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Gabriel de Castro Erzini

Controlo Remoto de Um Sistema de Aquacultura

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Automatic Control of an Aquaculture System

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Automatic Control of an Aquaculture System

Dissertation presented to the University of Aveiro to fulfil the requirements for obtaining the Master´s degree in Mechanical Engineering, supervised by Prof. Doutor José Paulo Oliveira Santos, Assistant Professor of University of Aveiro.

The jury

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Palavras-chave Aquacultura; Automação; Aquacultura em Portugal; Controlo remoto de um sistema.

Resumo Esta tese trata-se de aquacultura pelo mundo e Portugal especificamente. Com uma pesquisa feita, um "case study" e trabalho laboratorial, o objetivo é criar um sistema de controlo remoto capaz de controlar as variáveis físicas dentro de um sistema de aquacultura e monitorizar e retificar situações indesejadas.

Keywords Aquaculture; Fish-farming; Automation; Aquaculture in Portugal; Remote Control System.

Summary This thesis covers the automated aquaculture scenario around the world and specifically Portugal. With research done, a case study and laboratory work, the goal is to create a reliable remote control system capable of not only controlling the physical variables within an aquaculture system but monitor and rectify unwanted situations.

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List of acronyms

3G Third Generation

ºC degree Centigrade

ADC Analogue Digital Converter

AIA Avaliação de Impacto Ambiental

AMP Assuntos do Mar e das Pescas

APA Área Programática da Aquicultura

DGAV Direção Geral da Alimentação e Veterinária

DGRN Direcção-Geral dos Recursos Naturais

DGS Direção Geral da Saúde

ENM Estratégia Nacional para o Mar

EMFF European Maritime and Fisheries Fund

ESP Family of microcontrollers

FEEI Fundos Europeus Estruturais e de Investimento

GPIO General Purpose Input Output

GPRS General Packet Radio Services

GSM Global System for Mobile Communications

I2C Inter-Integrated Circuit

ICNF Instituto da Conservação e da Natureza das Florestas

I/O Input/Output

IP Internet Protocol

IPMA Instituto Português do Mar e da Atmosfera

KBytes Kilobytes

LUX Luminous Flux per unit area

ORP Oxidation-Reduction Potential

PAR Parabolic Aluminized Reflector

PC Portable Computer

PCB Printed Circuit Board

pH the symbol for the logarithm of the reciprocal of hydrogen ion concentration in gram atoms per liter

PIC Peripheral Interface Controller

PLC Programmable Logic Controller

PMP Plano Mar Portugal

POEM Plano de Ordenamento do Espaço Marítimo

PON Programa Operacional Nacional

PWM Pulse Wide Modulation

RAM Random Access Memory

RH Relative Humidity

ROM Read-Only Memory

SCADA Supervisory Control And Data Acquisition

SDIO Secure Digital Input/Output

SMS Short Message Service

SPI Serial Peripheral Interface

SSM Segurança e Serviços Marítimos

TCP Transmission Control Protocol

UART Universal Asynchronous Receiver/Transmitter

WPA Wi-Fi Protected Access

Units

cm centimeters

g grams

kPa kilo Pascals

mA milliAmperes

MHz Mega Hertz

mm millimeters

MPa mega pascal

ms milliseconds

mV millivolts

mW milliwatt

s seconds

V Volts

W Watts

Chapter 1

Introduction

1.1 Context

Along the years, with the current increase of population and overfishing, we face a situation where the demand of fish will be greater but the abundance will tend to be lesser. It is then necessary to find solutions that can overcome this serious problem and aquaculture could very well be one of them (Neori et al., 2004).

Like in practically all activities, there is space for automation and intelligent solutions. And it is with that mindset that a control system to monitor an eventual aquaculture system will be developed.

1.2 Can automation help sustain the fish demand?

In the year of 2005, the average consumption of fish per person (worldwide) reached an historical high of 18.9kg. These numbers along with the currently increasing population, justify the also historical highs of fish captured through fishing and aquaculture. However, the increased rate at which aquaculture production has been developing versus the stagnant one fishing, is significant (FAO, 2014).

In Portugal, during the year of 2012, the consumption of fish was three times greater compared to the rest of the world. To sustain this kind of consumption, the fish imported was roughly three times greater than the fish exported. The following table shows some fisheries numbers in Portugal, and can be used as an argument for aquaculture in Portugal. Not only does Portugal have a great marine area, there is a strong culture of eating fish yet very little is being produced (FAO Portugal Profile, 2005).

Table 1.1: Fisheries data of Portugal during the year of 2002. Adapted from FAO Portugal Profile, 2005.

Marine area	1 727 408 km2
Produced fish	195 597 ton
Exported fish	110 606 ton
Imported fish	335 455 ton
Consumed fish	420 447 ton
Fish consumed per person	40.6 kg

With such low levels of fish productivity compared to fish consumption in Portugal being a problem, systems capable of controlling and monitoring different parameters in aquaculture environments, like the one trying to be developed in this thesis, could be part of the solution to this problem.

1.3 Objectives

A remote system capable of monitoring and controlling variables from any part of the world like water circulation, level, pH, temperature and even feeding cycles. It is absolutely necessary that the system can be capable of rectifying abnormalities that can compromise the survival of the species. Besides that, the system must be able to alert someone whenever the system itself can not correct the abnormalities.

1.4 Thesis structure

This thesis is devided in five chapters.

In chapter 1, a brief introduction is made to identify the necessity and purpose of this thesis.

In chapter 2, a more in depth research is made, getting into a much more technical side of bureaucracy and technology concerning aquaculture and automation. It was possible to visit an aquaculture company during the making of this thesis, to better understand a real situation and difficulties felt when trying to grow in this industry.

In chapter 3, a real life system is proposed, identifying main components required for a functional and reliable system.

In chapter 4, a justification of chosen hardware is made, as well as choices and functionality of this very same hardware. It also covers the possible design of this product in a mass production scale.

In chapter 5, the system at it's final stage is analyzed as well as possible improvements and failed goals.

Chapter 2

State of the art

In this chapter, a general review of the state of aquaculture in the world and Portugal is made to better understand the role and level of automation in this area, and how it can be explored in a more intelligent and efficient way. Making this analysis is crucial, given that the development of a system like this could be applicable in environments that are sensitive to small changes that could have devastating consequences.

2.1 Aquaculture

In this section, the viability, necessity, legislation and norms, implementation in the past, present and future and productivity will be discussed with the objective of understanding the real advantages and impact of aquaculture.

2.1.1 Evolution of aquaculture

Aquaculture has been by many considered to be more of an art that science. In the old days, success and productivity were related to intuition and experience of the fish farmer. Steady steps were taken towards technology and investment in modern automated systems.

However, the advantages of automating an aquaculture system are immense and obvious. The fact that one can monitor and parametrize a whole array of variables, makes it possible to visualize the physical and biological state of the aquaculture system. This is a strong argument in favor of automation, not only because it allows you to know what is going on at any given moment but also helps create data bases that with time can make a difference when experimenting and comparing farm results. And most important of all, the possibility of setting alarms can be a game changer and prevent fish farm disasters. With time, like any other production area, automation in aquaculture has been continuously increasing (Malone & A. Jr, 1997).

2.1.2 The growth of aquaculture worldwide

The consumption of fish has been on the rise for the last 5 decades. The apparent consumption of fish per capita (worldwide) went from 9.9 kg in the 60s to 19.3 kg in 2012. This increase is due to factors such as the increase of population, better means of transportation and food distribution and improvement of fishing equipment (technological improvements). In the 60s, almost all the fish produced came from capture. Nonetheless, the increase of population and fish consumption forced aquaculture productivity to increase remarkably, representing 42% of the total production. (State & Fisheries, 2014).

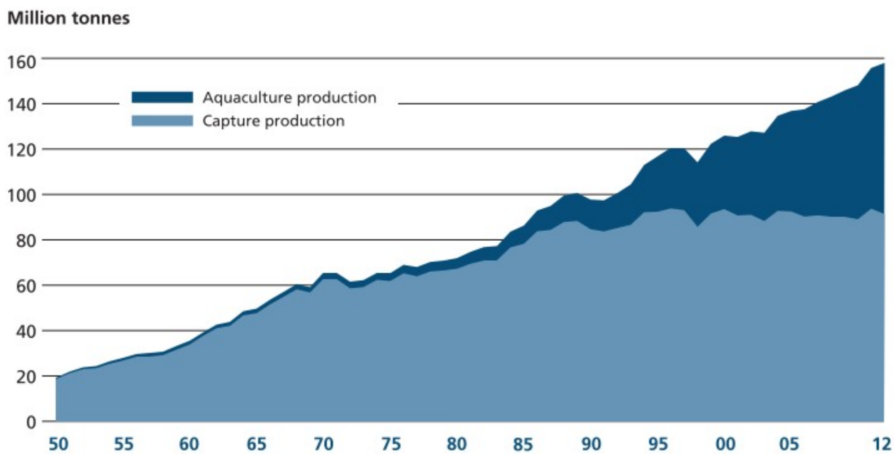


Figure 2.1: Aquaculture vs capture production of fish worldwide over the years. From State & Fisheries, 2014

2.1.3 Mariculture and inland aquaculture

The system developed will be more directed towards inland pond or tank aquaculture rather than offshore marine aquaculture for the following reasons. To start, the laws related to cages and nets are very strict, second, conditions in the ocean are much harsher and the types of sensors required for inland aquaculture are more common and better known (Dummett, 2004). Thanks to all the factors mentioned previously and others, inland aquaculture represents a much larger part of the total fish produced via aquaculture(State & Fisheries, 2014), as we can see in table 2.1.

Table 2.1: Table of aquaculture production worldwide. From (State & Fisheries, 2014).

Year	2007	2008	2009	2010	2011	2012
Inland Aquaculture	29.9	32.4	34.3	36.8	38.7	41.9
Mariculture	20.0	20.5	21.4	22.3	23.3	24.7
Total Aquaculture	49.9	52.9	55.7	59.1	62.9	66.6
	Million tonnes					

The particular growth of inland aquaculture is obvious, so from this point of view, it makes a lot of sense to invest in these areas. There is room for technology and practical solutions like the one that will be developed throughout this thesis.

2.1.4 Aquaculture in Portugal

Throughout the 70s, 80s and 90s, aquaculture in Portugal changed allot. Initially, aquaculture was associated with practically only low commercial value species of fish like the mullet (*Mugil spp.*), moving on to a production more inland orientated. In the 90s the advancements in this field allowed the sea bass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*), fish with a much higher commercial value, to be more popular and eventually the sole (*Solea spp.*). In the end of 2011, the licensed structures for the practice of aquaculture were 1570. The figure 2.2 illustrates the diversity and popularity of these structures (Ine & I.P., 2013).

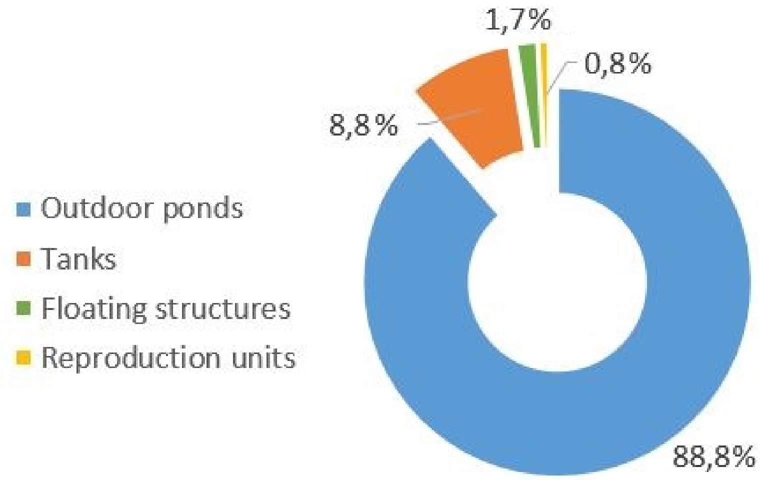


Figure 2.2: State of Portuguese aquaculture in 2011. Adapted from Ine & I.P., 2013.

Portugal has not been following the path that most of the world has, mainly thanks to the it's geographical and marine conditions. As it is shown in the following graph, Portugal has been developing the great majority of it′s aquaculture in the ocean, mainly mussel growing.

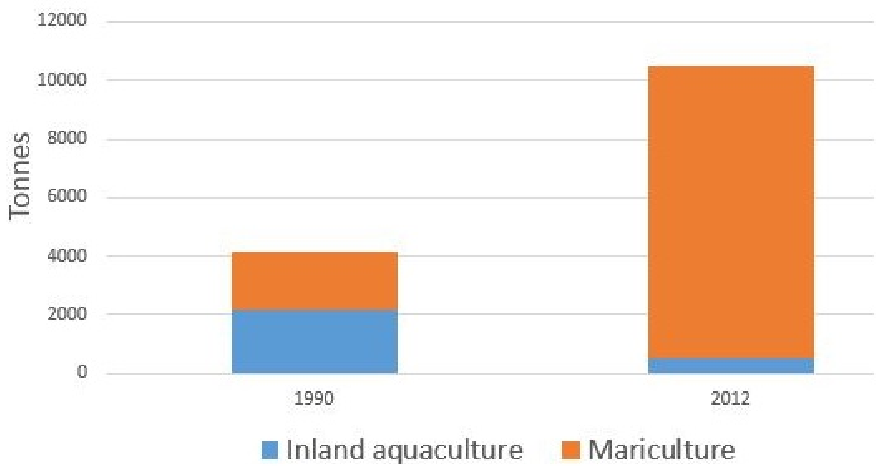


Figure 2.3: Production of Portuguese mariculture vs inland aquaculture. Adapted from Ine & I.P., 2013.

The system developed here would have to be different if it were to be applied in the mariculture versus inland aquaculture industry, because the functionality of the device would change drastically. The controlling and monitoring would be common to both, but the functions and parameters to monitor would be completely different. With this in mind, makes sense that the design would focus on inland aquaculture, given that it is the most practiced and in a much safer and controllable environment.

However, an alternative future solution, could be much more flexible. For instance, the processing unit could have all the different options programmed for all kinds of environments. Everything else like sensors and actuators could be mounted as separated modules, somewhat like an arduino[1]. This is a solution that can not be tackled properly for various reasons, the main ones being lack of time and resources.

2.1.5 Case study: AquaCria Portugal

During the elaboration of this thesis, it was possible to visit AquaCria's infrastructures to get an idea of how all the processes take place and of the technology used.

AquaCria is the main sole producing company in Portugal. The species of sole being produced here is *Solea senegalensis*[2].

Firstly, the species being bred will be introduced to understand what kind of conditions and cycles this fish goes through. Secondly, the difficulties and conditions this company faces will be exposed to see how the system being developed could actually be useful and integrated.

Solea senegalensis, the fish

Solea senegalensis is a flatfish with an oval and asymmetric body. The average size of this fish is 30 cm to 40 cm but can reach up to 70 cm in total length. Females reach sexual maturity around four years old. The optimal temperature for spawning ranges from 8 °C to 12 °C. This species is quite important for mariculture considering it's high market value ("FAO Fisheries & Aquaculture – Species Fact Sheets – Solea senegalensis (Quensel, 1806).

[1]arduino is a development board that can work with a simple module mounting system and is applied in various automation and control projects

[2]Scientific name for Sole.

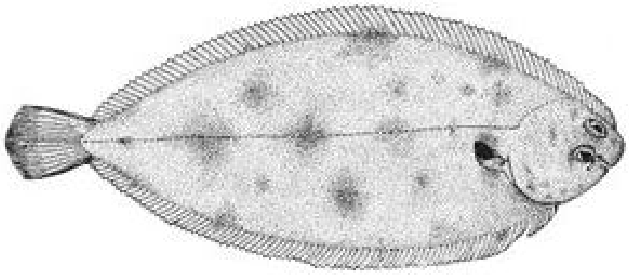


Figure 2.4: Solea senegalensis ("FAO Fisheries & Aquaculture – Species Fact Sheets – Solea senegalensis (Quensel, 1806)," n.d.).

The aquaculture cycle lasts between 16 and 18 months from the moment of spawning, until harvest at average commercial size of 350 g. The following scheme illustrates this cycle ("How to Farm Sole - The Fish Site," n.d.).

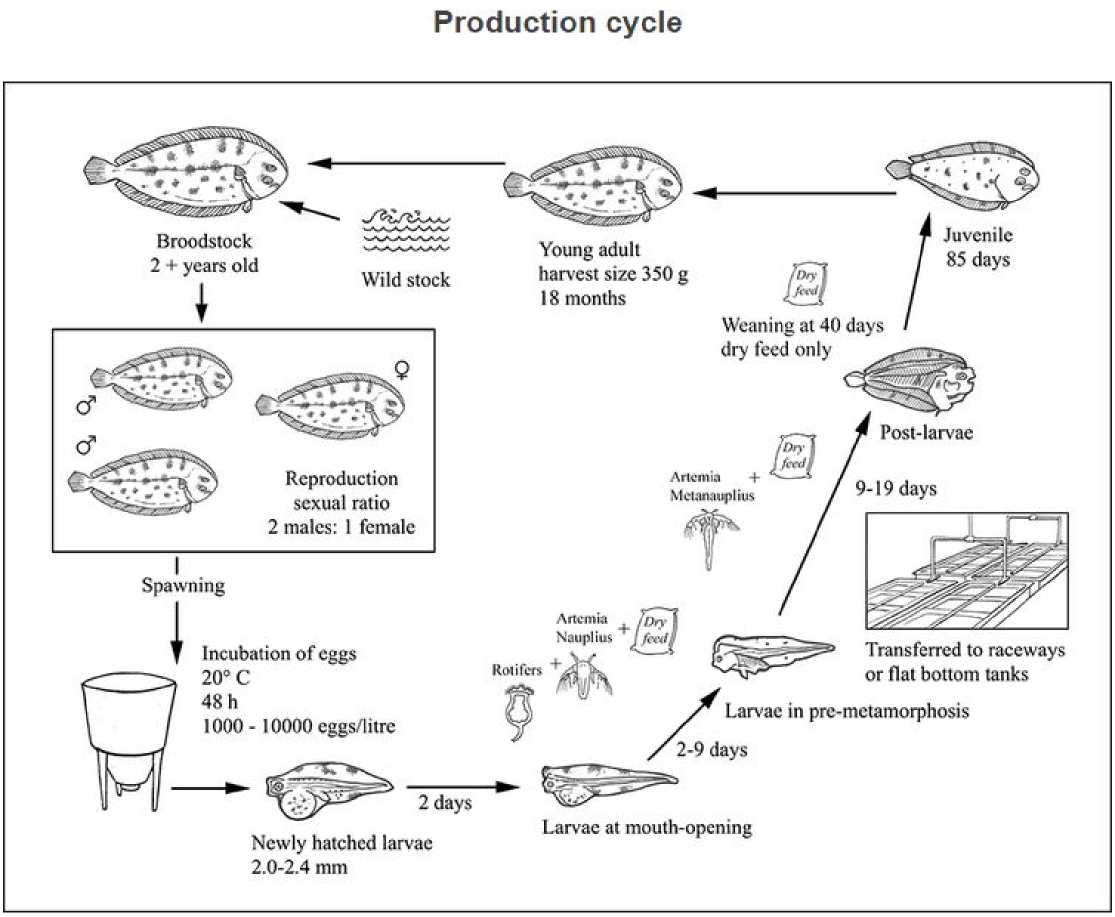


Figure 2.5: *Solea solea* ("How to Farm Sole - The Fish Site," n.d.).

In AquaCria's case, they receive the soles already at a juvenile stage. Then they are separated by size and move on to other tanks at different times due to a varied range of growth rates. This is a manual process. The first transition is made by sending the fish through tubes that connect tanks from different buildings (the soles are about 12 cm long at this point). Once they reach the main tanks, there are no tubes allowing the passage of the fish from tank to tank. They are caught with a net, and separated manually.

Obstacles faced by AquaCria

After a guided tour of the infrastructures it was possible to identify a few problems. Not all of them can be solved with the system developed for this thesis, but they will still be referenced for future considerations. The main problems encountered were:

1. The size and weight separation process of the soles, is a manual, slow and stressful one for the fish;

2. The water comes from a hole in the ground 50 meters deep and has to be processed before entering the tanks thanks to a high level of iron;

3. The control of water temperature is done manually and it is done through the regulation of room temperature and ventilation of the pavilions;

4. The pH measurements are made manually;

5. The tanks that hold the water that is used for all the other tanks where the fish are, were badly designed making it very hard to know the level of stored water. The water level management is also manual.

Problem resolution

Problem number 1 could be solved with a vision and scale system. Instead of a few dozens of fish being put in a box, then hand picked for each tank, they could very well pass through a rolling carpet, with a digital scale. Depending on the weight determined, they would advance on the carpet until reaching the correct exit for their weight class tank.

Problem number 2 can't really realistically be solved because it would require moving the whole infrastructure to a different place, in order to use a different water source.

Problem 3 is easily solvable, but not one to be solved with this thesis. Controlling the ventilation could be an automated process, where the micro controller or processing unit for example, would access the weather forecast through an internet connection and automatically plan the functioning ventilation cycles. The only problem here is that this is a very particular situation not common to all aquaculture companies, making it not viable to incorporate such a feature in the developed system.

Problem 4 will be solved for sure as there will be sensors capable of measuring pH and temperature for example, incorporated in the solution. This not only spares human resources, it can also work in sync with other features, such as turning on and off external component like pumps.

Problem 5 is another one that can't be solved with this thesis's solution. The water storage tanks would have to be redesigned in order to function properly and allowing a precise reading of the tank water level.

2.1.6 Strategic plan for aquaculture in Portugal

Of all the main forms of food production, aquaculture has been the one that most rapidly grew worldwide. The fact that Portugal has a very interesting coastline and large marine area is a big reason why aquaculture has been, not surprisingly, a focal point of national and European Community policies.

Recently, the National Strategy for the Ocean 2014-2020 (ENM - Estratégia Nacional para o Mar) and its action Ocean Plan (PMP - Plano Mar Portugal) established in its action program for the Aquaculture Programmed Area (APA - Área Programática da Aquicultura), the promotion of aquaculture together with the growth in consumption and respecting a matrix of regional development as one of the main objectives in order to find the balance between production and the needs of the consumer.

After making an assessment in 2009 by the strategy adopted by the European Commission in 2002 on the development of sustainable aquaculture, the strengths and weaknesses of this section were identified. With funding from the European Maritime and Fisheries Fund (EMFF), the European Commission plans to implement a strategic plan for aquaculture, important point for the National Operational Program (PON - Programa Operacional Nacional) during the period of 2014-2020.

In 2012, the zones with the best characteristics to have aquaculture structures installed and developed were identified, as preliminary work for the Marine Territory Planning (POEM - Plano de Ordenamento do Espaço Marítimo) (Aqu & Nacional,2014). There are three production regimes:

- extensive: feeding is exclusively natural;
- intensive: feeding is exclusively artificial;
- semi-intensive: a mix between natural and artificial feeding.

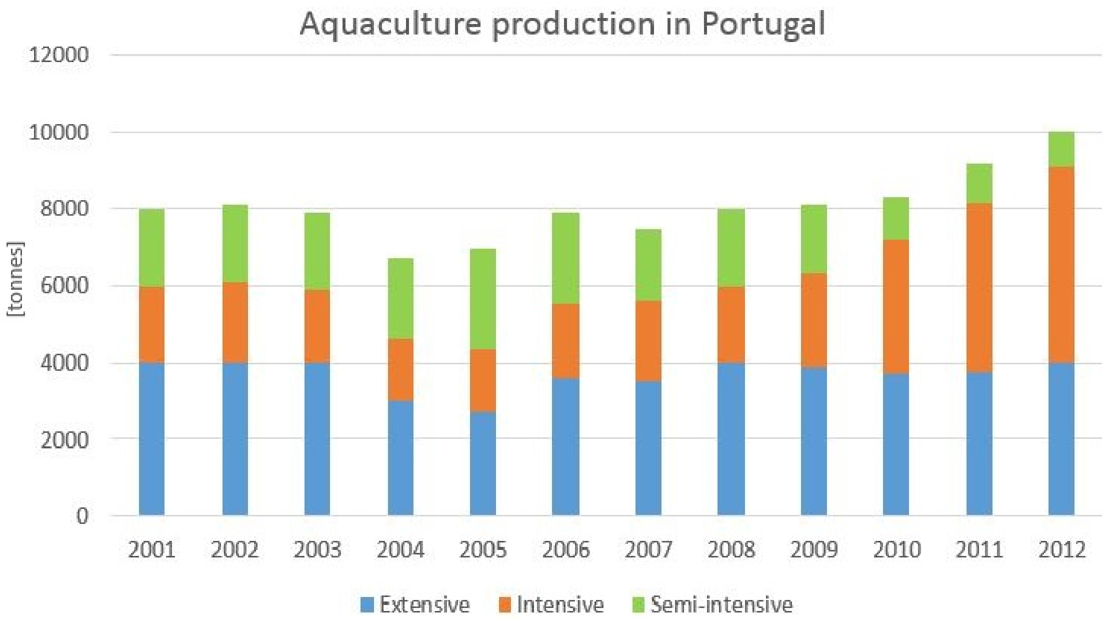


Figure 2.6: Aquaculture production in Portugal by types. Adapted from Plano stratégico para Aquacultura Portugesa 2014-2020

The support and encouragement to aquaculture, alongside the evolution of intensive production regimes are the main reasons why the system developed in this thesis, has to be able to work in the intensive production regime scenario. Such functionality is easy to incorporate thanks to the portability and storability of artificial food.

To practice aquaculture legally, these licenses among others are required: one that allows the use of water resources and another that allows the practice itself, both in marine or inland aquaculture. The following list demonstrates all the licenses and paperwork necessary to run legally such a business.

Use of water resources

- Responsible entities:

  - The Portuguese Environment Agency (APA - Agência Portuguesa do Ambiente I.P.);
  - Port Agencies;
  - Docapesca, S.A.;
  - Institute for Nature Conservation and Biodiversity (ICNF - Instituto de conservação da Natureza e Florestas), when in protected areas).

- Installation Process:
  - Law nº 58/2005 (water law);
  - Regulatory-Decree n.º9/2008(open sea);
  - Law-Decree nº 151-B/2013 (intensive fish farming).

- Duration of the authorization process: approximately 45 days.

- Validity of the license: up to 30 years, depending on factors like nature, size, associated investments and economic relevance.

Mariculture

- Responsible entities:
  - Natural Resources General-Directorate (DGRN - Direcção-Geral dos Recursos Naturais), Marine and Safety Services (SSM - Segurança e Serviços Marítimos), Regulatory-Decree n.º14/2000 e 16 Regulatory-Decree n.º9/2008 (coastal waters);
  - Institute for Nature Conservation and Biodiversity (ICNF - Instituto da Conservação da Natureza e das Florestas);
  - Portuguese Sea and Atmosphere Institute (IPMA - Instituto Português do Mar e da Atmosfera);
  - Town Council;
  - Port Captaincy (in case the port is situated under jurisdiction areas);
  - Directorate-General of Health (DGS - Direção Geral da Saúde);
  - Portuguese National Authority for Animal Health (DGAV - Direção Geral da Alimentação e Veterinária).

- Duration of the authorization process: approximately 4 to 6 months.

- Duration of the license: 15 years;

Inland aquaculture

- Responsible entities:
  - Institute for Nature Conservation and Biodiversity (ICNF - Instituto da Conservação e da Natureza das Florestas);
  - Portuguese National Authority for Animal Health (DGAV - Direção-Geral de Alimentação e Veterinária);

  - The Portuguese Environment Agency (APA - Agência Portuguesa do Ambiente) when there is the possibility of projects being susceptible to Environmental Impact Evaluation (AIA - Avaliação de Impacto Ambiental).

- Law-Decree n.º565/99, in case of the introduction of indigenous species in the flora and fauna.

- Authorization process duration: 6 to 12 months.

Because this kind of activity is still at a high rate of development, the bureaucratic side of things is far from being at an ideal state. With the goal to increase and diversify the offer of national aquaculture products, the Operational Program 2014-2020 for the Ocean and Fisheries related Subjects (AMP - Assuntos do Mar e das Pescas), financed by the Structural and Investment European Funds (FEEI - Fundos Europeus Estruturais e de Investimento), has as objectives:

- Reduce and simplify administrative procedures;

- Identify main hydric resources with potential for aquaculture;

- Increase, diversify and value aquaculture products.

2.2 Control systems for aquaculture

There are various types of designs for control systems utilized in aquaculture, for example (Lee, 2000):

- Closed loop controller or data logger systems;

- Programmable logic controller (PLC) systems;

- Microcontroller based systems associated to a SCADA software;

- Distributed control systems (DCS).

The systems can be designed in many ways. They will vary in robustness, viability, cost and features. No matter which system, they all have to include some mandatory hardware and software. For example:

- I/O drivers;

- Processing module and data acquirement;

- Human-Machine interface;

- Programmable alarms.

2.2.1 Academic solutions proposed by others

In one research project, the monitoring of cages in open sea was solved with the implementation of 3G technology, so that it would be possible obtain real time data regarding temperature, salinity, dissolved oxygen, velocity and direction of currents. The figure bellow illustrates this concept (Wang, Qi, & Pan, 2012).

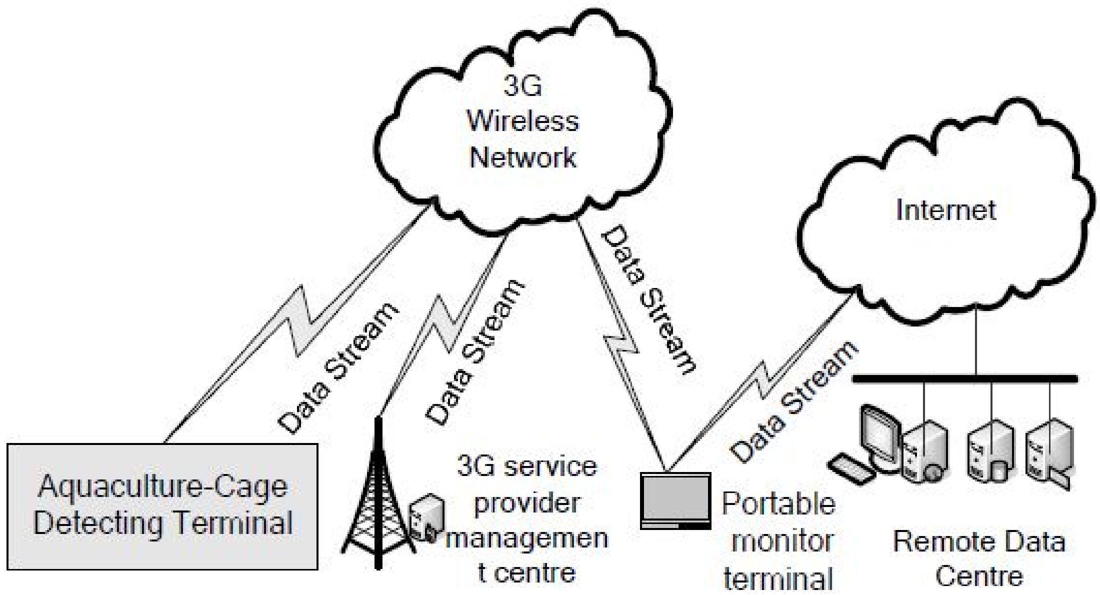


Figure 2.7: Scheme of wireless network solution proposed (Wang, Qi, & Pan, 2012).

In another research project, a solution was created for shrimp farming. Shrimp and fish are very sensitive to the quantity of dissolved oxygen in the water are grown in large artificial ponds or tanks. Large surface areas is an issue, and ZigBee modules were implemented. These modules can assume the role of slave or master and can re-transmit information between them in chain. Like this large areas can be monitored. The aim of this project was to monitor pH, temperature, water level and dissolved oxygen over a large surface area (Simbeye, Zhao, & Yang, 2014).

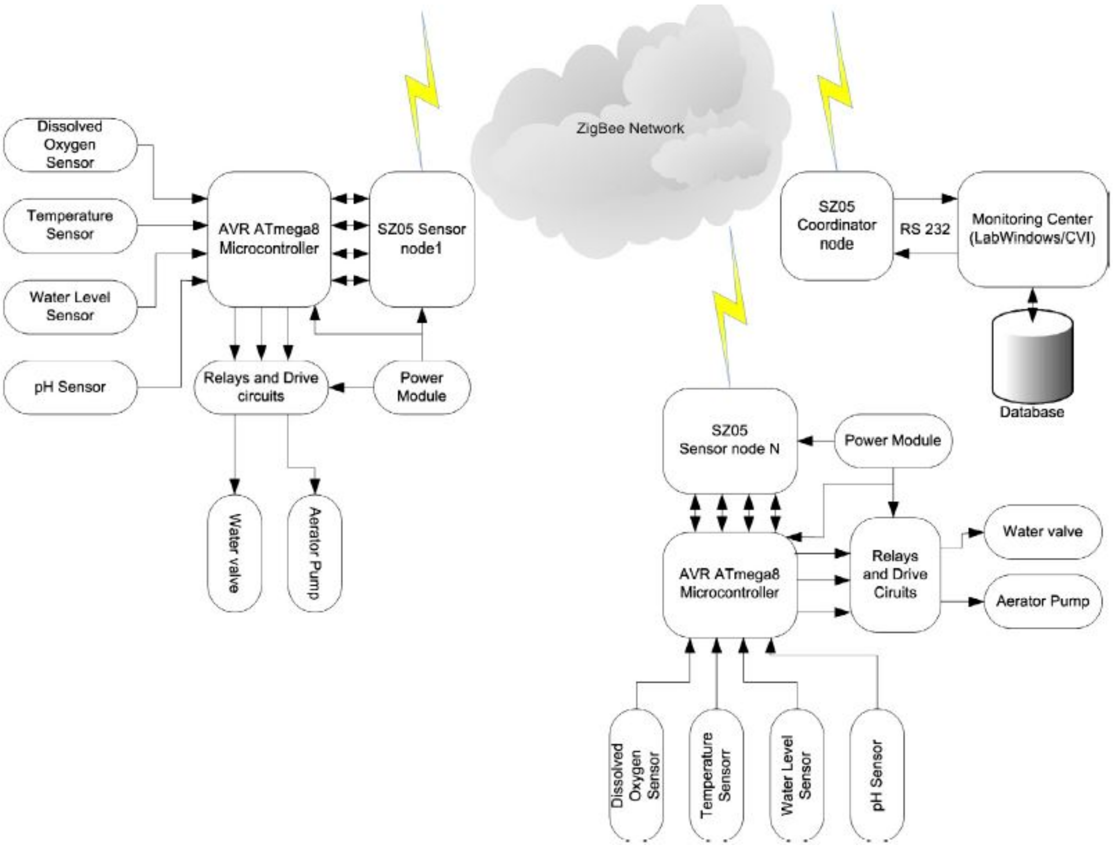


Figure 2.8: ZigBee Network and processing units scheme of proposed system (Simbeye, Zhao, & Yang, 2014).

Finally, a completely different research project, had the aim to determine the fish mass without having to remove them from tanks. Knowing the mass of fish is very useful because it is a main factor in selectivity and aquaculture. Basically, a camera photographs the fish, the image is then converted to it′s binary form and finally an algorithm estimates the mass of the fish. The relative error of this method is of ± 3% (S. Viazzi, Van Hoestenberghe, Goddeeris, & Berckmans, 2015). It might not be a priority when it comes to designing and automated aquaculture system, but it is certainly creative, effective and attractive from the engineering and aquaculture point of view. The following image shows how this camera and image processing occurs.

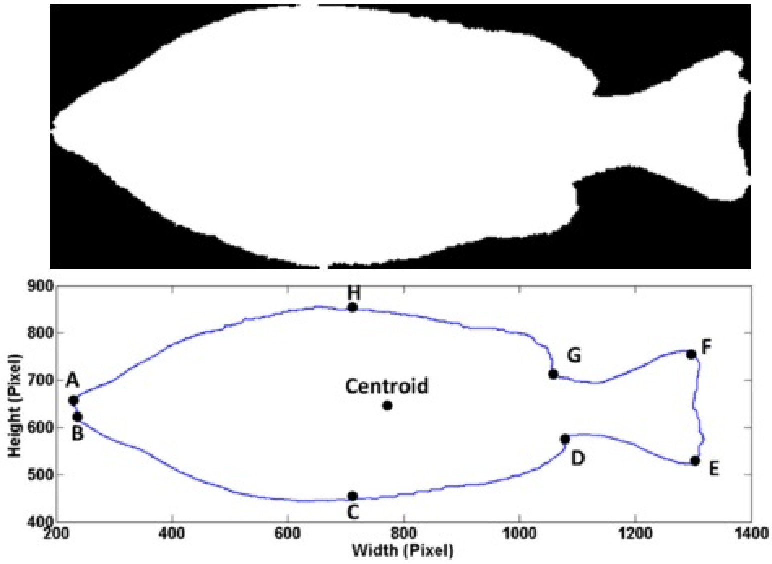


Figure 2.9: Image captured and processed to estimate the mass of the fish.From Viazzi, Van Hoestenberghe, Goddeeris, & Berckmans, 2015.

2.2.2 Existing solutions in the market

To evaluate the potential and impact a system like the one being developed in this thesis could have, a study concerning products currently on the market had to be made.

YSI

YSI is a company with an extensive line of products already developed. The model YSI 5400A ("YSI 5200A,"n.d.[3] .) is the cheapest one (2000 euros). This product monitors and controls from any part of the world. Some of its advantages are:

- Feeding timer;
- Capacity to interact with other devices as a slave or master in a network of a maximum of 32 devices;
- Graphical interface that makes configuration easier;
- Alarms in the form of SMS and e-mail;
- 8 relays that can be connected to other devices. This is very useful and necessary for easy control and managing based on events;
- 8 Inputs for a selection of different sensors than can measure properties like pH, temperature, salinity, conductivity, ORP/Redox, dissolved oxygen, dissolved solids and others.

[3]last accessed on 08-06-2015 in [https://www.ysi.com/5200A]

Figure 2.10: YSI 5200A product. From"YSI 5200A,"n.d..

In-Situ

In-Situ is a company known for various water related products, but recently it has grown into the aquaculture industry. One of their products is a floating device that gathers all kind of data from the water, In-Situ's Aquaculture Pond Buoy. Following actual customer feedback, this is very useful in large lakes or aquaculture structures thanks to the drifting and easy portability of this device that cuts down on labor, transportation and energy costs. The buoy has a price of approximately 2000 euros like the previously mentioned model ("Aquaculture Pond Buoy - In-Situ"n.d.)[4]. Some advantages are:

- Measurement of dissolved oxygen and temperature;
- Autonomous sensor cleaning system;
- Solar panel that provides all the required energy;
- Wireless module that allows all the data to be sent to a PC.

[4] last accessed on 08-06-2015 in [https://in-situ.com/products/aquaculture-management/fish-pond-management/aquaculture-pond-buoy/]

Figure 2.11: In-Situ's floating solar powered data station. From "Aquaculture Pond Buoy - In-Situ"n.d..

Seneye

Seneye has developed a low cost product (150 euros)that might not be as robust as the others presented above, but it's size means it can also be used for aquariums.. Some of the characteristics are ("Aquarium monitor system - Fish Tank water sensor - seneye," n.d.)[5].

- pH and temperature measurement;
- integrated LUX, Kelvin and PAR light meter;
- Theoretical ammonia concentration calculator;
- Hour to hour readings with alarms via sms or e-mail;
- Very interactive graphical interface were you consult all kinds of charts related to the data gathered over a span of 30 days.

Even though the price is quite eye-catching for all the positive aspects, to make the pH readings regularly, there is a card slot in the equipment that has to be changed monthly.

[5] last accessed on 08-06-2015 in [http://www.seneye.com/devices/seneye-home]

Figure 2.12: Seneye's aquarium data gathering product.From "Aquarium monitor system - Fish Tank water sensor - seneye," n.d..

2.3 Required features of the system to be developed

It is possible to conclude that the impact and growth of aquaculture is only increasing. This can only be an incentive to create and improve aquaculture control systems that are safe, practical and economically viable. And preferably applicable in all kinds of aquaculture regimes.

For this thesis, the system developed will have to respect certain requirements like assuring water quality, data gathering and an alarm system to guarantee optimal conditions for life at all times.

Chapter 3

Proposed System

In this chapter, all the functions and obligatory features of the system will be specified. All components will together form the best solution possible.

3.1 General system overview

The main goal when developing an aquaculture system concerning survivorship of any given aquatic species, is to guarantee the quality of the water because it is the biggest factor concerning survival chances of any given water living species.

For that, a series of sensors and actuators will be used to guarantee the following conditions:

- Maintain temperature within a pre-established window of values;
- Maintain pH within a pre-established window of values;
- Maintain water level constant;
- All the required data must be stored in data-bases;
- Relays that can operate in synchrony with a given piece of equipment making it possible to add desired features to the system, like for example, a peristaltic pump.

Meanwhile, no system or piece of hardware is 100% reliable and for that reason this very same system must be able to warn a responsible person in case it is not possible to repair a given anomaly. For example, if by chance the readings for temperature go above the pre-defined value, then something is wrong and an immediate warning in SMS or e-mail form must be sent to someone who can rectify the situation before the survivability of the species is put at risk. No matter what hardware is used, the alarm system must work in this fashion: four alarms must be defined. Two that establish the desired temperature range of the water, and two others that define a larger window. Assuming the value for temperature is under the minimum defined for the first window, if it continues to go down, it means that the system failed to take action and if it reaches the minimum of the second window, the warnings must be sent immediately. This concept is represented in the figure below.

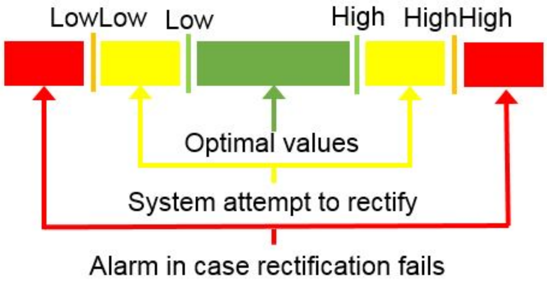


Figure 3.1: Alarm concept scheme.

Theoretically, with all the functionalities presented above fully functional, it is possible to have a system that takes care of everything without a regular intervention of a human. The person responsible can always check the data stored online and be confident of a notification in case something out of the ordinary occurs.

The following figure shows a range of possibilities of different hardware and software and how they will interact.

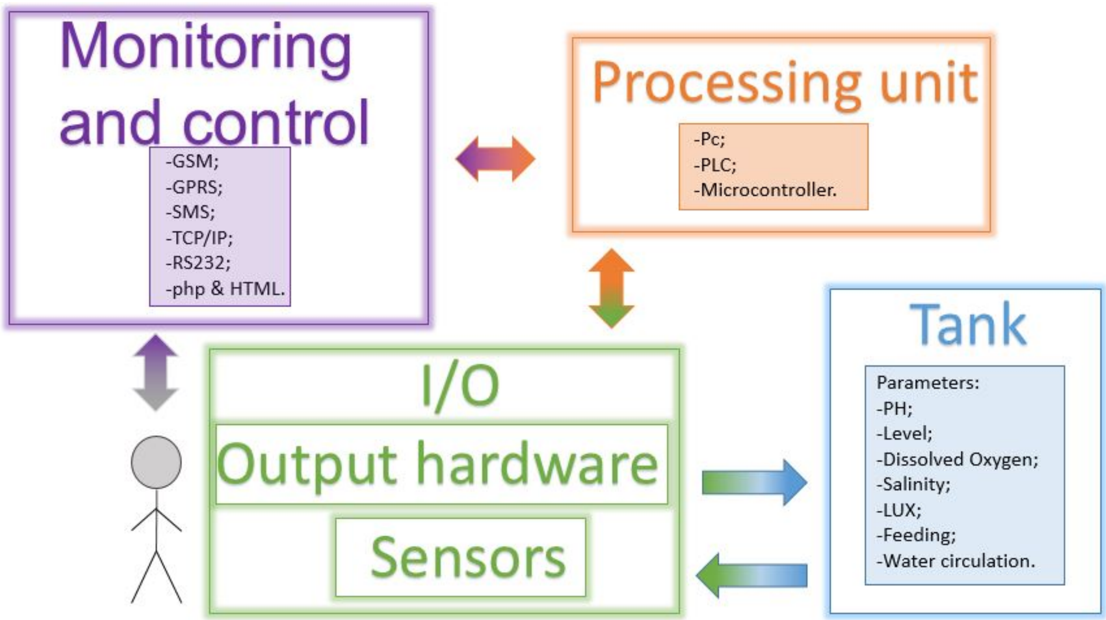


Figure 3.2: Scheme of proposed system.

3.2 Detailed description of the system

Based on the figure shown in the previous section, each one of the blocks will be described in detail.

3.2.1 Processing

Two components from the computing block were tested, specifically the PICS from the 16F and 18F family and also the ESP8266-12 module which is a microcontroller with integrated WiFi capabilities. In terms of features the ESP8266-12 far surpasses the PICS. Just the WiFi alone is a big bonus. The only problem concerning this hardware, was the fact that it is quite recent and not much has been done before. Some of it's characteristics are [1]:

- Has GPIO, I2C, ADC, SPI and PWM;
- Internal crystal of 80 MHz;
- 64 KBytes of instruction RAM;
- 96 Kbytes of data RAM;
- 64 KBytes boot ROM;
- 802.11 b/g/n protocol;
- Wi-Fi 2.4 GHz, support WPA/WPA2;
- Compatible with SDIO 2.0, SPI, UART and I2C;
- Power consumption inferior to 1.0 mW.

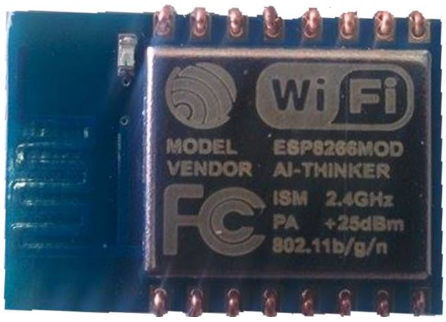


Figure 3.3: ESP8266-12 module used.

3.2.2 Control and monitoring

To be able to remotely control and monitor a system, it was necessary to make sure the following points were covered:

- Website to display data gathered and to set alarms;
- Website and database server host;
- WiFi connection to send and receive data;
- GSM module to be able to send alarms in the form of messages.

[1]last accessed on 22-10-2015 in [https://github.com/esp8266/esp8266-wiki/wiki]

Website

A website was needed so that any user could not only check the data obtained by the sensors but also define the alarms and duty cycles regarding the relays. Being able to do this online, means that you can do it from anywhere in the world. To create this website, the program WebMatrix[2] was used.

Figure 3.4: Main page of website created.

Hosting of website and database

All the data bases are up and running on a free server hosted by GearHost[3], that limits database size (5MB for the free edition).

When the PICs were being tested, a GSM module (SIM900A) was used to read and send data to the website. This no longer was necessary thanks to the WiFi capability of the ESP module. Even though the GSM module was not required, it is still used because it allows sending an SMS instantly when something fails.

WiFi connection

The WiFi connection was possible to achieve thanks to the chip chosen. The ESP module has that as a component in it's specifications and it makes the bridge between the hardware on the field and the website.

GSM module

The GSM module was the SIM900A, which is designed to be used in Asia. To work in Europe, the firmware had to be changed[4].

[2] WebMatrix is a free, lightweight, cloud-connected web development tool. http://www.microsoft.com/web/webmatrix/

[3] https://www.gearhost.com/

[4] The original firmware was replaced with 1137B01SIM900M64_ST_ENHANCE using the Series download Tools Develop 1.9 software.

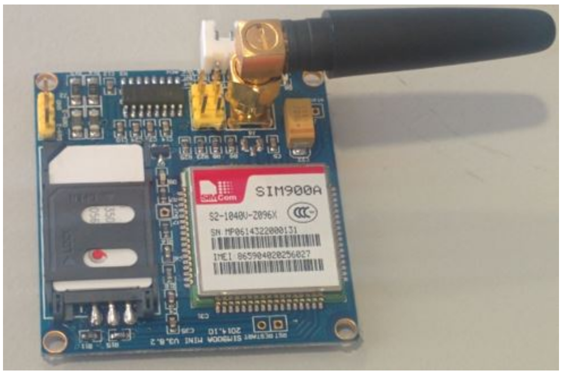


Figure 3.5: SIM900A module with a Portuguese sim card.

3.2.3 Sensors and output hardware

The sensors and output hardware are the the components that translate what happens physically to a language that the microcontroller can understand. The microcontroller can output a certain voltage that energizes a relay. This relay can be connected to any kind of hardware such as pumps, lights and heat sources.

Temperature sensor DS18B20

Temperature is one of the main factors when it comes down to assuring required living conditions of any species. Obviously, in a mariculture environment, one cannot control the temperature. However, in a tank based aquaculture system, temperature plays a role not only in survivability but also factors like artificial reproduction. Studies conducted, show that the efficiency of sex steroids used in artifcial reproduction varies depending on water temperature (Arantes, Santos, Rizzo, Sato, & Bazzoli, 2011).

The DS18B20 was chosen thanks to it's low cost, popularity and the fact that it is digital. Being a digital sensor just makes everything easier because the microcontroller has to interpret a digital word instead of input voltage. Some of its features are (Maxim Integrated, 2008):

- Power supply range is 3 V to 5 V;
- Precision of $\pm$ 0.5 °C when operating within a temperature range of -10 to +85 °C (extremely over dimensioned window);
- Programmable resolution between 9 and 12 bits;
- Converts the temperature to a digital word of 12 Bits in 750 ms (maximum).

Figure 3.6: Sensor DS18B20.

Differential pressure sensor MPX2010

The monitoring of the tank's water level is important. The oscillations are normally small because evaporation rates are not very significant. It is not possible to assure that a tank only will only lose water by evaporation. In the case of a leak for instance, the loss of water could happen at a much faster rate and a control system could interpret this situation as a dangerous one, hopefully sending out a warning in time for a repair.

For the level readings, the sensor MPX2010 was chosen. This is a differential sensor, which means that it has two tubes, and the difference of pressure between them can go up to 10 kPa, approximately the pressure of a column of water one meter high. This sensor generates an output voltage directly proportional to the pressure felt between the tube at atmospheric pressure and the one submersed under water. As we can see in the next figure, the variation is linear, where the corresponding output voltage is 0 mV when both tubes are at the same pressure and 25 mV if one were to exposed to air and the other one 1 m deep in water (Semiconductor, 2005).

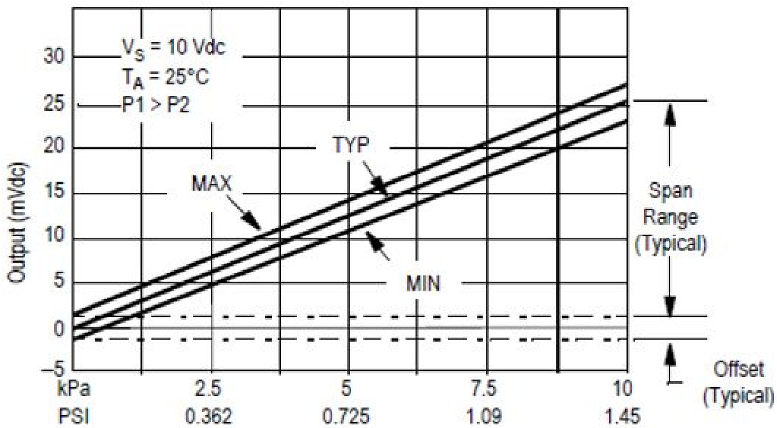


Figure 3.7: Output vs differential pressure of the MPX2010 (Semiconductor, 2005).

Some of it's technical characteristics are:

- Compensated temperature from 0 °C to +85 °C;
- Power supply range of 10 V to 16 V;
- Current: 6 mA;
- Sensibility: 2.5 mV/kPa.

To test the viability of this sensor, one of the tubes was submersed in water one week long to see if the output voltage would remain stable. A significant variation would not justify the loss of water by evaporation and the sensor would have to be discarded. The results obtained are shown in the following table:

Table 3.1: Table with obtained values to test the viability of the MPX2010 sensor.

Date,hour [day-month,time]	Output Voltage [mV]
07-05,17:41	4.5
08-05,20:20	4.5
11-05,19:19	4.4
14-05,20:06	4.3
16-05,02:00	4.2

The result was positive. Even though there was a variation of 0.3 mV, it was an expected one. Another good result was the fact that the output voltage did not increase, because this scenario would never happen considering that no water entered the bottle, which is not ideal.

The only problem of this sensor is that 25 mV is too small of a voltage to have a viable reading from the microcontroller. This signal has to be amplified so that readings can be obtained from 0 V to 1 V (maximum the ESP module can take at it's analog input).

pH sensor E201

The E201 pH sensor was ordered because it was by far the cheapest one in the market and good enough for the testing purposes of this thesis. This sensor is composed by an electrode and a circuit board that amplifies the signal.

The technical specifications[5] are the following:

- Heating voltage: 5 ± 0.2 V;
- Current: 5-10 mA;
- Detectable concentration range: PH 0-14;
- Test the temperature range :0-80 °C;
- Response time: ≤ 5 s;

[5] These specifications were supplied via email by the manufacturer.

- Stabilization time: ≤ 60 s;
- Component Power: ≤ 0.5 W;
- Working temperature: -10 ∼ 50 °C (nominal temperature 20 °C);
- Humidity: 95% RH (nominal humidity 65% RH);
- Lifetime: 3 years;
- Size: 42 mm x 32 mm x 20 mm.

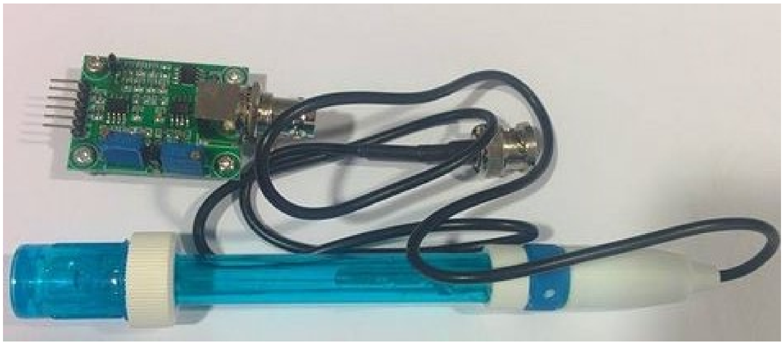


Figure 3.8: Picture of E201 pH sensor.

Solenoid valve

To guarantee the level of water in the tank, there must be a way to allow water to enter in a controlled manner. To do this a solenoid magnetic valve was used, more concretely, the MGV-FDZ4-1 model. This one in particular is normally closed and allows the passage of water when energized. Some of its features are ("MISOL DC12V Electric Solenoid Valve for Water",n.d.):

- Power supply: 12 V;
- Current: 240 mA;
- Operational between the pressure of 0.008 e 0.5 MPa;
- Operational between the temperature of 0 °C and 88 °C;
- Life: 70000 activations.

Figure 3.9: Solenoid valve. Picture from "MISOL DC12V Electric Solenoid Valve for Water",n.d.

.

Heat Source

The heat source used was built by VSI-THEM and is used in small aquariums. The heat source is up to the clients choice, the microcontroller outputs a signal to the relay. In this case the heat source can be supplied with a power from 220V to 240 and has 25W of power.

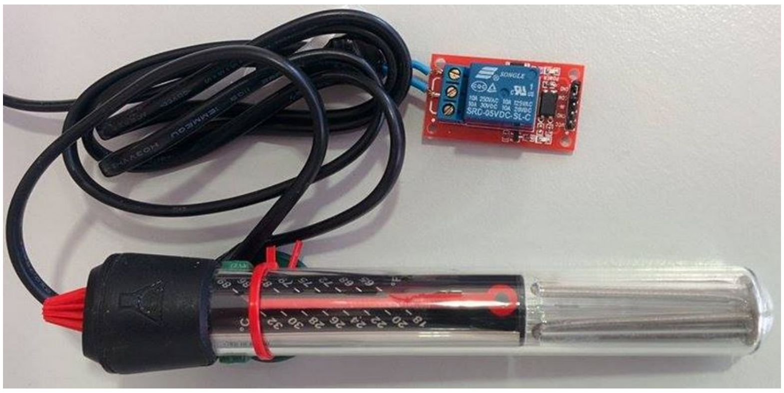


Figure 3.10: Heat source (picture of equipment used.

Other external hardware

Besides the external hardware mentioned previously, other elements such as filter pumps, oxygen pumps and peristaltic pumps can be connected to the relays. The microcontroller can then activate the relays according to the defined values. For this thesis these extra elements were not used because the equipment was simply not available. However, in no way does it affect the validity of this model.

Chapter 4

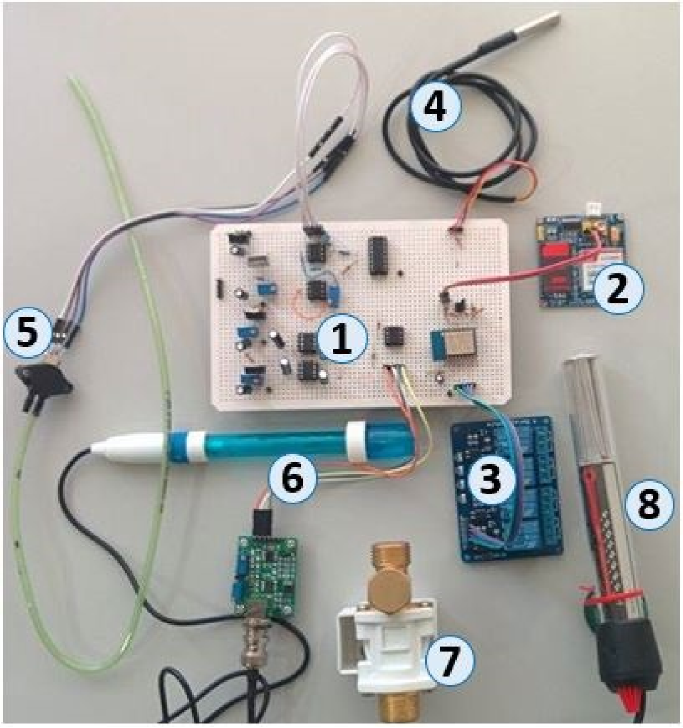
Implementation of the proposed system

In this chapter, the implementation of the hardware and its interaction with the software will be explained.

4.1 System implemented

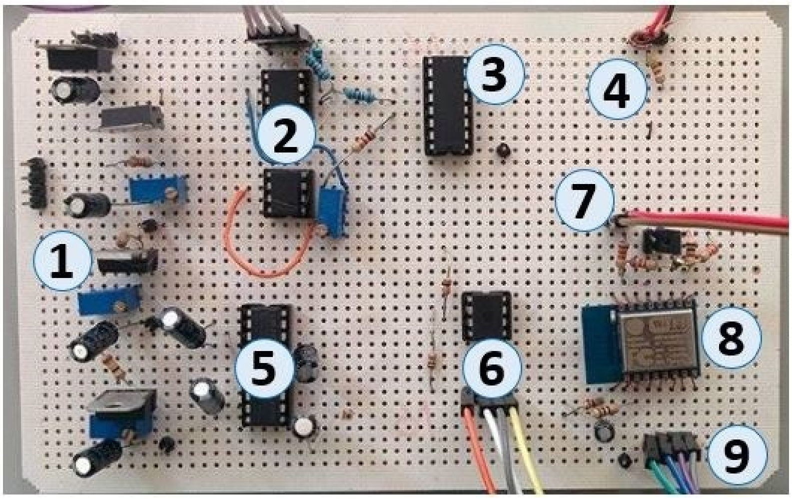
After choosing all the components that constitute the final solution, a PCB was designed to give the user a certain flexibility. This PCB contains all the circuits responsible for the power needed, all the inputs where the sensors are connected and outputs in forms of relays where you can connect all the external hardware. With a functional item like this one, the user can opt for different combinations of sensors and external hardware depending on the application.

The code stored on the module is ready to have all the functions working. However, there is a set of pins exposed so that the user can have the freedom of programming the ESP module himself/herself. The RS232 port is available also so the ESP and GSM modules can interact. Still here, the user could chose to not to have the GSM module connected and do something else with this port.



1 Circuit board prototype
2 GSM module
3 Relay board
4 DS18B20 sensor
5 MPX2010 sensor
6 pH sensor
7 Solenoid valve
8 Heat source

Figure 4.1: Early stages of developed system in the laboratory.



1 Power circuits
2 MPX2010 amplifying circuit
3 Multiplexer
4 DS18B20 circuit
5 Voltage inverters
6 pH sensor circuit
7 RS232 port
8 Heat source

Figure 4.2: Circuit board developed.

4.1.1 Powering the system

In terms of power it was necessary to look at all the components of the system and understand what the circuit would look like so it could power all the sensors, modules and external hardware. The required voltages are -10, -5, 3.3, 5, 10 and 12 V.

Components

The following components were used:

- MC7812CT voltage regulator;
- 3 x LM317 variable voltage regulators;
- 2 x MAX660 voltage inverters;
- Resistors: 1 x 240Ω, 1 x 330Ω and 1 x 3.3kΩ;
- 3 x 5kΩ potentiometers;
- 3 x 1μF and 4 x 10μF electrolytic capacitors.

The LM317 voltage regulators use a combination of resistor and potentiometer to adjust the exact voltage output. This formula shows how the output is calculated:

$$Vout = (1 + (R2/R1))$$

Electronic schematic

When powering the system, special care needs to be taken so the the input voltage does not exceed the 30V, maximum that the MC7812CT can tolerate.

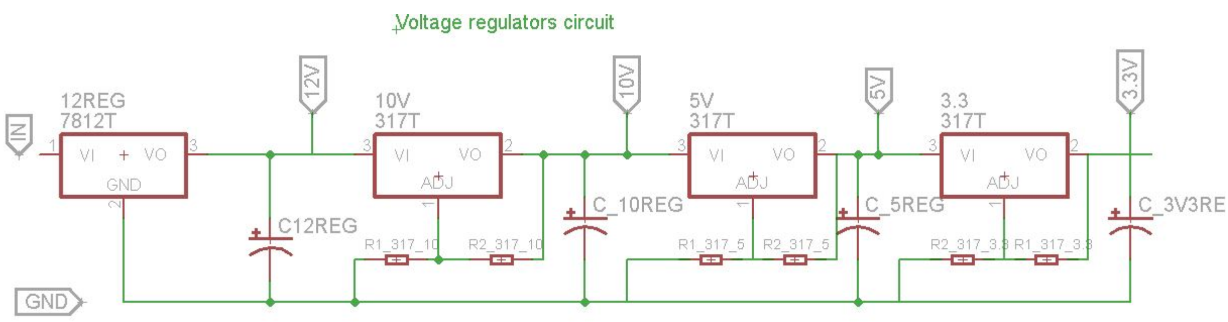


Figure 4.3: Electronic schematic of the powering circuit for positive voltages.

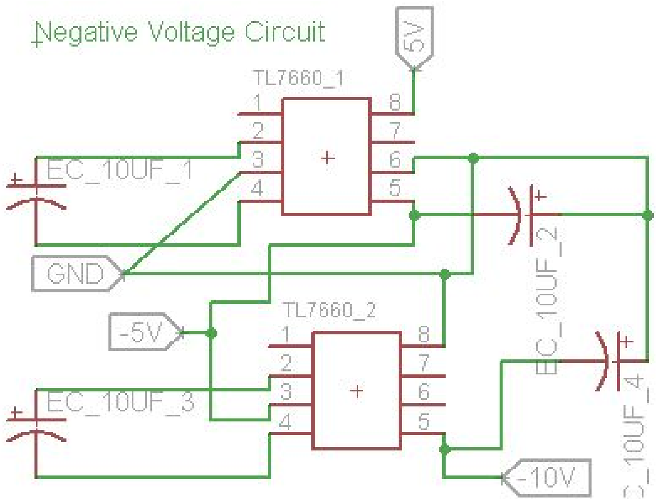


Figure 4.4: Electronic schematic of the powering circuit for negative voltages.

4.1.2 ESP8266-12 module

The ESP8266-12[1] module requires several connections besides the traditional VCC and GND, as it is possible to observe in figure 4.5.

Also, it is possible to see that there is a resistive divider (R14, R15 and R16), applied at the RS232 port because most of the USB to TTL Serial cables send signals of 5 V, which is too much and could damage the ESP module.

Some of the digital pins are connected to relays because they were the chosen ones to work as outputs in conformity with the code to activate external hardware.

The led was integrated for debugging purposes and can also be used in a different way if the user wishes to do so.

Components

The components used were:

- Resistors: 1 x 100Ω, 1 x 1kΩ and 1 x 10kΩ;
- 1x 0.1μF electrolytic capacitor;
- 4 x SRD-05VDC-SL-C relays.

[1]The information regarding how this module works was all found on this open source community website: last accessed on 29-10-2015 in [https://github.com/esp8266]

Electronic schematic

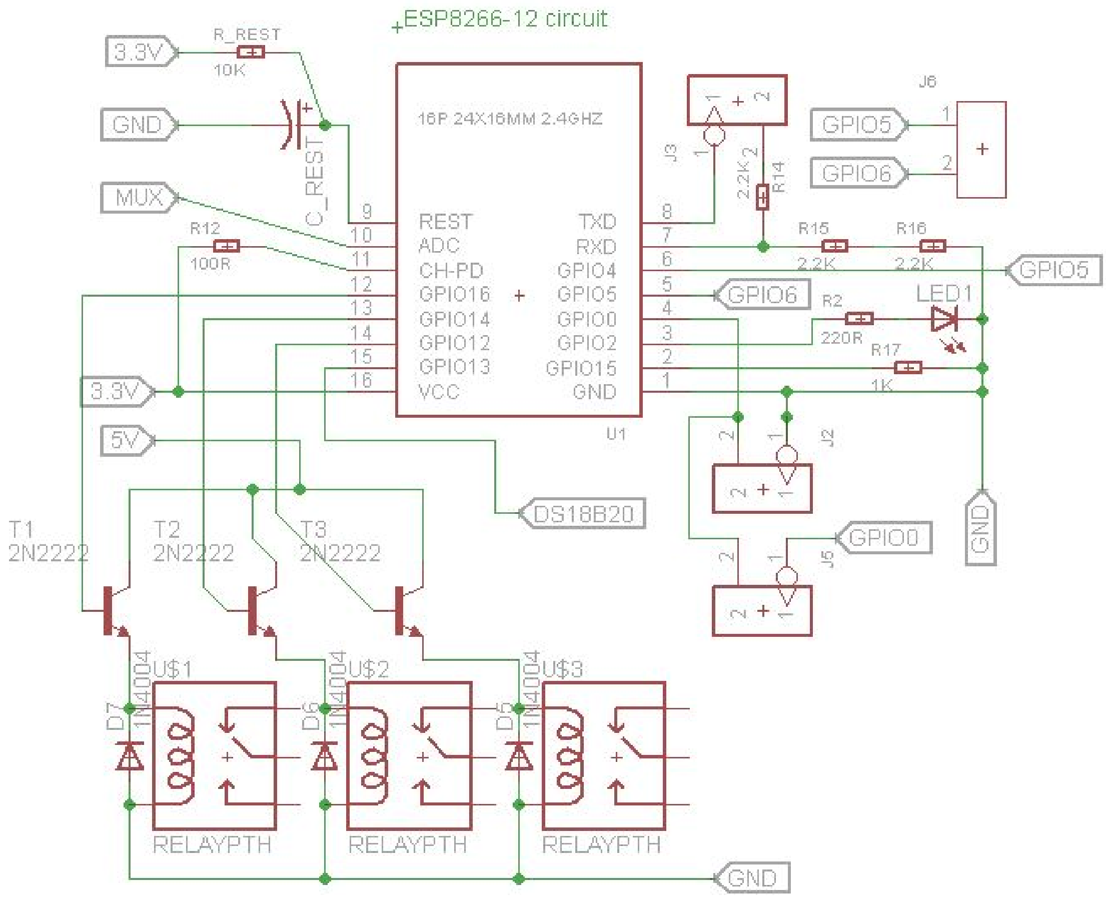


Figure 4.5: ESP8266-12 electronic schematic.

The ESP module, having only one analogue channel, could not have both pH and level sensors connected. To solve this problem, a multiplexer was used in order to pick which sensor to read. The MAX383CPE has a double 2:1 configuration, with only one being necessary. To pick which sensor's signal is passing through the multiplexer into the ESP module, a digital pin(GPIO0) has to be activated.

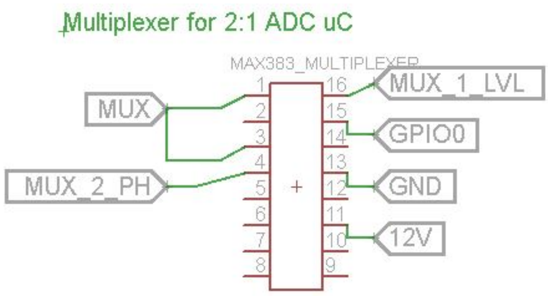


Figure 4.6: Multiplexer electronic schematic.

Code

Initially, the code was being written in Lua language. For some reason the module would crash after a few attempts at running the same cycle. Then a transition was made to C/C++, using the arduino IDE. This alternative was much better. Firstly the module did not crash at all, and it also is a much more familiar way of coding.

The following scheme demonstrates how the code is performing the operations.

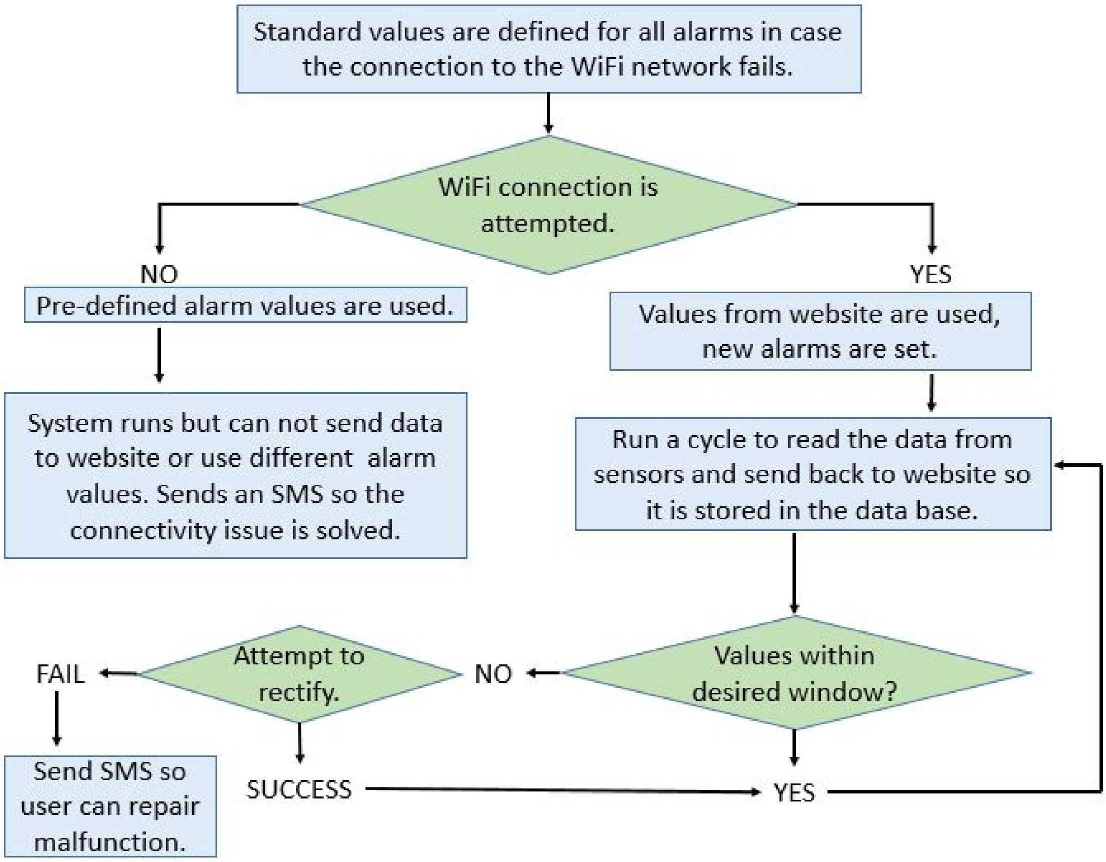


Figure 4.7: Code logic scheme.

4.1.3 DS18B20 Temperature sensor

To obtain the temperature it is necessary to send a set of commands in a certain order. The communication protocol used to achieve this, is OneWire, similar to I2C but with lower rates of data and longer reach. These are the commands sent to the sensor (Maxim Integrated, 2008).

1. Reset - master sends reset pulse;
2. CCh - SKIP ROM;
3. 4Eh - WRITE SCRATCHPAD;
4. 3 data bytes (TH, TL e config);

5. Reset - master sends reset pulse;
6. CCh - SKIP ROM;
7. BEh - READ SCRATCHPAD;
8. Reset - master sends reset pulse;
9. CCh - SKIP ROM;
10. 48h - COPY SCRATCHPAD;
11. A pull-up is applied while the process finishes.

Components

The only component that complements the sensor is a 4.7kΩ pull-up resistor.

Electronic schematic

The sensor is not actually represented. However the VCC, GND and Data cables of the sensor simply connect to the J7 jumper.

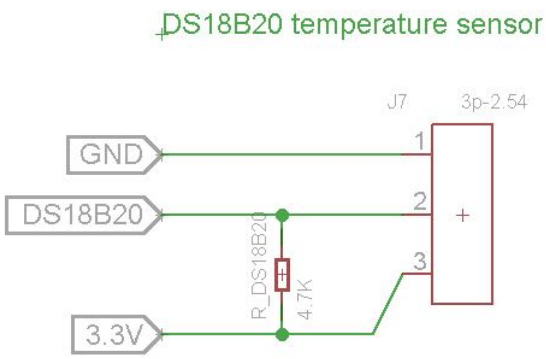


Figure 4.8: DS18B20 electronic schematic.

4.1.4 E201 pH sensor

This sensor generates a variation of voltage of -59mV per unit of pH from 7 to 0, and +59mV per unit of pH from 7 to 14 pH. However, the output voltage of the circuit is variable, and can be set to 3V to 5V (plus the variation per unit of pH). The problem here is the analog channel of the ESP module only tolerates up to 1V . So, in order to be able to make the pH readings, a circuit had to be designed.

The AD623 differential amplifier was chosen for this circuit.

By setting the pH sensor base output voltage to 3.71V (3.3V+ 7x0.059V),the difference between the sensor output and 3.3V at pin 2 and 3 respectively, of the amplifier, means the difference will always range from 0 to 826mV, as shown in figure 4.7. This is a perfectly readable value for the ESP module, yet it can still be amplified so that it can range form 0 to 1000mV. To do this the following formula was used, where G stands for gain and RG the value of the resistor to use (Analog Devices, 2008):

$$G = 1 \div 0.826 = 1.2$$

$$RG = 100k\Omega \div (G - 1)$$

$$RG = 100k\Omega \div (1.2 - 1) = 500k\Omega$$

A 1MΩ potentiometer was used to adjust the gain precisely.

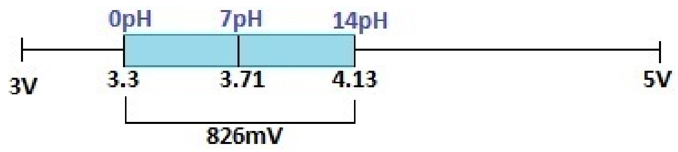


Figure 4.9: Scheme that illustrates the choice of base output voltage.

Components

The components used were the following:

- AD623 differential amplifier;
- 2 x 10kΩ resistors;
- 1 x 1MΩ potentiometer.

Electronic schematic

The circuit board that comes with the electrode is not represented in this electronic schematic.

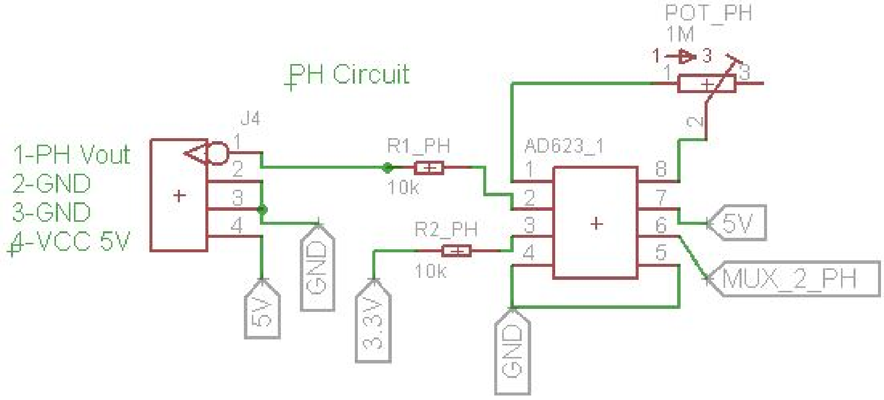


Figure 4.10: Electronic schematic for the pH sensor.

4.1.5 MPX2010 differential pressure sensor

As mentioned before, the MPX2010 sensor has a differential output voltage of 0mV to 25mV. Given that the analogue input can tolerate a maximum of 1V, the signal can be amplified 40 times ($1V/25mV$).

In this case, the sensor is differential because the level is proportional to the voltage difference between two of the sensor's pins. In this case, two uA741 differential amplifiers were used. One to isolate the differential voltage generated and another to amplify this very same voltage related to ground, around 40 times.

Components

The components used were the following:

- 2 x uA741 differential amplifiers;
- 1 x 1kΩ 4 x 10kΩ resistors;
- 1 x 5kΩ potentiometer.

Electronic schematic

Once again, the sensor is represented as a jumper. The only requirement is connecting the sensor to it.

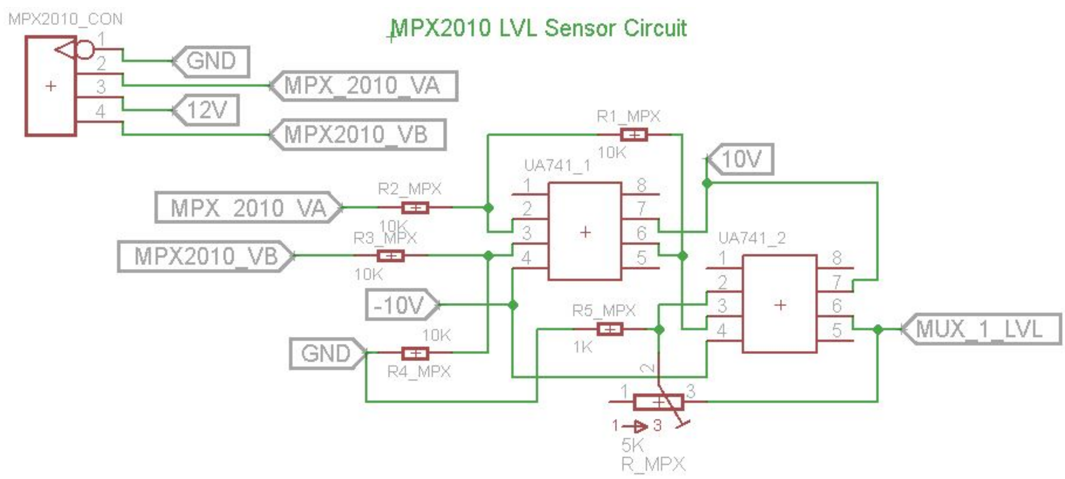


Figure 4.11: Amplifying circuit schematic for the MPX2010 sensor.

4.1.6 Sim900A GSM module

As shown in figure 4.6, the GSM module will only perform an action when something catastrophic (like the failure of a heating resistance) happens. This GSM module communicates with the ESP module via the RS232 protocol.

This module will operate according to AT commands that it receives (Datasheet SIM900A, 2009).

Figure 4.11 shows a more complex example of the first time data was successfully updated to the website via the GSM module not using the ESP WiFi capabilities. Sending an SMS is quite simple, but this example was chosen because it could be a solution in case the system developed were to be placed somewhere far from any WiFi spot, like offshore for instance.

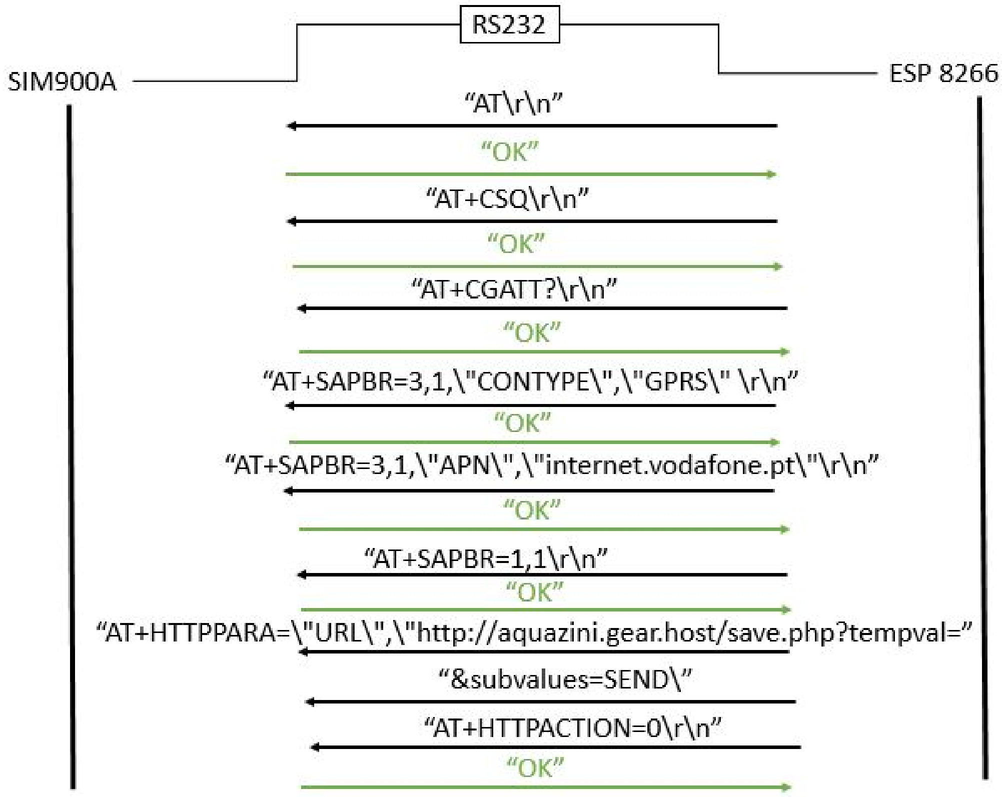


Figure 4.12: Uploading data to website with the GSM module.

One thing to note are the OK responses by the SIM900A module. These are very important, because they are the only way debugging can be done. If one command fails, the message or data upload will also fail. So making sure the OK is received is the main condition before sending any AT commands back.

4.1.7 Website developed

One of the most important parts of this project is the website. Without this element, the whole remote system would make no sense.

The website was build based on .cshtl, .php and .css files. Besides the main page shown in figure 3.4, there are 3 pages accessible:

1. Page that exposes the data stored in the database gathered by the sensors;

2. Page that exposes the last alarms defined;

3. The alarm definition page.

Date	Temperature	pH	Level
2015-09-01 11:52:04	16	6.6	87
2015-09-01 11:52:49	15	5.9	87
2015-09-01 11:53:14	15.7	6.2	86
2015-09-04 09:42:16	15.6	6.5	86
2015-09-04 09:42:46	15.7	6.4	87

Figure 4.13: Data stored and exposed on website.

Date	Temperature High high	Temperature High	Temperature Low	Temperature Low	Level High High	Level High	Level Low	Level Low Low	pH High	pH Low	Light System	Oxygen Pump	Filter Pump	Peristaltic Pump
2015-09-04 09:48:31	21.0	20.0	18.0	17.0	90	87	84	80	8.0	6.0	50	100	100	5

Figure 4.14: Last alarms defined website page.

Define tank setpoints

Temperature high high (ex: 21.5, oC)

Temperature high (ex: 20.5)

Temperature low (ex: 18.5)

Temperature low low (ex: 18.0)

Tank level high high (ex:90, %)

Tank level high (ex:87)

Tank level low(ex:85)

Tank level low low (ex:81)

pH high (ex:8.5)

ph low (ex:6.5)

Light system duty cicle (ex: 50 , 12 hours on during day =50%)

Oxygen Pump (ex: 100 , whole day on = 100%)

Filter Pump (ex: 100 , whole day on = 100%)

Peristaltic Pump (ex: 5 , 5 seconds ON/day)

SEND

Figure 4.15: List of all possible alarms that can be defined on the website.

4.2 Final PCB and production

The final task was to design a PCB for a possible production phase and estimate the cost that would be associated with the production of 500 units. [2].

Table 4.1: Price table of components.

Component	Price [euros]
ESP8266-12 x 500	1500.00
PCB x 500 (SEEED)	866.75
Resistors x 7500 (KOA Speer)	15.00
SRD-05VDC x 2000 (Song Chuan)	994.00
1N4004 x 2000 (Fairchild Semiconductor)	54.00
2N2222 x 4000 (Central Semiconductor)	1580.00
UA741CP x 1000 (Texas Instruments)	180.00
685CKH050M x 4000 (Cornell Dubilier)	84.00
LM317KCSE3 x 2000 (Texas Instruments)	580.00
AD623BNZ x 500 (Analog Devices Inc.)	1840.00
MAX660CPA+ x 1000 (Maxim Integrated)	3030.00
3296W-1-104LF x 2000 (Bourns)	2160.00
Cost per unit	25.76
Total cost per 500 units	12833.75

Neither the price of sensors nor work hours is considered in these values.

[2] Mouser [http://eu.mouser.com/] and Seeed [http://www.seeedstudio.com/service/index.php?r=pcb] websites were used for estimation. Last accessed at 30-10-2015

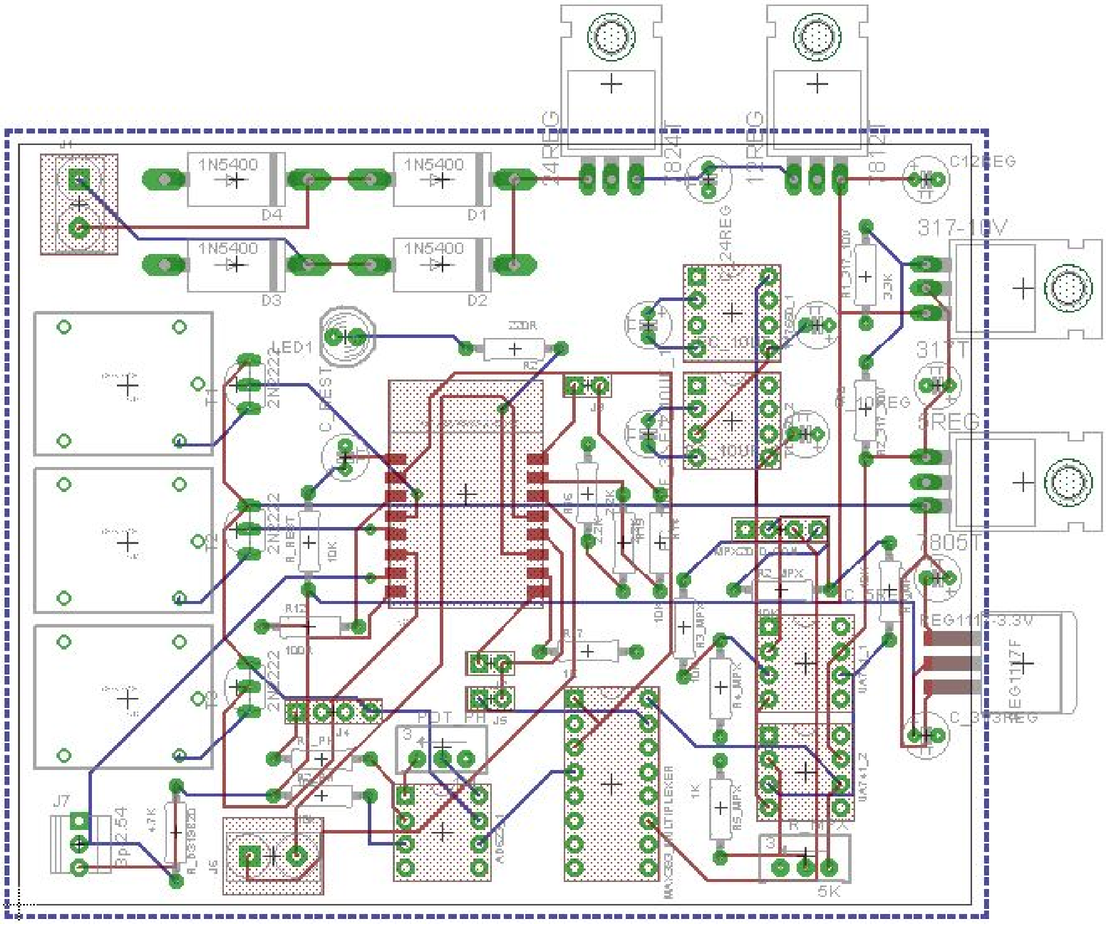


Figure 4.16: PCB design.

Chapter 5

Discussion

In this chapter, an overall view of the thesis will be made with the goal of criticizing the work done for future improvements and reflection on the positive aspects.

5.1 Discussion

After obtaining the final prototype, it is possible to say this system has achieved the initial goals proposed. It not only assures minimal water conditions (considering the available sensors and external hardware), but its surprising flexibility makes it an interesting product. Flexibility because it allows one to connect four different external devices to the users choice, a temperature sensor and a choice of two different analogue sensors, that in this case were pH and water level.

Capabilities such as GSM, WiFi and having an online platform makes controlling and monitoring an easy task, crucial in this business branch. The GSM capability also allows any given person to use the system in a place where internet is not available.

The final product could fit entirely in a 10x10cm PCB board, at an affordable price considering the full package of features. This also means that this device could be a solution for many aquarium lovers.

The world is changing at a fast pace. Solutions and improvements have to be found. Over fishing and population increase are two main reasons why capture production is starting to get stagnant and aquaculture production increasing. If that is the case, then there will always be room to improve aquaculture productivity. Like that, automation enters the cycle. Systems like the one developed in this thesis are just a small contribution to the development of aquaculture.

5.2 System limitations

The system is quite limited when it comes to sensor capability. One analogue port is not sufficient. Opting for a multiplexer fixed the problem, but the increase of cost with that came with this addition was not ideal, and adds another component that could fail, consequently complicating the system. For this reason, there are many missing sensors this system could have.

The website can be improved greatly in order to see actual graphs. The treatment of data is very important, and having simple tables to observe all the data does not do the system justice. A smart interface with charts, scrolls and colors, could help data interpretations significantly.

The final prototype is not the PCB version. Having a PCB version done, it would be very interesting to test the system under realistic working conditions in a commercial aquaculture facility like AquaCria.

5.3 Future Improvements

Having the study of existing products in mind and the research projects, it is reasonable to assume that the ultimate component would encapsulate all those features. The problem with something such as that, is at what point to draw the line between an item that is simple to use and can be used in most environments, from a hi-tech system that can fulfill all the needs but at much greater costs.

Following are suggestions for future improvements to the system:

- The website is very poor at the moment. To treat this kind of data, it is much easier to visualize it with graphs;
- Going for a full PCB version of the product;
- Incorporating a vision system. By doing this the price would go up significantly and would not be the most appropriate for all kinds of applications. This raise of price and complex feature, would not make so much sense for example, an aquarium. But aquaculture infrastructures could benefit greatly from this kind of technology;
- Incorporating monitoring and control over more than one tank;
- The implementation of an app could bring various advantages. Features like monitoring work done by employers (recording time and location of feeding) could not only help rate the work done by employers, but greatly improve food management;
- The system should have some kind of sound alarm in case it is used in a very tank concentrated room. This would make it easier to identify the tank having problems in case of an extreme problem (if one of many pumps in a room failed). Light systems could be used instead when dealing with noise.

Appendixes

Appendix A

Arduino IDE to program ESP8266

This feature was developed in order to program ESP modules in a familiar environment like the Arduino interface. The libraries available made the realization of this project much more simple, even covering deficiencies that other software like NODEMCU presented.

By following these steps you can then use the Arduino interface to program an ESP8266 module: [1]

- Install Arduino 1.6.5 from the Arduino website;
- Open Preferences window in Arduino;
- Enter http://arduino.esp8266.com/stable/package_esp8266com_index.json into Additional Board Manager URLs field. You can add multiple URLs, separating them with commas;
- Open boards menu and from tools select ESP.

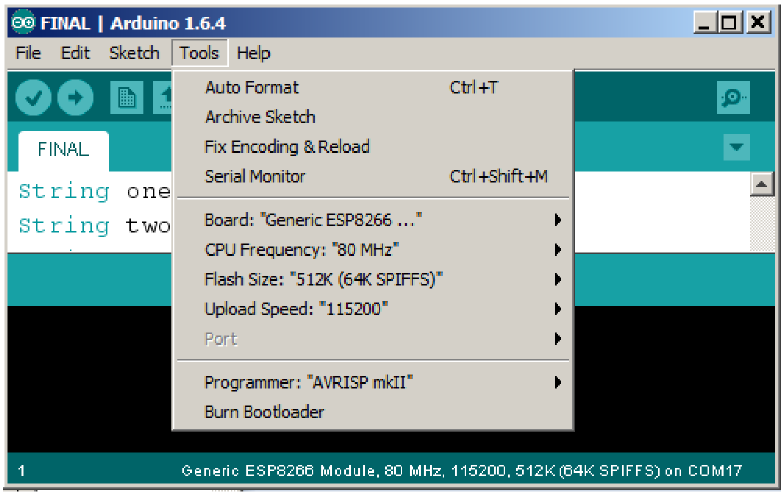


Figure A.1: Arduino IDE ready to program ESP module.

[1] A open source community webpage [https://github.com/esp8266/Arduino] last accessed 05-02-2016.

Appendix B

WebMatrix as webpage creator

WebMatrix is a great tool to create a website. It is very easy to use, integrating the hosting partnerships, the very smart and easy local preview, the database section and the possibility to create and program in all kinds of languages and formats.

It is very simple to make alterations after the website is published with the press of a button.

In my project these where the files created:

- Default.cshtml: file with the initial page information;
- inputvals.php: file that allows the insertion of data gathered by the sensors into fields;
- save.php: file that grabs sensor values and stores in database;
- tank1alarms.php: page where all the alarm values are defined;
- savetank1alarms.php: file that sends the alarm values defined by user to the a tank1alarms table in the database;
- tank1alarmstable.php: page that displays alarms defined online;
- tanks.css: style sheet for page;
- tank1data.php: page that displays a table with all the sensor values.

The database consists of two tables that were also created with WebMatix. One for the alarms defined and another for the values read.

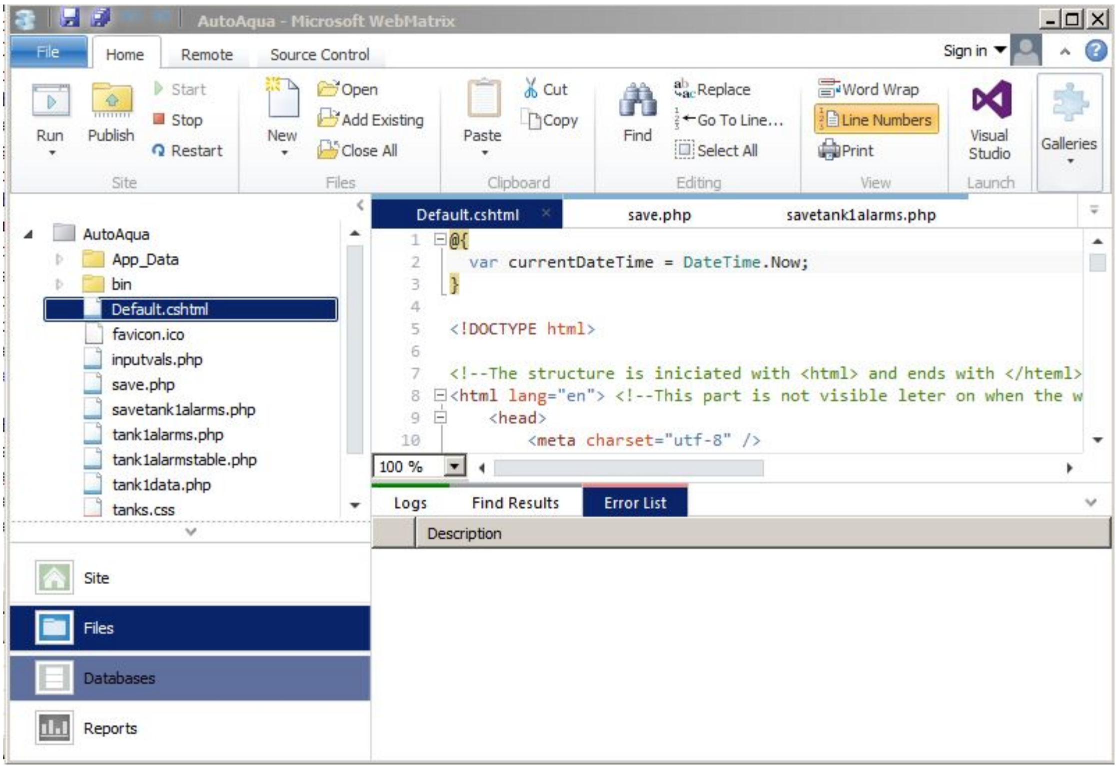


Figure B.1: WebMatrix interface.

Appendix C

Using sim900A in Europe

The sim900A can be achieved at a lower price with the downside of working only in Asia.

To use this device in Europe, it is necessary to change the firmware, and to do so you need the 1137B01SIM900M64_ST_ENHANCE and flash the device.

To flash the device you must connect the device to a computer and have SIM900 Series download Tools Develop 1.9 software installed.

Select the correct Port, a desired Baud Rate, the Core File (new firmware location) and Start Download.

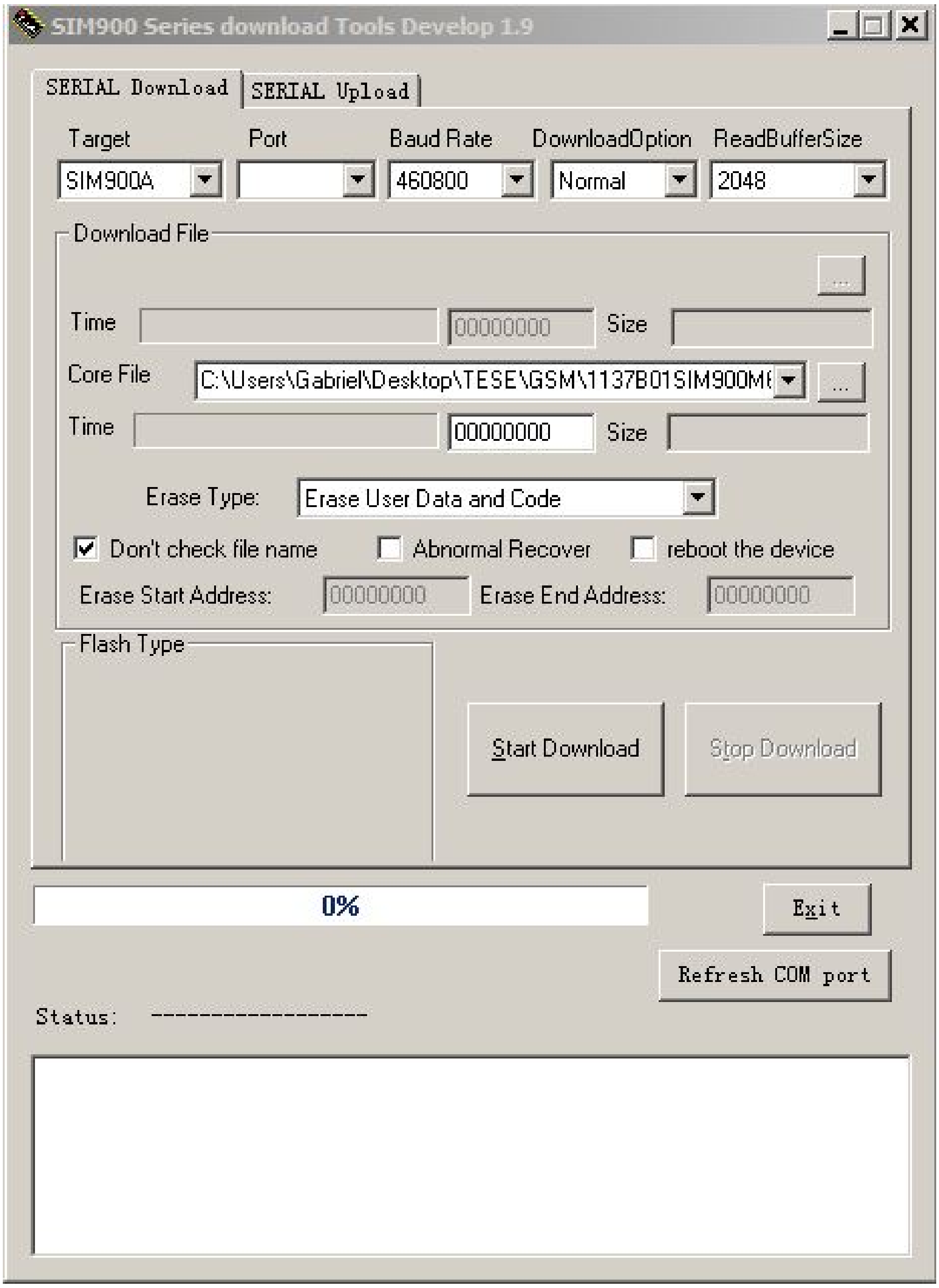


Figure C.1: Tools Develop 1.9 software installed interface.

Appendix D

Electric scheme

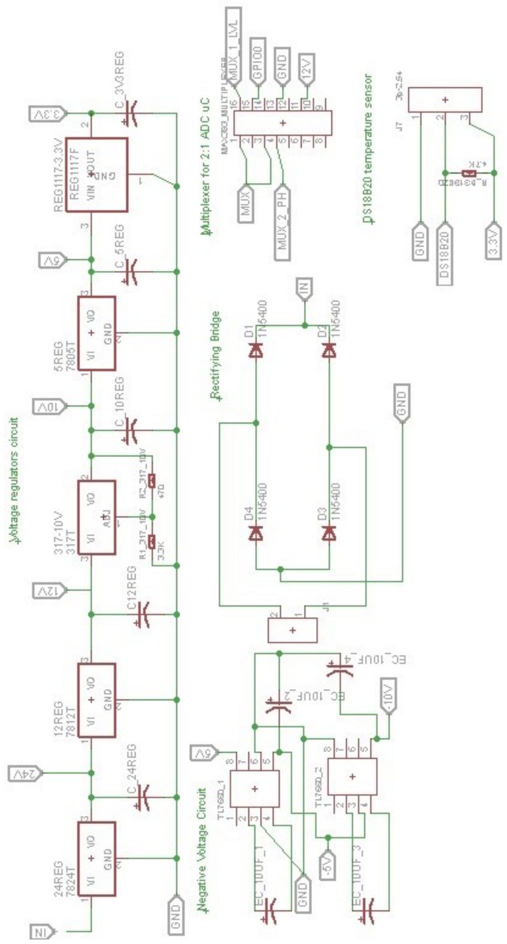


Figure D.1: Electric scheme part 1.

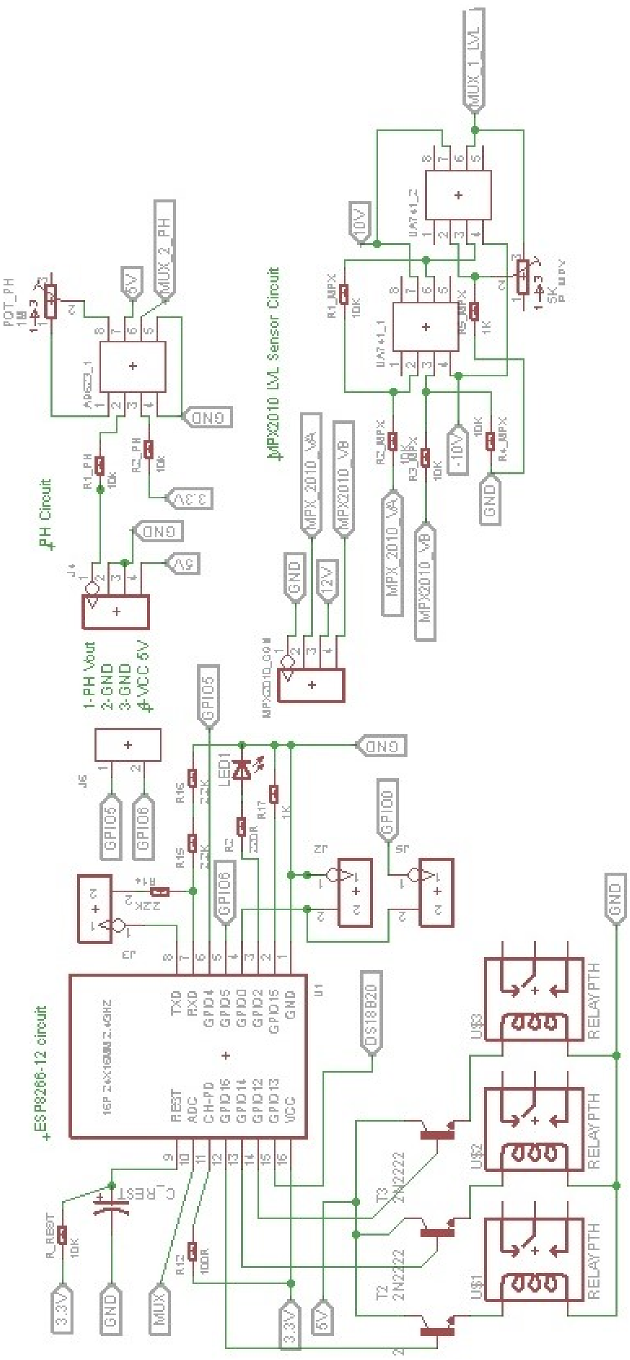


Figure D.2: Electric scheme part 2.

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