Instituto Superior de Engenharia do Porto

Interim Report

SWIMMING ROBOT

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Abstract

Nowadays, the world´s oceans suffer great sustainability problems that have to be met. At the same time, the state of the art for underwater vehicles is advanced. They can help solve the ocean´s problems and to increase this effect the robots are desired to be energy efficient, for example by mimicking naturally evolved fish movements. Interests for this important field of robotics has to be aroused already at a young age. Therefore, the "Swimming Robot" is a self-assembly toy for children – fun to play with and simultaneously teaching construction, programming and physics skills. That is why the product is prospected to have a unique selling point in the highly competitive toys market. The toy encourages creating and being creative.

To make this possible, it is essential to analyse step by step the challenges that have to be faced. Many technical aspects have to be studied or developed, especially concerning the fact that the "Swimming Robot" is a product that will be under water. Also the marketing concept developed in this report is important due to high competitiveness in this field.

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1. Introduction

1.1 Presentation

We are a team of four members assembled out of a total of 24 international students. We take part in the European Project Semester (EPS) 2013/2014 at the Instituto Superior de Engenharia do Porto (ISEP) that started in the end of February 2014. During the EPS program we worked on the project "Biologically Inspired Swimming Robot" that will be presented in the following. Additional classes about Teambuilding, Project Management, and Communication as well as about Marketing, Sustainability and Ethics & Deontology serviced the progress of the main project.

Name	Background Studies	Nationality	Photo
Alicia Moreno Ishii	Arquitectura Técnica	Spain	
Magdalena Heibeck	Naval Architecture and Maritime Technology	Germany	
Marcin Blazejewski	Mechanical Engineering and Computer Science	Poland	
Rasmus Gabriel Nybjörk	Electrical Engineering	Finland	

Table 1: Team Members

1.2 Motivation

Out of 14 project proposals our team chose to design, develop and implement a swimming robot that is biologically inspired. Our motivation is based on multiple reasons:

1. Oceans are of great importance to us. They cover 70% of the earth´s surface and contain 99% of its living space [1]. We are convinced that any research done in the aquatic field may help preserve biodiversity, find and use natural resources more sustainably, improve means of transportation, understand climate and weather, and finally improve our economy.

2. In addition we like the biomimetic approach of the task. Nature provides a database of solutions that - due to selective pressure - ensure a high degree of efficiency. In our case it was discovered that the appealing nature of fish movement involves higher

efficiency and a more remarkable maneuverability compared to manmade vehicles propelled by thrusters [2]. That is why we want to try discover the principles behind that, mimic them and apply them to manmade craft.

3. Lastly we are intrigued by the general idea of creating a moving robot and assessing our approaches through functional tests and professional feedback.

4. Teach children robotics/physics of swimming objects; draw attention to sustainability needs of ocean.

1.3 Problem

The world´s oceans are threatened by sustainability problems due to impacts created by humans. On the other hand humans strive for technological advancement with the main target of maximizing profits. That is why today´s robots are not only useful for industry to do repetitive processes but have meanwhile gained a high level of intelligence, which makes more applications possible. Regarding the aquatic field they can for example perform tasks of inspection, maintenance and repair in areas not possible or too dangerous for humans to access [3]. Despite it all the sustainability problems of the oceans are not yet met and public awareness about that fact is low. People producing smarter ideas and technologies are necessary to improve the situation while obtaining profitability at the same time.

1.4 Objectives

Our target is to encourage good education for children enabling them to develop our technologies with their expertise in the future. To evoke a general interest for technology children should have the opportunity to experiment with laws of nature and state of the art technologies rather than spending more time in classrooms receiving education in a conservative way. Our task is to make that happen. We want to develop a construction kit for a swimming robot with biomimetic features. By self-assembling the product and being able to change certain features the user naturally learns about robotics and the physics of swimming objects. For our project phase we schedule the design, development and implementation of a prototype that is able to perform basic features of the future product listed in the following chapter.

1.5 Requirements

The prototype is aimed to incorporate the following kinetic functions:

- Forward movement
- Left/right steering
- Up/down movement

In addition an opportunity shall be integrated to change specific physical features of the swimming object such as shape and size of fins, mass distribution and buoyancy.
To comply with the final idea of a self-assembly kit already the prototype should be a modular system - challenging yet feasible to build.

Lastly in the project proposal it is asked for power autonomy of 12hrs.

1.5 Project Planning

1.5.1 Gantt chart

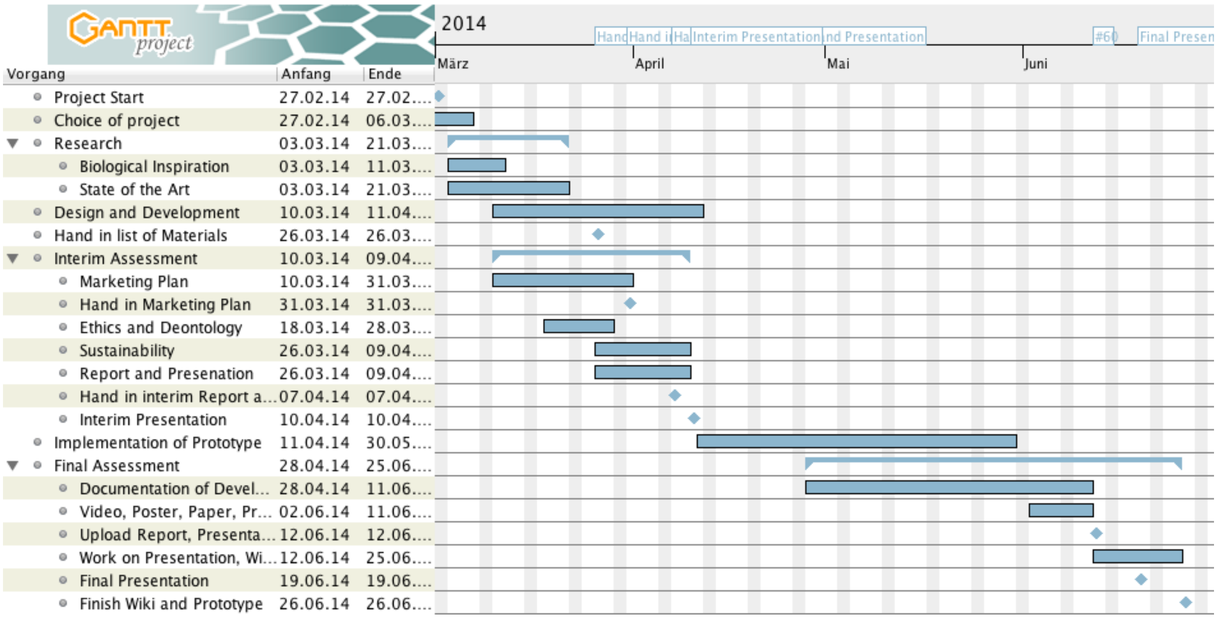


Figure 1: Gantt Chart

1.5.2 Task allocation

Task	Responsible
Biological inspiration	Alicia, Marcin
State of the Art: Robotic Fish	Magda
Structure/Architecture	Marcin, Magda
Motors	Marcin
Electrical Components	Rasmus
Choice of Material	all
Buoyancy and Stability	Magda
Marketing Concept	Alicia
Sustainability	Rasmus
Ethics and Deontology	Magda
Interim Report	all
Interim Presentation	all
Leaflet	Alicia
Build prototype	all
Final report	all
Final presentation	all

Table 2: Task Allocation

1.6 Structure of the report

The report begins by assessing currently existing technologies related to the product. Following to that, the marketing plan, sustainability issues and ethical concerns are presented. Based on this groundwork the technical development is explained and test results demonstrated. In the end the will be a conclusion summing up main ideas, test results and prospects to the future.

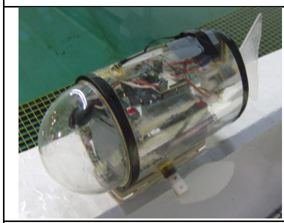
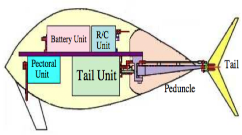
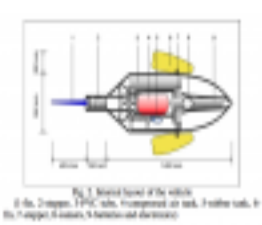
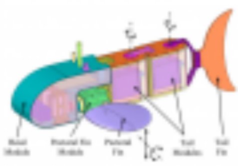
2. State of the Art

2.1 Introduction

Research on the state of the art is the basis for our product development. Regarding the considered problem the most suitable mechanical architecture and electrical components have to be detected.

2.2 Related Research and Products: Fish like robots

In the following an overview of state-of-the-art developments of biomimetic robotics in the maritime field is presented, comparing them by application areas and mechanical structures. This serves as groundwork to pick and combine existing ideas and develop a swimming robot that incorporates many functions while obtaining little complexity.

Picture/Sketch	Intended Application	Mechanical Architecture	Body Actuation	Source
	Inspection purposes; Note: this is the **existing prototype at ISEP**	Two pectoral fins for propulsion, one back fin for steering	3 servo motors	[4]
	Realizing high accuracy of fish movement; possible application area not stated	Special penducle/tail mechanism, bottom fin for steering	RC motor for propulsion two servo motors for up and down motion	[5]
	Semiautonomous Biomimetic Underwater Vehicle for Environmental Monitoring in shallow waters, able to carry payload	2 pectoral fins (1 DOF), 1 back fin, variable ballast tanks, compressed air balloon	3 stepper motors (1 per fin), compressed air tank	[6]
	Neural-based Control of Modular Robotic Fish with Multiple Propulsors	2 pectoral fins with 2 degrees of freedom, 2 moving tail segments	6 servo motors	[7]
	Toy for self assembling (floating)	1 moving back fin, manual direction control by pulling a	1 motor, Gearbox transfers motor	[8]

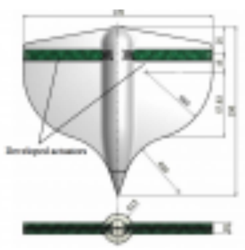
		stopper located at the base of the tail	rotation to swinging tail movement via crank and link rod	
	Toy for self assembling (halfway submerged)	1 moving back fin, manual direction control by adjusting the angle of the tail fin	Submarine Motor Mini and Underwater Gearbox move the tail via a crank and linkage rod mechanism	[9]
	Swim, walk, maintain station, crawl at bottom of sea, 5 degrees of freedom controllable	6 paddles/flippers at sides of cuboid body (3 on the one, 2 on the other) provide thrust and control	6 motors	[10]
	Amphibious Snake Robot that Crawls and Swims	Several identical segments with aligned output axes	1 RC motor per segment producing traveling waves	[11]
	Microrobot that can swim smoothly in aquatic medium; application in medical field and industry	Body with IPMC (ionic polymer metal composite) actuator	IPMC generates large bending motions under low driving voltage (s-shape swimming)	[12]
	Realizing smooth motion like manta with soft body	Rubber body (manta shape), two bending pneumatic rubber actuators with two DOF in front of the fins	Bending Pneumatic Rubber Actuator	[13]

Table 3: Mechanical Structure of Existing Robot

There are three main ways to actuate the body of the fish: use of motors, pneumatic or IPMC (ionic polymer metal composite) solutions. It was **decided to resort to traditional motors** because they are the most commonly used actuator and children should have the chance to experiment with that.

Furthermore, interesting ideas for single features contributing to the fish´s motion were found:

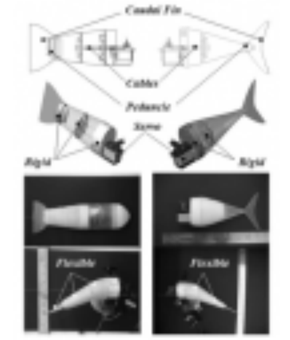
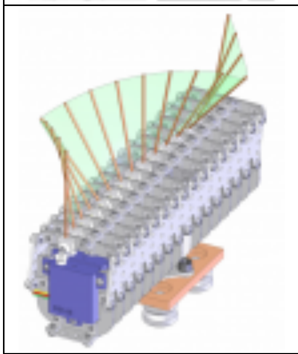
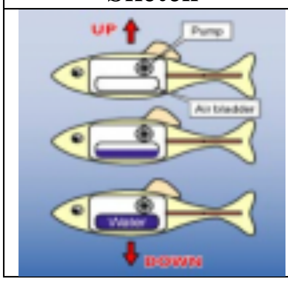
Picture/Sketch	Function/Application	Mechanical Architecture	Body Actuation	Source
	Quite accurate motion of back fin with only one motor	Back fin consists of 3 rigid pieces with flexible parts in between	1 servo motor	[14]
	Underwater vehicles that require a high degree of maneuverability, rapid accelerations and effective station-keeping	Stiff rays connected to actuator, flexible membrane in between	1 RC servo motor per ray	[15]

Table 4: Single Features of Existing Robots

2.3 Methods for Ascending and Descending

One of the major targets is to make the fish go up and down. The following methods for ascending and descending exist: [16]

Sketch	Description	Advantages	Disadvantages
	Pump/piston changes water amount in tank (altered relation between buoyancy and gravitation)	Diving depth of the robot fish may be controlled accurately	Slow response, space for tank/piston, source of air required for ascending

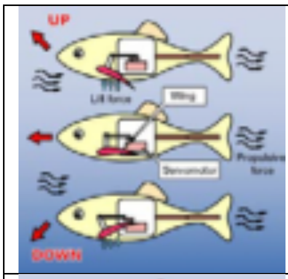
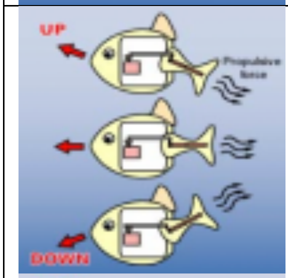
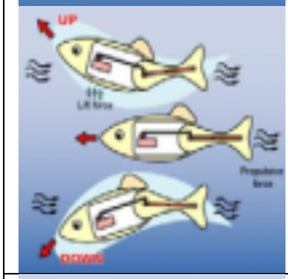
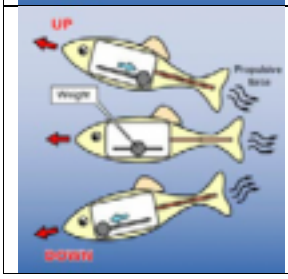
	Changing attack angle of pectoral fins	Quick response and high dynamic performance	Higher swimming speed required to utilize lift force of fins
 	Bending body to certain shape, move up and down by lift forces	Quick response and high dynamic performance	Higher swimming speed required to utilize lift force of fins + more complex architecture
	Changing barycenter and thus pitching direction by moving inside weight	Mechanism is only set inside of the body, so the motion of the mechanism isn't affected by the water flow	Space required in the body, questioned effectiveness regarding mass of changing weight in relation to overall weight

Table 5: Methods for A-/Descending

2.4 Motors

2.4.1 DC Motors

DC motors are electric motors, which rely on magnetic repelling and attraction between magnetic fields. Coil of wire inside the motor with current running through it produces electromagnetic field which being pulled and pushed creating torque, which rotates the motor.

In our project we use one 6-volt DC motor to provide very steady and easy to control movement of the fin responsible for robot propulsion in water. We had to consider different ways of translation of motion between one way rotation of the motor and the "flapping" movement of the fin. Exact examples and designs are provided in further part of the report.

Gears in DC motors allow the change of rotation speed and torque of the rotating shaft, with use of the same input motor. This gave us possibility to choose from a range of small, low cost 6V motors.

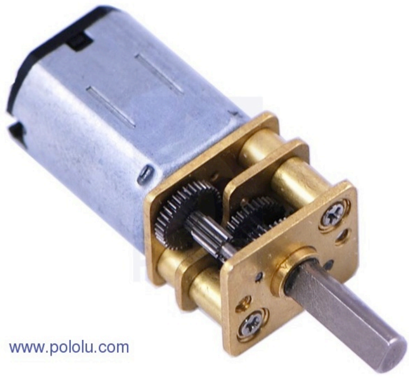


Figure 2: DC Motor

Considered motors are as follows:

6V DC Motors comparison table				
Model	Gear Ratio	Torque [kg-cm]	Rotations per minute	Free Run Current [mA]
POL-993	30:1	0.3	440	40
POL-998	50:1	1.1	625	100
POL-1101	100:1	2.2	320	80
POL-995	250:1	4.3	120	70
POL-994	**298:1**	**5**	**100**	**70**

Table 6: Comparison of DC Motors

All compared motors are available in inMotion store, with the same price of 14.95€ and exactly the same size 24 x 10 x 12 mm. Our choice was the motor with model number POL-994, marked in bold in the table. We choose this motor because our propulsion fin will require a lot of torque but not big rotational speed. One rotation of the shaft will give us one full "flap" of the fin, its amplitude will be easly modified with use of different shaft extensions. Also this motor is very compatible with Arduino control board which we will use a control unit for our robot.

2.4.2 Servo Motors

Servo motor is part of a servo system. A servo motor has a very precise position feedback, the motor can tell a responsible supervisory control exactly how many turns the motor shaft rotated. Along with servo drives, the servo motor used to run very accurately, for example, always keep a certain speed whether driving up or down a hill, or to always stay at a certain place with centimeter, millimeter - or micrometer precision, depending on application. Of course, provided that the resistance to movement does not exceed the design capacity. When the error margins of a few centimeters are acceptable invests rarely in a servo system.

Servodriverns task is to figure out what frequency, and / or current to the motor should be at any given time to complete their task. Servo Driver in itself can be controlled by a control system such as a programmable controller, or be ready programmed for specific tasks and then have one or more "start button".

A typical application of servo motors are two bands that have to go in exactly the same speed when you connect your two servo drivers and allows one to follow the other as a slave.

Another typical application is the control of radio-controlled models, such as aircraft, ships and automobiles. The servo in the picture is such a power that is used for radio-controlled models.

In cars, the word power in a similar fashion, the movement you make with the steering wheel / brake matched with a motion from a motor.

6V servo Motors comparison table				
Model	Range of Rotation	Torque [kg-cm]	Maximum Speed at Rated Voltage [°/s]	rated Current [mA]
hitec HS-422	180	3	286	130
HD- 1160A	180	2,7	165	180
AR-3606HB	360	6,7	165	300

Table 7: Comparison of Servo Motors

hitec HS-422 fit our purpose the best because it used less power and the other was slower than the HS-422 it is also works very good with our control unit Arduino uno R3.

2.5 Control Unit

A microcontroller (enchippdator, enkretsdator, chipset, etc.) is a small computer with CPU, RAM and program memory integrated complete with support functions (clock generator , watchdog, etc.) and different types of I / O devices (such as conversion of analog signals) on a single silicon chip (IC).

These circuits are optimized to operate and work together with other electronic components, and the most common application is embedded systems. They represent by far the most common type of microprocessor in terms of number sold circuits; according to a survey conducted in 2000 was over 90 percent of all microprocessors sold of this type.

Microcontrollers are available in many performance classes and with varying word length (4, 8, 16 , 24, 32 bits , etc.) but the division is far from rigorous . The simplest 4-bit circuits used for simpler rules and control systems and 8 -bit systems can be found in many consumer products. The more powerful 16 - and 32-bit circuits often have performance approaching that of modern personal computers and is used in broadband routers, mobile phones and cars.

The internal memory is generally divided into two or more categories: Writeable working memory and data memory respectively semi-permanent program memory, and sometimes more variants. The software is stored in the "ROM " and can not normally be changed without special tools. It is common that working memory ("RAM") is substantially smaller than the program memory ("ROM").

In development circles used application memory of the flash type (previous EPROM), as this can be rewritten. In production are changed often out against so-called OTP memories that can only be programmed once at the manufacture (or a mask ROM, for really long runs). The programs are written on personal computers in assembly language or high level languages like C, C + + and Basic. The transmission to the microcontroller 's program memory is called programming.

BOARD	INPUT VOLTAGE	FREQUENCY	DIMENSION	PRICE
Arduino Uno-R3	6-20 V	16 Mhz	7,6 x 6,3 cm	19.61 €
Arduino Pro Mini	5-12 V	16 Mhz	3,3x1,8 cm	9.95 €
MSP- EXP430G2	1.8-3.6 V	16 Mhz	6,8 x5,1 cm	4,95 €

Table 8: Microcontrollers

- Arduino Uno-R3 are based on Atmega328 microcontroller and have 14 digital I/O Pins (6PWM outputs), 6 analog inputs, 32k flach memory and 16 Mhz clock speed.

- Arduino Pro Mini are based on the ATmega168, it has 14 digital input/output pins, 6 analog inputs, an on-board resonator, a reset button, and holes for mounting pin headers. This board is intended for semi-permanent installation in objects or exhibitions, and it is suitable for small projects that do not require large processing capability.

- MSP – EXP43G2 LaunchPad are based on the MSP430G2x Value Line MCUs (Microcontroller Unit), this 10 USD board offers ultra-low power consumption, 16 kbyte flash, a 512 bytes SRAM and 20 pins. This device features a powerful 16-bit Reduced Instruction Set Computer (RISC) central processing unit (CPU), 16-bit registers, and constant generators that contribute to maximum code efficiency.

The arduino uno- R3 was the most expensive and biggest but we will use that one because it works best with the other components that we will use.

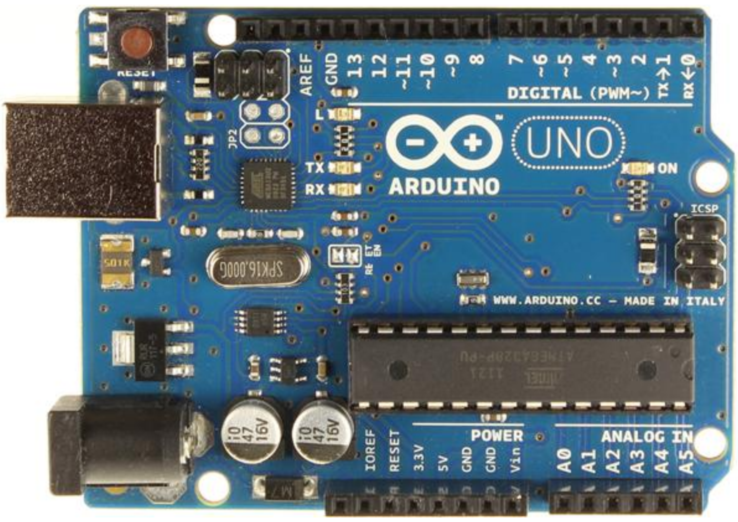


Figure 3: Arduino Uno-R3

2.6 Batteries

Battery cells come in two basic types, namely primary and secondary cells (disposable batteries and rechargeable). The term primary cell derived from that cell type is the primary source of electrical power and is not designed to be recharged. Primary cells convert energy from a chemical reaction into electrical energy that goes on until it is used up.

In the secondary cell is transformed in the same way the energy of the chemical reaction into electrical energy and the rearming made possible the process of going in the opposite direction. By using different types of anode and cathode materials and electrolyte obtained various properties of the battery cell.

2.6.1 Battery types

- Nickel cadmium - NiCd – using nickel oxide hydroxide and metallic cadmium as electrodes, the NiCd is used in applications that require long life, high discharge rate and low price. Main applications are two-way radios, biomedical equipment, professional video cameras and power tools. The NiCd contains toxic metals and is not environmentally friendly.

- Nickel metal hydride - NiMH – This type of rechargeable battery uses positive electrodes of nickel oxyhydroxide (NiOOH) and the negative electrodes use a hydrogen-absorbing alloy. NiMH batteries will not perform well in high rate discharge applications, typically providing only a small fraction of the rated capacity in these instances. NiMH batteries have higher energy than NiCd battery, but they have higher self-discharging rate and shorter shelf life.

- Lithium ion - Li-ion – Emerged in the early 90's, it has a high energy density, a relatively low self-discharge rate, no need for maintenance as well as the ability to provide high current to a system. This type of battery has some limitations, mainly in its maturity and the requirement for a protection circuit in order to maintain the voltage and current within the safe limits. The Lithium ion chemistry is lightweight, does not contain toxic metals like the lead acid batteries and lasts long enough to span the typical life of the product.

- Lithium polymer - Li-Po – Similar to the Li-ion batteries has its main advantages by being lightweight, very low profile, resistance to overcharge and the low chance for electrolyte leakage. On the other side of the scope it may become more expensive than the Li-ion as far as the cost-to-energy ratio may concern.

- Lead acid battery - is the oldest type of rechargeable battery. Despite having a very low energy-to-weight ration and low energy-to-volume ration its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio.

- Nickel- Zink - Ni-Zn is similar to the other nickel based batteries in that they use an alkaline electrolyte and a nickel electrode, but differs in voltage. The gain in voltage means reduction in cycle life. Ni-Zn batteries do not consist of any heavy toxic materials and can be recycled.

We will use a lead-acid battery because they are heavier so we won't need so much extra weight inside the fish and they are also a little bit cheaper, the operation voltage for all the components will be 6V so we will use a 6v battery.

2.7 Remote Control

Radio control is the use of radio signals for remotely controlling a device. The term is often used with regard to radio-controlled models that are controlled from a handheld transmitter. Examples of radio controlled models, model cars, model boats, model helicopters and model aircraft to be mentioned. Also, industrial, military, and scientific research used radio control, such as satellites and space probes. The military has also begun to ripple on various missiles and torpedoes.

Figure 4: Remote Control

Radio controls designed for hobby use usually use the 2.4 GHz or 35 MHz and 27 MHz, but under water radio controls don't work so we decide to make a remote control with a cable.

We are going to use a project case from sparkfun and we will use a PCB eurocard and solder 4 buttons and one potentiometer to control the movement of the fish, we will need a cable with 8 leaders because to get the buttons to work they need plus, ground and one for the signal, they will also need a 2.2kOhms resistor.

Figure 5: Remote Control Case

2.8 Shell and Materials

The shell and the fins are a very important part of the "Swimming Robot" because they are continuously in contact with water. There are many factors to consider like complete water resistance, as well as flexibility and strength of the material. It is essential to choose a material that will not decompose over time. The structure of the robot is

composed of a cylindrical tube (estimated diameter: 15 cm), a spherical head in the front and a plain cover in the back.
Also, it is good for a prototype to have transparent pieces in order to see how the components work inside. Two possible materials are considered to build the prototype:

Material	Advantage	Disadvantage
Acrylic / Poly Methyl Methacrylate (PMMA)	1. Completely transparent 2. High impact resistance 3. Rigid plastic 4. If it breaks or get damaged it will not shatter which is an essential requirement for a toy 5. Light weight 6. Mouldable into any desired shape 7. Can be sawed	1. Transfers heat poorly 2. Combustible 3. Expensive
Polyvinyl Chloride (PVC)	1. Excellent durability and long-life expectancy 2. Highly resistant to degradation 3. Chemical stability 4. Light weight 5. Requires little to no maintenance 6. Low cost material	1. Sensitive to UV and oxidative degradation 2. Not properly used it may be hazardous to health 3. Environmental effects

Table 9: Shell Materials

For the prototype PVC is the best solution because it is cheap and fulfils the requirements to test the functionalities. We are aware that PVC is a toxic material, which is why it may not be the most adequate material for a children's toy. The final product is considered to be made of acrylic because it is a less toxic material. The impacts of the acrylic's high costs have to be assessed in a future marketing plan.

3. Marketing Plan

3.1 Introduction

Buying educational toys for children becomes more and more popular with parents. There is evidence that children who play with construction toys have better spatial ability and creative capacity.
Children learn a lot from playing and making education enjoyable will help them to remember the things they learn and develop a positive attitude towards learning.

The "Swimming Robot" is an educational construction kit for children of an age range between eight and twelve. It has several features:

- Movement like a fish
- Steering (left/right and up/down) can be controlled remotely
- Easy to program
- Learn about physics of motion in the water by customizing parts

The "Swimming Robot" is not only a toy, but also an experience of experimenting with physics and robotics. Children can learn at the same time that they play.

The world of toys is very competitive and there are many products for the customer to choose from. The goal of the marketing is to identify customers' needs and meet those needs in a way that the product almost sells itself. [17] In following chapters the keys for the marketing plan will be developed.

3.2 Market Analysis

3.2.1 Macro Environment

The macro environment includes the major external and uncontrollable factors that can influence a business. These factors typically are the economical, demographical, political, technological, legal, socio-cultural and ecological environment.
It is important for a company to study its environment in overall to define the best possible target-marketing plan.

Economical environment

The European Union (EU) is the largest toy market in the world where consumers spent a total of 16.5 billion Euros on toys in 2011. The EU toy market represents 28% of the worldwide traditional toys' and games' sales.
Despite the current crisis in the EU, the global toy purchasing is projected to rise by about 7.5% annually until 2016. Nowadays games, puzzles and pre-school toys are the most popular type of traditional toys but it should be pointed out that construction toys were growing fastest in terms of sales in EU countries. [18]

The toy business is seasonal. More than 50% of the year's sales are done in November and December, especially in the countries of southern Europe.

Demographical environment

The population is often split into different market groups that can be targeted individually.

By the age of six kids have developed the cognitive abilities to follow directions and to understand step sequences. By the age of seven to eight years some children can build structures using sets with moving, motorized, or computer chip-based components. As a rule, the containing parts of the kits must be very wide in size, colour and shape to increase attractiveness to children.
Construction kits must have at least 100 pieces to provide sufficient material to create own designs. [20]

Recent reports show that the number of children who 14 years old and younger has been decreasing in the EU over the past decade. Nevertheless, the purchase of toys is rising because of a *growing senior population*, that likes to spend money on grandchildren, and *increasing divorce rates*, that make children member of two or more different families. (Erica Augustine)

Political Environment

The political environment in which the company operates has a significant impact on its international marketing activities. A company that is continuously aware of shifts in the government´s attitude and keeps up with frequently changing laws and regulations, will be able to adapt marketing strategies according to that.
The political environment is connected to the international business environment through the concept of political risk, that is the risk of losing money due to changes that occur in a country's government or regulatory environment.

Another key point is the taxes that the European Commission determines for exports and imports. On the European Commission´s website "Trade Market Access Database" there are stipulated all import/export duties and taxes, procedures and formalities, trade barriers and sanitary and phytosanitary issues depending on the "Product Code" and the country. [21]

Social environment

All types of games play a decisive role in the development of children. With adequate games children stand best chances of becoming healthy, happy and productive members of society. Kids who do not play or who do not have the opportunity to play, cannot adequately develop self-control. Over time, kids are to discover what they are good at, what they like, and what they are like, then they will need variety in their gaming experience and a broad assortment of toys to make that possible.

Toys are of essential importance when kids establish their first social relationships. Parents are the first playmates of the infants, but once children reach school age, they spend most of their playtime with mates. [22]

Technological environment

The toy industry is very innovative and companies invest a lot of money in market analysis, research, development and intellectual property protection. 60% of the toys in the market are new products each year. In 2011 90% of the companies launched a new reference, a percentage that in other industries drops to 40%.

It is also important that video games are becoming a substitute for traditional toys, especially when children are a bit older. The recent rise of cross-over toys that combine video games and mobile games and apps with traditional toys offers new market and technological opportunities for traditional toys and games to benefit from the rise in popularity of modern communication technology. [18]

Legal environment

On 30th June 2009 a new Toy Safety Directive, Directive 2009/48/EC, was published.
The member states must begin applying the new measures from 20 of July 2011, except for annex II part III (chemical requirements). Directive 2009/48/EC applies to toys defined as "products designed or intended, whether or not exclusively, for use in play by children under 14 years of age". It substantially amends the old directive in almost every safety aspect, fulfils the newest health and safety standards to the highest level. It also improves the existing regulations for toys that are produced in and imported into the EU in order to reduce toy related accidents and achieve long-term health benefits. [23]

In the EU toys are the product with the most notifications for regulatory non-compliance. The most frequent notifications are related to small parts (a choking hazard) the second most frequent are related to chemicals in toys exceeding regulated threshold values. The number of warnings issued in 2013 was 3.8% higher than in the previous year. The Commission attributes this increase to improved detection and enforcement by national surveillance authorities, rather than a rise in the number of dangerous products being distributed in Europe. [23][24]

Ecological environment

An extremely wide variety of materials are used in toys, and some of them contain Phthalates, Bisphenol A, harmful substances for humans and the environment. These issues will be discussed in the chapter on sustainability.

3.2.2 Micro Environment

The Micro Environment is made up of factors close to a business that have a direct impact on its business operations and success. These factors are suppliers, intermediaries, customers and competitors.

Suppliers

Suppliers are firms and individuals that provide the resources needed by the company and its competitors to produce goods and services. There are a huge variety of toy piece suppliers at a national and international level. For the implementation of our prototype we bought many components on the online stores of the companies Mouser Electronics and InMotion because of their wide range of products and reasonable prices.

Intermediaries

At the moment our target is the “Business to Business” market. The toys market is a very old market with lots of strong companies worldwide. A small business can hardly compete with only one product for sale. A new brand of construction toys could be created in the future operating mostly online to keep costs low. It is presumed though that the idea of a “swimming robot” has better chances to be sold to a toy company rather than selling it directly to the final consumer.

Customers

We set the main customer to be toy companies. There are plenty of them in the market and they are constantly looking for new ideas to develop and improve their toys or to create new ones.
There are some companies specialized in construction toys that are the most interesting to try to sell the “Swimming Robot”.

- Mattel. The toy giant is deeply involved in toy construction. They announced a $450 million purchase of Mega Brands, a Canadian maker of construction toys and arts and crafts. Mattel CEO Bryan Stockton, said "The construction play pattern is popular, universal and has one of the fastest growth rates over the past three years."

-Tamiya. The japanese company has a “Waterline Series” and an “Educational Construction Series” Lineup. Some products are similar to the “Swimming Robot” but do not have a remote control.

- LEGO. Mindstorms Lineup. LEGO blocks combined with advanced technologies can create remote controllable robots. At the moment there is no robot in the lineup of LEGO, which is waterproof and thus can be operated under water. The “Swimming Robot” could serve as a good main idea to develop a new toy and expand LEGO´s existing product portfolio.

Consumer

A recent survey reveals that parents have two main selection criteria when buying toys for their children: they search for the lowest price of toys the kids want and/or try to ensure a high educational value of the toy. Also Char Kochersberger, Toys 'R' Us store manager said "*Parents are coming more for the learning toys as opposed to the fun toys*". To sum it up, parents´ interest in buying educational toys is growing fast.

In close future a survey will be developed to assess parents ´and teachers´ specific preferences when buying a toy.

Final Consumer

In the European Union there are 78 million children that are the toy´s final consumers. They have to like the “Swimming Robot” because they are the ones who ask their parents for it.

According to Gizmag, an emerging technology magazine, the following toys are the ten favourite for kids in the technological field.

Toy	Company	Description	Funtions	Price2	Website
1. Sphero 2.0.	Sphero	Programmable ball	1.Roll on smooth, flat surfaces and carpet. 2. Can also float and spin in water. 3.Smartphone-controlled toy. 4. Compatible Android and iOS. 5. Multicolors LEDs.	94,53 €	http://www.gosphero.com/es/sphero-2-0/
2. Anki Drive	Anki	Smart cars	1. Can drive by themselves. 2. Compatible with iOS. 3. Battle mode. Players get to fire virtual pulse weapons or tractor beams at other cars on screen which disables or slows down the real-life cars.	50,90 €	http://anki.com/
3. litteBits	litteBits	Building blocks	1. Can attach to each other and create cool stuff with them. 2. Can combine them with ordinary objects.	72 €	http://littlebits.cc/
4. Ubooly	Ubooly	Plush toy	1.Listens and responds to a person's voice. 2.Has an iPhone or iPod Touch zip into the cuddly body. 3.Learning toy.	43,60 €	ıttp://www.ubooly.com/
5.Lego Mindstorms EV3	Lego	tic toy / Constructic	1. Construction experience. 2.Control your creations with a remote or from your smart device via Bluetooth. 3.594 bricks and a variety of sensors.	254,50 €	http://www.lego.com/es-es/mindstorms/
6. Sparkup Magical Book Reader	Sparkup	Audio book	1. Captures the audio for each page which kids can playback later.	43,60 €	ttp://sparkupreader.com
7. Nano-Falcon Helicopter		Robotic toy	1.Can hover, rotate, execute turns and fly about with the aid of an infrared controller.	36,15 €	
8. RoboMe	WowWee	Robotic toy	1.Customizable robot a face . 2.Program all kinds of quirky behaviors into it. 3. Compatible with iPhone or iPod Touch. 4.Remote visual telepresenc feature.	72,72 €	http://www.wowwee.com/robome/
9. LeapReader Pen	Leapfrog's	Educational toy	1. Learn how to write stroke-by-stroke. 2. The paper in the workbook incorporates embedded ink.	36,36 €	http://www.leapfrog.com/en-us/store/c/_/N-1z141oj
10. 14-in-1 Educational Solar Robot Kit		Robotic toy / Construction toy	1. Build 14 different robotic creatures and things. 2.Powered by the sun. 3. Capable of moving on land or water.	23,23 €	

Table 10: Ten coolest High Tech Toys for Kids. Gizmag.

Competitors

The toy industry is nowadays one of the most competitive industries in the European Union´s market. Companies have realized that children are a very responsive market target. Due to a great amount of competitors it is advised to make use of patents to save intellectual property.

There are two main competitors:

1. The companies to which we can sell our idea are at the same time our competitors. There are some similar products in the market right now. *Play-i* is a strong competitor. They have developed a good marketing plan and are having good results in sales. Also, *Tamiya* has two similar products in the market, but once you have built the robot you cannot change any components.

COMPANY INSTITUTE	PRODUCT	FUNCTIONS	WHAT TEACHES THE TOY?	AUTONOMY	CUSTOMER AGE	PRICE	COLOR TOY	HOMEPAGE
play-i	Bo&Yana	1.Are programmed and controlled through a tablet (iOS, Android). 2. Colorful lights in their "eyes" and "ears". 3.Peakers for playing back sound effects and music. 4.Sensors for noise, distance, infrared, accelerometers and gyroscopes are all programmable.	Basics of computer programming	Rechargeable batteries	5-12 years, customizable product	165,35 €	Blue	https://www.play-i.com/#our_robots
Tamiya	Mechanical Fish	1. Swim under water. 2.Swim in circles by changing the angle of the tail fin. 3. Waterproof.	How to build a robot	Batteries AAA 4 Hours	'+10 years	17 €	White Red	http://www.tamiyaparts.co.uk/live /catalog/tpproduct_info.php?products_id= 50378
Tamiya	Mechanical Blowfish	1. Swim in the surface. 2. Waterproof.	How to build a robot	Batteries AA 4 Hours	+10 years	18,13 €	Green White	http://www.tamiyausa.com/items/genius eries -educational-kits-50/robocraft-series- 39500/mechanical-blowfish-71114

Table 11: Similar Products in the Market

2. Other people that have same ideas to sell to the companies but we don't know who they are.

3.3 SWOT Analysis

SWOT is an analysis in which internal strengths and weaknesses of an organization, as well as external opportunities and threats faced by it, are closely examined to define a strategy. By understanding the weaknesses of one business it will be easier to manage and eliminate threats.

Strengths	**Weaknesses**
New toy concept	Lack of knowledge in certain fields
Teach robotics/physics/programming to children	Limited budget
Customizable toy	Lack of time to improve the prototype
Sell a toy and an experience at once	Difficulty of finding customers
Add more functions to the toy later	
Opportunities	**Threats**
The toys market is growing	Big companies already control the market
Market for construction toys in Europe is growing faster than other countries	Competitors´ low prices
Children become more interested in robotics	Advertising plays a key role in these market

Table 12: SWOT Analysis

3.4 Goal Setting

The company's long-term goals concerning the product need to be established. These objectives are set for five years and must be realistic. After setting the targets it is still necessary to keep investigating constantly if there are targets missing or market needs changing.

- Create a new brand for toys
- Increase the range of toys
- Develop a website with the possibility of online sales and technical assistance
- Develop compatibility of the toy with mobile applications
- Lower prices by increasing the amount of sales
- Reduce production costs for better profit margin
- Investigate new possibilities for intelligent toys

3.5 Segmentation

The market segmentation helps companies to better understand the needs of customers.
Drawing a conclusion to the previous market analysis and the SWOT analysis, it is interesting to construct a toy that can teach physics, robotics and programming.

3.5.1 Age segmentation

There are toys for the following age segments: infants, toddles, pre-school kids, pre-teens, teens (12 years and above) and adults / parents.
When children are six years old they have developed the cognitive abilities to follow directions and to understand step sequences. Reaching an age of 13 or 14 or older they begin to be more interested in video games. Experts recommend construction games for children of an age between nine and twelve years because they begin to define their personality and interests by interacting with their environment.

3.5.2 Gender Segmentation

Some toys are made according to what fits to a particular gender. For example, there are toys that are suitable for boys like water guns and cars, while others are suitable for girls like teddy bears and dolls. According to a recent market and industry analysis of Hasbro, the toy and game industry is dominated by products for boys. There are also plenty of toys for girls, but most innovations are achieved in the area boys´ toys. Children are outgrowing their toys much faster than they used to, and girls in particular outgrow toys aimed at their age groups faster than boys. Moreover, gender stereotyping by parents and society has an impact on children´s behaviour. This influences what types of toys are being manufactured. [18]

3.5.3 Social segmentation

In 2011 families spent the following money on toys per child: UK 499$, France 410$, Germany 398$, Italy 221$ and Spain 220$. Middle-class families represent the highest percentage in spending money on educational toys. That gives an idea at which kind of families the “Swimming Robot” should aim.

3.6 Strategy/Positioning

The aim of the company is to create a toy for children that has high educational value but is still fun to play with. According to the characteristics of the "Swimming Robot" the target market will be a boy between eight and twelve years from the European Union. Parents will appreciate it for being an educational toy. The final price for the toy could be targeted to 45 - 50 €, a price a quite lower that the normal robotics kits. [26]

4. Eco-efficiency Measures for Sustainability

4.1 Introduction

Sustainable development is about the long-term conservation of the water, earth and ecosystem productivity and reduces negative impacts on the environment and human health. There are three different dimensions:

1. Social sustainability, which is about building a long-term stable and dynamic society where basic human needs are met.

2. Economic sustainability, which is about conserving human and material resources in the long term.

3. Ecological sustainability, it could mean that economic growth must not be at the cost of a segregated and unequal society and a degraded environment. Society should instead aligned with the environment and human health can tolerate and which we term investing in these resources.

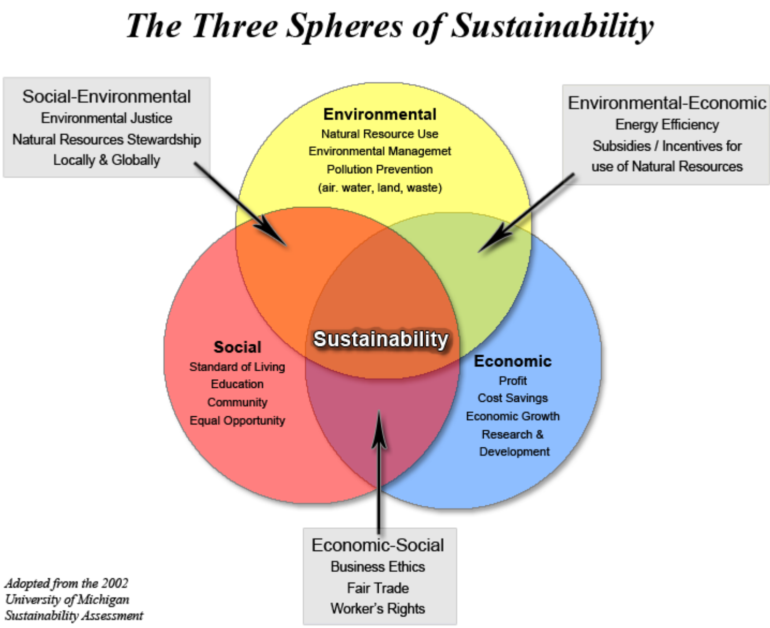


Figure 6: Spheres of Sustainability

4.2 Economical

Sustainable development means that no generation can consume more than that following generations have at least as many resources at their disposal. A lesson from the UN World Summit in Johannesburg in the fall of 2002 is that the old-time organization, regulations and policy instruments are inadequate to deal with the very radical shift needed. We have some knowledge about the global problems but considerably less about how to address them. This represents a major challenge for primarily social sciences to develop knowledge of new institutional conditions for sustainable development.

4.3 Material

Our toy will be made for kids and that's why it is important we use material that use less chemicals and are more ecofriendly so the kids isn't in contact with dangerous material.

4.4 Energy efficient

We will use a fish like movement to make the toy move more efficient and save more energy.

4.5 Different environmental problems

Eutrophication, overfishing, and contaminants in fish ... The list is long with problems that ocean ecosystems have to contend with. Although all sea related problems can differ radically geographically. An important factor is how fast water exchange area had. Baltic Sea, with its limited contact with the sea beyond, more affected by eutrophication and contaminants. Another factor may be the temperature. In cold seas break pollutants down slower than in warm seas. [27]

Climate change affects the oceans

Climate change is because humans emit large amounts of greenhouse gases, particularly carbon dioxide. The emissions come from our burning of fossil fuels. In a hundred years, the average temperature on Earth has risen between 1 and 6 degrees. Even now visible effects of climate change, especially in the oceans.

The climate has always varied, and periods of warmer climate have alternated with colder periods. The big problem now is that change happens so quickly that the environment, plants and animals do not have time to adapt to the changes.

Ocean gets warmer

One obvious effect is that the oceans get warmer. The effects will be most evident toward the poles. Even in our latitudes is shorter winters and decreasing ice cover directly affecting species that live in our seas.

Oceans will become more acidic

The atmospheric carbon dioxide absorbed in the oceans, and the carbonic acid thus formed lowers the pH. Oceans are becoming more acidic faster today than they made 55 million this year.

We know very little about the impact of acidification will be on marine ecosystems. The studies carried out to date on problems with calcification in animals with external or internal skeleton. Some scientists predict that coral reefs will be broken down and maybe even wiped out in as little as 40 years. [28]

Eutrophication

Every year, the Baltic Sea to more than 30 000 tons of phosphorus and nearly one million tons of nitrogen. There lives more than 85 million people in the catchment area and more than 55 million people residing near the coast or in the rivers which flow into the sea. From all of these people and their businesses, as industries, traffic and agriculture, pollution transported to the ocean by rivers and by atmospheric deposition . Some species in the sea taking advantage of the increased inputs of nutrients, while others may be more difficult to compete and decreases in size or disappear completely. Eutrophication can thus radically changing ocean ecosystem.

Eutrophication begins with an excessive supply of nutrients . Too much nutrients leads to increased growth of phytoplankton , for example . The amount of organic matter increases , and this in turn triggers a series of physical, chemical and biological changes in plant and animal communities , as well as changes in processes and in the bottom sediments.

When production of organic matter exceeds the normal consumption of the system , the excess material will not be broken down, and large ground areas will suffer from lack of oxygen and decreasing amounts of benthic animals . Many of these effects are closely related to and dependent on the type of area affected; different effects will dominate in different areas. Baltic Sea region , with its slow water exchange, particularly sensitive to eutrophication. [29]

Contaminants

Contaminants is a collective name for many types of substances that are harmful to biological life. Heavy metals and organic pollutants are two different groups. All though that most pollutants have fallen sharply since the 1970s, represents society's massive chemical use remains a threat to the Baltic Sea environment. The successful efforts to reduce PCB and DDT, however, shows that it is possible to lift a poor environmental situation.

The use of toxic chemicals in society must be radically reduced, ideally cease. Here the political decisions and process development in industry a crucial role in such a change to come about.

Overfishing

Fish's situation, it has recently come into focus, as many have observed changes in stocks. The intensification of fishing has affected populations of mainly cod and herring. today is it estimated that 75% of the major marine fishing areas in the Baltic Sea are either overexploited or fully exploited.

The fish species that are particularly affected by over-fishing is the slow growth and low productivity, often predatory fish. The Swedish list of threatened species ("Red List") occupies 35 fish species, of which ten are cartilaginous fish (sharks and rays). The list also includes economically important species such as eel, dogfish, cod, haddock, and turbot. How many fish can be caught in total, and how much each country can catch, set by the EU. As a basis for the negotiations to get advice from the International Sea (ICES). [30]

Foreign species

A couple of decades ago, interest in foreign species is not large. Occasional findings were regarded at most as curiosities. They had not yet realized the extent of the effects that introduced species can bring. Over the last ten years the interest risen properly. An foreign species is a plant, an animal, a fungus or a microorganism with the help of humans has spread outside of its natural range. This may have been quite deliberately or accidentally.

A species that lives in harmony with nature in their home region could cause a lot of confusion into a new environment that may lack the usual inhibitions. Some species may have a profound impact on their new environment, and there are several documented "disasters" with foreign species. The removal of an foreign species that have established themselves is almost impossible. One should therefore restrict the introduction of new species, especially if they know that they are causing problems elsewhere in the world.

Endangered species

Life has existed on Earth for three and a half billion years. Throughout this time, changes in species composition occurred. Species have become extinct as a result of naturally induced changes in climate and conditions of life, and new, better-adapted species have evolved from earlier forms.

During the Earth's geological history have extinction waves when several species disappeared in a relatively short period of time (measured in a biological time scale) occurred repeatedly.

The wave of extinction of species occurred in the last century, however, differs from the preceding chiefly by the number of vanished species per unit time is now higher than ever before in the biological history of life.

Dumping of waste

The sea has long been regarded as infinite and therefore as a convenient place to dump all sorts of human waste. Earlier in human history could safely marine ecosystems manage to break down a lot of organic waste so that the impact was probably negligible, except for the shallow bays and coastal areas. So it is unfortunately not anymore.

Garbage

There are many different kinds of garbage; plastic package, cardboard boxes, abandoned fishing nets, rope, cans and bottles. Most of the garbage comes from ships. The crew simply throw their waste into the water. Even storms and floods can bring trash from beaches and towns into the sea.

A large part of the rubbish is plastic. From ships are dumped annually more than 6.5 million tons of plastic in the ocean, which very slowly broken down. A plastic cup can persist for 100 years.

The garbage does not just look nasty out. They also kill. Each year, drowning or damaged thousands of seabirds, fish and mammals because they are stuck in fishing nets or packaging. Other starving after they have swallowed plastic bullets that cause them to feel satiated and then they do not eat properly.

5. Ethical and Deontological Concerns

5.1 Introduction

For this project ethics and deontology have to be considered for every decision made. The following analysis focuses on five main aspects that are especially related to this project. They are ethical issues on engineering in general, sales and marketing, academic issues, environmental concerns and liability.

5.2 Engineering Ethics

Here it will be referred to The National Society of Professional Engineers (NSPE) and their general rules for engineering called "Fundamental Canons".

5.3 Sales and Marketing Ethics

Concerning marketing issues we have to be aware that our value promotion has to be solid with the product. We cannot establish benefits that we are not sure about to mislead customers. Furthermore the future price of the product should reflect its true value and costs for usage and maintenance of the product should be fully presented to ensure that each consumer is aware of possible expenses.

5.4 Academic Ethics

It is our obligation to state the truth in all the deliverables and base conclusions on solid facts only. We have to mark cited sections and mention every source used. We should express ourselves clearly to prevent miscommunication. That includes explaining points plainly and justifying every conclusion. An academic ethic issue is also to meet our professors and their work with respect, for instance by taking part in their classes.

5.5 Environmental Ethics

Environmental issues have to be considered during the entire product lifecycle. That is the production process, its lifetime and recycling. We try to minimize the environmental impact of the product by choosing non-toxic substances, recyclable materials, and reusable components. An especially sensitive component is the battery that may not get in touch with the surrounding water. We take extensive care to prevent any leaking of toxic substances. Also we are aware that moving parts of the swimming robot and sharp edges may harm the environment and try to keep their impact as low as possible.

5.6 Liability

Lastly we have to be aware of our responsibility towards supervisors, clients, future customers and the law. If any error occurs, either unintentional or on purpose, we have to bear the consequences. To minimize the probability for that to happen we should gather information about requirements and expectations towards us and in return clearly communicate duties and rights to any other party we are interacting with. The following aspects have to be considered:

- While developing our new product we have to be aware of existing copyrights, trademarks and patents and must not infringe these intellectual properties (counterfeiting).
- We also need to be prepared being confronted by unsatisfied customers. Reasonable complaints have to be dealt with in an appropriate way. A good way to prevent unpleasant situations is defining terms of warranty in order to determine rights of clients and duties towards them beforehand.
- To prevent or at least reduce any potential risks for safety and health while using the product, for instance being cut by sharp edges or swallowing small parts, we have to provide safety instructions in a user´s manual. Especially because our swimming robot is a toy for children we have to advice parents about potential risks and their duties to prevent them. We try to design the construction modules in a way that a minimum of harmful joining technologies (screw-driving, soldering) is required to assemble them.
- In addition the legal framework provided by EU and local governments, which are directives about the usage of dangerous components or hazardous substances, have to be complied with.

5.7 Conclusion

The project is performed in respect to ethical and deontological concerns. Ethical thinking is applied everywhere possible and if contradicting matters arise, an appropriate compromise is tried to be found.

6 Project Development

6.1 Introduction

In this chapter the most suitable architecture for the "Swimming Robot" will be developed. After the principle numbers of fins, segments and actuators have been set, single components will be assessed. At the current status the robot´s hull and required ballast have been discussed more detailed. Information on waterproofing methods will be added in the future. Also this chapter will include functionalities, tests and their results.

6.2 Architecture

The goal is to produce a robot simple enough for the user to assemble oneself but at the same time realizing high degree of freedom while operated. Therefore a simple but efficient mechanical architecture is to be found.

6.2.1 Scope of Initial Development

The motivation for the first architectural approach was **obtaining little complexity by using the least number of motors**. As to be seen in Figure 6-1 a segmented back fin, which is actuated by two servomotors, can propel and steer the fish. An additional servomotor changes the fish´s barycenter and makes it go up/down.

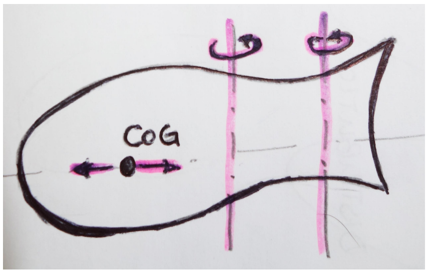


Figure 7: First Architecture

A major disadvantage of this architecture is that it is complicated to control. The servomotors have to produce a travelling wave in order to propel the fish. It might be a tough task for children to figure out how to alter parameters in order to achieve a desired response, for example steering left/right. It rather requires programming skills than the interest in handling and experimenting with technical elements. In respect to these thoughts, even though this architecture presumably requires the least number of moving components it is not the most suitable solution for the proposed problem.

The second approach was aimed to create a command-response-pattern that is easier to handle. Therefore an architecture closely related to the existing prototype was adopted: The robot has one back fin and two pectoral fins at the side of the body (see Figure 6.2). Unlike the existing robot not the pectoral fins but the back fin is used for propulsion - an approach more similar to the natural locomotion of fish.

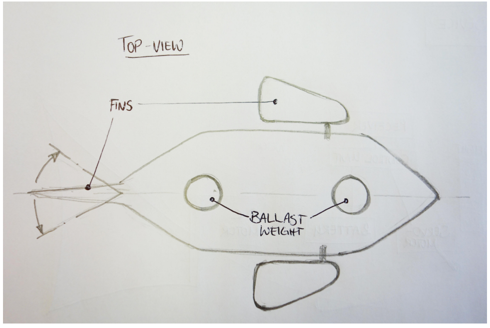


Figure 8: Second Architecture

In order to propel the robot with an oscillating back fin, both, higher frequency and torque than in the existing prototype, have to be applied. It was found that a servomotor is at risk to break easily due to the rapid direction changes. For this reason it is not suitable for this application. A longer lasting solution is to transfer the continuous rotation of a DC motor into a swinging tail movement, as described in the following chapter.

6.2.2 Mechanics of Transferring Rotational to Swinging Motion

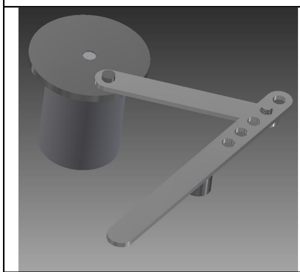
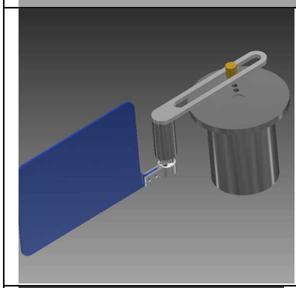
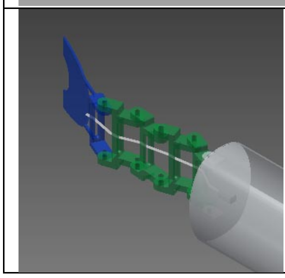
Sketch	Description	Advantages	Disadvantages
	Bar attached to motor, second bar that can rotate around a fixed axis, connection of bars leads to oscillating motion of different amplitudes	- Constant angular velocity, - Possibility to change amplitude of oscillation	- Space consumption, - Hard to make watertight
	Sliding connection of bar to motor, bar rotates around fixed axis	- Less space required, - Easier to make watertight (shaft opening), - Possibility to change amplitude of oscillation	- Inconstant angular velocity (risk of swimming in circles), - Possible friction problems in connection point
	Rotating shaft is bended, no effect in vertical direction due to enough space, transmits determined motion patterns to tail segments	- Undulation motion (can be more efficient than oscillation) - Freely customizable by bending shaft	- Possibly high friction and rattling at connection between shaft and segments

Table 13: Mechanics of Transferring Rotational to Swinging Motion

A consequence of replacing the servomotor by a DC motor is that left/right steering cannot be generated by the back fin anymore. An alternative mechanism will be assessed in the following chapter.

6.2.3 Devices to Steer in Horizontal Level

The following ideas were considered to enable steering in the horizontal level:

Possible Solution	Advantages	Disadvantages
Adjust angle of the oscillating back fin	Similar to fish locomotion	-Axes have to be aligned, -Hard to make watertight
Add fin at bottom	-High reliability (same mechanism is used for boats), -Easy command-response pattern	Additional servomotor and Shaft opening in shell required
Use existing pectoral fins	No additional components necessary	-Risk of rotational motion around longitudinal axis, -Steering by breaking leads to low energy efficiency

Table 14: Mechanisms to Steer

After evaluating the pros and cons of each possibility it was decided to implement an **additional fin at the bottom to steer the robot**. Furthermore, the pectoral fins will have a servomotor each: The effort to have both fins actuated by one motor – with help of cranks and linking rods – is higher than adding a second motor, which is quite cheap and small. This way the possibility is given to experiment how well steering only with the pectoral fins works.

6.2.4 Final Body Architecture

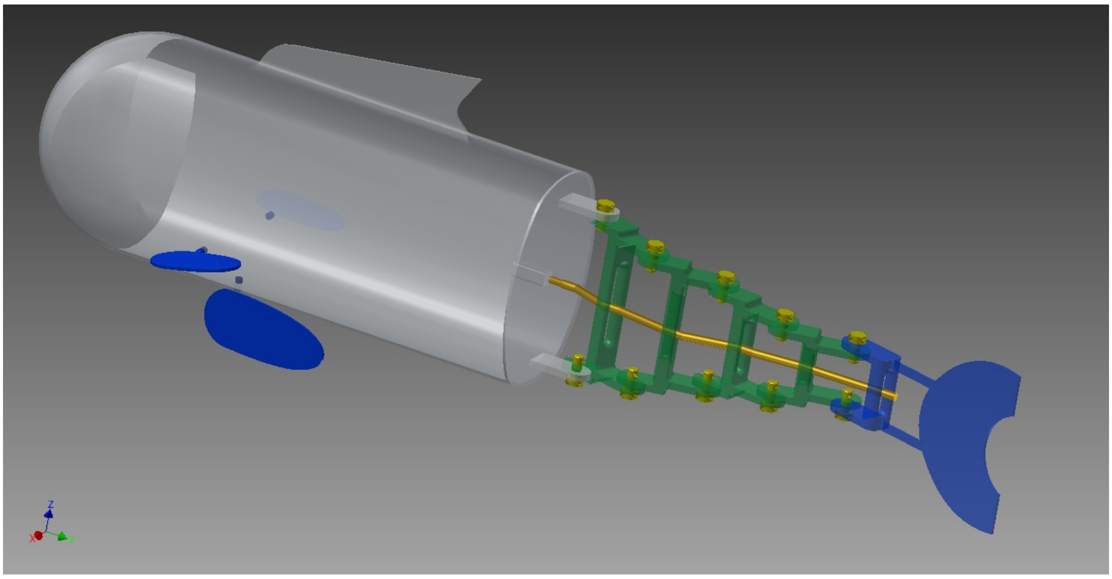


Figure 9: Final Architecture

- 2 servomotors actuating 2 pectoral fins
- 1 servomotor actuating 1 steering fin at bottom
- 1 DC motor with attached bended shaft actuating segmented back fin

6.3 Components

6.3.1 Hull/Shell

It was chosen to use a round shape for the main body because it is a cheap of-the-shelf product and there is the possibility to thread things onto it at the ends. A disadvantage of a round shape is its little stability against rotation around the longitudinal axis. This problem can be solved by a suitable vertical mass distribution and an adequate number of static fins attached to the body. As stated in the state of the art, the material for the prototype will be a PVC tube. It´s diameter is 16 cm, which is an available dimension of these pipes.

The front of the fish will consist of a spherical cape that can be either threaded onto the pipe or fixed with several screws. The sphere is projected to consist of acrylic to enable looking inside the robot during operation.

There will be a planar plate in the back of the fish screwed to the pipe. On top another spherical cape will be glued to create a streamline shape.

6.3.2 Ballast

To balance the robot in its entire weight as well as in longitudinal mass distribution we have decided to add at least two slots for ballast weights in the body of the robot. To change the amount of masses will be one of the later features for the user to experiment with and see how the robot´s position in the water changes (around transverse axis). The material of ballast weights used depends on the overall mass required to outweigh buoyancy. The following rough buoyancy calculation will provide essential information to scale the weights.

Archimedes´ Priniciple:						
The buoyant force is equal to the weight of displaced water:						
	F_buoy =	**V_displ.water * rho_water * g**				
If an object is fully immersed its volume is equal to the displaced water´s volume:						
	V_object =	**V_displ.water**				
The opposing downward force is a result of the object´s weight:						
	F_down =	**m * g**				
To balance a floating object the up- and downward forces have to be in static equilibrium:						
	F_down =	**F_buoy**				
That makes the required mass of the object dependent on its volume:						
	m =	**V_object * rho_water**				
Density of water	rho_water =	1000	kg/m^3			
Volume of object	Body	Height [mm]	Width [mm]	Diameter [mm]	Length [mm]	Volume [mm]
	Cylinder	-	-	150	300	5301437,6
	Total	-	-	-	-	**5301437,6**
Required mass	**m =**	**5,30**	**kg**			

Table 15: Calculation of required Ballast Weight

Considering the high amount of mass required **lead** weights will be used because of their high density and good availability. Semi-finished products can for example be small balls that may be put in canvas sacks and attached to the pipe or even poured in there and fixed with resin. Another option is to fix a belt with weights around the pipe body of the robot or hook a ballast mass at the bottom… (Further, more detailed ideas have to be developed here).

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