**Design Review II Report**

Senior Design

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**An Autonomous Hydroponic Herb Garden**



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1. **Executive Summary**

Hydroponic systems have existed for centuries, providing an alternative agricultural method to soil-based growing for large crop yields. Recently, hydroponic systems have attracted increased attention from the home grower market, as they provide a way to grow plants easily indoors, thereby allowing individuals living in urban environments to grow their own fresh produce. Our system would prove highly attractive to this emerging consumer market, as we plan to construct a fully automated, inexpensive, and compact hydroponic system. Using simple construction methods and easily available components, we will create a streamlined hydroponic system that will remove the hassle of manual hydroponic systems that require frequent adjustments.

1. **Introduction**

Hydroponics is a method of growing plants using a water based mineral nutrient solution, without soil. The culture of growing plants through hydroponics has recently seen significantly growth because the controlled environment of hydroponics makes it easier to grow plants that are not traditionally grown in certain climates. Compared to soil-based growing, hydroponic systems require less water, allow for greater control of nutrient levels, result in healthier plant growth, and are easier to keep pest and disease-free. Despite these benefits, hydroponic systems require significantly more maintenance. For these reasons, the demand for automated hydroponic gardens has evolved, opening the door for a profitable business venture, particularly in providing an inexpensive system for home grower with increasingly limited living space.

The main objective of our design is to create a fully-automated, counter-top, hydroponic herb garden. A successful product would provide consumers with the ability to grow herbs in urban living environments easily and cost-effectively. Nutrient Film Technique (NFT) was the hydroponic method chosen to best fit our design goals. NFT was chosen because it has proven produce quality herbs and is the leading method used for our desired plant production. Additionally, we found it requires less total water in the system when compared to other recommended methods for common herbs.

Our primary goal is to design a system capable of automatically monitoring and maintaining pH, electrical conductivity (EC), and temperature of the nutrient solution. The solution pH affects the rate of nutrient uptake at the roots and electrical conductivity gives a measure of the dissolved solutes of the nutrient solution, thereby representing nutrient concentration. An Arduino Mega will be used to operate the control systems by interfacing with sensors, a heater, and a solid-state relay connected to peristaltic pumps. The pH is monitored using a pH probe and regulated by supplying acidic and basic solutions to the nutrient solution using a peristaltic pump. The temperature is adjusted using a heater with built-in feedback. Electrical conductivity is measured with an EC probe and adjusted by adding concentrated nutrient solution using a peristaltic pump.

1. **Background Information**

Internet searches have revealed that there are several hydroponic systems available on the market today. However, most of the products on the market are manually operated and lack automatic feedback systems for pH, electrical conductivity, and temperature. The devices that do have semi-automated features, such as the ability to monitor and control pH, nutrients, and temperature automatically are extremely expensive ($1,500 or more) [5].

The Modern Sprout device’s [3] overall design specifications resemble our product closest due to the device being a window sill planter. Therefore we would have a similar target audience. Although the Modern Sprout device is aesthetically pleasing, it does not monitor pH, electrical conductivity, and temperature. Rather it uses a timer to periodically supply nutrients to the plants. SuperBox [4] is another comparable device that is semi-automated. However the SuperBox is much more expensive ($795) and there is no feedback system for the nutrient solution. Other countertop designs include the Aero Pro 7 [11] and Waterworks [12] which are also more expensive with less features. Therefore our design will fill the void for an inexpensive semi-automated system with feedback.

The journal search was primarily used to determine the conditions required for the plants to grow effectively and efficiently. It was found that the nutrient concentration, temperature, pH, and lighting are the main components that need to be monitored and regulated for the proper growth of a plant [1]. There are upwards of 20 elements required for plant growth (with the concentration measured through EC). Carbon, Hydrogen, and Oxygen are naturally occurring in solution, however, Nitrogen, Potassium, Phosphorous, Calcium, Magnesium have to be manually dissolved in the nutrient solution [1]. It is important to maintain the pH of the solution because it affects how well each nutrient can pass through the root cell walls to nourish the plants [4]. Each plant has an optimal pH range, thus the pH must be measured and maintained for proper plant growth [4].

The patent search focused on the nutrient monitoring and lighting for the system. Most patents relating to LED grow lights are for arrays of LED lights of varying frequencies used in mass market growing (patent #s CN 202901994 U, WO 2012003755 A1). One method for nutrient monitoring is outlined in a patent for optical methods which monitors in near real time (patent # WO 2013022535 A2). Another system uses ion monitoring to monitor nutrients supplied in aqueous form to a plant (patent # WO 2009066991 A2).

1. **Specifications and Parameter Analysis (See Appendix for detailed calculations)**

In an NFT system, the angled top reservoir allows for a continuous film of solution to flow through the root system. Ideally this solution will flow at 1 L/min. Therefore, it is necessary to choose a water pump with enough power to accomplish this task (accounting for head loss). The friction of the pipe (F), the velocity of fluid (V), the length of tubing (L), the diameter of tubing (D), and gravity (g) determine the head loss.

$$H\_{l}=F\*\left(\frac{L}{D}\right)\*(\frac{V^{2}}{2g})$$

It was found that the pump chosen has sufficient power to provide the necessary flow rate.

For this system to be sustainably autonomous there must be enough water in the main reservoir to allow for continuous flow of the nutrient solution. Therefore, it is important to account for solution evaporation on the surface and solution absorption at the roots. The amount of evaporated water per hour is determined by the evaporation coefficient (Θ), the water surface area (A), the humidity ratio in saturated air (xs), and the humidity ratio in the air (x).

$$g\_{h}=Θ\*A\*(x\_{s}-x)$$

It was found that with the tank size, which was determined by the design constraint of keeping the entire device on a counter top, there will be 1.77 gallons used per week (at 20oC) leaving 1.59 gallons in the container.

It is most practical for construction to use acrylic for the reservoir, but first it must be determined whether acrylic is able to withstand the water pressure. The resulting force is related to the average pressure multiplied by the area of the wall, acting at 1/3 the distance from the base to the water surface. It was found that the maximum force on the walls is 18.22N, well within the stress limits of acrylic. While the weight of the water on the bottom panel was found to be 124.91N.

 The temperature of the water must remain within the desired range at all times. Thus, we performed a heat transfer analysis for our water heater. First, to find the amount of heat required to rise the temperature we used the following formula using the specific heat of the solution (Cp), the mass (m), and the difference in temperature (dt).

$$Q=Cp\*m\*dt$$

Then, given the power rating of the heater we chose, we find time the heater should be left on to raise the reservoir temperature a specified amount. It was found that it would take 8.89 minutes to raise the temperature of the solution by 1 degree. The temperature changes required will be minor (around room temperature), so this is an acceptable rate of change.

 Finally the pH and nutrient solution dosages were determined for basil. It was found that the necessary adjustments were feasible given our system. It is important to note that most herbs require similar growing conditions and could also grow in our system (See Appendix i).

 For all calculations, we assumed that the nutrient solution had the same properties as water.

1. **Final Design Specifications**

As a group, it was agreed upon that a clear plastic (acrylic) would be desired for the majority of the device, so the interior is visible for the final expo. This is an aesthetic choice, and in reality is not optimal for a hydroponic system, due to the potential for algae growth. If this product were made for market we would use opaque injection molded plastic instead of acrylic and ABS for our plastic parts. Acrylic, however, satisfied several of our design requirements, including satisfactory strength and ease of fabrication. Additionally, due to this project being a budget constrained design, having the necessary acrylic free and available played a role in the decision as well.

As mentioned earlier, we settled on an NFT hydroponic system. The bare essentials of a NFT system are: a water reservoir (> 3 gallons), water pump, plant channel, and controls for any electronics (Arduino). For full automation we are also including a light fixture, pH and electrical conductivity probes, peristaltic pumps (to control addition of plant nutrients and pH up/down), an air pump, temperature sensor, and heating element.

The design is broken down into 3 separate elements: water reservoir, plant channel, and electronics chamber. The plant channel consists of an acrylic rectangle, with a 2.5 degree angled base. There are three 2” holes for plant cages spaced 3” apart. This resulted in the dimensions shown in the attached drawings in Appendix iv. The flanges on the top of the channel, are designed so it can rest on top of the water reservoir.

The reservoir of the herb garden has a few design requirements. Due to evaporation and water consumption we determined it must be able to hold 3 gallons of water. Additionally, the entire device must be <18” high, as a result of the standard cabinet height above a countertop being 18”. Finally, the electronics location should be above the water reservoir to minimize the risk of moisture damaging the electronics. From these requirements, and L shaped reservoir was chosen. The top half of the L is where the channel will rest, allowing water to flow through the channel, and fall back down into the main reservoir. The main water reservoir consists of a 19.5” W x 13” D x 10” H. with the missing portion from the L profile being a 19.5” W x 8” D x 5” H rectangle.

The final acrylic component is the electronics mount, which is the missing portion from the L profile, measuring 19.5” W x 8” D x 5” H. This section is attached with a magnetic clasp to the main reservoir. Within the electronics mount is the brain for the apparatus, as well as all the other components mentioned previously.

These 3 acrylic enclosures will be made by laser cutting the unfolded boxes profile in 0.25” acrylic, then heat bending this piece to form the desired shape. The profiled shape of these elements can be found in Appendix iv. It should be noted CAD drawings were made for 2 types of fabrication for the box. Heat bending is preferred, but if that proves too difficult, the laser cutter will be used to cut finger joints and bond them with epoxy. This has already been proven to be watertight through experimentation, while the heat bending technique is a newly found option.

As mentioned, there are several components within the electronics mount. This section has been placed directly above the main reservoir, so we can easily monitor and maintain the plants food supply. Here we have holes cut for direct access with the pH, EC, and temperature probes, with nutrient reservoirs that will be controlled with 3 peristaltic pumps to adjust pH and electrical conductivity. The pumps are bought off the shelf, and are mounted in a 3D printed ABS chamber. This chamber is fitted with 1/16” tubing sealed with 1/16” NPT press-fit tube fittings. This leaves the pump to apply as little as a single drop of solution at a time. This can be seen with detailed dimensions in Appendix iv.

Other features that will be in the electronics mount are 4 LED lights, which will indicate when it is time to refill the main reservoir, or any of the nutrient/pH solutions. To activate these LED indicators we will use a simple circuit that will act as a water level, this circuit is shown in Appendix v. The LED will be triggered when the circuit is open, which occurs when it is out of water. [10]

All parts have been chosen and are ready to order (shown in Appendix iii, with manufacturer, part number, and cost). Design and state variables are outlined in Appendix vi.

1. **Plan**

The plan of attack for the rest of the semester is outlined in the Gantt chart presented in the Appendix ii. Following Design Review II, with the CAD finalized and the Arduino coding completed, the components will arrive and Assembly will begin. Since the acrylic is already on hand, construction and optimization of the grow box will begin immediately. The Arduino code can be tested using test solutions of known pH, EC, and temp. Once all of the components arrive, and the coding is validated, the electronics box can be assembled. Simultaneously, flow analysis and solution calibration will be conducted to determine optimal growing conditions for our system. Once all of the growth parameters are set and the coding is completed, we will begin growing basil plants and preparing the device for presentation, adjusting as we see fit based on the rate of plant growth. The design of the website will begin around the same time, as a major aspect of our project lies in marketing our device.

1. **Problem Analysis (Risks)**

There are several problems that may arise in the completion of this project. One issue is proper waterproofing of the system, achieved only by choosing the correct joining and sealing method for the acrylic panels. Several different methods were discussed and tested and two solutions are being considered (finger joints and heat bending). If the chosen joining system fails leaks will occur and dramatically throw off the control system. Other problems will arise as we try to fine tune the control system. If the settling time is too fast, the shock of a sudden change in pH or nutrient levels may damage the plant. If the overshoot is too high, then the levels may move out of the desirable range on the other end of the limits. Maintaining the nutrient concentration and pH within the feasible ranges, without these issues occurring, is a main goal for the project.

In addition, by choosing to have a system with an electrical outlet as a power supply (the choice that is most practical for the consumer) the system is sensitive to electrical failures and power outages. Since the NFT system requires a constant flow of the nutrient solution, it is more susceptible to this sort of event and the plant will die if the issue is not resolved in a timely manner. Additionally, maintaining a constant film of the nutrient solution on the base of the grow tray may prove challenging to execute but is essential for successful growth using NFT.

Another issue that needs to be considered is water loss due to evaporation. If the evaporation rate is too high, the salt concentration of the water will increase rapidly and the need to add additional water may exceed the capability of the system. Finally, one goal is to have grow lights to provide the light for plant growth in apartments with no access to sunlight. However, grow lights are expensive and may be beyond the allotted budget.

1. **Conclusion**

In conclusion, we have outlined a design for a cost-effective and marketable product that drastically reduces the amount of effort required by home grower in an urban living environment. With cost and time constraints under consideration, we have shown the project is fully achievable once a few hurdles are overcome.

1. **References**

[1] Journal of Biological Education (Society of Biology). Summer92, Vol. 26 Issue 2, p107. 5p. 1 Black and White Photograph, 1 Diagram, 2 Charts, 1 Graph.

[2] Hershey, D.R. (1992d). Plant nutrient solution pH changes. Journal of Bio-logicalE ducation, 26, 107-111.

[3] http://modernsproutplanter.com/

[4]http://supercloset.com/product/grow-boxes/superbox-grow-closet/

[5] <http://www.purgro.com/grobot.html>

[6] <http://www.engineeringtoolbox.com/evaporation-water-surface-d_690.html>

[7] <http://www.engineeringtoolbox.com/heat-work-energy-d_292.html>

[8] <http://www.hydromatic.com/ResidentialPage_techinfopage_headloss.aspx>

[9] <http://www.savannahstate.edu/cost/eng-tech/faculty/jayjan2010/jay/hehslidec2.htm>

[10]<http://roshanzbg.blogspot.com/2013/06/create-simple-low-cost-water-sensor.html#.UwFWavldXyA>

[11] http://www.hydrofarm.com/

[12] http://waterworksgs.com

**X. Appendix**

**i. Specifications and Analysis**Most of our analysis was done on the reservoir of our hydroponic system which will be made out of acrylic. The dimensions of the reservoir are seen in the table below.

|  |
| --- |
| **Dimensions of Reservoir** |
| **Length (in)** | 18.50 |
| **Width (in)** | 12.00 |
| **Height (in)** | 3.50 |
| **Volume (in3)** | 777.00 |
| **Area (in2)** | 222.00 |
| **Volume (gal)** | 3.36 |

**Table 1:** Dimensions of Reservoir

The properties of acrylic are given in the Appendix.

 For all calculations we will assume the nutrient solution has the same properties as water and the basic fluid dynamic assumptions hold. Such as the fluid is incompressible, there is constant pressure and the flow is laminar. Therefore we can calculate the head loss of the pump. The tubing specifications are found in the table below. The tubing material is vinyl.

|  |
| --- |
| **Tubing Specifications** |
| **Diameter (in)** | 0.38 |
| **Length (in)** | 18.00 |
| **Friction** | 0.00 |
| **Area (in)** | 0.29 |
| **Flow Rate (l/m)** | 1.00 |
| **Velocity (m/s)** | 3.17E-09 |

**Table 2:** Tubing Specifications

Using these values we find the following head loss.

|  |
| --- |
| **Head Loss**  |
| **Hl(m)** | 1.23E-22 |

**Table 3:** Head Loss

Note that this value is extremely low so we don’t have to worry about the pump not having enough power to pump this distance.

 Next we determined that evaporation of the reservoir solution. This calculation was performed at two different temperatures.

|  |
| --- |
| **Evaporation of Water** |
| gh (gal/week) (20C) | 1.22 |
| gh (gal/week) (25C) | 1.59 |

**Table 4:** Evaporation of Water

We also need to find a way to determine how much water is used by the plant. There is a lot of information on tomato plants hence we tried to relate their usage to the amount of water a basil plant would consume. These values are seen in the table below.

|  |
| --- |
| **Water Intake** |
| intake (gal/week) (20C) | 0.55 |
| intake (gal/week) (25C) | 0.92 |

**Table 5:** Water Intake by Basil Plants

Then we are able to determine the total water usage per week and the resulting height of the water after a week.

|  |
| --- |
| **Water Usage in a week** |
| **Usage (20C) (gal)** | 1.77 |
| **Usage (25C) (gal)** | 2.52 |
| **Water left (20C) (gal)** | 1.59 |
| **Water left (25C) (gal)** | 0.85 |
| **height (20C) (in)** | 1.66 |
| **height (25C) (in)** | 0.88 |

**Table 6:** Weekly Water Usage

It is important to note that a lot of water is evaporated which could cause an issue with our system being completely autonomous. With evaporation the EC of the solution tends to rise, which could cause too many nutrients being in the solution. This is harmful to plant growth.

 Next we determined the water pressure on the walls of the reservoir. Along with this we also determined the weight of the water on the bottom wall. Note that all of these forces aren’t going to put enough stress on the acrylic to cause any deformation.

|  |
| --- |
| **Water Pressure on Walls** |
| **Pave (N/m2)** | 436.05 |
| **Fmax (N)** | 18.22 |
| **Fmin (N)** | 11.82 |
| **Weight (N)** | 124.91 |

**Table 7:** Water Pressure on Walls

|  |
| --- |
| **Properties of Acrylic** |
| **water absorption** | 3.00E-03 |
| **Tensile Strength (psi)** | 5470.00 |
| **Melting Temp (deg C)** | 160.00 |

**Table 8**: Properties of Acrylic

Lastly we did a heat transfer analysis on the water heater. Hence we found the amount of energy needed to raise the temperature of the water by 1 degree. This could then be multiplied by however many degrees difference there is between the desired and the measured temperature.

|  |
| --- |
| **Heat Transfer - Heating Water** |
| **Q (watts)** | 100.00 |
| **Cp (kJ/kg K)** | 4.19 |
| **Mass of water (kg)** | 12.73 |
| **del T (1)** | 1.00 |
| **Q(kJ) (1)** | 53.35 |
| **Time (1) min** | 8.89 |

**Table 9:** Heat Transfer Analysis

 With all the analysis complete we want to look into how to dilute the nutrient solution. The table below shows the conversion factor and the relating amounts of water and solution needed to create a preferred solution.

|  |
| --- |
| **Nutrient Solution** |
| **Conversion** | 1 gal:750 gal |
| **Volume (gal)** | 3.36 |
| **Water (gal)** | 3.36 |
| **Nutrients (gal)** | 4.48E-03 |
| **Volume (liters)** | 12.72 |
| **Water (liters)** | 12.70 |
| **Nutrients (liters)** | 1.70E-02 |

**Table 10:** Nutrient Solution

We also determined the amount of pH up/pH down we need per gallon of water to change the solution’s pH

|  |
| --- |
| **pH up/pH down** |
| **Conversion** | 1ml:1gal |
| **pH (ml)** | 3.36 |

**Table 11:** pH up/pH down in solution

 The last thing we looked into were plants that had similar growing specifications to basil so that we could essentially grow several different plants at the same time with our hydroponic system. The table can be found in the appendix. We see that several herbs have very similar specifications. These herbs include mint, oregano, parsley, sage, and thyme. Scallions also have very similar specifications.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Plant Name** | **Lighting conditions** | **Lamp Type** | **Temperature** | **pH** | **PPM/TDS** |
| Basil | High Light | T5 | warm | 5.5-6.5 | 700-1120 |
| Mint | High light | T5 | warm  | 5.5-6.5 | 1400-1680 |
| Oregano | high light | T5 | warm | 6.0-7.0 | 1120-1400 |
| Parsley | high light | T5 | warm | 5.5-7.0 | 560-1260 |
| Sage | high light | T5 | warm  | 5.5-6.5 | 700-1120 |
| Scallion | high light | T5 | warm | 6.0-7.0 | 980-1260 |
| Thyme | high light | T5 | warm | 5.5-7.0 | 560-1120 |
|  |  |  |  |  |  |

**Table 12**: Plant specifications

**ii. Gantt Chart**

**iii. Parts List**





iv. Drawings

|  |
| --- |
| Description: :Capture3.PNGElectronics MountPlant Channel |
| Description: :Capture1.PNGABS nutrient reservoir |
|  Description: :Capture.PNGPeristaltic Pump Mount |
| Description: :Capture2.PNGAssembly of previous four drawings |
|  |

v. Water level sensor

 

vi. Design and state variables

|  |  |
| --- | --- |
| **State Variable** | **Design Variable** |
| High Cost of sensors | Dimensions |
| Height of System | Hydroponic Method |
| Weight | Sensors |
| Stress on Walls | Heater Power |
| Room Temperature | Grow Lights |
| Plant Height | 12 Volt Input |
| Head Loss | Feedback System |
| Heat Transfer Rate | Ardiuno |
| Efficiency  | Grow Lights |
| Fluid Dynamics- Mixing | Nutrient Solution |
| Evaporation |   |