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Ideas and Solutions for Nation-building

Development of an Indoor Hydroponic Tower for Urban Farming

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Abstract: Urban farming is one of the key solutions to global food insecurity, however due to land scarcity inside urban areas, implementation of this solution is challenging. To address this, urban hydroponic farming is introduced since hydroponics is an effective way of conserving both water and space. However, hydroponics itself is complicated because there are more growing factors that can affect the growth of plants. This can be addressed by constantly monitoring the system parameters, therefore this study shows the design, fabrication, and testing of an indoor hydroponic tower prototype coupled with an automated monitoring system. The study includes an analysis on various parameters such as, plant length, leaf height, fresh weight, water temperature, ambient temperature, relative humidity, pH level, water level, and total dissolved solids. An Arduino-based monitoring system was built from scratch and was utilized to collect the necessary data along with physical instruments for better calibration in data collection. Plant growth, environmental conditions, and sensor accuracy showed that the indoor hydroponic tower was a success in terms of its design for urban farming, productivity and performance, and its automated monitoring system.

Key Words: vertical hydroponics; indoor farming; data acquisition system; hydroponic tower; arduino

1. INTRODUCTION

Agriculture plays an important part in the growth and development of a country. Having an agricultural industry allows a country to produce its own food—among other supplies—which, therefore, does not necessitate the need for the trade and importation of goods from other countries. In short, agriculture allows for the self-sufficiency of a country in terms of its food supply and other agricultural products. Rutledge, et al. (2012) writes that "agriculture is the art and science of cultivating the soil, growing crops, and raising livestock", and it also encompasses the preparation and distribution of plant and animal products for consumer use. Through its definition, the certainty of the importance of agriculture in reinforcing a community's food security is, therefore, established.

Many experts, environmentalists, agriculturists, and politicians have come up with different solutions that tackle the issue on the Philippines' level of food security—one of these solutions is called "urban farming". Urban farming is the process of growing, cultivating, and producing food within densely-populated cities ("What is Urban Farming?", n.d.)

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Hydroponic systems are presently being experimented on and assiduously employed in the available lands within the confines of the Philippines. Current urban farming applications that exist in the Philippines may still be seen to take up a large land area as horizontally-oriented hydroponic system designs are mostly utilized—a fact which limits the integration of hydroponic systems into urban areas due to the circumstance of allowable space. In addition to the previously-mentioned limitation, these manually-operated hydroponic systems that are presently set up require daily monitoring, and thus, may become easily neglected due to inadequate attention. Furthermore, outdoor and greenhouse-type hydroponic systems are also subject to the varying conditions of the weather which may, therefore, cause these systems to become unproductive during the rainy seasons. These outdoor hydroponic systems are also, consequently, prone to pest infestation due to the large open space that the plants are exposed to—therefore, theoretically allowing for indoor hydroponic systems to be the better choice of operation (Dyna-Grow, 2018).

2. THEORY

Hydroponics is the art of growing plants without soil. With hydroponics, plants are grown in an inert medium, and a balanced, pH adjusted nutrient solution delivered to the

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roots in a highly soluble form ("What is Hydroponics?", n.d.). This allows plant to uptake its food with very little effort. There are several types of hydroponics systems—some of which are the wick system, the deep-water culture system, the ebb and flow (or flood and drain) system, drip systems, the nutrient film technique (NFT) system, the aeroponic system, and the simple nutrient addition program (SNAP) system.

The N.F.T. is one of the most popular types of hydroponics systems. It is versatile and modular due to the nature of its components. It works by delivering nutrient solution to the plants by means of using a water pump. Gravity then guides the water back to the main reservoir. A key element of a good N.F.T. is how the nutrient solution flows over the roots. The word "film" is ideally a small amount of water flowing through the channels to allow plants get sufficient amount of oxygen. Most commonly used plants in this setup are lettuce, basil, and salad greens.

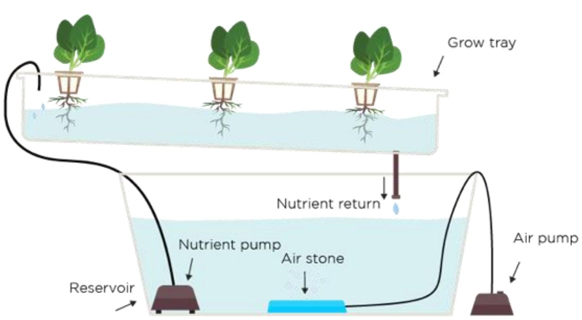

Fig. 1. Nutrient Film Technique (NFT) system.

The materials needed for an NFT system include reservoir, air pump and air stones, airline tubing, water pump, NFT channels, net pots, growing medium and hydroponic nutrients. Manufacturers produce PVC rain gutters or downspout channels designed for transporting rainwater from roofs to the drainage line. Most of the downspout channels have a dimension of 2-by-4 inches which is just right for hydroponic applications (Hopper, 2016).

The reservoir serves as the holder of the water and nutrients wherein the water pump is also located. At minimum, small plants should receive at least ½ gallon per plant, medium size plants should receive at least 1 gallon, and large plants should receive 2 ½ gallons of water. It is recommended to choose an opaque reservoir to reduce light penetration and minimize algae growth. Lids should also be sealed to avoid evaporation, pests and contamination issues. Water temperature should be maintained at 18 to 25 degree Celsius for optimal plant growth ("Hydroponic Reservoir," n.d.).

The growing medium commonly used for hydroponic growing is rockwool – which is a non-degradable medium composed of granite and limestone that is superheated and melted then spun into small threads, absorbing water easily. Another medium is grow-rocks such as expanded clay aggregates and are used to provide support for plants.

Table 1. Growing Conditions for Lettuce

Name	Ideal Range
Fluorescent Light	6500 k
Ambient Temperature	21.1℃ - 26.6 ℃
Relative Humidity	50% - 80%
pH Level	5.5 - 6.5
Electrical Conductivity	0.8 S/m - 1.2 S/m
Total Dissolved Solids	560 ppm - 840 ppm

Maintaining ideal growing conditions of plants is key to producing high quality yields. Shown in Table 1 are the ideal growing conditions for lettuce gathered from different online sources and scientific papers. It is recommended to follow these conditions to ensure plant growth and plant health, however, realistically speaking, these ideal conditions are seldom achieved especially in an open-type or not fully-controlled systems. Factors such as different locations, different climate, and different capabilities of a grower can make it more challenging for these conditions to be achieved. To resolve this issue, there are several ways to still make these systems successful such as choosing a plant with better temperature tolerance, adding a simple ventilation system, and partially automating the system.

Automation is an essential aspect in order to minimize human intervention, however with technical and budget constraints, most growers only partially automate their system through timers. Fully-controlled hydroponic systems are expensive and are usually implemented for systems with more plant capacity such as commercial grow rooms or warehouses to payback the cost of their automation system faster.

There are several practices that must be observed in order to successfully sow and harvest a plant using a hydroponic system. This include seeding and germination, transplanting, growing, and harvesting. Details on these practices are discussed in the next chapter.

3. METHODOLOGY

In building the prototype, the main goal was to create a hydroponic system that is suitable for urban farming therefore should be compact, low maintenance, and cost-effective. To create a system that is compact, the prototype was designed vertically similar to a tower, hence the title. This will allow multiple layers of planting areas in a relatively small space. To design a low-maintenance system, selected parameters such as lighting and ventilation were automated through timers. Automated monitoring system also allowed easy access to the current and past environmental condition status. Moreover, placing the system indoors reduces the need for further maintenance especially for pest and weather issues. Lastly, for a system to be cost-effective, an open-type hydroponic system was implemented to reduce the cost of fully controlling the conditions while still producing high quality yields. For a small system that will be used for personal or residential purposes, fully automating the system is not practical due to the relatively small plant capacity. Therefore, for this system, parameters for plant growth were only monitored and not controlled. Adding to that, the prototype was composed of readily available and inexpensive materials to reduce the costs of construction, thereby making it more cost-effective.

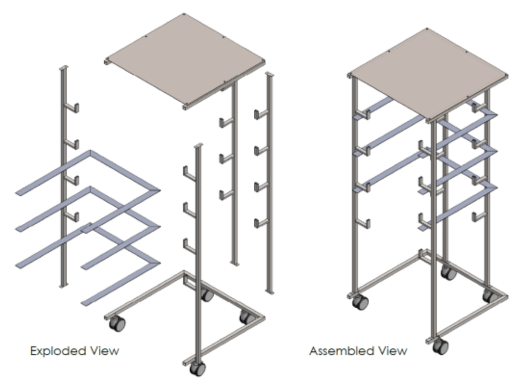

Fig. 2. CAD Model of the Indoor Hydroponic Tower Prototype.

Fabrication of Tower. The frame serves as the structural support that will hold the NFT channels and other devices such as the artificial lights in place. In choosing the right material for the frame, the researchers considered several factors such as costs, durability, and availability. The indoor tower had a total dimension of 2.2'x2.2'x7' and was made from galvanized steel bars.

N.F.T. Channels. Polyvinyl chloride downspout tubes were used as the NFT channels where the nutrients will flow. Leak tests were done after 24 hours of drying. ½" translucent flexible hoses were used to connect one level of the channels to the next.

Lighting and Ventilation. The indoor hydroponic tower uses a T5 fluorescent tube consuming 8 W to 14 W with daylight color temperature between 5600 K to 6500 K as substitute for natural light. Average PAR reading was 33 mol per m^2s 7in from the light source. A mechanical timer for the lights was programmed to turn on for 18 hours and off for 6 hours. A small electric fan was used to ventilate the tower for 2 hours after every 3 hours. This allowed proper air circulation that can improve plant growth.

Reservoir. The reservoir contains the nutrient solution which is a soil substitute for the system and it will give the plant nourishment. The reservoir also houses the pump which would be utilized for water circulation in order for the nutrients to reach the different levels and channels. The water pump utilized had a maximum flow rate of 1500 L/hr and a max head of 1.6m which makes it suitable for the hydroponic system. The air pump for both set-ups had an 80 L maximum capacity which is within reservoir specifications.

Protection and Enhancements. To ensure yield quality, modifications were done to address the problems present such as unwanted pests and light recovery. Therefore, a light reflector made from foil insulation was used to cover all sides of the tower except the front.

Fabrication of DAQ. The monitoring system designed for the hydroponic tower was an Arduino-based data acquisition system seen in Figure 4. Itcollected six different parameters using five sensors (DHT11 Temp and Humidity Sensor, One-wire Water Temperature Sensor, pH Pro Meter Sensor, Ultrasonic Ranging Sensor, Light Sensor). An LCD display was included to easily monitor the current condition of the system. An SD module and Real Time Clock Module were used to store data for 27 days for further analysis of the performance of the system after the growing period. The data acquisition system was programmed to collect data every 5 min. Calibration was done to selected sensors through the program such as the DHT11 and pH Pro sensor due to a small offset value.

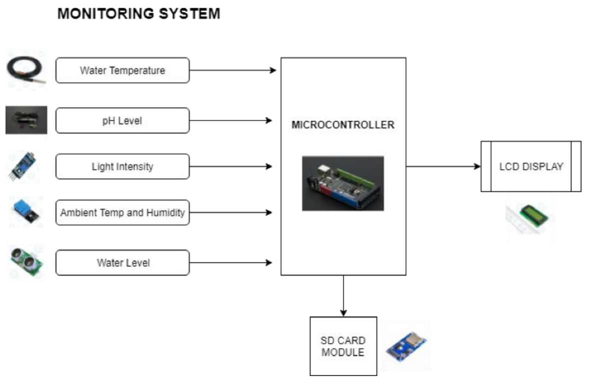

Fig. 3. Schematic Diagram of the Monitoring System


Fig. 4. Actual Data Acquisition System

Plant Cultivation. The planting process comprised of several steps such as pre-germination, transplanting, growing, and harvesting using Romaine lettuce seeds as seen in Table 2. The pre-germination stage for both set-ups lasted for ten days wherein the true leaf or third leaf of the seedling was made to develop. After which, the plants were transplanted into the net pots for cultivation. During this period, data collection was done every three days. On the 27th day, the grown plants were harvested and weighed for analysis.

Table 2. Timeline for Plant Cycle

Time Elapsed	Description
Day -10 to Day 0	Germination stage wherein first roots and baby leaves become visible
Day 0	Transplantation to the system
Day 0 - Day 27	Growing and cultivation
Day 27	Harvesting

Instrumentation and Calibration. Various measuring devices were required to attain necessary data. To measure the water level, a tape measure was used. The Fluke digital thermo-hygrometer measured the ambient temperature and relative humidity. The pH level of the water was used to record the pH level of the water in the indoor tower. The total dissolved solids were quantified using a TDS meter in parts per million (ppm). An automated data acquisition system measured the light intensity, ambient temperature, relative humidity, water level, water temperature, and pH level along with the manual data gathering. Individual calibration of the meters was done in order to have an accurate reading before gathering data from the system. For the pH meter, a pH buffer calibration solution of 4.0 and 7.0 was used. For the thermo-hygrometer device, the instrument was assumed to be properly calibrated since it is being constantly used and maintained by the technicians of the Mechanical Engineering Laboratory.

4. RESULTS

Results of the research are categorized into three main parts. First are the results of the plant growth in the hydroponic tower in a 27-day cycle period. Second are the accuracy results of the constructed data acquisition system compared with standard instruments. Third are the environmental conditions data recorded in the automated data acquisition system throughout the cycle period.

Growth of the romaine lettuce from the hydroponic tower was very successful as seen in Figure 5. The plants thrived in the indoor growing conditions, showing that the lighting was enough for their photosynthetic requirements. Leaves were observed to be very green and crispy. Roots were also long and healthy. Plant length. leaf count, and fresh weight of the system is shown in Table 3.

Plant Growth

Fig. 5. Hydroponic Tower Plant Growth Progress

Table 3. Final Plant Growth Results for Indoor Tower

Indoor Plants	Ave	Max	Min
Plant Length (mm)	210.5	260	160
Leaf Count	10	13	7
Total Fresh Weight (g)	21.9	51.39	4.5

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Data Acquisition System

The constructed data acquisition system was considered to be accurate with a percent error of less than or near 5% relative to standard instruments. Seen in Table 4 is the average percent error of the sensor values of the DAQ system.

Table 4. Average Percent Error of DAQ sensors relative to standard instruments

Environmental Condition	Average % Error
Water Level	6.158
Water Temperature	2.317
Ambient Temperature	4.375
Relative Humidity	8.593
pH	1.540

Environmental Conditions from DAQ

The data acquisition system was able to gather data of different environmental conditions from the sensors with a total of 7952 data points. Seen in Table 5 are the group statistics of the air temperature (AT), relative humidity (RH), water temperature (WT), and pH level (PH).

Table 5. Environmental Conditions Group Statistics recorded in the DAQ system.

Cond	N	Mean	Std. Dev
AT	7952	29.26	1.167
RH	7952	64.6	7.027
WT	7952	28.68	0.988
PH	7952	7.90	0.192

Figures 6 to 11 show the data log acquired for the indoor DAQ with 24-hour monitoring for each day as seen. All six parameters were carefully monitored after the 27 days cycle. Logs showed that some conditions were not in optimal range, however, there were also no conditions that exceeded the tolerable range of the romaine lettuce therefore plant growth was still considered successful. Figure 9 shows that the mechanical timer installed was working perfectly as the lights are switched on 18 hours a day, and off for 6 hours. In Figure 10, a sudden decrease in pH is observed because manual adjustment of pH level was done but was not successful as the amount was not enough. In Figure 11, it can be seen that the water level was continuously decreasing as plants absorbed more water when it gets bigger. Towards the end, the reservoir reached a critical level, thus it was refilled back to its original level.

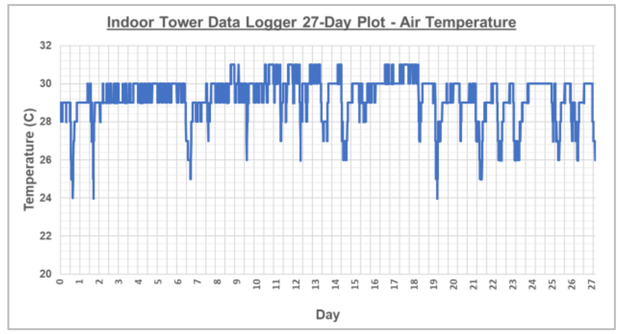

Fig. 6. Indoor Tower Air Temperature Log

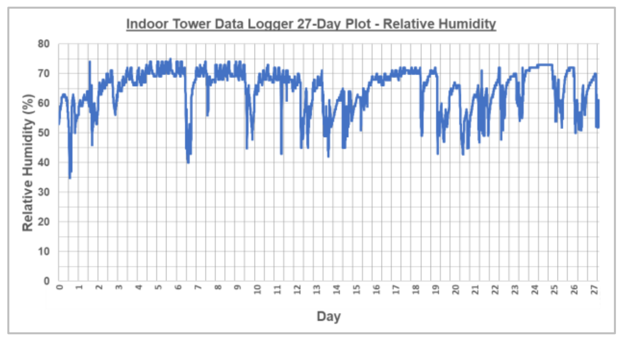

Fig. 7. Indoor Tower Relative Humidity Log

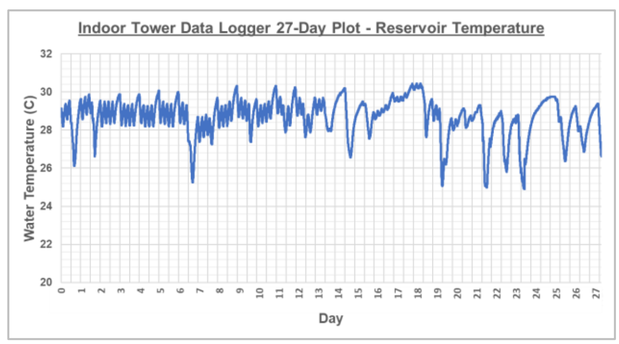

Fig. 8. Indoor Tower Water Temperature Log

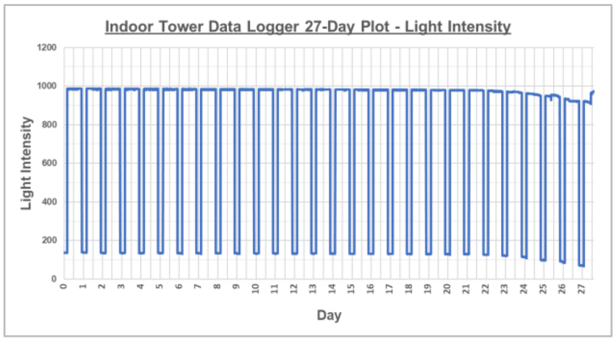

Fig. 9. Indoor Tower Light Intensity Log

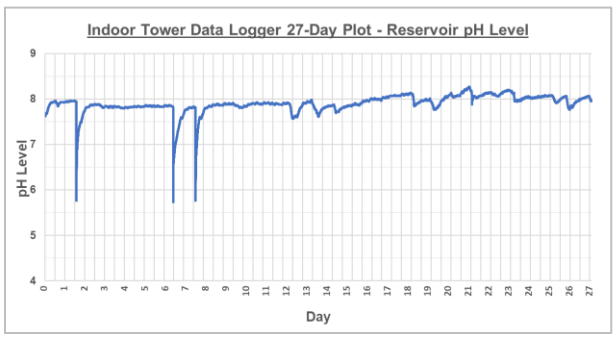

Fig. 10. Indoor Tower pH Level Log

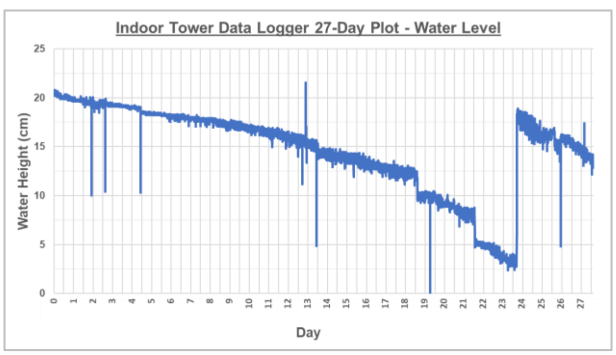

Fig. 11. Indoor Tower Water Level Log

5. CONCLUSION

Hydroponic Tower Design for Urban Farming. The design, fabrication, and operation of the indoor hydroponic tower system were successfully completed without any major problem. The system which occupies only 4.84m^2 of space but with a capacity of 52 plants proved to be suitable for the urban setting due to its compact structure. At the same time, the transportation of the system was made convenient due to its modular design.

Hydroponic Tower Plant Productivity and Performance. The planting and harvesting for the hydroponic tower spanned 27 days wherein the students were able to acquire significant data which indicated the overall system function and performance. Based from the results of the data gathered where average plant weight was 21.9g, it can be seen that the hydroponic tower had a considerable amount of yield that could potentially be a profitable equipment. The hydroponic tower also did not fail during the whole planting cycle and only require little maintenance.

Data Acquisition (DAQ) System Validation. The data acquisition system was validated through comparison with standard instruments. Results show that the sensors were accurate in measuring different parameters as the percent error computed was relatively low - close to or less than 5%. This proves that the sensors were properly calibrated and tested. With this, the information gathered from the SD card is confirmed to be reliable, therefore accurately describing the performance of the whole system.

6. RECOMMENDATIONS

Additional parameters, such as inlet flow rate, dissolved oxygen in the reservoir, CO_2 level, can be included in the data acquisition system to better analyze the system. Mobile and web monitoring applications could be another feature for the system to improve the functionality of the tower by providing information on the current condition of the plants and level of nutrients with auto-generated graphs for accessible monitoring.

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