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Device for Characterization of Physical Contact of Fish in Aquaculture

Miguel Ramos Silva Costa Tenente

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Supervisor: José Carlos dos Santos Alves

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Resumo

Desde há muitos anos o peixe faz parte da roda dos alimentos do ser Humano. Logo, sempre existiu muito a cultura da pesca nos grandes oceanos e outros mares. Contudo, essa pesca tem-se tornado excessiva para conseguir corresponder a necessidade do aumento da população nas últimas décadas. Esta pesca excessiva trouxe um grande desequilíbrio da cadeia alimentar de muitas espécies. Isto traz percussões para o meio ambiente, e também para nós. Foi então assim que se decidiu criar as piscinas de aquacultura, onde fazem a produção de peixe em cativeiro de um modo sustentável. Contudo, a população em geral continua a procurar mais o peixe selvagem que o peixe de aquacultura, principalmente pelo seu sabor e tamanho.

É normal que existam grandes diferenças entre um peixe selvagem e um peixe de aquacultura. Sendo que um vive num espaço "sem fim", e o outro é limitado a uma piscina. Um vive num ambiente selvagem e de contacto com outras espécies, já os peixes de aquacultura apenas estão inseridos num ambiente próprio e isolado. Os biólogos acreditam que esse ambiente influencia os altos níveis de stresse dos peixes de aquacultura e consequentemente o desenvolvimento do seu corpo. Este projeto serve para fundamentar esta teoria dos cientistas e tentar criar um ambiente mais saudável para que os peixes de aquacultura de modo a que se tornem mais procurados pelo comprador.

O projeto desta tese consiste na criação um peixe idêntico a um Bodião-limpador, um peixe inofensivo para as outras espécies com a função de limpar a superfície de outros animais. Pretende-se que o design tenha uma figura atrativa para os peixes do ambiente onde vai ser inserido. Num momento em que haja uma interação, o protótipo faz a leitura de uma tag transponder passivo (PIT), que foi previamente implantada nos peixes em estudo. Complementa essa informação com o valor da aceleração do impacto dada pelo peixe, com o objetivo de diferenciar se o peixe identificado realmente entrou em colisão com o protótipo, ou se simplesmente se moveu nas proximidades do protótipo.

Para se conseguir este protótipo, foi necessário fazer o design do peixe na plataforma *Autodesk Fusion 360*, e posteriormente imprimir. Dentro da impressão da carapaça foram inseridas quatro antenas e um acelerómetro. As antenas têm o propósito de fazer a leitura das PIT tags, e o acelerómetro faz a medição da aceleração do impacto, no caso de haver uma. Toda a informação que vem dos sensores é lida por um sistema baseado num microcontrolador, em que posteriormente envia para por porta serie diretamente para um computador. O Computador por sua vez vai estar a correr um programa executável com a funcionalidade de ler a informação que recebe para aloca-la num ficheiro.

Abstract

Fish have been part of the Human food chain for many years. Therefore, fishing culture has always existed in the great oceans and seas. However, this fishing has become excessive in order to meet the needs of the growing population in recent decades. This overfishing has led to an imbalance in the food chain of many species. This has repercussions for the environment, and also for us. This is when aquaculture pools were created, where they produce fish in captivity in a sustainable way. However, the general population still looks more for wild fish than farmed fish, mainly because of their taste and size.

It is normal that there are big differences between a wild fish and an aquaculture fish. One lives in an "endless space", the other is limited to a pool. One lives in the wild and in contact with other species, whereas farmed fish are only in their own isolated environment. Scientists believe that this environment influences the high stress levels of farmed fish and consequently the development of their bodies. This project aims to support the scientists' theory and try to create a healthier environment for farmed fish so that they become more attractive to buyers.

The project of this thesis boils down to the creation of a fish similar to a Bluestreak Cleaner Wrasse, a harmless fish for other species with the function of cleaning the surface of animals. It is intended that the design has an attractive figure for the fish of the environment where it will be inserted. In a moment of an interaction, the prototype reads the Passive Integrated Transponder (PIT) tag that was previously inserted in the fish under study. It complements this information with the acceleration value of the impact given by the fish. This is to differentiate if the fish really hit the prototype, or if it simply passed by.

To achieve this prototype, it was necessary to design the fish on the *Autodesk Fusion 360* platform, and then print it. Four antennas and an accelerometer were inserted inside the print of the carapace. The purpose of the antennas is to read the PIT tags, and the accelerometer measures the acceleration of the impact, in case of having one. All the information coming from the sensors is read by an system based on a microcontroller, which subsequently sends it by serial port directly to a computer. The computer in turn will be running an executable program with the functionality to read the received data and allocate it in a file.

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O projeto aqui realizado não foi um trabalho de 6 meses, mas sim de um curso. Portanto, quero usar este espaço para agradecer a todos os envolvidos na minha vida académica.

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Miguel Tenente

"If you only do what you can do,
you will never be more than you are"

Mestre Shifu, Kung Fu Panda 3

Contents

1 Introduction **1**
1.1 Context . . . 1
1.2 Motivation . . . 2
1.3 Goals . . . 2
1.4 Document Structure . . . 3

2 Literature Review **5**
2.1 Introduction . . . 5
2.2 RFID . . . 5
2.2.1 PIT tag . . . 8
2.3 Related Projects . . . 10
2.3.1 Estuarine fish movement . . . 12
2.3.2 Ornithological Research . . . 13
2.3.3 Summary . . . 14

3 Development **15**
3.1 Hardware . . . 15
3.1.1 Components selection . . . 15
3.1.2 3D Design . . . 20
3.1.3 Final Assembly . . . 21
3.1.4 Block Diagram . . . 24
3.1.5 Challenges and Solutions . . . 25
3.2 Software . . . 25
3.2.1 Arduino . . . 25
3.2.2 Data Collection . . . 31

4 Results **33**
4.1 Setup . . . 33
4.2 Final Results . . . 34
4.2.1 Fish Weight Results . . . 35
4.2.2 Daily Results . . . 36
4.2.3 Day Parts Results . . . 37
4.2.4 Threshold . . . 37

5 Conclusions and Future Work **39**
5.1 Conclusion . . . 39
5.2 Future Work . . . 39

A Results Analysis Tables **41**

References **43**

List of Figures

2.1 RFID system structure [1] 6
2.2 PIT tag hardware [2] 9
2.3 PIT tag to be used 9
2.4 A schematic illustration of the project [3] 13
2.5 Bird feeding project [4] 14

3.1 LID650V40 decoder and the Power Supply [5] 17
3.2 ADXL345 17
3.3 Antenna 18
3.4 Antenna field lines [6] 19
3.5 Experimental Setup 20
3.6 3D Shape 20
3.7 Final 3D design 21
3.8 Final Result of the 3D Print 21
3.9 Assembly inside the fish 22
3.10 Fixing the two shells 22
3.11 Fitting the heat-shrink sleeve 22
3.12 Fish painting 23
3.13 Box Assemble 23
3.14 Block Diagram 24
3.15 Excerpt from the `accelerometer` function 26
3.16 Excerpt from the `accelerometer` function 27
3.17 Acceleration module graph 27
3.18 Derivative graph of the modulus of acceleration 28
3.19 Test to determine threshold 28
3.20 Excerpt from the `reader` function 29
3.21 State Machine 30

4.1 Setup in the fish tank 33
4.2 Sample of Data Collection 34
4.3 Graph with the final values 35
4.4 State Machine 38

List of Tables

2.1 Frequency Bands and Applications 6
2.2 Passive and Active RFID comparison [7] 7
2.3 RFID tags classification [8] 8
2.4 The use of PIT tags and its application [9] 11

3.1 Registers for each axis [10] 26
3.2 Sensibility table [10] 26

4.1 Daily results above the average 36
4.2 Daily results below the average 36
4.3 Day parts results 37

A.1 All findings 41
A.2 Final results 41
A.3 Accelerometer values 41

Symbols and Abbreviations

FDX	Full-duplex
HDX	Half-duplex
IMU	Inertial Measurement Unit
LF	Low Frequency
PCM	Physical-Contact Machine
PIT	Passive Integrated Transponder
PLA	Polylactic Acid
RFID	Radio Frequency Identification
RTLS	Real-Time Accurate Location System
SM	State Machine
SCL	Serial Clock
SDA	Serial Data
SDG	Sustainable Development Goals
UN	United Nations

Chapter 1

Introduction

This chapter will identify the problem and its context, the goals to be achieved, and the motivations behind the project. This chapter will also provide the thesis structure.

1.1 Context

In the eyes of many, fish have always been considered simple organisms with low complexity in terms of their nervous system and behaviour. However, recent studies have demonstrated that fish not only interact within their shoals or as a response to stress, but they also have the ability to negotiate social transactions throughout their life cycle.

Consider the textbook example: the case with the cleaner fish-client fish mutualistic relationship, where the the cleaner fish finds a food source in the client fish's dead skin and parasites, whereas the client fish finds a means of hygiene in the cleaner fish. Even in the absence of deworming, there is a positive stimulus associated with the tactile stimulation of the cleaner fish towards the client fish.

This project's goal is to investigate the client fish's demand for social contact during cleaning interactions, not as a complementary benefit, but as a main source of reward.For this purpose, the development of a Physical-Contact Machine (PCM) was idealized to act as a cleaner fish. The PCM will integrate an accelerometer and PIT tag reader antennas. The integrated accelerometer will determine whether or not the client fish have interacted with the PCM by measuring the variation of acceleration in all its axes upon impact. The antennas will be placed alongside the bottom of the PCM fish, to identify which fish have come near it. Finally, the client fish will be tagged near the dorsal fin with PIT tags beforehand. Under these conditions, it will be possible to determine which fish only approach the PCM and which ones touch it. This will be helpful to create a database for easier interpretation by marine biologists in the study of mutualistic relationships in aquaculture fish.

In short, the aim is to achieve a prototype that can characterise the physical contacts of aquaculture fish. To this end, a 3D printed design of a cleaner fish will be created. Inside this shell will be included antennas and an accelerometer. The antennas will serve to read tags that will be

implanted in the fish, and the accelerometer is to define if there was really any interaction by the fish. All this information will be sent to and processed by a microcontroller, which will then send all the necessary information to a computer. In turn, the computer will store all the information collected in a file, to be analysed later.

1.2 Motivation

Climate change is the most pressing concern to life in Planet Earth for our generation and many to come. As such, the United Nations (UN) have set 17 Sustainable Development Goals (SDGs) that member states have committed to meet by 2030. Naturally, some of these SDGs aim towards conservation of the environment and preservation of species. Upon reviewing all SDGs, Goal 14 particularly stands out for this thesis: "Conserve and sustainably use the oceans, seas and marine resources for sustainable development"[11] [12].

Industrial fishing has a deep negative impact to aquatic life, and consequently to all life on Earth. This industry removes 93 million tons of food source from long established food chains [13], often times at a rate that does not allow for sustainable replenishment of fisheries. Furthermore, the growing world population and increased food requirements [12] keep putting pressure on the industry to continue its unsustainable fishing practices, creating irreversible unbalances in ecosystems that depend on aquatic life. Fish aquaculture has been deemed a possible solution to mitigate the impact of industrial fishing. However, that has not been enough, as the consumer still prefers wild fish for its characteristics (e.g. flavour and size).

This project aims to promote the production of aquaculture fish that closely resembles wild fish in terms of characteristics to influence consumer's choice to opt for farmed fish. Ultimately, this project may aide in the conservation and protection of our oceans by allowing life and nature to take the space it requires to thrive.

1.3 Goals

Scientists strive to understand if fish in an aquaculture environment seek out friendly interactions with fish of a different species, and if this helps to lower their stress levels. With that objective in mind, this project aims to aid said researchers by creating a prototype that aids in the collection of the necessary data to that end.

In order to meet the scientists' objectives, it is necessary to create a prototype that looks like a fish. This designed fish has to be able to take readings of PIT tags, and know if the read fish has touched it or not. And, at the end, it has to save all the information collected in a file. That file will be used by scientists to do their own analysis.

Concisely, this thesis has the following objectives:

- Create a design that looks like the fish that the scientists want;
- Read the PIT tags, implanted on the live fish;

- Know if the detected if the read fish has touched or just passed by;
- Record all the data and save it in a file.

1.4 Document Structure

Chapter 2 provides an overview on relevant topics regarding the project. These topics include how RFID technology works; what are PIT tags and their role in animal behavior study; finalizing with applications of the former technologies in animal studies.

Chapter 3 has the description of the development of the whole project. It starts by explaining and justifying the choice and assembly of all the hardware. Then it explains the work developed in the software area.

Chapter 4 shows the results of the tests made for the prototype. There is also a brief justification for these results.

To complete the thesis, the Chapter 5 concludes the dissertation by summarizing the key contributions provided, summarizing the work done, and some aspects that could improve the results. This chapter also presents some proposals for some improvements to do in future works.

Chapter 2

Literature Review

2.1 Introduction

To study and observe behaviour in biology it is necessary to identify each individual under study with tags. The most used tags are the Floy tag and the PIT tag. Floy tag is a highly visible tag that is attached to the back of the fish, such as a tag attached to a price label to a piece of clothing. On the opposite, the PIT tag is not visible because it is injected inside the fish, and can only be read by a magnetic reader. These tags are similar to those used by veterinarians to identify lost pets[14]. Each type of tag has advantageous or disadvantageous characteristics, depending on the application. For this project, the PIT tag is the most suitable option since it allows the creation of an autonomous data collection system.

As it was contextualized in the previous chapter, this project will focus in building a PCM. The PCM will integrate two components, which are an accelerometer and PIT tag reader antennas. In the following lines, it will be explained the key concepts for this project, that involved technologies and devices applied throughout the project. First, it will introduce the RFID technology and the reader, and then, the PIT tags. Finally, some projects that have a resemblance to this project and used similar technologies with other species.

2.2 RFID

RFID works for identification of items/objects [7]. Therefore, a Radio Frequency Identification (RFID) is, basically, a contact-less automatic identification technology, such as barcodes, magnetic stripe, etc. As the name states, this kind of technology uses radio waves to capture the data.

This technology was introduced in the 1940´s and 1950´s and has seen a drastic increase in the number of applications and implementations in the recent years. Some of the areas that have confirmed use of this technology are security, library, airline, military, animal forms, sports, and other areas. In this project, the technology will be used for engineering and biology purposes [7].

A RFID system consists of tags, antennas and readers. The tags store information that identifies people, animals, or objects, and the readers automatically collect it[15]. The tag is an integrated circuit which is attached to an antenna. It is worth to mention that the antennas are the first point of contact for tag readings [7].

The antennas are also connected to the reader. The way that the RFID system structure works is as follows: the reader sends a signal through its antenna, which supplies power and instructions to the tag. The tag transmits its ID to the reader and is consulted in an external computer to recognize the object. The Figure 2.1 shows in detail the whole process of identification [15] [1].

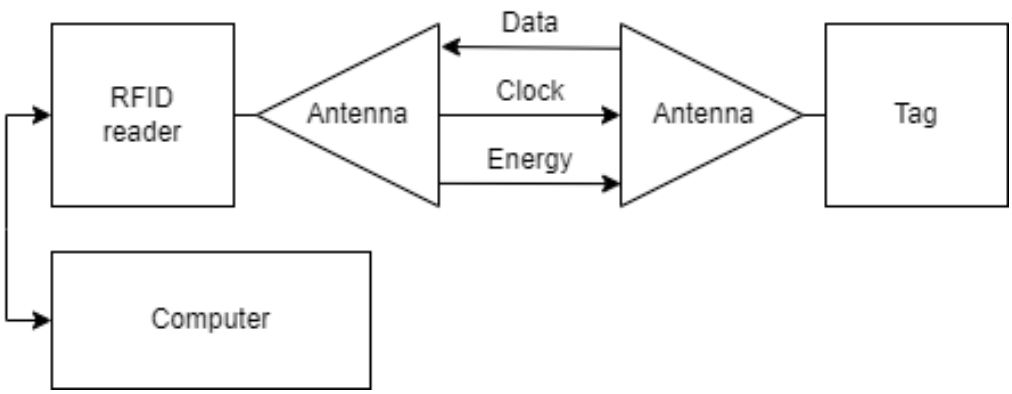

Figure 2.1: RFID system structure [1]

RFID system is based upon tags and reader´s communication and range of communication/reading depends on operating frequency. The frequency could be classified into high frequency, intermediate frequency and low frequency. The Table 2.1 shows the principal characteristics of each category and their applications [7].

Table 2.1: Frequency Bands and Applications

Frequency Band	**Characteristics**	**Typical Applications**
Low 100-500 kHz	Short to medium read range Inexpensive Low reading speed	Access control Animal identification Inventory control Car immobiliser
Intermediate 10-15 MHz	Short to medium read range Potential inexpensive Medium reading speed	Access control Smart cards
High 850-950 MHz 2.4-5.8 GHz	Long read range High reading sped Line of sight required Expensive	Railroad car monitoring Animal identification Toll collection systems

However, the main categorisation of RFID technologies is divided into two: Passive RFID and Active RFID. The principal difference between these categories is the passive tags do not require an internal power source, while the active tags are powered by internal batteries [15]. There are other differences between these two categories and can been seen in the Table 2.2.

Table 2.2: Passive and Active RFID comparison [7]

	Passive RFID tag	**Active RFID tag**
Power Source	External (Reader provided)	Internal (Battery)
Tag Readability	Only within the area covered by the reader, typically up to 3 meters.	Can provide signals over an extended range, typically up to 150 meters.
Energization	A passive tag is energized only when there is a reader present.	An active tag is always energized.
Magnetic Field Strength	High, since the tag draws power from the electromagnetic field provided by the reader.	Low, since the tag emits signals using internal battery source.
Shelf Life	Very high, ideally does not expire over a life time.	Limited to about 5 years, the life of a battery.
Data storage	Limited data storage, typically 128 bytes.	Can store larger amounts of data.
Cost	Cheap	Expensive
Size	Smaller	Slightly bulky (due to battery)

A passive RFID tag has no internal battery, and is typically used in small-scale tracking operations. Since a passive tag has no internal power source, it is powered by the energy transmitted by the RFID scanner. Passive RFID tags are generally the most commonly used tag by companies that have a large inventory of physical assets. This is due to its cheap cost and for having a longer life expectancy.

While a passive tag has no internal power source, an active RFID tag is equipped with an internal battery and a transmitter. This means that an active tag is capable of continuously transmitting signals to an RFID reader up to 150 metres away, depending on frequency levels. The use of these tags became popular among companies that wanted to build a real-time accurate location system (RTLS).

There is also another type of tag that is centered between active and passive tags, namely the semi-passive RFID tags. A semi-passive tag behaves as an intermediate option, offering a mix of features extracted from the capabilities of both active and passive tags. It contains an internal battery as well as an antenna and a microchip. However, it has a shorter range than active

tags but longer than passive tags. This tag is seen as an ideal and inexpensive solution for the use of RFID tracking systems for monitoring environments and conditions, such as temperature-controlled transit.

There are a variey of RFID Tags. According to Auto-ID Center, RFID tags can be divided into 5 classes. Table 2.3 shows the differences between all classes [8].

Table 2.3: RFID tags classification [8]

Class	Description	Functionality	Remarks
1	Read Only	Passive tags	Data can be written only once during tag manufacturing and read many times
2	Write Once and Read only	Passive tags	Data can be written only once by tag manufacturer or user and read many times
3	Read/Write	Passive tags	User can read/write data many times
4	Read/Write	Semi-passive tags	Can be coupled with on board sensors for capturing parameters like temperatures, pressure, etc.
5	Read/Write	Active tags	Can be coupled with on board sensors and act as radio wave transmitter to communicate with reader.

The choice of tag to be used depends a lot on its applicability. Fortunately there is a wide range of options and all with different characteristics. The class 1 tags, the most used, come with a factory id, which doesn't allow you to rewrite its content, but only to read it. The class 2 tags, on the other hand, allow you to insert the content only once, and then its purpose is only to read it. However, classes 3, 4 and 5 allow rewriting the content multiple times.

To carry out this project it is necessary to identify each fish individually in a shoal, so that we know which one has interacted. For that it is simply necessary to read at short distances a personal tag previously implanted. In other words, within RFID technologies it makes sense to use a low-frequency passive type from class 1, specifically, the PIT tag, which will be described in the following section.

2.2.1 PIT tag

In the 1980s scientists began using internal PIT tags to measure the movement of fish. However, the tool proved so useful that it has since been extended to study the movement of mammals, amphibians, reptiles, birds and invertebrates. At the moment, PIT tags are used by vets to identify domestic animals and to track cattle and zoo animals. As shown in Figure 2.2, the PIT tag consists of an integrated circuit chip, a capacitor, and an antenna coil encased in glass. There are several

sizes of PIT tags; the choice of size depends on the study animal. Generally, the tags are cylindrical in shape, about 8-32 mm long and 1-4 mm in diameter [16].

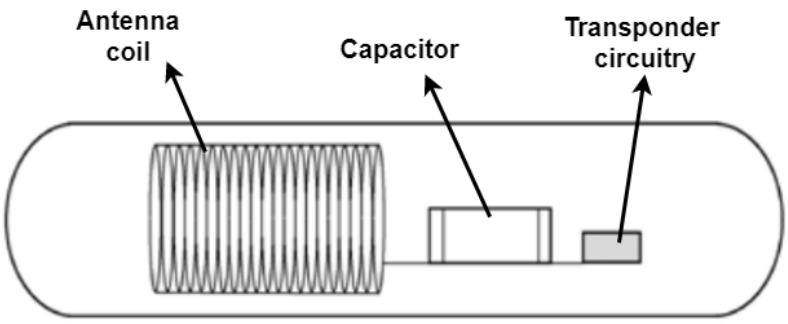

Figure 2.2: PIT tag hardware [2]

There are two types of PIT technology, the full-duplex (FDX) and half-duplex (HDX). The FDX system's scanner transmits an electromagnetic charge, through the antennas, to detect and receive, simultaneously, information from the nearby PIT tags. While scanners used on the HDX system first send the signal to charge the tag and then stop and wait for the response of the nearby tags, and then begin the cycle again. Because of this cycle, the HDX system has a slower detection rate of 14 reads per second against a rate of 30 reads per second from the FDX systems. The tag from the HDX system has a capacitor to momentarily store energy from the scanner, therefore it has a stronger signal that can range a bigger distance than the FDX tag [16]. All the features explained above demonstrates that the FDX system is a smart and accurate choice for this project, since it is intended for detection of fishes in short-distances.

Often the suffix "-A" or "-B" is added to the FDX. For instance, "FDX-A" denotes the data modulation protocol with the response frequency well-removed from the excite/carrier frequency. Instead, "FDX-B" denotes a protocol with a response frequency close to the exciting frequency [2]. The FDX-A PIT tags were imposed, as they were the most available on the market for purchase.

For this thesis it is only necessary to read the tag at short distances, so it makes sense to use the PIT tag FDX-A, with the advantage of being a more economical choice. As the tags are going to be injected in juvenile fishes, it is better to choose a tag with dimensions adaptable to their size, so it was selected the smallest tag of 1.4x8.5 mm. The tag to be used is shown in Figure 2.3.

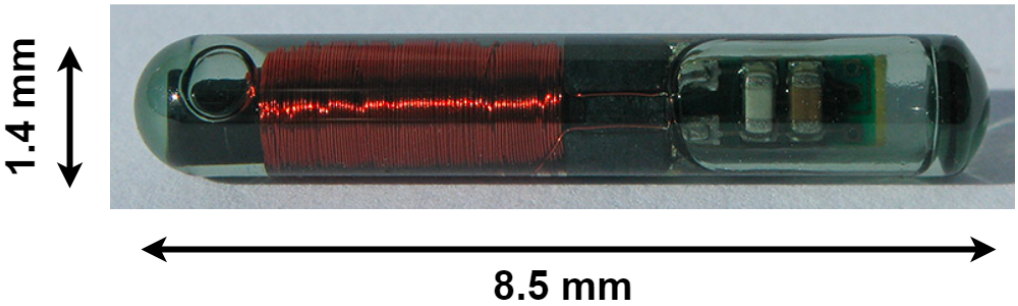

Figure 2.3: PIT tag to be used

2.3 Related Projects

Researching related projects aims to gain further knowledge about the technologies that could be used in these kinds of projects. Also, considering related projects contributes to analyze and explore other applications and detection forms in similar or different species. Finally, what is sought with this section is to study the contribution of the technology that will be used in this project to the biology field, specifically in the animals' behaviors and to identify the diverse applications that can be developed from the use of this technology.

PIT Tags have permitted diverse investigations of animals, for instance in assessments of growth rates, movement patterns and survivorship for many species in a trustworthy way instead of marking them in a "traditional" way. (Externally marking) [9].

According to Gibbons and Andrews [9], the use of PIT tags in wild animals in the field of biology started with fisheries studies, specifically in mapping fish movement. However, small mammals and other species have demonstrated the success of this method.

The article "PIT Tagging: Simple Technology at its best" presents some case studies that support the PIT tag technology despite its limitations and throughout these case studies it is showed the different applications with the use of this detection method.

Some of the species treated in the case studies are the following: fisheries and ichthyological research, steelhead, and coho salmon. PIT tagging has also found widespread use in studies of many wild animals, with the array of species being as diverse as sea otters, penguins, and crayfish [9] .

Furthermore, different applications can be derived from this technology. Some of the applications illustrated in the article were behavior, physiology, conservation, and commercial harvest. Table 2.4 is a summary table that was elaborated to present the information and have a better understanding of the information.

Table 2.4: The use of PIT tags and its application [9]

	Behavior	**Physiology**	**Conservation**	**Commercial Harvest**
Authors or Researchers	Sloman and Colleagues	Roark and Dorcas	Boarman and Colleagues	Pengilly and Watson
Species under Study	Fish	Corn snakes	Desert tortoises	Red king crabs (Paralithodes camtschaticus)
Aim	Expose the fish to sublethal levels of copper affected social interactions and dominance hierarchies among rainbow trout	Investigate temperature variation among individuals, within different parts of the body, an between digestive and non digestive state	Conservation	Determine harvest of red kings crabs
Method	PIT tag antenna placed around a feeding station	Temperature--sensitive PIT tags	PIT tags were attached to the carapaces with epoxy before the tortoises were released	By injecting tags into commercially inconsequential parts of the body, the investigators were able to track crabs in the processing facility
Results and conclusions	The fish that differ in social status may also differ in their susceptibility to copper accumulation, with subordinate being more vulnerable to uptake	PIT tags that measure temperature could become especially useful in questions related to animals thermal preferences	Several tortoises were documented to use the culverts, indicating the potential effectiveness of ecological underpasses for avoiding road mortality	The use of an automated monitoring system would be effective at detecting a high proportion of PIT-tagged crabs

All these applications could be summarized of the aim to track the behavior of a specie and to prove an action that will contribute to knowledge in different fields, such as biology, business (wood and commercial harvest), among others.

It could be said that between these cases presented in the table, the ones that resemble to this project is a combination of the first and the last column of the table. (Behavior and commercial harvest). Since, the aim of this project is to know if fishes in an aquaculture environment search for friendly interactions with fishes of different species, and if this helps to lower their stress levels.

2.3.1 Estuarine fish movement

Another article related found, in terms of PIT Tag technology used and specie under study (fishes) is called "Use of PIT tag and underwater video recording in assessing estuarine fish movement in a high intertidal mangrove and salt marsh creek". The article was published in the year 2008 and consist of the use of PIT tag to track the movement patterns in relation to habitat availability[3]. In this case, there were 4 different species under study. The habitat was a small mangrove creek within the subtropical Burrum River estuary in Queensland, Australia. The technique used in this case was a stationary PIT adapted to the saline environment. A plus of the project in description is that it had an underwater digital video camera. Another thing is that the quantity of fishes injected with PIT tag were 75 from a tidal creek connected to the main channel of the estuary and the days of analysis were 104. The quantity of detection obtained in this case were around 5000. Also, it was implemented other devices to analyze possible inundations in the creek and make some relations between this phenomenon and to the timing of fish immigration to and emigration from the creek. The devices were a high-resolution digital elevation, more specific 2.5m cell size model from airborne light detection and ranging (LIDAR) and aerial imagery [3].

For this study, the PIT tag reader design and operation was as follows, there was an autonomous antenna system which has an open loop inductor coil antenna connected to tuning circuits and those circuits were connected to a reader unit and a data logger. In this case, the electronics needed to be in weatherproof enclosures, they were positioned in a nearby mangrove tree. It is worth to mention that the system described above was powered by a 12 V battery and charged by a 165 W solar panel. This type of mechanism allowed an uninterrupted use. Regarding the antenna, the large of it was 8 m since it was along the creek on study and covered a depth of 2 m. It was the system elaborated like this so the fish swimming in and out of the creek could be detected by passing through the antenna system. Another characteristic of the antenna is the operation, it operates on a half-duplex system at 134.2 kHz. Therefore, the way it works was that the reader generated a close-range, electromagnetic field that immediately activated the tag, which transmitted a unique alphanumeric code to the data logger if the PIT tag was present [3].

Also, since saline water could derive some problems in terms of detection radius, the gate voltage was set between 300 and 1000 V to maximize the antenna´s detecting range. There was a second gate installed 2 m apart from the first gate. The aim of the second gate was mainly to boost detection efficiency and track direction and speed travel. This gate was also connected to the reader [3].

The following image will explain in greater detail the functioning of the system and its operation.

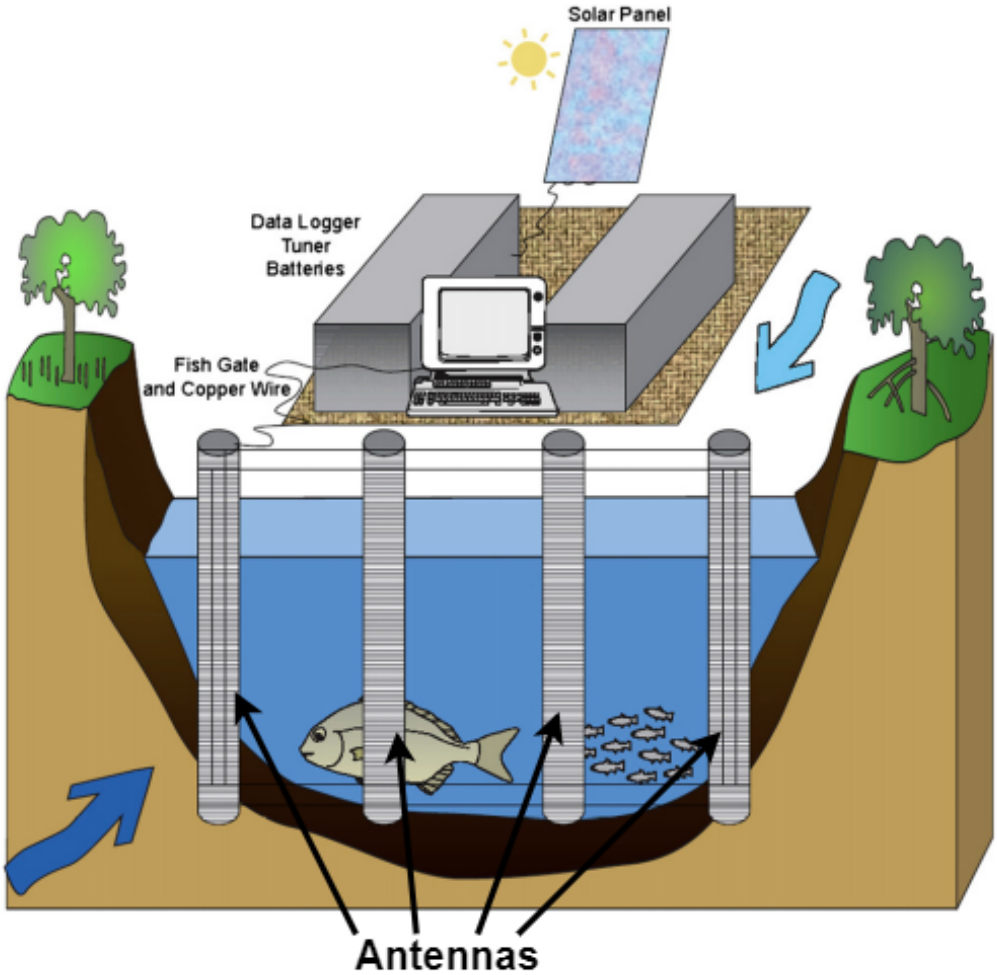

Figure 2.4: A schematic illustration of the project [3]

2.3.2 Ornithological Research

The most similar project found was the one that developed the monitoring of bird feeding behaviour in Ithaca, New York. Basically, a few bird food stations were installed around the city, where an antenna is installed in the perching area that will read the tag. This will help to better understand the feeding routines, the competition behaviour, the influence of the weather, etc [17].

This project sought to use a low-cost RFID technology. As a reader, it was chosen the *UB22270* module from the *Atmel Corporation*. It is a reader that works with low frequencies, and is powered by a 12V battery. This reader only allows the reading of one antenna. What for this project is enough, because as it can be observed in the Figure 2.5, if the antenna is strategically well placed in the feeding place, it can perfectly make the reading of the tag implanted in the chest of the bird [17].

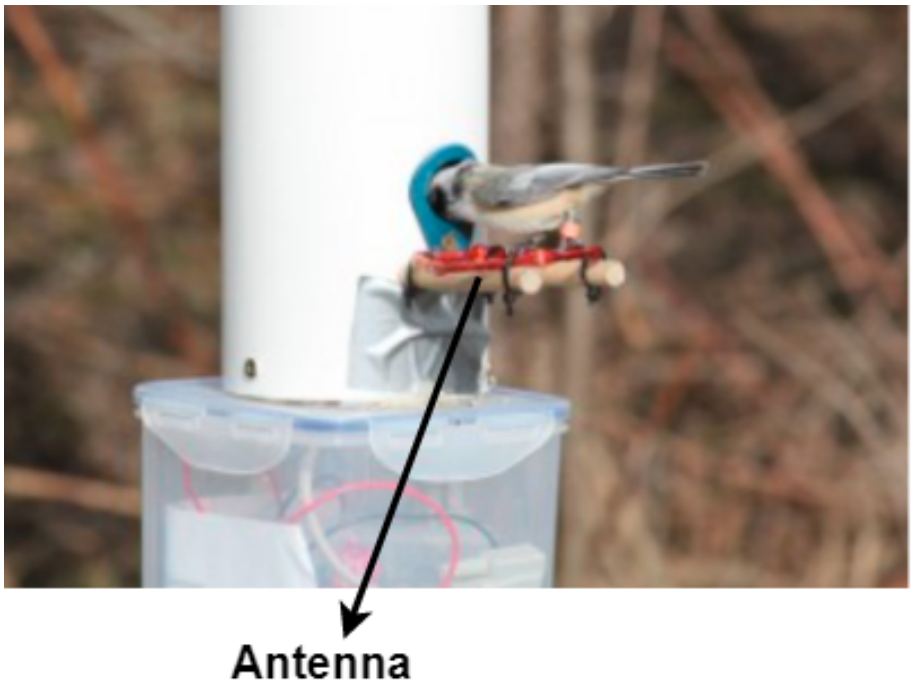

Figure 2.5: Bird feeding project [4]

This project also uses a microprocessor (*PIC16F688*). The microprocessor controls the reading time, meaning that if it does not detect any tag reading then it checks the battery status and with those values it decides if it makes reading intervals so as not to consume too much power. If the tag is read, the microprocessor collects the tag id and the day and time of a real-time clock. All the collected data is in turn compressed to a line and allocated in a memory unit integrated in the circuit [17].

2.3.3 Summary

According to the research about similar projects, it can be concluded that PIT tags are a very powerful tool in biology when it comes to the study of animal behaviour. Although the related projects presented above do not have the same aim of this project, the research was related to animal behaviour analysis and can prove the practicality and usefulness of the PIT tags. As none of them mentioned studying the contact behaviour with other fish species this project can demonstrate a new applicability of RFID technologies in the field of biology.

Nevertheless, it was possible to make a brief study of the type of RFID technology used in their projects. It is assumed that all RFID reading devices have to work at low frequency. The difference is the number of readings that each reader can do and the number of antennas that can be integrated in the circuit. The choice of the reader and the antennas' type depends a lot on the application and the dimension of the project.

Chapter 3

Development

The prototype aims to fulfill three tasks, which are the following:

- Read the PIT tags, implanted on the live fish;
- Know if the detected fish has touched or just passed by;
- Record all the data and save it in a file.

To achieve these goals it was necessary to combine both hardware and software design. This chapter will show the development and procedures that have been taken to achieve each task and therefore obtain the final product.

3.1 Hardware

3.1.1 Components selection

The assembly of the whole system requires a set of components and equipment. To read the PIT tags it is necessary to have an RFID reader and its respective antennas. Also, an accelerometer is needed, because it defines whether or not there have been impacts. Another component required is a microprocessor, since it processes the information coming from the reader and the accelerometer, and sends it to a computer that will store it in a file. In order for information to pass between devices, some kind of communication protocol is required. Therefore it is required that the microcontroller can have serial port and I2C communication. The other devices, accelerometer and RFID reader, just need to have one of these protocols now mentioned.

The prototype fish has to look like a Bluestreak Cleaner Wrasse. The Bluestreak Cleaner Wrasse is a small fish with an average length and diameter of 10cm and 2cm, respectively. Both the antennas and the accelerometer will be placed inside the design of this fish. Therefore, the selection of the components is restricted. The pieces mentioned have to fit inside the fish, and still fulfill their purpose.

3.1.1.1 Microprocessor

First of all, the microprocessor was chosen. This will be the centre of all operations. It will receive the information from all the sensors, process that information, and then send all processed data to a computer to be analyzed.

It was chosen the *Arduino*, which is a device widely used in embedded systems for routine tasks. The fact that there are diverse resources for Arduino microprocessors, in terms of information and usage, allows to find a solution, rapidly, if a problem emerges. And it meets the requirements for the project which are: supports serial port communication and works according to the I2C protocol. Arduino also has the advantage of having a platform that allows to write code, compile it and send it to the device.

More specifically the "Arduino Mega ADK" was used. Although it is a powerful microprocessor for the necessary tasks, this Arduino brought the advantage of being able to use 4 different serial ports. This feature becomes useful in the case of having a serial port communication with more than one device.

3.1.1.2 RFID Reader

For the choice of the RFID reader, two requirements needed to be met. First, it had to be able to read more than one antenna, so there could be a divergent choice of antenna positions. Secondly, it was imperative that the reader had some communication capability with the *Arduino*, either by serial port or by I2C protocol.

Although there are some LF reading RFID systems, it was complicated to find a device that could use more than one antenna. For example, the RDM6300 is a RFID reader that operates at 125 KHz. It meets the requirement of communicating via serial port, and is powered by 5 VDC. It is a very economical and affordable option. However, it does not meet the requirement of connecting to more than one antenna [18].

The most suitable reader found was the LID650V40 decoder. This decoder operates at a frequency of 128 kHz, which is necessary to read tags at a low frequency. Moreover, it allows a constant reading of 4 antennas without any overlapping between them. The reader used in the project communicates according to the RS232 protocol, so it was necessary to integrate a MAX232 in the communication circuit with the microprocessor. The MAX232 is a level converter, which transforms signals from a serial port to signals suitable to use in microprocessor circuits, such as lower level CMOS logic, as is the case with the microprocessor used. The decoder is powered with 12V by an external power supply connected to a 240VAC outlet [5].

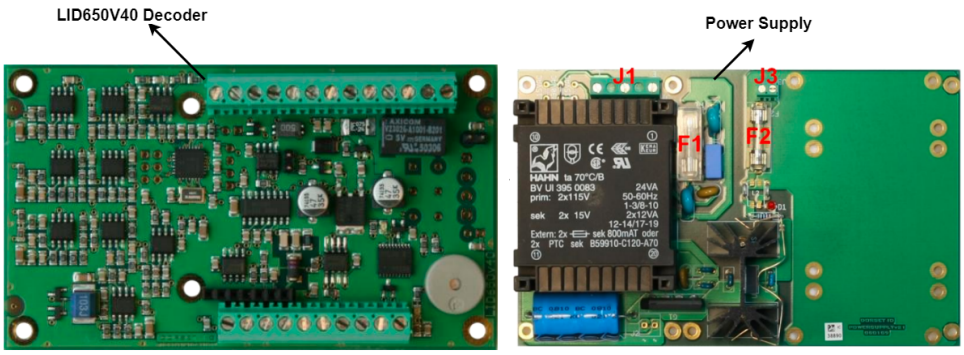

Figure 3.1: LID650V40 decoder and the Power Supply [5]

3.1.1.3 Accelerometer

As for the choice of accelerometer, it is necessary that it has the ideal dimensions so as to fit inside the shell of the fish. It is also important that it has some way to communicate with the Arduino.

There is a huge variety of accelerometers that fit the required characteristics. Including the IMU (Inertial Measurement Unit) which also offers the possibility to include gyroscope and magnetometer. Such as the SEN-15335, which offers all three applications. But these features would not have applicability in this project.

As mentioned earlier, there are a wide variety of choices for accelerometers and they all have the same characteristics. The selection factor was strongly associated with the affordability of the product. Within these parameters, we found two accelerometers with the same affordability: the ADXL345, and the ADXL335. The main difference between the two was the fact that the ADXL335 only had a maximum range of ± 3 g and the ADXL345 had a maximum range of ± 16 g.

The chosen accelerometer was the ADXL345. The ADXL345 is a small 3-axis accelerometer with a choice of $\pm$2g, $\pm$4g, $\pm$8g or $\pm$16g ranges. And I2C interface is available as a digital output. The ADLX is well suited for this application as it measures the dynamic acceleration resulting from shocks [10].

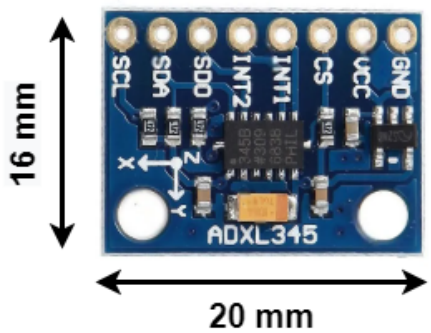

Figure 3.2: ADXL345

In terms of the positioning of the accelerometer inside the shell of the fish, it makes no difference. This is because in the end what will matter is the modulus of the three axes, and not the individual value of each one.

3.1.1.4 Antennas

For the selection of antennas, there were two types: ferrite core and air core. Usually, air core antennas are tuned for higher frequency locating while ferrite core antennas are tuned for lower frequency. The ferrite core antenna operates by using the ferrite material to "concentrate" the magnetic component of the radio waves through the pickup coil. This means that the ferrite core allows to increase the inductance value (L) of a coil using fewer turns.

We made tests for both types of antennas, with ferrite core and without, to see which would fit the project better. Initially, tests were made with both types of antennas, previously purchased and suitable for LF readings. Both showed to be effective for reading the PIT tags, however they were antennas of large dimensions for the structure of the fish, so it was decided to try to make antennas for the appropriate dimensions. With copper wire it was made a small coil of about 40 coils with a maximum diameter of 2cm, the same diameter as the body of the fish. It was measured the self-induction level of this coil giving a value of 30 µH. When it was connected to the reader, it was realized that the range reading was really low, so it did not read the tags. Then, a ferrite bar was placed in the centre of the coil, and the antenna started to read the tags. It was measured the self-inductance level of the antenna with ferrite in the centre, and the value increased to 220 µH. This is because the ferrite bar helps to concentrate the magnetic component.

Two conclusions were drawn according to the tests carried out. The higher the self-inductance value, the higher the reading range. And that for small antennas it is advantageous to place a ferrite core, to help concentrate the magnetic field, and consequently increase the self-induction value.

The RFID antennas must be compact and efficient, making the ferrite core antenna an ideal solution. The best option found is in Figure 3.3 with a self-inductance value of 330 µH. This allows the antenna to have a read range of approximately 4 cm when the PIT tag is in parallel with it [6].

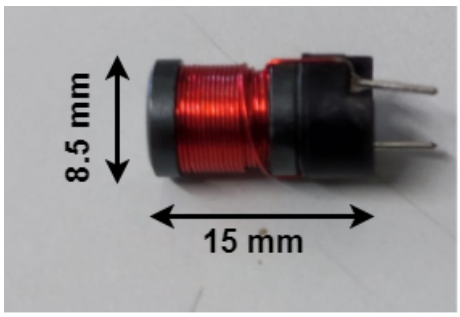

Figure 3.3: Antenna

Figure 3.4 shows the magnetic field lines created by the antenna. And, additionally, it also illustrates the best orientation of the position of the PIT tags so that the reading has a greater range. Although the image shows an air core antenna, its purpose is only to show the direction of the electric field in relation to the position of the coils. That is, that the electric field passes through the inside of the coils, and around them, just like in a ferrite core antenna.

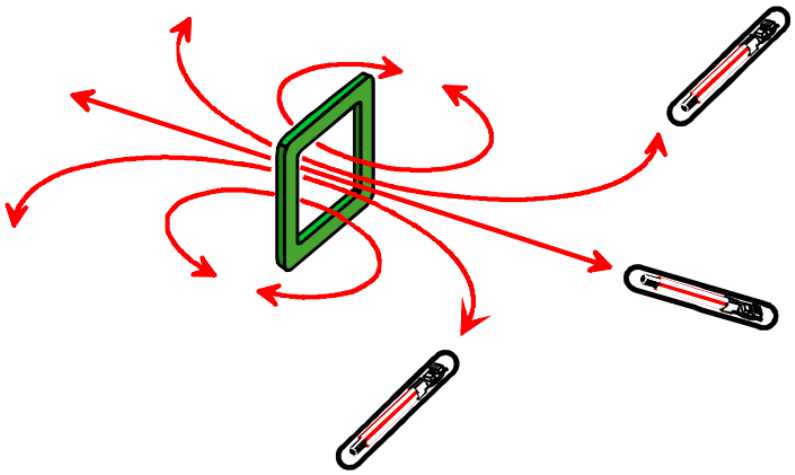

Figure 3.4: Antenna field lines [6]

According to the picture above, it can be seen that the best orientation for the PIT tags will always be parallel to the field lines formed by the antenna. As the tag will be injected along the dorsal column of the fish, it is necessary to find the best orientation to place the antennas to have a greater detection range. For that, a series of tests were performed with the antenna and tag position in parallel and with both in perpendicular. It was detected that in fact when both elements were in parallel the reading distance was greater than when they were in perpendicular. This is because in parallel both elements had to be almost touching each other, while in parallel they could be distant up to approximately 4 cm.

In terms of number of antennas, as previously mentioned, the RFID reader can support up to a maximum of 4 antennas. So, some tests were made to certify which would be the best number of antennas to use in order to have a greater reading range along the fish body. However, it didn't take long to realize that it was obvious that using 4 antennas in a row would give a greater range. Also because there was no risk of one antenna underreposing its magnetic field on the others, because the reader only activates one antenna at a time, to proceed to the respective scan.

3.1.1.5 Preliminary Test

To conclude this topic, an experimental setup has been constructed, which includes all the elements described throughout this subchapter. The antennas and the accelerometer were placed in a styrofoam bar with the same disposition that would be inside the fish design, as shown in Figure 3.5. This was to confirm that there would be no electromagnetic interference between the antennas and the accelerometer, since they were going to be in close proximity to each other. And to make

sure that the antennas could read the PIT tag under the same environmental conditions of a fish, the assembly was tested in salt water.

Figure 3.5: Experimental Setup

3.1.2 3D Design

To develop the 3D model of the fish shell, the *Fusion 360* platform from *Autodesk* was chosen. It is an open source tool that provides innovative tools to establish a connection between digital design and engineering. It enables the creation of digital prototypes and the use of 3D printing workflows. It is also an excellent choice for the vast support resources available, which helped in the creation of this design.

The project aims to understand what kind of curiosity and interaction the aquaculture fish would have with fish that, in wild conditions, would live alongside them. In this case, the fish selected to be replicated is the Bluestreak Cleaner Wrasse. So the design has to have a similar shape with approximate dimensions. As shown in Figure 3.6, a background image was used to obtain the desired shape. It was given a length of 10 cm and a diameter of 2 cm, the perfect size to make it look like the intended fish and the components fit.

Figure 3.6: 3D Shape

With the shape done, the interior space still has to be prepared to assemble the components. For that, the fish was divided in half and a cavity was created inside each half. On one side two fittings were added to fix the accelerometer. But to make sure that everything would have room, an outline of each antenna and the accelerometer was placed inside, in the positions that were discussed in the last subchapter. Lastly, a hole in the top of the fish was drilled, providing an access point to all cables, which will pass through said hole. The description of this paragraph can be seen in Figure 3.7.

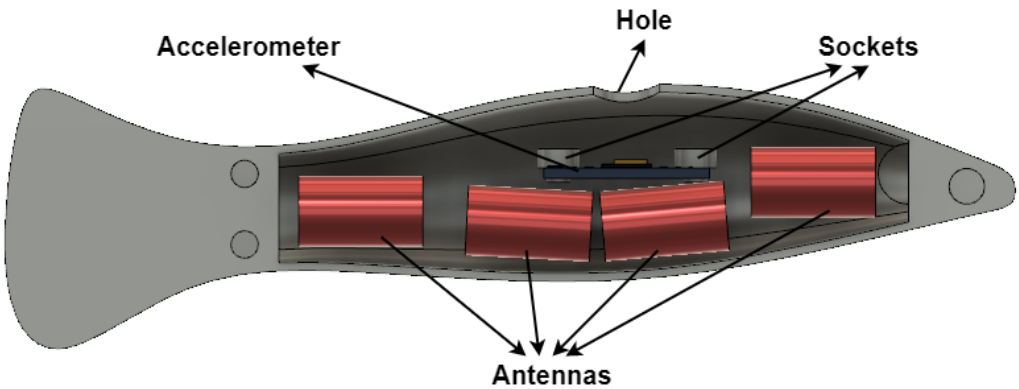

Figure 3.7: Final 3D design

Figure 3.8 is the result of 3D printing in PLA the design, made after being cleaned and prepared for component insertion.

Figure 3.8: Final Result of the 3D Print

3.1.3 Final Assembly

With all the material collected, it is time to do the final assembly. Since the prototype will be used in water environment, it is necessary to make sure that the whole electrical system is waterproof.

As already mentioned in this chapter, the antennas and the accelerometer will be installed inside the 3D print of the fish. To do this, each component was coated with Epoxy Araldite and placed in the intended places: the accelerometer was glued on the sockets, and the antennas were placed in a row along the fish, as shown in Figure 3.9.

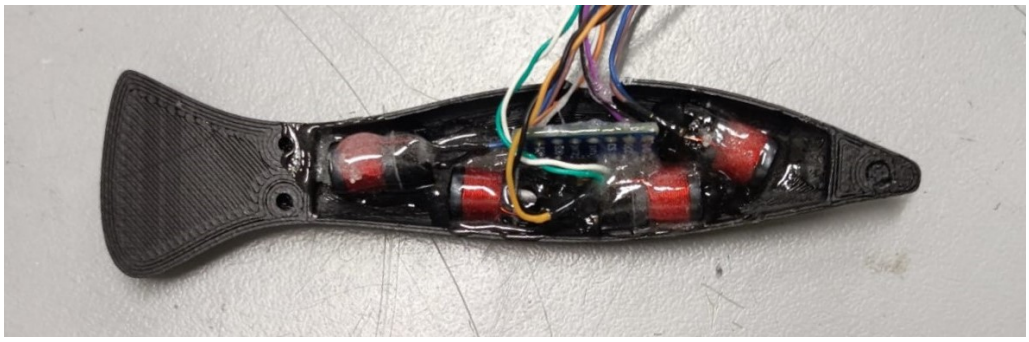

Figure 3.9: Assembly inside the fish

Epoxy was then spread on the edges of each printed half, which were, in turn, pressed against one another. Figure 3.10.

Figure 3.10: Fixing the two shells

The application of Epoxy Araldite was an effective way to ensure that the fish was well sealed and to guarantee that all the electronics were waterproofed. Then, the wires were wrapped inside a heat-shrink, which ensured they were protected from water. Figure 3.11.

Figure 3.11: Fitting the heat-shrink sleeve

To finish, the fish was painted blue to give it a more realistic appearance. This is shown in Figure 3.12.

Figure 3.12: Fish painting

Figure 3.13 shows the box that was used where everything was allocated within its proper space. The cables were placed in cable glands.

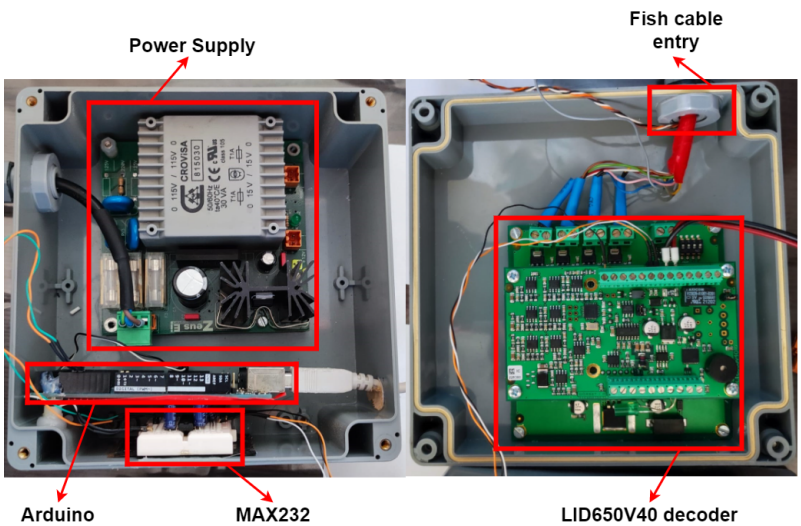

Figure 3.13: Box Assemble

3.1.3.1 Tests

When the whole prototype was assembled, it was prudent to make some RFID reading tests under salt water. This is because salt water has other properties and minerals that air does not have, which may have some influence on the reading behaviour of the antennas. So, since the prototype will be operating in salt water, it is necessary to do some tests to ensure the total functioning of the project.

The fully assembled prototype was placed in a saltwater tank and the RFID reader was connected. With a tag, similar to the one that would be injected into the fish, the tests were carried out. Happily, from the results obtained, the reading had the same behaviour as out of water. That is, the antennas made a correct reading of the tags, and maintained a reading radius of approximately 4 cm.

3.1.4 Block Diagram

For a better understanding of the hardware side of this project, an electrical schematic was made as shown in Figure 3.14.

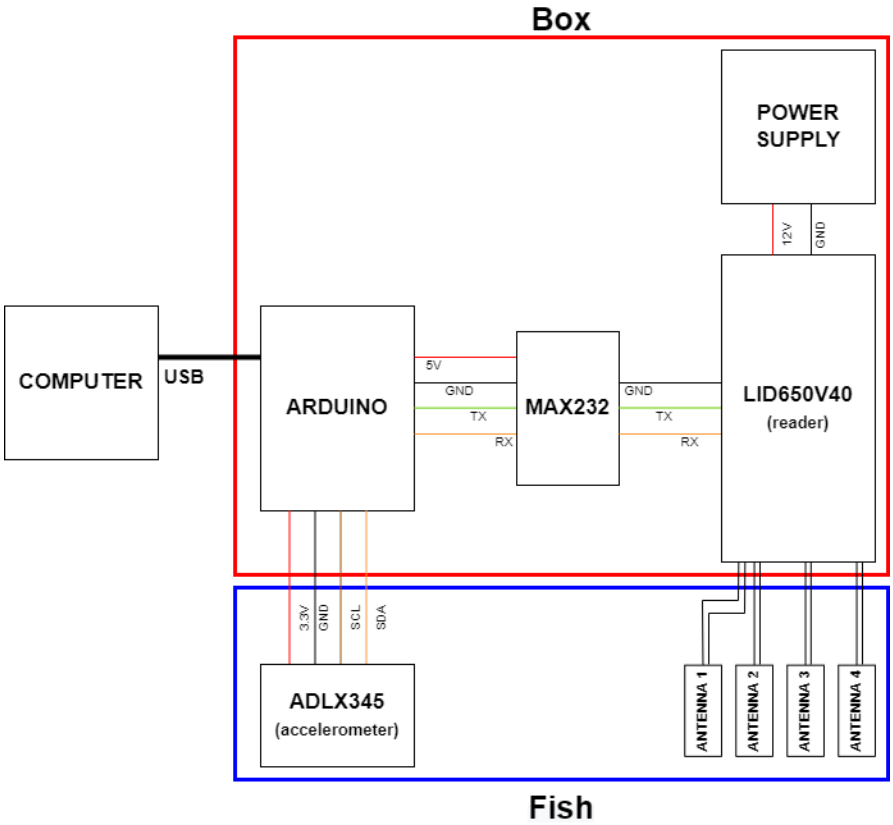

Figure 3.14: Block Diagram

The developed electronic circuit is a simple and easy to understand circuit. Although it is not shown in the schematic, both the Power Suplly and the Computer are powered by the electrical plug. In turn is the Computer that powers the Arduino through the USB cable, the same cable that the Arduino uses to pass information. And, as already explained before, is the Power Supply that powers the reader with a voltage of 12 VDC.

The Arduino ends up being a central point of the electronic circuit. It powers the accelerometer with a required voltage of 3.3V with the proper connections for I2C communication, namely, the SCL and SDA. It is also the Arduino that supplies the MAX232 with a voltage of 5V. In turn, the MAX232 will convert the 12V signal levels from the TX and RX of the reader to the 5V input values accepted by the Arduino.

According to the image, it is clear that the Arduino is the centre of the whole system, because it communicates with all the devices. It receives the value of the three acceleration axes from the accelerometer, and also receives the id read by the antennas connected to the reader. With all the

information collected, the Arduino sends everything to the computer, where it will allocate it in a text file. However, this will be further explained in the next Subchapter 3.2.

3.1.5 Challenges and Solutions

With all the prototype assembled and the code tested the initial testing phase began. When the prototype was turned on, it was noticed that the accelerometer was blocking all the Arduino's operations. However, the accelerometer kept working fine when the reader was off. This was because the information that went through the I2C communication cables, between the accelerometer and the Arduino, were suffering electromagnetic interference from the antenna cables. This happened from the moment that the cables were closer together when the heat shrink sleeve was tightened.

For the whole system to work, it was necessary to avoid this disturbance between the cables. The solution was to wrap the antenna cables in a coaxial cable and solder the points to the ground. This was the only way to guarantee that the cables would be isolated. Also this allowed to keep all cables tightly packed in the same heat shrink sleeve without any electromagnetic interference.

3.2 Software

This subchapter explains the software development. There are two sides to the software that was written for the project: the program running on the Arduino, and the executable program for data collection on the computer.

3.2.1 Arduino

The final code inserted in the Arduino is composed by two functions and one main function where a state machine was developed, which manages the system inputs and outputs. The functions correspond to each task assigned to the fish: the chip reading and the accelerometer reading.

For the development and compilation of the code was used the Arduino IDE. The Arduino IDE is a multiplatform development tool with a graphical interface that is simple to use, but also has flexibility for more experienced users. It is a program that brings together features and tools to streamline the process of software development.

3.2.1.1 Accelerometer Function

Below, the function that controls the output of the accelerometer will be presented, along with its process until it reaches an intended value. The final intended value is the calculation of the derivative of acceleration, to help better understand if there was a touch or not.

As the `accelerometer` function uses the I2C communication protocol, it is necessary to include the `Wire.h` library, which contains implementations by Arduino for both I2C and TWI communication protocols. Through this library, it is possible to make the connection from the device's unique address (0x53) [10]. It is intended to read the values of the records tabulated in 3.1. To read them all, it started with the first register, and with the `requestionFrom()` function

it was requested to read the 6 registers. Then, using the `read()` function, it was read the data from each register. As the outputs are two complements, it was combined appropriately to obtain the correct values.

Table 3.1: Registers for each axis [10]

Register	Axis
0x32	X-Axis Data 0
0x33	X-Axis Data 1
0x34	Y-Axis Data 0
0x35	Y-Axis Data 1
0x36	Z-Axis Data 0
0x37	Z-Axis Data 1

The sensor output values depend on the selected sensitivity, which can range from ±2g to ±16g, according to the Table 3.2. The default sensitivity is ±4g, so the output needs to be divided by 128 to get values from -2 to +2g. The 128 LSB/g means that there are 128 counts per g.

Table 3.2: Sensibility table [10]

Sensitivity	Counts per g
±2g	256
±4g	128
±8g	64
±16g	32

In Figure 3.15 shows a sample of the code that was explained previously in this subchapter

```
int ADXL345 = 0x53;

Wire.beginTransmission(ADXL345);
Wire.write(0x32);
Wire.endTransmission(false);
Wire.requestFrom(ADXL345, 6, true);

X_out = ( Wire.read()| Wire.read() << 8); // X-axis value
X_out = X_out/128;
Y_out = ( Wire.read()| Wire.read() << 8); // Y-axis value
Y_out = Y_out/128;
Z_out = ( Wire.read()| Wire.read() << 8); // Z-axis value
Z_out = Z_out/128;
```

Figure 3.15: Excerpt from the `accelerometer` function

At each routine, the function is called and collects the acceleration data from each axis to form a vector. The vector is used to calculate the module, followed by the module's derivative. The slopes of the tangents provides information on the variation of the acceleration to filter fish bumps

from noise (eg. ondulation, fish swimming nearby). With all calculations done, the values of the new module and the current time are stored in global auxiliary variables, for the calculation of the derivative in the next routine that the function is called. It is possible to follow what is explained in the code excerpt in Figure 3.16.

```
unsigned long t = millis();

//Module calculation
module = sqrt (pow (X_out, 2) + pow (Y_out, 2) + pow (Z_out, 2));

//Module derivative
derivative = ((module - module_aux)/(t - t_aux))*GAIN;

//Save values
module_aux = module;
t_aux = t;
```

Figure 3.16: Excerpt from the `accelerometer` function

In Figure 3.17 shows a graphical representation that illustrates the evolution of the value of the modulus at rest, and when it is hit. In Figure 3.18 is represented the graph of the derivative value of the modulus, also initially at rest and when it is hit.

From the graphs, it is possible to see the advantage of using the derivative value. Both graphs allow to identify when it was the moment of the bump. However there are significant differences between one and the other. After the crash, the acceleration value takes a certain time to reach stability. While the derivative value warns the moment of the crash and returns to stability, almost instantaneously.

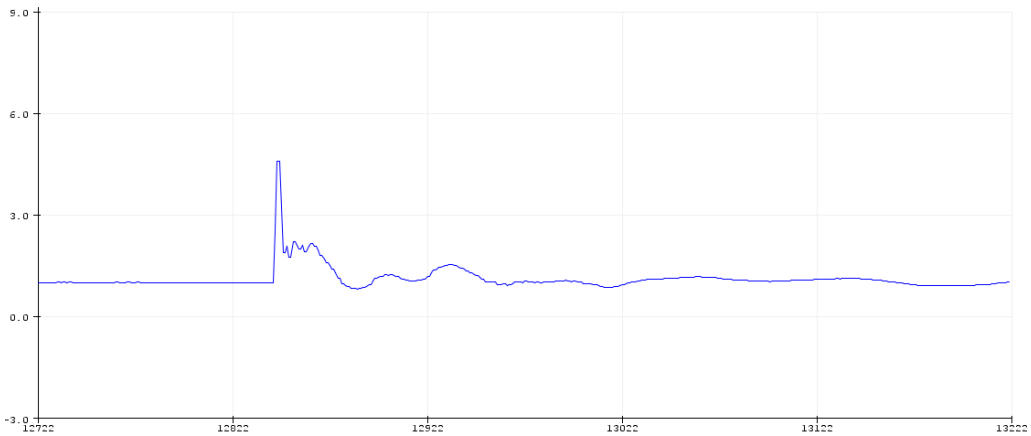

Figure 3.17: Acceleration module graph

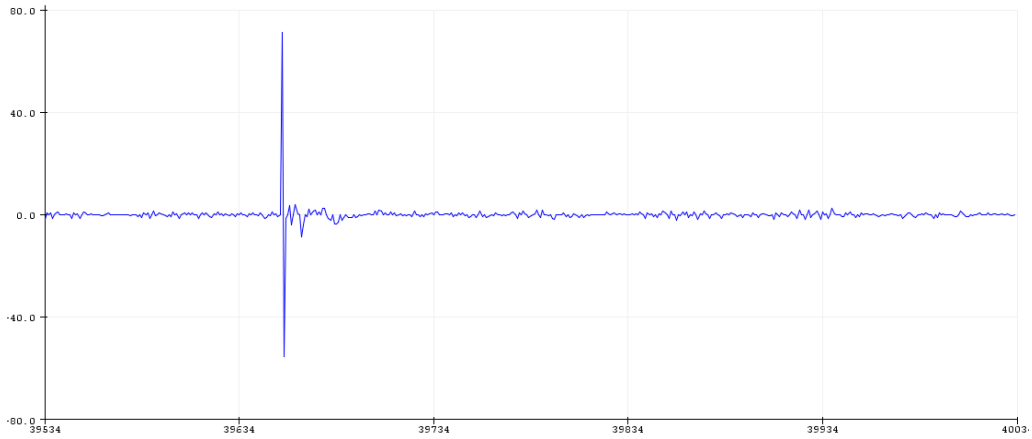

Figure 3.18: Derivative graph of the modulus of acceleration

In order to be able to define when there has been a touch or not by the value of the derivative, it is first necessary to define a threshold value. The threshold value is defined in the code as *TOUCH* and helps to distinguish the noise and standard oscillations from the environment, from the core values that represent a legitimate impact.

To arrive at a threshold value, it was necessary to perform a series of tests. For these tests, the ADXL345 (the accelerometer used in this project) was hung, in the air. Figure 3.19 demonstrates how the setup was done.

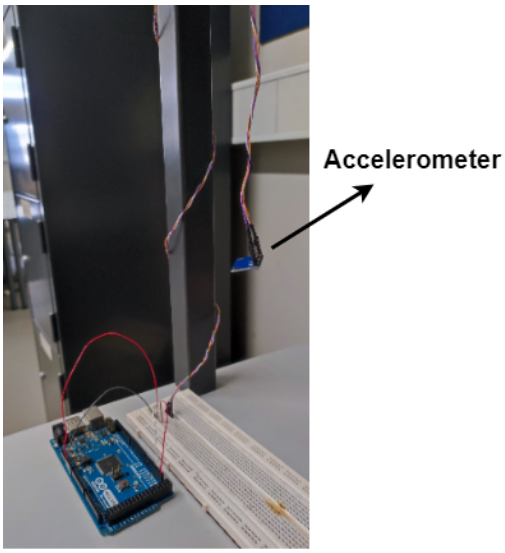

Figure 3.19: Test to determine threshold

With the setup assembled, it was written code that allowed to change the threshold value for any value of the user's choice. The user just had to insert it in the *Serial Monitor* of the Arduino IDE. At the same time, whenever the derivative value passed the introduced threshold value, the code would print those values. This was to help to get a notion of the range of values that the derivative could assume. Then, over the course of some tests tapping the device, a final threshold value was reached. The achieved value was $15m/s^2$/s.

However, this process for determining the threshold value as a fish hit is not the most correct. This is because a hand strike in the air will be different from a fish strike under water. It is known that this value obtained is not the best for the real conditions of the experiment, but what was done out of water was to obtain a preliminary value to be adjusted when placing the prototype in real conditions.

3.2.1.2 Reader Function

As previously explained in the Hardware subchapter (3.1), the Arduino and the RFID reader are connected via serial port. However, it was first necessary to reprogram the RFID reader to put the necessary characteristics for the communication between the device and the Arduino. For that a proprietary application of the device was used, which gave access to all the information of the reader, and also allowed to change some characteristics. The main change made was to set the data rate to 9600 bps.

Through the serial port connection, the function `reader` will receive a segmentation of 14 bytes, which together carry the information of the name of the reading chip and its antenna, among other information not relevant to the project. After some tests, it is known that the name of the read chip is contained in the fifth segment of data up to the tenth segment of data. And right after that, the reading number eleven corresponds to the antenna of the respective reading. Both the chip id and the antenna number are stored in global variables, so the `main` function can access those values. At the end of reading the 14 bytes, the function returns to the `main` function. It is possible to see this code in Figure 3.20.

```
#define CHIP 5
#define ANTENNA 11

int cont = 0;

while (true) {
    if (Serial1.available()) {
        int dt = Serial1.read();
        cont++;

        if ((cont > CHIP) && (cont < ANTENNA)) {
          fish = fish + String (dt, HEX);

        }
        else if (cont == ANTENNA) {
          antenna = String (dt, HEX);
        }

        else if (cont == 14) {
          return;
        }
    }
}
```

Figure 3.20: Excerpt from the `reader` function

3.2.1.3 State Machine

After executing the functions described above, the values assigned to the global variables fish and derivative will be used as input for the State Machine (SM), Figure 3.21. The SM starts in *Wait* (state 0), where it waits for a reading of the antennas (*fish != ""*), or the collision of a fish (*derivative >= TOUCH*), or both at the same time. If it detects both, it means that there was a *Fish Bump* (state 3), in which case it sends a string. If a tag is read, it changes state to *Fish Nearby* (state 2), where it waits 250 ms for the derivative get a value higher than the threshold *TOUCH*. If it happens, it goes to state 3, otherwise it returns to the initial state and also sends a string with the events. If the SM is in state 0 and receives a *Strong Disturbance* (state 1), the SM will wait 250 ms for an opportunity to receive some information from the reader. In case of no success it returns to the initial state, or, otherwise, it goes to state 3, because it detected a *Fish Bump*.

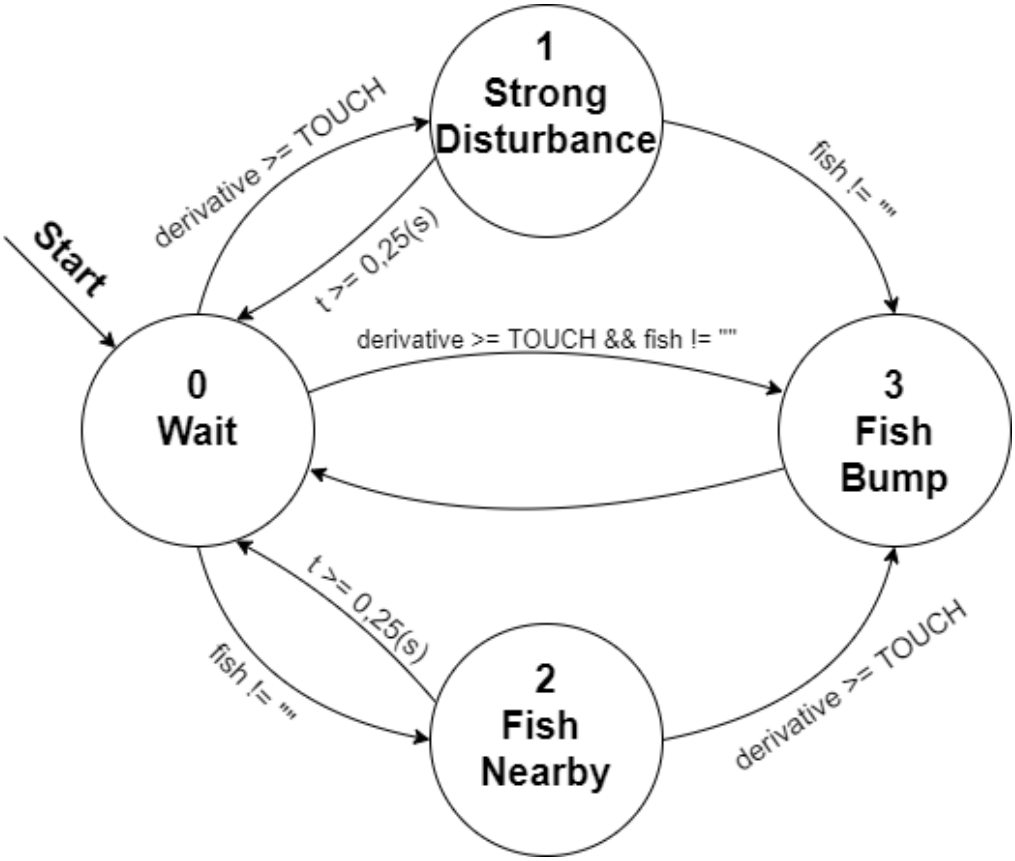

Figure 3.21: State Machine

The string that the SM sends in states 2 and 3, are sent over the serial port. This string is made up of the set of the past events. It has the format "ID/Antenna/Touch/Derivative". The "ID" and the "Antenna" corresponds to the id of the read tag and the respective antenna. The "Touch" has the value of true (T) or false (F) in case there was a collision or not, respectively. And the "Derivative" has the derivative value of the accelerometer.

3.2.2 Data Collection

The string with the events sent by the Arduino is received by the serial port of a computer running an executable program, written in python, with the purpose of collecting data.

When it starts running the executable program it only begins to collect data after having all the essential conditions: have the Arduino connected to the computer and a file created. If there is no Arduino plugged to the computer, the program prints a warning to do so. And to create a file, the program prompts the user to provide a file name. The date and time of its creation is added to the file name to make it distinct from all the others.

The program only closes on the user's command. When this happens the program returns a file with all the stored data. In the header, it reports when the data collection started and when it ended, and its respective duration. Following that, it has a table filled with all the events, with a structure as follows: "Fish Id/ Antenna/ Touch/ Accelerometer/ Date/ Time".

Chapter 4

Results

4.1 Setup

The data collection was carried out in a saltwater tank provided by *SeaLife* to do my prototype tests. The tank had a volume of 0.45 m^3 (1x1x0.45), and it was located in a space at a stable temperature of 25 degrees Celsius. The aquarium had a controlled system that simulated the lights of a day. So, every day the lights were turned on in a gradual way to simulate daybreak. This happened between 6am and 8am. And the same thing happened to simulate sunset, where the lights would start to go out between 6 and 8pm.

Inside the tank were 6 sea bream (*Sparus Aurata*), each one of them with the chip injected in the dorsal fin area. On top of this tank the prototype box was placed on a support and the respective fish went into the water to be in contact with the fish under study. Figure 4.1 shows the setup.

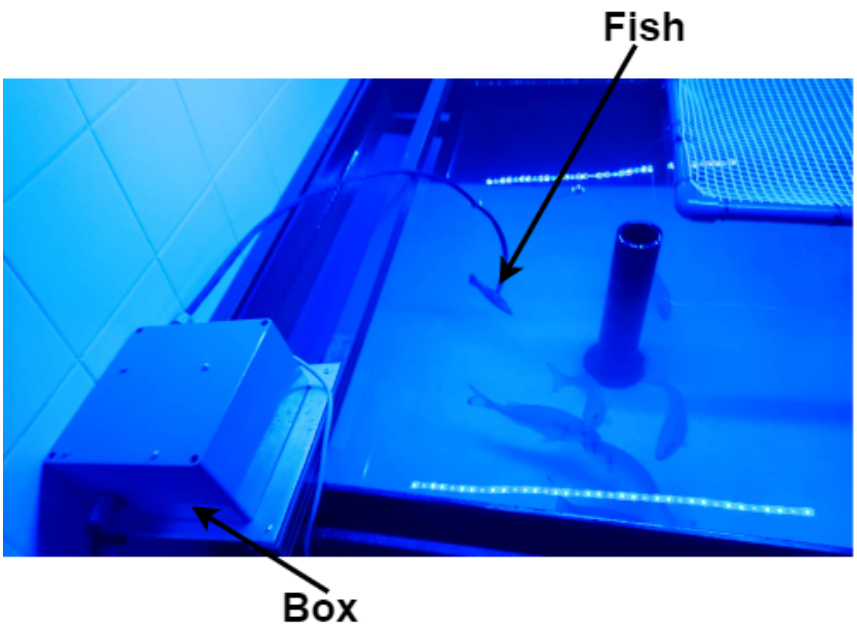

Figure 4.1: Setup in the fish tank

4.2 Final Results

At the end of the data collection, in total there have been 532 results in a total of 21 days. However, not all readings are assumed, only the ones in the "Touch" column are true (T), which means that 470 fish touches were detected.

To analyse the collected data, it was chosen to use the *Pandas* library from the *Python* language. It is a good option as it provides extremely streamlined forms of data representation. This helps to analyze and understand data better. Also, using *Pandas* helps to shorten the procedure of handling data, because what would have taken multiple lines in *Python* without any support libraries, can simply be achieved through 1-2 lines with the use of Pandas, saving time to do a better data analysis.

The data was collected every day, and when the user gave the command to finish collecting the data, the program running on the computer returned a text file with all the data. Figure 4.2 shows a sample of one of the collections.

```
Start of data collection:   2022-07-26 14:46:39.791892
End of data collection:     2022-07-27 13:13:38.109041

Duration of data collection:    22:26:58.317149


Fish ship   Antenna     Touch       Accelerometer       Date        Hour
07e8baff    2           T           44.74               2022/7/26   16:25:57
07e8baff    1           T           31.74               2022/7/26   17:48:55
07e6b945    2           T           41.65               2022/7/26   18:38:43
07e6a857    2           T           28.65               2022/7/26   20:19:27
07e87b98    1           T           22.38               2022/7/26   20:26:25
07e6b945    3           T           43.33               2022/7/26   20:39:42
07e87fd7    3           T           51.37               2022/7/26   21:25:53
07e87fd7    1           T           26.05               2022/7/26   21:25:53
07e6a857    4           T           25.71               2022/7/26   21:46:56
```

Figure 4.2: Sample of Data Collection

At the beginning of the file it indicates the start of the collection, the end and how long it lasted. After that, it has all the received data in order of event. Each event has a set of associated information: the id of the read fish, the antenna of the respective reading, if the fish touched or not the PCM, the acceleration value of the respective touch, with the date and time of the event.

For the analysis of all the results in this Chapter, the threshold value used was the one defined in Subchapter 3.2.1.1. However, in Subchapter 4.2.4 a new threshold value will be defined based on the values acquired in the experiment.

4.2.1 Fish Weight Results

Figure 4.3 shows a graph with the final results of each fish, which indicates the number of touches throughout all the tests and the final weight of the fish. The table is sorted in descending order by number of touches. The initial weight of each fish is not known, but it is known that at the beginning of the experiments they all had identical weights.

To help identify each fish in the data that will be presented, they were associated with names of some characters from the animated film *Finding Nemo*.

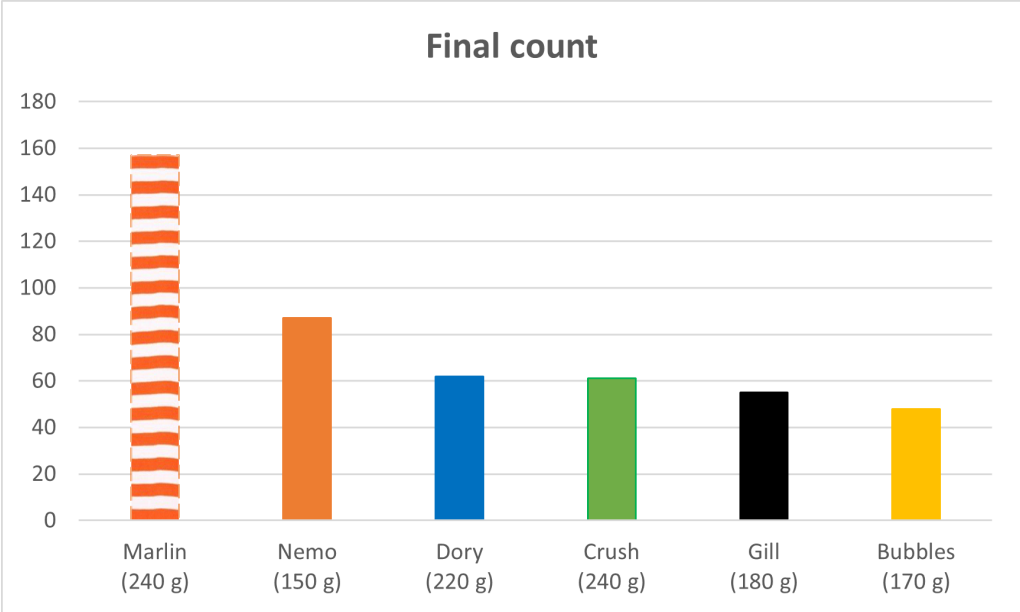

Figure 4.3: Graph with the final values

The results shown above do not reflect any great influence of the presence of the fish on the final weight. This is because the fish *Nemo* was the second fish that had the most contact with the prototype and, at the same time, the lightest fish in the shoal. This may also be due to the fact that it is the smallest, as its dorsal area is smaller and it is more likely to detect the chip than fish that have a larger dorsal area.

During data collection, it was necessary to go to the tank to feed the fish and clean their tank. During this process, it was detected that there was one fish that stood out from the rest of the shoal, by its energy and big appetite. Curiously this fish is *Marlin*, the one that had the most contact with the prototype, with a difference of 70 touches from *Nemo*. This is a big difference compared to 25 touches between *Nemo* and *Dory*, the second and third fish in the table respectively.

4.2.2 Daily Results

In the end there was an average of 22.38 daily readings. The Tables 4.1 and 4.2, show the daily readings taken from each fish. Table 4.1 shows the readings taken above the average and table 4.2 shows the readings taken below it. The tables are arranged in the same order as the previous graph (4.3). The details of the tables will be explained below.

Table 4.1: Daily results above the average

	First Part				Second Part						
Fish id	7/12	7/17	7/18	7/19	7/25	7/26	7/27	7/28	7/29	7/30	7/31
Marlin	7	10	14	5	8	11	21	7	15	13	11
Nemo	7	6	10	7	5	8	4	2	8	4	4
Dory	1	5	4	5	4	1	4	8	4	3	3
Crush	7	7	7	1	3	5	5	6	2	1	4
Gill	3	6	8	4	4	3	5	7	6	2	0
Bubbles	2	8	2	1	0	5	4	11	2	2	2
Total	27	42	45	23	24	33	43	41	37	25	24

Table 4.2: Daily results below the average

	First Part							Second Part		
Fish id	7/10	7/11	7/13	7/14	7/15	7/16	7/20	7/22	7/23	7/24
Marlin	0	3	7	2	6	4	8	1	3	1
Nemo	1	2	3	2	5	2	4	1	1	1
Dory	1	3	1	3	3	2	3	3	1	0
Crush	1	3	4	0	0	0	2	2	0	1
Gill	1	0	1	1	2	1	1	0	0	0
Bubbles	0	0	2	1	1	2	0	0	2	1
Total	4	11	18	9	17	11	18	7	7	4

According to the tables above, it is to be noted all the fish were in similar "moods". That is, on the days when there was more contact with the PCM, in general all the fish showed the same interest. Conversely, on days when there was less contact with the PCM, in general all the fish showed less interest. This may be due to the fact that if one fish of the shoal is very excited about the prototype, it may arouse the curiosity of the others around it.

Along the data collection, it was necessary to take the PCM out of the water for two days, in order to understand how the animals would behave when it would enter again in the tank. This is why there is a division of two parts in the two tables: the *First Part*, and the *Second Part*. The prototype was taken out of the water on day *7/20*, and perhaps this is the reason why this day belongs to the table with the least activity, because it only collected data for half the day. From this division it is possible to see that at the beginning the shoal took a while to adapt to the presence of a different body of its species, however they got used to it after 7 days. On the *Second Part* of

the tests, the adaptation was much quicker, taking only 3 days. This could mean that they already had some memory of the existence of this strange body.

4.2.3 Day Parts Results

The Table 4.3 contains the count of the number of bumps in each phase of the day during the whole experiment. The day was divided into 4 phases, all spaced 6 hours apart starting at midnight. This table was made to see if there were phases of the day when the fish would be most active, and to try to understand why.

Table 4.3: Day parts results

Day parts	Total fish bumps
Night [0h, 6h[	151
Morning [6h, 12h[	95
Afternoon [12h, 18h[	53
Evening [18h, 24h[	171

It is noted that in the *Afternoon* period the activity is much lower than the rest of the day. Curiously, they were only fed once, on average always at 12 o'clock. And at the same time the tank was being cleaned. This may mean that they were less active because they were digesting and also adapting to the temperature of the clean water (acclimatization).

In fact there is more activity at times when there is less light in the tank. This could mean that they only interacted at times when they felt less danger because it was darker, or when they didn't feel the presence of people nearby.

4.2.4 Threshold

As explained in the previous chapter, the value defined as threshold is not the most correct one, and a better one would be defined with the real values of the results. Figure 4.4 is a graphic with shows three lines that represents the mean, minimum and maximum accelerometer values for each individual fish, and the total.

From the graphed values we can see that fish strokes can have significant variation in the accelerometer value. The aim is to determine whether the level of impact was intentional or accidental. It is possible to see from the total average of the hits that a threshold value of 35 m/s^2/s can be considered. However, there are individual fish that have an average lower than this value, so these values should be taken more into consideration. Giving a final threshold value of 25 m/s^2/s.

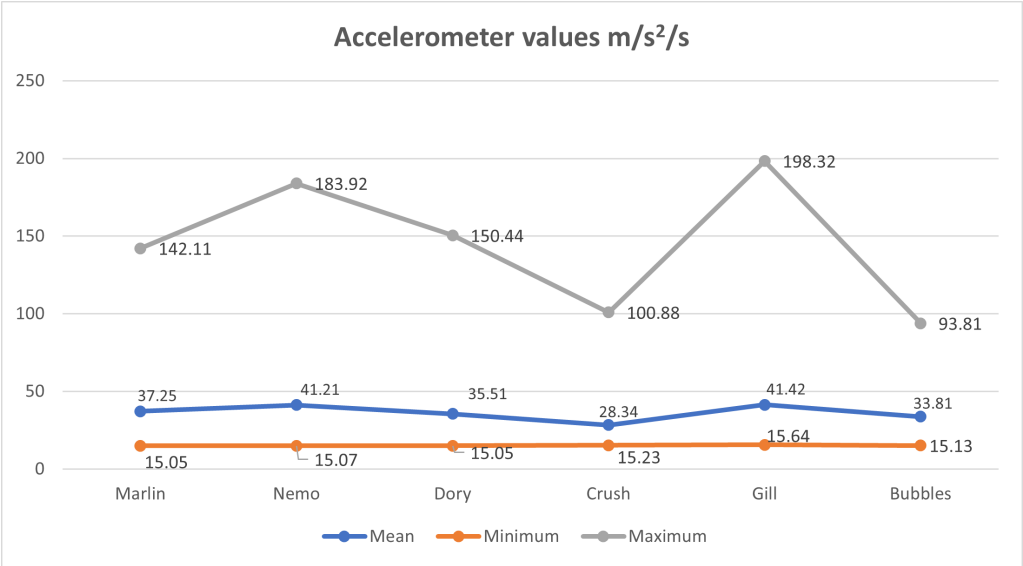

Figure 4.4: State Machine

Chapter 5

Conclusions and Future Work

5.1 Conclusion

To conclude, all the project goals were achieved. First, the prototype of a Bluestreak Cleaner Wrasse was developed. Secondly, the prototype reads the PIT tags injected on the live fishes. Also, the accelerometer complies with giving the information if the studied fish gave a bump to the prototype or simply passed close. Finally, also it was accomplished to collect and save all the data obtained throughout the testing period.

According to the biologists research proposal, it seems that there is no relationship between weight and the number of interactions. However, it is not known if there was any hormonal or stress-related changes, further research is needed to determinate this in the biology field. Another conclusion is that for a broader research,it will be helpful to have a longer period of testing time and different ecosystems to see the behaviour of the fishes and to obtain a larger sample between the fishes and the PCM.

5.2 Future Work

This project has a lot of potential to be greatly improved and explored. It has already been demonstrated that the project can be useful for the study of fish behaviour, so with some improvements it might be possible to obtain better results.

It would be very useful to cover up the communication cable of the antennas and the accelerometer. The cable is notorious, since it is a black cable that comes out from the dorsal column of a small fish. In some cases it can become a little intimidating because it is something very different from what exists in nature. It would be interesting to use some kind of green textile to disguise the cable from a column of seaweed. Also, in the same sense, it might be useful to get another type of material and painting on the fish to make it more realistic.

A new idea to help the PCM look more alive in front of the other fish in the tank is to place a servo motor attached to the cable outside the tank. The servo motor would make a repetitive motion to the cable, and consecutively move the PCM. Nonetheless, it would then be necessary

to filter the information coming from the accelerometer to distinguish the movements of the servo from the fish bumps.

This project uses an arduino to read the data from the RFID reader and the accelerometer, and postriorly sends the information by serial port to an external computer, which will allocate it in a file. One way to reduce the number of devices needed for data collection, would be to replace the arduino by a Raspberry Pi. The Raspberry Pi could simultaneously receive and allocate the data. And, the Raspberry Pi would allow to run two different threads, where one would read the RFID reader and the other the values from the accelerometer. This allowed to have a more correct derivate calculation of the accelerometer.

It would be beneficial for the study of fish behaviour if there were video proofs. For this purpose, a camera would be required and placed inside the tank, which would record whenever the prototype detected a touch. This would allow the scientists of this study to understand what kind of interaction the fish have.

Appendix A

Results Analysis Tables

Table A.1: All findings

Fish id	Final count
Marlin	173
Nemo	99
Dory	70
Crush	69
Gill	67
Bubbles	55

Table A.2: Final results

Fish id	Final count	Weight (g)
Marlin	157	240
Nemo	87	150
Dory	62	220
Crush	61	240
Gill	55	180
Bubbles	48	170

Table A.3: Accelerometer values

Fish id	Mean	Minimum	Maximum
Marlin	37.25	15.05	142.11
Nemo	41.21	15.07	183.92
Dory	35.51	15.05	150.44
Crush	28.34	15.23	100.88
Gill	41.42	15.64	198.32
Bubbles	33.81	15.13	93.81
Total	36.26	15.05	198.32

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