Human Interaction Reduction in Hydroponics Systems

Fernando A. Rivera Collazo
Master of Engineering in Manufacturing Engineering
Rafael Nieves, Ph.D.
Industrial Engineering Department
Polytechnic University of Puerto Rico

Abstract *— Hydroponic is a topic that is growing every day. Hydroponic can be defined as the crop method without the use of soil. Hydroponic systems provide the capacity to produce large amount of healthy vegetables free of toxics in reduced spaces. The advantages of the hydroponics methods has included the capacity to produce large crops in less time than normal agriculture methods, free of toxics and easier to control pests. These methods bring new opportunities to explore the integration of actual sensing technologies on the agriculture. Sensing and communication technology is growing at an accelerated pace and the integration of these topics on one of the humans basic needs (Need to be fed) is fundamental. This article pretends to brings automated options for average people and/or small business to produce their own healthy food in almost every place, reduced spaces and with a minimum effort.*

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

INTRODUCTION

One of the basics needs of the human being is the need to be fed. Across the time the man were in the constant search of techniques and/or methods to obtain food in an easy way in order to use the time in an efficient way. Several techniques and methods like hydroponics, acuaponics, aeroponics, etc. were tested and/or implemented from 1600's in order to protect the crops against the environmental factors (Temperature, humidity, wind, bugs, etc.). Hydroponics systems are methods or techniques designed to control environmental factors without the use of earth for the growing of the crops. Some of these techniques include the Nutrient Film Technique (NFT), Wicks System, Water Culture, Ebb and Flow System (Flood and Drain), Drip System (recovery or non-recovery), Aeroponic System and some other variations of them. Nowadays there are sensors and gadgets that can be helpful to perform automatically some task of the hydroponic growing process. In addition hydroponics systems designs have been improved over the time an there still are opportunities for improvement in designs improve the performance and efficiency of the hydroponics systems.

PROJECT DESCRIPTION

Operation and maintenance of hydroponics systems requires constant monitoring and human interaction in order to maintain an acceptable operation of the system and obtain an optimum crop performance that achieve the quality standards. Today's days the average people lifestyle includes several tasks and responsibilities (work, studies, child care, house and car maintenance, etc.) and everyday more and more people wants to include fresh and healthy food free of toxic on their diet.

An excellent option to obtain fresh food without spends a lot of time and space must be a self-sufficient hydroponics systems. This can allow average people to operate and maintain a hydroponic system without spend a lot of time and effort and without takes extended and advanced courses about the techniques and methods of hydroponics operation and maintenance.

PROJECT OBJECTIVES

The objectives of this research have included:

- Design hydroponics systems that require 50% less human interaction for system operation and 25% of reduction in setup time.
- Develop an automated system capable to control water flow, Parts per Million (PPM),

pH (Measure of how acid/basic water is) and lumens.

- Implement the designed system and obtain acceptable harvest. Column Format Instructions.

PROJECT CONTRIBUTIONS

The main contributions of this research will be:

- Cost reduction due to a 50% of workforce reduction.
- Improve efficiency and capability of the system by a reduction in setup time by 25%.
- Improve System quality by the reduction of the human factor and improving the efficiency of resources management.

LITERATURE REVIEW

In order to produce food in any places and any environment without the use of earth and dedicating less time or human interaction, it is necessary design automated hydroponics systems. The use of several sensors like pH meter, PPM meter, Flow meter, Level meter, lumens meter, etc., that take the measure and send the signal to a controller that can control and/or adjust these variables if some of them are outside the permissible tolerance for the correct operation of the system. These systems allow the possibility to grow crops almost in all places and the possibility to all people to have fresh food in all kind of homes.

The most common and simple hydroponic system is the conventional NFT system. This system consist in place the seedling in a long sloping irrigation channel where a mixture of water and nutrients were introduced at the high end of the channel flowing through the roots after which it drains into a reservoir where a pump re-introduced the mixture again at the high end of the channel, repeating the watering process.

To start this process it is necessary to start the seed growth process by sow the seed into growing media and place it on a germination table with a continuous flow of water until the roots can be visible. Then the seedling is transplanted to the hydroponic system.

This conventional system requires enough human interaction for the following step:

- Sow seeds on growing media.
- Transplant the seedling from the germination table to the Hydroponic system.
- Prepare the Nutrient mixture.
- Verify and monitor mixture nutrients specifications (pH, PPM, Temperature, Flow).
- Verify and monitor environmental conditions (Temperature, humidity, Light intensity, wind, etc.).
- Plants inspections for anomalies like diseases, pest infections, mineral deficiency, etc.

Another challenge for these systems is the requirement of a source of energy for the correct functionality of the pump. If this source of energy fails, the system fails and the harvest could spoil.

METHODOLOGY

The main purpose of this design project is the reduction of human interaction on Hydroponic systems. To fulfill with this main purpose of this project some objective were developed on section 1.2. In order to achieve the metrics describes by these objectives describes in section 1.2; the methodology to be followed will be the six sigma improvement strategy, DMADV. This strategy consists in five (5) phases:

- **Define Phase:** This is the first phase of DMADV methodology. In this phase the problem statement, project goal, scope, resources and stakeholders are defined. An effective tool for this phase is the project charter. In order to define the customers and the requirements, a useful tool is the "Voice of Customer".
- **Measure Phase:** The main purpose of this phase is to know what the system needs. This phase is essential to establish a baseline or start point to start to look for improvement in order to achieve or satisfy the system needs. An effective tool to look for what is causing the

problem is a value stream map, cause and effect diagram and fish bone diagram. It is very important to identify what you really needs to measure and establish data collection plan.

- **Analyze Phase:** In this phase the data is analyzed and evaluated in order to determine or look for options to achieve the goals. The purpose of this phase is seeing what does the data tells you. Many tools and options can be uses to understand the data and find the real root cause of the problem in order to look for a solution to start a plan for improvement. Tools like “Cause and Effect Diagram” and “Fish bone diagram” can be used also in this phase identifying the most significant causes that affect the process.
- **Design Phase:** The objective of this phase is to design a solution to solve the real root cause of the problem. It is important to know how the problem has to be fixed. Useful tools to take a decision for the best solution can been brainstorming, decision matrix or weighted criteria matrix, To-Be Maps and a Plan Do Check Act. A successful implementation requires careful planning.
- **Verify Phase:** In this phase the main objective is to verify the design performance and outputs in order to prove that the proposed design provide the expected results and achieve the established goals. This phase determine if the proposed design works as expected.

RESULTS AND DISCUSSION

To develop this project the methodology of DMADV is defined on this section.

Define

The “Define” phase contains the Problem Statement, Project Goal, Project Y, Scope and Benefits.

Problem Statement

Operation and maintenance of hydroponics systems requires constant monitoring and human interaction, in order maintain an acceptable operation of the system. Today’s days the average people lifestyle includes several tasks and responsibilities (work, studies, child care, house and car maintenance, etc.) and everyday more people wants to include fresh food on their diet. An excellent option to obtain fresh food without spend a lot of time must be self-sufficient hydroponics systems. A self-sufficient hydroponics system provides the opportunity to any person to operate a hydroponic system easily and continues with his diary activities. On the other hand this represents the opportunity to increase capacity and/or reduce labor hours for commercial hydroponic systems.

Project Goal

The main goal of this project is based on the reduction of human interaction on hydroponic systems operation by 50% in order to reduce the labor hours and improve the capacity of the process.

Project Y

Y= Labor hours reduction
Y(2) = Production time reduction
Y(2) = Maintenance time reduction

Scope

Scope includes: Process and maintenance of hydroponics systems.

Scope excludes: Construction of the hydroponic system.

Factors do not harm: Crops quality.

Benefits

Hard Saving: Reduce labor hours by 50%.

Measure

Measure Data was provided by “Hydroponicos Borinquen”. “Hidroponicos Borinquen” it is a company dedicated to the agriculture which uses hydroponic systems as the method to obtain the crops. The following diagram shows how the process is actually performed.

Actual Process

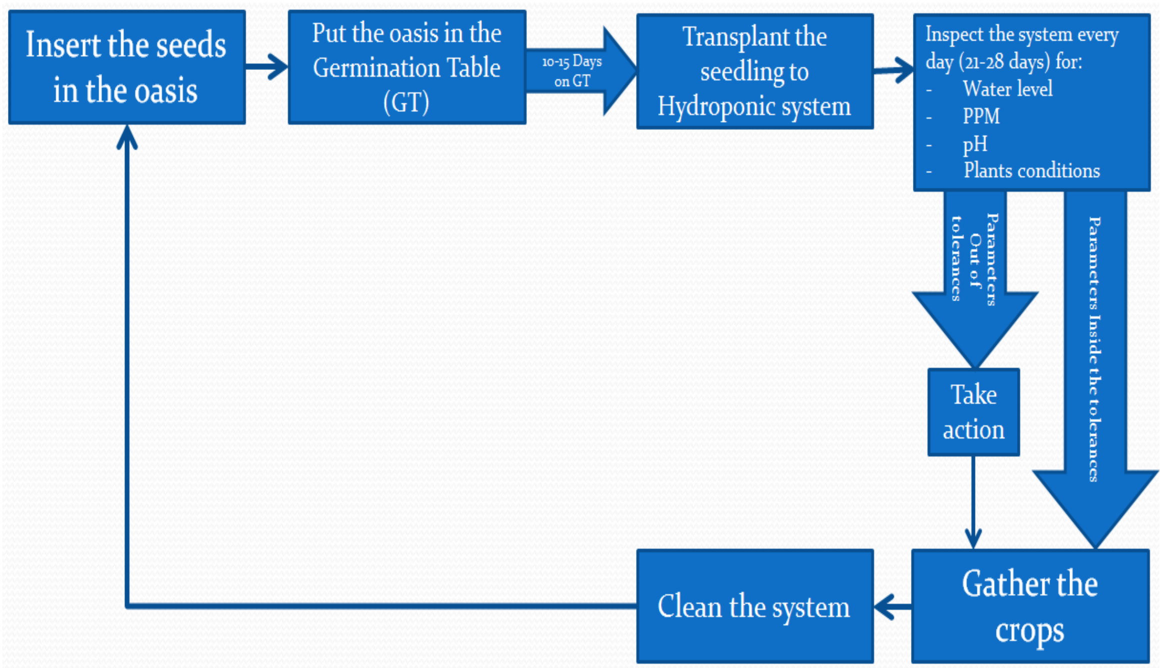

Figure 1
Process Flow Diagram

Human Interaction Reduction in Hydroponics Systems

Supplier	Input	Process	Output	Customer
System owner	Set-up Maintenance Monitoring	Construct the System	Final Product (Mature Plant or Fruit)	Supermarkets Restaurants Individual customer Owner
Hardware	Materials for construction Chemical for clean and disinfect Water Pump	Set-up the crop Prepare Nutrient mix	Functional System	Owner
Hydroponics Equipments store	Seeds for growing Mineral for Nutrient mix	Monitor the system	Product Quality (Plants with the required specs)	Owner
Metrology or Lab equipment store	pH Meter PPM Meter Thermometer Humiditty Meter Timer	Gather the crops Clean the system	Product Quality (Plants with the required specs)	Owner

Figure 2
SIPOC Diagram

Factors (X's) that impact Total Labor Hours

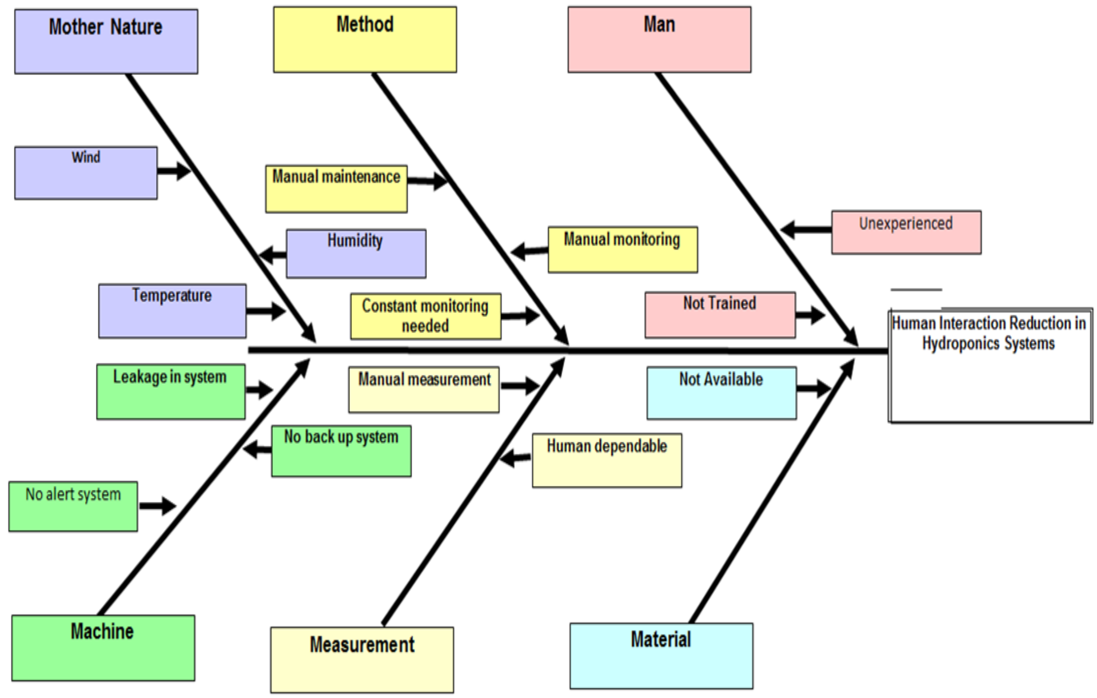

Figure 3
Fishbone Diagram

Table 1
Method & Time Consumed

Process Step	Labor Hours (1 Employee)	Labor Hours/Year	Method
Transplantation	**4 hours/crops (21-28)**	69hrs/year	Seedlings are transported from germination table to the hydroponic system.
Monitoring	**2 hours/day**	730hrs/year	Inspect nutrients solution for pH, PPM, Conductivity, fluid level, fluid flow. Inspect plants health (color, appearances and pest).
Gather the crop	**4 hours/crops (21-28)**	69hrs/year	Once the crop achieve the expected size and maturity, it is collected and packed
Clean the system	**8-10 hours/crops (21-28 days)**	175hrs/year (worst case)	After each crop hydroponic system must be cleaned. Each tube must be cleaned with Clorox and a brush to remove

* Data based on Hidropónicos Borinquen each system (720 plants system) and method.

Analyze:

After collect the data on measure phase, the data was analyzed using technic as fishbone diagram and Pareto chart.

Factors (X's) that have most impact on Total Labor Hours

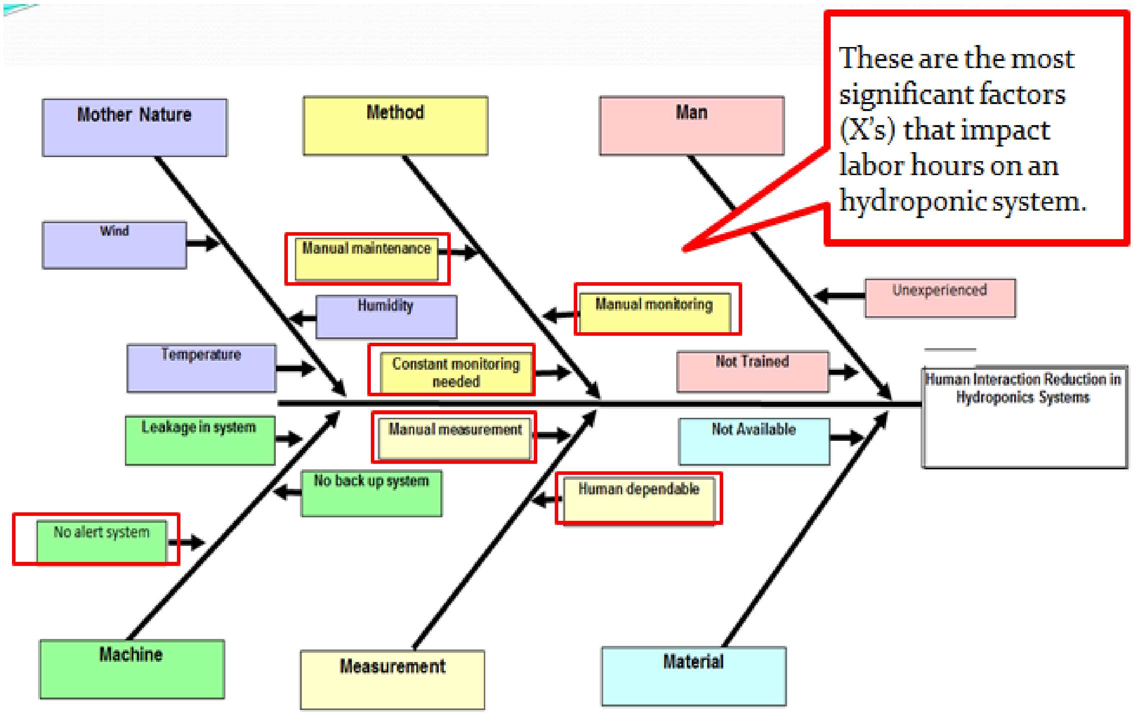

Figure 4
Analyzed Fishbone Diagram

Table 2
Pareto Chart Table

Process Step	Labor Hours/Year	Cumulative Amount	Cumulative %
Monitoring	730	730	68%
Cleaning	175	905	84%
Gather the crop	69	974	90%
Transplantation	69	1043	97%
Fill the oasis with seeds	35	1078	100%

* Monitoring process represents the 68% of the total labor hours for production and maintenance of a hydroponic system.

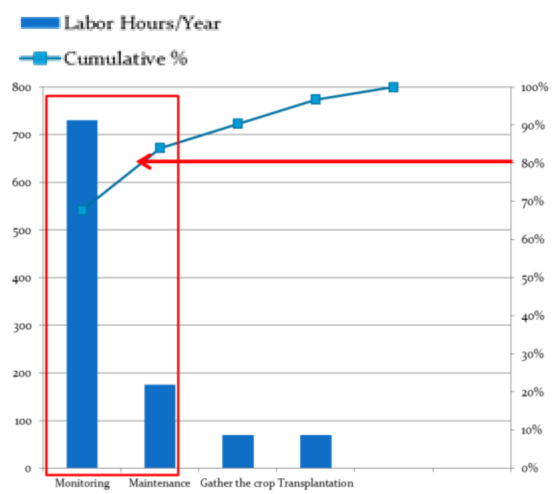

Figure 5
Pareto Chart

Data Analysis

The total labor hours for a hydroponic of 720 plants on “Hidroponicos Borinquen” are 1078 hours/man.

Process flow diagram shows visually how the process is actually performed.

SIPOC diagram shows a wide vision of the process, the require resources, how to obtain the resources and how this resources impact the process or what are the outputs of the process.

Fishbone diagram shows that the most significant factors (X’s) that affects or requires more labor hours are related to “Method”, “Machine” and “Measurement”.

Pareto Chart shows that monitoring process represents the 68% (730/1078) of the Labor Hours for production and maintenance of a Hydroponic system.

In order to fulfill with the goal of 50% of labor hours reduction it is necessary to reduce the total labor hours to 539hours/man.

A reduction of the 73.8% (539/730) on the monitoring time can be enough to achieve the goal.

Due to Monitoring time represents the 68% of the total time; it is required to take actions to reduce the time consumed during monitoring process.

Actual System and Method

Actual equipment and method of “Hidroponicos Borinquen” provide 720 plants per system per crop.

Only one operator can operate two system at the same time (2*720=1440plants/crop).

This provides approximately 17 crops per year.

This system & method produce a total of 24480 plants (lettuce) per year per system. Each plant is sale at $1.00 minimum.

It is mean that one operator can produce $24480/year.

Design

Actual method to monitoring hydroponics system is completely human dependable. This involves constant human interaction and a lot of effort. An Automated System that provides system owner’s the capacity to monitoring and inspect the system remotely will eliminate the requirement to physically inspect the system. Today’s days exist some pre-assembled or completely assembled system that provides the capacity to monitoring the system remotely. Unfortunate these equipment or system are expensive and has very low capacity compared to traditional system. A traditional system of 18 lines and 8 holes per line (144 plants) has an average cost $200. Automated system cost could vary from $400 to $6000+, relying on automation level and system capacity.

Another way to obtain an automated and reliable system at an affordable cost is to develop and construct an own customized automated system [1]. It can be possible using a customizable and open system that can allow managing equipment in order to control the variable on the process (temperature, humidity, pH, PPM, flux, lumens, tank level, nutrient level, irrigation time, etc.). A good open system develop this automated system could be an Arduino system.

Arduino

It is an open-source hardware and software used for electronic projects [2]. It can allow telling to the system what to do, by program the code and send the bunch of instructions to the microcontroller.

Why Arduino?

- It is inexpensive
- Easy to use and programming
- Open source (Hardware and software)
- Can be operating on most common operating systems (Windows, Macintosh OSX, and Linux).

Due to this is an open source system, it has the capacity to add any sensors and control. This provides different levels of automation rely on the requirements and available budget. It is possible to obtain a fully automated system that can monitor and control all variables remotely (recommended for indoor grow) or to control the necessary variables like pH, PPM, tank level, flux, pump timer and monitoring camera (recommended for outdoor growth on tropical climate) or a basic automation principles like a pump timer [3]. In order to achieve the goal inside the scope of this project, taking into consideration tropical climate, it is appropriate to monitor and control only pH, PPM, tank level, flux, pump timer and monitoring camera.

The necessary components to create a customizable automated system are listed below.

Table 3
Components & Price Table

Component	Quantity	Price	Total
Arduino Mega 2560	1	$9.44	$9.44
esp8266	1	$5.98	$5.98
Ethernet Shield W5100	1	$10.99	$10.99
Peristaltic Pumps (2)	2	$24.95	$49.90
pH Electrode Probe and Connection to Arduino	1	$56.95	$56.95
Electrical Conductivity Sensor	1	$65.00	$65.00
pH Up/Down Solution	1	$20.70	$20.70
5V Relay Modules for Arduino (5 - you could also get combined ones in a shield)	5	$2.39	$11.95
12V Solenoid Valve	1	$6.95	$6.95
DHT11 or DHT21 or DHT22 Humidity/Temperature Sensor	1	$4.75	$4.75
Weatherproof TTL Serial JPEG Camera with NTSC Video and IR LEDs	1	$54.95	$54.95
3.2" TFT LCD Shield + Touch Screen	1	$22.98	$22.98
Real Time Clock Module	1	$10.54	$10.54
Water Level Sensor Float Switch (2)	2	$8.50	$17.00
Photosensitive Sensor for Arduino	1	$2.54	$2.54
Breadboard	1	$2.55	$2.55
Set of Wires	2	$2.91	$5.82
Grow LED Lights	1	$19.99	$19.99
Sockets for Grow Lights	1	$7.59	$7.59
9V Power adapter	1	$6.95	$6.95
12V power adapter	1	$8.95	$8.95
		Total:	**$402.47**

∗ The software cost is $0, because we'll only use free & open source software.

This system will be capable to monitoring and control hydroponics systems factors, like pH, water level, flux, lumens, water cycles and the capacity to observe the health and physical aspect of the plants.

Verify

In order to verify the proposed design, how the system works is described as follow:

How Does It Work?

Sensors (Temperature/Humidity sensor, Lumens Sensor, Electrical Conductivity (EC) Sensor and pH Sensor) will be inside the nutrients solution tank to be in constant monitoring of the nutrient solution. Two small tanks (one with pH up solution and another with pH Down Solution) will be located at the top of the nutrient solution tank, each one connected to a Peristaltic Pumps in order to maintain the pH level of the nutrient solution tank inside the established tolerance based on lectures taken by sensors. A real time clock module will be installed to control the water cycles of the system. In addition Level sensors (High and Low) will be installed on the nutrients solution tank to assure that the tank has the required level to operate the system. The installation of the cameras will be required to monitor the physical appearance and health of the plants and at the same time provides security. Sensors and features will be correctly connected to the Arduino Hardware (Arduino Mega and Ethernet Shield) while Arduino hardware will be connected to the network via Ethernet. Arduino software will be used to program Arduino hardware in order to be able to process the data obtained by

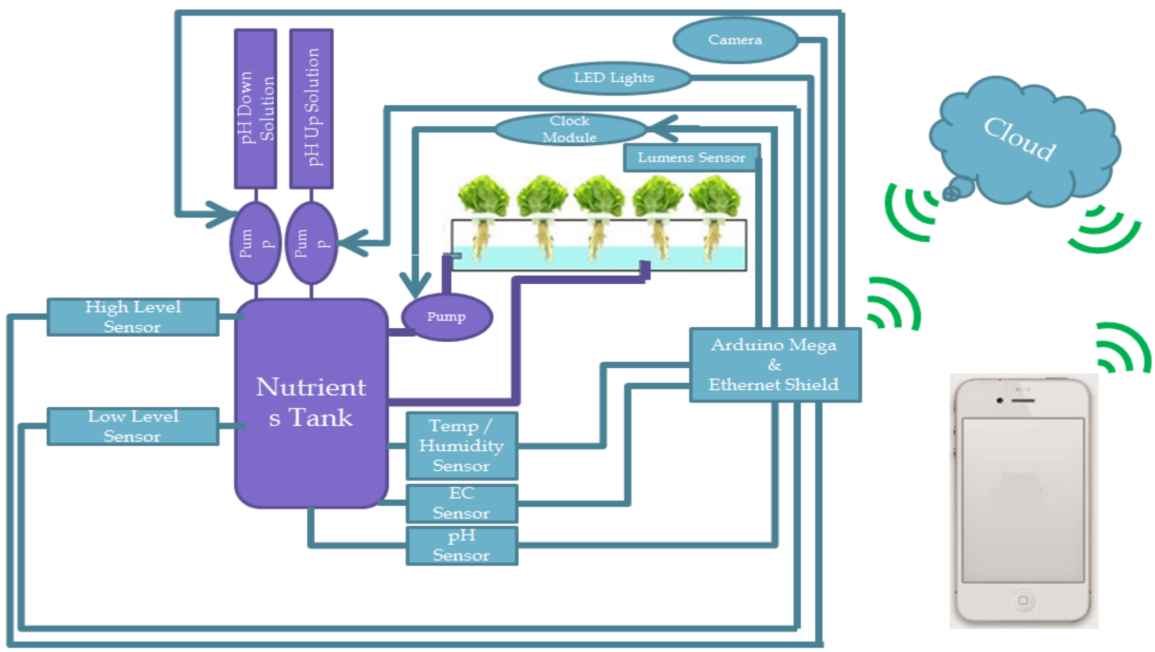

Figure 6
Proposed Arduino Hydroponics Automated System Design

sensors, analyzed and send the corresponding signal the actuators. The program will include pH tolerances, lumens tolerances and water cycles set-up. These variables will be controlled fully automatic [4]. Other variables like Temperature, Humidity, Water level, Electrical Conductivity will be programmed to send an alarm if some of these variables exceeds or decrease the established parameters. The alarm will be sent to the cloud and received on any device connected to the network (Smartphone, PC, Laptop, etc.). Another feature included in the program will be the camera operation where the system owner will be capable to monitor the system remotely with his smartphone or Laptop.

Conclusions

After analyzed the collected data and provide improvement solutions, it can be concluded that the implementation of an Automated System allows reducing the monitoring time from 2 hours/day (730 hours/year) to 2 hours/week (104 hours/years). This is a reduction of 85.75% of the monitoring labor hours. Due to the total labor hours are 1078, the improvement on monitoring time represents the 58.07% of the total labor hours.

Only 2 hours weekly are necessary to monitoring the system. This is only to verify hidden factor like first signs of pest or sickness on the plants.

This improvement allows one operator to easily operate four (4) systems at the same time (It is the double of actual capacity) on Hidroponicos Borinquen.

Taking in to consideration the cost of the automated system ($402.47) and the minimum cost of one (1) plant $1.00, this represents a revenue increment of $24077.53 the first year, without impact the actual workforce.

On a domestic system, it represents the possibility for any person to operate and maintain a hydroponic system efficiently without impact their daily activities.

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