Deliverable H: Prototype III and Customer Feedback

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Abstract

The following report will outline the results of previous prototypes, and our most recent prototypes. It will also review previous feedback and incorporate new feedback from peers and users for the purpose of identifying possible improvements. The newest prototype focuses on calculating the flow rate and pressure needed using our current system of nozzles to remove algae off of hydroponic rafts using shear force. It is recommended to have a basic understanding of pressure and flow and to review the referenced research papers. The report will also review our physical comprehension prototype.

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1. Introduction

The purpose of this document is to discuss the previous prototypes and their results as well as the third round of prototyping. This includes discussing the original prototyping plan, as well as the process and progress of the prototypes. The third round of prototyping included two different prototypes, an analytical prototype and a physical prototype. The analytical prototype used research and calculation to determine a theoretical pressure required for each nozzle in the water jet system. The physical prototype is an approximate half scale of the concept as a whole. For both of these prototypes the objectives and test plan and results will be discussed. Lastly, the group will ask for feedback from potential users of the product and reflect on peer feedback.

2. Previous Prototype Results

The first prototype, done in the first round of prototyping, for this project was a quarter scale, low fidelity, physical, and comprehensive cardboard prototype of the concept. This prototype’s goal was to communicate with members of the team and others if necessary, what the concept actually looks like. While this was a very inaccurate project, it allowed the group to visualize how the concept functions in real life.

The second prototype, done in the first round of prototyping, was a medium fidelity, physical, focused prototype for the circuitry of the machine. This prototype was important because it was a major component for the automation of the machine, which was one of the most important design criteria given by the client. This prototype used an arduino, a solenoid valve, a motor, and infrared sensors. The group used a rough set up connecting these various components using a relay board. Then coding was done and uploaded to the arduino. This prototype helped the group test the feasibility of the circuit, as well as integrating the different parts of the circuit. Several different things were discovered during this prototype. This included the arduino and relay board needing pull down resistors, as well as various unexpected behaviors. These discoveries are useful because they will help to inform the third round of prototyping on the fifth prototype which is the physical prototype. The Final prototype will be using circuitry and so this first interaction of the circuit allowed the group to discover which areas to troubleshoot and fix for the final prototype.

The third prototype, done in the second round of prototyping, was testing the pressure of the nozzles. After the prototype, we noticed that the jet stream's pressure was mainly on the edges of the nozzles, and was very weak in the center. The pump that we used has high pressure however it has a low flow rate. The pressure drops to unusable because the nozzle system needs a high flow rate. This prototype allowed the group to determine that we need a different pump with a higher flow rate to fix the low pressure of the nozzles. The water pressure must function correctly as it is what cleans the algae off the rafts.

3. Third Round of Prototypes

3.1 Analytical Prototype

3.1.1 Objectives and Test Plan

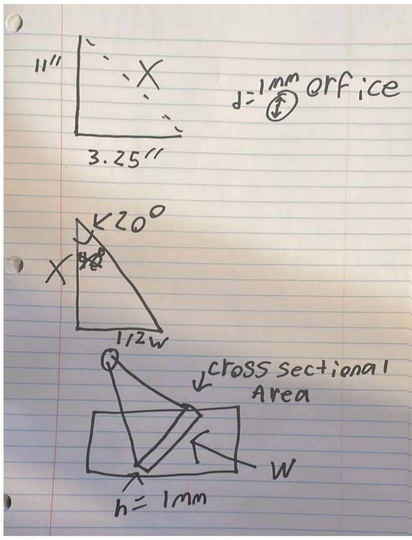
This prototype is an analytical and focused prototype that we will use to support our solution concept on Design Day, more specifically related to the design criteria for cleanability. The objective of this prototype is to calculate the percentage of raft surface area that will be cleaned after running through our design, as well as the minimum pressure and flow required to reach this value. While researching calculations that take into consideration critical factors such as the number and placement of the jets and the cling factor of the algae on the board, we came across a research paper related to algae adhesion that influenced our testing process.

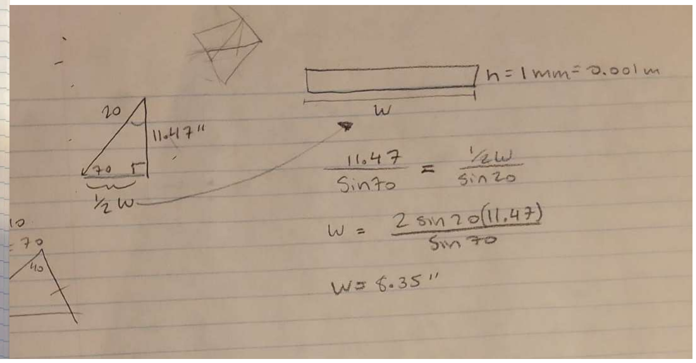
3.1.2 Calculations and Results

We started by researching the force required to remove algae from the high density polyethylene plastic rafts. We theorized that if we can find the force required to remove a cell of algae from the plastic, then we could calculate the velocity of water required to create an equivalent drag force. Using the velocity of the water and the diameter of our nozzles, we were able to figure out the pressure and rate of flow required to accelerate the water to the required velocity. We decided to omit the effects of gravity and air resistance to simplify the calculations, and also because they would be negligible; gravity will accelerate the water at -9.8m/s^2, however, the water will reach the board in less than 1 second and we assume it will be moving much faster than 9.8m/s. To account for this we added a large safety factor to our results.

We found a research article which discusses using water to shear algae cells off of insulators in coastal environments. The research paper aimed to calculate the effects of soaking algae in salt water on shearing algae off silicone using water. To do this, they set up flow chambers with cultures of 2 different species of algae, “B. braunii (UTEX 572)” and “pelagic diatom T. rotula (CCMP3362)”. To test the difference between salt soaked algae and algae which was not treated with the solution, the experimenters set up flow channels for both. We are interested in the results of their freshwater experiments. After the experimenters grew the algae cells in the flow chambers, they flushed out the flow chambers with a low flow rate so that only adhered algae cells remained. The results provide the shear force required to remove the cells in newtons, and the flow rate at which they achieved 80 percent of all algae cells removed. We used their results from the microfluidic flow chamber for our calculations.

We calculated the velocity of the water that was used to achieve 80 percent cells removed using the cross sectional area of the flow chamber and the volumetric flow rate of the water. Afterwards, we realized that we could calculate the cross sectional area of the water when it hits the raft using the distance of the nozzles from the raft, the angle of the water coming out of the nozzles, and the diameter of the nozzles. Rather than doing redundant calculations, if we take the cross sectional area of the experimental flow chamber and of the water hitting the raft and convert them into a ratio then we can use this ratio and the flow rate from the experiment to get the flow rate required per nozzle to remove algae from the rafts. After calculating the flow rates from the nozzles, using the diameter of the nozzles and the flow rate of the water we could calculate the pressure required to obtain that flow rate out of the nozzles. Using the pressure and the flow rate we are able to find a water pump which is guaranteed to clean 80 percent of the algae off the rafts, and a better pump will produce a greater percentage of cleanability.





Data Results: 80% Clean ability

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$$A\,(experiment) = 5800um^{\times} 42um = 243600um^2$$

$$A\,(Board)\,212090um^{\times} 1000um = 21209000um^2$$

$$\frac{2120900um^2}{243600um^2} = 870.648604269$$

$$6_e11\frac{\imath m^3}{\min}\times 870.648604269 = 5.2238916e + 14\frac{um^3}{\min} = 0.13800061652684914GMP$$

The flow rate for the board:O. 13800061652684914 GMP

$$P = \frac{Q^2}{(835.21^x D^4)}$$

$$= \frac{(0.138^2)}{835.21^x\,(0.0393701)^4}$$

$$= 9.49PSI$$

Flow Rate of Experiment converting from uL/min^3 to um^3/min^3

Q = 600 uL/min = (6 x 10^11)um^3/min

Cross sectional area of the experiment using the product of the height(42 um) and the width(5800 um) of the flow chamber. A = cross sectional area

A = 42 um x 5800 um

Calculating the cross sectional area of the water when hitting the board. This uses the nozzle which is furthest from the board because it will require the highest flow rate and pressure.

The height of the jet stream is the diameter of the nozzle (1mm), the width is calculated using trigonometry. The nozzle is 11 inches above the board and hits the board 3.25 inches away from the nozzle position horizontally. We can use this to calculate the distance of the tip of the nozzle from the surface of the board. Using pythagorean theorem ($a^2 + b^2 = c^2$) we were able to find the length of the hypotenuse which was 11.47 inches. Next we used the sine law to find the width of the area on the board that would get sprayed. By splitting the triangle created by the stream of water in half to make it a right triangle (like in the image) we were able to just input ½ w into the sine law and isolate for w to get a width of 8.35 inches. (11.47inches)/(sin70) = (½ w)/(sin20). w = (2sin20(11.47))/(sin70), w = 8.35 inches. We converted inches to um.
Area (Board) 212090um * 1000um = 212090000um^2
Cross sectional area of the board divided by cross sectional area of the experiment.
212090000um^2 / 243600um^2 = 870.648604269
Flow rate of the experiment multiplied by the ratio and converted to gallons per minute.
6e11 um^3/min * 870.648604269 = 5.2238916e+14um^3/min = 0.13800061652684914 GPM
Flow Rate for the board: 0.13800061652684914 GPM
We used this website to find the formula for getting the psi required to maintain the calculated flow rate of the nozzle based on its diameter.
http://irrigation.wsu.edu/Content/Calculators/Sprinkler/Nozzle-Requirements.php
P = Q^2/(835.21*D^4)
= (0.138^2)/(835.21*(0.0393701)^4)
= 9.49 psi
To get the flow rate required for all nozzles we need to multiply the calculated flow rate by the number of nozzles (6).
0.13800061652684914 GPM * 6 = 0.82800369916 GPM
To remove 80 percent of algae cells from the board we need a pump with a flow rate of about 0.83 GPM and a pressure of 9.5 PSI. These calculations are based on experiments which use a single type of algae. The experiment also uses silicone while our boards are made out of high density polyethylene. We also neglected gravity and air resistance slowing down the water. The results are much lower than expected because 9.5 PSI is less than 1/3rd of the average water pressure from a hose in a North American home. Based on the description of how well the algae sticks to the board from the client our calculated results are not a realistic representation of the required pressure and flow rate. However it does help us to realize that using a pressure washer is way too much pressure which is good because the pressure washer we tried in a previous prototype did not have adequate flow. Based on research on dishwashers from previous deliverables we will probably use a flow rate and pressure much higher than this but also much lower than our initial concept.

3.2 Physical Prototype

3.2.1 Objectives and Test Plan

The objective of this physical prototype is to demonstrate all critical components of our concept. This will be a high fidelity, fully comprehensive version that will be used on Design Day as a method to test the necessary criteria of both the client and class expectations, specifically usability and automation. The goal of this prototype is to assure that all components - mechanical and automated - function in sync to exhibit a working prototype. The outcome of the prototype will allow us to determine any issues that might arise, as well as eliminate any dilemmas. The critical component used in this prototype is the moving mechanism as it demonstrates the process the rafts undergo within the prototype. We will build a frame out of 1” square mild steel tubing based on our 3d CAD design for our ½ scale prototype. Afterwards we will connect our rail systems for the platforms by threading holes into the rails and bolting them to holes which will be drilled in the frame. We will have to design and 3d print mounts for connecting the motors to the frame. Then will drill mounting holes for our lead screw nuts into our platforms. We must connect the lead screws to the motors using couplers. We will mount bearings to screw the tops of the lead screws. We will cut the belt for the horizontal actuator and mount the belt to the horizontal carriage. We will mount the pulley for the end of the belt to the frame. We will design and 3d print mounts for connecting our nozzle system from a previous prototype. We will drill holes through our frame to bolt our rollers to the frame.

3.2.2 Results

We will complete the final prototype before design day; however, it will not be finished in time to show it fully working for this deliverable. We ran into numerous issues, and we fixed most of these issues; however, after disassembling the prototype to fix the issues, it needed to be reassembled. For these reasons, we can only document a frame that is primarily bare in this report.

We began working on the prototype as planned. We designed and 3d printed mounts for the motors, rails, and platforms. Some parts were printed without enough tolerance and broke while trying to use them. Other parts took a long time to print and failed while printing numerous times, which delayed our work. While waiting on prints, we continued working and drilled mounting holes for everything into the frame. We drilled some holes in the wrong position but fixed them relatively quickly.

While designing in CAD, we did not leave room to put some bolts through the frame. The bolts needed to go through a hole blocked by structural beams very close together. We caught this error before we began working, and the solution was to use an alternative mounting solution with 3d printed parts which caused more delay. We cut some PVC pipe to the correct length and drilled out the inner diameter of the pipes to a larger size so that we could seat bearings into them using a compression fit. The bearings have an 8mm inner diameter, and the design uses 8mm bolts to secure them to the frame. We made an error in sourcing bolts and only had smaller sizes. Since we used the wrong-sized bolts, the rollers spin poorly on the bolts instead of the bearings, and some sag onto support beams below them. We will fix this by changing the bolts; however, it required disassembly. The rollers also block holes for bolting other parts of the frame, which requires them to be attached last, so they are not currently connected.

The Rail systems for moving the platforms that carry the rafts up and down use aluminum extrusion beams with grooves. Rubber wheels run inside the groves in the beams on either side, compressing the beams between the wheels, providing a gantry that rolls smoothly but is also rigid. The wheels' spacing depends on the hole spacing of the gantry plates they bolt into. While sourcing parts, we purchased the wrong plates, and this caused the wheel spacing to be off significantly. Since the plates are vital to the prototype and we did not have enough time or budget to buy new ones, we had to make them ourselves. We had some aluminum plates, cut them to size, and drilled the appropriate holes. However, we drilled the holes in the wrong spots and used aluminum plates that were too thin. The plates must be thick because half the wheels connect to the plates with eccentric spacers. The spacers have an off-center hole so that when they turn, the location of the bolt moves. The ability to move allows for tightening the wheels against the frame. However, the spacers need to go through the gantry plate, and if the plate is not thick enough, they protrude the plate, preventing the bolts that go through them from being appropriately tightened. We had a thicker aluminum plate for mounting the electronics in a previous prototype. We removed the electronics from the plate and managed to salvage enough to make new gantry plates. The new plates worked all right; however, the hole spacing was still slightly off. The mounting method for the platforms to the plates no longer worked with the new plates because of differences in size. We also planned on reusing bolts we already possessed to save money; however, these bolts were of assorted lengths, and we had to cut many of them to the correct length using a Dremel with a cutoff wheel to make them work, which slowed us down. In the end, we had to strip the frame.

We took everything apart and reprinted most of the 3d printed parts. The gantry plates and the mount for the platform are now a single part to fix the inaccuracies in our custom plates. This part resulted in a weaker, less reliable, and lower fidelity prototype. The issues we encountered do not have significant impacts on the overall concept. However, it does help us to make minor changes which will make the final concept easier to manufacture. We need better planning for our bolts, making sure they are all the correct size and easily accessible when installing and removing them. We also need to make sure to change the parts which we incorrectly sourced. There will not be any 3d printed parts on the final concept, so they are only a concern on our prototype. This prototype can be reassembled and completed in a few hours. Afterward, we will fix the coding from our previous prototype to work with our higher fidelity prototype. Finally, all the electronic parts we disassembled to get the aluminum plate must be reassembled and mounted securely.

5. Feedback and Comments

The group assembled a google forum as well as an introduction and description of the project to send to potential users. These users were found by finding people who use hydroponics as well as the growcer unit on instagram, our group found seven such accounts. These seven accounts were sent out google forum and brief message. Unfortunately none of the people we reached out to have responded, and as such we were unable to obtain potential user feedback despite our efforts.

Some other comments include that the design has now been switched from a wall mounted solution to a table solution. As a table solution the machine would need to replace the current table the growcer unit has and sit in that area. To make up for this the group came up with the idea to put a table top on top of the machine so it can clean boards and still be used as a table.

6. Conclusion

In conclusion, the previous prototypes were discussed and the third round of prototyping was analyzed. The first prototype in this third round was the analytical prototype on the jets in the machine. The pressure required to remove algae from the boards was 9.49 psi. This number was calculated based on some research the group did to find an experiment, which may explain the lower than expected value. The second prototype in the third prototyping round was a physical prototype. Unfortunately this prototype was unable to be completed by the deadline, but the group has plans to complete it for design day. This was due to many unexpected issues that arose during the prototyping. Overall this was a learning experience in which the group discovered that more, smaller testing stages may have been a good idea. Lastly the group attempted to get feedback from potential users, but this was unsuccessful due to the people we reached out to not responding.

7. References

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