Automated Hydroponic System Design with Minimal Human Interaction

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Abstract — *The design of an automated hydroponic system follows from the need of having a system that works through difficult situations. A situation involving a power outage is considered a major problem since the plants in the hydroponic should not be kept without water for more than a couple of hours. If it occurs, the plants will not be able to be harvested and it would result in economic and time loss. Having an automated system would prevent this disaster and would provide the owner some help by showing what it needs. This being more nutrient solution in the reservoir tank, showing the pH level of the solution, or even letting the owner know through phone communication about a power outage. For different types of hydroponics there are different methods of application but they all follow the same needs. For easy application and better understanding of the system, electronic integration with Arduino is used. This design covers the basic needs of the hydroponic system while providing easy manufacturing and integration.*

Key Terms — *Arduino, Hydroponic, Sensor, System.*

INTRODUCTION

Throughout history, there has been different methods of growing plants. There's soil growing, Coco growing, aeroponics, aquaponics and hydroponics. Soil growing, which is the traditional way, has always been used but the grower must be experienced in knowing how much water the plants need in order to harvest healthy plants. Too much water would leave the plants without oxygen, while too little water would leave the plants dry. Hydroponics solves this problem by giving more control to the person growing the plants, using less water, and having a design where oxygen is not blocked by the soil. William F. Gericke, professor at the University of California, Berkeley, discussed his research in February, 1937, about growing tomato vines only using water and nutrients and had better results than growing them with soil [1]. Although a hydroponic system is a great way to grow plants, the person maintaining the system should always be aware that it is running correctly without any problems. Some factors to look after would be the water level of the tank, the pH level, water pump and oxygen pump working correctly. If one or more of these factors are failing, the plants cannot be harvested and there would be economic and time loss. While a person would take time verifying these factors, a more efficient way should be considered for better time efficiency and monitoring.

PROJECT DESCRIPTION

Using a hydroponic system is an excellent way of growing plants since it is efficient and gives great results. The operation of these systems requires constant monitoring to achieve the expected outcome. Since these systems depend on electricity for the water pump, power outage should be taken in consideration since the plants could die depending on how long the system is turned off. Although a person can monitor the system daily, a self-sustained hydroponic system would help by showing its performance and what it needs exactly to keep working properly in a less time-consuming approach. If a power outage occurs, the system could keep running for a couple of hours with a battery. Developing such system would help farmers harvest plants in an organized manner and in a less time-consuming process. The problem of the power outage would be resolved for some time until the power is back or another way of maintaining the system working without electricity is considered.

PROJECT OBJECTIVES

The objectives of the design project of the hydroponic are:

- Design a self-sufficient hydroponic system.
- Manufacture the system.
- Present the values of the factors (nutrient solution level, pH level).
- Have the system perform efficiently.
- Have the system working for at least 3 hours with only the battery.

PROJECT CONTRIBUTIONS

The contributions this project will provide are:

- Improve maintenance efficiency.
- Less human interaction.
- Provide a backup option in case of power outage.
- Cost efficient.
- Easy manufacture.

LITERATURE REVIEW

By definition, “Hydroponics is the scientific use of chemicals, organic and inorganic materials, and technology to grow plants independently of soil” [1]. Different types of hydroponic systems have been used through time, but the Nutrient Film Technique (NFT) is the one that will be analyzed. The nutrient film technique was created by English scientist Allen Cooper in the 1970’s, which helped commercial hydroponics expand globally [1]. It consists of a system which pumps nutrients as a film of water through a channel, which is at an angle. The roots of the plants, which are placed on the channel, would be in contact with the film and the solution then goes to the solution reservoir in which the process of recirculation happens. The plants that will be used in the hydroponic system will be lettuce, the common types would be looseleaf, butterhead and romaine. After the type of lettuce is decided, the seeds will be on a germination table for some time until it has long roots for the system. Once the lettuce grows, it is then passed to the hydroponic system. Following the article of Abdel Razzaq Al-Tawaha, a water flow rate of 20L/hr, or 0.33L/min, is considered for the system since it was observed as more effective for better growth of lettuce [2]. This type of system functions with basic components, which would be the nutrient solution, water pump and oxygen pump. Figure 1 shows how the system works together with the components.

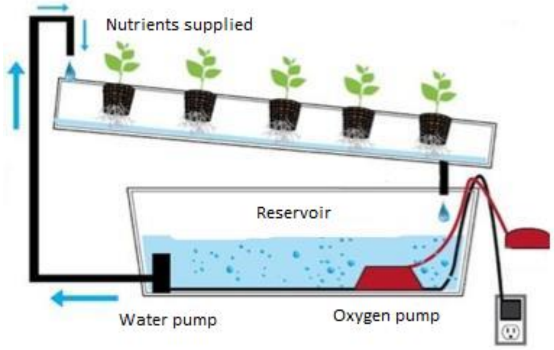

Figure 1
NFT Hydroponic System

The size of the hydroponic system depends on personal use, the quantity of vegetables to obtain, and available space for the system. Longer PVC pipes will help for quantity while building the system vertically helps for less space occupied. The spacing for the lettuce in the channel should be 8 inches or more. Recommendations according to Eunice (2022) of the nutrient solution for the system are considered. The nutrient solution in the reservoir should have a required pH level between 5.6 and 6.2. The recommended macronutrient amount of growing lettuce in hydroponics would be 5 Nitrogen, 15 to 20 Phosphorus, 20 to 40 Potassium. An example would be to have water soluble fertilizer with NPK of 5-18-30. The recommended micronutrient amount would be calcium (15-0-0 NPK). Each nutrient would be mixed separately with water, then both would be mixed to make the solution [3]. The reservoir tank may be of any size depending on how big the hydroponic system and tubes will be. A 27-gallon tote is a great size for any system. A hydroponic design will be developed to notify the person the pH level of the solution and the water level of the tank using different sensors. These would be pH level sensor and a type of water level sensor to determine the height. These would indicate the person if the system needs more solution mixture for pH balance or if the nutrient solution level in the reservoir is low. These sensors will be connected to an Arduino Mega, which is a type of programmable microcontroller, in order to obtain the information. The water and oxygen pumps, which will be running constantly, will have their own circuit connected to the power supply. In case of a power outage, the system will change from the power supply to a battery using a relay module. A 12-volt (V) DC water pump is recommended in order to connect it to the power circuit easily and have it working with the battery. The same goes with the oxygen pump. The batteries to be used could be a combination of AA batteries for 12V, or a Lithium-Ion rechargeable battery with specifications to determine the running time. Having all of this would make the system work efficiently. Since the main problem for these systems in Puerto Rico is power outages, the battery will provide power for the system to run for some time. Farmers that work with the cooperative OASIS Synergistic Technologies have had this problem before and have lost plants from their system since the nutrient solution stops running in the system, leaving the plants to die. This results in economic and time loss. Also, there was a power outage in Puerto Rico recently due to hurricane Fiona and people lost their plants due to not having a running system. The hydroponic system designed should work successfully and the objective of having the system running with the battery, at least 3 hours to provide time for backup, should be accomplished.

METHODOLOGY

A list of materials with their prices is listed in Table 1 with the total cost of the system being $515.41. After getting these materials, the design is then implemented. It follows the image shown in Figure 2, in which there is one 2-inch diameter PVC pipe of 3 feet. There is 5 holes of 2in diameters, with 6 inches between them. The 27 Gallon tote is near the pipes and the battery is inside the house, to prevent any water damages since the system is placed outside. The water and oxygen pumps are inside the tote, the Arduino Mega is placed on the side of the tote, and the power module near the battery and power supply. The pH sensor is placed near the tote and the water level sensor attached on the wall of the tote. The system consists of 2 sensors (pH and water level) connected to the Arduino. A $120V_{ac}$ to $12V_{dc}$ adapter is connected from the house or farm into the relay module, while the 12V-12Ah Lithium battery is connected to the other part of the relay module. The output of the module powers the Arduino, water pumps and oxygen pump, and the Arduino will then supply 5V to power the sensors. An LCD Screen is also connected to the Arduino to show the pH values and if the water level is high or low. While connecting the oxygen pump, a resistor of 27.6 ohms (Ω) is used in series since the pump works with 6V. Figure 3 shows a schematic of the connections from the power supply without the sensors. The 27.6Ω resistor is made by joining different resistors by their ends. One 20Ω, two 3.3Ωand one 1Ω resistors are used, 10 watts (W) each. The water pumps are connected in series with the clear tubing, having one water pump inside the tote and the other on top of the lid of the tote. For the nutrient solution, All Ponics helped by providing their lettuce starter kit which includes the nutrients to make the solution following the size of the tote, germination table and romaine lettuce seeds. They also provided some measuring cups for the solution ingredients for a 15-gallon tote. Since the tote being used is of 27 gallons, the nutrient solution level in the tote is a little higher than half the tote. The nutrients consist of water-soluble fertilizer (8-15-36), calcium and magnesium. Once these nutrients are mixed in the water, which gives a pH balance of 6.5, the system is put to the test. The lettuce seeds are put through the process of germination. This process is done in about 3-5 days and the seeds are then transferred to the system. After everything is added, the system is put to the test for days with the power supply and then with only the battery to observe for how long the system runs in case of a power outage. The voltage of the battery is then measured every hour until the system stops running. The pH probe sensor used with the Arduino is compared to the water quality meter sensor bought to verify if it works accordingly. The pH level and nutrient solution volume are measured after one week of having the system running. The water flow of the system is measured to be 3.5L/min. The flow rate of the solution should be less for the PVC pipe, about 0.35L/min, for optimal growth. A flow rate of 0.24L/min will then be compared to the results obtained from the 3.5L/min flow rate.

Table 1
List of Materials

Materials	Cost	Quantity	Total
CQRobot Ocean: Contact Water/Liquid Level Sensor	$16.99	1	$16.99
GAOHOU PH0-14 Value Detect Sensor Module + PH Electrode Probe BNC For Arduino	$35.88	1	$35.88
Winkeyes DC 12V Submersible Fountain Pump with 118" High Lift, 3.6W	$12.58	2	$25.16
Saim DC 6V Mini Air Pump Motor for Aquarium Tank Oxygen Circulate 2 Pcs	$8.98	1	$8.98
Battery Lead Acid 12V 12A Rechargeable	$49.97	1	$49.97
PVC Pipes Schedule 40 Plain end 2inx10ft	$25.19	1	$25.19
Husky 2in PVC Cutter	$30.46	1	$30.46
PVC Cap 2in	$3.38	1	$3.38
2in PVC Schedule 40 90-Degree Elbow Fitting	$4.42	2	$8.84
2in PVC Schedule 40 Socket Cap	$2.59	1	$2.59
8 oz. Regular Clear PVC Cement	$7.96	1	$7.96
HDX27 Gal. Tough Storage Tote	$12.98	1	$12.98
UDP 1/4in ID x 3/8in OD x 10ft Clear Vinyl Tubing	$3.39	1	$3.39
ELEGOO Mega R3 2560 Project Starter Kit Compatible with Arduino IDE MEGA - Including 16 Tutorials CD	$36.99	1	$36.99
DC Backup Battery Switching Module, 5V-48V 10A Battery Charging Automatic Switch Adapter Emergency Power Controller Module	$9.93	1	$9.93
Digital Multimeter	$32.97	1	$32.97
Water Quality Meter, pH and Temperature	$35.90	1	$35.90
DAYKIT 10 Pairs 12V Male+Female 2.1x5.5MM DC Power Jack Plug Adapter Connector	$7.99	1	$7.99
HONJIE 10W 1 Ohm Power Resistor Ceramic Cement Resistor Axial Lead White - (10Pcs)	$7.99	2	$15.98
HONJIE 10W 20 Ohm Power Resistor Ceramic Cement Resistor Axial Lead White - (10Pcs)	$5.99	1	$5.99
HONJIE 10W 3.3 Ohm Power Resistor Ceramic Cement Resistor Axial Lead White - (20Pcs)	$7.99	1	$7.99
SunFounder IIC I2C TWI 1602 Serial LCD Module Display Compatible with Arduino R3 Mega 2560 16x2	$9.99	1	$9.99
uxcell PVC Clear Vinyl Tubing, 8mm (5/16") x 10mm (3/8") Plastic Tube Flexible Water Pipe 5m	$13.49	1	$13.49
Imagitarium Bubbling Column Airstone 2-Pack	$3.79	1	$3.79
Imagitarium Clear Airline Tubing	$9.99	1	$9.99
25 ft. 14 Red Stranded CU THHN Wire	$10.98	1	$10.98
25 ft. 14 Black Stranded CU THHN Wire	$10.98	1	$10.98
Commercial Electric 3/4 in. x 66ft. Weather Resistant Electrical Tape, Black	$3.83	1	$3.83
Commercial Electric 8 in Wire Stripper with NM Ripper	$19.97	1	$19.97
All Ponics Lettuce Starter Kit	$25.00	1	$25.00
CyberPower CPUAC1U1300 Universal Power Adapter 3-12 Volt/1300mA with Folding AC Plug and 2.1 Amp USB Charge Port and Includes Multiple Interchangeable Tips	$21.88	1	$21.88
Total Cost =			**$515.41**

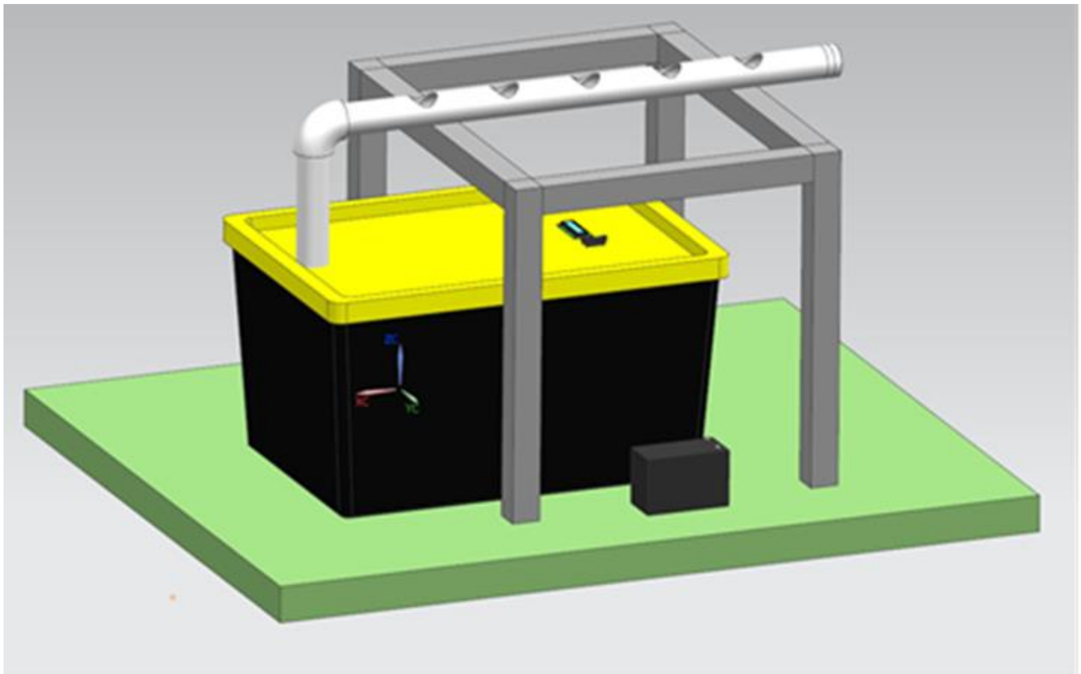

Figure 2
Hydroponic System

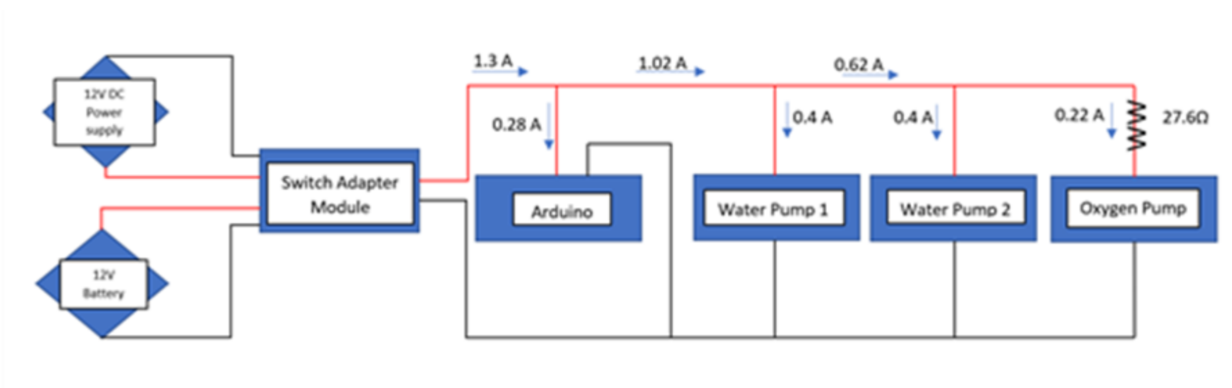

Figure 3
Electric Circuit Implemented

RESULTS AND DISCUSSION

The system works according to the design. The system runs great with the power supply adapter. It powers the water and oxygen pumps, the Arduino with its sensors and the LCD screen. Having the system run with only the battery gave surprising but favorable results. The system was expected to run for at least 9-16 hours since the systems circuit with the materials would require 1.3 Amps and the power output is of 8.98W. 9 hours being from 12 Amp-h divided by 1.3A, and 16 hours being 144Wh (12V x 12Ah) divided by 8.98W (power drawn from the circuit). The system ran for at least 20 hours. The voltage from the battery was measured each hour for 11 hours, then it was left running during the night with the last measurement of the system running being 9 hours later. The last measurement was taken another 9 hours after, but the system stopped running when the battery reached a voltage of 4.96V. Figure 4 shows the values of the battery's voltage for each hour measured.

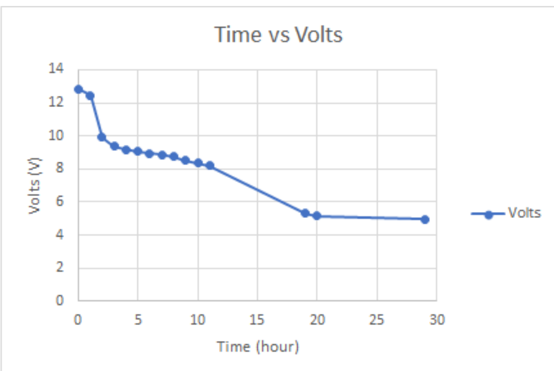

Figure 4
Battery Voltage Graph

Measurements between the hours 20 and 29 could not be recorded, but it shows that when the battery reached less than 5V, the system stopped running. For the system running at least 20 hours, it can be explained that since the system was designed for a current of 1.3A with the power supply adapter, the battery supplied less since it only supplies what is needed to run. For the pH sensor, values of the probe sensor used for the Arduino was compared with a complete pH and temperature sensor. These probes were calibrated in different ways, and although it should have given the same results, the sensors gave different ones. When measuring the pH level of the nutrient solution for the system, the pH level was of 6.56 at the start. This value is favored since it is close to the recommended pH value between 5.6 and 6.2. With the Arduino's pH probe, the measurement for the nutrient solution gave a pH value of 3.5. The procedure of calibrating this probe is complex since its data sheet does not give clear instructions. An attempt of calibrating it again was made but it gave far worse results, even giving negative pH values. After having the system running for 1 week, the pH level was of 6.15 and the nutrient volume in the tote was of 6.75 gallons with the system running with a flow rate of 3.5L/min. The 0.41 difference in pH level shows that the lettuce is absorbing the nutrients for the solution while the volume of the solution in the tote, starting from 15 gallons, reduced to 6.75 gallons due to the lettuce absorbing the solution but mostly from evaporation since the lid is not completely closed. The water level sensor provided information to the Arduino and the LCD screen showed that the nutrient level in the tote was low. The volumetric flow of 3.5L/min is 10 times what is needed for this very small system. The results for the lettuce growth in this design, as seen in Figure 5, follows 3 to 4 leaves of lettuce during the first week of transplanting them with stem length between 1-1.5 inches. Applying a closely recommended flow rate of 0.24L/min produced better results. The lettuce showed a faster growth rate since it absorbs the nutrients more effectively. This is because the nutrient solution at a lower flow rate lets the lettuce obtain oxygen without being completely dry. A higher flow rate does not let the lettuce obtain oxygen and absorb the nutrients effectively.

Figure 5
Growth of Lettuce in One Week

Conclusions

The system implemented runs according to the design. It runs perfectly and it reached the objective of running for at least 3 hours with only the battery. This system ran for an outstanding 20 hours, which gives the owner of the hydroponic plenty of time to find another way to sustain their plants. The Arduino pH probe used was not of use since the calibration procedure is confusing and does not give correct results. The water quality meter sensor was easier to calibrate and gave favorable results. It is not part of the circuit design and it is not used with Arduino, but it gives the correct pH value and it is powered by batteries. Which means that if there is a power outage, this sensor can still be used. The water level sensor was easy to install and to program, it is recommended for this kind of system. Recommendations for future development would be to use an Arduino Nano since it uses less energy to function and better run time with the battery would be achieved. Depending of your hydroponic, the capacity of the battery can be less than 12Ah. A good battery capacity would be 7Ah, it would run the system for at least 3 hours and it would cost less. For measuring the pH level of the system, better pH probes can be used but they are expensive. The water quality meter used is a perfect one but some buffer solutions must be bought separately since it needs to be calibrated after some time. Strips that measure pH levels are a great substitute since it does not depend on electricity and they are not expensive. A better DC water pump with controllable flow rate can be bought but it must have easy application for the circuit to be considered. It should also provide information of the pump pressure, flow rate and voltage used. Overall, this design exceeded expectations. The system designed for testing was not adequate since the flow rate was much bigger than needed. A solution to this is to use a bigger hydroponic where the flow rate is divided to different pipes. That way the hydroponic can harvest much more quantities of lettuce. The system designed is self-sufficient and runs efficiently. It also shows the nutrient solution level of the tote and less human interaction is needed. This system designed will help people with their hydroponics and plants in case of future power outages occurring for a long period of time.

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