Aquaponics System
An EPS@ISEP 2014 Spring Project

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ABSTRACT

The goal of this project, one of the proposals of the EPS@ISEP 2014 Spring, was to develop an Aquaponics System. Over recent years Aquaponics systems have received increased attention due to its possibilities in helping reduce strain on resources within 1st and 3rd world countries. Aquaponics is the combination of Hydroponics and Aquaculture and mimics a natural environment in order to successfully apply and enhance the understanding of natural cycles within an indoor process. By using this knowledge of natural cycles it was possible to create a system with the capabilities similar to that of a natural environment with the benefits of electronic adaptions to enhance the overall efficiency of the system. The multinational team involved in its development was composed of five students, from five countries and fields of study. This paper covers their solution, involving overall design, the technology involved and the benefits it could bring to the current market. The team was able to achieve the final rendered Computer Aided Design (CAD) drawings, successfully performed all the electronic testing, and designed a solution under budget. Furthermore, the solution presented was deeply studied from the sustainability viewpoint and the team also developed a product specific marketing plan. Finally, the students involved in this project obtained new knowledge and skills.

Categories and Subject Descriptors

• **Social and professional topics~Model curricula** • **Hardware~Electromechanical systems** • **Social and professional topics~Sustainability** • *Social and professional topics~Project and people management* • *Social and professional topics~Codes of ethics*

Keywords

Aquaponics, sustainability, natural environment, efficiency

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1. INTRODUCTION

During the first week of the EPS@ISEP 2014 [1], students were presented with several project proposals, including the one to develop an aquaponics system, incorporating eco-friendly sustainable techniques. The team that chose this project was composed of five students, with different nationalities and backgrounds. Anna was a Spanish Mechanical Engineer student, Arlene an English student of Electrical, Electronic and Energy Engineering, Gwénaël was a French student of Environmental Sciences, Natalia was a Polish studying Logistics and, finally, Sean, a student of Product Design from the UK. The team stated that "*as a group we were all interested in creating our own aquaponics system as this is a system/technique that is becoming ever more popular throughout the world, more so in poorer regions and where water is a limited resource.*"

The goal was to design and build an aquaponics system, as sustainable as possible, to support both fish and plant culture, based on water recirculation. The system should be able to monitor and control the most important system parameters, to ensure optimum conditions for both fish and plants. This means using sensors to check temperature and other parameters. The overall budget for the prototype was 250 € [2] and there were a number of mandatory requirements namely: to reuse provided components or low cost hardware solutions and to use open source and freeware software. EPS teams are instructed to adopt the International System of Units (NIST International Guide for the use of the International System of Units) and to be compliant with the Machines Directive (MD), Low Voltage Directive (LVD) and Restriction of the use of certain Hazardous Substances (RoHS) Directive [2].

Being a multicultural team, with no previous knowledge of each other's way of work, one of the first tasks its members are faced with, during team building activities, is to define their own set of conflict resolution rules – Team Work Agreement – using the mechanism proposed by Hansen [1]. The resulting document, signed by all team members, is archived in the team folder. After, another high priority task is the creation of a work plan and the corresponding Gantt chart. The project was divided into smaller parts and created the list of the tasks that need to be completed. Afterwards, each task was allocated to the team members according to their skills and knowledge. Natalia was responsible for the marketing plan, Sean for the product design, Arlene and

Sean for the communication (since they are native English speakers), Gwénaël and Sean for the ecological footprint and sustainability issues, while Anna was in charge of the ethical and deontological concerns. All other tasks, such as studying the project and collecting background information, search for components and materials, development of the aquaponics system and the project development, besides producing all deliverables needed for evaluation purposes, were responsibilities of all team members.

Although this paper is more focused on the technical aspects of this work, according to the EPS rules [1], the students also had to address other aspects concerning their project, namely the detailed project planning and scheduling for the entire duration of the work, the marketing plan for this product, the ethical and deontological concerns related to the product development and lifecycle, and their project management. These aspects, presented in Section 3, are detailed in the team final report [7].

Bearing these ideas in mind, this paper is structured into five more sections, namely: State of the Art, covering related work and methods/technologies within the product; Project Development including overall architecture and components; Experimental Tests and Results presenting the results of tests performed on the prototype; Conclusions, discussing the final thoughts and achievements and, finally, some ideas for Future Developments.

2. STATE OF THE ART

The team started by making a study of the state of the art in this scientific field, focusing in Aquaculture and Hydroponics, and their integration, *i.e.*, Aquaponics, which is based on a natural productive system. It can be described as the combination of Aquaculture and Hydroponics and this is where the name comes from: Aqua-ponics. Hydroponic systems rely on the use of nutrients made by humans for optimum growth of plants. Nutrients are manufactured from a blend of chemicals, mineral salts and trace elements to form the "perfect" balance. Water in hydroponic systems must be discharged periodically, so that the salts and chemicals do not accumulate in the water, which could become very toxic to plants. Aquaponics combines the two systems in a symbiotic environment, cancelling the negative aspects of each. Instead of adding toxic chemical solutions to cultivate plants, Aquaponics uses highly nutrient effluent from fish that contain virtually all the nutrients needed for optimum growth of plants. Aquaponics uses plants to cleanse and purify the water, after which the water is put back in the aquarium. This water can be re-used but must be topped up at certain stages due to losses from evaporation and plant usage. A simple flood and drain system is what will be operated so the plants are able to receive oxygen and small breaks from the water to reduce the chance of root-rot [3 – 6].

The next subsections introduce theoretical aspects related to aquaponics and outline currently available producers/suppliers of such systems, mentioning also its main components.

2.1 Methods and technologies

In order to build a prototype with a high quality standard an in depth research into Aquaponics was performed, covering the existing methods and technologies.

2.1.1 Nitrogen cycle

The nitrogen cycle is the process by which microorganisms convert the nitrogen in the air and organic compounds (such as within soil) into a usable form (see Figure 1). This is an invisible process that is essential for aquaponics systems to work. It is responsible for the conversion of fish waste into nutrients for the plants. Without this process, the water quality would deteriorate rapidly and become toxic to both the fish and plants in the system. The water in Aquaponics does not need to be treated chemically to make it 'safe', nor does it have to be replaced. In aquaponics, a system is said to have 'cycled' when there are sufficient quantities of bacteria to convert all the ammonia into an accessible form of nitrogen for the plants. The bacteria colonize naturally the system, *i.e.*, the water column and biofilter (clay pebbles in our case) [8, 9].

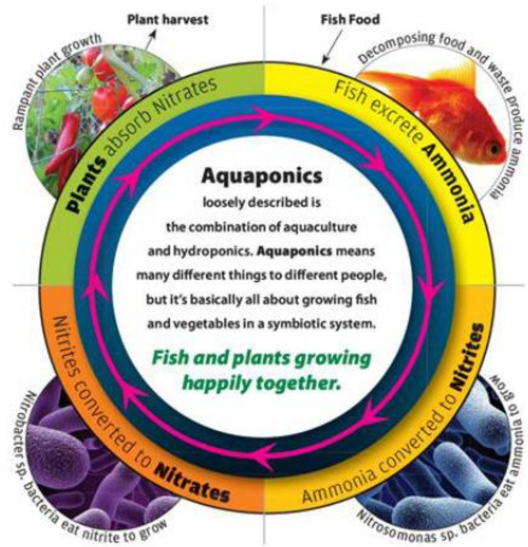

Figure 1. The nitrogen cycle in an aquaponics system [10].

The bacteria convert the ammonia into nitrite and then the bacterium converts the nitrite into nitrate (NO_3). Nitrate is a very accessible nutrient source for plants. Fish will also tolerate a much higher level of nitrate than they will ammonia or nitrite. When all these bacteria are found in sufficient numbers in order to convert all of the ammonia and nitrite being produced in a system, it is said to have 'cycled' [11].

In short, aquaponics is an intensive aquaculture system [12] with a "debugging" system constituted by microorganisms to decompose the organic materials present in the fish's dejects into salts (nitrates, phosphates, *etc*.) and, finally, a hydroponics system to perform the biofiltering of these salts originated by the microorganisms, ensuring that no accumulation of decomposition products occurs.

2.1.2 Illustrative example

It is in fact a near self-sustaining ecosystem, which requires minimal input and includes live bodies within an ecological cycle (Figure 2):

1. Fish are fed and produce excrement rich in nitrogen (ammonia (NH_3) and urea), phosphor and potassium. This excrement is the source of nutrients for the plants. The fish food returns to the water in the form of fertilizer (excrement). Since ammonia is toxic for fish, the water has to be filtered to reduce the level of the ammonia so the fish will survive [13].
2. The water of the tank is pumped and sent to grow bed where plants/vegetables are grown in a neutral substratum of expanded clay balls. Complex natural reactions are set up where bacteria transform ammonia into nitrites then nitrates.
3. Plants can use the nitrates and absorb them by their roots.

4. This produces a natural filter, which clears the water of its toxic components, avoiding increasing the concentration to toxic levels.
5. The clean water is sent back to the tank.
6. The water on return will at one point be open to the air to oxygenate it (this oxygen will be useful for the fish, plants and bacteria).

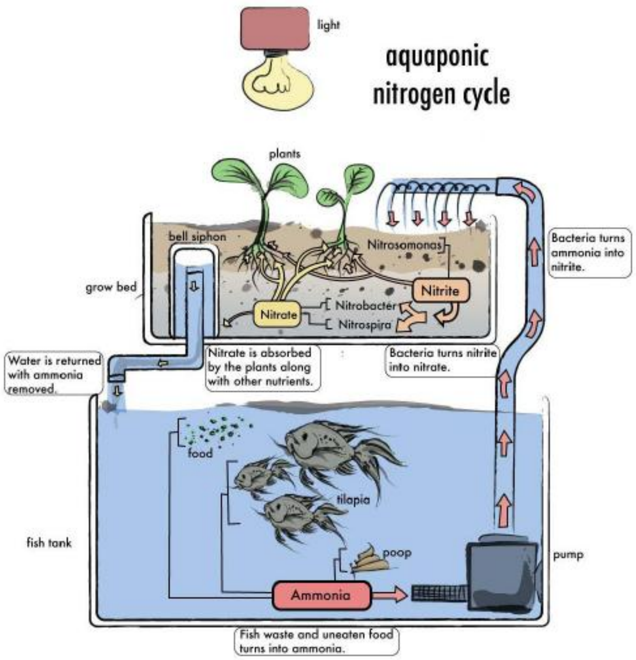

Figure 2. Work principle of an aquaponics system [10].

2.1.3 Types of aquaponics systems

There are three commonly used types of aquaponics systems [14]:

1. Media filled beds are the simplest form of Aquaponics. They use containers filled with media of expanded clay or similar. Water from a fish tank is pumped over the media filled beds, and plants grow in the media. This style of system can be run two different ways, with a continuous flow of water over the rocks, or by flooding and draining the grow bed, in a flood and drain or ebb and flow cycle.

2. Nutrient Film Technique (NFT) is a commonly used hydroponic method, but is not as common in Aquaponics. NFT is only really suitable for certain types of plants, generally leafy green vegetables as larger plants will often have root systems that are too big and invasive.

3. Deep Water Culture (DWC) works on the idea of floating plants on top of the water allowing the roots to hang down into the water. This method is one of the more commonly practiced commercial methods.

Since the media based system has been found to be the most reliable and the simplest method of Aquaponics, the current prototype is built this way. Additionally, this kind of set-up requires the least maintenance in comparison to the types presented above [14].

2.2 Related work

The state-of-the-art survey analysed several prototypes under development as well as existing commercial aquaponics systems. Currently, it is possible to find on the market many aquaponics systems [7] but, from the research conducted, no commercial producers of aquaponics systems were found in Europe. However, if the intended market is specified as being the Indoor Aquaponics then the market shrinks vastly. This market can be further reduced by adding the term ‘Designer’ to the aquaponics system, as many consumers do not want to decorate their home with unpleasant objects. Overall, there has been identified only one real competitor in the household aquaponics market which can be seen in Figure 3. All other systems reviewed lack the necessary appealing design to be placed indoors as an adornment.

Figure 3. Aquafarm [15].

2.2.1 Back To The Roots

Back to the Roots is a US company established by a group of Berkeley students. In their online shop they offer for sale two products: one is the Mushroom Kit (to grow our own mushrooms) and the other one is the Aquafarm (Figure 3), which they describe as a “Self-cleaning fish tank that grows food” [16]. The Aquafarm is a simple set-up product that enables the consumer to have a small Aquaponics system within its home. The design is basic and simple to manufacture, however it is prone to failing after a short period of time due to its design. The difference between the proposed system and the Aquafarm is that it is able to monitor parameters within the water to ensure the fish’s safety, and uses a traditional aquarium, with a simple LED system, to enhance the viewing of the tank.

2.2.2 Backyard Aquaponics

Backyard Aquaponics is a leading edge aquaponics company launched in Western Australia. Initially it was just a group of people offering support and information for people interested in the subject of aquaponics. Today, the company is still a well-known provider of books, magazines and DVD concerning the topic but it is also a rapidly developing online store offering a wide range of aquaponics systems. Backyard Aquaponics provides worldwide shipping for some of their products. The rest is available in their retail store located in the Western Australia [17]. The cheapest and the smallest system offered by this company is the balcony aquaponics for 995 USD, and definitely not an adornment object to have in the living room.

2.2.3 Nelson Pade’s shop

Nelson Pade’s shop is a USA family company that has been designing and researching aquaponics systems for nearly 25 years. They launched their online shop in 2005 and are still expanding. The shop does not ship their products outside of the USA [18].

The smallest and cheapest product is an aquaponics system for use at home or school priced around 3000 USD. This system is already a "small supermarket" – it can produce about 50 kg of fish and almost 1500 heads of lettuce a year, but it's not a pretty solution to be indoors.

2.3 Components

During materials procurement phase, the students got acquainted with the characteristics of some electrical components and materials needed for the construction of aquaponics systems (namely power sources, actuation systems, sensors, and controller systems), in order to understand their differences and make a sensible choice of the materials to use in the prototype.

There are some basic components that every aquaponics system needs, regardless of its type. There can be some variation in what is actually used for each component, usually dependent on how much money it is intended to spend. The following components are all needed for an aquaponics set-up.

2.3.1 Fish tank

Apparently any waterproof packing container can be used as water-tight, food-safe and fish safe. The material must be resistant to water, avoid to contaminate or not impart colour to water and be transparent (and its transparency should not change over time), at least for the major part of the container. Its size depends on the number of fish to accommodate and on the size of the grow bed. To build this prototype the team chose a 28 l tank, made of acrylic glass (Plexiglas). Its shape should facilitate spontaneous constant cleaning of the transparent area [19].

2.3.2 Grow beds and growing medium

An aquaponics media filled grow bed is simply a suitable container that is filled with a growing media such as gravel, hydroton (expanded clay) or lava rock. It performs four separate functions: (*i*) provides support for the plants and for the roots to take hold; (*ii*) is responsible for mechanical filtration; (*iii*) is a source of mineralization; and (*iv*) is a biological filter.

A grow bed can be made of a variety of materials but care should be taken to make sure it fulfils certain criteria. First and foremost, it should be safe to use and should be made of materials that will not leak unwanted chemicals into the water, or that will affect the pH of the water [20].

The grow bed was built from 5 mm acrylic and filled with small plant pots that would hold the expanded clay pebbles as they are the lightest and the cheapest media available. This grow bed must be provided with a system allowing the water to leak back into the fish tank in cascade form, to promote the water oxygenation.

2.3.3 Pump

A water pump is needed to circulate the water from the fish tank through the grow bed and back to the tank. The velocity of the water flow must be sufficiently fast so as to periodically renew all the fish tank water but cannot be too fast to allow the microorganisms to adhere to the growth bed – usually, a good estimation is 5 m^3/d to 23 m^3/d [21]. The selected pump was the Syncra Silent 0.5 Multifunction Pump.

2.3.4 Tubing

Tubing is needed to carry the air and water through the system. Water pumps generally use half inch tubing while air pumps are set up for quarter inch tubing. Plastic tubing is available in both clear and black; black tubing deters algae from growing and clogging the tube.

2.3.5 Plants

There are over 300 different aquaponics plants. The major group that will not grow are root vegetables [21, 22]. Since the Aquaponics System is described as a small kitchen garden, it is recommend growing common herbs such as basil, thyme or rosemary.

2.3.6 Fish

Climate and available supplies are the major factors that need to be considered before choosing the type of fish for an aquaponics system. The fish and plants selected for the Aquaponics System should have similar needs as far as temperature and pH. There will always be some compromise between the needs of the fish and plants, but, the closer they match, the biggest the success [23]. The number of fish in the system is a constant subject of debate among people who practice aquaponics. To ensure the safety of fish and plants, the parameters of the water should be frequently controlled and level of fish stock should be adjusted to the test results [13].

In the Aquaponics System, the tank will be stocked with Convict cichlids (*Amatitlania nigrofasciata*) since they do not require much space and are easy to take care [24].

3. PROJECT DEVELOPMENT

This section presents the preliminary studies performed to design the Aquaponics System, including the mechanical and electrical architecture, and to define the set of functionalities.

3.1 Eco-efficiency measures for sustainability

The design and development of an Aquaponics System emphasizes the eco-efficiency measures for sustainability considered during the system development. During the project, the team had to address the three spheres of sustainability, namely the environmental, economic and social impacts associated with the product they purpose to develop, as well as its lifecycle analysis [7].

From the stated problem, the team's idea focused on the sustainability of the system [7]. Practiced in a classic way, agriculture and aquaculture present big economic and environmental inconveniences. Agriculture requires important contributions in fertilizer and water, which are broadcast in the earth with a bad yield: a large part of these contributions gets lost in the ground and does not benefit the plant, causing waste and pollution. On the other hand, the intensive breeding of fish generates a large amount of organic waste, which threatens the environment when released. Combining these two cultures cancels out the negatives of each by working together [5].

In the EPS@ISEP Energy and Sustainable Development module, the team addressed the set of eco-efficiency measures for sustainability to take into account during the project development and latter industrialization and commercialization. It is of particular importance to state that the economic impact of aquaponics can be extremely large if done correctly. As with regular farming, aquaponics requires land in order to set-up the system. Initially aquaponics is very expensive with its set-up costs compared to agricultural farming due to the need for tanks, piping, media, etc. But this initial cost is reduced by larger profit margins due to aquaponics allowing plants to grow faster and is an organic system with the plants being healthier than unnaturally fertilized plants. Couple this fast, healthy growth of plants with a large fish farm below and the aquaponics system is a two for one. Also, organic foods are on the rise across the world. People nowadays look to healthy alternatives to cheaply manufactured/processed foods. With the world now looking to save money and eat well this is possible by combining two forms of farming at once. Organic plants/vegetables coupled with organic fish not reared in an overcrowded farm. Furthermore, the future is green and with the reduction of natural resources straining. Aquaponics reduces the strain on resources by allowing the user to both breed and eat the fish within the system and grow/harvest the plants that are produced. This system is not completely sustainable but for the future it has a large reduction on key resources such as water, requiring only 10 % compared to agricultural farming.

Through sustainable manufacturing and the use of recycled materials (glass, plastic, *etc*.) the team believed that they could create a product with little impact on the environment. This footprint would be continuously kept low by the correct use of the system which would need up to 90 % less water than traditional farming and the only real input would be the energy to power the electronic system.

3.2 Marketing plan

In parallel with this study, in the Marketing and Communication module, the students defined the market plan for the product. They researched the market and identified the customer's requirements the best they could, to define a product that fits into these needs. This knowledge allows the team to create a customer orientated marketing strategy and develop an integrated marketing program. With this purpose, the team performed an environmental analysis, consisting of a Political, Economic, Social and Technological analysis (PEST-Analysis) of the macro-environment and of the micro environment, and a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, defined the strategic objectives for the project, performed the market segmentation, defined the positioning of the product and, finally, defined the marketing mix.

Based on the market analysis [7], the team decided to target the household market, as a small system would be easier to control and keep sustainable compared to a large (small farm) sized system. Such a system would also allow creating an aesthetic product for the home, easier control over the environment and would require a smaller electronic system. Even though there are many aquaponics systems in use at a large scale, there are not many for indoors usage, making this area an interesting target market. With the recent increase in both sustainable products and the purchase of organic foods, there is a large market share available for quality aquaponics systems.

The students also concluded that there are three regions in the world where organic food production gained popularity during the last 15 years - the USA, Australia and countries of the European Union (EU). Since the main competitors are operating within the Australian and American market, the team chose the countries of the EU as their target region.

To fully achieve these objectives, the design is focused on creating an aesthetic and attractive look for a modern indoor Aquaponics system.

3.3 Ethical and deontological concerns

Finally, in the Ethics and Deontology module, the students analysed the ethical issues surrounding the product as well as more general ethics on a wider range of issues. In several cases, ethical conflicts and difficulties are encountered in the process of developing, launching and selling a new product. These conflicts can often be complicated and, in order to be able to find the right solution and have everyone's best interests at heart, it is needed to adopt a concrete set of ethics. Regarding the ethical and deontological concerns faced by the students while developing the aquaponics system, they addressed aspects related with engineering ethics, sales and marketing ethics, academic ethics, environmental ethics, liability aspects, and intellectual property rights.

3.4 Design

Since the project proposal did not impose any restraints on the physical appearance of the product, the team could be creative.

The initial design aim was to be sleek and simple, avoiding to be an intrusive object in the home. This is where the cylindrical shape came into the design. However, the development of this main idea came quickly through the research stage of the project. It was found that the cuboid tank would contain more water due to its corners, when compared to a cylindrical shape. This would also improve the well-being of any fish kept within the tank as fish prefer a large body of water to swim freely.

The change of shape provided a stronger base for the tank but produced weak spots at the corners. This would be tackled by metal supports hidden behind the veneer/plastic strips that would wrap around the base and top. The design would incorporate the Light Emitting Diode (LED) strips around the underside of the grow bed for aesthetic appeal [19]. Therefore, the grow bed design follows the shape of the cuboid tank apart from an area taken out the back middle section. This allows the pump to sit in the middle of the tank and feeding of the fish with ease. This area will often be covered from view by the plants growing within the Grow bed and does not take anything away from the physical appearance of the tank itself (Figure 4).

Figure 4. Design of the system.

3.5 Mechanical architecture

3.5.1 Bell siphon

To ensure even and intermittent (periodically fills and empties the growing bed) flow of water throughout the grow bed, it was decided to use a simple method inspired by the bell siphon (Figure 5). This method simply involves a tube with a smaller diameter than the pump tube so that the grow bed could fill with water as the smaller tube could not expel the rising water as quickly as it was being pumped into the grow bed. This small tube would be surrounded by a similar guard/filter to stop any waste/dirt.

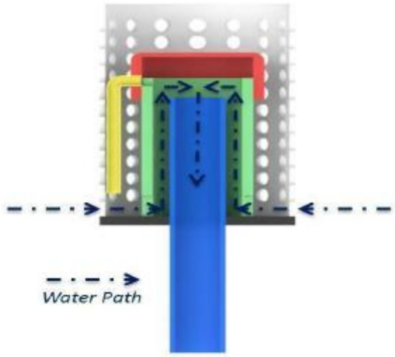

Figure 5. Bell siphon water path [25].

3.5.2 *Fail safe development*

Originally it was planned and designed to have small cut outs where the pipe entered the grow bed as fail safes in-case the bell siphon/stand pipe failed. It was found that these cut outs would not direct the water directly back to the tank and this could lead to splashes over the side of the tank. The development of this was to use a single pipe at a pre-set safety level.

The pipe itself would be larger than the pump pipe so that it could remove the water quicker than it was coming in to the grow bed so that it would not spill over the side or reach the height of the electronics casing. The fail safe stand pipe can be seen in Figure 6 and clearly shows its large size to easily remove the water. Two holes were placed to limit the height of water in the growing bed, thus preventing the water entry into the housing with the electronics and itself spill out of the fish tank (detailed in the recess behind the electronics housing in grow bed, as depicted in Figures 7 and 8).

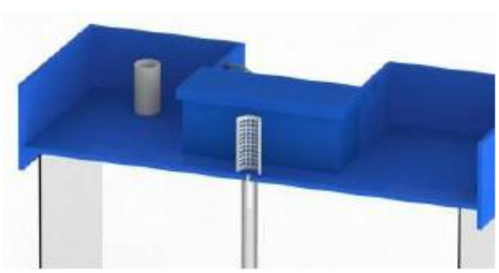

Figure 6. The fail safe stand pipe.

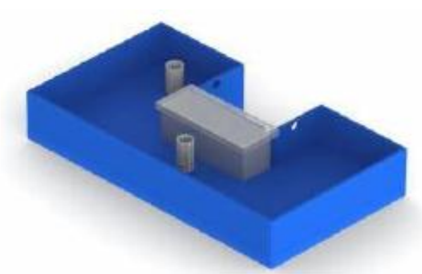

Figure 7. Final grow bed design.

3.5.3 *Grow bed*

Much of the grow bed (Figure 7) was developed during the development phase to fit with the changing electronic and design demands. Cut outs were added to the bed to allow the pump tubing to go straight into the bed instead of sitting atop a side (Figure 8). The sides of the bed were increased by 10 mm to allow extra space for water. As can be seen in Figure 9, holes were added for the stand pipes, and stabilizing features were added to keep the bed in place.

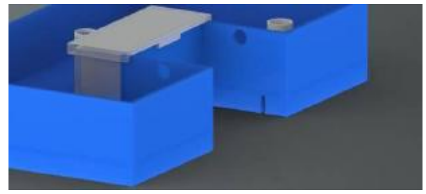

Figure 8. Cut outs in the grow bed.

Figure 9. Grow bed cross-section.

3.5.4 *Electronic housing*

The placement of the electronics was an area which required a large amount of time due to the safety risk between electronics and water. It was decided to create a small space within the grow bed for the electronics (Figure 10). This small area would come with a lid for easy removal of the electronics while also keeping them safe from water splashes. The housing should also include a small cut out from the back where the wires could pass through so that the lid could stay secure.

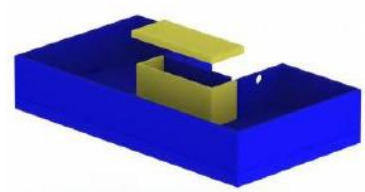

Figure 10. Electronic housing.

3.6 Electrical architecture

Aquaponics systems need to frequently check the water temperature and pH level [26]. Therefore, the Aquaponics System will monitor temperature, pH and the ability of oxidation / reduction potential (ORP) of the tank, display the results on a Liquid Crystal Display (LCD) screen and control the water flow. A microcontroller board will be responsible for performing these tasks automatically. The next step was to choose the components and assemble the electronic control system.

The motherboard chosen is the Arduino Duemilanove ARDU-004, programmable with the free Arduino software. It has 14 digital pins operating at 5 V, which can be used as an input or output, as well as 6 analog inputs. The selected LCD module, which is small and cheap, is connected to the power supply (5 V) and to the Arduino motherboard. The temperature sensor chosen is the DS18B20. It is waterproof, has a temperature range sufficient for the application and is powered by the data line to the Phidget Interface Kit 8/8/8 Model: PHD-1018_2. The ASP2000 pH sensor was selected to measure the pH level from 0 to 14. It requires a pH/ORP adapter (PHD-1130) to connect to the motherboard. Since all selected components need 5 V power supply, the choice was the INM-0761 power supply, which outputs sufficient current for the whole control system (2.5 A).

3.7 Functionalities

The Aquaponics System operates as following:

1. The water from the fish tank is pumped in the grow bed by the water pump. The pump is controlled by the Arduino, manipulated by the relay and programmed to switch on/off at certain intervals.
2. When the water level reaches the upper limit of the siphon bell, the grow bed must be emptied and refilled. This process should operate intermittently throughout the time duration that the pump is turned on. At this moment plants are provided with necessary nutrients and then water flows back to the fish tank through a small pipe.
3. Sensors within the tank send information to the Arduino, which is then displayed on the LCD screen.

If, for an unknown reason, the siphon bell does not work, or is not sufficient to discharge the water at the same rate that the pump fills the grow bed, the two side outputs must ensure that the water level inside the grow bed does not increase and overflow out of the aquaponics system.

4. EXPERIMENTAL TESTS AND RESULTS

Prior to the ultimate test (whether or not the integrated aquaponics system works), the team specified the following set of functional tests to be completed by the end prototype in order to be considered functional: (*i*) the water must be pumped from the tank to the grow bed at a set time according to the Arduino, (*ii*) the water must then slowly drain from the grow bed over a set period of time, (*iii*) the fail-safe pipe must remove all water in case of a pump malfunction, (*iv*) sensors must relay information to the user at all times through the screen, and, finally, (*v*) both plant and fish culture must live together safely in a symbiotic environment.

4.1 Functional tests

Tests were performed to ensure that all components would be safe within the electronic system. Additionally, were completed tests to check three different areas of the electronics: (*i*) relay, (*ii*) current driver, and (*iii*) sensors. All these tests were accomplished successfully.

4.2 Final assembled system

Figure 11 depicts a photo of the assembled Aquaponics System.

Figure 11. Picture of the Aquaponics System.

As it is possible to see in Figure 12, on a later stage of the project implementation, it was decided to build a specific box for holding all the electronics and also the water pump. On the detailed picture of this box, it is clearly visible the information concerning the pH and temperature of the water displayed on the LCD.

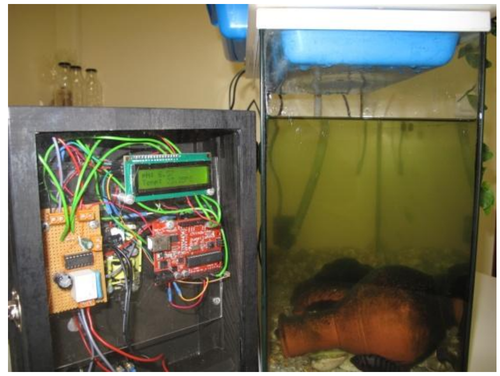

Figure 12. Picture of the final assembled system.

The system has been running successfully for about a year. It has sustained six Cichlid (*Amatitlania nigrofasciata*) fishes together with two ornamental plants: maidenhair fern (*Adiantum capillus veneri*) and creeping fig or climbing fig (*Ficus pimila*). During this period, the plants had to be pruned several times due to extensive growth.

5. CONCLUSIONS

The main objective was to create a working system that supported both fish and plant cultures and, through research and development, it is believed that a system has been created that can complete the required objective and be aesthetically pleasing. Due to the electronics put in place within the system and the necessary tests conducted, it is possible to monitor the system and ensure optimum conditions permanently. In order to be sustainable, it is believed that the system should run at 15 min to 30 min intervals. This would save power compared to a continuous system and provides plants extra oxygen in order for quicker growth. The students state that "*we have completed the requirements and also expanded so that the system will be successful within the intended target market due to an aesthetic design and simple functionality.*"

Regarding the process, the team reports that: "*After moving swiftly through the design stages and using all aspects (ethics, marketing, etc.) to create a quality design, we found that it was possible to create a simple product that fitted our needs. However, the technology/electronics that would be incorporated in the system also affected the final design due to restraints regarding size and placement. Taking this into account we developed an attractive system that combines art and technology together. Through development we were pushed to change many features of the design and many of these simplified the final product and led to an overall cheaper and easy to manufacture prototype. Overall, we found that from the initial brainstorming to the final renders, our ideas of a successful and quality aquaponics system had changed vastly. This knowledge was gained mostly through research and we believe that this led to the creation of a desirable and functioning system that fits well into the intended markets.*"

In the end of this project, the team members gained new knowledge and skills difficult to achieve in a traditional capstone project. The project itself is a fact of sustainable fish breeding and plant cultivation biology. Having the smart aquaponics system is an asset to the users, and this effort to add electronics and computing was a successful exercise of union of the chores of various aspects in which each specialty can only be enriched by the harmonization of all the different knowledge needed.

6. FUTURE DEVELOPMENTS

Aquaponics is a climate smart agriculture system that allows people to take the wild nature for the comfort of their homes.

Regarding future developments, it would be interesting to create a cheaper product made from recycled materials to be shipped / manufactured within third world countries. The benefits of aquaponics systems within these countries would be immediately felt due to the increase in both food and water resources.

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