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AQUAPONICS FOR RURAL COLOMBIA

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ABSTRACT

Aquaponics farming is both efficient and environmentally friendly. It can be used where there isn't fertile land and where water access is limited. This makes it a great solution for families in rural Colombia to grow fresh food in their own backyard. Current prefabricated aquaponic systems cost $3000 or more to purchase [3] and rely on a stable electrical grid. Our solution is low cost at $563 U.S., made of easily accessible materials, and uses a manual hand pump instead of an electric pump. An optional sensor system will run off of solar power and help the user monitor the fish and crops.

Instead of selling a prefabricated system, our final product is an open source instruction manual so that anyone can build their own. The prototype system is fully operational; cycling water with the hand pump was successful and the fish and plants can easily taken care of. Our design is set to be implemented in Colombia through a workshop run by members of our team in May 2019.

BACKGROUND

People in rural Colombia will benefit from a new agricultural product that will make farming easier and more accessible to everyone. Currently, many people can not afford the expensive equipment needed to farm large crops and most lack access to land. Land is not an evenly distributed resource as 57% of farmers in Colombia own only a combined 2% of the farmable land. [1] The lack of fertile land also stems from the mountainous terrain and deforestation which has led to widespread soil erosion. [1][2] Large amounts of water is another resource traditional farming requires, but ongoing dumping of toxic chemicals in rivers and streams leave many people without easy access to clean water. [1]

Aquaponic farming does not require fertile land and recycles water so that a large supply isn't needed. Growing crops and fish together creates an efficient, symbiotic system. The waste from the fish is converted to nitrates by naturally occurring bacteria and the crops take in the nitrates as fertilizer. The tank of fish and the plant bed only needs to be connected through the circulation of water to do this. Aquaponics is an environmentally friendly farming method as little to no waste is created and no synthetic fertilizer is needed. It can also be used for a large distribution of crop types, and producing fish in addition to crops provides a more rounded diet. However, aquaponic systems currently cost upwards of $3,000 to buy already assembled. [3] This cost prevents people in rural Colombia from purchasing them. We intend to lower the cost dramatically and create a design that anyone could build in their own backyard.

The requirements of this design came from considering the stakeholders involved. The end user will be the aquaponics farmer in Colombia. They may also be the end consumer of the fish and crops, or the end consumer may be the farmer's family or others in the community. Our team as the system designers, our customer and project fiancer Dr. Marcos Esterman (ISE Professor), our team guide Bill Nowak, and Rochester Institute of Technology are additional stakeholders that were taken into consideration.

Table 1 shows the customer requirements we determined using interviews with Dr. Esterman and students from Universidad Autónoma de Occidente de Cali in Colombia who were also working on a seperate aquaponic system. One is the highest priority and nine is the lowest.

Table 1: Customer Requirements

Category	Number	Priority	Customer Requirement
Cost	CR01	9	Inexpensive
Function	CR02	3	Accurately tracks water parameters
	CR03	9	Low wasted water
	CR04	3	Low fish death
	CR05	3	Low crop death
	CR06	9	Little to no externally supplied electricity required
	CR07	9	Fish waste managed
	CR08	3	Provides suitable environment for fish
	CR09	9	Produces sufficient crops
	CR10	9	Produces sufficient fish
Size	CR11	3	Small shipping size
	CR12	3	Low shipping weight
Structure	CR13	9	Made from locally sourced materials
	CR14	3	Resistant to Colombian climate
Useability	CR15	3	Easy to set-up and tear-down
	CR16	1	Quick to set-up and tear-down
	CR17	9	Easy to use
	CR18	3	Displays parameters clearly
	CR19	9	Low user supervision required

The most important requirements we identified related to making sure the system was suitable for growing the fish and crops successfully, as this is its primary function. In addition, it needed to be inexpensive and easy to use so that it would have an advantage over other aquaponics systems and traditional farming techniques.

Based on our customer requirements, we were able to produce a list of engineering requirements, shown in table 2.

Table 2: Engineering Requirements

Category	Number	Source	Engineering Requirement	Measure	Ideal Value	Improvement	Satisfaction
Function	ER01	CR2	Ability to sense and record pH				Sensor Output
	ER02	CR2	Ability to sense and record temperature				Sensor Output
	ER04	CR2	Ability to sense and record turbidity				Sensor Output
	ER05	CR3	Water volume replaced per week	%	1	Minimize	Extended Testing
	ER06	CR8	Can maintain O2 level (with user interaction)	mg/L	4	Maximize	Extended Testing
	ER07	CR8	Can maintain pH level (with user interaction)	pH	6-9	Hold Constant	Extended Testing
	ER08	CR8	Does not create sudden pH changes in water				Extended Testing
	ER09	CR8	Prevents contaminates from entering water				Extended Testing
	ER10	CR8	Allows fish access to a light source				Extended Testing
	ER11	CR8	Fish density	kg/m^3	60	Minimize	Calculation
	ER12	CR7	Ability to dispose of undissolved solids				Extended Testing
	ER13	CR7	Ability to dispose of dissolved solids				Extended Testing
	ER14	CR7	Ammonia levels	mg/L	0.1	Minimize	Extended Testing
Structure	ER17	CR14	Reliable in hot weather	°C	38	Maximize	Extended Testing
	ER18	CR14	Resistant to rain				Extended Testing
Useability	ER19	CR16	Set-up and tear-down time	day	1	Minimize	Stopwatch
	ER20	CR15, CR17	User manual is clear and comprehensive				User feedback
	ER21	CR17, CR18	User interface is simple and intuitive				User feedback
	ER22	CR6	Only solar or manual power required				Extended Testing
	ER23	CR19	Farmer interaction time per day	minutes	30	Minimize	Extended Testing
Material	ER24	CR01	Cost	$USD	25	Minimize	Cost Analysis
	ER25	CR13	Made from materials that can be found in Colombian hardware store or that can be salvaged				
Output	ER26	CR04, CR05, CR09, CR10	Protein output	g/day	28	Maximize	Calculation
	ER27	CR04, CR05, CR09, CR10	Carbohydrate output	g/day	62	Maximize	Calculation
	ER28	CR04, CR05, CR09, CR10	Fat output	g/day	3	Maximize	Calculation

DESCRIPTION OF DESIGN

The plants fit into individual holes in foam rafts that sit in a plant bed filled with at least four inches of water for the roots. There is no soil or other grow medium needed. The plant bed is raised above the fish which are kept in two 55 gallon drums. Separating the fish into two tanks allows harvest cycles to be staggered. A filter and a hand pump are connected to the fish tanks. The hand pump draws water from both tanks at an even rate and pumps it up into the plant bed. This will raise the water level in the plant bed. The drain of the plant bed is designed with a U-bend so that once the max height is reached, it starts flowing out of the plant bed and returns to the fish tanks. A second, overflow drain acts as a back up if the flow into and out of the plant bed are not equal. An arduino based sensor system sits beside the fish tank with pH, temperature, turbidity (dirtiness of the water), and oxygen sensors in the water. Farmers will be able to easily see if there is an imbalance that endangers the fish or crops. Figure 1 shows the CAD model for the design and figure 2 shows the final prototype.

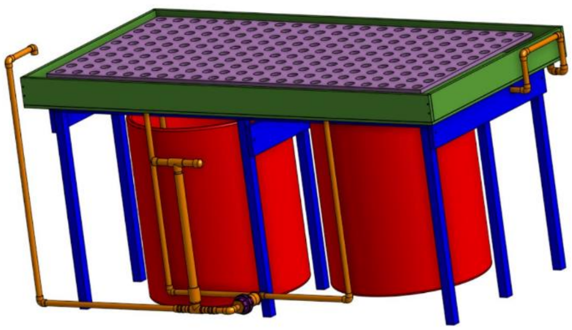

Figure 1: Full CAD model.

Figure 2: Final prototype assembly.

PLANT BED

The plant bed reservoir has a plywood bottom with four walls made of 2x6" boards. The inside surface of the reservoir is covered in two layers of Flex Seal liquid to prevent leaking. The drain system connects through a hole in the plywood using a thick-wall PVC connector.

Floating on top of the water are 4 rectangular sheets of insulation foam with evenly spaced holes. The plants sit in these holes and their roots reach down into the reservoir to absorb nutrients.

HAND PUMP

A hand pump was used to meet CR06 and CR19 of this project. It uses manual labor instead of an electric pump so the system doesn't need to be plugged in. To minimize the labor required, our recommendation is to pump twice a day for 20 minutes only.

The hand pump is built entirely out of PVC. The inner plunger has an O-ring seal that creates a vacuum when pulled up and has a hard stop built in so it can't be pulled out. Check valves on the inlet and the outlet prevent backflow. For stability, it was attached to piece of wood that provide a place to put your foot for leverage.

FILTER

The filter is incorporated into the piping system and sits between the fish tanks and the hand pump, preventing solid waste from entering the hand pump and the rest of the system. The 2 in. diameter of the filter PVC allows a large surface area for the filter foam to clean the water and dispose of solid waste as water is pumped through, meeting the needs of CR08. The foam inside the filter can be accessed through the threaded coupling, removed by a string and cleaned by simply running water through it in the opposite direction. This meets the needs of CR08, by giving a way to dispose of the waste. The larger the surface area of the filter foam also provides the more space for the nitrifying bacteria.

Figure 3: Hand pump.

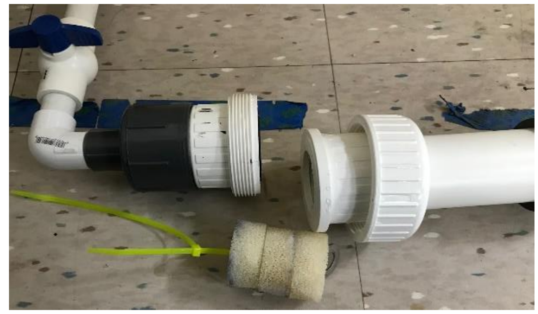

Figure 4: Filter and threaded coupling.

SENSOR SYSTEM

An Arduino based sensor system was designed to monitor parameters of the water such as temperature, pH level, turbidity, and dissolved oxygen. This satisfies customer requirements 2 and 8. The cost of the oxygen sensor ($170) is prohibitive for this project and, while it is helpful for testing and research, it is not included in the marketable design.

These values are displayed on a LCD display, viewable through a Bluetooth connection using the app we developed for Android and are also logged onto a MicroSD card. The data stored on the SD card can be viewed in an Excel document containing macros which show a graph of the parameters over time.

Our system is powered from a Li-ion battery pack which is charged from solar panels during the day by using a solar charge controller sampled to us from Analog Devices. A high-level schematic showing basic connections is shown in Figure 5 below.

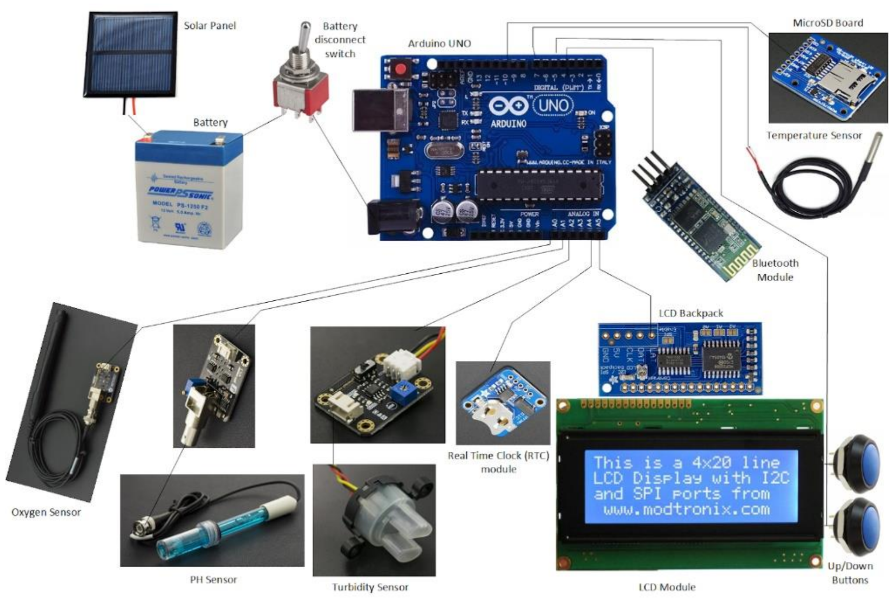

Figure 5: High level schematic of sensor system

SUPPORTING FEASIBILITY EVIDENCE

NUTRITIONAL OUTPUT FEASIBILITY

Analysis was conducted to determine if the system could supply enough nutrients in a small footprint for it to be viable. Several fish and crop parameters like fish density, feeding needs, and crop nutrition density [4][5] were calculated with websites Nutritionix and Aqua-Calc (both calculators and nutrition databases). It was found that a system containing 40 fish in a 0.4 m3 tank, a 1.44 m2 raft of pinto bean plants, and a 1.44 m2 raft of tomato plants could supply, on average, 28.2 grams of protein, 62.5 grams of carbohydrates, and 3.07 grams of fat per day. These outputs are not continuous; the numbers given are the averages over several harvest cycles. The nutritional output is equivalent to about 50% of the protein, 25% of the carbohydrates, and 6% of the fat required by one person's diet. The conclusion is that a device that supplied such a significant portion of a person's diet in such a small footprint would be useful.

$$Number\ of\ plants = \frac{(N_f)(M_f)(F_R)(D_P)}{F_{RR}}$$

Where: N_f is the number of fish
M_f is the mass of the fish [mass/fish]
F_R is the fish feeding rate [(mass food / mass fish) / day]
D_P is the plant density [# plants/ m^2] [6]
F_{RR} is the fish feeding ratio [(mass food / day) / m^2] [7]

STRUCTURAL ANALYSIS

When designing the plant bed and support structure, differing strengths and factors of safety were checked to ensure the safety of the structure. Axial (tension and compression, $\sigma = \pm\frac{P}{A}$) and shear ($\tau = \frac{VQ}{It}$) stresses were checked for both plywood and legs and the resulting factors of safety for the materials were found to be well above 1. The legs were checked for buckling by comparing the axial force on the leg (P) to the critical bending equation for both ends fixed ($P_{Cr} = \frac{4\pi^2 EI}{L^2}$) and the factor of safety was found to be much greater than 1 ($S_b = 1 \ll \frac{P}{P_{Cr}}$).

Finally, the plywood was checked for max deflection using an online calculator for a simply supported rectangular plate [8] and the plywood was found to have a maximum deflection of .2 mm which is acceptable. Overall, our structure was found to meet all factor of safety needs and should be able to properly support our aquaponics system.

POWER CALCULATION

To evaluate if the power system could function off grid, a power study was performed. The system will generate power from solar panels. That power will be converted through a charge controller to both charge a battery and provide power to the system. At night, or when the sun is not out, the battery will provide power to the system instead. To test the feasibility of this and to find the power requirements for solar panels and batteries the following table shows the calculations. The results are that the solar panels need to be at least 4.629 W to power the system and, if only on battery power, the system would be powered for approximately 0.6 days or 14.4 hours. We believe this will power the system enough overnight and on cloudy days since energy is still generated from the solar panels on cloudy days.

Table 3: Power calculation breakdown.

Component	Voltage (V)	Current (A)	Power Required (W)	Energy per day (Wh)
Full system	9	0.150	1.350	32.40
Battery	Voltage (V)	Capacity (Ah)		Total Energy (Wh)
tenergy 2 cell 7.4V 2.6Ah	7.4	2.6		19.24
Assuming full charge, and no supplemental power		Time until drained:	0.594	Days
Solar panel	Sun Hours		Watts Required (W)	
	7		4.629	

RESULTS

Our final prototype (shown back in figure 2) was a success. It was able to hold twenty 2 lb tilapia split into two tanks and 60 lettuce plants. Tilapia and lettuce are both hardy, making them ideal for prototype testing. More nutrient dense crops, like tomatoes and pinto beans that were discussed earlier, are recommended to be used in later testing. Aerator stones were used to ensure oxygen levels stayed high enough to keep the fish healthy. These are electric powered, but testing will need to be done to learn if they are necessary to maintaining oxygen levels in the fish. The pump is easy to use and the system of valves in the pipe makes it easy to regulate water levels.

PLANT BED SEALANT TEST

The plant bed reservoir was filled with water after being treated with one coat of sealant. There were noticeable leaks through some of the screw holes and some of the seams between the pieces of wood. Sealant was re-applied to the problem areas, and an entire second coat was applied to the plywood bottom of the reservoir. After being filled up with water again, the reservoir leaked through knots in the side walls. A second coat was then applied to the side walls, after which the reservoir was fully sealed. Based on the results of this testing, at least two coats of sealant are required on all internal surfaces of the reservoir, with extra attention given to screws, seams, and knots. For our system, this required almost four quarts of sealant. As a result, we are recommending using a tarp with holes cut for drains instead as this will save money and is easily replaceable if needed.

PUMP FLOW RATE TEST

The flow rate the average person can achieve with our hand pump design determined our recommendation of pumping the system twice a day for 20 minutes. We timed 20 strokes (up and down) and measured the volume that was moved in that time. We then extrapolated that to find the time it would take to cycle 55 gallons or one fish tank's volume. The average across team members was 14.8 minutes. We recommend 20 minutes to pump 55 gallons of water because it is likely the flow rate will slow as the person tires.

DRAIN SUBSYSTEM TEST

Following installation of the drain to plant bed, the drain was tested to see the flow rate back to the fish tanks. Unfortunately, the rate was significantly slower than the rate of water pumped into the plant bed. To account for this, overflow drains (positioned over the fish tanks) were installed to ensure the water level doesn't overflow the plant bed.

DISSOLVED OXYGEN TEST

Two electric air stone aerators are currently needed in each fish tank to keep the dissolved oxygen high enough in the fish. Reducing it to one air stone per tank caused the fish to cluster at the surface which is a sign that the oxygen level had dropped dangerously low. The air pumps run on AC, making them incompatible with the solar panels, and would draw more current than the solar panels can produce. With more time, a different air pump or a different aeration method would be found.

CONCLUSION AND RECOMMENDATIONS

Currently the full system is running with plants, fish, and grow lights. The system is fully functional, but we did have to deviate from our goal of not having to plug the system in because of the necessity of the air stones.

The project came in under our budget of $2,000. The full system costs $563, significantly cheaper than buying a prefabricated system at $3000. The total cost the sensor system is about $200 (not including the oxygen sensor which would cost an additional $170), this is an optional purchase to replace daily water tests, helping decrease the interaction time spent on the system.

We recommend to future builders of this system to use a tarp instead of Flex Seal to waterproof the plant bed. Four quarts of Flex Seal were required to fully seal the plant bed costing approximately $120. Using a tarp and a small amount of aquarium grade silicone instead will save significantly on the cost of the system.We would also recommend using a waterproof coating spray or paint on the exposed wood of the system to protect it from rain when used outside.

Having an aquaponics design that anyone can build with little to no skill is an ideal solution for families in rural Colombia and worldwide who want to grow their own food in an efficient and environmentally friendly way. Our team is excited to be implementing our design through workshops in Colombia in May 2019.

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