Report

Autonomous Environmental Buoy/Regatta Beacon

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Abstract

Buoys are nowadays more important than ever before. They come in a multitude of types and can perform various functions. Nevertheless, the market is not exhausted yet and it does need a breath of fresh air. For this purpose we undertook the task of constructing an original buoy with two major applications: collection of weather data and assistance in autonomous sailing boat regattas.
First we analysed the market of buoy manufacturers and their products. We focused on three of the buoys’ aspects: construction, functionality, and innovation. As far as construction is concerned, we examined the design and the layout of the buoys’ components, the type of materials buoys are made of, and the hardware they use. In terms of functionality, we researched the buoys’ possible functions and how exactly they perform them. With this background knowledge we decided roughly what our buoy should look like. We then proceeded with a more extensive research on each individual component, and finally made a list of those that we could use. Some of the major tasks of our project

included designing an original stainless steel structure, preparing signal and power schematics, and programming the software.
The final product of our project is a functioning buoy. It consists of a fibreglass hull, a stainless steel structure, and various electronic components including Wi-Fi and GNSS antennas, CTD and wind sensors etc. Because of its small size and lightness, and the fact that it can perform many functions including weather data collection, storage, and sending, the buoy constitutes a favourable alternative to many other buoys. Moreover, it combines two major and significant applications, i.e. collection of weather data and assistance in regattas, which makes it the first of the type. Nevertheless, the buoy unfortunately does have two limitations. First of all, it can only hold up a total weight of around 40kg. Secondly, it cannot be used on the sea or ocean.

Glossary

Introduction
CTD – Conductivity, Temperature and Depth sensor, developed by ISEP.
EPS - European Project Semester, type of ERASMUS Student Exchange program in which we are participating.
GNSS - Global Navigation Satellite System, is a system of satellites that provide autonomous geo-spatial positioning with global coverage.
LSA - Autonomous Systems Laboratory, department of ISEP.
UV - Ultraviolet light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays, that is, in the range between 400 nm and 10 nm.

State of the Art
µC – Microcontroller.
Accelerometer - Is a device that measures acceleration.
BD - Blu-ray Disc is an optical disc storage medium designed to supersede the DVD format.
Bluetooth - Is a wireless technology standard for exchanging data over short distances from fixed and mobile devices, creating personal area networks with high levels of security.
CAN - Controller Area Network, type of communication interface.
Catenary - The curve that an idealized hanging chain or cable assumes under its own weight when supported only at its ends.
CD - The compact disc, is an optical disc used to store digital data.
CEC - Consumer Electronics Control, type of communication interface.
CPU - Central processing unit, is the hardware within a computer that carries out the instructions of a computer program by performing the basic arithmetical, logical, and input/output operations of the system.
Crown - The bottom portion of an anchor.
DVD - Is an optical disc storage format, who offer higher storage capacity than compact discs while having the same dimensions.
E-compass – Electronic compass.
FEUP - Faculdade de Engenharia da Universidade do Porto, University of Porto faculty.
Fluke - The triangular blade at the end of an arm of an anchor, designed to catch in the ground.
GPIO - General Purpose Input/Output.
GSM - Global System for Mobile Communications, communication standard.
Gyroscope - A gyroscope is a device for measuring or maintaining orientation, based on the principles of angular momentum.
Hall effect - A phenomenon that occurs when an electric current moving through a conductor is exposed to an external magnetic field applied at a right angle, in which an electric potential develops

in the conductor at a right angle to both the direction of current and the magnetic field.
HDMI - High-Definition Multimedia Interface, type of communication interface.
Holding power - The value of the maximum pulling force an anchor accepts without dragging in given conditions.
I/O – Input/output.
I2C - Inter-Integrated Circuit, referred to as I-squared-C, type of communication interface.
I2S - Also known as Inter-IC Sound, Integrated Interchip Sound, type of communication interface.
IEEE - Institute of Electrical and Electronics Engineers, a professional association of engineers dedicated to advancing technological innovation and excellence. It is specialized in creating international standards about electronic, IT, communication etc. technologies.
LAN - Local Area Network, is a computer network that interconnects computers in a limited area such as a home, school, computer laboratory, or office building using network media. LED - Light-Emitting Diode.
Li-ion - Lithium-ion.
Luminous flux - A measure of the total “amount” of visible light emitted by a source.
NiCd - Nickel-cadmium.
NiMH - Nickel–metal hydride.
PCB - A printed circuit board is used to mechanically support and electrically connect electronic components.
RAM - Random-access memory, is a form of computer data storage.
RCA - Is a type of electrical connector commonly used to carry audio and video signals. The name “RCA” derives from the Radio Corporation of America.
RF - Radio Frequency.
SD card socket - Secure Digital card socket.
Shackle - Any of several devices, such as a clevis, used to fasten or couple.
Shank - The stem of an anchor, at the top of which is the anchor ring.
Stock - the crosspiece at the top of an anchor’s shank, either fixed or removable.
SLI – Start, Light, Ignition, a term used in the automotive industry.
SPI - Serial Peripheral Interface Bus, type of communication interface.
Swivel - A link, pivot, or other fastening so designed that it permits the free turning of attached parts.
Thimble - A metal ring around which a rope splice is passed.
Transformer - Device used to transfer electric energy from one circuit to another, especially a pair of multiply wound, inductively coupled wire coils that effect such a transfer with a change in voltage, current, phase, or other electric characteristic.
UART - Universal Asynchronous Receiver/Transmitter, type of communication interface.
UHF - Ultra High Frequency, radio frequency range of electromagnetic waves between 300 MHz and 3 GHz.
Ultrasonic - Acoustic frequencies above the range audible to the human ear.
UMTS - Universal Mobile Telecommunications System, is a third generation mobile cellular system for networks based on the GSM standard.
USART - Universal Synchronous/Asynchronous Receiver/Transmitter, type of communication interface.
USB - Universal Serial Bus, is an industry standard developed that defines the cables, connectors and communications protocols used in a bus for connection, communication and power supply between computers and electronic devices.
VHF - Very High Frequency, range of radio frequency electromagnetic waves from 30 MHz to 300 MHz.
Wi-Fi - Is a technology that allows an electronic device to exchange data wirelessly (using radio waves) over a computer network.
WLAN - Wireless Local Area Network.

Marketing Plan
B-to-B - Business to Business.

R&D -Research and Development.
ROI - Return on investment is used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments.
SWOT - Strengths, Weaknesses, Opportunities and Threats.
WoM - Word of Mouth, is the passing of information from person to person by oral communication.
WRSC - World Robotic Sailing Championship.

Energy and Sustainability
EPA - Environmental Protection Agency.
ISO - Is the International Organization for Standardization; it is an international standard-setting body composed of representatives from various national standards organizations.
LCA - Life Cycle Assessment.
WBCSD - The World Business Council for Sustainable Development.
WOC - World Ocean Council.

Ethics and Deontology
Code of ethics - Set of rules and principles concerning ethical way of behaving.
Deontology - Part of ethics concerning duties and obligations of human beings.

Project Development
EPDM - Ethylene propylene diene monomer.
Equilibrium position - Is a condition in which all acting influences are cancelled by others, resulting in a stable, balanced, or unchanging system.
Fibreglass - Is a fibre reinforced polymer made of a plastic matrix reinforced by fine fibres of glass.
GND - In electrical engineering, ground or earth can refer to the reference point in an electrical circuit from which other voltages are measured, or a common return path for electric current, or a direct physical connection to the Earth.
Hull - A hull is the watertight body of a floating vessel.
MAX232 - Is and integrated circuit that converts signals from an RS-232 serial port to signals suitable for use in digital logic circuits, TTL, and the other way around.
MCU - MicroController Unit.
Net force - Is the overall force acting on an object.
Potentiometer – device to regulate the voltage supply.
TTL - Transistor–transistor logic, is a widespread integrated circuit family.
Voltage regulator - Is designed to automatically maintain a constant voltage level.

1. Introduction

1.1 Group presentation

In the middle of February 2013 we started with a programme called the European Project Semester. Out of a total of 13 people that took part in it at the Instituto Superior de Engenharia do Porto, there were three teams created. Our team consisted of four members and was called Team 3 (Table 1-1). Within the scope of this programme, we were working on a major project that lasted the whole semester and were attending classes that complemented it.

Table 1-1 Team members

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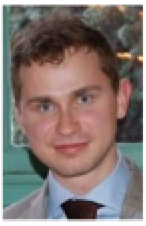

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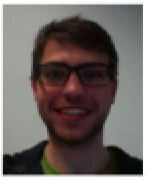

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1.2 Motivation

There were two major concerns we had in mind when selecting the topic of our project. The first was the will of working on something interesting, and perhaps even entertaining. The second was the uncertainty of the feasibility of a given topic. After some time of brainstorming, our final choice was the "Autonomous Environmental Buoy/Regatta Beacon". The reasons for this were threefold. First of all, it stood out among all other topics; it seemed especially interesting. Secondly, Bennet is a surfer and in general a water sports fan, therefore it was related to his interests. Moreover, none of us knew at that time much about buoys, let alone an electronic buoy, and we wanted to challenge ourselves and learn something new and perhaps useful in our future.

1.3 General Information

A buoy is a device that is used in water in such a way that it floats being partially submerged, as exemplified in Figure 1 1. It can be found at places where there is a lot of water, such as the open ocean, a river, a bay, a lake. There are many different types of buoys serving a wide range of functions, for example: warning navigators about dangers, collecting data for weather agencies, providing ships with the means of mooring. Depending on these functions, a buoy can have a size ranging from as small as a football to as big as a phone booth. The smallest buoys often do not contain any electronic equipment; they consist of an empty hull and are used, for instance, to mark the location of an anchor. The bigger buoys are mostly equipped with a multitude of electronics such as sensors, solar panels and batteries.

Figure 1-1 Example of a buoy

1.4 Project description

The task of our project was to design and construct an electronic buoy. The buoy was intended to be relatively small compared to some of the biggest existing ones, but rather complex as it was to have a number of electronic devices that would allow it to perform two different functions (these are detailed in section 1.5 below). Part of our project had been previously completed at the point when we started it, i.e. there was already an existing hull (Figure 1 2). It is a light fibreglass structure that resembles planet Saturn. It is empty inside and it possible to access the interior by unscrewing six bolts and taking off the cover.

Figure 1-2 Existing hull

1.5 Objectives

The general objective of the buoy was to measure, store and send data from its location in a river. It was intended to have two major applications:

1. assistance in autonomous sailing boat regattas

In this function the buoy was supposed to perform two tasks:

- inform the sailing boats about its location so that they travel in the right direction
- provide judges with the necessary weather data to assess each boat's performance

2. collecting environmental data

The buoy was supposed to make measurements of selected weather conditions at a chosen site and period. Nevertheless, its future application was to be limited to Douro river and for a seven-day period.

1.6 Requirements

There is a number of requirements that needed to be fulfilled in order for the buoy to be operational. One of the most important was the necessity of having a specific structure attached to the hull. First of all, because of the constant exposure to sun and saltwater, it had to be made of a material resistant to corrosion and UV radiation. Secondly, it should provide the space for the attachment of some of the equipment. Furthermore, it was highly important that it was able to carry all possible loads that it would be subject to (weight of the electronic equipment, wind, rain, waves, etc.). Moreover, it was necessary that it did not exceed a certain weight to make sure it did not cause the hull to sink. In addition, it was significant that the structure had the right shape so that the centre of gravity was exactly in the centre as seen from above, and so that it was possible to take off the hull's cover. The second requirement referred to the buoy's electronic equipment. In the first place, it had to be waterproof. For this purpose, most of it should be placed in a special tightly sealed box and located within the fibreglass hull. All connections and plugs that came out of the box should be waterproof as well. Furthermore, all the electronic equipment had to have a defined power consumption so that it was possible to select the right type of battery. Moreover, it should have a known voltage supply in order to provide the required amount of power. In addition, it was important to know the weight and dimensions of every electronic component. This helped to determine the size of the box and to calculate the buoyancy of the buoy. It was also important to know the types of connections the sensors should have. A helpful general requirement was to assess, as far as possible, such aspects of the equipment as economy, reliability, maintenance, and ability to be reconfigured. For example, the structure that clasps the hull had to be designed, considering the possibility of attaching solar panels if they proved to be required in the future.

2. State of the Art

2.1 Introduction

The market for measuring buoys is already accessed. A general distinction can be made between measuring buoys and signal buoys. For choosing the right components and getting as much information about existing buoys, and their components as possible, we decided to analyse some of the existing buoys as well as the specific components a buoy should have. After our analyse we can conclude that, both commercial produced buoys and uniquely developed prototypes (e.g. in university research) are already on the market. In order to find the best solution that will distinguish our proposal from the existing ones, specific environmental conditions and a buoy's functional requirements have to be considered in our decision process. The following list shows the most important features a buoy needs to fulfil:

- UV resistant
- Saltwater resistant
- Waterproof hull

- Quick release system
- Stainless steel (for outer construction)
- Seagull protection

In this chapter we will present a summary of technical specifications regarding some of the already existing buoys, the main competitors in this field. Then we will discuss the features of the components we have considered for the buoy we will develop: anchors, sensors, data storage, batteries, communication, control unit (CU), camera, and blinking lamp.

2.2 Competitors

Before we thought about "how to develop a buoy", we did research about our competitors. We focused on relatively small buoys with the same features as the buoy we intend to build. The function of the buoy in regattas will be new, so we put our focus on environmental buoys. We found out that more advanced environmental buoys had following features:

Table 2-1 Competitors [1] [2]

Technical specifications			
Product Name	Wavescan Wave Buoy	Wind LiDAR Buoy	Mini II Buoy
General properties - Material	Polyethylene, Aluminium, Stainless steel	Polyethylene, Aluminium, Stainless Steel	Polyethylene
- Equipment	Flash light LED based, 3-4 nautical miles range IALA recommended characteristic Positioning GPS (Inmarsat-C, Iridium, Standalone Receiver)	Flash light LED based, 3-4 nautical miles range IALA recommended characteristic Positioning GPS (Inmarsat-C, Iridium, Standalone Receiver)	Flash light LED based, 3-4 nautical miles range IALA recommended characteristic Positioning Standalone GPS Receiver
Buoy dimensions - Mass - Height - Diameter - Net Buoyancy - Mast Height	924 kg 5.6 m 2.8 m 2700 kg 3.5 m	1200 kg 6.1 m 2.8 m 2500 kg 3.5 m	320 kg 1.8 m 1.25 m 410 kg ---------
Power supply	Solar panels 180 W (45W x 4) Solar panel angle 17° (to horizontal) Lead-acid battery bank 248 - 736 Ah Lithium backup 272 - 2176 Ah	Solar panels (optional) 180 W Lead-acid battery bank (optional) Up to 248 Ah Lithium battery bank Up to 9792 Ah	Solar panels 60 W (10W x 6) Solar panel angle 63° (to horizontal) Lead-acid battery bank 124 Ah Optional lithium batteries 816 Ah
Processing	32-bit microprocessor 512MB flash memory, approx 10 years of raw data Real-time operating system (Linux) Low power consumption Large number of serial and analogue inputs Flexible data acquisition software	512 MB data storage Real-time operating system (Linux) Large number of serial and analogue inputs Flexible data acquisition software	32-bit microprocessor 512MB flash memory, approx 10 years of raw data Real-time operating system (Linux) Low power consumption Large number of serial and analogue inputs Flexible data acquisition software
Data communication	Short Range GSM/GPRS UHF/VHF radio (two-way) Long Range Inmarsat-C and Iridium (two-way) ARGOS (one-way)	Short range GSM / GPRS UHF / VHF radio (two-way) Long range Inmarsat-C and Iridium (two-way) ARGOS (one-way)	Short Range GSM/GPRS UHF/VHF radio (two-way) Long Range Inmarsat-C Iridium (two way)

2.3 Anchors

2.3.1 Required information

In order to choose an appropriate anchor it is required to have a prior knowledge on a few aspects. The first and probably most important is the type of bottom that the anchor is going to be placed in. Depending on the type of soil, some anchors will perform better than others. The same anchors when placed in a different bottom will have different performances, sometimes even diametrically different. The second aspect is the load data. In general, there are different anchors for low and high loads. The third aspect is the mooring line configuration. It is important whether it should be catenary or taut leg. Additionally, not always the most expensive or strongest lines are required [3]. An extensive research on this issue is included in Appendix A.

2.3.2 Functions of an anchor

A good anchor must guarantee reliable and consistent performance in relation to three of its functions. First of all, it must be able to gain a hold in the bottom. Secondly, it must be able to provide sufficient holding power to keep a buoy from dragging it. Thirdly, the anchor “should be able to either maintain or regain its hold when the wind or current changes the direction of pull” [4]. If a given anchor does not fulfil these criteria, it is necessary to select another one [4].

2.3.3 Soil evaluation

As mentioned before, the type of bottom has a significant influence on the performance of an anchor. In fact, “the selection of a suitable bottom for anchoring is a much more critical factor than the design of the anchor” [5]. All types of bottoms can be put into four categories [5]:

1. Sand

It is the best type of bottom for anchoring. First of all, it is relatively easy for anchors to penetrate. Secondly, it provides a high holding power. Hard sand is preferable over fine-grained sand. Suggested anchors: pivoting-fluke anchors and non-hinged scoop anchors.

2. Mud

It is a more complex type of bottom than sand. First of all, it has a low shear strength. For this reason any anchor that is designed for this type of bottom needs to have a “broader shank–fluke angle and greater fluke area” [5]. Secondly, mud often constitutes only a thin layer on top of some other type of soil, so anchors that can penetrate through the mud to the underlying material will hold more. Suggested anchors: Fortress anchor.

3. Rock and coral

Most types of anchors do not set in well in these bottoms. Typical anchors with flat, parallel or slightly bent flanks are not of much use here. The anchor must have flanks that protrude from the anchor’s axis to its sides at an angle of even 90 degrees. Additionally, anchors usually cover a great distance and take more time to set into rocks. Suggested anchors: Claw, CQR, Delta.

4. Shale, clay, grassy bottoms

These are the most difficult types of bottoms where the weight of an anchor is more important than its design in terms of its holding power and ability of penetration. Suggested anchors: CQR, Delta

2.3.4 Anchor types and their specification

Based on the collected background information, we narrowed the possible choices to a total of six anchor types, all of which belong to drag embedment anchors. For organizational reasons two separate tables gathering the selected anchors' main features and their advantages and disadvantages have been organised (Table 2-3 and Table 2-3). Figure 2-1, 2-2, and 2-3 depict the first three considered types: Danforth, CQR, and Delta:

- **Danforth anchor**

A type of lightweight anchor with flat parallel flukes

Figure 2-1 Danforth anchor [6]

- **CQR anchor**

Short for coastal quick release anchor. An anchor that is designed to bury itself into the ground by use of its plow shape:

Figure 2-2 CQR anchor [7]

- **Delta anchor**

A type of anchor with curved, joined flukes:

Figure 2-3 Delta anchor [5]

Table 2-2 Comparison of Danforth, CQR and Delta anchors [4] - [8]

	Danforth anchor	CQR anchor	Delta anchor
Material	cast galvanized metal/ light aluminium composite	galvanized metal/stainless steel hand-forged steel	one-piece steel casting
Application	hard sand/mud soft sand	sand, rocky bottoms	mud, hard sand, kelp
Principle of operation	flukes dig the anchor into the bottom and the anchor buries itself and part of the anchor line	lands on its side and when pulled buries itself	sets itself in the bottom with its shank parallel to the bottom when pull on
Price	Danforth standard galvanized 3,5lbs (~1,5kg) - $25 (~19 EUR) - £33 (~39 EUR)	Lewmar CQR galvanized 15lbs (6,8kg) - $425 (~324 EUR) - £299 (~351 EUR)	Lewmar Delta 9lbs (4kg) - $90 (~69 EUR) - $140 (107 EUR)
Estimated holding power	sail boat size: ≤ 10 ft ~ 72kg	sail boat size: ≤ 20 ft (>72kg)	sail boat size: ≤ 24 ft (>72kg)
Recommended chain size	3' x 3/16"	1/4" (6mm)	1/4"
Advantages	- Light weight for the amount of holding power - Develops an amazing amount of resistance force - Good holding power in soft mud and sand where many other anchors may not hold as good - Their flat design makes storage in a locker easier than plough or claw type anchors	- Good holding power over a wide variety of bottom types - Great in sand and on rocky bottoms	- Sets in most bottom types with good consistency - Less expensive than a CQR - Slightly superior to CQR in holding power - Greater potential holding for the same size and weight of a CQR anchor
Disadvantages	- Not recommended for very soft or loose mud, and for rocky bottoms - Can have difficulties penetrating kelp and weed-covered bottoms	- Does not do well in soft bottoms - It is not exceptional in any one particular type of bottom - It may not reset well if it breaks free - Relies on weight to penetrate the bottom	- Has problems setting and resetting in soft bottoms

Figure 2-4 to Figure 2-6 depict the other three considered types: Claw, Spade, and Fisherman's. Their main features are pointed out in Table 2-3 that follows.

- **Claw anchor**

As its name suggests, the flukes of this type of anchor resemble a claw:

Figure 2-4 Claw anchor [4]

- **Spade anchor**

An anchor type with flukes resembling a spade:

Figure 2-5 Spade anchor [9]

- **Fisherman´s anchor**

A traditionally shaped anchor having flukes perpendicular to the stock of the anchor and connected by a shank:

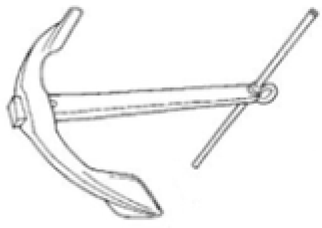


Figure 2-6 Fisherman's anchor [10]

Table 2-3 comparison of Claw, Spade and Fisherman’s anchors [2] - [11]

	Claw anchor	Spade anchor	Fisherman's anchor
Material	high-grade steel cast in a single piece	galvanized steel, aluminium, stainless steel	galvanized steel
Application	sand, mud, coral, ledge, rocky bottom	thick weed, sea-grass, kelp	heavy grass, weeds, rocky bottoms, hard sand
Principle of operation	lands on its side and when pulled buries itself	digs itself into the bottom when pulled on	it is not a burying anchor; one arm digs into bottom and one lies exposed
Price	Lewmar Horizon Claw Anchor 11lbs (5kg) - $44 (~32 EUR) - $50 (~38 EUR)	Spade anchor S40 12lbs (~5,5kg) - $270 (~206 EUR) - £159 (~187 EUR)	Paul E. Luke Storm Anchor 40lbs (~18kg) - $650 (~496 EUR)
Estimated holding power	sail boat size: 15-25 ft (>72kg)	sail boat size: ≤ 21 ft (>72kg)	sail boat size: 12-25 ft (>72kg)
Recommended chain size	1/4" (6mm)	1/4" (6mm)	
Advantages	- Can do a 360 degree turn without breaking out - Similar performance to plow anchors at a lower weight - Sets quickly in most bottoms - Resets easily when wind or current changes	- Greater efficiency of the fluke than in a CQR or Danforth - Lands at the optimum angle for penetration every time - Begins to dig in as soon as it lands on the bottom - Any load sufficient enough to move the anchor will cause it to bury further - Less likely to break than a traditional convex anchor	- Good in heavy grass, weeds, rocky bottoms or hard sand where one arm can penetrate a crevice - It can dig through weed and hook into cracks in the rock - Is a good all-around anchor for all types of bottoms
Disadvantages	- Fairly low holding power-to-weight ratio - Generally has to be over-sized to compete with other anchor types - Can have difficulty penetrating weedy bottoms and harder mud	- To set easily it needs the shank to be lifted off the bottom slightly and this is difficult or impossible to do with a chain rode	- Not good in mud or loose sand - Ancient in its design - Less holding power-to-weight ratio than more modern anchors - With changing wind and tide, it can lose its holding power - Very heavy compared with more modern anchors

2.3.5 Conclusions

After assessing the above options, we have decided that it would be best to use the following anchors:

- For sand: **Danforth anchor**

The Danforth anchor has many advantages. First of all, with its price oscillating between 20 and 40 EUR, it is very cheap, especially when compared to other anchors like the CQR, which costs above 300 EUR. Secondly, it is the lightest of all, which is particularly important as we want the buoy as lightweight as possible. Thirdly, it possesses a good holding power in soft sand and mud where many other anchors may not hold as well.

- For rocky bottom: **Claw anchor**

First of all, the Claw anchor is relatively cheap. With its price not exceeding 40 EUR, it strikingly beats other types of anchors. Secondly, it resets easily when wind or current changes, and it can make a 360 degree turn without breaking out. Thirdly, its design is particularly meant for rocky bottoms.

2.4 Sensors

2.4.1 Introduction

In order for the electronic buoy to be able to collect any type of data it needs to be equipped with what is called a sensor. The generic definition of a sensor is as follows: “a device that responds to a physical stimulus (…) and transmits a resulting impulse” [12]. As far as the buoy is concerned, the physical stimuli consist of weather conditions such as wind direction and speed, pressure, dew point. In fact, weather buoys can be equipped with a multitude of sensors that respond to many different kinds of stimuli. For example, the station 62029 – K1 buoy owned by the UK Met Office collects the following data: wind direction, wind speed, wave height, average period, atmospheric pressure, pressure tendency, air temperature, water temperature, dew point, and wind chill. [12] [13]

2.4.2 Types of sensors

Examples of sensors for a weather buoy and their construction/principle of operation [14]:

* Buoy orientation sensor.
The wind sensor on a buoy would be of no use if it was not accompanied by an orientation sensor. The reason for this is quite simple - the buoy is not stationary, it rotates, and therefore, does not have a constant orientation. Consequently, any measurements of wind made on a buoy need to be corrected with the measurements of the orientation sensor. It usually “incorporates a hall effect compass sensing the earth’s magnetic field” [11].

- Air temperature sensor.

The air temperature on a buoy is often measured with a platinum resistance thermometer. It is a device that takes advantage from electrical resistance of platinum, a feature which increases approximately linearly with absolute temperature. Therefore, by passing a current through it and measuring the resulting voltage, it is possible to determine the temperature (of course, with the use of an appropriate calibration equation). Moreover, in order to obtain accurate and reliable data, it is necessary to protect the thermometer against solar radiation, rain, and splashes from waves. This is usually achieved by means of a special shield surrounding the thermometer [11] [15] [16].

- Air pressure sensor.

One of the popular air pressure sensors used on buoys is the Vaisala BAROCAP® product. It measures pressure by detecting dimensional changes in its silicon membrane. As the pressure around the sensor rises or falls, the membrane deforms causing a change in the height of the vacuum gap inside the sensor. This in turn changes the sensor’s capacitance, which is measured and converted into a pressure reading. [15] [17]

- Current speed and direction.

An example of a sensor measuring the current speed and direction is the Doppler Current Sensor

3900 (Figure 2 7). It works by transmitting “a short acoustic pulse into the water every second” [11], and then receiving the sound that is reflected by water. Because of the phenomenon known as the doppler effect, this sound has a slightly different frequency from the initial acoustic pulse. By sensing this difference in four directions, and referring it to a hall effect compass, the sensor is able to determine the vector averaged current speed and direction [11] [18].

Figure 2-7 Doppler current sensor 3900 [18]

2.4.3 Wind speed and direction sensor

Wind sensors can be divided into two important types: ultrasonic and mechanical. Ultrasonic wind sensors (Figure 2 8) usually consist of two pairs of transformers that are installed opposite each other in a vertical fashion. When they are set to work, the pair of transformers emit and receive ultrasonic sound waves. The time waves take to travel from one transformer to another allows the wind speed to be calculated. Moreover, “using the combined measurements from several transducer pairs” [19], it is possible to determine the wind direction [19] [20] [21]. Figure 2 8 presents a common ultrasonic wind sensor:

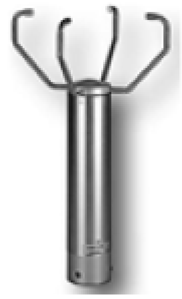


Figure 2-8 Typical ultrasonic wind sensor

Mechanical wind sensors come in many different types, but always consist of the same two components: a sort of propeller and a vane. As far as the wind speed is concerned, a typical mechanical wind sensor has a four blade propeller installed at the end of a longitudinal shaft/housing. When rotated, the propeller produces an AC sine wave voltage signal that is then appropriately interpreted. As for the wind direction, a typical mechanical wind sensor has a flat and thin vane on the other end of the housing. When the wind direction changes, the vane turns and a precision potentiometer senses the change in its angle. The typical mechanical wind sensor is presented in the figure below (Figure 2-9) [22].

Figure 2-9 Typical mechanical wind sensor [22]

The Davis anemometer, as illustrated in Figure 2 10, is a mechanical type of wind sensor. It can measure both wind speed and wind direction. It is strong enough to stand up to hurricane-force winds, yet sensitive enough to detect a small breeze.

Figure 2-10 Davis anemometer

The specifications of the Davis anemometer are listed in Table 2-4:

Table 2-4 Davis anemometer specification

Product name	Davis anemometer	
Dimensions	470 mm x 191 mm x 121 mm	
Weight	1,332 kg	
Connector	Modular connector (RJ-11)	
Cable length	12m	
Cable type	4-conductor, 26 AWG	
Measurement of	Wind speed	Wind direction
Sensor type	Solid state magnetic sensor	Wind vane and potentiometer
Accuracy	+/- 3 km/h	+/- 7°
Resolution	0,1 m/s	1° (0° to 355°)
Range	1 to 322 km/h	0° to 360°
Sample period	2,25 seconds	1 second
Output	1600rev/hr = 1mph V = P(2,25/T) V – speed in mph P - # of pulses per sample period T – sample period in seconds	Variable resistance 0 – 20KΩ; 10KΩ = south, 180°

2.4.4 CTD sensor

The CTD sensor, shown in Figure 2 11, is a complex device that serves to measure three important state variables – conductivity, temperature and depth (thus the acronym CTD).

Figure 2-11 CTD

The specifications of the CTD sensor developed at LSA are listed in Table 2-5.

Table 2-5 CTD sensor specifications

Product name	CTD		
Size	366 x Ø95mm		
Power Supply	8-30V		
Power consumption	1,5W/12V		
Communication	RS232 or I2C		
Quantity	Conductivity	Temperature	Pressure
Sensor	7 electrodes	PT 10	Oad cell
Unit	mS/cm	°C	dbar
Range	0-70 mS/cm	-5°C to 35°C	0-100 dbar
Resolution	+/- 0:01 mS/cm	+/- 0,001 °C	0,2% full scale

2.4.5 GNSS receiver

GNSS, an acronym for Global Navigation Satellite System, is a satellite system that allows to determine the geographic location of an object anywhere in the world [23]. It operates on the principle of signals being sent from satellites to a receiver on earth. This receiver is a device that receives, processes, and decodes navigation signals and thereby determines its location [24]. One of many such devices is the Superstar II, a piece of hardware as seen in Figure 2-12. Its specifications are listed in Table 2-6:

Figure 2-12 Superstar II

Table 2-6 GNSS receiver specifications [25]

Product name	Superstar II			
Size	46 x 71 x 13 mm			
Weight	22g			
Input voltage	+3,3 or + 5VDC			
Power consumption	0,8 W			
Communication ports	1 TTL serial port capable of 300 to 19200 bps			
	1 TTL DGPS port capable of 300 to 19200 bps			
Input/output connector	20-pin dual-row male header			
Atenna input	MCX female			
Operating temperature	-30°C to 75°C			
Humidity	5% to 95%			
Signal reacquisition	< 1s			
Position accuracy	Single point L1	WAAS L1	DGPS (L1, C/A)	
	< 5m CEP	< 1,5 CEP	<1m CEP	
Measurement precision	L1 C/A code		L1 carrier chase	
	75cm RMS		1cm RMS	
Data rate	Measurements		Position	
	5Hz		5Hz	

2.4.6 Conclusion

At this point the first prototype of the autonomous environmental buoy will only need four types of sensors: CTD sensor, wind speed and direction sensor, orientation sensor, and a GNSS receiver. All of these devices are readily available at the Autonomous Systems Laboratory. The orientation sensor is an integral part of the microcontroller STM32F3 Discovery, and thus does not need to be added. The wind sensor we are going to use is the Davis anemometer, the CTD – the one developed at LSA, and the GNSS receiver – Superstar II.

2.5 Data Storage

2.5.1 Introduction

When collected, data has to be stored. There are 2 sorts of data storage, primary and secondary data storage. Primary storage typically refers to storage or memory directly connected to and accessed by a computer's CPU (for instance RAM). Secondary storage, on the other hand, does not directly connect to a CPU and is non-volatile memory. Other differences between the two include the amount of data typically stored on such memory and the speed at which the data is processed [26]. According to The University of Rhode Island [27], the benefits of secondary storage are:

- increase of capacity,
- increase of reliability (they are non-volatile storage devices),
- reduce of cost (secondary storage is cheaper than primary),
- reusability of the secondary storage devices.

In our case the primary data storage will take place inside the microcontroller. Secondary data storage can be done in different ways [28] [29]. These are detailed in the section that follows.

2.5.2 Different types of data storage and their specifications

Secondary storage can be realised in different ways. The most appropriate methods are:

- Hard Disk

A hard disk (Figure 2-13) is a method of data storage that stores and provides relatively quick access to large amounts of data. A hard drive is generally the fastest of the secondary storage devices, and has the largest data storage capacity (up to 4000 GB). Hard drives however, are not very portable and are primarily used internally in a computer system. Another major disadvantage is that it is very susceptible to damage from physical shocks.

Figure 2-13 Hard disk [30]

- Optical disk

An optical disk (Figure 2-14) is an electronic data storage medium from which data is read and written to by using a low-powered laser beam. It is a flat, circular, plastic or glass disk on which data is stored in the form of light and dark pits. There are three basic methods of storing data on an optical disk: Read-only (e.g. CD and CD-ROM), write once read many (e.g. CD-R) and rewritable (e.g. CD-RW). The three main types of optical disks are:

- CD: a form of data storage that can transfer data up to the speed of 0,2 MB/s. A standard 120 mm CD holds up to 700 MB of data, or about 70 minutes of audio. There are two types of CD: CD-ROM and CD-RW.
- DVD: an optical disk storage media format that can be used for data storage. The DVD supports disks with capacities of 4.7 GB to 17 GB and access rates of 0,6 MB/s to 1,3 MB/s. A standard DVD disk stores up to 4.7 GB of data. There are also two types of DVD's: DVD-ROM and DVD-RW.
- BD: there are 2 types available: Re-Writable and Read Only. Their capacity can vary between 25 and 128 GB.

The main advantages of this storage medium is their low price and the fact that some types do not allow users to overwrite data. Disadvantages are the slow seek time and the fact that data can degrade with time.

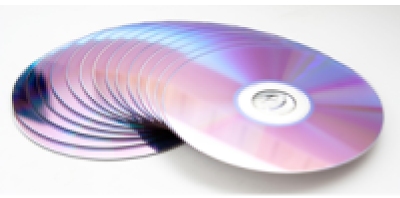


Figure 2-14 Optical disk [31]

- Flash drive

A flash drive (Figure 2-15) is a small external storage device that consists of flash memory. USB flash drives are removable and rewritable. They are a solid-state storage medium that is both inexpensive and durable. Currently, USB 2.0 flash drives on the market are able to reach a data transfer speed of 60 MB/s and USB 3.0 has transmission speeds of up to 640 MB/s. Common used USB Flash drives vary in sizes from 2 GB to 16 GB, but in special cases the capacity can be increased to 512 GB.
The main advantages are the very fast seek time and the fact that it is very portable. On the other hand, flash memory has disadvantages. Like all flash memory devices, the main problem with flash

memory drives is that they only can sustain a limited number of write and erase cycles before the drive fails [32]. Anther disadvantage is the limited capacity.

Figure 2-15 Flash drive [33]

- Flash Memory cards

Flash memory cards (Figure 2-16) are non-volatile computer storage chips. These memory cards currently vary in sizes between 1 GB to16 GB. Flash memory cards have most of the flash drive's characteristics. They are inexpensive, durable, and are very small. The most used formats are Secure Digital cards (SD card) [34] and micro Secure Digital cards (microSD). There are three formats for regular SD cards , SD (capacity up to 2 GB), SDHC (capacity up to 32 GB), and SDXC (capacity up to 2000 GB). Data transfer speed depends on the speed class the SD-card belongs to, as printed out in Table 2-7:

Table 2-7 Speed classes for SD-cards [35]

Class	Minimum Speed
2	2MB/s
4	4MB/s
6	6MB/s
8	8MB/s
10	10MB/s

Figure 2-16 SD card

In Table 2-8 we made a comparison of the different secondary storage devices:

Table 2-8 Comparison of secondary storage devices

	Hard disk *e.g. WD MY PASSPORT* [36]	**Optical disk** *e.g. DVD*	**Flash drive** *e.g. Toshiba USB 3.0 Flash Drive* [37]	**Flash memory card** *e.g. Sandisk SDHC Extreme* [35]
Maximum capacity [GB]	500	4,7	32	32
Data transfer speed [MB/s]	30-40	1,3	100	30
Dimensions [mm]	83 x 110 x 15 (*w x d x h*)	120 x 1,2 (*ø x h*)	21 x 69 x 10 (*w x d x h*)	24 x 32 x 2.1 (*w x d x h*)
Mass [g]	140	15	15	2,5
Power consumption for transferring data	High	High	Low	Low
Price per storage capacity [EUR/GB]	0,16	0,21	0,94	0,78

2.5.3 Conclusion

We can conclude that for our application, a small, power efficient, and robust data storage unit is recommended. Therefore we have two options: a flash drive or a flash memory card. Our choice mainly depends on the dimensions and the weight. Due to their dimensions, their lower prices per storage capacity and the fact that they are reconfigurable (if you add more sensors, you can increase the data storage capacity) of flash memory cards, our final choice will be the use of a micro flash memory card (microSD, microSDHC or microSDXC).
An important remark to make is the fact that a flash memory device only has a limited number of write and erase cycles before the drive or card fails. Due to this fact, we will have to replace the flash memory card after some time.

2.6 Battery

2.6.1 Introduction

“A battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy” [38]. [39] states that “a battery is an electrochemical cell (or enclosed and protected material) that can be charged electrically to provide a static potential for power or released electrical charge when needed”. We can conclude that a battery is an electrochemical cell that can convert stored chemical energy into electrical energy. There are two main types of batteries, primary batteries and secondary batteries. The difference between them is that secondary batteries can be recharged after all their chemical energy is consumed. In our case, it is recommended that we use rechargeable batteries; otherwise a lot of money will be spent on primary (non-rechargeable) batteries.

2.6.2 Different types of secondary batteries and their specifications

There are different types of secondary battery types: [40] [41]

- Lead-acid

Lead–acid batteries were invented in 1859 by French physicist Gaston Planté. These batteries are one of the oldest rechargeable battery systems. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power-to-weight ratio. They remain the technology of choice for automotive applications (SLI) because they are robust, tolerant to abuse, and because of their low cost. A disadvantage is the presence of lead, a toxic heavy metal.

- Nickel-cadmium (NiCd)

The NiCd battery was invented by Waldemar Junger and patented in 1899. The battery uses nickel oxide hydroxide and metallic cadmium as electrodes. Sealed Ni-Cd cells were at one time widely used in portable power tools, photography equipment, flashlights, emergency lighting, and portable electronic devices. The superior capacity of the Nickel-metal hydride batteries and their lower cost, has largely expanded their market share. Further, the environmental impact of the disposal of cadmium has contributed considerably for the reduction in their use. Within the European Union, they can now only be supplied for replacement purposes; however they can be supplied for certain specified types of new equipment such as medical devices.
Larger ventilated wet cell NiCd batteries are used namely in emergency lighting, standby power, and uninterruptible power supplies.

- Nickel-metal-hydride (NiMH)

A practical replacement for NiCd is the Nickel-metal-hydride battery; it has higher specific energy with fewer toxic metals. NiMH is used in medical instruments, hybrid cars, and industrial applications.

- Lithium-ion (Li-ion)

The li-ion batteries are mostly used for portable consumer products, such as in laptop computers, moderate to high-end digital cameras, camcorders, and cell phones; it is more expensive than nickel- and lead acid systems and needs protection circuit for safety but it contains no environmental hazards.

- Li-polymer (Li-Po)

Lithium-polymer (Figure 2-17) differs from other battery systems in the type of electrolyte used. To make the modern Li-polymer battery conductive at room temperature, gelled electrolyte is added. All Li-ion polymer cells today incorporate a micro porous separator with moisture. The correct term is "Lithium-ion polymer" (Li-ion polymer or Li-polymer for short). Li-polymer offers slightly higher specific energy and can be made thinner than conventional Li-ion, but the manufacturing cost increases by 10 to 30%. Despite the cost disadvantage, the market share of Li-polymer is growing. Li-polymer cells also come in a flexible foil-type case; while a standard Li-ion needs a rigid case to press the electrodes together, Li-polymer uses laminated sheets that do not need compression. A foil-type enclosure reduces the weight by more than 20% over the classic hard shell. [42]

Figure 2-17 Lithium-polymer battery [43]

The table below (Table 2-9) sums up the characteristics of the different secondary batteries:

Table 2-9 Comparison of secondary batteries [40]-[44]

	Lead-acid	Nickel-cadmium (NiCd)	Nickel-metal-hydride (NiMH)	Lithium-ion (Li-ion)	Li-polymer
Specific energy density (Wh/kg)	30-50	45-80	60-120	150-190	130–200
Cycle life	200-300	1000	300-500	1200	>1000
Fast-charge time (h)	8-16	1	2-4	1 or less	1 or less
Nominal cell voltage (V)	2	1,2	1,2	3,6	3,6
Self-discharge/month (%)	5	20	30	5	5
Toxicity	Very high	Very high	Low	Low	Low
Price	Moderate	Low	High	High	Very high

2.6.3 Conclusion

We can conclude that a lithium-polymer battery has the best performance properties. Especially the high specific energy density and the high nominal cell voltage are big advantages. Lithium-polymer batteries are the best option when you have to take weight into account. The only disadvantage is the price. Nevertheless, as LSA already has lithium-polymer batteries available, our first choice goes to Li-polymer batteries, to build the electrical circuit for the first prototype. An important remark is the fact that Li-polymer batteries cannot be mass produced in 6V packs because their nominal cell voltage is 3,6V. Therefore our second choice will be the usage of NiMH batteries due to their high specific energy density and their low toxicity.

2.7 Communication

2.7.1 Introduction

In our project we need a communication device for two purposes:

- To exchange data with the user on demand (send data from sensor / receive updates of program code),
- to communicate automatically with autonomous sailing boats (send data from sensors).

According to this, we need bidirectional communication. We also want it to be an inexpensive open-source solution (to make the buoy as cheap as possible). For sustainability and autonomy reasons, it should be power efficient, which probably will imply limitations on the range of communication.

2.7.2 Related projects and products

We were searching for products, similar to ours, which also need to communicate wireless. We found two exemplary solutions in already existing buoys:

- Coastal Monitoring Buoy CMB 4280 - it can use one (or more) of these communication techniques [11]:
  - Radio Modem, Frequency of 370 to 470MHz,
  - GSM Modem,
  - VHF Radio Transmitter,
  - UHF Radio Transmitter,
  - Argos Transmitter.

- “A Low-Cost Sensor Buoy System for Monitoring Shallow Marine Environments” [45] uses the following:
  - RF module with frequency range of 2394 to 2507 MHz [46].

As the buoy is intended to cooperate with autonomous sailing boats we have also checked what kind of communication they use, and came out with these examples:

- Wi-Fi [47],
- GSM [48],
- HF radio modem with frequency of 869.525MHz [49],
- Bluetooth module [48].

Generally, the technology used depends on the purpose of the device and the intentions the developers give relevance to.

2.7.3 Communication technologies and their specifications

There are many wireless communication technologies which differ in speed, range, effectiveness, and in several other characteristics. Below there is a short description of often used standards nowadays.

- **GSM** is “the world’s most widely used cell phone technology” [50]. It is the second generation standard for mobile networks. The distinctive characteristic of GSM is the use of SIM cards as unique identifiers inserted into devices. GSM can use two main techniques of data transmission: GPRS and EDGE. GPRS allows data transfer at speed of 30 to 50 kb/s. EDGE, the newest solution, gives theoretical data transmission speed up to 296 kb/s.
- **UMTS** is “a third-generation (3G) broadband, packet-based transmission of text, digitized voice, video, and multimedia at data rates up to 2 Mb/s” [51]. It is based on GSM standard, and it is an improved technology for mobile devices. It also allows its users to connect to the internet. It is mostly used in mobile networks all over the world.
- **Wi-Fi** - broadly known group of standards for wireless networks (especially computer networks). Nowadays it is becoming probably one of the most popular WLAN creating technique in the world. Depending on particular standard (defined by IEEE) it uses different radio frequencies and provides its users with different data transmission speeds (up to even 1Gb/s). In local applications it is common that devices need to connect to access points (special devices functioning like a hub), in order to get access to a network. There is also a second mode of Wi-Fi: Ad-hoc, which allows devices to connect with each other directly [52].
- **Bluetooth** - well-known wireless communications standard especially for short-distance connections. Often used to provide wireless communication between simple devices to replace traditional wirings. Connection is made directly between devices with average speed of 1Mb/s data transfer. The Bluetooth uses open-source standard regulated by IEEE organization [53] [54] [55].

All described communication standards are compared in Table 2-10 below, using their crucial characteristics:

Table 2-10 Comparison of communication units

	GSM	UMTS	Wi-Fi	Bluetooth
Max range [m]	35 000	1500*	150	100
Max data transmission speed [Mb/s]	0,23 (EDGE)	21,6	1024	40
Power consumption	high	high	moderate	low
Need of in-between device	yes	yes	No (Wi-Fi Direct)	No
Cost of module [EUR]	50 - 150	100 - 550	10 - 50	5 - 90

* when fully operational

Besides the communication modules compared in Table 2-10, sometimes an additional antenna is needed to extend the power of signal (the price of an antenna is around 10 EUR):

2.7.4 Conclusion

As it can be concluded from Table 2-10, the compared technologies in some characteristics differ a lot, in some are very similar. GSM and UMTS can be eliminated, considering this project, because of their high power consumption, expensiveness, and low data transfer. What is more, these types of communication are dedicated for long-distance applications. Wi-Fi and Bluetooth are more suitable for our purpose. Finally, we choose Wi-Fi as the best solution. Wi-Fi cards are very cheap, have wider signal range and larger data capacity than Bluetooth. What is more, the autonomous sailing boat FASt (described in [47]) from FEUP (one of University of Porto's faculties) is compatible with IEEE Wi-Fi standards so that further tests of buoy-boat communication can be easily done.

2.8 Control Unit

2.8.1 Introduction

In the project we need to have multifunctional a control device to manage functions such as receiving data from sensors, saving data marked with GNSS time stamp on data storage and controlling communication with user. According to that, the obvious solution is to use an integrated microcontroller board (Figure 2 18) that can easily be customized. This is the reason why specific microcontroller boards are compared in this State of the Art section.
A microcontroller is “a compact microcomputer designed to govern the operation of embedded systems in motor vehicles, robots, office machines etc. (…). A typical microcontroller includes a processor, memory, and peripherals“ [56]. It is an extremely small device what makes it applicable almost everywhere. Very often, microcontrollers are sold not as a single devices, but already attached to PCBs with numbers of peripherals, additional pins, and small circuits to make it easy to use in various purposes.

Figure 2-18. A microcontroller [57].

2.8.2 Different microcontrollers and their specification

Table 2-11 presents five different products we have selected, (including three suggested by LSA) to compare their characteristics:

- STM32VL Discovery,
- STM32F3 Discovery,
- STM32F4 Discovery,
- Raspberry Pi model B,
- Arduino Uno.

Table 2-11 Comparison of µC boards. [57] - [58]

Product name	STM32VL Discovery	STM32F3 Discovery	STM32F4 Discovery	Raspberry Pi B	Arduino Uno
Price [EUR]	8	13,5	12	28	17
Voltage needed [V]	5 or 3.3	5 or 3	5 or 3	5	3,3 or 5
Working temp. [°C]	-40 to +85	-40 to +85	-40 to +85	0 to +70	-40 to +85
Microcontroller:	STM32 F100RBT6B	STM32 F303VCT6	STM32 F407VGT6	ARM1176JZF-S	ATmega328
- Flash memory [kB]	128	256	1024	-	32
- RAM [kB]	8	48	192	512*1024	2
- Core frequency [MHz]	24	72	168	700	16
- Number of pins [-]	64	100	100	26	-
- Max. current consumption [mA]	15,4	66,2	93	-	0,2
- Supported interfaces (number):	- I2C (2) - USART (3) - - SPI (2) - CEC (1) - - - - -	- I2C (2) - USART (3) UART (2) - SPI (3) - CEC (1) - I2S (2) - CAN (1) - USB (1) - -	- I2C (3) - USART (4) - UART (2) - SPI (3) - CEC (1) - I2S (2) - CAN (2) - USB (1) - SDIO (1) - Ethernet (1)	- I2C (1) - - UART (1) - SPI (1) - - - - USB (2) - SDIO (1) - Ethernet (1)	- I2C (2) - USART (1) - SPI (1) - - - - - - -
Number of I/O	51 GPIOs	45 normal GPIOs, 42 5V Tolerant GPIOs	82 GPIOs	8 GPIOs	14 digital I/O, 6 analog inputs
Fixed interfaces				- HDMI - LAN - RCA video	
Special features		- accelerometer - gyroscope - E-compass	- accelerometer - 2 motion sensors - microphone	- SD card socket	

2.8.3 Conclusion

Our choice is the STM32F3 Discovery kit. It has a powerful microcontroller with numerous serial interfaces (e.g. USART, SPI), and many GPIOs. Even though the F4 series one is more powerful, contains Ethernet interface and has the possibility of easily attaching external memory such us SD card (SDIO interface), it does not have an E-compass included. The E-compass is an essential sensor to calibrate the wind direction. Having it already in the control unit, a purchase of an external one is not needed. What is more, the high computing power of F4 is not necessary in the buoy we develop. Why have we chosen one of STM32 Discovery kits? LSA, our client, suggested it – they already have them, so there is no need to spend money for the purchase. Moreover, they have experience with these microcontrollers, so we can get support from LSA. It is relevant to mention that we have no experience in the microcontrollers area, so this was an important criterion.

2.9 Camera

2.9.1 Introduction

Adding a camera would implement a financial benefit, because we could record, and sell the moment when the boats pass the buoy There are different kinds of cameras available on the market. Offers range from basic cameras to cameras with a lot of special features. It is obvious that prices will increase with extra functions and benefits.
In our case we have to keep in mind that there are important placement conditions:

- Corrosion resistance,
- UV-radiation,
- saltwater-surrounding.

In terms of developing the prototype as cheap, but sustainable, as possible, different options appeared. We thought about three options:

- Buying a waterproof camera,
- buying a basic camera and a waterproof case/hull,
- buying a basic camera and build a self-made waterproof case/hull.

2.9.2 Camera types and their specifications

In Table 2-12 you can find the main features of the different camera types:

Table 2-12 Comparison of cameras

Product name	*Superyacht Underwater Colour Surveillance System* [59]	*GoPro Hero 3 - black edition-* [60]	*Logitech HD Webcam C270* [61]
Price [EUR]	250	449	19,99
Dimensions [mm] (*l x w x h*)	188 x 40 x 95.5	59 x 41 x 21,2	208,2 x 76,2 x 152
Mass [g]	363	73	907
Power supply voltage [V/mAh]	12 / 500	3,7 / 1100	/
Waterproof [yes/no]	Yes	Yes	No
UV-proof [yes/no]	Yes	No	No
Working temp. [°C]	-5 to 70	/	/
Others: - Interface - Resolution - Waterproof (depth) - Battery type	- 420p - 20m	- SB/SD - 1080p - 60m - 1050mAh lithium-ion	- USB
Special features	9 LEDs	- Ultra wide angle - Ultra sharp - Internal memory - Waterproof housing	
Advantages	- Small - Integrated datalogger	- HD - Housing	- Price
Disadvantages	- Price - Energy consumption - Dimensions	- Power consumption - Price - Charging option	- Non waterproof

2.9.3 Conclusion

We have 2 options for the addition of a camera depending on the amount of money the client want to spend. The first one is to buy an expensive waterproof camera. In this case we would suggest a 360° waterproof camera (e.g. Superyacht Underwater Colour Surveillance System) as shown in Figure 2-19. The second option is to buy a cheap camera (Logitech HD Webcam C270) and place it in a water- and UV-proof hull, as shown in Figure 2-20.

Figure 2-19 Proposal 1: Superyacht Underwater Colour Surveillance System

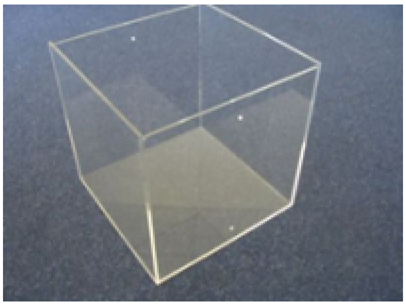


Figure 2-20 Proposal 2: water- and UV-proof hull

2.10 Blinking lamp

A blinking lamp on top of the steel structure will ensure that the buoy is visible for ships. When we visited the shop “dismotor” in Matosinhos to inform about the anchor, the salesman advised us that Figure 2-21 would be the best option for a buoy placed in a river to ensure moderate visibility.

Figure 2-21 S12 blinking lamp [62]

This blinking lamp is standard provided with a lamp of 12V/10W with a luminous flux of 100 lumen. Because we want to reduce the power consumption, our final choice will include a 12V LED, called “BA15S”. The luminous flux of the LED is 90 lumen with a power consumption of 3W. For a similar luminous flux, we reduce the power consumption with a factor 3.

3. Marketing Plan

Primary Remark:

Within the context of merchandising the product after finishing the prototype, the current status is still that a range of important and marketing-essential decisions have not been made. Even though the circumstances for running an appropriate analysis are not totally given at the moment, we worked out as much as possible.

3.1 Introduction

In times of worldwide rising online sales, it is an absolutely essential step to analyse the world market. Our future customers are able and willing to search international markets, taken from international acting companies. Therefore, in addition to studying customers´ needs, it is indispensable to analyse competitors, as well as their strengths and weaknesses on a global market.
Our product, the buoy, will probably fit in different markets with varying needs. Being equipped to implement two different functions, the buoy can be seen as an ´environmental measuring unit´ for all kind of researching purposes on the one hand, and on the other hand as a ´regatta buoy/beacon´ especially developed for autonomous sailing regattas. During planning/development it will be a priority to make the buoy adaptable. For the stated reasons we will have different markets to analyse, and approximately also to aim at.

The planned first function, the measuring feature of the buoy already exists. The main field of application is to monitor environmental data for scientific statements and analysis (e.g. buoys function as a tsunami early warning system in the Indian Ocean). Most of the existing buoys are individually produced unique items, which serve the specific needs of the project/mission/customer. Governmental/private weather stations or services, companies as well as the maritime sector in total depend on environmental data (either provided by a third party or measured by themselves). Focusing on an industrial use of our buoy or the measured data as a product, and also on private institutions, it might be possible to penetrate a niche (B-to-B).
At the same time the second planned function offers expandable future prospects. To develop a regatta buoy, especially for autonomous sailing regattas, could implement new unknown needs in this relatively young industry/market. We also provide new additional features like the camera.

3.2 Market Analysis

3.2.1 Macro Environment

According to a report of the German “GESELLSCHAFT für MARITIME TECHNIK e.V.” (Association of Maritime Engineering), in 2001, the marine technology sector had already reached a total volume of 150bn EUR sales per year in 2000 and will increase at least the next twenty to thirty years [63]. Present statistics confirm this development. The future outlook in this sector will mainly be influenced by eco-political and economic trends, such as: usage of renewable energy, sustainable usage of maritime resources or monitoring of climate- and environmental changes. The report also highlights the structure of the German marine technology sector. The dominant companies on the market are small and medium-sized businesses. This can be reflected to the world market, where similarly structures exist.
In addition referring to the “WORLD OCEAN COUNCIL” the so-called “Growing Multi-Use Ocean” is taking place. Offshore renewables like wind farms, shipping, mining/dredging, aquacultures or

submarine cables, to list just a few, are expanding markets which list a global solid monetary increase [64]. Especially the offshore wind turbine market provides a significant increase. An annual investment of 3.4bn EUR to 4.6bn EUR is listed in 2012 and numbers are supposed to go up [65]. Due to presumable further development and new technologies for utilising the renewables, it could be an interesting option. Particularly for wind turbines, stored data of wind power/current/waves etc. (long time measurements) are an important factor for analysing locations to place a wind farm or a wind turbine [66]. These are things we are able to provide. In line with this information it appears that the macroeconomic environment in context of the maritime technology sector (in our case: measurements) is affected by economical, technological, natural, political, and cultural factors:

- **Economic environment**:

As illustrated above, the international business development in our sector is expanding. Although the world economic crisis, especially the European crises, is still a big issue, investors/enterprises are still keen to invest with profitable success. Focusing particularly on Europe and Portugal, looking at proceedings during this ongoing crisis, it becomes clear that the wind energy sector is still at its starting point. Even barriers are insurmountable at the moment; it might be an interesting future market. Not only was the first offshore turbine inaugurated in summer 2012 on an innovative floating foundation called “WindFloat” in Portugal but also new factories have been built recently [67] [68].

- **Technological environment**:

In general, these days the pace of innovation is constantly accelerating. Innovations in using renewable energies are expected. New technologies in context of implemented components for our buoy could have an impact on the effectiveness, as well as on the price. These aspects could make it possible to develop new markets, and for instance, to make the buoy more affordable also for private usage.

- **Natural environment**:

From the nature´s point of view, it is and will always be important to measure relevant data and to evaluate it. Nowadays the restriction of pollution is still of prime importance. Therefore, it is unavoidable to register environmental and climatic changes as soon as possible, to ensure a quick political/economical reaction.

- **Cultural/Social environment**:

The general public, society at large, experiences a raising ecological awareness. Hamper the climate change by recycling material, driving a fuel saving automotive and/or saving up raw materials, leads to a new importance. It is an international concern to harm pollution, pay attention to our planet, and save energy. As a result an intensified urge for environmental knowledge is appearing. E.g. more and more privately run weather stations get installed. Private measured data is available from different sources worldwide. Due to the Internet, private meteorologists have become interested in measuring data, analysing it, and making it available online.

- **Political environment**:

In most parts of the world, but especially in Europe, the political parameters are given to adopt a technology like the one we propose to develop. Politics fund maritime measuring technology (e.g. in Germany), and also support entrepreneurial start-ups [69]. Besides inner-European trading will be supported by trade agreements.

Even if the economical/technological environment supports further research and development, the on-going European crisis could harm a further proceeding from a political point of view. Especially in Portugal, expenses are being cut at the moment and projects like ours could be harmed by a lack of budget. The finance ministry of Portugal has blocked the majority of educational benefits and expenses for research purposes until the end of 2013. The researching sectors of almost all universities suffer and will keep on suffering from these savings. 41 Highlighting the legislation of mooring and placing buoys, it became apparent that placing a buoy needs to be confirmed by the responsible department, but it is in general possible for scientific as well as private purposes [70].

3.2.2 Micro Environment

- **Internal**:

In association with being an upcoming start-up, consisting of four advanced students in Portugal with no experience in marketing this kind of product, we will analyse global competitors but primarily choose a specific target market for earning know-how and market share. We don´t have any previous information or management structures we can build on. Every strategy, every single step has to be created and implemented by dealing with a limited budget. The fact that all team members have gained their knowledge at different faculties in Poland, Belgium, and Germany can be helpful and supportive. Also the single motivation of all members to implement a successful, profit-gaining product is a plus.

- **Suppliers**:

Concerning the value chain management, international trading, and procurement is becoming easier. Political trade barriers are minimised and make it possible to largely ensure the availability of all required resources and components. In addition, most of the components are mass-produced articles, which are obtainable worldwide. Already chosen regional suppliers like "ALTO–Perfis Pultrudios, Lda", will provide us with more specific components like the hull. As a result, the procurement of materials and components will not be a problem and suppliers can be chosen by quality, prices, reliability, and matching company philosophy. As it is helpful, an option could be to use existing supplier networks to compare and select them. The introduction of online networks shortens the´time-to-market´ and makes it possible to focus on more important matters like the development, production or marketing of the product.

- **Intermediaries**:

Although it will be hard to realise intermediaries at the moment, future approaches could contain this marketing option. In addition to direct B-to-B marketing, it could be helpful to find and activate partners/intermediaries who could add the product to their assortment (e.g. Sailing-outfitter, electronics stores, etc.).

- **Customers**:

Referring to the two different main functional fields of application, several different target markets/customers are needed to consider. On the one hand businesses/governmental institutions/research establishments/private individuals **(1)** that have an interest in measuring environmental data in a maritime surrounding, on the other hand research institutions/regatta attendants/sailing clubs and federations, who could be interested in receiving the measured data for sailing purposes **(2)**.

(1)

In order to analyse the market, we contacted geographic faculties in Europe which have already developed buoys to get more information about buoy developing, coast protection, collected data usage, and customers´ needs. According to Dr. Vanselow´s (R+D Centre West coast, University Kiel) professional point of view, especially offshore-energy companies have really specific needs that require development experience in context of offshore conditions. Referring to his experience in developing measuring buoys for business usages, it is almost impossible to compete with commercial suppliers. International wind energy companies´ won´t choose our product at the moment if they have other options. A market penetration in this B-to-B area is really difficult [71]. In order to find more customers in other markets, one option might be to include governmental and promoted areas. Governmental institutions, research centres (biologists, meteorologists or oceanographers) might have an interest in measuring data in a watery environment. Also private individuals could have an interest in our product, doing private research. Plenty of measuring data is provided online, published by private people with their own weather station. E.g. some websites online contain information measured by buoys located in lakes [72].Cities or councils could be an option as well. Areas, cities that have a big interest in tourism (e.g. Porto or even smaller ones), and have a connection to waters could place the buoys near the coast in front of the skyline, the river or a lake and publish the measured information online. The optional attached camera would make it even more interesting for tourism purposes. All in all it appears that different markets are interesting for the further planning. Business markets, governmental markets as well as consumer markets are an option.

(2)

Another target market, which is also the primary reason for developing the buoy, is the autonomous sailing "sport". Currently no compatible measuring buoy exists. The competitions are annual happening regattas that proceed under different conditions and following various aims (Atlantic crossing, offshore etc.). "In many fields of robotics, competitions with memorable goals cause the attention of media and the interested public, and therefore give a strong incentive to research and development in the particular area" [73].

As shown in Table 3-1, the first competitions were established in 2006. Since the beginning other competitions have been founded and the events became more famous. The attendants are primarily university departments from different countries, which are supported by government aid as well as the competition itself.

Table 3-1 Summary of different regattas

Name	Homepage	Established
World Robotic Sailing Championship	http://www.roboticsailing.org/	2008
The Microtransat Challenge	http://www.microtransat.org/	2006
Sailbot	http://sailbot.org/	2006

Analysing Figure 3-1 leads to the result that the numbers of participating boats are still increasing and an upward trend exists.

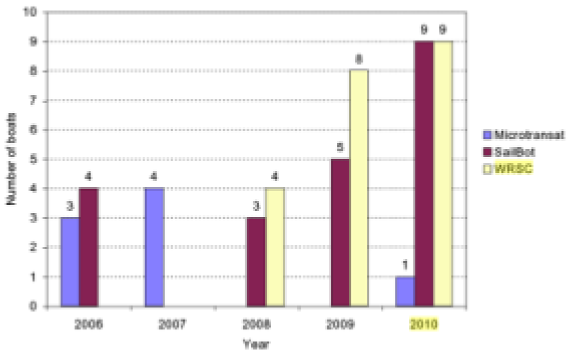


Figure 3-1 Number of boats competing in Mircotransat, SailBoat, and WRSC [73]

One of the main goals of the Microtransat is to achieve the Atlantic-crossing. As seen in Figure 3- 1, in 2010 just one boat attempted and it failed. The on-going trend in developing and achieving the goals combined with the statement above highlights the trend of the "market". To cross the Atlantic a lot of measurements and further developments need to be made. For this reason the university departments as well as other institutions interested in a successful crossing (e.g. shipping companies) have a need to earn as much information as possible. Our buoy could provide the needed information and also deliver additional benefits like the camera function.

Thinking about the question "Who needs measured data in context of a maritime environment?", human sailors have been considered as well. Sailing as an Olympic event is a popular sport that is dependent on wind and the circumstances on the water. Professional sailors have an unavoidable need for weather information and analysing its possibilities, if they want to sail appropriately. Currently, no specialised buoys for sailing purposes exist. Information is provided online by third party services or locally at the spot. For a market research purpose, we surveyed some members of the "Sailing Team Germany" to get more information about their specific needs during training sessions and competitions. Sixty-one professional sailors of the "Sailing Team Germany" (http://www.sailing-team-germany.de/) answered the survey. Evaluating the survey below (Figure 3-2 to Figure 3-6) it seems that sailors have their specific unsatisfied demands. For sailors it would be helpful to "scan" the whole training area, for example a real-time connection between the buoys and the supporting motorboat (coaches) would be a great benefit (Figure 3-5). In general, the professional sailing sport could be a target market as well. Countries compete which each other to win competitions. In case of selecting this kind of market, focusing on coastal countries with huge sailing history and present participation at international sailing regattas could be an option. To mention a few: Germany, Portugal, GB and France.

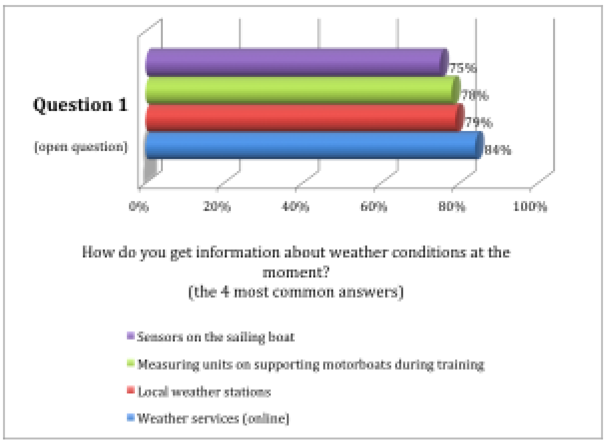
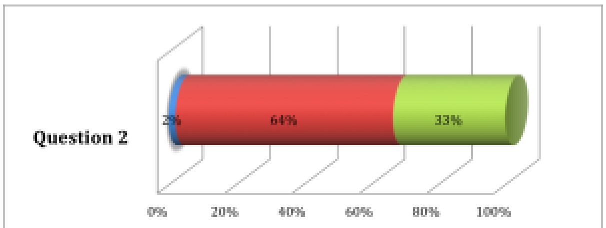
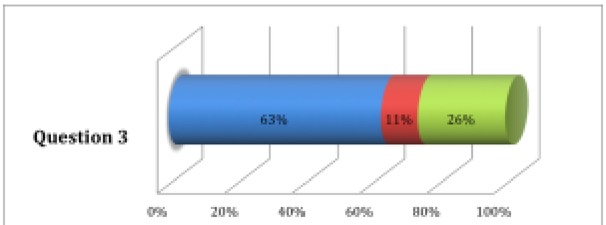


Figure 3-2 Survey Question 1



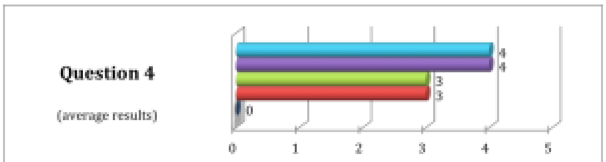
	Would it be possible to moor the measuring buoy on conditions of competition?
Yes!	2%
No!	64%
I don't know!	33%

Figure 3-3 Survey Question 2



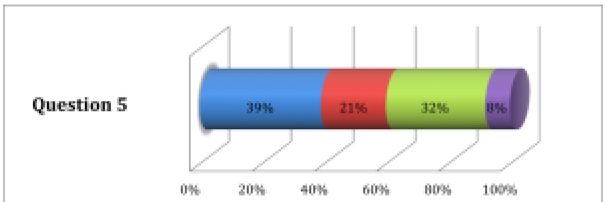
	Would it be possible to moor the measuring buoy on conditions of training?
Yes!	63%
No!	11%
I don't know!	26%

Figure 3-4 Survey Question 3



	What is the most necessary benefit/function the buoy or system needs to provide besides measuring the weather conditions?
Real time monitoring	4
Cover the whole regatta area	4
Analyse data directly or later	3
Easy to moor and transport	3
Others	0

Figure 3-5 Survey Question 4



	How much could you or your association afford to buy a buoy/system?
Currently nothing	39%
Less than 5.000 EUR	21%
5.000 - 10.000 EUR	32%
10.000 - !5.000 EUR	8%

Figure 3-6 Survey Question 5

Note: The technique would not be allowed in competitions according to international regulations and survey results (Figure 3-3).

- **Competitors**:

In an international environment the majority of buoy-producing companies serve different markets. As summarised in Table 3 2 the majority is producing inflatable signal- /mooring buoys or unique measuring buoys for R&D and business purposes. Also some suppliers provide commercial measuring buoys in different categories and for various needs. During the competitor analysis it has been approved that the market mainly consists of small and medium-sized businesses that score with long-time experience. Other competitors could be educational institutes and university faculties. During our research we found several different departments (mostly in Germany) that develop or have developed unique buoys with the same functions.

Table 3-2 Competitors that produce measuring buoys for business and scientific purpose

Company/Institute	Product	Price	Function	Customer	Homepage
Lalizas	Regatta buoy	€ 75,53	Marking the course	Organiser of Regattas	Link
Fugro OCEANOR AS	SEAWATCH Mini II Buoy	N.A (On request)	Measure environmental data	Offshore Energy Sector	Link
Wirtschaftsakademie	Measuring buoy	N.A. (On request)	Measuring environmental data		Link
BlueSky Wetteranalysen OEG	Measuring buoy for inland waters	N.A. (On request)	Measuring environmental data for private purposes	Tourism, Sport, Farmer, Cities, Research centres	Link Link 2

In addition, we did a research for specific suppliers to check what the benefits of other buoy components/systems are. Thinking about other purposes for our technique/electronic, it might be a possibility to just sell the technology of the measuring unit instead of selling the whole buoy. It became apparent that most suppliers already acquired a lot of experience in the maritime measurement businesses, and captured market shares. To compete with them we need to find solutions/strategies that gain market shares rapidly. Table 3-3 lists a couple of German competitors that offer maritime measurement modules similar to the functions we offer.

Table 3-3 Developers/Suppliers of measuring buoys/components

Name	Info	Homepage
Jebo Elektronik	Supplier Measuring Units/Electronics	www.jebo-elektronik.de
Helzel Measurements	Measurement Systems, Provider of Ocean Data	www.helzel.com/de/9310-wera-ocean-data
SIS Sensoren Instrumente Systeme GmbH	Supplier Measuring Units/Electronics	http://www.sis-germany.com/index.htm

At the bottom line it becomes clear that established competitors score with experience, already existing market shares, client base, and over years gained know-how in a professional environment. Trying to compete with their strengths will be challenging at the beginning. From our point of view internal weaknesses could be advantages. Being a start-up with no structure means simultaneously that we are much more flexible in comparison with our competitors. Penetrating new markets, or putting it another way, creating other markets based upon our flexibility could be one possibility to get customers and work profitable. Contacts for instance to the *Sailing Team Germany* offer huge possibilities in order to create markets.

3.3 SWOT Analysis

To formulate strategies and clear objectives, an essential step is to analyse the business from a resource based view as well as its external environment. Including the results of the previous market analysis it is possible to outline specific Strengths, Weaknesses, Opportunities and Threats (SWOT) for our company, product, and intentions.

Table 3-5 SWOT – breakdown

Strengths	Weaknesses
Young motivated and adaptive team International team with different backgrounds Flexibility Two different functions Open Source technologies Customisation / Reconfigurability - Modular system - Standard interface (Quality) (Easy to handle/transport) Price/Affordability Innovative (Regatta Function) Support by ISEP	Lack of experience Lack of knowledge in the range of programming/electronics No existing market share No existing marketing-/procurement structures Limited budget Limited amount of time to launch product
Opportunities	**Threats**
Expansion of product and further developments - "Sailing Team System" - "offshore bouy" - adding sensors Earn experience (team, product, …) EU market potential Growth and new markets - Wind Energy - Autonomous Regattas Corporations Governmental support Connection to WRSC Connection to German Sailing Team	Product acceptance in some markets More experienced competitors European crisis – economic depression Similar product (here: data) is available online and for free

3.4 Strategic Objectives

In the interest of outlining a well-performing marketing plan, it is necessary to define strategic objectives in a limited duration (usually three to five years) to aim at. As a result of setting concrete aims, it will be possible to control and approve the on-going planned progress of our business in the future.

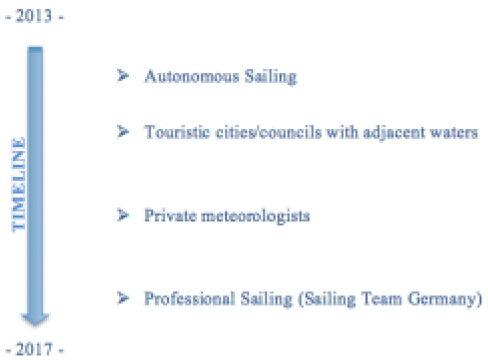


Figure 3-7 Market entrance as a function of time

Further objectives:

- Gain as much experience/know-how in the first years as possible
- Improve products, structures, systems etc.
- Reach Break-Even-Point after three years
- Sale of five buoys in 2014
- Sale of forty buoys in 2017
- Penetrate markets in order of time
- Geographic expansion
- Customer satisfaction
- Establish company, its policy and name by 2017
- Expand product line (Professional Sailing)

3.5 Segmentation

As a result of the analysis regarding the product, company, and surrounding, a SWOT-breakdown (Table 3-4) highlights the main aspects. Strengths and weaknesses shown from the resource-based-view as well as opportunities and threats from the market-based-view give an outline of the current situation. Concluding the above analysis´, it stands out that some markets are more interesting for our start-up than others. At the beginning of the analysis the focus was set on the increasing wind-energy-sector that seemed to offer great opportunities. Referring to the statement of Dr.Vanselow again, it will be almost impossible for a start-up to win market-shares without know-how and the necessary budget [71]. Combining this statement with results out of the analysis, the priorities need to be changed. Measure environmental data to find wind farm location in Europe or elsewhere is a really important but difficult issue. Energy businesses will probably not work with an inexperienced start-up. At least for the moment it is too risky. The high number of adept competitors and a lack of R&D resources create market barriers, which are difficult to overcome. In future plans, precisely in times like these, where scarcity of raw materials and ecological awareness are global, huge issues, it could be interesting to include these markets and support finding the right location for them (e.g. wind farms). In our case the attractiveness of markets depends on the difficulty of the market entrance. According to the SWOT-analysis (Table 3-4), the market segment has to meet the requirements of an easy access with small or non-existing market barriers. The circumstances of our start-up as well as our product will lead to the tasks of locating and penetrating new or at least young markets as well as to create new needs in different segments. Regarding this conclusion, it is possible to choose from several of the analysed markets and set objectives (Figure 3-7). In order of priority the most attractive markets are differenced by the two main functions:

- Regatta Function
  - Autonomous sailing (1)
  - Professional sailing (2)
- Measuring Unit Function
  - Touristic cities/councils with adjacent waters (3)
  - Private institutes/associations, hobby-meteorologists (4)
  - ——————————————————
  - Scientist/research institutes/governmental authorities
  - Renewable energy businesses.

In terms of being a start-up the basic idea of developing the buoy leads to four target markets/segments for the planning period. As shown in the analysis, the prime objectives of autonomous sailing boats are not reached. The increasing numbers of participating boats and in addition, the regattas show the interest in research. Future perspectives might contain extra budgets for developing purpose if, e.g., shipping companies could benefit. Furthermore there are no competitors at the moment. The innovative function and compatibility with established boat protocols might create needs, from which the customers (in this case universities and research facilities) could benefit. For these purposes detailed information needs to be provided (Data sheets, user manuals, etc.). In general, the advantages of different functions for sailing and measuring could also develop benefits for other purposes. Due to the modular system, the certainly manageable size and weight, the ability of reconfiguration and the addable gadgets like a camera, we could also aim at other markets. For scientists, tourism, and water sport our buoy with its equipped features could be enrichment. In the present there are not many commercial competitors for private or business purposes in Europe. One producer of buoys for measuring data, BLUESKY Wetteranalysen (Table 3-3 Developers/Suppliers of measuring buoys/componentsTable 3-2), placed their products primarily in the Austrian and Swiss markets. They offer measuring buoys for lakes and rivers, which provide direct information about the current situation at both, lakes and rivers. Their customers are mostly cities/townships which use the data for tourism and watersports, for instance. To segment this market geographically, highlighting tourism, Portugal in particular is famous for being loved by tourists. In 2010, almost seven million international tourists visit Portugal [74]. Pressing forward in these markets and offer the buoy to cities/townships could gain a lot of customers. Channels of distribution would be short and we would be seen as a regional supplier. In case of choosing Porto as an example for placing the buoy in the Douro River, benefits like providing live weather data on a touristic homepage as well as having camera broadcast footage, could be generated. In addition the city of Porto would support local students and companies which supports an image improving. Similar benefits could be generated for non-corporate purposes. The modular system provides optional sensors to choose from. Private persons/meteorologists could customise their specific buoy and profit by flexible features and approximately proportionate affordability. In terms of our objectives it also appears that professional sailing sport is an interesting segment to aim at. The survey outcome as well as personal conversations between our start-up and the Sailing Team Germany resulted in the interest and need of a customised measuring system for training purposes. In order to accomplish the objectives to serve this prospective segment, it is unavoidable to earn as much experience as possible during the first years and develop a customised product before 2018 that supplies the individual requirements of this customer.

In total all segments are based on the same characteristics. Target-segments are geographical or for occupational reasons close to waters/coasts and have a need of measured and provided maritime data. The general customers we aim at have information-requirements either for themselves or for providing it to third parties. Involving also the fact that we are a group of four advanced students in Portugal, who don´t have any experience in marketing or developing our product, we will firstly concentrate on the inner European market for earning know-how and experience. Highlighting the Portuguese and German market, in especially penetrating the regatta market as well as tourism market, offers small barriers easy to bypass. At first implementing our product in the market of autonomous regattas means we could adopt a pioneer role and adjust our product as well as our marketing to this specific market within its needs. Simultaneously, an improved understanding of segments and customers would be gained by presenting the product to touristic cities just as private meteorologists/scientist. The amount of obtained experience will be an influencing factor for the companies´ further proceedings in other markets (e.g. professional sailing or renewable energy businesses).

3.6 Strategy/positioning

We want to act and be seen as a sustainable, motivated young company that cares about the environment and the people´s needs. Therefore, we will be oriented towards the customers from the start. We are interested in innovations and in developing new ways of living, working, etc. supported by sustainable customer relationship management. For long-term planning, based on the market segmentation and SWOT – breakdown (Table 3-4) we try to work also product-oriented. High quality, reliability and on-going development in correspondence with gaining know-how and experience are our internal main objectives. Successful positioning of our product on the chosen target markets, like regattas or cities/townships assumes a concrete strategy that is supporting our objectives. Regarding to the already done analysis and its results, following the flanking strategy is probably the most appropriate marketing approach we could use. Instead of attack already existing leaders/products directly, we are going to penetrate segments where competitors have not established either strong positions or have not even placed products or earned market shares. For circumventing market barriers as well as similar products, it is necessary to serve a differentiated product that satisfies unknown, new-created needs. In our case the buoy is a differentiated object, targeted to young, less penetrated segments like the regatta boats, tourism as well as professional sailing that are segmented by geographical or occupational reasons.

To gain as much market share in the next years as possible, one of the main target segments is the regatta market. We are going to penetrate the Portuguese market as well as the German market from the beginning. Additionally, it might be possible to extend the distribution to participants at the regattas from other European countries. Besides earning market shares another long-term objective is to gain know-how and experience. In order to be the brand leader and improve the regatta function constantly in this segment, the start-up´s aim is also to establish its brand, policy and products during the first planning period. Simultaneously, we will also try to sell our product to touristic cities and other areas that could have an interest in it. We will concentrate on Portuguese cities with a touristic background (e.g. Porto) and advertise our product/brand/company by means of being a local producer that supports Portuguese tourism. Trying to provide more information to tourists and helping to make the areas more interesting could be one position to aim at. Further private meteorologists will be handled as a worldwide target segment. Even though it could turn out to be an attractive segment, the focus will be on regattas, touristic areas and sailing during the first years. Even though expenses are admittedly short, the customisable buoy will be part of our online catalogue. In total we will offer two buoys that can be ordered with different functional benefits depending on customer´s interests and needs. One buoy will only aim at regattas and the sailing sport in general and the other buoy will include the measuring function and will be customisable in context of customer needs. In the first year the attention will be placed on the regatta market. In the following future we will try to acquire also customers in tourism. A realistic number to aim at would be ten buoys per year. In long term planning, fifty buoys launched per year is an alternative amount that seems to be realistic when more know-how is gained, and market shares have expanded. Next to the current target markets we are going to improve the existing buoy for these markets, as well as develop a customised system for professional sailing. R&D will be connected to the “Sailing Team Germany” closely, developing a solution just for their purposes. In this case we make sure that the already existing connection to the team is continuing and the sailors´ needs will be satisfied. In general customer satisfaction is one of the main objectives in our business and is supposed to be reflected in all operative processes.

3.7 Adapted Marketing-Mix

Product:

Two different kinds of buoys will be offered. One option, the “VDG 1”, named after Vasco da Gama, will be the buoy including the regatta function. This one is strictly aimed at the participants in the autonomous sailing regattas. The other option will be an individual composed measuring buoy, named “X-Buoy”. The customer can choose different components of a pre-selected range of sensors/items to build his own measuring unit. The “X-Buoy” will be directed to touristic cities/councils and private people/meteorologists in cooperation with the benefit of customisation.
In order to aim just at European markets at the beginning, we are going to deliver it to customers by truck. The buoy will be delivered in an accurate and safe packaging. For the first installation, the first act of mooring the buoy, one team member will be around and helps installing it. At the beginning, without any market share and less customers, personal service is still possible and shows a special concern of our company, not only for the product´s fitness but also for the customer. Aiming at long time relationships with the customer this is a good way to start.
We also will provide special lashing straps and trailer appliance for the buoy to attach it and make it possible to transport

Pricing:

At the moment it is not possible to define concrete pricing. We have several different ideas in mind, but without doing a rough cost-analysis after finishing the prototype, it is barely possible to confirm them. Keeping the idea of earning a lot of market share, we are going to use a relatively adjusted penetration strategy. Unfortunately, equipped with no previous know-how, a reasonable price is necessary for placing the brand, but also the product, in customers’ minds. Therefore we try to set a static price for our “VDG1” buoy and a flexible (depending on the chosen components) for our “X-Buoy”.
In order to keep the price relatively down, we need to save costs. Adding the calculation - Fixed costs + variable costs = total costs - it appears that in order to raise our numbers of sales, we are going to save cost, because increasing numbers of sales influence the fixed costs by decreasing them.
After three years it is scheduled to change the pricing. In combination with reaching the break-even-point after three years, probably increasing sales numbers, and gained experiences, it is scheduled to change the pricing strategy. Following the penetration strategy until then, highlighting the quality, and reliability will justify higher prices.
During the marketing plan period other tools may be realised as well. For instance, if the city of Porto would order 4 buoys to place it in the Douro River discounts may be given. Pricing differentiations will also be made within the services. Portuguese customers (sailors, private individuals, cities etc.) will earn a discount because of geographical propinquity compare to German customers.
All pricing concerns are still hypothetical and have to be confirmed.

Place:

Within the planning period of the distribution system, we divide it in two separate phases. In the first phase, until the end of 2016, only direct marketing takes place. The advantages of direct marketing (e.g. easier to control; contact to ultimate buyers) supports our marketing strategy in context of creating intensive long-time relationships’. The most famous channel of distributing is the Internet. Nowadays, running a company homepage is a ´must-have´ in terms of making the buoy available to an international audience. Interested parties will be able to get information about the company as well as the products, and establish contact which intensifies the personal selling. Also participations at

maritime, electric fairs and international sailing events in Europe (e.g. Kieler Woche, Hanseboot, Germany; World Robotic Saiong Championships; Microtransat Challenge) as well as tourism fairs (e.g. BTL – International Tourism Exhibition; Lisbon, Portugal) will take place. Products will be configurable and available at fairs/exhibitions. Because of the modular system, interested people are able to choose components for their individual buoy.
Due to the objective of earning as much know-how as possible during the first phase, the distribution system is supporting this strategy.
In the second phase (either started in the end of the current planning period or the following one) intermediaries might be activated. Dependent on future processing and numbers of sales, it might be an option to place the buoy also in product offerings of local sailing outfitters or electronic stores.
In addition an online shop could be provided on the homepage, once the buoy-production is more established.

Promotion:

To promote product-sales and announce the item to possible customers, it is necessary to provide information and influence purchase decisions as good as possible. E.g. creating a corporate identity customers can appreciate and adopt is an issue of importance (see above: 3.6 Strategy/Positioning). Different tools for communicating with customers are possible and generally divided in direct- and indirect marketing. The intent of promoting the product directly requires effort in indirect marketing as well. At first an online presence needs to be created. Because of poor budget, a gratis provider will be chosen. For instance, Jimdo provides a free-of-charge website kit named JimdoFree (http://www.jimdo.com/pricing/jimdofree/). In addition Jimdo offers the option of upgrading to professional kits, once the business is working profitable.
The information provided on our homepage will be available in English, German as well as Portuguese and be supported by advertising videos combined with pictures of production and examples of application. Another online marketing tool will be Facebook, where a company account will be created and steadily updated.
The main focus in promotion will still be on direct marketing. Personal contacts, including information transfer, will sustain our strategy. Especially at the beginning potential clients, highlighting the regatta and touristic market, will be contacted by team members to support the personal dialogue and advertise our product with its functions. First marketing campaign, concerning the tourism segment, a product demonstration could help to create new needs. We could place the prototype in the Douro River, e.g. in front of the “Ribeira”, create a homepage with live-data broadcast including live-stream and post the link on the official City of Porto ”facebook” page. Due to this action the touristic division of Porto would be informed about the product and also gets an impression of how the reactions of their cliental, international tourists, could look like. Sending it via email to the relevant department could also be an option.
In addition leaflets/flyers and postcards for each function will be printed to help placing the product in the different segments. At fairs as well as special events concerning the products/its functions leaflets and flyers will be given to interested people and institutes to inform them about our product. Exhibition stands at fairs are too expensive at the moment, but team members will join fairs to hand in information personally. Once the marketing budget is increasing (e.g. after reaching the break-even-point) fairs will be included in direct marketing and budget plans. Detailed brochures, send out to interested people on request, will be provided as well. Also individually written info-post will be sent out to potential clients (e.g. autonomous boat developer; touristic cities; private meteorologists). Another cheap possibility for promoting the product/company could be to apply and participate at national/international research programmes or competitions for students. Usually participants of governmental funded competitions or programmes draw media interest. Science magazines or university publications may refer to the buoy with its special functions. This would be an easy but first

of all effective way to earn publicity.
Further “WordOfMouth”-marketing (WoM) is an instrument to count on. Because target markets, like autonomous sailing, are quite new, international dialogues between R+D departments might transfer information about the product as well (always provided that the aims of customer satisfaction are reached). Selling buoys to touristic cities probably will implicate WoM-marketing as well. If one city is activating the buoy, attention will be called to other tourism offices as well.

In conclusion, all targeted segments will be informed via Internet, brochures, leaflets and mail. The regatta segment as well as touristic cities will be contacted directly. This includes personal meetings as well. Particular team members are responsible for specific segments. To finalise the promotion policy, the third targeted segment, private meteorologists, will only be served via Internet and circular mails. E.g. private weather stations will be contacted and informed. On the basis of budget during the first planning period, but especially during the first year, this minimal attacked segment will be penetrated at least. For the same reason, because of probably initial high marketing expenses in the first year, investments in Google AdWords will happen later on, to position the website better and make it more searchable.

3.8 Budget

In order reaching the set objectives, an allocation of the given marketing-budget of 5000 EUR needs to be done for the following year. To establish the brand as well as the product and lay the foundation for reaching the break-even-point after three years, set in budgets for marketing purposes are necessary even though profits will not be skim off during the first years.

Table 3-5 Financial Plan for the first year 2014

	Website	Fairs (Journey, booth etc.)	Travel (CRM)	Leaflet	Brochure	Posters	Video	Branding
January	-	-	-	300,-	-	-	-	80,-
February	-	-	200,-		600,-	-	-	80,-
March	-	-	200,-		-	-	300,-	80,-
April	-	-	300,-		-	-	-	80,-
May	-	-	500,-		-	-	-	
June	-	-	500,-		-	-	-	
July	-	-	400,-		-	-	-	
August	-	-	400,-	100,-	-	-	-	
September	-	-	300,-		-	-	-	80,-
October	60,-	-	200,-		-	-	-	80,-
November	-	-	,-		-	-	-	80,-
December	-	-	-		-	-	-	80,-
Total = 5000 EUR	60 EUR	-	3000 EUR	400 EUR	600 EUR		300 EUR	640 EUR

In the following years cost centres like Google AdWords, additional travel costs and fairs needs to be included. Therefore a budget increase needs to be made.

3.9 Control of strategy

Monitoring the marketing plan includes all defined strategies, guidelines and objectives. The efficiency of planning depends on the correct realisation of set strategies. Therefore controlling is an essential step. Based on operating numbers like market share in percentage, sales per year or return on investment (ROI), a monthly/annual check of the specified objectives is recommended. As a result variations will be highlighted and procedures/plans can be adjusted. For controlling purposes Google AdWords, sales figures, marked mails or customer surveys can be helpful as well. For instance one main objective in planning is customer satisfaction. To monitor this important issue, acquired customers could receive a survey containing questions about service, product and benefits. Also cliental recommendations and complaints should be checked.

Controlling the proceeding in terms of reaching the break-even-point (Figure 3 8) an analysis should be done. The break-even point is reached when cost or expenses and revenue are equal in context of sales. The hypothetical analysis in Figure 3 8 would state that the break-even point is reached, if 36 buoys are sold by the end of a planned period.

Figure 3-8 Theoretical Break-Even Analysis

3.10 Conclusion

For successful achievement of defined objectives, a range of marketing options need to be adjusted and implemented correctly. An appropriate segmentation as well as positing combined with an adapted marketing-mix are inevitable requirements. Therefore all options lead in the same direction and are supposed to support each other.
At the beginning we try to push forward in flanking other competitors, or more detailed, flanking occupied segments. This approach redeems our disadvantages and will help to gain market shares more quickly. Already done analyses have eventuated in two fields of interests from the start. First of all autonomous sailing and secondly touristic cities are the segments to aim at. Reasons like being a start-up with no experience/know-how, working still on prototypes etc. minimise chances of a quick earning of market shares. For this very reason we try to work customer oriented from the start. Services, customer care, complaint management are designed for creating and maintaining long-lasting customer relationships. Simultaneously we will work product-oriented in order to increase products quality, know-how and experience as quick as possible. We will start slowly. At first offering two buoys that can be ordered with different functional benefits, gives us time to concentrate on customer relationships and the quality of our products.
All in all we want to implement our products in autonomous sailing and tourism segment. In addition R+D is closely connected with the GermanSailingTeam to develop a customised solution concerning their special needs. Personal support/service as well as an intensive after-sales-management shall support our main objectives and help to make our business profitable by no later than three years.

4. Eco-eficiency Measures for Sustainibility

4.1 Introduction

One of the most discussed topics in the modern world is the human impact on the planet's environment. Nowadays an important question that needs to be asked is: how does the human species influences our planet and its environment as far as pollution, resource requirements, mining or general behaviour are concerned? In this context the expression "sustainability" appears frequently; but what is sustainability and why should we act/live/plan sustainable in our private life? In our case another question comes up: how to be sustainable from the engineering and development point of view?
According to Marni Evans "sustainability is improving the quality of human life while living within the carrying capacity of the Earth´s supporting eco-systems." [75]
In another perspective "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [76] It appears that from an economical perspective the main problem, but also solution, is to achieve a healthy balance of preserving a healthy planet, support the quality of life of communities/individuals and run a profitable, profit-gaining enterprise. To specify these concerns, the ´Three Es´ of sustainable development, illustrated in Figure 4 1, are probably the best way. Dependent on finding the balance between "social well-being and equity", "economic prosperity and continuity" and "environmental protection and resource conservation", conflicts occur among different interest groups. The "Es" are hard to separate, as they are interconnected and compete against each other.

Figure 4-1 The three E's of sustainability [89]

In this context the eco-efficiency strategy needs to be mentioned as well. The World Business Council for Sustainable Development (WBCSD) describes eco-efficiency as a management strategy of doing more with less [78]. In reality, eco-efficiency is achieved through the pursuance of three core objectives:

1. Optimizing the use of resources.
2. Diminishing environmental impact.
3. Increasing product or service benefit.

During all the steps in our development progress, we consider the listed aspects in order to find the most sustainable and eco-friendly solution for developing and producing the requested prototype. While processing it turned out that especially five general ways of thinking were particularly helpful:

- Think of long-term solutions,
- think of resource conservation,
- think of local economy,

- think of balance and fairness,
- think about welfare.

4.2 Materials.

In this section we approach the general aspects we kept in mind during the development of the prototype. Besides that, we discuss main environmental concerns relating to the materials used in the prototype.

4.2.1 General concerns before and during the development.

Before starting a project it is important to think thoroughly about every step of the process. In order to make a proper prototype we had two meetings with our client in the first weeks, so we knew perfectly what he expected from the electronic buoy. After these meetings we brainstormed, within our group, about how we were going to build the prototype. From the beginning, we held “sustainable engineering” in the back of our mind during all further brainstorm sessions. The three most important aspects we thought of were:

- • The reuse of materials and reduction of raw material.

Because we have the opportunity to work with the Autonomous Systems Laboratory (LSA), we have the chance to use a lot of their materials instead of buying new ones. They already had a catamaran to measure meteorological data on rivers, so we can reuse a lot of the meteorological and electrical equipment. They can provide us with the batteries, the microcontroller(s), the hull of the buoy, the wind sensor, among other components.
On the other hand, we want to reduce the usage of material. In our first drawing of the steel structure, we made a big and heavy construction (Figure 4-2).

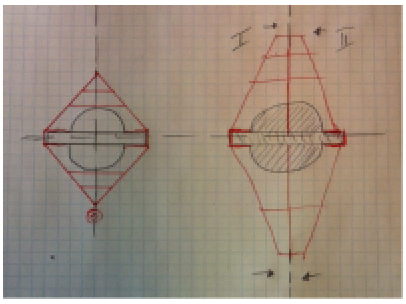


Figure 4-2 First drawing of the stainless steel structure

However, after giving it some more thought and listening to Mr. Fernando Ferreira’s very helpful suggestions, we obtained the second drawing (Figure 1-4 and Figure 4-4) This design is beneficial in a couple of ways. First of all, it uses less material. Second, it makes it easier to take out the cover of the hull.

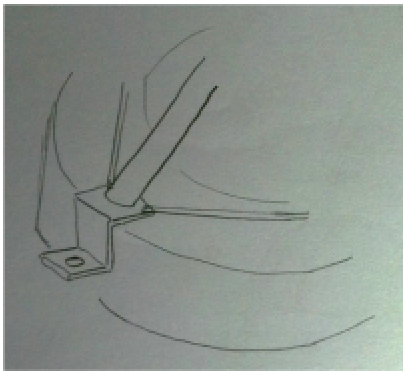


Figure 4-3 Detail of second drawing [by Prof. Fernando Ferreira]

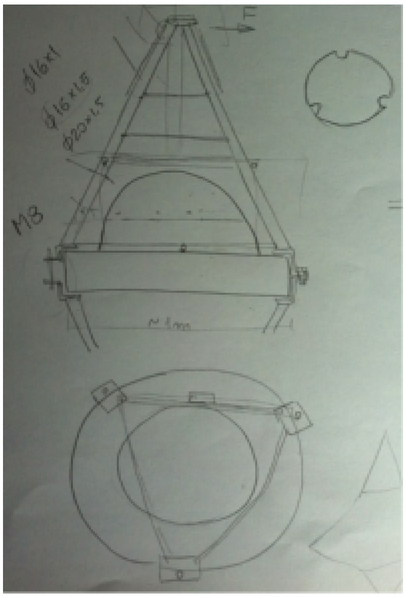


Figure 4-4 Second drawing [by Prof. Fernando Ferreira]

- Reduction of power consumption.

Due to the fact that the buoy has to stay into the water for at least 7 days, we have to avoid useless power consumption. Therefore the electronic equipment in the buoy will be energy-efficient. One of the most important factors in the choice of every component was the power consumption. Therefore the buoy will consume only the power that is needed for its main functions.

- Use of eco-friendly materials.

Because the buoy will operate in a river, the influence of its presence has to be negligible for the marine ecosystem. Therefore all the materials that are used in the production of the buoy will be environmentally friendly. We can use the ISO 14000 series to make our product and company aware of the environmental issues [79]. ISO is the International Organization for Standardization; it is an international standard-setting body composed of representatives from various national standards organizations. The 14000 family addresses various aspects of proper environmental management. A standard that is interesting for our new company is the ISO 14020 standard [80]. It is a (self-declared) environmental label that you can obtain when you work in an environmental friendly way.

4.2.2 Batteries.

The main environmental impacts of batteries are:

- Mining and usage of heavy metals.

The mining of heavy metals results in a lot of environmental problems, such as erosion, sinkholes formation, loss of biodiversity, and contamination of the soil and groundwater. In some cases, additional forest logging is done in the vicinity of mines to increase the available room [81]. Other consequences of mining are excessive noise, vibration and air pollution which interferes with the comfort of the public and impairs the economic welfare of adjoining properties [82]. Especially lead is a dangerous metal that is used in most of the batteries in automotive applications. Over 19 million cars and trucks are sold each year in North America and each car contains approximately 12 kilograms of lead. It means that every year more than two hundred thousand tons of lead are used in the automotive industry. The problem is that lead is extremely toxic. It can cause brain and kidney damage, hearing impairment and learning and behavioural problems for children [83].

- Disposal of the batteries.

Batteries contain heavy metals such as mercury, lead, cadmium, and nickel, which can contaminate the environment when they are improperly disposed [84]. Therefore, it is really important that batteries are properly recycled. It is common that countries found an institution to collect and recycle the batteries (for instance “Bebat” in Belgium [85]).

The best solution for both problems is the usage of rechargeable batteries. There are a lot of different types of rechargeable batteries as presented in section 2.6 Batteries of chapter 2. A comparison between the different properties can be revised in Table 2 9 in that same chapter. Life cycle assessment (LCA) allows studying the environmental aspects and the potential impacts of a product throughout its life: from raw material acquisition through production, use and disposal. You have to include everything in the comparison, starting from a raw material and ending with the disposal of your product and the recycling of its components. The life cycle of a battery (Figure 4-5) can be schematized this manner:

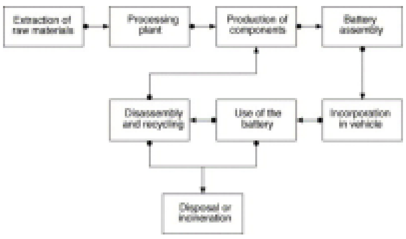


Figure 4-5 Life cycle of a battery [86]

Our main objective is to use 100% recyclable batteries that are rechargeable. These will have the following advantages:

- Extraction of raw materials has to take place only once or in the optimal situation the battery used is made out of recycled materials
- When the life cycle of our battery ends, it is 100% recyclable whereby we provide components for other products and disposal or incineration is not needed.

We chose to use lithium-polymer batteries because of their good performances, their low environmental impact in comparison with other battery types, and the fact that they are 100% recyclable. Umicore is a company specialized in metal applications. They developed the world’s first recycling process (Figure 4 6) enabling metal recovery from used Li-ion, Li-polymer and NiMH batteries with minimum environmental impact [87].

Figure 4-6 Umicore Battery Recycling

In [86] the researchers came to the following conclusions concerning the environmental impact (Figure 4 7) and the energy efficiency (Table 4 1) of the different secondary battery types:

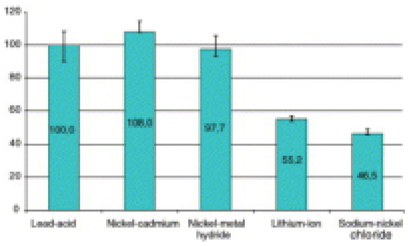


Figure 4-7 Environmental impact of the different secondary battery types [86]

Table 4-1 Battery properties [86]

	$E_{specific}$ (Wh/kg)	Number of cycles	Energy efficiency (%)	Losses due to heating (%)
Pb-acid	40	500	82,5	
NiCd	60	1350	72,5	
NiMH	70	1350	70,0	
Li-ion	125	1000	90,0	
NaNiCl	125	1000	92,5	7,2

Another important conclusion of the article was "(…) that the impacts of the assembly and production phases can be compensated to a large extent when the collection and recycling of the batteries is efficient and performed on a large scale." [86]. Out of the comparison in Table 2 9 (section 2.6 batteries), Figure 4 7, Table 4 1 and the conclusion of the article, we can conclude that we can use Li-ion, Li-Polymer (the environmental impact and energy efficiency of Li-Polymer batteries is similar to the impact from Li-ion batteries) or NaNiCl batteries. Our choice to use lithium-polymer batteries was influenced by the fact that LSA already owned them.

4.2.3 The electronic components.

In the selection of every electronic component we have to keep several things in mind. The weight cannot be too heavy, the power usage has to be as low as possible, the component has to suit all the requirements, etc. Another important factor we should think of is the ability to recycle the electronic components properly because they contain heavy metals and other toxic materials. E-waste is a system whereby electronic items can be properly discarded and recycled without posing a threat to the environment. The Environmental Protection Agency estimates that only 38% of e-waste, regarding to computers, is recycled, the rest of the electronics go directly into landfills and incinerators [88]. Because we want to dispose our electronic components in an environmental friendly way, we have to be very careful when we dispose them. The most convenient environmental hazards of e-waste are shown in Table 4-2:

Table 4-2 Environmental impact of e-waste [89]

E-Waste Component	Process Used	Potential Environmental Hazard
Cathode ray tubes (used in TVs, computer monitors, ATM, video cameras, and more)	Breaking and removal of yoke, then dumping	Lead, barium and other heavy metals leaching into the ground water and release of toxic phosphor
Printed circuit board (image behind table - a thin plate on which chips and other electronic components are placed)	De –soldering and removal of computer chips; open burning and acid baths to remove final metals after chips are removed.	Air emissions as well as discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium cadmium, and mercury
Chips and other gold plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	Hydrocarbons, heavy metals, brominated substances discharged directly into rives acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air emissions of brominated dioxins, heavy metals and hydrocarbons
Plastics from printers, keyboards, monitors, etc.	Shredding and low temp melting to be reused	Emissions of brominated dioxins, heavy metals and hydrocarbons
Computer wires	Open burning and stripping to remove copper	Hydrocarbon ashes released into air, water and soil.

The main electronic components that we are going to use are “a printed circuit board”, “chips and other gold plated components”, and “computer wires”. On that account we have to make sure that when our products have to be disposed, an environmental friendly company takes care of the disposal and recycling.

4.2.4 The hull

The hull of the buoy (Figure 4 8) was already made of fibreglass by ALTO, a local company specialized in the production of composite materials.

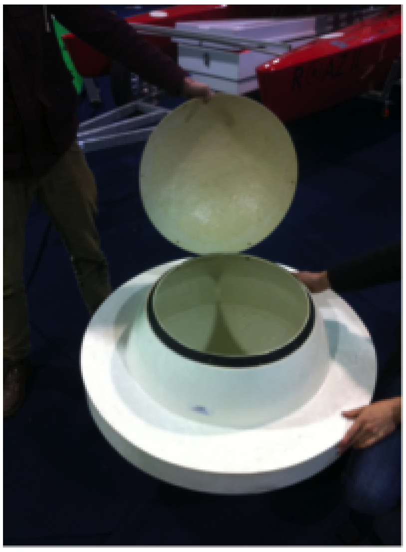


Figure 4-8 The fibreglass hull

Fibreglass is a fibre reinforced polymer made of polyester resin reinforced by fine fibres of glass. When glass is drawn into fibres its tensile strength increases enormously. In combination with the polyester resin, fibreglass is the strongest available construction material on equal-weight basis. Other big advantages are that it is chemically inert, salt will not damage the hull and it does not degrade due to UV radiation. One disadvantage is the manufacturing process; styrene is used in the process and it can cause hazardous air pollution harmful to breathe at extensive levels. A solution for this problem is the use of gelcoats [90], or to automate the process and in that way reduce human participation. Another negative environmental feature of fibreglass is its disposal because it cannot degrade.
Therefore other solutions for recycling have to be found. By heating it you get a molten fluid that you can separate in recyclable components. Some examples of the use of these recycled components are:

- Insulation,
- reinforcement of a concrete mixture,
- making of new fibreglass objects

4.2.5 Stainless steel structure

The already existing fibreglass hull is too small and not functional enough to provide the required space for all of our equipment. Therefore, it is just part of the buoy's overall structure and it needs to be accompanied by something more that makes the structure complete.
Our initial thought was to make the complementary part from stainless steel. The advantages of this material are the following: [91] [92]

- Corrosion resistant.
- high strength and ductility,
- easily fabricated,
- relatively light and easy to transpor,
- low level of leaching into water,
- 100% recyclable without any degradation or deterioration of quality,
- long term life.

The production of one kg of stainless steel generates a significant amount of CO2 emission and waste, as shown in Table 4-3:

Table 4-3 Waste and CO2 emission in the production of one kg of stainless steel [93]

	100% primary	100% recycled
Energy (MJ/kg)	73	23
CO_2 (kg/kg)	7,1	3,9
Waste (kg/kg)	2,8	0,6

However, the main advantage of stainless steel is the fact that it is 100% recyclable, and that the amount of CO2 emission and waste decreases when you recycle the stainless steel. In fact it is the most recycled material in the world: 60% of all the stainless steel is recycled globally; in the United Kingdom the recycled amount is 94% [93].

4.3 Product´s life cycle assessment

In the marketing plan we mentioned that the production and sales will increase in the following years. Therefore, we need to think of a decent way to develop our product on a large scale, beginning with the raw materials and ending with the recycling and/or disposal process. A life cycle assessment (LCA), as the one illustrated in Figure 4-9, is a convenient way to do so:

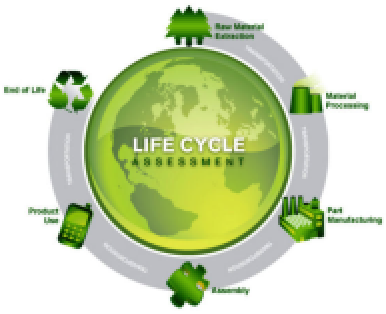


Figure 4-9 LCA [94]

An important thing to keep in mind during the LCA are the three Es; you have to find a balance between economic prosperity, environmental protection and social well-being & equity.

4.3.1 Raw material extraction, Material processing, part manufacturing and assembly

Our company will purchase the finished components to assembly the buoy. Afterwards we will program the microcontroller, wire the electronics and assembly all the parts to the steel structure. Therefore we can bundle “Raw material extraction, material processing, part manufacturing, and assembly” into one section. We need to do thorough research on the companies where we will order our components.
The buoy will contain many different materials; from the sustainable and environmental point of view, heavy metals, fibreglass and stainless steel will be the most important ones.
As already mentioned in section 4.2.2, section 4.2.4 and section 4.2.5, the mining of heavy metals, production process of fibreglass and the production of stainless steel are environmental and/or human unfriendly processes. For that reason we will try to work only with suppliers who have a good environmental consciousness and who care about their employees’ safety. A way to check this are ISO 14000 standards. These standards were developed to ensure a decent environmental management. It does not state requirements for environmental performance, but maps out a framework that a company or organization can follow, to set up an effective environmental management system. This effective environmental management system will guarantee that environmental impact is being measured and improved.
We try to use (local) suppliers for our materials so that the logistic environmental impact is as low as possible. We have to keep in mind that transport is only one factor that contribute to the environmental impact. A factory in China that uses environmental friendly technologies can be a better choice than a producer that uses environmental harmful methods to create their product in the vicinity of Porto. A profound study has to be done before we make every order.

4.3.2 Product use

In the design we will make the product as sustainable as possible. We will ensure that the power supply is as low as possible, that we use as less materials as possible and we do not harm the environment as already mentioned in chapter 4.2.1 General concerns before and during the development. In that way we will try to deliver an environmental friendly product. With every delivery we will add a user manual, which will contain instructions about the proper usage of our product; it will also contain the guidance for maintenance, this way our product will be applied correctly.

4.3.3 End of life

The disposal and/or recycling of the materials is/are discussed in section 4.2:

- Batteries.

There are special institutions in most of the countries that are responsible for the disposal and/or recycling of batteries (e.g. bebat in Belgium [85]).

- Fibreglass.
  By heating fibreglass you get a molten fluid that you can separate in recyclable components. Some examples of the use of recycled components are:

- Insulation,
- reinforcement of a concrete mixture,
- new fibreglass objects can be made.

- E-waste.

We have to make sure that when the e-waste has to be disposed, an environmental friendly company takes care of the disposal and/or recycling.

- Stainless steel.

Stainless steel is 100% recyclable.

4.4 Suggestion to improve the proposed sustainability in the future

In this section we point out further possible improvements to our prototype to make the ultimate product more sustainable.

4.4.1 Solar panels

In our final product the addition of solar panels is necessary. It would be the best option to substitute the dependence of battery power. Therefore we provide space where solar panels can be mounted. These solar panels will recharge the batteries in the buoy. Consequently a boat trip to the buoy to replace the dead batteries is avoided. The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution of the air or global warming emissions.

Solar power has the following main advantages: [95]

- Creating energy is a water intensive process. In the U.S., electricity production accounts for more than 40 per cent of all daily freshwater withdrawals. Solar photovoltaic systems do not require any water to generate electricity.
- The resource is available everywhere, although some areas receive less sunlight than others, depending on the climate and season.
- The resource is almost inexhaustible. In contrast to oil, the sun will be here for a long time.
- Photovoltaic cells make no noise.
- There are no moving parts in a solar cell, therefore the maintenance is low cost and they are easy to be installed.
- Solar power technology is improving consistently over time as people begin to understand all of the benefits offered by this technology.

On the other hand the use of solar power has some disadvantages: [96]

- The initial cost of purchasing the solar panels can be quite high. Therefore a lot of governments encourage the use of solar panels by subsidize a part of it.
- Most of the photovoltaic cells are made out of silicon and other toxic metals. Proper disposal is very important to prevent the risk of contaminating the air, soil and water.
- The angle how the solar panels are placed is very important.
- Visual impact.

We think, considering this product in particular, there are more advantages than disadvantages. The main reason is the fact that when the buoy can work autonomous for a longer period, a weekly boat trip to the buoy will not be necessary. The integration of solar panels will increase the proper working of the buoy.

4.4.2 Generator driven by the current of the river

Another way to provide the batteries with power is the addition of a generator driven by the current of the river. A load, placed in the hull of the buoy, would be shifted due to the current of the river; consequently this movement would generate electrical power with the aid of the generator.

4.4.3 Certificates and councils.

We, as a company, have to try to be as sustainable as possible. A way to “measure” sustainability are the ISO standards; therefore we have to obtain an ISO 14000 certificate [80].
Another way to improve our knowledge about the oceans/rivers environment is to become a member of the World Ocean Council (WOC); WOC is an alliance of companies, associations and other organizations that form the platform for coordinating collective action in developing solutions to the ocean/river environment and sustainability challenges facing the ocean/river business community. [97]
Companies, associations, organizations (research, academic, scientific) and individuals are invited to become a Member of the WOC by:

- Agreeing to the “WOC Member Statement”.
- Submitting the “WOC Member Contribution Pledge”.
- Submitting their WOC Member contribution.

The benefits are that you increase your knowledge about the oceans/rivers environment by sharing yours with other companies and vice versa.

5. Ethical and Deontological Concerns

5.1 Introduction

In everyday life people should always pay heed to ethical way of behaviour. Being human implies following some moral rules which can be considered in different aspects. For instance, teachers should comply with a particular set of rules regarding acting against their pupils, pupil's parents etc.; companies workers should behave in a moral way towards their co-workers, clients, and superiors; engineers should always care about their products’ safety. In our project we could consider ethics and deontology in all its bearings, yet we divided our analysis only into five main aspects which are especially related to our work. These are the following:

- Engineering ethics issue,
- sales and marketing ethics issue,
- academic ethics issue,
- environmental ethics issue,
- liability issue.

5.2 Engineering ethics issue.

Engineering ethics is probably the most important aspect we should consider in this project. Each company or organisation defines its own code of ethics and claim that its members strive to follow these rules. Those rules may vary for different types of engineers, e.g. civil engineers can have a different code than electrical engineers. Because the field of engineering we study is different for each of us, we decided to apply the general engineering ethics code in our work. Many organizations provide a universal ethics standards. For example, The Royal Academy of Engineering created the *“Statement of Ethical Principles”* which includes four main issues: *“Accuracy and Rigour; Honesty and Integrity; Respect for Life, Law and the Public Good; Responsible Leadership”* [98]. Another organization, The National Society of Professional Engineers (NSPE), defines a more detailed code of ethics. However, it also contains few general rules called by them “Fundamental Canons” [99]. We decided to consider ethical and deontological concerns by means of these canons which recommend engineers, in the fulfilment of their professional duties, to:

- *“Hold paramount the safety, health, and welfare of the public”.* [99]

We should design the buoy to be safe for its users. It will contain many electronic parts and a battery as a power source. Regarding that we will make sure that all components are in accordance with international or European safety regulations. What is more, it will be a heavy (+/- 40kg) construction with large dimensions. To make it safe while moving it, and easy to carry, we will attach special handles. We will also install additional legs making it easy to stand (e.g. on board of a boat). An appropriate user manual containing warnings about accidents, dangers, and risks of using the buoy will be provided by us, with the product. It will also instruct users how to operate it properly.
Our product is not harmful directly to people in another way. For the most of its lifetime, it will be working without physically interacting with people.

- “*Perform services only in areas of their competence*”. [99]

We are still undergraduates so this duty is not entirely concerning us. Nevertheless, we are working on an engineering project so we are responsible for our results. It would be highly inappropriate to perform engineering work without the necessary qualifications and backup knowledge about issues we are working on. To make sure that we do everything correctly we have consulted any uncertainty with proper experts such us our project supervisors or specialists they recommended.

- “*Issue public statements only in an objective and truthful manner*”.

“Engineers shall be objective and truthful in professional reports, statements, or testimony. They shall include all relevant and pertinent information in such reports, statements, or testimony (…)” [99]. Our team tries to follow these guidelines. In this report it is applied especially in the “State of the Art” chapter, where we objectively compare many different components and technologies, and clearly justify our final choice.
It is not only the matter of written statements, but also the spoken ones. During our scholarship we perform several presentations. We shall give only true information and base our statements only on facts.

- “*Act for each employer or client as faithful agents or trustees*”. [99]

This statement is addressed mostly to professional engineers. In our case we should take into account just that our client has some expectations towards us. Considering that, we are ethically obliged to strive for obtaining the best possible results. If something goes wrong, we should admit it to our client and look for a proper solution.

- "*Avoid deceptive acts*". [99]

An engineer should always act in a fair and dependable way. It is reprehensible to steal other's work and ideas or deliberately use a worse solution to, for example, avoid more effort. In our work we are honest and clear. Everything we write and present is an effect of our own hard work. If we use an external source of knowledge, we refer that clearly. If we use not our own ideas, we do it only with its owner's permission. We do not violate patents laws or infringe copyrights. To make sure of that, we use only open-source technologies (when it is possible) as we were advised at the beginning of the project.

- "*Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.*" [99]

This one implies the general attitude an engineer should have "on behalf of a greater good". Responsibility, ethics and law are concepts we should keep in our minds all the time. Although we are still young and undergraduate engineers, we try to adapt this ethical attitude.

5.3 Sales and marketing ethics issue.

Marketing is also a significant part of our project, therefore we should consider ethical concerns related to it. According to SMEI - Sales & Marketing Professional Association, to provide high standards of marketing performance people should support their actions with the "International Code of Ethics for Sales and Marketing" [100]. We chose two statements (out of eleven) that seem to be the most important regarding our project. These are the following:

- "*I believe prices should reflect true value in use of the product or service to the customer (…)*". [111]

We cannot set the real price of our product, since we are working on the first prototype right now. However, estimating the most possible price of our final product designed for mass production, we will try to make it adequate to the efforts we put to produce it and the cost of used materials/components. In other words, we will try not to set the price that is bigger than it should be.

- "*I pledge my efforts to assure that all marketing research, advertising, and presentations of products, services, or concepts are done clearly, truthfully, and in good taste so as not to mislead or offend customers*". [111]

As it can be seen in chapter 3, we did a solid marketing research. When describing our product to potential customers, we obviously would like to highlight its advantages, but still we will be honest with our recommendations. We will not make promises to the clients which the buoy cannot keep

5.4 Academic ethics issue.

From the academic point of view our duty is to write in all the deliverables (report, paper, leaflet etc.) only truth and conclusions based on solid facts. What is more, we should write in an understandable way, explain our points plainly and justify our conclusions. Another important point is to clearly mark every quotation we make and source we use as support. We claim, what can be easily checked in this report, that each part which is not entirely made by us (e.g. some drawings, researches) is marked

and every used source is clearly mentioned.
An ethical concern regarding academic issues might be also our attitude towards professors and courses conducted by them within the framework of EPS. We shall treat them and their work with respect, for instance by attending and actively participating in their classes.

5.5 Environmental ethics issue.

According to the Internet Encyclopaedia of Philosophy, “*The field of environmental ethics concerns human beings’ ethical relationship with the natural environment*” [101]. It is somehow an extension to “classic” ethics theories. Nevertheless, it is also an important issue to consider. The buoy will be in permanent direct contact with the water environment. Most likely, it will not affect anyhow the life of any animals (no moving parts, sharp edges etc.). What is broader brought up in chapter 4, we work on minimizing its influence on the environment by, for instance, using non-toxic substances, recyclable materials or reusable components.

5.6 Liability issue

The last but not least issue we have to be aware of is liability. There are many rules we have to think about in order to avoid unpleasant situations. And it does not matter if it is a result of unwilling or intentional action, we have to be ready to face the consequences. To minimize the probability that such a situation occurs we have to always keep in mind what are our responsibilities to:

- Supervisors/client,
- future customers,
- the law.

Considering our project as an academic work, we should come up with our supervisors' and client's expectations and work in a way they want us to. If we do not, we may fail some subjects or even the whole project which means we do not get ECTS credits necessary to complete the semester.
Considering our future customers, we should be ready for dissatisfaction with our service in some cases. Then, we will have to compensate somehow reasonable complaints and be ready for unpleasant situations .A good thing would be defining clear terms of warranty in order to have a kind of contract determining the rights of our clients and our duties towards them. It will also have a good influence on our reputation and reliability.
Working on a such project and implementing a new product in the market we should be sure that our actions are not against the law. For instance, we cannot infringe any copyrights or patents. Talking about patents, it is good idea to apply for our own patent which will protect our ideas from being stolen. Another concern is following EU and local government directives about usage of dangerous components or hazardous substances. Our team is aware of meeting such liabilities if necessary, yet we will try to avoid situations which may lead us to doing it.

5.7 Conclusion.

To sum up, we are aware of importance of ethical and deontological concerns in our project. We apply ethical thinking in agreement with the engineering work everywhere it is possible. Sometimes it might be hard to balance between ethics and other important issues, yet we always try to find an appropriate compromise.

6. Project Development

6.1 Components

Table 6-1 contains the list of materials that we need to use in the project:

Table 6-1 List of materials

Part	Product	Price [EUR]	Quantity	Source
Fibreglass hull	Fibreglass hull	/	1	ALTO
Steel structure	Stainless steel structure	600-700	1	Metal workshop
Anchor	Danforth anchor	40,78	1	Diamotor
Rope	Nylon rope 50m x 12mm	28,23	1	Diamotor
Chain	Stainless steel chain 3,5m x 6mm	43,19	1	Diamotor
Eye bolt	Eye bolt INOX 12 x 120mm	11,65	1	Diamotor
Thimble	Thimble INOX 12mm	1,45	1	Diamotor
Swivel v 1.0	Swivel INOX 10mm	24,00	1	Diamotor
Swivel v 2.0	Swivel v 2.0	28,00	1	Diamotor
Rope clamp	Rope clamp INOX 10mm	2,60	2	Diamotor
Shackle	Shackle INOX 10mm	3,20	1	Diamotor
Wind speed and direction sensor	Davis Anemometer	100,00	1	LSA
CTD sensor	Developed by a professor at ISEP	/	1	LSA
Battery	Lithium-polymer battery 12V 22Ah (option 1)	270,00	1	Deben.com
	NiMH battery 6V 4,8Ah (option 2)	35,00	?	Overlander.co.uk
Microcontroller	STM32F3 Discovery	13,50	1	LSA
Data storage	Flash memory card, microSD	25,00	1	www.sandisk.com
	Parallax microSD card adapter	13,00	1	LSA
Communication module	RN-XV WiFly Module	35,00	1	www.inmotion.pt
GNSS module	Novatel Superstar II receiver	/	1	LSA
	Novatel GPS-701-GG antenna	/	1	www.novatel.com
TTL/RS232 converter	MAX232	1,20	3	LSA
Voltage regulators	L7805CV: 6V to 5V regulator LM1086: 6V to 3,3V regulator	1,00 1,30	1 1	ISEP
Connectors	Bulgin PX0730/S 3-way socket	11,90	2	pt.farnell.com
	Bulgin PX0747/S 4-way socket	13,20	?	
	Bulgin PX0738/S 6-way socket	15,30	1	
	Bulgin PX0842/B USB connector	11,90	1	
Waterproof boxes	GW44428 IP56 plain	18,7	1	www.gewiss.com
	GW44438 IP56 deep	22,2	1	
Rubber tape	EPDM (3 mm x 25 mm)	8	1	Multiferracha
Blinking lamp	Case + LED	18,00	1	Diamotor

In Table 6-2 you can find the features of the electronic components we used or want to use in the prototype:

Table 6-2 Electronic components

Component	Voltage [V]	Current [mA]	Power Consumption [W]	Dimensions: length-width-height [mm]	Mass [g]
NiMH battery 4,8Ah	6	-	-	100-50-10	360
Davis Anemometer	3.3	0.197	0.0007	470-121-191	523
STM32F3 Discovery	5	13.536	0.068	96-65-20	irrelevant
Flash memory card, microSD	3.3	50	0.165	irrelevant	irrelevant
Parallax microSD card adapter	3.3	0.5	0.002	29-26-12	irrelevant
RN-XV WiFly Module	3.3	38	0.125	34-24-10	irrelevant
Novatel Superstar II GNSS receiver	3.3	151.515	0.5	78-45-10	irrelevant
Novatel GPS-701-GG GNSS antenna	5	35	0.175	185-185-69	500
CTD sensor	12	125	1.5	365-100-100	1937
Blinking LED lamp	12	250	3		300

6.2 Structural

6.2.1 Steel structure

The fibreglass hull cannot constitute, from a structural point of view, the entire buoy. First of all, it does not provide enough space to attach all necessary components. Secondly, because of its geometry (many round surfaces) it would not be easy to connect to it, for example, the wind sensor. Moreover, the hull is not tall enough; the LED lamp would hardly be visible from a larger distance, and all components would be subject to a more frequent contact with water. Therefore, in order to have a functional buoy, there must be an external frame that holds onto the hull. This frame must fulfil a

number of requirements. First of all, it must be made of a material resistant to the effects of saltwater and UV radiation. Secondly, it must provide enough space to attach the antennas, sensors, and lamp. Moreover, its geometry must ensure that the buoy is resistant to wind and waves. Furthermore, it must be strong enough so that it does not break.
The very first and general design of this frame consists of a stainless steel structure that clasps the hull all around its ring and protrudes upwards and downwards with four tubes. It consists of two vertically symmetrical parts that are put together with the use of bolts. In the upper part of the structure there is a horizontal platform for the box with the electronic equipment, and an additional place to attach the lamp and antennas. On the other hand, in the lower part there is a enough place to attach some sort of ballast and connect somehow an anchor. Figure 6-1 presents a drawing of this rough idea.

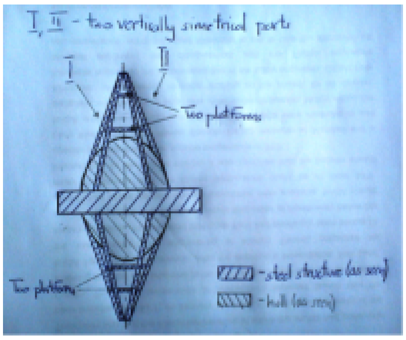


Figure 6-1 First idea on the steel structure

However, after giving it some more thought and listening to Mr. Fernando Ferreira’s helpful suggestions, we came up with the second design, as shown in Figure 6-2:

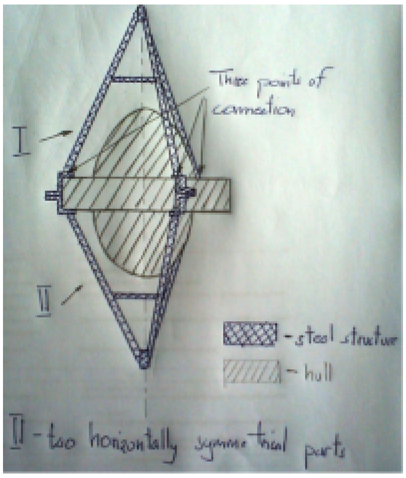


Figure 6-2 Second design of the steel structure

This design differs in a few ways from the first one, namely:

- It has a total of six tubes, instead of eight,
- the structure does not clasp the whole ring of the hull, but it is merely attached to it in three places,
- it consists of two parts which are divided in the horizontal plane, instead of vertical.

This design is beneficial in a couple of ways. Firstly, it uses less material. Secondly, it makes it easier to take out the cover of the hull. Thirdly, it is easier to combine both parts in the horizontal plane.
In an attempt to find an even better design, we invented the structure seen in Figure 6-3. It differs from the two previous designs in a few important ways. First of all, it is not symmetrical in neither plane. Secondly, it is considerably shorter. Thirdly, it possesses three significant features: a rod for

putting on the ballast in the form of circular plates with holes in the middle, sufficient space for placing the CTD sensor, and an eye bolt for the attachment of the rope for an anchor.

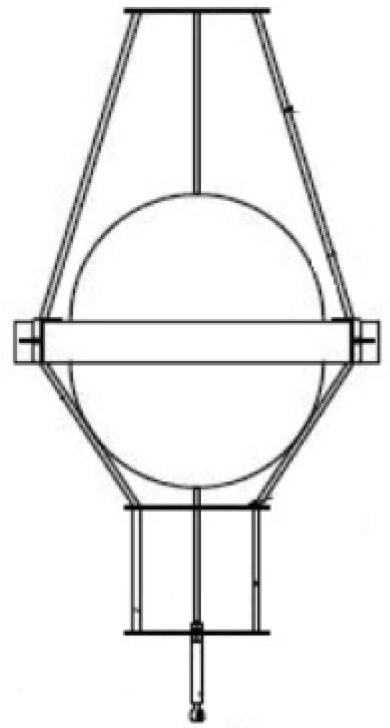


Figure 6-3 Third design of the steel structure

However, this structure has a major disadvantage – it could be easily broken if a strong twisting force occurred.
After evaluating all of the designs, we devised the final one seen in Figure 6-4:

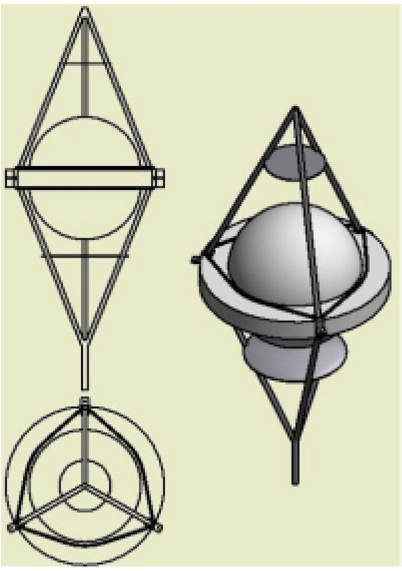


Figure 6-4 Final design

In essence, this design constitutes a mixture of all the three previous ones. However, before it has reached this final look, it underwent some smaller and bigger changes, especially in terms of the “fasteners” - circular tubes that connect the “holders” (pieces that directly embrace the hull’s ring). The role of these fasteners is to prevent the structure from spreading apart to the sides under the force of weight of the structure itself and the components attached to it. In total there are six of them, three in the upper part and three in the lower. Just like in the second design, this structure is divided horizontally in the middle of the hull. These two parts are connected tightly to one another with the use of three bolts that go through three flat plates that protrude from the hull's ring. In the upper part of the structure there is a horizontal, circular plate to which the wind sensor, lamp and antennas can be attached. In the lower part, on the other hand, there is a similar plate, but of a greater diameter so as to provide the space required for the CTD sensor. At the very bottom we see a cylindrical rod for the placement of circular weights (Figure 6-5) as the ballast. Because these weights can have a mass ranging from as small as 0,5 kg to as big as 20 kg, they can be easily arranged in such a way as to obtain a desired total weight accordingly to the existing needs.

Figure 6-5 Weight [102]

At the bottom of the cylindrical rod there is a threaded hole for an eye bolt to which the anchor line can be indirectly attached. Drawings of the overall structure, along with those of each part separately, can be found in appendix B.

6.2.2 Mooring

In order to make sure that the buoy stays in one place on a river, it needs to be connected to an anchor. However, the anchor is only a part of the overall system that is required for the buoy. This system consists of: one anchor, two swivels, one shackle, one thimble, one nylon rope, one chain, and one eye bolt. The order in which all of these parts are connected is presented in Figure 6-6. First there is an anchor which lies on the bottom of the river. The next part is a strong swivel that is attached to the anchor on one end and to a chain on the other. The chain's other end is connected to the rope with a shackle that goes through the rope's thimble. The rope then goes up until it reaches the other swivel where it goes through a thimble. The rope is fastened with two stainless steel clamps. The swivel's other end is connected to the eye bolt that is screwed into the threaded hole in the steel structure.

Figure 6-6 Mooring system

The cylindrical rod has an additional small hole, as seen in Figure 6-7. Its role is to provide the possibility of introducing a "blocker" – a sort of small cylinder. Once the eye bolt is screwed into the threaded hole, it is necessary to drill in it a small groove in the place of the small hole in the cylindrical rod. After this, it is possible to place the blocker in place so that part of it enters the groove, and part stays in the hole in the wall of the cylindrical rod. The remaining space inside the whole can be filled with some material to prevent corrosion.

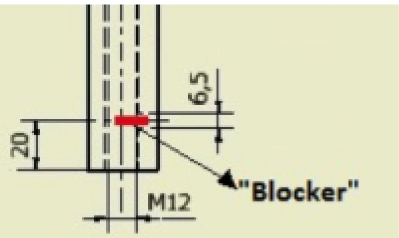


Figure 6-7 Method of locking the eye bolt

6.2.3 Buoyancy and stability

An important aspect of the electronic buoy will be the buoyancy. Buoyancy can be defined as "the ability to float in a liquid or to rise in a fluid" or "the property of a fluid to exert an upward force (up thrust) on a body that is wholly or partly submerged in it". [103] If the buoyancy of an (unrestrained and unpowered) object exceeds its weight, it tends to rise. An object whose weight exceeds its buoyancy tends to sink. This states that the force of buoyancy has to be bigger than the weight of the buoy. After a brainstorm session within our group and a meeting with Mr. Fernando Ferreira we concluded that the buoy will float in the river just underneath the "Saturn-ring" as shown in Figure 6-8:

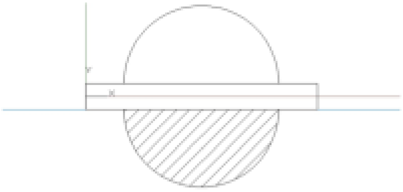


Figure 6-8 Buoyancy force (56,50kg)

This situation is best for the overall stability and the ”Saturn-ring” can give an additional buoyancy force when it is needed. In this situation the volume that is underneath the water surface can be calculated with:

$$\text{Volume} = \frac{2}{3}\,\pi\, r^3$$

$$= \frac{2}{3}\,\pi\,(0{,}3\ \text{m})^3$$

$$= 0{,}0565\ \text{m}^3$$

The buoy will be submerged for a volume of 0,0565 m^3 (an important remark that we have to make is that we do not have the original drawings of the fibreglass hull. Therefore we have to assume that the submerged volume is a perfect hemisphere and we have to rely on the measurement of the radius: r = 0,3 m).

The force of buoyancy can be calculated with the law of Archimedes:

$$\text{Force of buoyancy} = r_{water} \times V_{submerged} \times g$$

$$= 1000\ \text{kg/m}^3 \times 0{,}0565\ \text{m}^3 \times 9.81\ \text{m/s}^2$$

$$= 554{,}27\ \text{kg . m/s}^2 = 554{,}27\ \text{N}$$

At the end, the overall weight of the electronic buoy has to be lower than the force of buoyancy (= 554,27 N). The overall mass that can be attached on the fibreglass hull can be calculated on the following manner:

$$\text{Maximum mass} = \frac{F_{buoyancy}}{g}$$

$$= \frac{554{,}27\ \text{N}}{9{,}81\ \text{m/s}^2}$$

$$= 56{,}50\ \frac{\text{N}}{\text{m/s}^2} = 56{,}50\ \text{kg}$$

Another calculation can be made for the ultimate maximum mass that can be attached to the fibreglass hull. In this case the buoy will be submerged until half of the “Saturn-ring” is underneath the water surface, like shown in Figure 6-9:

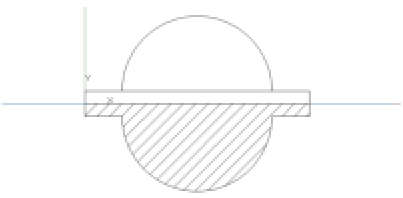


Figure 6-9 Buoyancy force (83,3kg)

The volume underneath the water can be calculated by adding the volume of the cylinder to the volume we calculated above:

$$\text{Volume} = \frac{2}{3}\pi r^3 + \pi r^2 h$$
$$= \frac{2}{3}\pi (0{,}3\ m)^3 + \pi (0{,}45\ m)^2 (0{,}05\ m)$$
$$= 0{,}0565\ m^3 + 0{,}0318\ m^3$$
$$= 0{,}0883\ m^3$$

The corresponding force of buoyancy now can be calculated:

$$\text{Force of buoyancy} = r_{water} \times V_{submerged} \times g$$
$$= 1000\ kg/m^3 \times 0{,}0883\ m^3 \times 9.81\ m/s^2$$
$$= 866{,}22\ kg\ .\ m/s^2 = 866{,}22\ N$$

The overall mass that can be attached on the fibreglass hull can be calculated on the following manner:

$$\text{Ultimate maximum mass} = \frac{F_{buoyancy}}{g}$$
$$= \frac{866{,}22\ N}{9{,}81\ m/s^2}$$
$$= 88{,}3\ \frac{N}{m/s^2} = 88{,}30\ kg$$

We can conclude out these calculations that, in the first case (Figure 6-8) a mass of 56,50 kg can be placed in the water. The weight of the fibreglass hull is 16,50 kg, so 40,00 kg can be attached to the hull. An additional 31,00 kg can be added until the ultimate mass is reached, as shown in Figure 6-9.

To confirm our calculations we did a practical test (you can read further details about this test in section 6.4 Tests), where we filled the fibreglass hull with water until the hull reached the desirable depth. With the volume of the water we can calculate the maximum mass we can attach to the hull:

Table 6-3 Practical test about buoyancy

	V [l]	V [m³]	Weight [N/m³]	Mass [kg]
Water level underneath the "Saturn-ring"	50	0,050	490,50 + 161,87* = 652,37	50,00 + 16,500 = 66,50
Water level in the middle of the "Saturn-ring"	75	0,075	735,75 + 161,87* = 897,62	75,00 kg + 16,50 = 91,50

*An important remark to make is the fact that in this test the weight of the fibreglass hull has to be included. We placed the hull in the water were it will cause a force on the surface; then we added water into the hull to enlarge this force. 16,50 kg has to be added to the 2 results.

Because the results of the practical test differ from the results of the calculations, we can conclude that the shape of the hull is not a perfect hemisphere, it is bigger. Because we want to obtain the highest safety level as possible, we will make further calculations with the lowest masses: 56,50 kg and 88,30 kg.

Now we calculated the ultimate maximum mass that can be attached to the fibreglass hull, we will take a look to the loads:

Table 6-4 Loads (for this prototype)

Load	Mass (kg)
Stainless steel structure	18,00
Fibreglass hull	16,50
Batteries	Max. 5,00
CTD sensor	2,00
Watertight case with electronics	2,00
Wind sensor	0,50
Blinking lamp	0,20
Total:	**44,20**

The total mass of the loads, placed in the water, will be 44,20 kg. These loads will cause a force equal to:

$$\text{Force of the loads} = m_{loads} \times g$$
$$= 44{,}20 \text{ kg} \times 9{,}81 \text{ m/s}^2$$
$$= 433{,}60 \text{ N}$$

Out these calculations we can conclude that the buoy will be buoyant and that we can add an additional ballast with a mass of 12,30 kg. If we add this ballast, the fibreglass hull will be submerged until the water level is exactly underneath the ”Saturn-ring”.

Another important factor of the buoyancy is the stability. An object can be buoyant, but if it is not stable it can turn over. A floating object is stable if it tends to restore itself to an equilibrium position after a small displacement. For example, floating objects will generally have vertical stability, as if the object is pushed down slightly, this will create a greater buoyancy force, which, unbalanced by the weight force, will push the object back up. Rotational stability is of great importance to floating vessels. Given a small angular displacement, for instance due to a wave, the vessel may return to its original position (stable), move away from its original position (unstable), or remain where it is (neutral).
The key words in this story are the centre of gravity and the centre of buoyancy. The centre of gravity is the point in a body where the gravitational net force will act. The centre of buoyancy is the centre of gravity of the volume of water which a body displaces.
When the fibreglass hull is completely upright the centre of gravity and the centre of buoyancy are on the same vertical axis. This results in a stable hull.
For most ships the centre of buoyancy is below the centre of gravity and the ship is said to be “metastable” (Figure 6-10). When the ship tilts, the centre of gravity remains in the same position related to the ship; the centre of buoyancy moves to fit the new centre of gravity of the volume of water replaced by the ship. At first the gravity force and the buoyancy force create a righting torque that tries to move the ship back to the upright position. If the ship is tilted too much, the centre of buoyancy moves to a position where the buoyancy and gravitation force starts to create a moment that will capsize the ship.

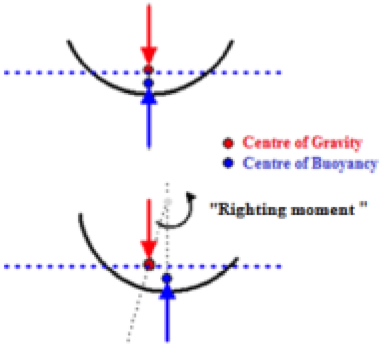


Figure 6-10 Centre of gravity and centre of buoyancy

The best option for the fibreglass hull is to find a solution where the centre of gravity is beneath the centre of buoyancy. In that case any angular displacement will produce a “righting moment”. To obtain this, it is very important that the heaviest parts, such as batteries, are placed as low as possible. We will include the battery in the fibreglass hull to lower the point of gravity. In the end, an additional ballast will be placed with the same purpose.
The steel structure (18 kg), the fibreglass hull (16,5 kg), batteries (max. 5 kg), CTD (2 kg) and the case with the electronics (1,7 kg) are the heaviest parts of the prototype. Their placement in relation with the point of buoyancy will determine the overall stability. In the first situation, where the water is exactly underneath the “Saturn-ring” and the buoyancy force is 554,27 N, the centre of buoyancy will be placed as shown in Figure 6-11.

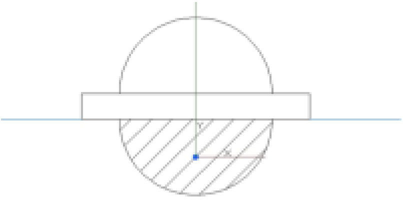


Figure 6-11 Centre of buoyancy (56,5kg)

The batteries and the case with the electronics will be situated around the point of buoyancy, therefore they can be neglected. The symmetric stainless steel structure will clasp around the ”Saturn-ring”, so we can safely say that 3/8 of the mass of stainless steel is underneath the centre of buoyancy. Also the CTD, 1/4 of the fibreglass hull and the ballast will be under the centre of buoyancy.

Table 6-5 Mass above the centre of buoyancy

Load	Mass (kg)
5/8 of the stainless steel structure	11,25
3/4 of the fibreglass hull	12,38
Wind sensor	0,50
Blinking lamp	0,20
Total:	**24,33**

In Table 6-6 you can consult the mass under the centre of buoyancy:

Table 6-6 Mass under the centre of buoyancy

Load	Mass (kg)
3/8 of the stainless steel structure	6,75
¼ of the fibreglass hull	4,12
CTD sensor	2,00
Ballast	12,30
Total:	**25,17**

We can conclude that, when we add a ballast of 12,30 kg, the point of gravity will be at the same height as the point of buoyancy, whereby we can say that the prototype will not be stable.

A solution for this problem is to add more ballast. When we add more ballast the fibreglass hull will submerge deeper. We can keep adding ballast until the water level is in the middle of the ”Saturn-ring” (the maximum mass we can add is 44,10 kg). The perfect balance between ballast and the depth of the buoy has to be determined with further tests.

6.2.4 Water-resistance of the hull

The electronics will be placed in the interior. Therefore it is necessary to provide a waterproof environment. After recognising the imperfect condition of the existing rubber-tape at the clasp and the fact that the lid is not perfectly sealed, we started thinking of other possibilities to make the hull water-resistant. In addition, from day one the bolted connections were not waterproof and some threads were loose. In collaboration with “ALTO – Perfis Pultrudidos, Lda.” (ALTO Contact) or more precise, Mr. Mario Alvim, we discussed different solutions.

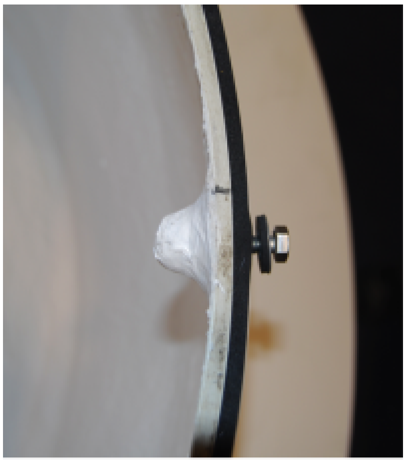


Figure 6-12 Glass reinforced plastic cover

Firstly the buoy hull was taken back to “ALTO” where the nuts have been replaced and covered with a layer of glass reinforced plastic. As a result the threaded connection is impermeable to water (Figure 6-12). “Alto” provided us with rubber washers as well. The washers shall seal the threaded connection and support the objective of making the buoy hull waterproof (Figure 6-13).

Figure 6-13 Bolts with rubber washers

Concerning the existed rubber tape, we planned to replace it with a thicker one. In consultation with an expert we removed the 3mm rubber tape in order to replace it with “EPDM” (Ethylene Propylene Diene Monomer). On the recommendation of the expert we bought “adhesive EPDM rubber tape (5mm x 25mm x10000mm)” at “Multiborracha, Acessórios de Borracha e Plásticos, Lda.“ (Multiborracha Contact) and attached it to the buoy hull. Unfortunately the tape was too thick. The lid did not fit on the main body of hull anymore. For that reason we bought adhesive EPDM rubber tape (3mm x 25mm x10000mm) again and attached it to the hull instead (Figure 6-14).

Figure 6-14 EPDM rubber tape (3mmx25mm)

As seen in Figure 6-15 the general imperfect compatibility of lid and the main body of the hull is a problem. Due to some practical water-tests it became apparent that water was still running through the gaps. Although the rubber tape has been replaced accurately and sealing the threaded connection was a success, we still could not guaranty a moisture-free interior.

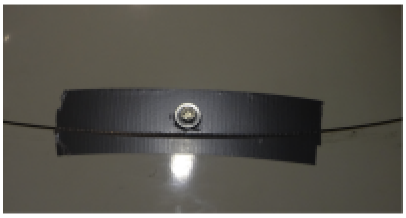


Figure 6-15 Closing gaps by using "Duct Tape"

This is why we decided to close the gaps by placing "Duct Tape" at the lid-main hull connection (Figure 6-16). For practical reasons it turned out that placing the tape before screwing in the bolts is the better alternative.

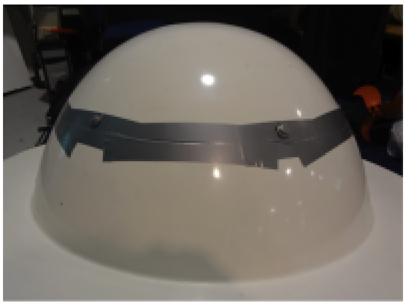


Figure 6-16 Waterproof hull

To grant a water-repellent surface and guaranty that components placed in the inside are safe, this is the cheapest, most effective solution at the moment, but should not be a long-term solution. The "Duct Tape" provides a time-dependent saltwater and UV-resistance [105] [106].

6.2.5 Layout of the electronic components in the inside

As mentioned above, batteries as well as all electronics like microcontroller, Wi-Fi module or GPS will be placed as low as possible in the interior of the hull. In order to protect them we came up with different ideas to ensure the safety of the components right from the start. One of the first ideas is shown in Figure 6-17. For a different project at "LSA" a self-made acrylic glass box protects the electronic components. The top of the box is detachable and a rubber layer between the lid and the main box provides a waterproof connection, if screws close it.

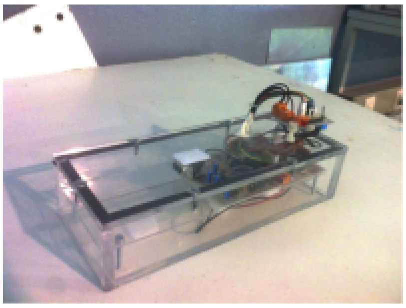


Figure 6-17 Self-made acrylic glass box

After consulting José Almeida of LSA on the topic, we decided to buy a waterproof box that is particular designed for these purposes. He suggested choosing boxes from “Gewiss S.p.A.” (Link) and showed us an example which can be seen in Figure 6-18.

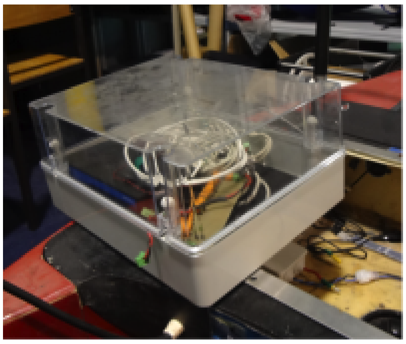


Figure 6-18 “GEWISS” watertight surface-mounting box

Further „ALTO Ltd“ has provided us with an extra glass fiber reinforced tier for placing it in the buoy and connect all components to it. The extra tier has a diameter of 450mm. This is 10mm less than the opening of the buoy (Figure 6-19).

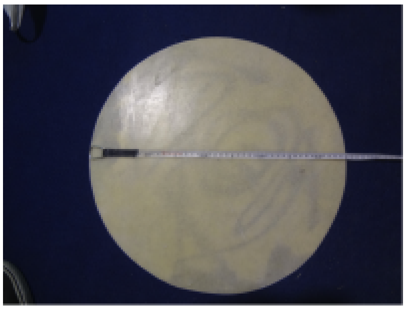


Figure 6-19 Extra tier; diameter of 450mm

The idea is to connect containers to the tier with clips/ribbons and attach the tier to the inner surface of the hull. Because of the necessary dimensions the boxes have to be stackable. Two boxes will be placed on top of each other. Plugs and waterproof interfaces which are easy to connect will be used and support the step of changing batteries. Therefore it is necessary to have matching boxes concerning dimensions (Table 6-7). We chose two similar overall dimensioned containers with equal width and length:

Table 6-7 Length, Width, and Height - containers

	D	E	F
1) IP56 GW 44 428 (plain)	254 mm	208	98
2) IP56 GW 44 438 (deep)	254 mm	208	167,5

The “IP56 GW 4428” box (Figure 6-20) will contain all kind of electronics. The batteries will be placed in the “IP56 GW 44438” (Figure 6-21).

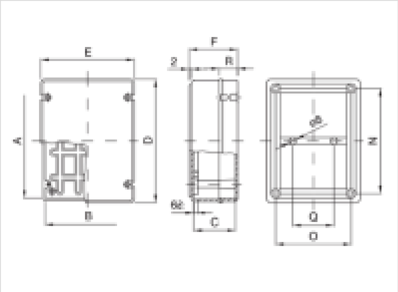


Figure 6-12 1) IP56 GW 44 428 [4]

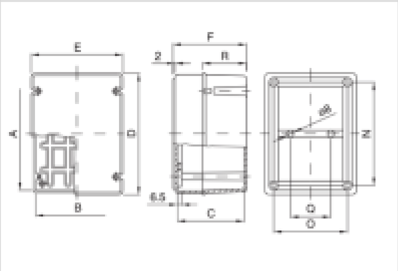


Figure 6-13 1) IP56 GW 44 438 [4]

The surface-mounting boxes are developed for industrial uses. The double insulation supports the protection of the components. Although the containers will be placed in the inside of the buoy, it has a limited resistance concerning UV rays, mineral oil impact and a perfect resistance concerning saline solutions [107].

Figure 6-22 shows a paper profile on top of the glass fiber panel. The paper dimensions are equitable with the dimension of the containers. The boxes will fit in the centre of the extra tier. For reasons of buoyancy and stability it is important to have heavy parts as low as possible. The box with batteries will be at the bottom and the electronics above it.

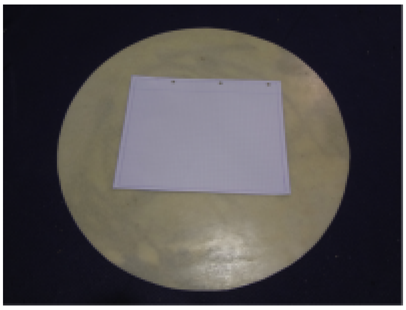


Figure 6-22 Template of the container in the extra tier

For checking the space inside the boxes and comparing it with the necessary components, we draw template and placed microcontroller, SD-socket and GNSS module in there. As can be seen in Figure 6-23, the box has still enough space for an additional microcontroller as well as for the Wi-Fi module.

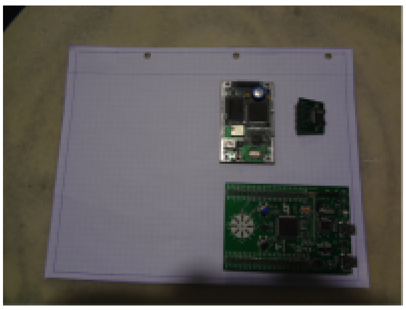


Figure 6-23 Container sized template with electronics

It is confirmed that we are able and qualified to buy the boxes when it is necessary. At the moment it is still not completely defined how the layout of the electronics will look like in the end.

6.3 Electronics

6.3.1 General approach

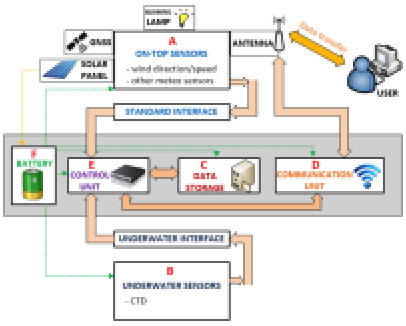


Figure 6-24 Electronics architecture

The first general concept was to create several different parts responsible for different tasks, such as: underwater measurements, on-surface measurements, data storage and transferring, and power supply. We started to improve and expand that idea what led us to the final solution of the electronic architecture shown in Figure 6-24.
On the top of the buoy, there will be a GNSS receiver (to define buoy location and synchronise actual time), place for a solar panel, blinking lamp and, the most important, a platform for sensors to measure conditions above the water surface (A). Data from these sensors will be sent via standard interfaces to the control unit (E). There will be also a second platform for sensors needed to be placed under water (B). All data will be collected in a data storage device (C) and then sent to the user using an antenna connected with wireless communication unit (D). The antenna might be placed either on the top or inside the hull which depends on needed signal strenght. Every component that needs electric energy will be supplied by rechargeable battery (F) which will be able to be connected to a solar panel in the future. Components C, D, E, and F (the grey area) will be placed inside the fibreglass hull and protected against water.

6.3.2 Signals

As it can be seen in Figure 6-25 the first idea was to have 2 MCUs: one slave to collect data from sensors and send them into SD card (on the right side of the picture) and one master to communicate with external devices via Wi-Fi and download data from the slave if requested. This approach provides us with the following interfaces: 4x RS232, 1x SPI, 1x I2C, 1x CAN, 1x USB.

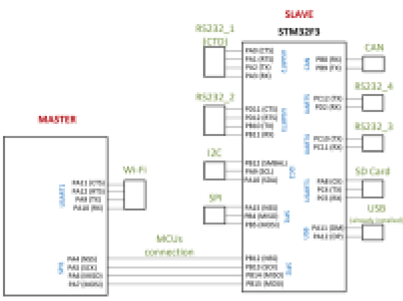


Figure 6-25 First signal schematic

After many consultations and revisions this solution had to be changed into the one presented below on Figure 6-26.

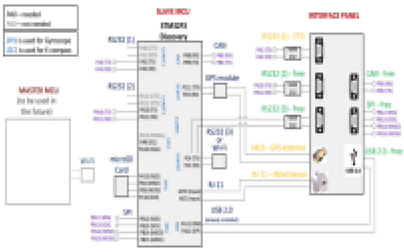


Figure 6-26 Final signal schematic

The STM32F3 Discovery board supports many interfaces, but 2 of them (SPI and I2C) are already used for built-in peripherals (Gyroscope and E-compass). One SPI is used to connect a microSD card socket and the last one can be used to attach an additional sensor. Unfortunately, according to the MCU datasheet [57], all 3 SPIs cannot be used simultaneously with all USARTs and UARTs (which are necessary for RS232 connection). This is why only 3 RS232 can be mounted. Also the Wi-Fi module needs an UART interface what reduces the number of RS232 to 2. Wi-Fi however is supposed to be connected to the slave MCU only temporarily for tests. For the future development, when an appropriate master MCU has to be chosen, the Wi-Fi module can be removed from the slave. Why is there no master MCU included in this solution? This is because the master MCU has to be a proper controller, containing an operating system to manage complex functions. Choosing one, would be too time consuming for this project.

The schematic presented on Figure 6 26 contains only data transferring lines, no electric lines are included there. Finally, the following interfaces are available: 3x RS232 (or 2, which depends on Wi-Fi) from which one is used for the CTD sensor; 1x CAN; 1x SPI; 1x RJ-11 which is used for the wind sensor; 1x USB which can be used either for a connection with the second controller in the future or as a free connector for any other device or sensor.

6.3.3 Power supply

Devices used in the project need the following DC voltage levels:

- 12V - e.g. CTD sensor,
- 5V - e.g. STM32F3 Discovery board,
- 3.3V - e.g. microSD card socket, wind sensor.

The first solution was to use a 12V battery supply as these batteries are very popular and easy to find. With that approach we would be able to power, for instance, a CTD sensor directly from the battery and we would need 2 voltage regulators to power 5V and 3.3V operating devices. In this case the energy losses spent on voltage conversion would be big because the voltage difference is at least 7V. This is why, after consultation with the supervisors, we decided to use 6V batteries. The voltage can be then converted from 6V to 5 and 3.3V what reduces the energy losses. However, the 12V supply is still needed. This can be resolved in 2 ways: 6V to 12V regulator may be used or additional 12V battery may be applied. We decided, for the best power efficiency, to use additional 12V battery (or serial connection of 2 6V batteries, which have to be used anyway). Finally, powering all components will be realised as it is shown on Figure 6-27.

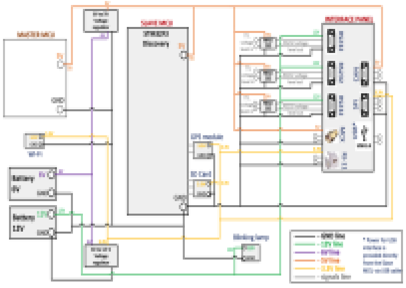


Figure 6-27 Power supply schematic

Devices needed to be powered are gathered in the Table 6-8.

Table 6-8 Devices needed to be powered

Device	Voltage needed	Voltage regulator used
CTD	12 V	None
Blinking lamp		
STM32F3 Discovery		
2nd MCU (optional)		
MAX232 converters	5 V	6V to 5V linear regulator
GNSS antenna (MCX connector)		
Wi-Fi module		
microSD card socket		
GNSS receiver	3.3 V	6V to 3.3V linear regulator
Wind sensor (RJ-11 connector)		

Each component has to be grounded to the common ground. Besides the powering wires of currently chosen components, there should be a possibility of easily attaching voltage lines into not used interfaces, in order to provide voltage to sensors to be added in the future. This can be done by attaching parallel wires to already existing ones. Exemplary voltage lines are presented on Figure 6-27. To convert the voltage to needed levels we use linear regulators due to low price and availability at ISEP. As it can be seen at the schematic, there are components named MAX232. These are voltage level converters. They change TTL standard level (used by output signals of almost every microcontroller) into RS232 standard level which uses wider voltage range. MAX232 converters also need external power supply.

In order to know the number of batteries needed for the system to be autonomous (for some period of time), power calculations had to be done. First, we calculated current and power consumption of each component. Sometimes each of these two values was given in device's datasheet, sometimes only one. If so, the second value could have been easily calculated from the following very simple formula:

$$P = I \, x \, U / 1000 \,,$$

P - power [W],
I - current [mA],
U - voltage [V].

Secondly, we simply added each power consumption value to get the overall value. Results are presented in Table 6-9:

Table 6-9 Power calculation for used devices

Device	Operating voltage [V]	Current (typ) [mA]	Power consumption [W]
Wind sensor	3.3	0.197	0.001
Wi-Fi module	3.3	38	0.125
GNSS receiver	3.3	152	0.5
MicroSD card socket	3.3	0.5	0.002
MicroSD card	3.3	50	0.165
Subtotal (for 3.3V devices)		240.697	0.793
STM32F3 Discovery	5	13.336	0.068
3x MAX232	5	15	0.075
GNSS antenna	5	35	0.175
Subtotal (for 5V devices)		63.336	0.318
Blinking lamp	12	250	3
CTD	12	125	1.5
Total (for all devices)		679.033	5.611

To estimate power demand of the whole system, also power dissipation of voltage regulators has to be taken into consideration. To calculate it, the following equation can be used:

$$P_d = (U_{out} - U_{in}) \times I_{load} / 1000 ,$$

where
P_d - power dissipated [W],
U_{out} - output voltage [V],
U_{in} - input voltage [V].
I_{load} - load current [mA].

Power losses of voltage regulators are shown in Table 6-10.

Table 6-10 Power dissipation in voltage regulators

Regulator	U_{out} [V]	U_{in} [V]	(U_{out} - U_{in}) [V]	I_{load} [mA]	P_d [W]
6V to 3.3V	3.3	6	2.7	240.697	0.650
6V to 5V	5	6	1	63.336	0.064
				Total:	0.714

Comparing to power consumption of all other devices, power losses in regulators are significant. Dissipated power is equal to 13% of power needed for devices work.

At this point we can estimate that power needed by the system is around 6.3 W. Assuming the use of one 6V NiMh battery with capacity of 4.8 Ah, we can perform the following calculations:

- multiply 6V by 4.8 Ah, what gives us 28.8 Wh;
- divide obtained number of watt-hours by power consumption of the system:

28.8 / 6.4 = 4:57 h

This result is the number of hours that this system can work continuously using one fully charged NiMH battery. For instance for 1 day (24 h) of work, 5 of these batteries would be needed.
It is important to note that this estimation was made assuming that each device works continuously, what means that e.g. data on SD card is being written all the time and Wi-Fi module is sending/receiving data all the time. To significantly decrease the power consumption, the use of stand-by modes may be applied.

6.3.4 Physical implementation

All electronic devices, except the CTD, blinking lamp, wind sensor and antennas, will be placed inside the white fibreglass hull. To make sure they will be protected against water, they can be put inside a small waterproof box (what was broadly described in section 6.2.4 Water-resistance of the hull). On the top of the box there will be two wholes: one for power wiring, second for signal wiring. Wires will be put together into a bigger cable which reduces number of needed wholes/connectors and protects them against water. One of these cables will go from an electronic box into a battery box and will contain three wires: 3.3V line, 5V line, GND line. In this case, to make the battery box easily removable form the hull, the cable has to be connected via waterproof connector, such as Bulgin [108]. The second of these cables will go from a battery box up to the interface panel on the upper side of the hull and will contain four wires: 3.3V line, 5V line, 12V line, GND line. It also has to be easily removable so the use of Bulgin connector is necessary. The last (third) cable will be linked between electronics box and interface panel. This one does not have to be easily removable (so use of special connector is not needed) but it has to be thick enough to collect at least 15 wires sending signals to all interfaces. The idea of having an interface panel on the hull is to make the buoy more reconfigurable. The panel will have all interfaces connectors (all of them waterproof) which are for this moment: 3x RS232, 1x CAN, 1x SPI, 1x USB, 1x RJ-11 (or equivalent pin-numbered connector), 1x MCX, 1x SMA. If any new sensor is needed to attach, the white hull does not have to be opened. The layout of this system is simply presented on Figure 6-28.

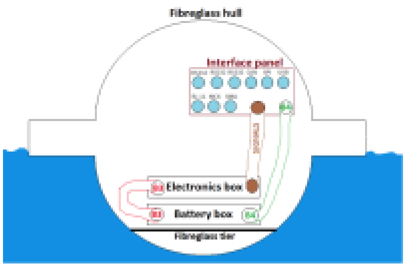


Figure 6-28 Waterproof connections inside the hull

B3(red) is a Bulgin 3-pin connector, B4(green) is a Bulgin 4-pin connector. Red, brown and green lines represent thick cables gathering small wires. In order to change the batteries, the electronics box can be moved to the side, all B3 and B4 connectors can be disconnected and the whole battery box can be taken out of the hull. To make it possible, all wires and cables have to be long enough. Why the battery box is put under the electronic box? Battery box will be the heaviest component inside the hull. Thus, as far as stability is concerned, the lower it is placed the better. Moreover, it should be placed as near to the centre as possible. Size of both boxes makes it impossible to put hem next to each other. This is the reason why one of them has to be under the second one.

6.3.5 Data processing

The data received from the sensors has to be stored. For that purpose, we attached a microSD socket to the microcontroller as already discussed in section 6.3.2 Signals. The process of data storage is shown in Figure 6-29:

Figure 6-29 Data storage process in the microcontroller

The data storage rate is different for the function you want to use. After a meeting with the client, we concluded that one measurement each second from the GNSS sensor, CTD and, wind sensor is wanted for the regatta function. For the environmental function the data storage rate will be one measurement each minute, so battery power can be saved for a longer autonomous period.

In the first prototype we will collect data from the GNSS sensor, CTD and, wind sensor:

- GNSS sensor

The GNSS sensor will be used for measuring the current location and adding a timestamp to the data. The sensor provides different types of data. For us the $GPGGA is the most important format:

$GPGGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx*hh

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

1 = UTC of Position
2 = Latitude
3 = N or S
4 = Longitude
5 = E or W
6 = GPS quality indicator (0=invalid; 1=GPS fix; 2=Diff. GPS fix)
7 = Number of satellites in use (not those in view)
8 = Horizontal dilution of position
9 = Antenna altitude above/below mean sea level (geoid)
10 = Meters (Antenna height unit)
11 = Geoidal separation
12 = Meters (Units of geoidal separation)
13 = Time in seconds since last update from diff. reference station
14 = Diff. reference station ID#
15 = Checksum

The GNSS sensor will output one measurement each second. For the regatta function this is ideal, but for the environmental function we only need one output each minute. Therefore, a delay of 1000 milliseconds has to be added in the programming after a successful reading. We will use the "Novatel Superstar II" as a receiver. To improve the accuracy we will have to add an antenna.

- CTD

The CTD sensor will send data about conductivity, temperature and pressure (as a result of p = p0 + r x g x h) at intervals of 100 ms using the following format:

!id#+ppp.ppp,+tt.ttt,+cc.ccc,+ss.ss<cr>

1 2 3 4 5 6

1 = Id of the card
2 = Value of absolute pressure [dbar]
3 = Value of temperature [°C]
4 = Value of conductivity [mS/cm]
5 = Value of conductivity
6 = Carriage Return (hex 0D)

In this case average values need to be calculated because of the data transfer rate of 10 measurements each second. This is possible by integrating an "average filter" in the programming:

$$\frac{1}{n}\sum_{i=1}^{n} a_i = \frac{1}{n}\left(a_1 + a_2 + \cdots + a_n\right)$$

- Wind sensor

The anemometer we will use, is the Davis Anemometer 7911. It will provide us with the wind speed and direction. The anemometer has the following specifications [109]:

Range

Wind Speed:…………0.5 to 89 m/s, 1 to 322 km/h
Wind Direction:…………0° to 360° or 16 compass points

Accuracy

Wind Speed:…………1 m/s, 3 km/h, or ± 5% (whichever is greater)
Wind Direction:…………±7°

Measurement Timing

Wind Speed Sample Period:…………2.25 seconds
Wind Direction Sample Interval:…………1 second

The sensor gives two different outputs. The first one is related to the wind speed. The wind sensor will send a pulse to the microcontroller each time the cups rotates one time. The output will look like Figure 6-30:

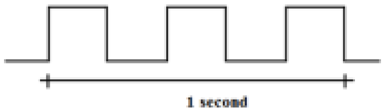


Figure 6-30 Output wind speed anemometer

In the datasheet we can find that:
1600 rev/hr = 1 mph
If we know this fact, we can calculate the following relation:
1 rev/s = 3,6 km/h
If we write a program in the microcontroller that counts the pulses each second, send by the wind sensor, we can calculate the wind speed in km/h each second.
The second output is provided by a voltage regulator. The potentiometer in the wind sensor will send a voltage in between 0 and 3,3V, regulated by an inner resistor, to the microcontroller. 0V means that de weather vane is turned 0°, as shown in Figure 6-31, 1,65V means it is turned 180° (Figure 6 32) and 3,3V means it is turned 360°.

Figure 6-31 Weather vane is turned 0° → 0V

Figure 6-32 Weather vane is turned 180° → 1,65V

The microcontroller receives the voltage and can calculate the wind direction. The STM32F3 is able to do this, because it has an integrated E-compass that, if we know the positional relation between the wind sensor and the microcontroller, can calculate the absolute wind direction.

6.3.6 Programming

We program in the programming language C. [110] states that "*C is a general-purpose programming language with features economy of expression, modern flow control and data structures, and a rich set of operators.*". We will use IAR Embedded Workbench, an integrated development environment, to program and test in. This software contains a C/C++ compiler and a debugger tool.

For the first tests we will try to connect the CTD, wind sensor and GNSS sensor to the microcontroller and read one measurement each second. We will build in a delay of 1 second to obtain this. In the future this process can be optimized by calculating the average of certain output like we discussed in section 6.3.5 Data processing.

- Flowchart of the program

For the first approach we use the following structure (Figure 6-33):

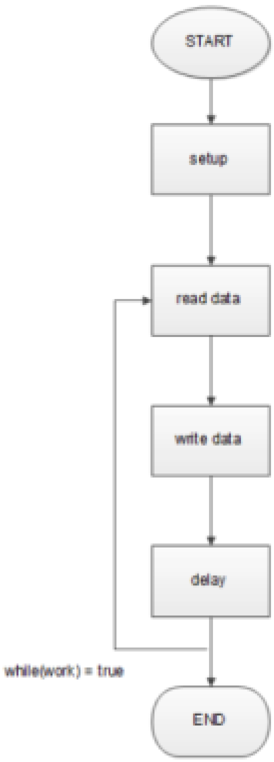


Figure 6-33 Flowchart of the programming

- Overall structure

The overall structure of the program we will try to run on the microcontroller will contain the following parts:

1. Declarations/variables

```
string gnss;
string ctd;
string wind;
GPIO_pin_1
GPIO_pin_2
...
boolean work;
```

2. Initialization

```
void setup{
    setup_gnss();
    setup_ctd();
    setup_wind();
    setup_sd();
    work = true;
}
```

3. The main loop

```
void loop{
    while(work) {
        read_data ()
        write_data ()
        delay(1000);
    }
}
```

4. Sub programs

```
void read_data{
        gnss = read_gnss();
    read_ctd()
        ctd = read_ctd()
    Read_wind()
        wind = read_wind()
}
```

```
void write_data{
    write_gnss()
    write_ctd()
    write_wind()
}
```

In part 1 we declare the variables we need to use. For instance, a string called “gnss” to store the collected data from the GNSS module, the pins we need to apply to connect the SD socket with the microcontroller, and a boolean variable “work” to check if the program is running fluently. In part 2 we will run the setup of the connection between GNSS module, CTD, wind sensor, SD socket, and the microcontroller. Here we will declare that the boolean “work” is true. The third part is the actual loop that the microcontroller is going to run. It will read data from the sensors, write it to the SD card, and wait one second, while the boolean “work” is true. The fourth part is the development of the sub programs. The program read_data() will read data from the sensors and put it in to the corresponding string. For instance, read_gnss() will read the data from the GNSS sensor and store it in the corresponding string “gnss”. write_data will write to the SD card, e.g. write_gnss() will write the string “gnss” to the SD card.

6.4 Tests

In order to check whether the buoy is working correctly, we conducted or will conduct the following tests:

6.4.1 Test for the buoyancy force of the fiberglass hull

The first test we wanted to do, was to test the buoyancy force of the fibreglass hull. Because we did not had the drawings of the hull, we had to do the calculations with the assumption of a perfect hemisphere. After a meeting with Mr. Eduardo Alexandre Pereira da Silva, we decided to test it in a practical manner. Our idea was to fill the fibreglass hull with water, as shown in Figure 6 34, until it was submerged to the wanted depth.

Figure 6-34 Test for buoyancy of the fibreglass hull

In the beginning we started adding water in the hull, 5 litres at a time, and when the water level was near the wanted level (exactly underneath the "Saturn-ring") we started adding smaller amounts. We could conclude that an addition of 50 l would give the wanted result.
After this test we added more water to get the ultimate maximum mass, that means until the water level is in the middle of the "Saturn-ring". We could conclude that 75 l of water forces the hull to reach the ultimate depth. An overview of the results is shown in Table 6-3.

We can make the following conclusion:

- When we want to keep the water level under the "Saturn-ring", the buoyancy force will be 652,37 N,
- when the water level may rise to the half of the "Saturn-ring" the buoyancy force is equal to 897,62 N.

If we compare this with the theoretical buoyancy forces (554,27 N and 866,22 N), we can explain the difference because of the fact that the fibreglass hull is not a perfect hemisphere, but it is bigger.

6.4.2 Tests if the fiberglass hull is waterproof

The second test we wanted to conduct, was to test if the fibreglass hull was waterproof. When we first examined the hull, we concluded that the present rubber would not be sufficient. Therefore, we replaced the old 3 mm thick rubber with 3 mm thick EPDM as discussed in section 6.2.3 Water-resistance of the hull. After we replaced the rubber, we tested it for the first time. The result can be seen in Figure 6-35:


Figure 6-35 Water leaking out of the fibreglass hull

We can conclude that the hull was not waterproof. A second test was conducted, where we taped “duct tape” over the holes and connection in between the top and the main body of the hull, as shown in Figure 6-16. Out of this test we could conclude that the fibreglass hull was waterproof. An important remark we have to make is the fact that this is just a temporary solution for the problem.

6.4.3 Test for communication between the computer software and the microcontroller

For the first test concerning programming, we decided to set the communication between STM32F3 Discovery board and a computer software. As a software we used IAR Embedded Workbench which includes all necessary tools (such as debugger and compiler). We connected 2 devices using USB interface. The USB connector is built in the STM board. To try the communication we used a DEMO program provided by STM [111]. We compiled the program and uploaded it into a microcontroller. As a result several LEDs were blinking showing that the communication had been set correctly (Figure 6-36).


Figure 6-36 MCU-PC communication test

6.4.4 Test if the Gyroscope and E-compass work correctly

Using the same DEMO program as described in subsection 6.4.3, we also tested if build-in MEMS Gyroscope and E-compass work. To test the Gyroscope, we turned on the mode in which, depending on the direction of tilting the board, corresponding LED was blinking. For instance, if we tilted it to the right, the right red LED on the white circle turned on (Figure 6-37).

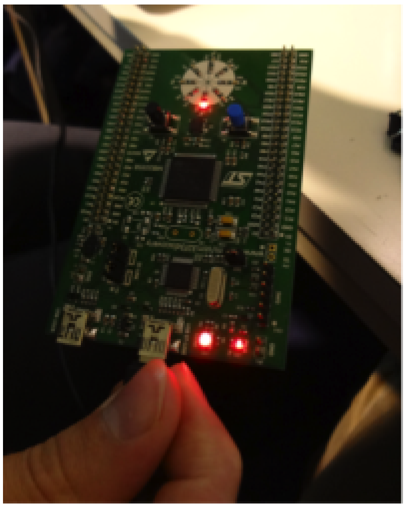


Figure 6-37 The Gyroscope test

To test the E-compass we used another mode in which one LED from the white circle, which is currently the closest to the north direction, turns on. If we turned the board in horizontal plane, LEDs were changing. It showed us that the north detection is not accurate because LEDs did not always point the same direction. It may be caused by using only 8 LEDs to cover the directions from whole 360° area.
Generally, the test showed that both Gyroscope and E-compass are working.

6.4.5 Test if the wind sensor works correctly

To check if the Davis Anemometer works correctly, we asked Mr. Joao Paulo for some help. First, he cut out the RJ-11 connector and the isolation from the cable to give us an access to the wires: Figure 6-38 a).

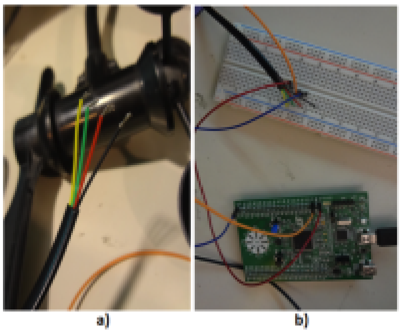


Figure 6-38 Wiring of the Anemometer;
a) sensor´s wires; b) connectin with MCU

Next, using the electronic multimeter to measure conductivity, we checked if both wind speed and wind direction sensors are not broken. They seemed to work properly. After that, according to the Anemometer's datasheet [112], we connected needed wires to the MCU board as it is shown on Figure 6 38 b). We connected only the wind direction sensor which gives an analogue output of DC voltage, depending on inside potentiometer position. We powered the sensor using 3 V external voltage pin available on STM32F3 Discovery board. Using one of available ADCs on the board, we were able to collect and process given data. To present the results we wrote a simple program (Figure 6-39): depending on the voltage given by a sensor, different LED turns on (Figure 6-40). We also connected a multimeter to check the changing output voltage.

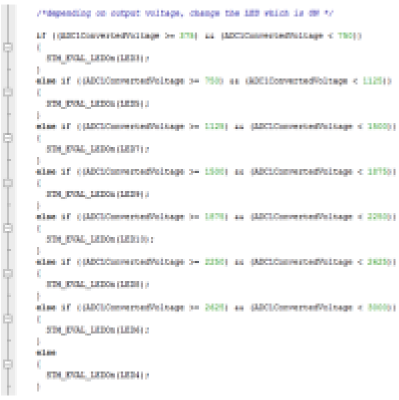


Figure 6-39 Code used to show working of wind direction sensor

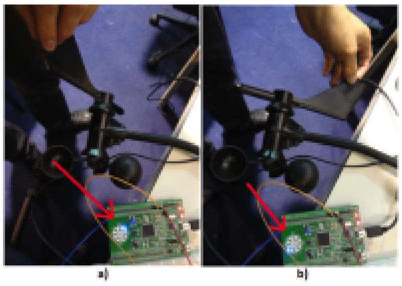


Figure 6-40 Working exemplary program:
a) one position of the potentiometer, b) another position of the potentiometer

6.4.6 Future tests

Due to our lack of experience and knowledge in certain fields of study, we did not conduct every test we wanted to do. Therefore further tests have to be done in the future:

- Test for collecting and storing data,
- test for the right power supply and autonomous time,
- test for buoyancy and stability of the fibreglass hull and stainless steel structure,
- test for the anchor's holding power,
- test for sending data,
- final test in Douro river.

6.5 Project Planning

6.5.1 Tools

Different instruments support the organisation and planning of large, but also smaller projects. Known as helpful tools we used "Gantt Chart" and "Scrum Model". Using a "Gantt Chart" that is designed to assist in developing a project plan, assigning resources to tasks and tracking progress, we decided to utilise our former defined tasks to give the project a more detailed structure and set milestones within the given timeframe. This step includes defining durations and specific dates from the beginning of the project to its end which offers all kind of stakeholders a look at the progress of the project at all times. For internal, more detailed planning we used the procedure model "Scrum" in the end. This model tries to reduce complexity by being transparent, verifiable and easy adaptable. Each day, every team member updates the fourteen-day "Sprint" which includes specific, former defined, personal tasks. As a consequence, everybody is aware of the processing, as well as problems and recent changes.

6.5.2 Planning

At the beginning we started brainstorming. Focussing at the topic we did research regarding the project. In addition our client, “LSA”, expected us to develop a “storyboard” (Figure 6-41) which was supposed to have all types of necessary functions included. Because of the “storyboard”, it was possible to expand the former researches as well as make them more specific. We used the elaborated information to allocate all possible tasks to a single team members (Table 6-11). This task-allocation offered an overview but also helped every single team member for organising himself:

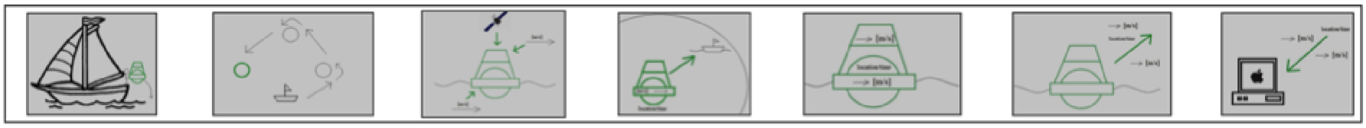


Figure 6-41 Storyboard “regatta function”

Table 6-11 Task allocation team 3

Task	Responsible
Background knowledge	Bennet, Konrad, Mateusz, Toon
Mooring the buoy (anchor)	Mateusz
Buoyancy and stability	Toon
Sensors	Mateusz
Battery and power calculations	Toon, Konrad
Microcontroller	Konrad
Data storage	Toon
Antenna and communication	Konrad
Camera	Bennet
Steel structure	Mateusz
Components testing	Bennet, Konrad, Mateusz, Toon
Installing buoy components	Bennet, Konrad, Mateusz, Toon
Marketing	Bennet
Sustainability	Bennet, Toon
Ethical and deontological concerns	Konrad
Interim Report	Bennet, Konrad, Mateusz, Toon
Interim Presentation	Bennet, Konrad, Mateusz, Toon
Leaflet	Mateusz
Final report	Bennet, Konrad, Mateusz, Toon
Final Presentation	Bennet, Konrad, Mateusz, Toon
Video	Bennet
User Manual	Toon
Poster	Mateusz
Paper	Toon

Based upon these facts and the given deadlines we created a “Gantt Chart”. As can be seen in Figure 6-42, the “Gantt” gives an overview on set milestones and linked activities/tasks which were supposed to be finished at specific dates. Specific dates were for example the “Interim Report Presentation”.
Once created, “Gantt Chart” may be modified and updated during the project period. Because of missing experience, minor changes in our ´Gantt Chart´ had to be made. Some tasks needed more time, than expected. Also, some of them were more intensive than the other ones.

In Figure 6-42 the final Gantt-chart of team 3 is shown:

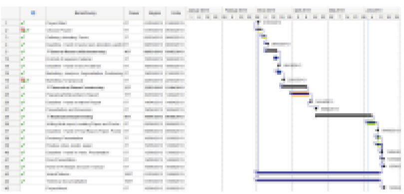


Figure 6-42 Final gantt-chart team 3

For more detailed planning we also used the “Scrum” model. For a two-week-period we developed “Sprints” which included specific, single tasks that were supposed to be easily handled by one team member. As a matter of fact, also during the single “Sprints” some activities were more intensive than others. Therefore, sometimes two members of the group were dedicated to one task. The model itself offers a perfect overview for all single tasks (Figure 6-43).

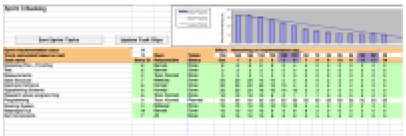


Figure 6-43 Screenshot of sprint three

Looking at “Sprint 3” (Figure 6-43) and “Sprint 4” (Figure 6-44) it can be seen that we fulfilled all the defined tasks for this two-week-period. Even if “programming” was not finished in “Sprint 3”, “programming” was a part of “Sprint 4” where all tasks have been finished until the deadline.

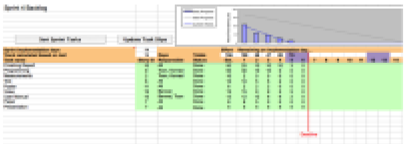


Figure 6-44 Screenshot sprint four

6.5.3 Real Procedure

As mentioned before, a lack of experience as well as new, unknown projects can easily cause delays. Problems appear, periods of time are not well planned and as a result the deadlines are hardly to observe.
In total we roughly put one thousand working-hours in the project. Developing the buoy with all its needed features has included planning, organisation, calculations and measurements, research, programming and drawings. After a couple of weeks it appeared that we had to focus on three main elements: Steel structure, electronics and programming as well as the buoy hull. At this moment, the project aim still was to hand in the finished buoy with all its functions. After a few weeks it became clear that we had to change the scope. In consultation with our client and supervisors, we redefined all objectives. As a result the scope changed and we had to edit the “Gantt Chart” as well as the “Scrum”. The experience of supervisors and our client made it possible to set possible objectives which are compliable in the given time.
Caused by missing experience and required knowledge apart from our fields of studies, we had to change the scope twice. The current and final objectives can be defined as intermediate objectives, if having a completed “Autonomous Environmental Buoy/Regatta Beacon“ is the main objective. We are supposed to hand in the finished drawings and calculations of the steel structure as well as theoretical electronic schematics and basic done programming. In addition the marketing plan, sustainability, ethic and deontology chapters need to be finished as well.

7. Conclusions

7.1 Discussion

This project has proven to be exactly what we thought it would be: difficult and complex, yet interesting and educationally valuable. Before we even started the actual work, we first needed to learn a considerable amount about different types of buoys - what they consist of, and how they perform their functions. It took us quite a lot of time, but it allowed us to have a better view on how to get started and then proceed with further work. There were many things we needed to consider, discuss and decide on. This included, for example, the anchor, lamp, and microcontroller. The two tasks that took up a considerable amount of time and effort were the structure and programming. At this point we regret that we did not have more experience in these fields before beginning the project; perhaps then we could achieve more and with a better quality. Nevertheless, as a result of working on this project, we have all broadened our knowledge in many different ways: we know a lot about buoys, sensors, anchors, buoyancy etc. In a general view, we believe the project was a success. First of all, we have managed to design and acquire the steel structure. With it, it is possible to make progress in other parts of the project such as mooring, and layout of components. Secondly, we have determined the buoy's buoyancy, both on paper and in practice, and thus we have confirmed that it is certainly floatable. Thirdly, we have researched, selected and bought all the necessary parts that make up a complete mooring system. In this way we are sure that once the buoy is placed in the river, it will not run away. Moreover, we have chosen a microcontroller that best suits the buoy, and partially programmed it so that it is possible to operate the wind direction sensor. Furthermore, we have the wind and CTD sensors, microcontroller, GNSS receiver, SD card socket, and lamp. Lastly, we have put a lot effort into the market analysis, ethics, and sustainability. Of course, it would not be possible to accomplish all of this individually. It took an organized and tuned team work to arrive to this point. However, we did not always cooperate perfectly; it was especially hard for us in the beginning when we barely knew one another. With time, however, we started displaying better and better team work qualities, e.g. we divided work between ourselves, and held frequent meetings at ISEP. As a result of the 4 month work we have definitely improved our teamwork skills. We know better how to cooperate, how to express and receive criticism, how to come to a mutual agreement etc. Nevertheless, we cannot consider our final work as a complete success as there are still many aspects of the buoy that need to be finished, as we discuss in section *7.2 Future Developments.*

7.2 Future Developments

Although we have already put much effort into the project, and a lot has already been accomplished, there are still many goals to achieve. Some of them are highly important and cannot be omitted if the buoy is ever to be placed on the river. On the other hand, some are just possible future additions that could make the buoy more functional.
First of all, the fibreglass hull needs to be made completely watertight. Without this, there is a risk that water might get in and destroy the electronics, and maybe even cause the buoy to sink. The hull can be made watertight by placing on it a "rubber skirt" (Figure 7-1) – a piece of rubber tape that is permanently attached to the cover's outer surface, near its bottom edge, so that when the cover is in place, the tape can create a tight connection with the hull body's outer surface, thus preventing the access of water.

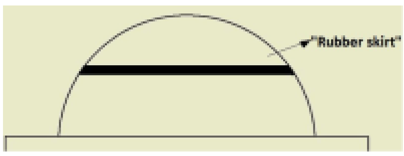


Figure 7-1 "Rubber skirt"

Another method that can be applied is to duct tape the groove between the cover and the hull body. However, it has three disadvantages: it is time-consuming, unprofessional, and most importantly - uncertain, once it might work, and once not. The best solution, but also most radical, would be to create another fibreglass hull whose cover would have a different geometry and features. As far as water tightness is concerned, it is also necessary to acquire appropriate watertight connectors for the interfaces. Secondly, the remaining components, i.e. communication module, GNSS antenna, batteries and box for the hardware, need to be acquired. Once all these components are present, they must be somehow arranged, some inside the hull and some on the steel structure, and connected. Moreover, it is necessary to finalize the software and set it running. In this way the buoy will be able to perform its primary purpose: collect, store and send data. Another important feature that is needed to be added is a fibreglass cover for the lower part of the steel structure, as seen in Figure 7-2. Its purpose is to surround the ballast, and space around the tubes so as to protect the CTD and prevent things from deposing on the ballast. Of course, before putting the buoy in the river, some tests would need to be carried out to check if all these modifications are in working order.

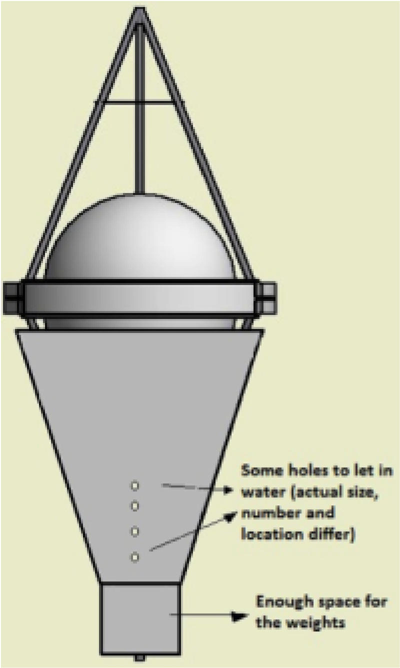


Figure 7-2 Fibreglass cover

In order to extend the period during which the buoy can operate, it would be wise to consider mounting solar panels. However, first it would be required to determine the place where they could be attached, their exact type, and the amount of power they would have to provide. Furthermore, in order to measure more state variables there could be added more sensors. Moreover, special handles could be added to the hull so as to make it easier to transport it.

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Appendices

appendix_a._mooring_a_buoy.pdf

appendi_b_x-buoy_-_technical_drawings.pdf