Nadav Avni B00584102
Yangyuanlong Gao B00569500
Aaron Mcgrath B00145107
Monday, April 4, 2016

Client: John Batt, Aquatron Laboratory

Supervisor: Dr. Jason Gu, Dal Tech

Aquatron Filter Final Report

ECED 4901: Senior Design

Good Day Mr. Batt

The following is a progress report for the drum filter you commissioned to be constructed for the Aquatron Laboratory at Dalhousie University. Enclosed you will find the following:

- Project budget
- Mechanical design
- Electrical design
- Control specifications
- Progress made thus far
- Progress to be made over the next two weeks

Please note that we, at your leisure, will be present at greater frequency and for longer periods at the Aquatron Laboratory to hasten the construction of the final prototype.

Thanks very much.

Sincerely

Nadav Avni Yangyuanlong Gao Aaron McGrath

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0.0 Abstract

This report will outline the design and construction of a drum filter commissioned by Mr. Batt of the Aquatron Laboratory at Dalhousie University. The purpose of this filter is to clear the solid waste that accumulates as a by-product of hosting aquatic life at the laboratory. The background of this commission is introduced, followed the methodological approach of the design, possible solutions to the problem, results obtain, a brief discussion, and future recommendations.

1.0 Introduction

1.1 Background

The Aquatron Laboratory, located in the Life Science Centre at Dalhousie University, undertakes research projects using fresh or salt water. The concentration of required solutes in the water varies depending on the experiment in question. Particulate matter, resulting from the presence of aquatic animals and chemical precipitates, amasses in the system. Filtration is therefore an essential function for the aquaculture system to function properly (Summerfelt, 2005).

Unfortunately, the particulate matter accumulates in the system at an unsatisfactorily high rate. This leads to a decrease in the overall efficiency as filters must be replaced often and the system must be shut-down at intervals. There are also man-hours consumed as the filters must be cleaned and replaced manually. To prevent this rapid waste accumulation a new filter must be introduced to the system. Mr. Batt, the manager of the Aquatron Laboratory and the external supervisor of this project, commissioned a drum filter to meet the requirements of the laboratory. Ali (2012) writes that drum filters using a mesh are efficient, reliable, run for a long time, and have low operating/maintenance costs.

Though drum filters do exist on the market, one of the appropriate size is not readily available. The cost of having one designed to custom specifications may also be too prohibitive to commission. Moreover, even if a filter was designed with the appropriate specifications in mind, the problem may not be entirely solved. The solution is therefore to build a prototype to test the effectiveness of a drum filter in this environment and to provide feedback that will guide future designs.

1.2 Project Objectives

The filter required by the Aquatron Laboratory must:

- Be Self-Cleaning
- Be Self-Contained
- Be able to operate for long periods of time
- Be able to handle overflow
- Have an option for computer integration with the Siemens PLC control system
- Not exceed an estimated $500 external budget
- Run on an available 115V 60Hz power source
- Not exceed certain dimensions
- Be able to filter fresh and saltwater

The drum filters are either gravity-fed or suction-fed. The suction-fed variety requires a more complex system that includes a vacuum apparatus and would be beyond the scope of this project. The gravity-fed variety passively allows for overflow, is much simpler to design and build, and is more cost-effective. A variety of drum filter called a cake drum filter, as described in Filtration and Separation (2003), is a variable alternative, however would require regular replacement of a custom-made filter.

The dimensions of the tank are restricted to a base of 36”x1’9.75”, with a half circle of 11” diameter cut out of one of the long edges of the base. An illustration of this dimension is shown in figure 1. If it proved to be necessary the half-circle restriction can be removed.

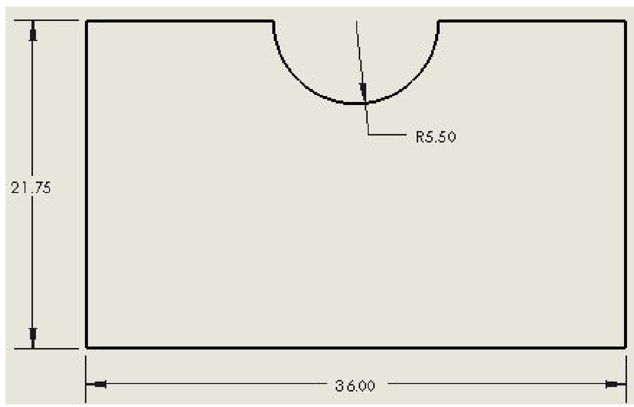

Figure 1: Dimension restrictions for the drum filter tank

1.3 Report Outline

This report will first outline the methods used by the group to plan the design of the project. It will then explore the possible solutions to the design problem and will report on the results obtained for the solutions explored. The in-progress final product will then be discussed and recommendations made for improving and enhancing the product in the future. References and appendices will follow, but are specifically referred to in the body of this report. The contributions of each group member are included at the end.

2.0 Methods

2.1 Mechanical Design Methods

Since the primary design requirements are mechanical in nature, the electrical design requirements are driven by the mechanical system. Ultimately, the electrical components of the project would act as control, driver, feedback, and sensory systems for the mechanical prototype. Thus, electronic components would have to be designed after the mechanical components are, at the very least, roughly outlined.
Since the group is made up of electrical engineering students, a great deal of assistance would be required for an effective mechanical design. Due to budget, time, and complexity constraints it is imperative that the mechanical prototype be built only once, with minimal subsequent adjustments. As such, when a

mechanical portion is theoretically designed, feedback from professors and the technicians at the Aquatron Laboratory must be taken into consideration and may initiate a drastic redesign. The prototype designs must take into account stress dynamics, cost, complexity, ease of construction, and electrical integrability, Once these requirements are met the electrical portion of the system may be designed to accommodate the mechanical design. Testing the mechanical components in isolation prior to integrating the electrical components is required to reduce the chances of damaging both the electrical and mechanical components.

2.2 Power Requirement Methods

The only available power source for the filter system is 115V at 60Hz. Thus, each powered component of the system should either run directly off of this source, or have an appropriate converter. These converters should have power outputs sufficient to accommodate subsequent components in the system, and should seek to minimize cost and space.

When selecting components, it would be ideal if they could be powered off the 115V source. If this component stresses the design specifications of the system, a suitable converter would have to be found. The power rating of this converter would have to be sufficient to power any subsequent components and other converters.

To ensure minimal failure, each component will go through three testing stages to ensure the power supply is adequate. The first stage involves testing the component with a laboratory power supply. The second stage involves testing the component in isolation with the selected power supply. The third stage involves integrating the power supply and component with the system. At each of these stages it will be decided if the component or the power supply must be reconsidered.

2.3 Interface Design Methods

The purpose of the user interface (UI) is to facilitate interaction between the user and the electrical control system (discussed later) which controls the mechanics of the system. The design process for the UI involves identifying which components of the system the user would want to control, and then designing a user-friendly UI that includes a control mechanism for each of these components. The following are what would be explored as potential components for the UI:

- LCD display
- Emergency button
- Working indicator
- ON/OFF
- Manual control
- Speed control
- Direction Control
- Clean ON/OFF

An ideal UI design would accommodate all the components and connect them to the electrical system. The UI would also have to be able to be attached to the tank and protect the electrical components from moisture emanating from the system.

Once the ideal UI was designed it would have to be constructed as a rough prototype for testing and streamlining purposes. During the use of the rough prototype it would be decided if there were any controls that the UI required but were not present. As well, any superfluous controls would be eliminated.

2.4 Cleaning System Methods

Since the system is required to be self-cleaning, design of a passive or automatic cleaning system is essential. The hypothetical cleaning system must be:

- Cost-Effective
- Able to function for long periods of time
- Easy to Construct
- Reliable
- Able to fit within the size restrictions of the system
- Able to clear waste at an appropriate rate

Once a cleaning system is theoretically designed the above factors are considered and then contrasted with the factors for other theoretical iterations. Since it would be resource intensive to build and test a cleaning system, a simple design would take precedence over other designs. This simple design would be the one that is built and tested for the final prototype. The simplicity of the design would allow it to be altered quickly, easily, and at low-cost in case it requires streamlining.

The testing for the cleaning system would be performed in three stages. The first stage involves running the cleaning system in isolation to ensure that it functions as anticipated. The second stage involves integrating the cleaning system with the rest of the filter system in a "dry" test, with no filtrate used in the test. The third stage involves running the entire system with the introduction of the filtrate. At each of these stages it will be decided if the design iteration is sufficient or if it must be redesigned.

2.5 Control System Methods

To keep the system operating within the design parameters a control system should be included. This control system would receive feedback from the mechanical and electrical systems and would operate the drivers within the electrical system. Once a component that was destined to communicate with the control system is tested in isolation, and found to transmit and receive the appropriate signals, it would be connected to the control system to test its functionality. If it was found to respond appropriately it would be ready to be integrated into the existing electrical system.

3.0 Proposed Solutions

3.1 Mechanical Proposed Solutions

Mechanical Design Version 1

After initial research the team came up with a first concept for the Aquatron Filter. Because there is an inlet pipe and draining tray outlet pipe in the central axis of a rotating drum the group thought it would be ideal to build a central bearing system that accommodated the fixed piping and allows the drum to rotate. The initial drawings are shown in Figure 2.

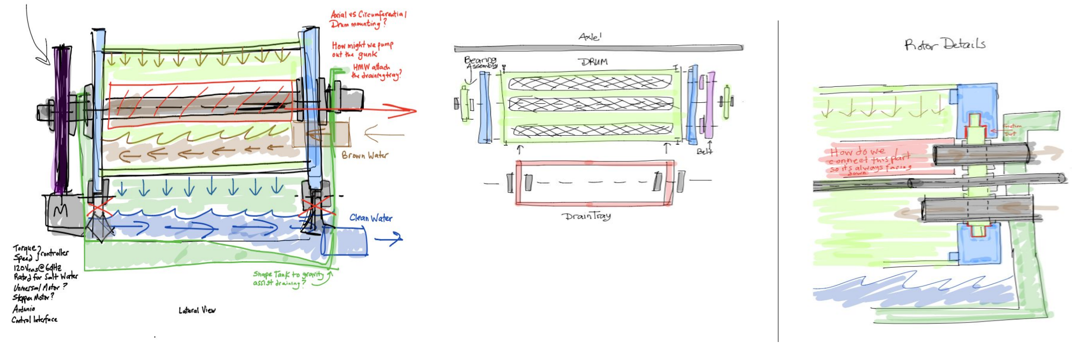

Figure 2 - Initial Mechanical Concepts

Once the initial sketches were completed a first CAD model was created. As electrical engineers it has been a few years since a CAD program was employed. After meeting with Professor Warner to discuss the mechanical viability of the initial sketches it was decided that SolidWorks would be a better software than Solid Edge with which the group was more familiar. The main reason for using SolidWorks is it has more analytical capabilities. The team felt that being able to do stress analysis on assemblies would be important, considering the importance of mechanical design for this project. The first rendering of the overall system is shown in figure 3.

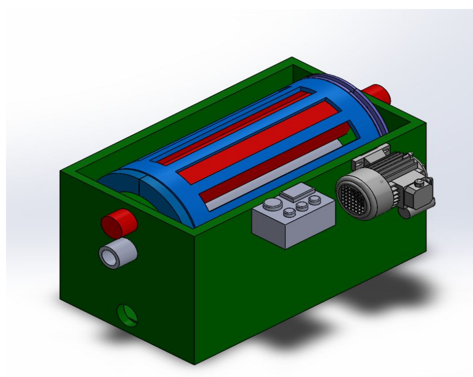

Figure 3 - Original Mechanical Concept Rendered using SolidWorks

The initial concept was crude, but all the required elements are in place. The tank, the drum, motor and the control panel are all there. The team originally envisioned an 8” bearing assembly based on 2” plumbing to allow the drum to rotate around a fixed central axis that would accommodate the inlet and outlet pipes.

As shown in figure 4 the initial CAD was rough and important details had yet been fully understood. The red part in the section view of figure 4 is the draining tray which shows the concept of using the ends of the draining tray as part of the connection to the tank of the filter. The grey part is the dirty water inlet pipe where lab water would flow into the drum. The idea for this pipe was to drill holes in a 2” PVC pipe and use it to support the weight of the drum. This concept relies on the strength of the inlet and outlet pipes to support the weight of the drum.

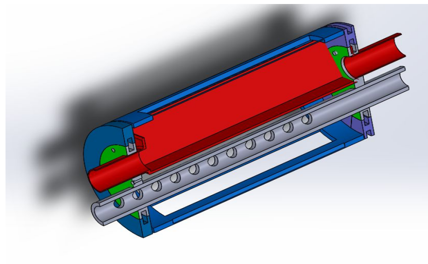

Figure 4 - Section View of Original Drum

In figure 5 the initial front and rear axle assemblies are shown as isometric exploded views. Notable at this point are the wheels and track that are intended to allow the blue and purple parts to rotate around the stationary green parts which connect to the inlet and outlet pipes that were to serve as an axle for the drum. A track on the outside circumference of the purple part was intended to accept a drive belt that would connect through the wall of the tank to the motor. Having the belt going through the tank was later scrapped because the team wanted to keep the tank as water tight as possible and a belt would likely transport water outside the tank, creating a safety hazard and potentially damaging the equipment.

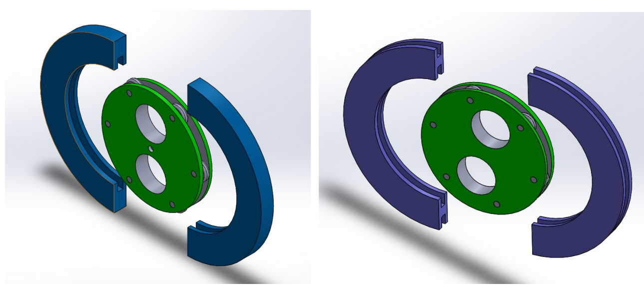

Figure 5: Front and Rear Axles

The tank must perform several mechanical functions. The walls of the tank must support the couplings for the piping and the drive shaft. In this design these coupling connect through the basin wall and support cantilevered inlet and outlet pipes. The volume of the tank must be large enough to accommodate the volume of the drum and all the pipe fittings. At the same time the tank and footprint must fit an area of 36” x 21”. The basin must be waterproof and completely leak free at this stage the team was expecting the to fabricate the tank out of ½” PVC, which turned out to be relatively costly.

Mechanical Design Version 2

By mechanical iteration 2 the design had started to look more realistic. Notable refinements at this stage were the addition of a sprinkler system to wash the drum mesh, a control panel and a drum concept that was expected to be easier to fabricate.

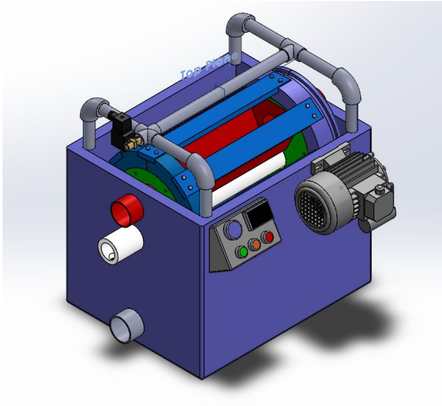

Figure 6: Mechanical Design Version 2

During iteration 2 the team was relying heavily on using the 3D printer to deal with the question of fabrication. This turned out to be an unrealistic plan as the 3D printer is costly, requires significant time, and is also limited in to a volume of 11” x 11” x 11”. At this stage in the design process the team thought it would be realistic to 3D print the front and back of the drum as special parts and then join both parts together using spindle made of ½” PVC plastic. The drum envisioned during iteration 2 is shown in figure 7.

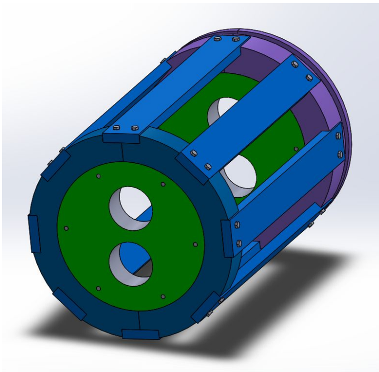

Figure 7: Mechanical Design Version 2 Drum Assembly

Once the team was satisfied with the second iteration of the design a meeting was set up with Dr Warner, who raised some concerns about the central bearing concept. For one, the parts are relatively complex to machine or 3D print. Another concern was sealing the bearing system to keep water and organic material out of the rotating parts and prevent jamming of the rotational mechanism. The third concern was running a belt through the wall of the tank to couple with the motor; a concern mentioned above.

Mechanical Design Version 3

To address the concerns raised by version 2 of the drum a cantilevered design was proposed as shown in figure 8. In this concept the drum would be supported by a face mounted flange bearing at the rear of the tank and a face mounted drive flange would connect the driveshaft to the drum. The dirty water inlet and the draining tray outlet would be cantilevered in from the front side of the tank and the bearing assembly at the front and back of the tank could be removed. By cantilevering the parts in the assembly the team would use commercially available bearings to enable rotation rather than design the complex custom part with an unknown probability of failure.

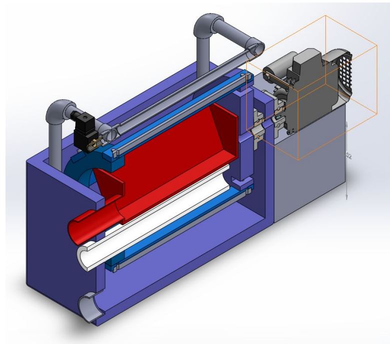

Figure 8: Mechanical Design 3. The Cantilevered Drum Concept.

During revision 3 the team was still expecting to use a 3D printer or to machine the ends of the drum and join them using spindles of PVC. At this stage the white mesh mount components show in the drum in figure 9 were brought forward as a way of attaching the mesh to the drum. The idea here is that the drum would be wrapped in a mesh material and the mesh mounts could be tightened systematically to hold it in place. This iteration was the first attempt to solve the issue of attaching the mesh around the circumference of the drum. The team met with the client to discuss version 3 and incorporated the feedback into version 4. The drum for this version is shown below in figure 9.

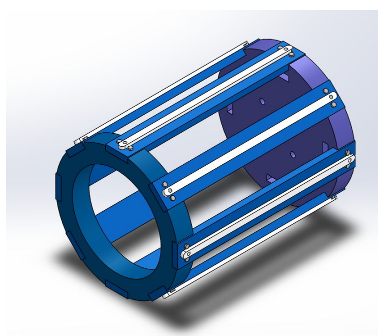

Figure 9 - Drum Concept that Relies Heavily on High Tech Fabrication Technology

Mechanical Design Version 4

In revision 4 the height of the tank was changed to accommodate the requirements of 3” female PVC coupling for each inlet and outlet on the tank shown in white in figure 5 shown below. The previous models were built using 2” openings and the type of coupling required was unknown, this tank is shown in figure 10. While this iteration demonstrates a movement toward a design that incorporates real physical parts it also underscores the idealism of CAD based design. CAD is a powerful tool but the ease with which one can design parts in CAD does not reflect the reality of acquiring or fabricating parts.

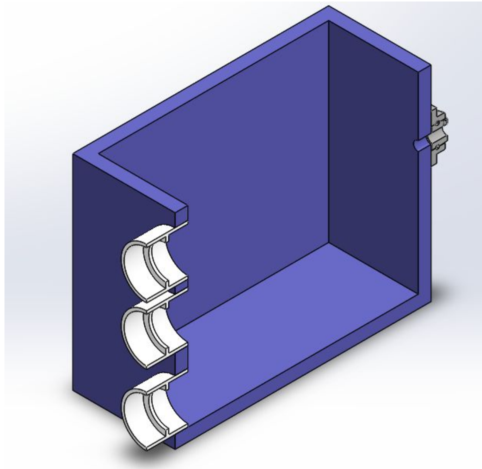

Figure 10 - Mechanical Design Version 4 Tank with 2” Couplings and Bearing.

While still absorbed in the idealism of CAD the team continued to refine the drum by adding circumferential straps around the perimeter of the drum for attaching the mesh and prevent dirty water from escaping into the clean water section. The drum concept is shown in figure 11.

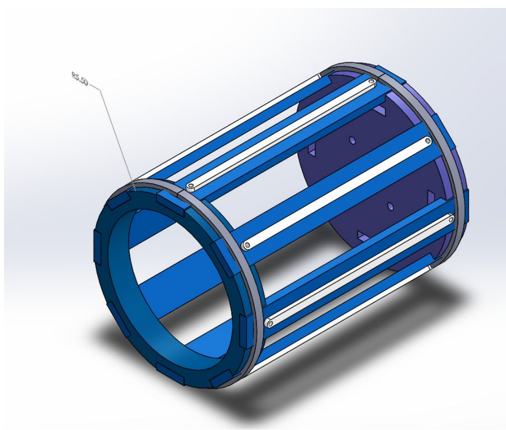

Figure 11 - Mechanical Design Version 4 Drum

Mechanical Design Version 5

By version 5 the team had looked into 3D printing and machining the front and end faces of the drum and determined that 3D printing too expensive and machining also blew out our budget. 3D printing was estimated at about $1000 while machining was expected to cost $250. The budget target was to stay under $500.

The client asked the group to present our design to the maintenance team at the Aquatron Lab. The maintenance team is made up of talented trades people who work with plumbing, machining and carpentry. When explaining the challenge of fabricating the drum one of the team asked; “Why don’t you just cut it out of a 12” PVC pipe?” This turned out to be the start of a cheaper concept that was relatively easy to fabricate. As can be seen below the team was planning to use 12” end caps and cut a hole in one to allow the inlet and outlets to enter into the drum. The windows for the drum are simply cut out with a jig-saw.

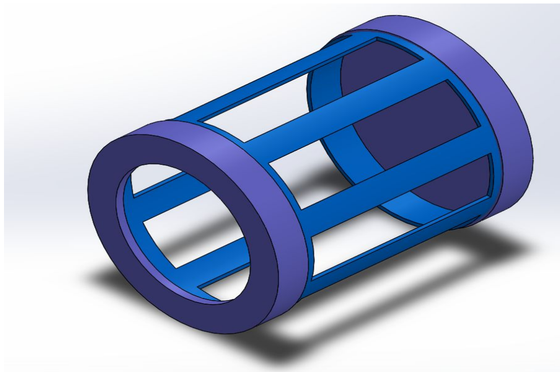

Figure 12 - Simplified Drum with End Caps

Mechanical Design Version 6

Version 6 of the filter is shown in figure 13. Notable in this revision is the introduction of an assembly called the cradle which can be seen in figure 14 along with the drum showing the rim of ½" PVC welded to the 12" PVC pipe.

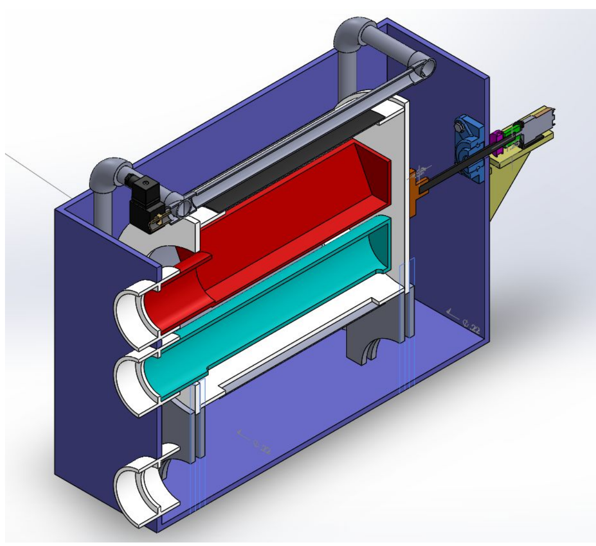

Figure 13 - Mechanical Design Version 6

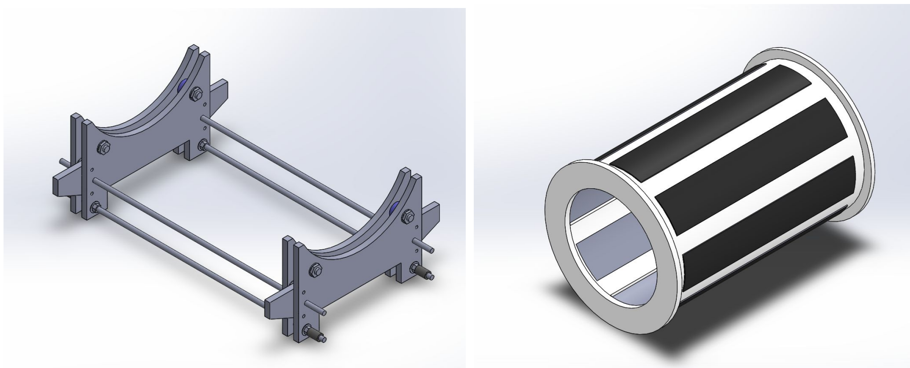

Figure 14 - Cradle and Drum with ½" PVC End Caps

The concept with the cradle was to build an assembly that would hold the drum so as to only allow rotation on a set of bearings and no translation. A right view of the cradle and drum assembly along with the motor attached to the drive shaft are shown in figure 15. Attaching the mesh was simplified on the suggestion of Steve Fowler from the Aquatron lab, who suggested PVC glue to secure the mesh to the inside of the drum.

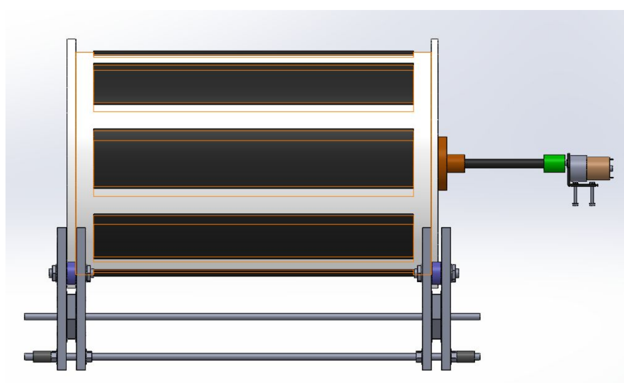

Figure 15 - Cradle and Drum Assembly

Mechanical Design Version 7

The latest version of the mechanical design is shown in figure 16. The face mounted drive bearing has been moved to the outside of the tank where it will be free from corrosion. A bearing seal has been added made of ½" PVC that accepts an O-ring which can been seen on the inside of the tank in figure 16 and figure 17. The bearing seal adds rigidity to the tank as an added benefit.

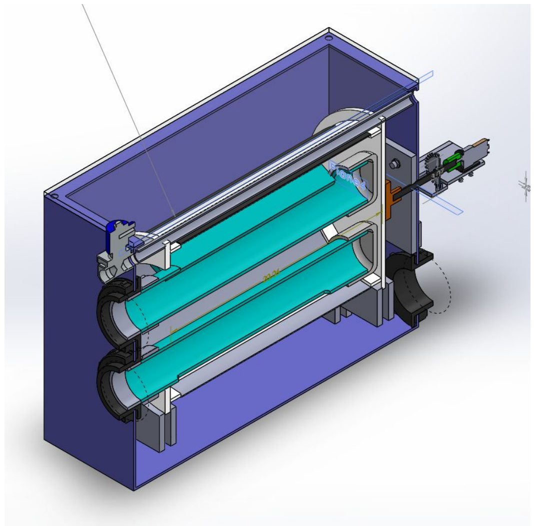

Figure 16 - Mechanical Design Version 7

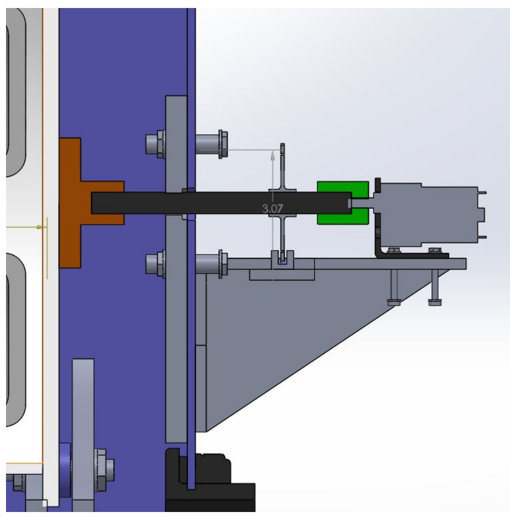

Figure 17 - Drive Shaft Seal & Support

The assembly with the tank suppressed in shown in Figure 18. One can observe the sprinkler tube with the solenoid valve at the top of the image. The inlet and outlet tube with the expected couplings that fit into the black bulkhead fittings of the tank are shown.

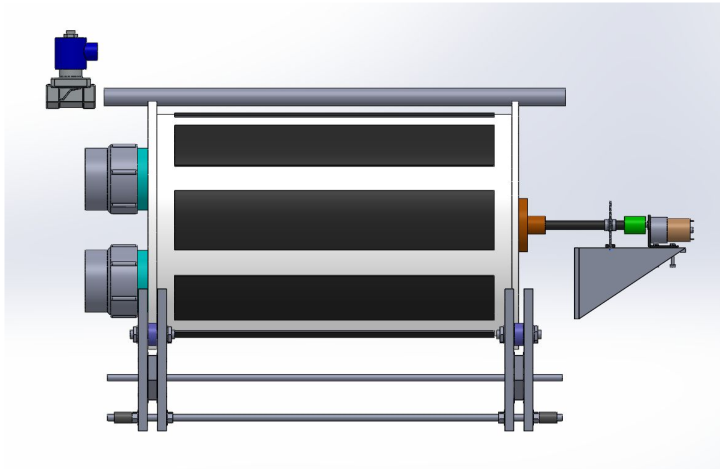

Figure 18 - Assembly with Tank suppressed

Figure 19 shows the motor assembly which include an optical tachometer and the required optical disc which was 3D printed, the only part that will be fabricated in that way. Below the motor is the cleaned water outlet coupling. This revision moved the outlet coupling to the back of the tank to accommodate installation requirements specific to the Aquatron lab.

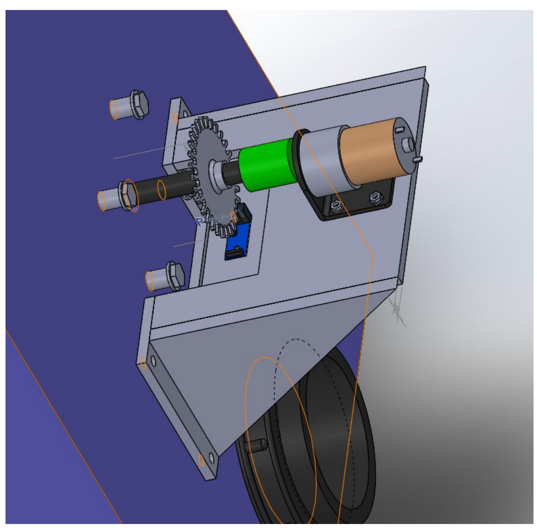

Figure 19 - Optical Tach/Motor/Alignment Couple

Motor Selection

In order rotate the drum filter, a motor drive is essential. In general, there are two types of electrical motors, DC and AC. The speed of the rotation must be controlled, and should be able to be adjusted from 5 RPM to 20 RPM. DC motors have a better speed control over a wide range and a high starting torque. This is the reason a DC motor was chosen at the very beginning and the AC motor idea entertained later was subsequently discarded. The reason for switching back to the DC motor was the focus on power output rather than torque.

As electrical engineering students, the intuitive idea is to find a motor with the proper power output. At the onset it was difficult to calculate without the rough drum specifications guiding the design. However, the group still estimated the power requirement for the motor using an alternative method by researching a motor used to power a washing machine with a similar sized drum. A typical washing machine has an AC motor with output electrical power 325W, and a corresponding real mechanical output power 285W caused by some losses. The working condition would be different since the container will be completely filled with water, a situation different from the drum filter. The ⅓ HP motor was deemed sufficient.

The next question for us is which motor is fit for this project, AC or DC? In checking the specifications for a real DC motor, typically a 1/3 HP one, the weight was found to be 19.2Kg, plus a gearbox. The total cost was over $1000. Thus a table was made to compare the two motors. Since Mr. Batt is a customer, this table was provided for him. He agreed that a change from a DC motor to a single phase AC motor was in order. This comparison is shown in table 1 below:

Table 1: AC versus DC motor Comparison

Parameters	*DC Motor with Gear Box*	*Single Phase AC Motor with VFD*
Speed Control	*Gear Box and PWM Voltage Control*	*Variable Frequency Drive: $300*
Power Supply	*AC to DC Power Converter: $200*	*120 VAC*
Weight	*19.2 kg*	*8.62 kg*
Maintenance	*Brushes need to be replaced periodically*	*Durable*
Total Cost	*$1,500*	*$700*
Bottom Line	*Expensive and Heavy*	*Lighter, Cheaper and More Durable*

At this point, the main reason to change from a DC motor to an AC motor is that the DC motor was more expensive and heavier for a same power output. In a future consult with Mr.Batt, he informed the group that there was only single phase power source in the Aquatron lab. Thus the only choice is to use a single phase AC motor. In order to confirm that a single phase AC motor would work properly an experiment was performed on a 1/3HP motor

Using a variac to test the speed regulation on this motor it was found the current was very high at starting, but decreased to rated current once the rotation speed increased to a certain point. A sharp clicking was heard during the motor start, which indicated that this motor contains a split phase starting circuit with a centrifugal switch as shown in Figure 20.

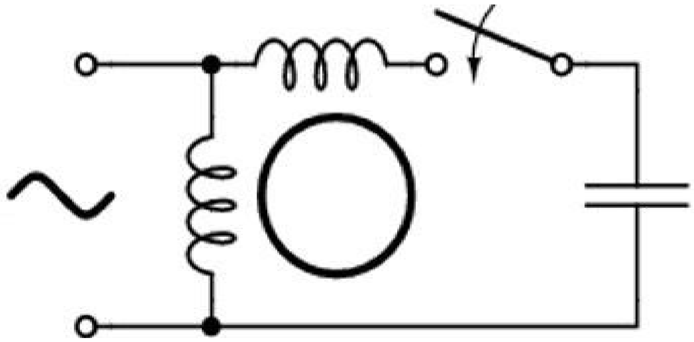

Figure 20: Single phase AC motor starting circuit

The switch is used to disconnect the starting winding of the motor once the motor approaches its normal operating speed. This switch will automatically close if the speed changes to the speed lower than a operating speed, which is much higher than 20 RPM. Below this critical speed the driven current is much higher than the rated current. Therefore, the centrifugal switch will not allow the motor to run at a low speed, thus it was decided that this motor could not be used.

After these considerations a DC motor was reconsidered. After some research it was determined that the high starting torque of the DC motor would allow the drum to be rotated at a lower power than anticipated, saving on the cost and space of a high-power motor.

The purpose of the motor is to drive the rotation of the drum. The motor was selected such that the drum can be rotated at approximately 5 RPM for normal use. The 5 rpm value was chosen on the advice of Ali (2013). As there may be a need for the motor to rotate the drum in both directions for cleaning, a full bridge circuit was used. The angular velocity of the drum is controlled using PWM delivered to the L298N full bridge driver circuit. The motor used in the prototype is a 10W permanent magnet series DC motor with a nominal speed of 5000 rpm connected to the drive shaft through a gearbox that reduces the speed 24 RPM and multiplies the torque by 208. PWM can be used to adjust the speed of the motor. The power for the motor is 24V DC which is converted from 115VAC through a 24 Watt power supply shown in figure 22. The speed and direction control for the motor rotation are delivered from the microprocessor to the L298N H-bridge chip shown in figure 21.

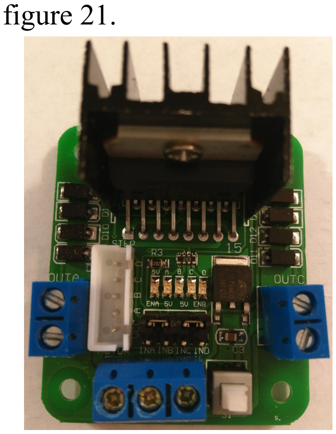

Figure 21 - L298N Full Bridge Driver

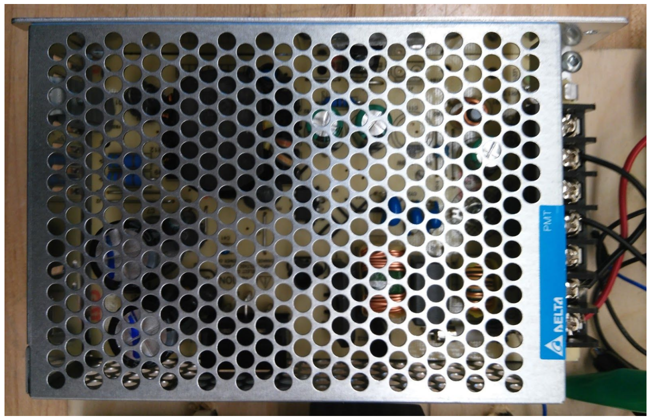

Figure 22 - 24V DC power supply

The motor's job is to induce rotation at a constant speed under a variable load. The load includes the drum itself as well as the water and the associated organic material. The team estimated the load in order to estimate the required power for the motor so that the motor and the budget could be approximated. The calculation is was based on Newton's 2nd law in angular form:

Torque [N·m]= moment of inertia [kg· m^2] *angular acceleration

The moments of inertia of a thin cylindrical shell with open ends of radius r and mass m can be expressed as I=m r^2 The drum has a thin cylindrical shell shape. From estimation using SolidWorks, the total weight would be 3.4Kg. Also the radius r is 20cm. Thus I=3.4* 0.2^2 =0.136Kg.

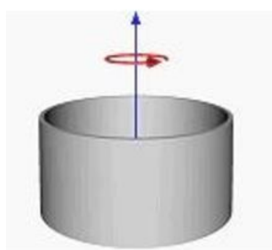

Figure 23: Moment of Inertia of Thin Cylindrical Shell.

The desired maximum speed was 20 RPM. It was assumed the drum will reach 20 RPM within 2 seconds. With calculation, 20 RPM rotation speed is equivalent to 2.09 rad/s. Thus the angular acceleration would be 1.05 radius/ s^2 . Therefore torque =0.136*1.05=0.1428 Nm. Considering losses and frictions, the total required torque would be less than 1 Nm. We also know that required Power (W) = Torque (N.m) x Angular velocity(rad/s). With these values the required power comes out as 2.1 W. Therefore with a generous margin for error a 10W series DC motor, was deemed sufficient for the load.

3.2 Power Requirements Proposed Solutions

The DC motor that was selected can be powered off a 115/24V 24W AC/DC converter as previously discussed above. In order to ensure that the motor does not suffer an excess of current, a current sensor was added to communicate the current to the microcontroller and the user via the LCD. Using the current sensor code can be implemented to deactivate the motor if the mechanical load causes the motor to stall in order to protect the motor.

Since the solenoid purchased would require a 12V 40W power supply, the 24V supply was deemed insufficient. A 115/12V 100W AC/DC converter was acquired to meet these demands. A high power output from this supply was deemed necessary as it was proposed that this supply could act as a supply for the rest of the components instead of purchasing another converter or relying on the 24V supply, which approached its rated output driving the motor alone. The increased cost and size of this 100W supply were negligible compared to a 40W – 60W source, which would also have met the requirements for the solenoid, but may not have been able to comfortably power the other components.

The microcontroller required a 5V source. At first the motor driver, which had a 5V regulator built into it, was used as a supply. This supply was deemed too noisy, and drew current from the already overtaxed 24V supply. A capacitor was added to reduce the noise, but there was still the current problem to contend with. A solution to this problem was to use a 5V phone charger, as they are readily available and can convert power directly from the 115V source. Another solution explored was to introduce separate 5V regulator, powered by the 12V source. It was found to be reliable, used little space, and met the power requirements of the microcontroller. A capacitor was added to the output and ground pins of the regulator to reduce noise. Delivering power has been an interesting challenge in this design.

3.3 User Interface Proposed Solutions

Once all the components of the UI were decided upon, a CAD drawing was created to attempt to accommodate all of the components within a minimal space. This drawing also attempted to be aesthetically pleasant and to be reasonably fast, cost-effective, and easy to construct. This interface is shown below in figure U. What is not shown is that the inside of the UI has enough room to accommodate the breadboard, all circuit components, and the wiring.. The rear panel of the UI will be secured to the outside wall of the tank with bolts, and the side and lower panels will be secured to the rear panel using a combination of glue, welded plastic, and/or screws. The front panel is designed such that it can be lifted off by hand, exposing the wiring and electrical components. There will be a hole drilled through the bottom of the tank to pass all the external wirings of the system, including the motor, solenoid, and external power.

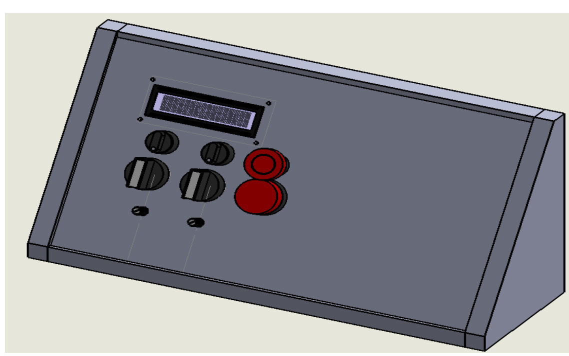

Figure 24: Ideal User Interface Design Containing All Theoretically Required Components

The prototype UI was constructed by securing the proposed components to a piece of wood and having the solderable breadboard freely-rotating on a platform. This allowed wiring to be reorganized at will and the breadboard to be soldered at the convenience of the group. This prototype was used for testing integrated components. A picture of this prototype UI is shown in figure 25.

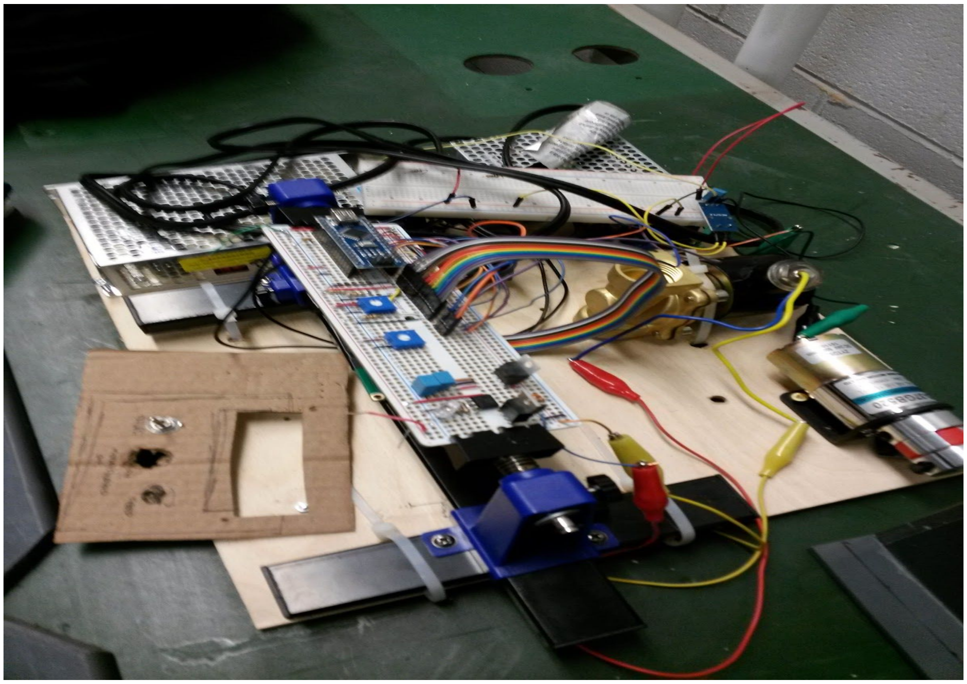

Figure 25: Prototype UI and Electronics

3.4 Cleaning System Proposed Solutions

There are two main overarching design considerations for the cleaning system; passive or automatic. The automatic system involves stimulation from the microcontroller to control an electrically-driven cleaning apparatus. The passive system involves a structure that directs waste away from the system and into the sewer.

The main passive solution proposed was influenced by the US patent US 7293658 B2 and is shown in figure 26. In this configuration the waste accumulating on the inside wall of the drum filter fall into the trough which connects directly to the sewer.

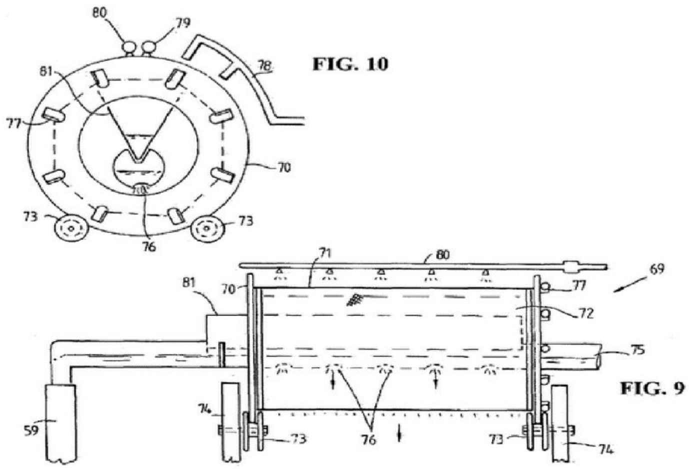

Figure 26: Sprayer, trough and wheel support Details for the Drum Filter from patent US 7293658 B2

An addition to this proposal would add a “scraper” to the top of the trough to increase the amount of waste collected in the trough and to prevent undue accumulation. Another addition would involve adding “scoops” to the inside of the drum filter that would hold the waste until it passed directly above the trough. This would increase the clearance rate and would prevent loose waste from simply tumbling about the inside of the drum, creating a potential blockage and increasing the torque demand on the motor.

Another passive cleaning proposition, also influenced by the above patent, is the addition of nozzles spraying filtered water from a superior position to the drum. This would dislodge any waste not being removed by gravity and would keep waste from drying and potentially becoming too adhesive. The water from the nozzles would flow constantly while the main system is functioning. The water used in the cleaning system would either come from the bottom of the tank, pumped up to the nozzles using a sump pump, or would be pumped from the clean water reservoir of the laboratory.

A passive system proposed to safeguard against overflow is the addition of a bulkhead at a height just below the bottom rim of the drum. This would ensure that the water never obstructs the drum. This bulkhead would deliver the overflowing water directly to the next stage of the system.

Active systems were also proposed in place of, or to be used in tandem with, passive systems. A mechanical system that actively scraped the insides of the drum was proposed and then immediately discarded as there were too many restrictions, including building cost, complexity, and poor use of space. A more realistic proposition involved using an idea similar to the continuously open nozzle system mentioned above, except with a solenoid valve. The solenoid would be opened or closed by stimulation from the microcontroller. A manually opening solenoid, stimulated with a switch, was also proposed as an alternative method or as a fail-safe.

3.5 Control System Proposed Solutions

The electrical control system design chart is shown in figure 27 contains 9 parts; DC motor drive L298N, DC motor, optical speed sensor, current sensor, solenoid valve, water level sensor, LCD screen, 555 timer for manual control and arduino board for auto control. Also there is two power supplies which are not shown in figure 6. One 24V power supplies for 24V DC and the rest electrical control part, the other 12V DC power supply is for solenoid valve since it will consume high current at working condition. The DC power supplies, DC motor, rotary speed sensor, DC motor driver,arduino board, LCD screen, solenoid valve, and current sensor have been purchased.

The microprocessor has been programmed for the speed detection, cleaning system operation, and sensory systems. The microcontroller decided upon was the Arduino Nano chip, as it is open-source, user-friendly, cheap, reliable, and has the necessary number of inputs. The biggest benefit of the Arduino chip is the speed and ease with which functions like LCD display, analog to digital conversion and pulse width modulation can be implemented compared to the same functions using embedded C. The Arduino ships with libraries for all the important hardware functions and high level methods that allow rapid prototyping.

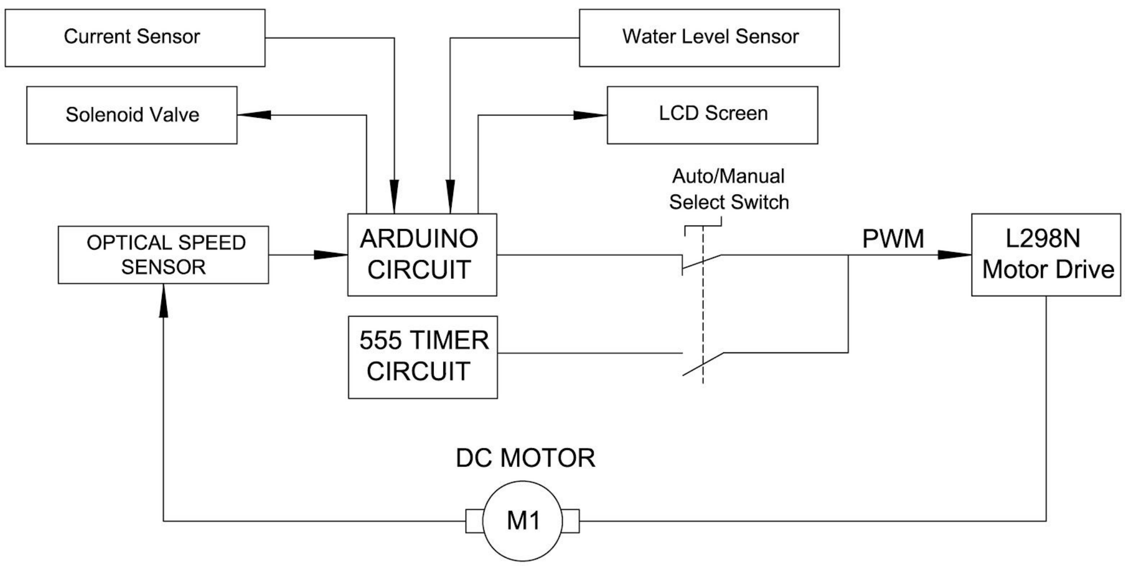

Figure 27: Control System Design Chart

The speed of a DC motor can only be controlled by changing the armature current. However, in order to directly adjust the armature current a variable resistance must be added, lowering the overall efficiency. Therefore, a pulse width modulation (PWM) control must be used to reduce the energy consumption. The first schematic electric circuit uses a 555 timer to change the duty cycle of the output square wave, which would be connected to a MOSFET to control the average value of voltage (and current) fed to the motor by turning the "switch" on and off at a fast rate. Figure 28 shows the schematic electric circuit.

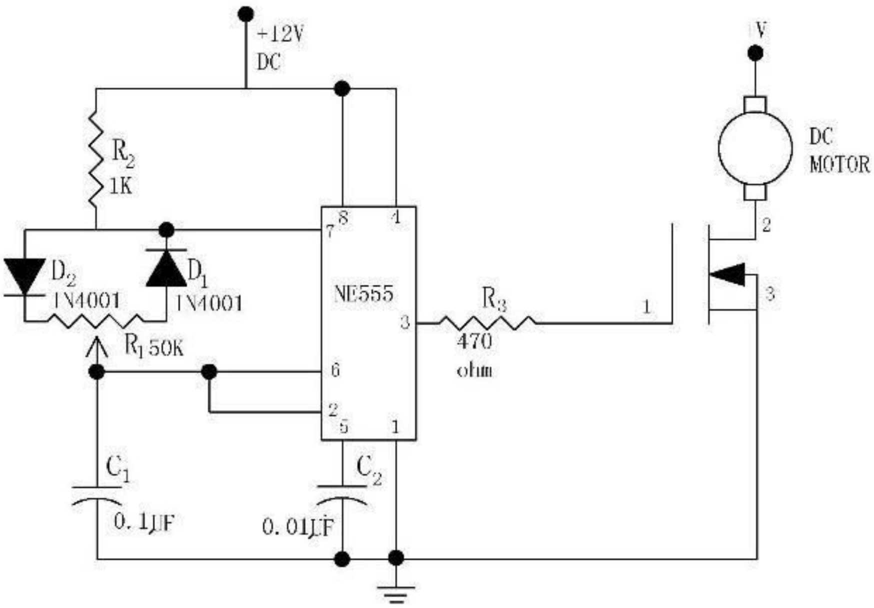

Figure 28: Circuit for Manual Speed Control

The duty cycle, as a fraction of total period that the output is high is: R1/(R1+R2), The potentiometer R1 has the range from 0 to 50K, R2 is 1K, the duty cycle has a range from almost 0 to 100 percent. A 5PRM to 20 RPM rotation can be realized using this iteration.

An H bridge to reverse the polarity of the current flow through the DC motor can be used to reverse the control. This circuit can be simply illustrated by figure 29, shown below:

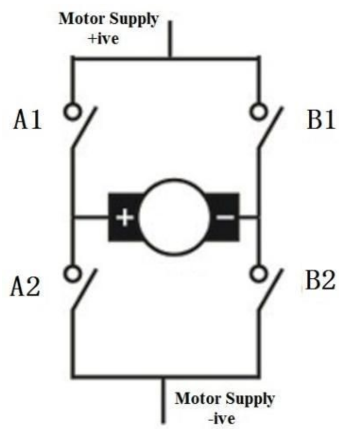

Figure 29: Basic H Bridge Circuit

What should be noted from the above figure is that there are four switches within the bridge which can enable a voltage to be applied across a motor in either direction, as shown in figure 30. However, either of the A or B transistors cannot be "on" at the same time as this will lead to a short circuit. In order to solve this problem an interlock function in the real circuit or a software solution in the microcontroller may be implemented. Another potential benefit could be the dynamic brake function. By closing either the lower two or upper two switches, as shown in figure 31, the motor's generator effect will work against itself, such that the motor can be dynamically braked.

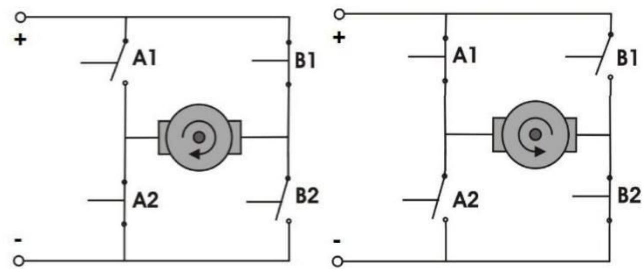

Figure 30: Control for both clockwise and counterclockwise rotation

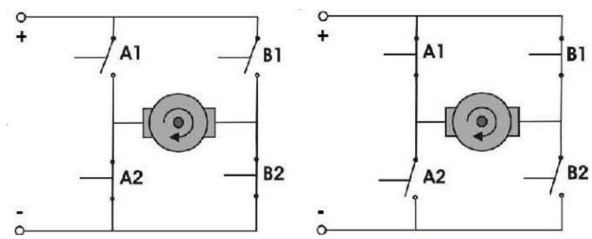

Figure 31: Dynamic brake function

In this project feedback from a rotary speed sensor to regulate the rotation speed of the drum filter could be implemented by adding an optical wheel speed sensor or a hall-effect sensor. Regardless of the type of the sensor a pulse signal will be produced. This signal will be fed back to the control circuit to achieve feedback control. A block diagram as shown in figure 32 will describe the entire system. Regulating the feedback signal to make it compatible to the circuit may be necessary.

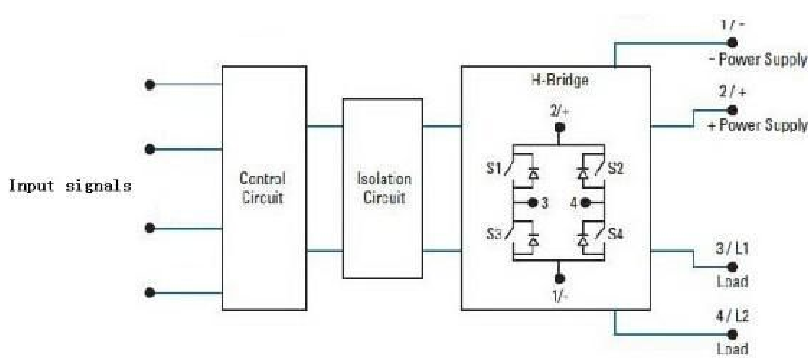

Figure 32: Block diagram for the control system

As presented above, an H bridge is required. A full-bridge drive or two half-bridge drivers to implement the circuit may be used. This hardware configuration would avoid flaws in programming the microcontroller, which could lead to the failure of the MOSFETs. Thus, following the datasheet of IR2104s, the schematic circuit diagram as shown in figure 33 describes the half bridge driver system.

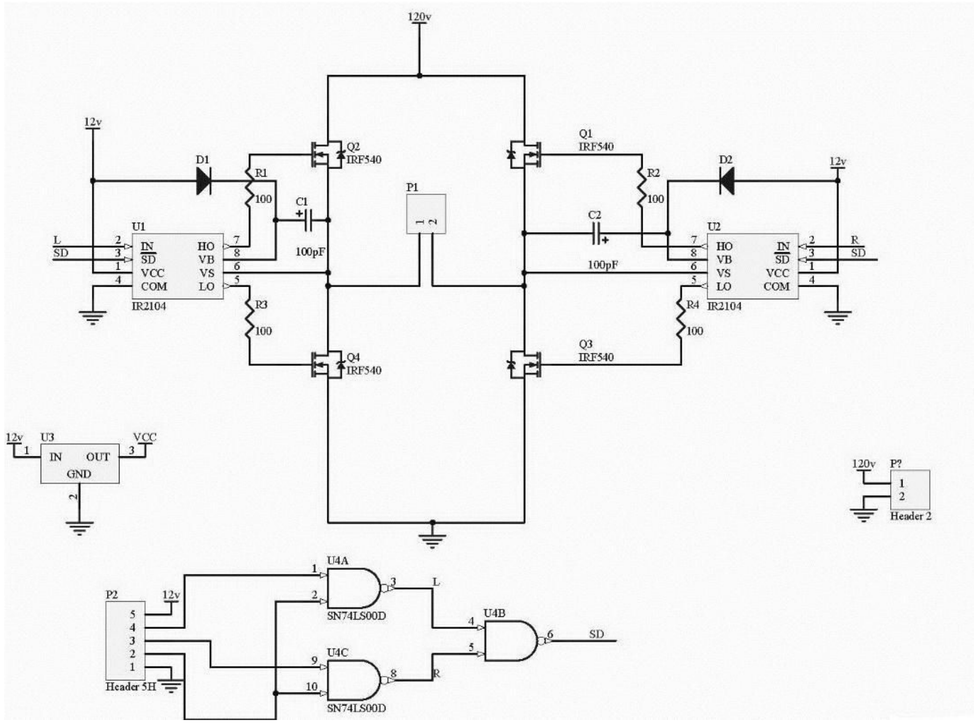

Figure 33: H bridge circuit with IR2104s half bridge drive and IRF540 MOSFET

There are 5 pins in header 5H (on the lower left). Pin 3 and pin 4 select the direction of the rotation by setting logic "1" signal on either pins. Pin2 is the input PWM signal, to determine the rotation speed. For chip IR2104s, it is a high voltage, high speed power MOSFET and IGBT driver with dependent high and low side referenced output channels. The lead IN is the Logic input for high and low side gate driver outputs (HO and LO), which is in phase with HO. And SD is the Logic input for shutdown. Figure 37 is the logic input and output signal diagram for the H bridge. When Pin3 is high and Pin4 is low, the left side HO will keep low and thus the left side LO will keep high. That means MOSFET Q2 will be off while Q4 will be on all the time. For the right side IR2104s, the HO and LO output will change simultaneously when the PWM input signal changes. Therefore, Q1 and Q2 will be on and off, respectively, at different times. The current will go through Q1, motor and Q4 when Q1 is on and Q2 is off, the motor will brake when Q1 is off and Q2 is on. However, the brake cannot be seen directly as the frequency is very high. Thus the observer can only see the speed changes when the PWM signal changes. Similarly, when Pin3 is low and Pin4 is high, the motor will rotate in reverse with speed change.

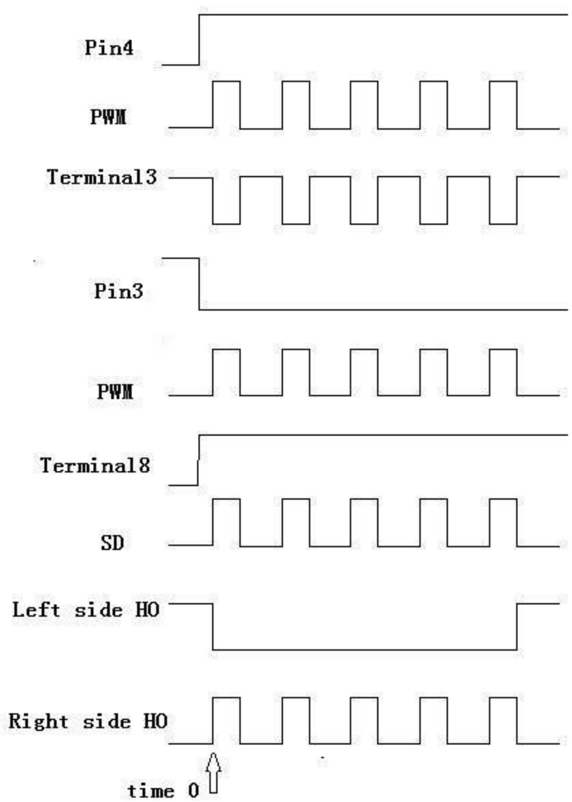

Figure 34: The Logic Input and Output Signal Diagram for the H Bridge

For feedback purposes it may be necessary to measure the rotation speed of the motor's shaft. There are two speed measurement iterations at present; a hall sensor or an optical sensor. For both iterations the working principle is the same; to count the number of the pulses within a certain time and calculate the speed from this value. For a hall sensor a permanent magnet in the shaft is required. The hall sensor would be stationary on the stand. A 5V signal will be emitted while the permanent magnet is close to the sensor. For an optical sensor an encoder disk with evenly distributed perforations would have to be built and fixed to the shaft.. When the disk rotates, the perforations on the mask will block or unblock the LED light, which will provide either 0 or 5V output. The main difference between the two is that the optical sensor will provide a more accurate speed measurement as it will count multiple times per rotation.. The main drawback for an optical sensor is that it has a relatively short lifespan. Infrared and visible light emitting diodes life is often quoted to be 100 000 hours, but this is based on the average lifespan of a single, 5 mm epoxy encapsulated emitter. The hall sensor has a very long lifespan; approximately 30 billion operations. The accuracy and the ease of acquisition have made the optical sensor the natural choice.

This optical sensor uses a LM393 low offset voltage dual comparator to achieve an output voltage between 0 and 5V when a encoder blocks or does not block the LED light. Figure 35 and 36.

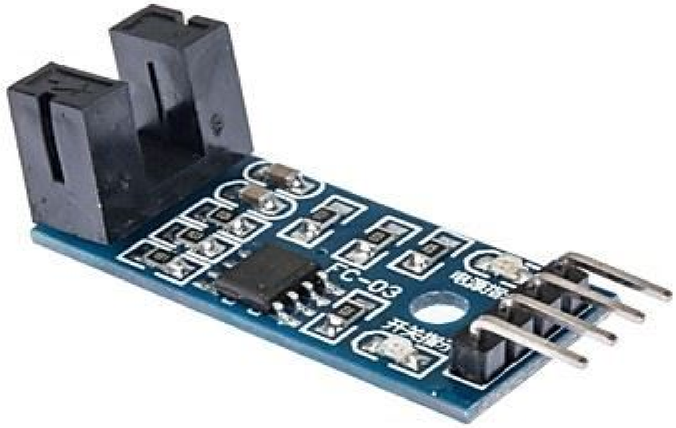

Figure 35: LM393 Optical Sensor

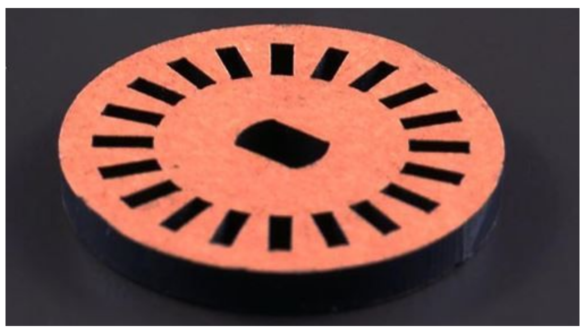

Figure 36: Optical Tachometer Encoder disk

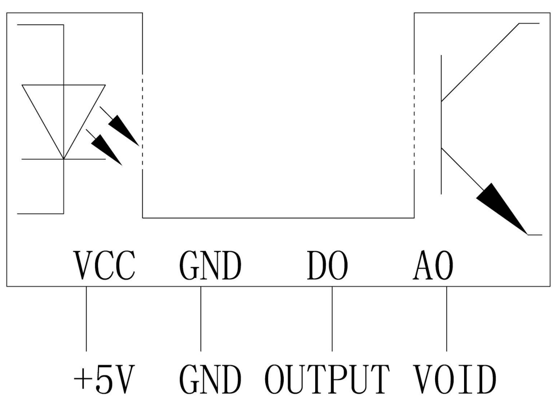

Figure 37: Optical Sensor Pin Mapping

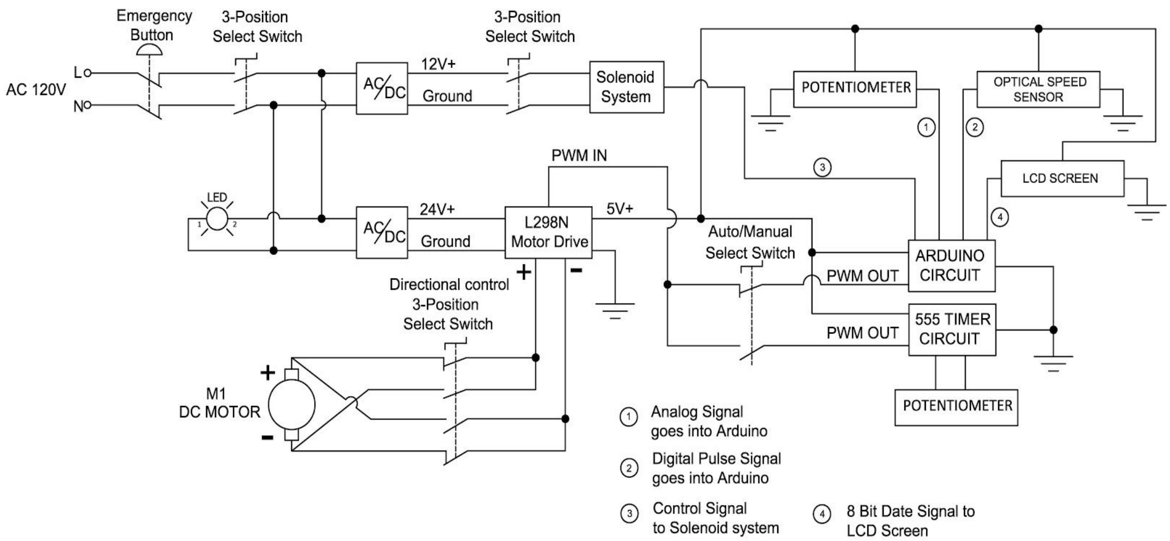

Figure 38: Schematic diagram for the entire electrical control system

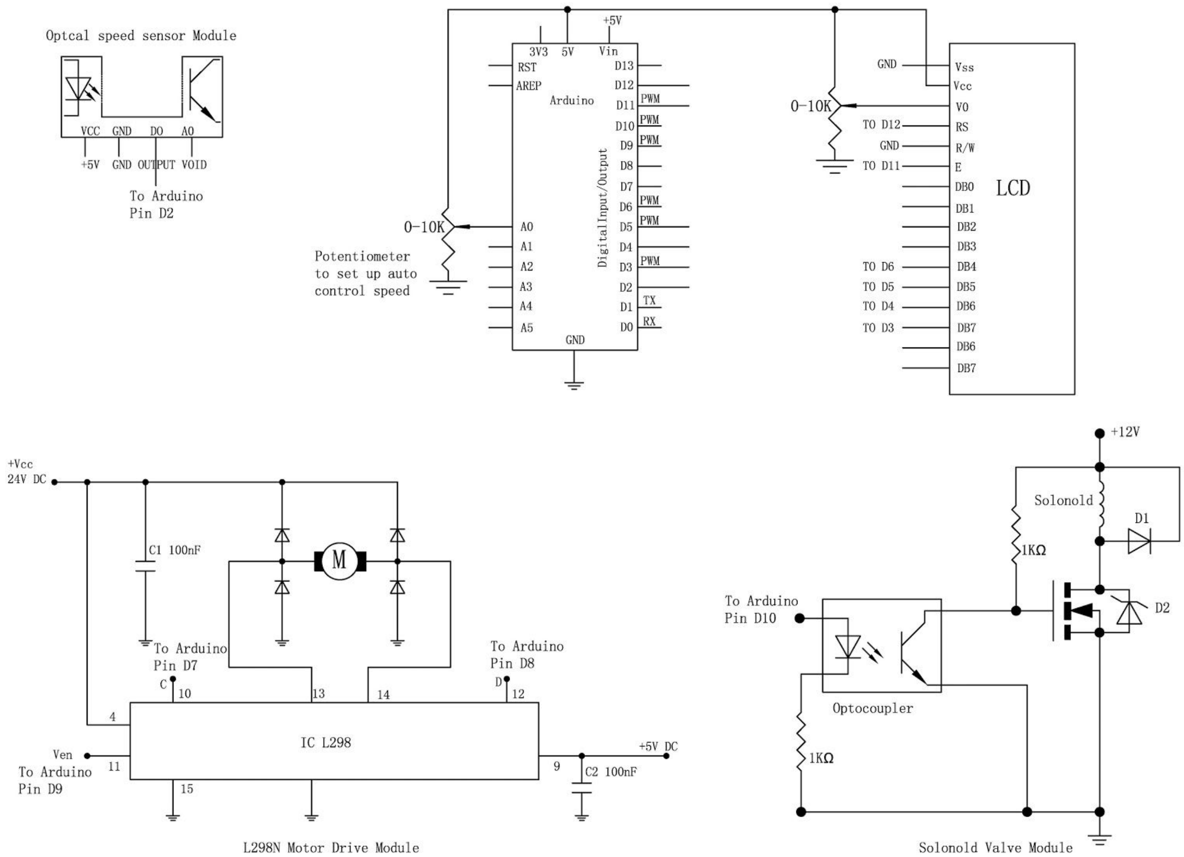

Figure 39: Functional Circuit Connections

Arduino nano was chosen for use in this project because it can be mounted onto a breadboard. The Nano provides 12 digital input/output signal pins. It also provides 8 analog pins that can do 10 bit analog to digital conversion. Pin D2 and Pin3 were used for interrupts for the speed sensor and the alarm system. Pins D4 to D13 were allocated to the LCD screen, the PWM signal for the motor and the solenoid valve control. A0 and A1 pins were used for ADC speed control and the current sensor monitoring. Further details are found in the appendix.

4.0 Results

4.1 Mechanical Design Results

The current design iteration from the methods proposed above is shown in the following figures.

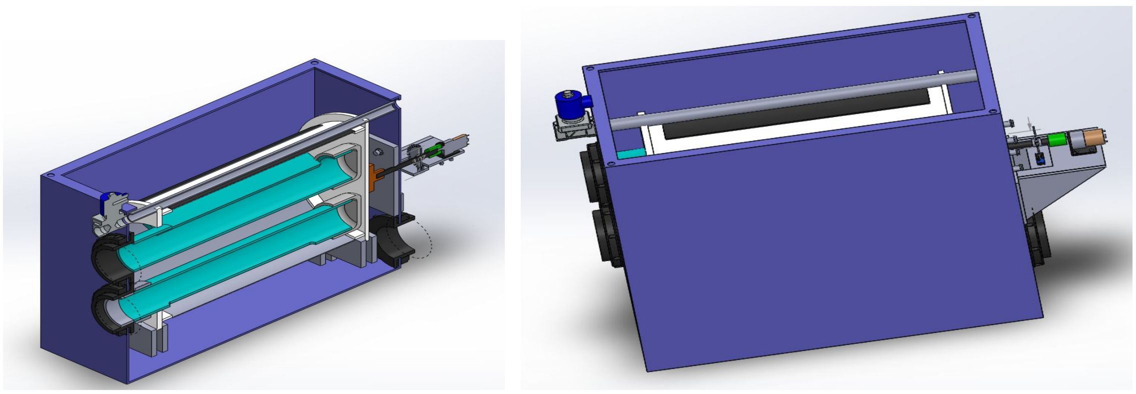

Figure 40 - Final System Isometric and Section Views

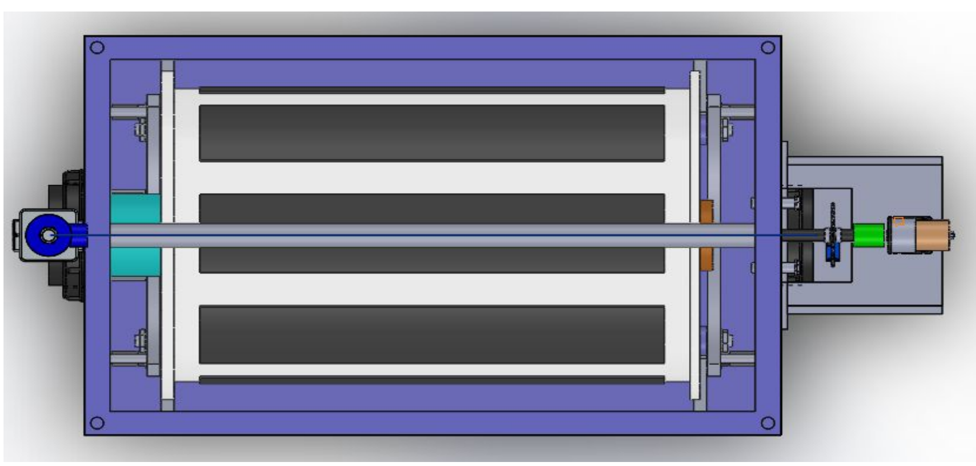

Figure 41 - Top View showing Drum, Motor, Optical Tach and Sprinkler System

Figure 42 - Positions of the inlets and outlets

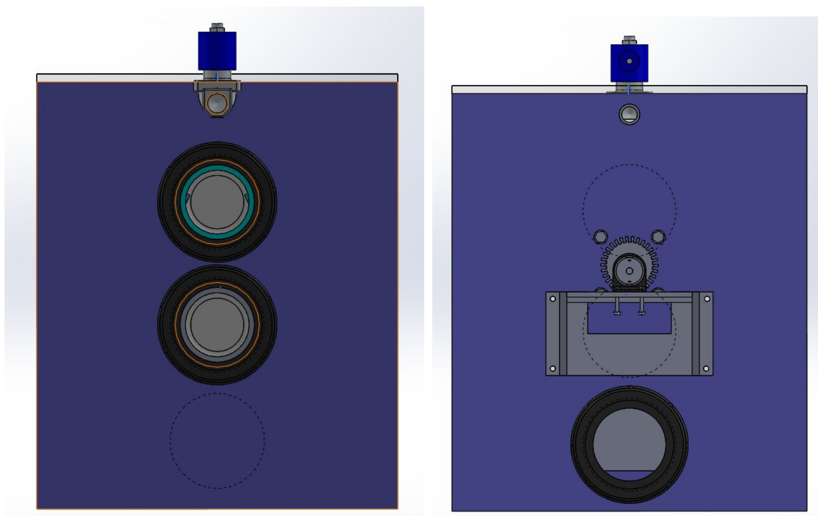

Figure 43 - Inlets, Outlets and Motor.

In order to confirm a 10W DC motor could work for this project. The 24 Volt, 10W permanent magnetic DC motor with integrated gearbox of the gear ratio 250:1. The rated speed of the shaft is 20 RPM when the motor runs at 5000 RPM. The shaft connected with a coupler with the diameter of 5mm. A string was wrapped around the coupler and a load was attached to the string. The load was pulled by the rotating motor while the current was monitored. Results are shown in table 2.

Table 2: Load test on the DC motor

Weight (Lb force)	Input voltage (V)	Current (A)
2.5	24	0.06
5	24	0.17
7.5	24	0.20
10	24	0.61(overload)

Since the motor is rated 10W, the theoretical max current would be 0.42A. Since there were no weights less than 2.5Lb available, linear regression was used to estimate that the max weight the motor can drive is 8.57lb. Therefore, the torque T=8.57Lb*5mm=42.86Lb.mm=0.191N which is higher than the required torque which was previously calculated. The 10W motor is deemed acceptable for this application.

4.2 Power Requirements Results

Prior to using the 24V motor a load test was performed with the current monitored to make sure the motor was able to meet the torque requirements and that the 24V power source was sufficient for the task. The load test determined that the torque generated by the motor was sufficient to overcome the load. Once the load was assembled in the aquatron laboratory other frictional forces became apparent. It may be likely that a higher torque motor is required. The acquisition of a voltage supply with a higher power rating may become necessary to accommodate this new motor. A more ideal situation would be to be able to use the 12V supply, as it does not even reach half of its rated power during normal function. This would require that the new motor have a rating of under 50W.

The 12V power supply was shown to be able to accommodate all of the components of the system with the exception of the current 24V motor. All significant noise in the components was minimized using capacitors. In laboratory tests the solenoid and the electric system were able to run continuously for 10 minutes of time with no change in function. Since the solenoid will only be running for a part of the time in practice this 10 minutes of function was deemed acceptable for the current system to be used in a water flow experiment.

The 5V regulator has been sufficient to power the microcontroller and subsequent components (current sensor, LCD screen, motor driver, solenoid driver). The signal becomes clean with the introduction of the capacitor, and only draws 5W from the 12V source. The 12V source has an available 50W to be used for a potential motor.

4.3 User Interface Results

As the prototype UI was being used the relevancy of the components was discussed amongst the group members. It was decided that the UI should be simplified, and that more control could be given to the software than to the hardware. This would mean the final UI would be smaller, more user friendly, more aesthetically pleasant, easier and more cost-effective to construct, and easier to troubleshoot potential problems. A discussion with the external supervisor cemented this proposition. The components that remained are as follows:

- LCD screen
- ON/OFF
- Clean mode ON/OFF
- Alarm

Another component to consider would be the manual/automatic control. Though this component has some redundancy, and must have additional components included with it, it could be useful for experimental purposes. Moreover, a failure in the software, the microcontroller, or a connection to or from the microcontroller would either shut down the system or cause it to act uncontrollably. The switch to manual would allow the system to run while repairs were made.

The current prototype UI has been useful for quick wiring and troubleshooting. It has been simple to add and test components on a solder-free breadboard prior to soldering the component or otherwise securing it to the wooden board. Since the UI will most likely change considerably over the final stages of the design it is most likely that this modular configuration will remain as a working prototype until the very last stages of the design process. The final design of this UI would most likely look similar in shape to that shown in figure U, except it would be smaller and have fewer components.

4.4 Cleaning System Results

The configuration chosen for the prototype involves an automated nozzle system controlled with a microcontroller and a solenoid. The spray from the nozzles directs the waste on the inside of the drum to fall into the clearance trough. The physical structure of the trough and the nozzles are discussed in the mechanical section of this report. The solenoid was chosen to accommodate a ¾" fitting to match the normal pipe fittings used in the laboratory for clean water. A picture of the solenoid is shown below in figure 44.

Figure 44: Solenoid Valve for Controlling Sprinkler System

The first test of the solenoid involved power tests at voltages up to and including the rated voltage. Table 3 shows the results of this test. The power source used for this test has a power rating of about 45W, so it is fair to say that the solenoid achieved its power requirements. It should also be noted that the solenoid opened at around 5V, and was open fully at a rated 12V.

Table 4: Solenoid Test

V	A	P (W)	State
1	.2	.2	closed
2	.45	.9	closed
3	.7	2.1	closed
4	.95	3.8	closed
5	1.2	6	Open
6	1.45	8.7	Open
7	1.6	11.2	Open
8	1.9	15.2	Open
9	2.05	18.45	Open
10	2.4	24	Open
11	2.6	28.6	Open
12	2.8	33.6	Open

The system was designed to turn on (open) with 5V stimulation of a CMOS from the microcontroller. Once the MOSFET is active, the terminals of the solenoid experience their rated 12V. A pulldown resistor was placed between the gate of the MOSFET and the ground to prevent false positives. An optocoupler was placed between the microcontroller output and the MOSFET gate to isolate the microcontroller from the 12V source, preventing high currents from damaging the microcontroller. To reduce the current through the optocoupler a resistor was placed between the ground and the emitting terminal of the optocoupler. A flywheel diode was placed between the two terminals of the solenoid so that current would not pass through a closed MOSFET and overcome the power limit. Originally a resistor was placed between the 12V power source and the solenoid to reduce current passing through the solenoid. With results obtained during experimentation, and on the advice of a technologist, this limiting resistor was removed. This resulted in a more "open" solenoid as the current was able to reach its rated value. A schematic of the control system for the solenoid is shown in figure 45.

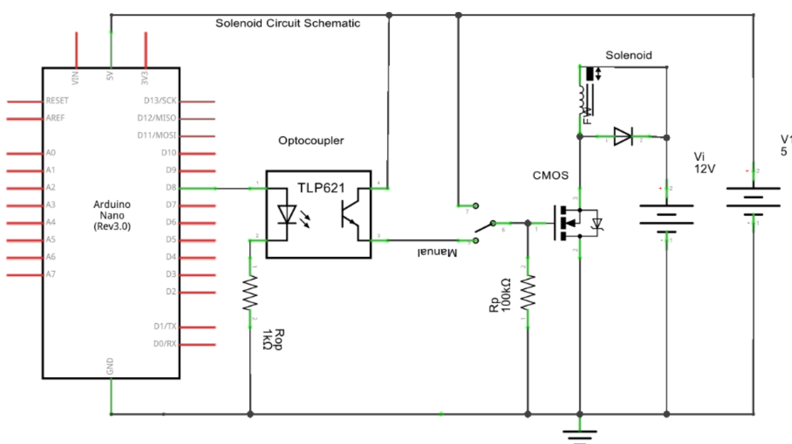

Figure 45: Circuit schematic for the activation of the solenoid in the cleaning system

The mesh provided for the drum filter has hold of about 2mm in diameter. These holes were made large on purpose to test the overall effectiveness of the cleaning system. If it is decided that the clearance rate is sufficiently high and is not at risk for overflow a smaller mesh can be introduced. Dolan et al (2012) have a method for determining an appropriately sized mesh for different drum filter specifications. This method may be used in future iterations. There are diminishing returns, according to Fernandes et al (2014), in decreasing the mesh size, and significantly lower clearance rates are associated with a slightly smaller screen size, indicating that a larger sized screen may be optimal.

4.5 Control System Results

The H bridge circuit shown in Figure 33 was connected to a 555 PWM signal generator (shown as Figure 44). This H bridge circuit works satisfactorily. The motor can rotate in both directions with variable speed.

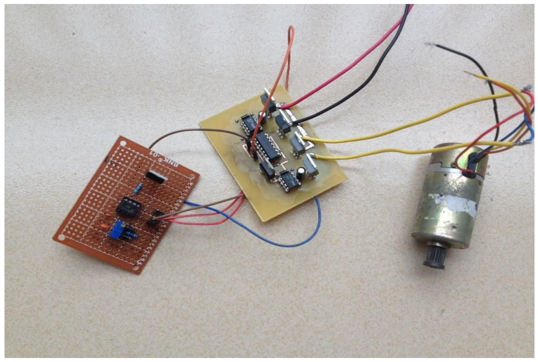

Figure 46: H Bridge Control Board Connected to a 555 PWM Signal Generator

Since a DC motor was chosen H bridge circuit we built during the first semester is over qualified for the current requirements. Also this H bridge circuit will occupy a larger space. An H bridge DC can be easily obtained. This product is relative cheap and compact.

Below is the schematic circuit of a L298N IC chip which can be used for the current motor configuration. This circuit is based on the IC L298 from ST Microelectronics. L298 is a dual full bridge driver that has a wide operating voltage range and can handle load currents up to 3A. The IC also features low saturation voltage and over temperature protection.

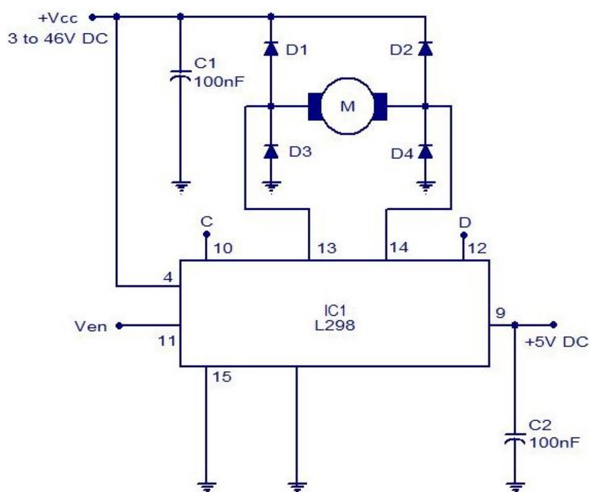

Figure 47: Schematic circuit of a L298N IC chip.

In the circuit diode D1 to D4 are protection diodes when voltage spikes occur. Capacitor C2 is the logic power supply filter and capacitor C2 is the supply voltage filter. The state of the motor will depend on the logic level of the pins 10, 11, 12 and it is described in table 4 shown below the circuit diagram.

Table 4: Logic for Motor Driver

Inputs		Function
V_{en} = H	C = H ; D = L	Forward
	C = L ; D = H	Reverse
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't care

This L298N has the same functionality as the H bridge circuit with IR2104s half bridge drive. The reason for using the L298N is that it is easy to obtain..

The control system in its current iteration is shown in figure 48. There are some loose solders that must be located and fixed.

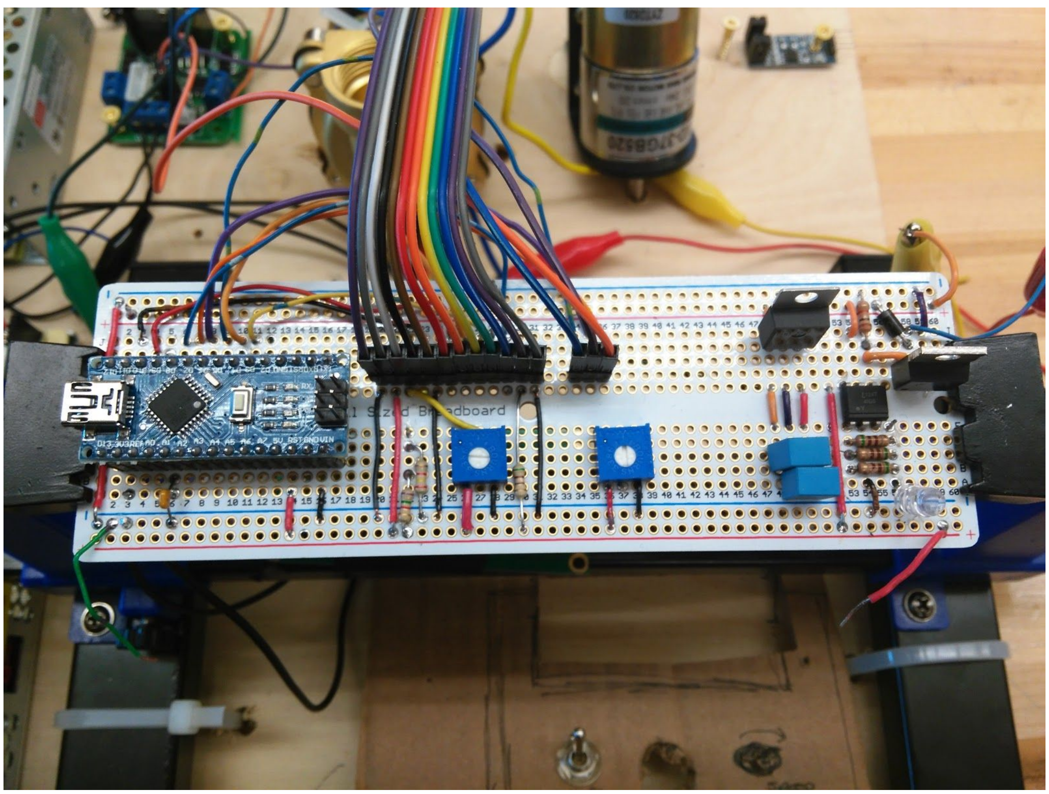

Figure 48: Arduino Nano Based Control System

4.6 Project Budget

Table 5: Project Budget

Title	Unit Cost (CAD $)	Quality	Total Cost (CAD $)			
Shipping	15	2	30			
Potentiometers	8.5	2	17			
24V DC 20RPM Motor with Gear Box	6.6	1	6.6			
L298N Dual H Bridge Motor Drive	3.2	2	6.4			
Coupling for the motor shaft	3.9	2	7.8			
Hall Speed Sensor	1.8	2	3.6			
Optical Speed Sensor	1.8	2	3.6			
Motor stand	1.3	1	1.3			
Emergency Stop Button	1.3	1	1.3			
Knob switch	0.6	2	1.2			
3-position switch	2.9	2	5.8			
110AC to 24V DC, 25W Power supply	9.9	1	9.9			
LED light	0.4	1	0.4			Mr.GAO
Fuses	0.2	2	0.4			Mr.Nadav
Female to female wires, 40pieces	0.5	1	0.5			Mr.Aaron
110AC to 12V DC, 75W Power supply	36.26	1	36.26			Mr.John
Solderable Circuit Board	9.93	3	29.79			
Arduino Uno Board	5.5	3	16.5			
Current Sensor	2.32	1	2.32			
Solenoid Valve	20.75	1	20.75			
Drive Shaft	25	1	25			
Flange Mounted Bearing	13	1	13			
Bearings	3.39	4	13.56			
NMOSFET	3	2	6			
Switches	20.34	1	20.34			
Shipping	24	1	24			
LCD Display	8	1	8			
Tactile push button	8	1	8			
Gas	0.9	100	90			
Arduino nano	9	2	18			
Tank 27"*12"*20"	220	1	220			
PVC pipe	free	1				
Mesh	free	1				
Scews	free	several				
Threaded Rod	free	4				
Total			647.32			

5.0 Discussion

5.1 Discussion of Mechanical Design

Though a more powerful motor may have to be acquired due to a higher than anticipated amount of friction, the current mechanical design iteration is functioning as expected. There are no major design flaws and a redesign is not necessary at this moment. The next step for the mechanical involves a continuation of the construction process.

5.2 Discussion of Power Requirements

At this juncture it is recommended that the 12V power source remain in place to power the microcontroller and its associated components. Since this supply only uses about 50W out of a rated 100W, any future motor or other such component can take advantage of the additional 50W. Failing to meet this criteria will result in the group having to purchase an additional power supply. An acceptable alternative would be the acquisition of another motor that satisfies the torque requirements and can also rely on a 24V source. These acquisitions will depend on the cost of available and acceptable motors.

5.3 Discussion of UI

The modular prototype UI shown in figure 25 will be used until all other components have solidified their place in the system. Once these are finalized an elegant UI can be constructed with a similar design as that shown in figure 24.

5.4 Discussion of Cleaning System

The electrical components of the cleaning system have been tested in isolation and in integration. The cleaning system is ready for a water flow test, but must wait for the mechanical components (the trough and the plumbing) of the cleaning system to be constructed. At this moment a 20sec:60sec (1:3) ratio of ON/OFF for the system is estimated to be correct, but will be confirmed with experimentation.

5.5 Discussion of Control System

The circuit is working as anticipated. There are some loose solders that must be addressed. Once the mechanical portions of the design are finalized the control system will be re-tested in more realistic conditions. In their current state the control system is expected to function with few errors.

6.0 Conclusion

The prototype is expected to be completed by the end of the project term. The bottleneck in the fabrication process continues to be the mechanical construction. Once each portion of the mechanical design is finalized the electrical systems can be introduced and experiments under more realistic conditions can be performed, with the requisite alterations made to the design. The completion of this report will allow the group to focus more time and energy into the design and fabrication process.

7.0 Future Recommendations

Since the mechanical portion limited the rate of progression, future projects involving the completed mechanical prototype can focus almost exclusively on electrical and control systems. Experiments with the complete system and under different conditions will make shortcomings apparent, which will then drive future mechanical improvements. More monitoring systems can be introduced to the completed system, and the system can be operated remotely and with greater control. Mechanical and electrical parts may be optimized or customized to operate for longer periods of time, with lower friction, and/or at higher efficiencies. Since aquaculture systems are becoming more prevalent and profitable (Pfeiffer, 2010), an optimized version of this drum filter may offer a low-cost solution for waste buildup.

8.0 References

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9.0 Appendix

9.1 Aquatron OS Code

```
#include <LiquidCrystal.h>

//Port Configuration
LiquidCrystal lcd(12, 11, 5, 4, 13, 9);     //LCD Pins
int filterModeSpeedPort = A0;               //ADC Motor PWM input (.1uF to ground)
int PWMPin = 6;                             //Motor PWM Output Port D6
int solenoidPin = 10;                       //Solenoid Control Port D10

//Motor Variables
int sensorValue = 0;                        //ADC Motor PWM input storage

//Tach Variables
volatile int rpmcount = 0;                  //see http://arduino.cc/en/Reference/Volatile
int rpm = 0;
unsigned long lastmillis = 0;


void tachometer()
{
  rpmcount++; //Increment rpmcount every falling edge of tach

  if (millis() - lastmillis >= 1000)  ///Run Once a second (Hz)
  {
      rpm = rpmcount * 2;      //Convert frecuency to RPM
      rpmcount = 0;            // Restart the RPM counter
      lastmillis = millis();  // Update lasmillis

      //Update Terminal
      //Serial.print("\t");
      //Serial.print("RPM =\t"); //print the word "RPM" and tab.
      //Serial.print(rpm); // print the rpm value.
      //Serial.print("\n");


   }
}


void setup()
{
  lcd.begin(16, 2);      //Initialize 1602 LCD
  lcd.print("Hello Aquatron!");    // Print a message to the LCD.

  Serial.begin(9600);     //Debug Terminal @ 9600bps

  pinMode(7, OUTPUT);    //Motor Direction Pin
  pinMode(8, OUTPUT);    //Motor Direction Pin
  pinMode(10, OUTPUT);   //Solenoid Control Pin

  //Tach
  attachInterrupt(0, tachometer, FALLING);//interrupt cero (0) is on pin two(D2).
  //Maybe Irrelevant...
  //pinMode(2, INPUT);//Enable Pull Up for Tach
  //digitalWrite(2, HIGH);
}
```

```
void filterMode()
{
  //Disable Solenoid
  //Enable Motor
  //Display Speed, Mode
  //Use Pot 1 for PWM Motor Speed
}

void cleaningMode()
{
  //Enable Solenoid
  //Enable Motor
  //Display Speed, Mode
  //Use Pot 2 for PWM Motor Speed
}

void solenoidTest()
{
  digitalWrite(solenoidPin, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1000);               // wait for a second
  digitalWrite(solenoidPin, LOW);    // turn the LED off by making the voltage LOW
  delay(1000);
}

void loop()
{
  lcd.setCursor(0, 1);  //Cursor to column 0, line 1 which is line 2
  lcd.print(millis() / 1000); //Number of seconds since reset:

  //Motor Speed
  sensorValue = analogRead(filterModeSpeedPort);
  sensorValue = sensorValue >> 2;   //Truncate 10bit ADC to 8bit ADC to eliminate effect of noise
  analogWrite(PWMPin,sensorValue);   //Update Motor Speed

  //Enable Motor Control Pins
  digitalWrite(7, HIGH);
  digitalWrite(8, LOW);

  //solenoidTest();

        //Update LCD
      lcd.setCursor(6, 1);  //Move Cursor to column 9, line 2
      lcd.print("RPM = ");
      lcd.print(rpm);

      //Current Sensor
      int currentSensor = analogRead(A4);
      //currentSensor = currentSensor >> 1;
      float current = currentSensor * 0.034375*1000;
      int mAmps = (int)current;
      Serial.print("\t");
      Serial.print("Current =\t"); //print the word "RPM" and tab.
      Serial.print(mAmps); // print the rpm value.
      Serial.print("mA \n");

}
```

10.0 Group Contribution

Aaron McGrath B00145107	-Provide convenient transportations -Code -SolidWorks -Soldering
Nadav Avni B00584102	-Cleaning system electronics -User interface design -Mechanical construction -Mechanical idea generation -Parts purchasing -Current sensor circuit -Voltage regulator circuit -Circuit testing -Background research -Report organization -Presentation
Yangyanglong Gao B00569500	-Motor identification -Load test and calculation -Manual control circuit design -IR2104s half bridge drive design and implementation -L298 motor drive test -Optical Sensor circuit -Arduino programming -Electrical circuit draft drawing -User interface design -Mechanical construction -Parts purchasing -Circuit testing -Background research -Report writing -Presentation

11.0 Gantt Chart

12.0 Spherical Wave Engineering