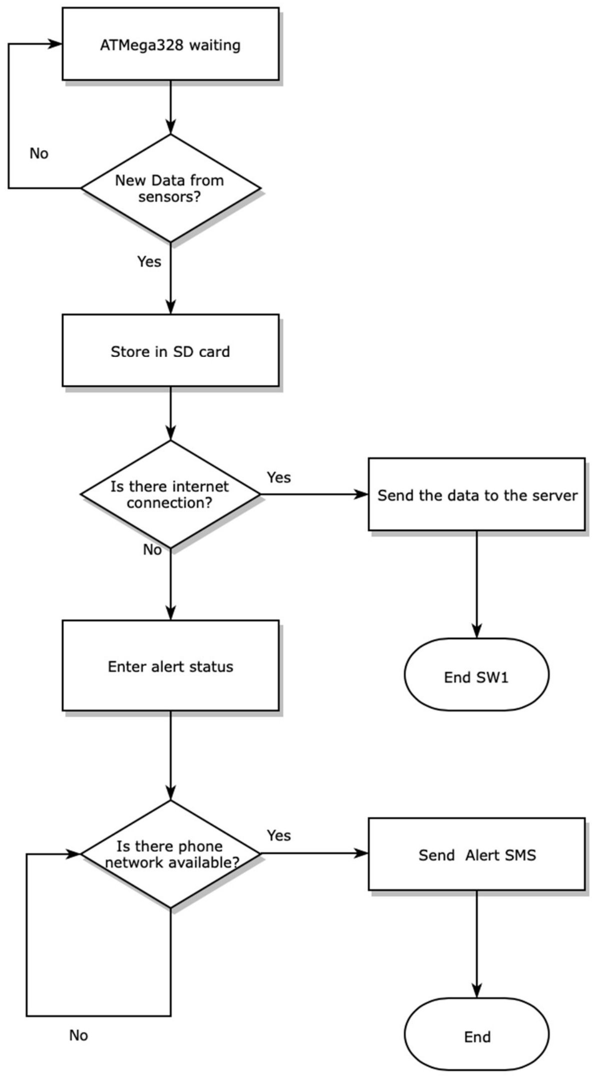


Figure 6: Microcontroller Software Flow

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.

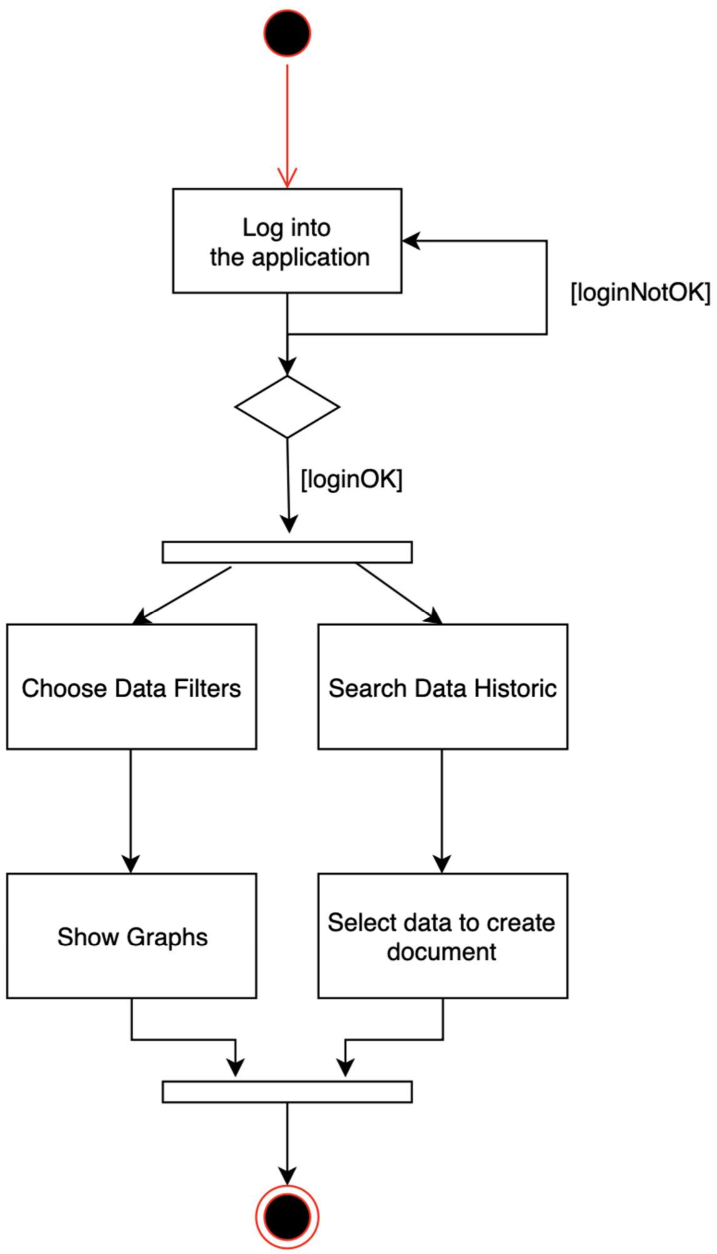


Figure 7: Desktop Application

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)

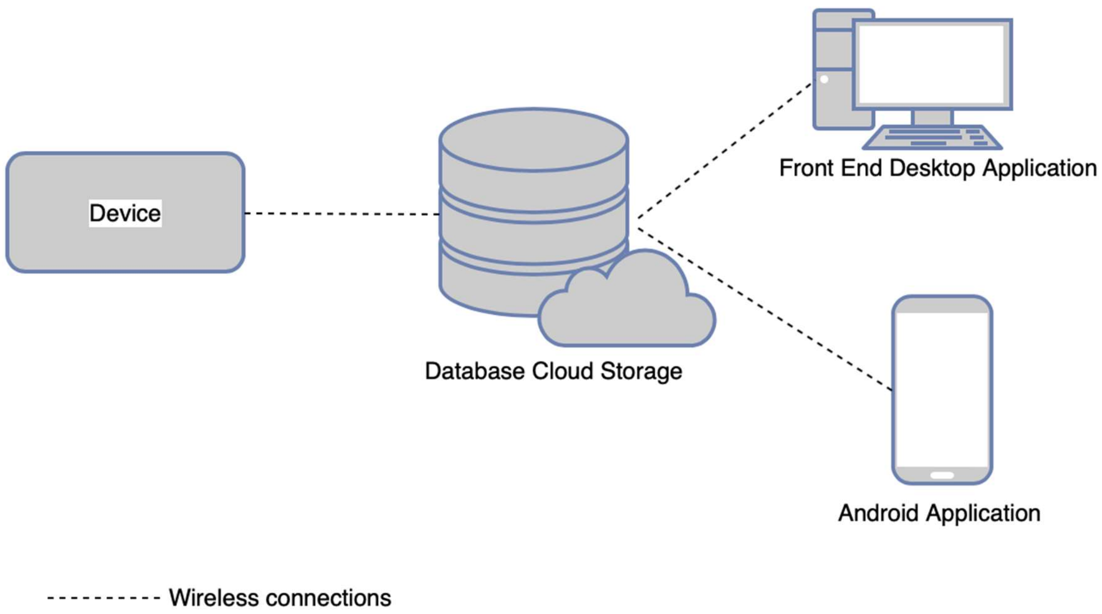


Figure 8: Network diagram

2.6. Calculation and Simulation

After doing some research, we noticed that the maximum current for competition boats with the dimensions of the boat that is going to be used in this project (1m long) is between 60A and 80A. Those current values are reached when the motor is working at its full power capabilities. At those values of power consumption, these boats reach on average 50 mph. The boat that is going to be used in this project does not need to reach high speeds. As the company CERSE stated, it just needs to move slowly on the water. That means, that we do not need to apply that much current to the motor when moving the boat. Despite that, we should also have in mind that our boat is going to be heavier than those competition ones, as we are going to add to it the battery pack (which will be around 6kg) and the solar panel (around 3kg) and the rest of electronic components and sensors. Having this in mind, we can estimate the average value of current being applied to the motor when moving to 10A.

When analysing the voltage of the boats that are currently in the market with the same size as the one in the project, we can see that the voltage varies between two different values: 11.1V and 14.8V. This means that, depending on the motor that is going to be used in the end, we will need 3 or 4 battery cells. Let's assume that our motor needs 14.8V. In this case, we will need 4 batteries connected in series to reach the nominal voltage of the motor.

Let's first analyse the current consumption every hour, to get the total amperes per hour that we need from our batteries in order to power the whole system:

Table 1

Component	Current	Time an hour	Power
Motor	10A	0.17h	10*0.17*14.8V = 25.16Wh
Microprocessor	120mA	1h	0.12*1*5V = 0.6Wh
Total			25.76Wh

In order to calculate the number of hours that each of the components is going to be working, we assume that each of the 7 outputs that the microprocessor has, will have an output of 20mA. Also, the boat will be moving for 5 minutes every 30 minutes (will take samples at a place for 20 minutes before moving to the next place, which could take it 5 minutes moving).

The batteries that are going to be used in the project are 3.7V and 40Ah (as specified later on in the document). This means that having 4 of these in series, we would have a total of 14.8V and 40Ah. Let's calculate for how many hours could the batteries power the boat with no solar panels:

$$Time = \frac{14.8 * 40}{25.76} = 22.98\ hours$$

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. We are going to use 2 of these in parallel, which would give the same output voltage but double the current output, which will help to charge the batteries twice as fast.

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

$$Power\ a\ day = 8h * 5W = 80Wh$$

This means that the number of extra hours of power that the solar panel can give us a day is:

$$Time = \frac{80}{25.76} = 3.1h$$

After all the power calculations, we can state that the number of hours that the boat can work without having to stop to get charged with the chosen components and the consumption assumptions made is:

$$Time\ without\ charging = 3.1 + 22.98 = 26.08h$$

After this time, the boat will need to get charged. With the chosen charger (14.8V and 8A), the charging time would be:

$$Charging\ time = \frac{40Ah}{8A} = 5h$$

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**
• Communicate over UART with the microcontroller, minimum 19200 bauds. • The location error must not be over 15m	A. Connect to Raspberry Pi or ATMega328 port via UART sending the coordinates of its position. B. Move the system to observe the error and accuracy comparing the results with a location system.

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
• Connect to the designated server and send the specified data to have an update every 20 minutes. • Connect to the network with the highest speed (2G/3G/4G) to minimize latency. The minimum speed should be around 40kbits/s	A. Obtain the data from the server and make sure that it is being sent correctly by login into the database platform. B. Send SMS to designated number to test connectivity 2G C. Send 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
• Receive and transmit data through CAN at 100 kbps. • Receive and transmit data through SPI at 9600 bauds. • Processing CPU to manage the output and input data (1 sample per channel per 10 seconds) Manage load balancing of the sensor data if load is bigger than processing of the microcontroller. • Manage power supply for the communication unit and the sensors	A. Send data of a predetermined size to check if the data sending rate of the microcontroller is the appropriate one (Check with Putty or UART connection) 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)

3.4. USB/SD Card

Table 5

REQUIREMENTS	**VERIFICATION**
• Receive and log data from the microcontroller. • Log data from the sensors as well as the errors of the system (1 sample every 10 seconds)	A. Compare data from the database cloud with the SD data.

3.5. LED

Table 6

REQUIREMENTS	**VERIFICATION**
• Be visible with intense sunlight (110,000 lux).	A. Ensure that the LED is visible when flashing an intense light on it.

3.6. Auxiliary microcontroller

Table 7

REQUIREMENTS	VERIFICATION
• Send location and emergency data in case the main microcontroller ceases to work (This is an emergency measure that would be implemented depending on the progress of the project)	A. Check if, when the main microcontroller gets disconnected, this one sends the location information to the server.

3.7. Solar panel

2 waterproof solar panels of 10W and 12V

Table 8

REQUIREMENTS	VERIFICATION
• Charge batteries in 4 hours (half of the average sunlight hours in a day) even if it is a cloudy day. • Be waterproof to splashes, so that the system does not get harmed if the water from the lake or river wets it.	A. Fully discharge the batteries and charge them fully, measuring the time consumed. B. Take out the solar panel from the waterproof cover and put paper instead. Wet the cover and then remove the paper and check if it is wet.

3.8. BMS

The BMS that is going to be used is a 14.8V, 4S, 30A. This means that it manages the charge of 4 batteries in series with a total voltage of 14.8V, and can take up to 30A.

Table 9

REQUIREMENTS	VERIFICATION
• Communicate with the microcontroller with CAN communication with a speed of 100kbps. • Be able to analyze the charge in every battery cell (4 cells in this project). • Have a larger maximum current than the charger's output.	A. Check if the microcontroller receives the battery charge data from the BMS. Check the speed at which the data is being received.

3.9. Batteries

4 individual cells of 3.7V and 40Ah connected in series. This gives an output power of 14.8V and 40Ah.

Table 10

REQUIREMENTS	VERIFICATION
• Last for 20 hours without charging, and powering all the electric and electronic components of the boat (25.76Wh).	A. Place a load equal to the average power consumption of the whole system, and check if the batteries are able to power this equivalent system during 20 hours.

3.10. Charger

Charger of 110V of input and 14.8V 8A of output.

Table 11

REQUIREMENTS	VERIFICATION
• Input of 110V. • Output of 14.8V	A. Check the charger datasheet and the output with a voltmeter.

3.11. Desktop Application

Table 12

REQUIREMENTS	VERIFICATION
• Retrieve and process data from database or web service • Graphical representation of the measurements of the graphs. • Filter and search data • Authentication to access the data • Show data with delay of at most 15 minutes	A. Compare data from application a SD data B. Represent sample data in a processing software (MATLAB) and compare the accuracy of the desktop application. C. Correct filtering by location and type of sensor. D. Measure real time clock delay.

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:

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

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.

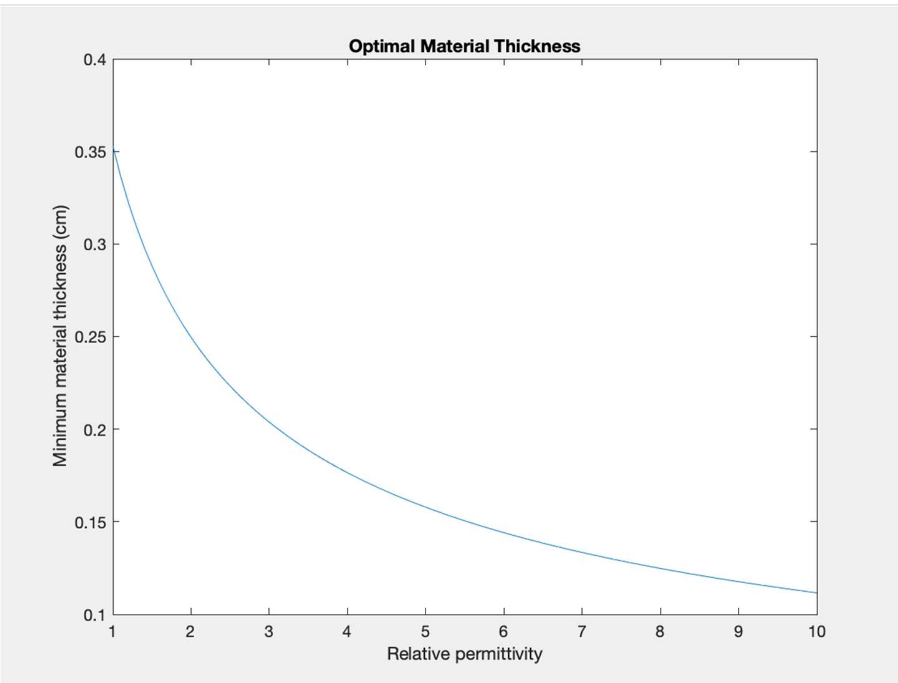
Given a signal of 850MHz and a plastic for the radome of relative permittivity to 3,5 (for this example), the width of the radome (or in its defect the width of the boat material) should follow the following rules, in order not to affect the antenna adaptation.

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
LED	(2)	$0.7
SD reader	FPS009-3004	$7.59
Solar Panel	ECO-WORTHY 10W 18V	$55.8
BMS	Daier E880	$10
Charger	Wate 14.8V, 8A	$18.8
CAN BUS adapter for Arduino (connection between BMS and micro)	-	$66
Batteries	AA Portable Power Corp PLH-12211218C	$636

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

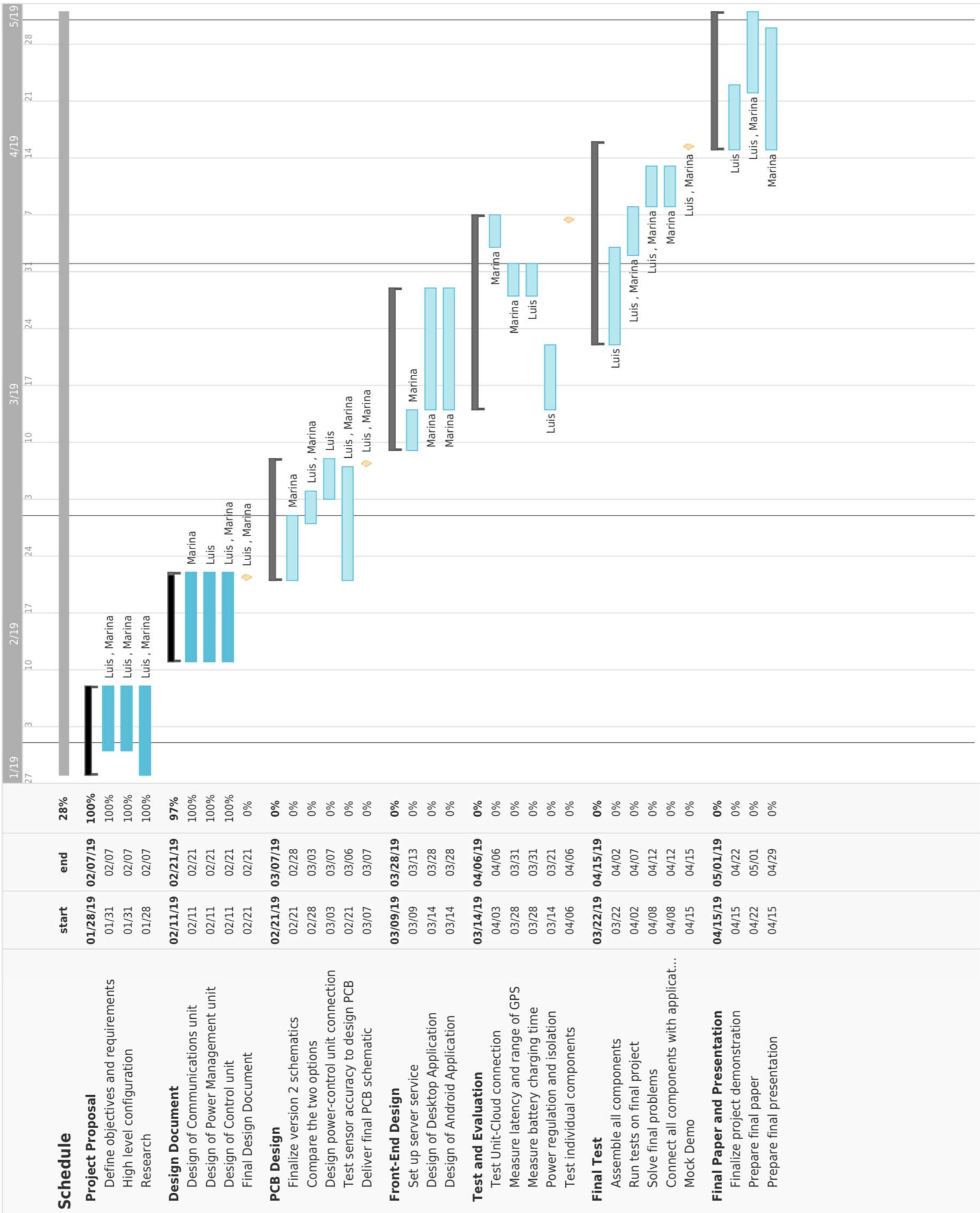


Figure 9: Schedule

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