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Chapter

# Automation and Robotics Used in Hydroponic System

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## Abstract

Hydroponic system requires periodic labor, a systematic approach, repetitive motion and a structured environment. Automation, robotics and IoT have allowed farmers to monitoring all the variables in plant, root zone and environment under hydroponics. This research introduces findings in design with real time operating systems based on microcontrollers; pH fuzzy logic control system for nutrient solution in embed and flow hydroponic culture; hydroponic system in combination with automated drip irrigation; expert system-based automation system; automated hydroponics nutrition plants systems; hydroponic management and monitoring system for an intelligent hydroponic system using internet of things and web technology; neural network-based fault detection in hydroponics; additional technologies implemented in hydroponic systems and robotics in hydroponic systems. The above advances will improve the efficiency of hydroponics to increase the quality and quantity of the produce and pose an opportunity for the growth of the hydroponics market in near future.

**Keywords:** hydroponic systems, sensors, microcontrollers, automation, neuronal networks, robotics

## 1. Introduction

It is estimated that the total world population could reach 9.15 billion in 2050 [1], and to increase the global food production, even more advances in agriculture must be made intensive in crop yields and in practices that are more friendly with the environment. Hydroponics is a method of growing plants in a water solution without soil. If the roots are suspended in a liquid medium or supported using an inert medium, the system is known as Nutrient Film Technique (NFT). In NFT systems, the plants (lettuce, leafy crops and herbs) are grown in channels (gullies) and fed continuously at a rate of approximately 1 L $min^{-1}$ (**Figure 1**).

On the other hand, if the roots are floating (pool), the system is known as deep floating technique (DFT). The DFT systems (**Figure 2**) are long, cement or wood rectangular reservoirs and lined with a durable polyliner. To keep the plants in net pots, holes are perforated in a foam board which rest on the surface of the water.


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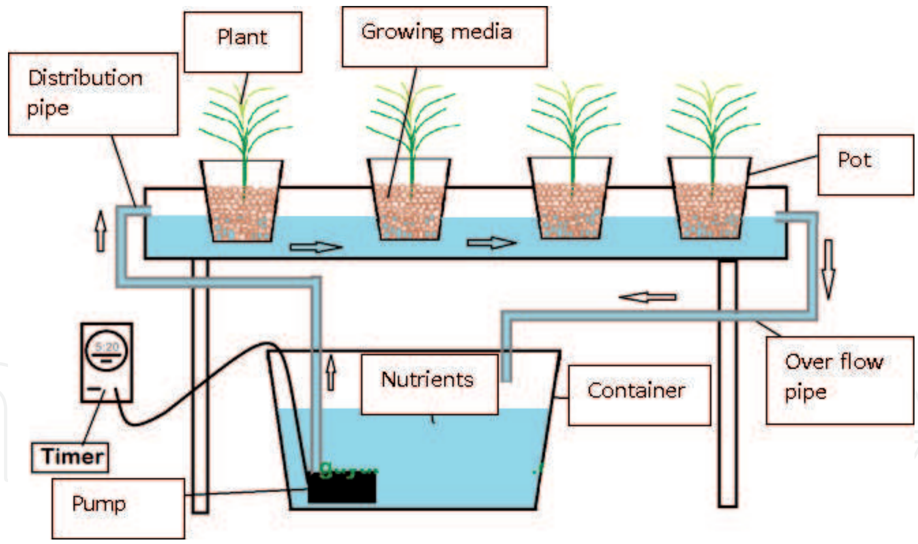


**Figure 1.**
*Nutrient film technique.*

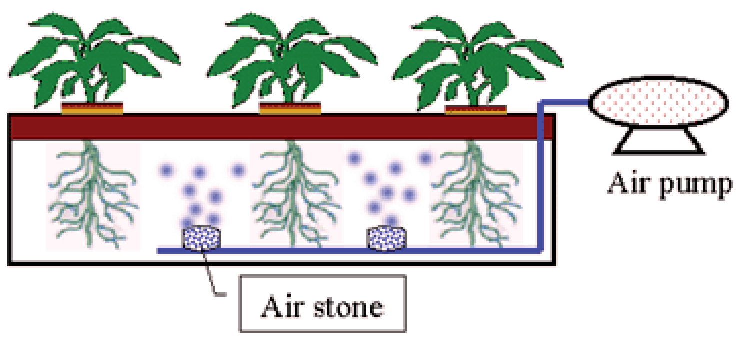


**Figure 2.**
*Deep floating technique (courtesy of Hydroponicsfarm).*

Aeroponic systems are very similar to NFT systems, differing primarily in the spatial arrangement of cultivation channels. The cultivation space is optimized for the aeroponic plants are grown suspended in air, having as support PVC pipes which can be arranged horizontally or vertically, enabling a better exploitation of areas and installing a larger number of plants per square meter surface of the oven, obtaining thus a direct increase of productivity [2, 3]. Hydroponic systems, such as the deep flow technique, nutrient film technique or aeroponic systems, are essential tools in plant factories [4]. To accomplish with this, hydroponic systems must collect a lot of information, since this allows a better diagnosis of the problems and better understand the development of hydroponic crops. Automatic sensors not only have the ones that can be read at predefined intervals, but also the readings of these sensors are stored so that higher results can be obtained for analysis and diagnosis resulting in higher crop yields and friendlier practices with the environment. These days, there are microcontrollers (**Figure 3**) on the market that are compatible with a wide variety of sensors and can be used for automatic monitoring and robotics.

The emergence of Internet of Things (IoT) has allowed farmers to automate the hydroponic culture (**Figure 4**). Monitoring of water level, pH, temperature, flow and light intensity can be regulated using IoT, which allows for machine to machine interaction and controlling the hydroponic system autonomously and intelligently employing deep neural networks [5]. The pH of the nutrient solution for most nutrient film technique is 6.0–7.0 for most plants grown in recirculating nutrient solution and 5.4–6.0 for substrate culture [6]. There are also powerful computers that could store all this information and build a big database.

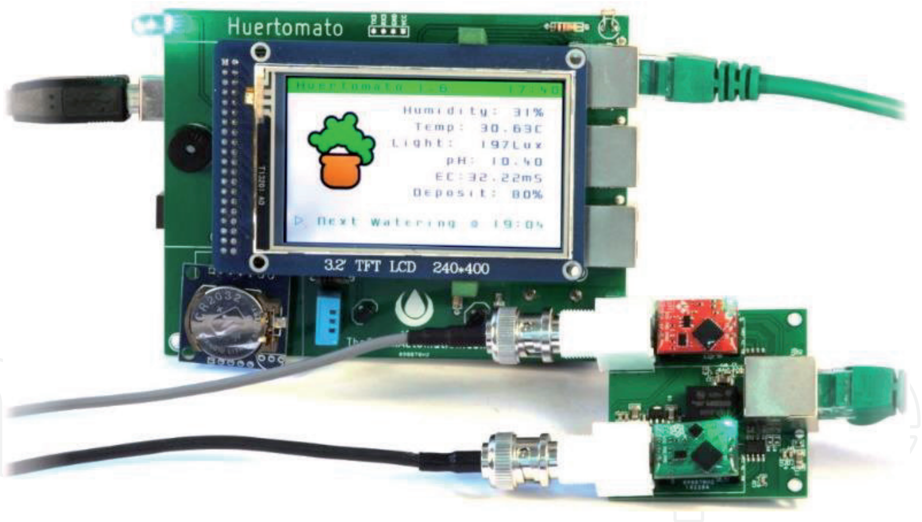


**Figure 3.**
*Huertomato microcontroller for measuring of humidity, water and air temperature, light, pH, electrical conductivity (courtesy of Arduino).*

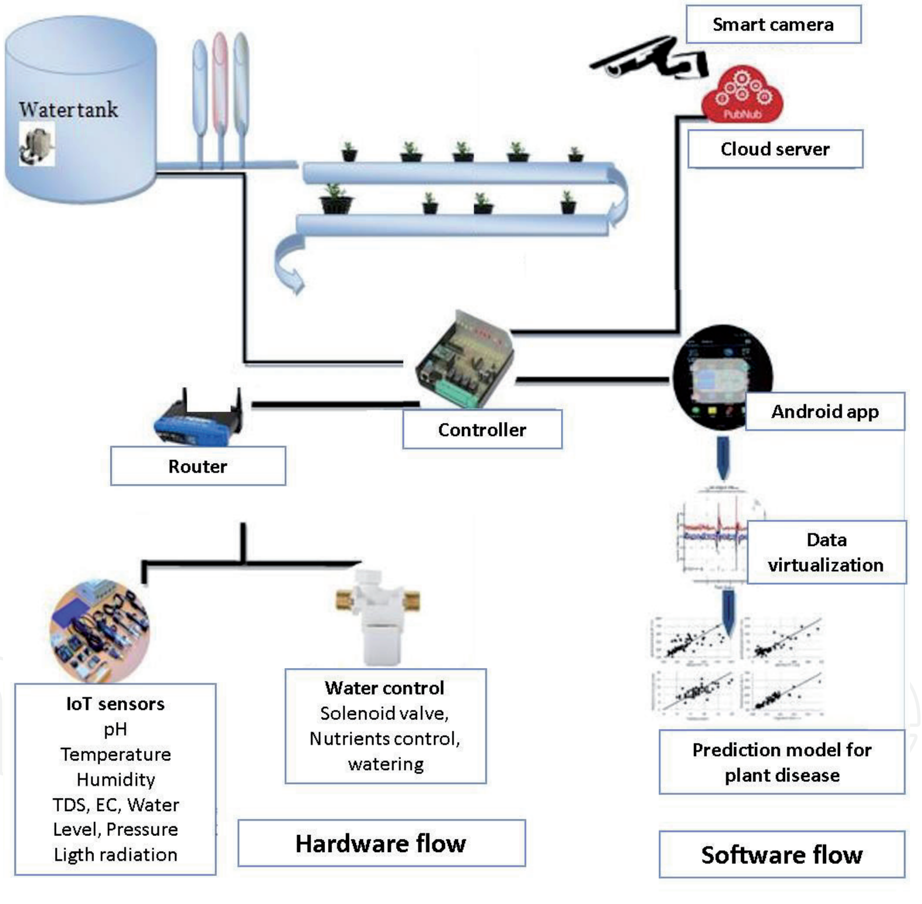


**Figure 4.**
*Schematics of internet of hydroponics (courtesy National Institute of technology, Trichy, India).*

It has been implemented a smart hydroponics system (**Figure 5**) that automates the growing process of the crops using Bayesian network model, which classifies and predicts the optimum value in each actuator to autonomously control the hydroponics farm [7]. Finally, we raise topics related to robotics for hydroponic systems (**Figure 6**). Hydroponic systems cover approximately 35,000 ha in the world and further research is needed to develop new hydroponic systems to reduce the cost of energy and materials required for crop production. Therefore, this chapter aims to be a practical guide to those interested in hydroponics automation and robotics to produce vegetables.

**Figure 5.**
*Automatic grow cabinets for growing plants at home (courtesy of HG-hydroponics).*

**Figure 6.**
*Robot for hydroponic systems (courtesy of Iron Ox Company).*

## 2. Automation in hydroponic systems

All possible variables in root zone must be monitored for automation of the hydroponic system and sensors of pH, the electrical conductivity (EC), light, the ambient temperature, the temperature of the solution, the humidity and the carbon dioxide, the dissolved oxygen and the oxidation–reduction potential must be considered as they directly affect the growth of hydroponically grown plants (**Figure 7**). The transpiration can be measured with either water ultrasound level sensors or load cells. If the area or volume of culture is large, several sensors must be placed to adequately control the entire crop. Ion sensors (17 essential elements in plant nutrition) are still studied for their durability and stability [8].

### 2.1 Hydroponic system design with real time OS based on microcontroller

It was developed a complete automation hydroponic system for maintaining stable electrical conductivity, pH, growth light and monitoring $CO_2$, temperature and humidity. The system consisted of an ARM Cortex-M4 microcontroller running ARM (**Figure 8**) embedded operating system, the official real time operating system (RTOS). The system read the pH level and nutrients on the nutrient solution of hydroponics system, as well as the temperature, humidity, $CO_2$ levels and the

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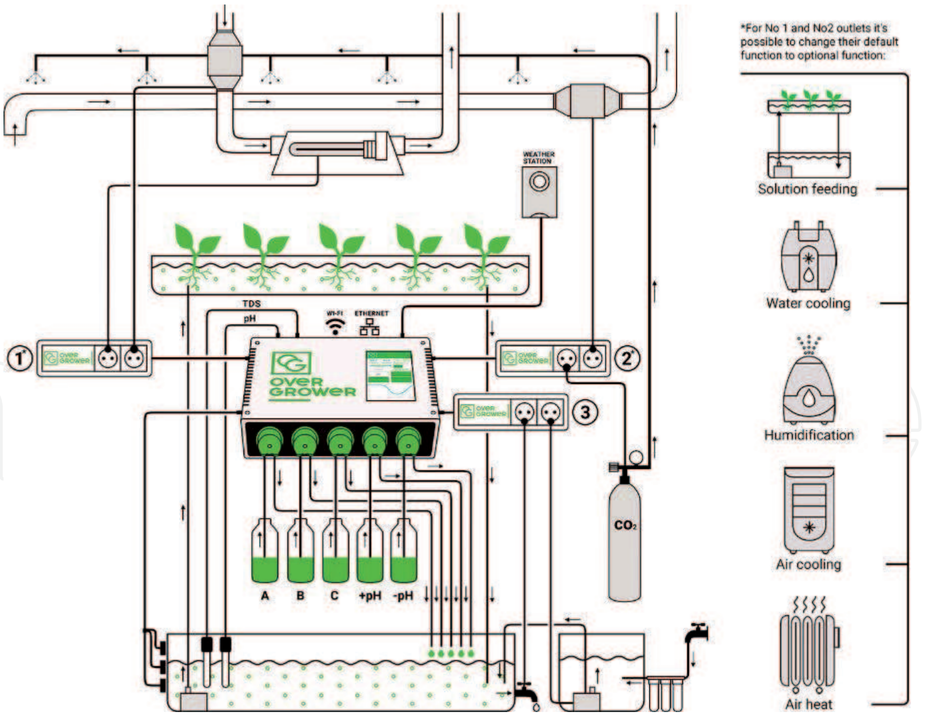


**Figure 7.**
*Hydroponics automation system (courtesy of over grower).*

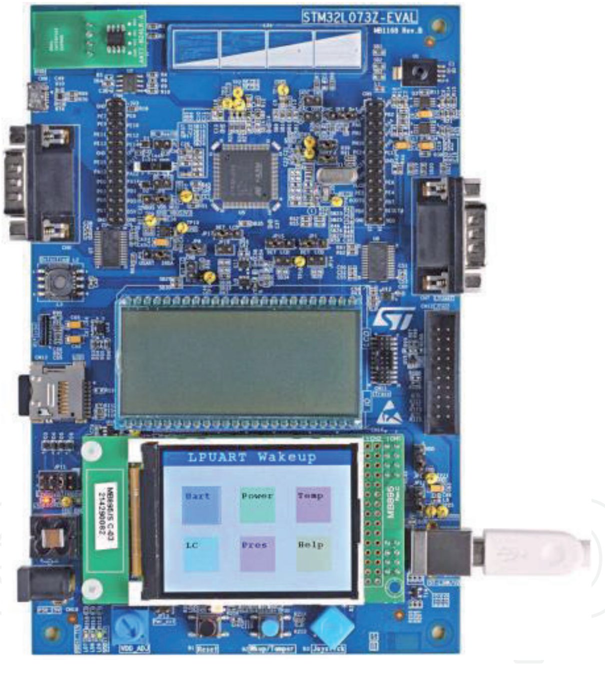


**Figure 8.**
*ARM cortex-M4 microcontroller (courtesy of developer arm).*

light intensity around the system; in addition there were LED light three lines each a different configuration on each line that was used for the lighting of plants and light color was selected and the system data were saved in SD Card.

In addition, the system was capable to control desired concentration level with variation of less than 3%, pH sensor showed good accuracy 5.83% from pH value 3.23–10. Growing light intensity measurement was 105 μmol/m$^2$/s therefore, the lights were turned on at least 17 h/day to fulfill plant light requirement. RTOS gave good performance with latency and jitter less than 15 μs, system overall show good performance and accuracy for automating hydroponic plant in vegetative phase of growth. If the system was turned on, the computer program turned off three pumps (stir pump, water pump and the dosing pump). After initialized an LCD module, then initialized serial and serial to PC for $CO_2$ sensor. The program read the system configuration data that were stored in the SD card and initialized global variables with the configuration. Later program will update the LCD display. The program started up the sensor to read data sensors, push button to read the buttons provided, mixing to perform compounding nutrients hydroponics, timer flush to set watering plants, timer lights to regulate time lighting plants by LED lights. A timer was started up for minimum water and a sensor to detect the presence of water in nutrients within of a container. Once the water was activated, then timer watered the plants. The pH sensor recorded the initial pH value in the solution, then adding the pH solution up 5 mL and compared the pH sensor measurements obtained with the instrument (**Figure 9**).

A total of 600 s was taken by DHT22 humidity sensor sampling every 30 s and the readings were compared with the measuring instrument. Twenty-five minutes were taken by MH-Z19 sensor with readings every minute in rooms, results were compared with measuring instruments. The system initially provided nutrients for 5 mL and then the system recorded and calculated the amount of nutrients needed. A distance of 30 cm from LED to plant hole was settled to use a meter for Quantum PAR (photosynthetically active radiation). A LED coefficient was obtained by dividing average light intensity (ALI) with lux. The coefficient of LED and ALI can be used to find daily light integral (DLI) during 17 h. RTOS performance was obtained using square wave input signal and measuring input signal versus output signal delay using oscilloscope. The difference of humidity data retrieval between DHT22 sensors and measuring devices was very small. $CO_2$ data retrieval between MH-Z19 sensor and measuring devices at room had a difference for each room relatively equal amount, then for the sensor MH-Z19 in this case with a correction factor, so the results obtained are close to the results of measuring instruments. A correction factor of 260 ppm was used for the MH-Z19 sensor against the initial

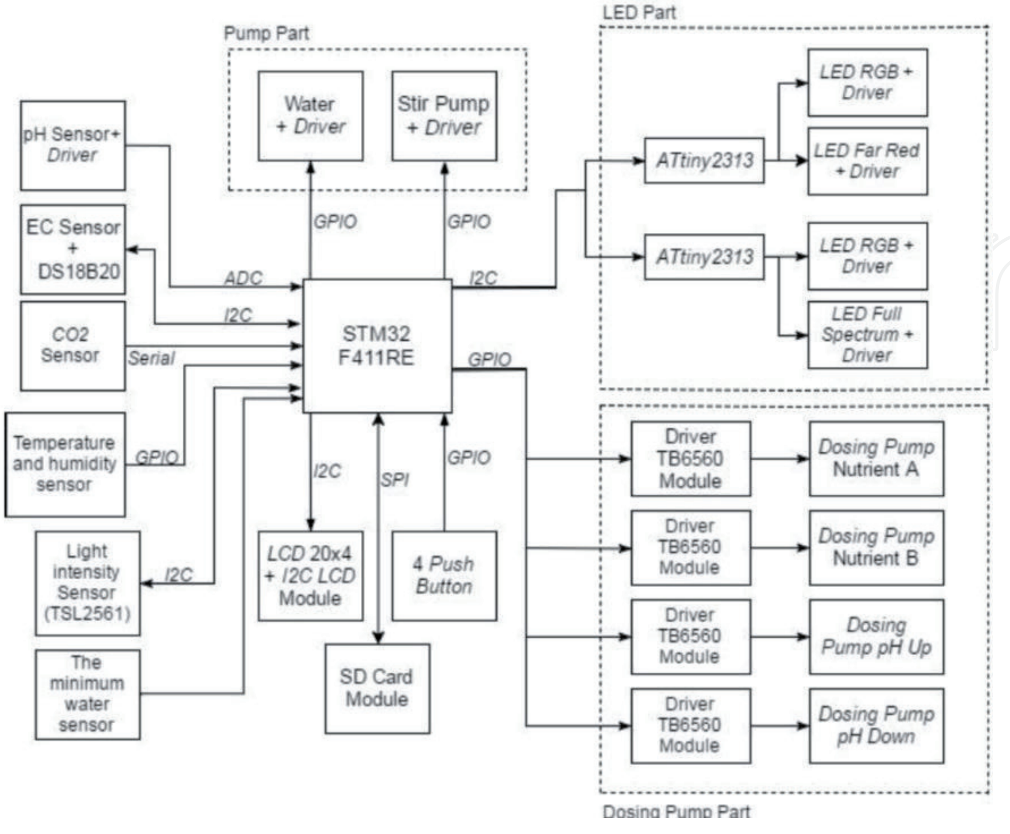


**Figure 9.**
*Block diagram of system.*

value. The growing light intensity was measured at 25 cm from light source. The result showed each growing light produces difference intensity ranging from 6.03 to 10.74 μmol/m$^2$/s, to fulfill plant light requirement on at least 17 h day$^{-1}$. From the results of pH meter sensor, the difference obtained is so small so that the pH meter sensor can be used to read the pH suitably. When taking data for RTOS experiment (**Figure 10**), the main programs still running while the experiment still ongoing.

The yellow signal is a given signal and the other signal is a signal output from each thread. Time latency (in microseconds) was very small. The results showed that hydroponic automated system performed well. RTOS ran all the tasks with a latency less than 15 μS. Environment sensor overall showed good result, temperature reading error was less than 4%, humidity reading less than 5.36% and $CO_2$ sensor accuracy was calibrated 260 ppm from initial value. System was capable to mix nutrients in 80 s with error less than 3.48%. Light intensity measurement showed different result for different color spectrum in order to fulfill daily light plant requirement we need to turn on the light at least 17 h day$^{-1}$. The vegetable grew well and can be harvested in 5 weeks [9].

### 2.2 pH fuzzy logic control system for nutrient solution in embedded and flow hydroponic culture

The fuzzy-based control system was developed for maintaining a proper acidity level of nutrient solution used in potted flower cultivation of Chrysanthemum embedded and flow hydroponic cultures. Two control valves maintained the nutrient solution pH at a desired set point as follows: (1) acid valve (to manage the addition of acid solution necessary) and (2) base valve (to keep the addition of base solution necessary) (**Figure 11**). The developed control algorithm was based on membership functions of fuzzy arrangement.

Fuzzy rules had 21 linguistic statements to achieve smoothness, by trials and errors using the membership functions based on the operator skills and experience. The fuzzy logic controlled nutrient solution pH and increased the smoothness of the pH the during control course. The culture vessel consisted of six blocks, each of which containing four potted flowers. The nutrient solution flows into and fills the cultivation bench until a certain level, 5–10 cm from pot base. The embedded system kept the plant growth media in 10 min, before it then flows back into the tank and flows into the next block. The flow rate of the nutrition used in this experiment was 2.4 L min$^{-1}$ and the measuring apparatus was Hanna pH-meter (HI8710E model).

The control system maintained 0.3 M $H_3PO_4$ and 0.4 M KOH, which flowed constantly from Marriott tube. The valve used was of solenoid type with 1/8 in. in diameter. Calibration of the pH-meter was done on voltage basis using PCL-812PG

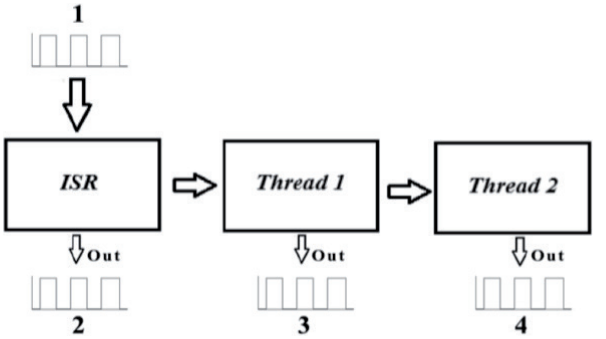


**Figure 10.**
*Experiment of RTOS.*

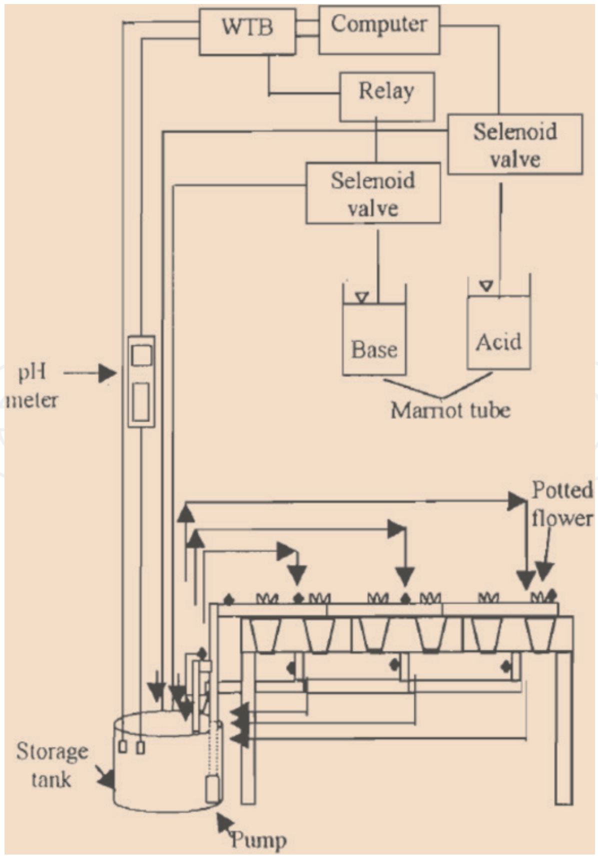


**Figure 11.**
*Embedded and flow system with pH control system.*

interface. Marriott tube was also used to calibrate the flow rate as well as on the relay circuit. The measurement result of the pH of nutrient solution was in the form of DC voltage and was transferred to 88 shunt circuit in order to get input voltage at a range of 0–5 V conforming to the working voltage of the PCL-812PG interface. This voltage became the reference digital signal for the computer to conduct data processing with control program. The output of the control action was the duration of the solenoid valve opening depended upon the input signal. A solenoid valve was activated by a relay circuit, which obtained voltage from the computer.

Process error (E) was calculated based on the difference between the set point (Sp) and the actual pH. If an E positive value was obtained, it indicated that the position of the actual pH was above the Sp and negative value of E indicated that the position of the actual was under the Sp. The error difference (dE) was the change in E to time. The error difference (dE) was the change in E to time. If the dE were positive, the error E had the tendency to increase. Conversely, if dE were negative, the error E decreased. Every numeric variable was plotted into a fuzzy system consisted of Large Positive (LP), Fair Positive (FP) and Small Positive (SP), Zero (ZO), Large Negative (LN), Fair Negative (FN) and Small Negative (SN). The control action was based on decision matrix in which there are criteria of Quick Acid (QA), Fair Acid (FA), Slow Acid (SA), Neutral (ZO), Quick Base (QB), Fair Base (FB) and Slow Base (SB).

The measurement result of the pH of nutrient solution was in the analog form of DC voltage and was transferred to defuzzification by means of weighting to the absolute membership value from every label with the membership degree obtained. A change in valve opening time, either for base tube or acid tube was due to the final output of the fuzzy. The computer program for the control system was developed using the Pascal language in DOS environment (**Figure 12**). The output voltage from the PCL-812PG had a range of 0−+5 V. The debit of the base and acid

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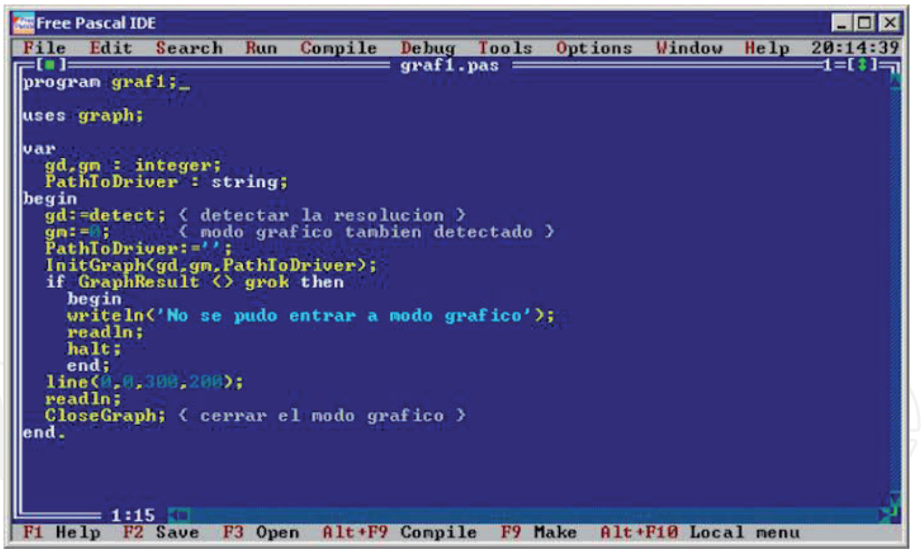


**Figure 12.**
*Pascal environment.*

flows from the Marriott tube was kept constant at 1.3 eels for base solution and 4.3 $cm^3\ s^{-1}$ for acid solution. There were differences in the heads of the air inlet and outlet at the Marriott tubes for base and acid solutions, respectively. The initial pH of the solution was above the set point and kept on moving to reach the pH = 6. To change the pH solution from 7.0 to 6.0, it took 26 s and a 100 s to increase pH from 6.0 to 7.0. That indicated that at the same period of time $[H^+]$ freed by the $H_3P0_4$ acid was more than that of the ion $[OH^-]$ freed by the KOH base.

The supplied voltage from PCL to relay circuit was on when the voltage reached 1.4 V and off when the voltage decreased to 1.1 V. The pH of the nutrient solution in first block can be controlled to approach the set point of pH = 6. To decrease the pH toward the set point it requires 68 s. After reaching the set point. The pH of the solution did not change very much due to the small change in $[H^+]$ concentration. Moreover, the straight line approaching the set point tendency of the error curve during the control indicates that the fuzzy logic control can maintain the solution pH at the set point. An overshoot not occurred in this pH control. The nutrient solution pH in second and third block can be controlled faster than in first block. The same phenomena occur in third block and the following blocks. In that manner, the set point indicates that the fuzzy logic control can maintain the solution pH at the set point. Both of valves frequently open in turns since the control load was still high at the start up. This frequency decreased at the following blocks [10].

### 2.3 Hydroponics in combination with an automated drip irrigation system

A grapevine rootstock in hydroponics in combination with an automated drip irrigation system was developed, which consisted of a hardware and software of the automated hydroponics system for grapevine in pots. Each pot had the same amount of fertilizer and the drip irrigation system was used. It was also constructed a time-based closed loop hydroponics and used a microcontroller for supplying the water to the pots (**Figure 13**). The irrigation system consisted of a 200 L water storage tank, containing Hoagland solution, which was modified to regulate the optimum 6.2 pH and electrical conductivity levels between 1.0 and 1.3 $dS^{-1}$ for the green cuttings of grapevine. Nutrient solution has been renewed when its EC level reached to 1.5–1.8 $dS^{-1}$. A submersible pump operating at 12 DCV was installed inside the water storage tank. A steel structure was built to keep pots at height of 1.5 m from the ground level of the greenhouse and water storage tank and controller

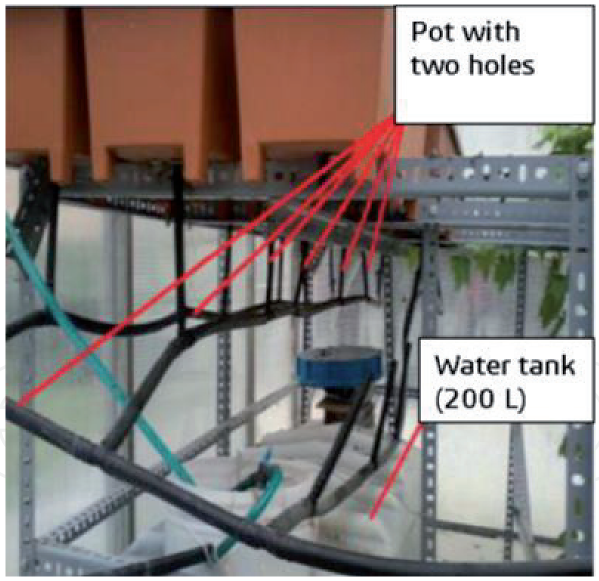


**Figure 13.**
*Grapevine experimental setup.*

circuit were installed immediately under the pots. The excess water was easiest to return to the reservoir by the drainage pipes connected to the drainage holes of the pots. Electrical conductivity of the irrigation water (ECw) was measured by an EC59 meter. Pots were irrigated with the same amount of nutrient solution. The required water was supplied by using 16 inches of diameter pipes with 4 L $h^{-1}$-drippers at a spacing of 33 cm, with three drippers serving each pot. Some connection apparatus and valves were used in the irrigation system to integrate all items.

At the beginning of the test, all substrates were filled up to field capacity, then the automated system started irrigation at 4 h intervals and run the submersible pump only 1 min throughout the whole growing season so that this irrigation management kept the soil moisture at the level of field capacity in each substrate since excess water was drained to the reservoir back after each irrigation event. The controller circuit, in which main power supply was 12 DCV, providing power to the controller and relays, but it was reduced to 5 DCV for microcontroller by using a regulator of 7805 and relay (**Figure 14**).

The program providing the automation in the hydroponics system was simple and basic and very easy to load into the memory of the microcontroller, which repeated the actions throughout the whole growing season. The dosage of water was determined according to the pumping time of water. The microcontroller switched on relaying to pumping water to the root territory only for 1 min. After that, supplying of water has been stopped to the pump and then waited for 4 h of interval for the next irrigation session. The system took over the irrigation events successfully for the whole growing season. The system conveys a properly balanced nutrient solution to the plant root area. The system saved water and fertilizer, but the water level in the reservoir must be checked with 2- or 3-weeks interval or water level sensor should be added to the controller circuit. Perlite due to its characteristics has more advantages as being used in the hydroponics system as compared with peat and peat + perlite (1:1, v:v). This system can be used for small producers from small hydroponic systems [11].

### 2.4 Automatic system for hydroponics (HydroAS)

HydroAS could produce fodder in 6 days. The system controlled autonomously the desired agronomic conditions for production and fodder flow. The automatic

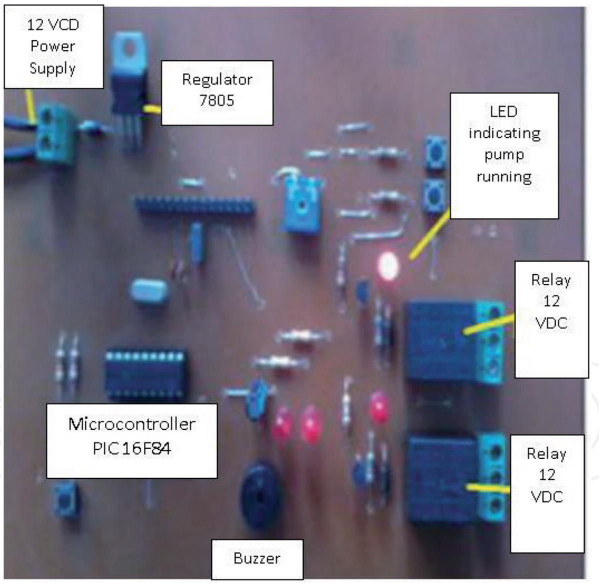


**Figure 14.**
*Controller circuit.*

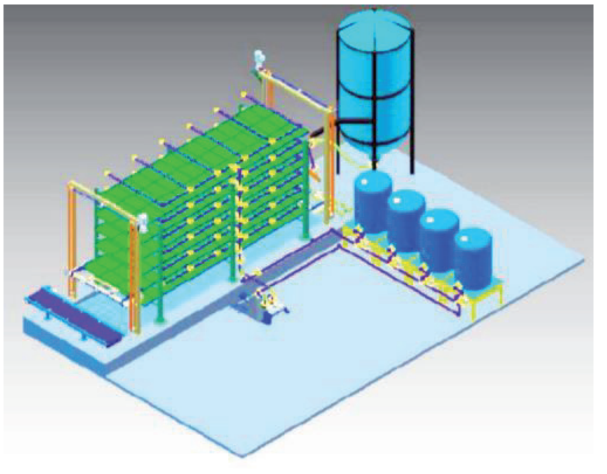

**Figure 15.**
*Fodder production system.*

solution comprised: the mechanical structure, the mechanical and hydraulic components, and the control system to automate the hydroponic automatic system. The mechanical structure consists of the following parts: (a) mechanical structure of six storeys; (b) conveyor to exit the produced fodder off the system; (c) two elevators, at each top of the six storey structure; (d) a fodder sowing system, which placed the seeds in the trays; (e) two pushers at each of the elevator, which pushed the trays in the structure and (f) unloading system, which extracted the finished fodder in the trays (**Figure 15**).

The electrical components comprised the power, sensor and actuators circuits (**Figure 16**). The power circuit consisted of depicted the protections and transformers to obtain 24 DCV to supply the S7–300 programmable logic controller (PLC), sensors and the command circuit, which were mainly digital, inductive and magnetic, that indicate start/end limits for the actuator's movement such as level sensors applied in the nutrients and water reservoirs. The actuators used were (a) two motors for the vertical movement of the elevators; (b) two pneumatic cylinder for the pusher; (c) two worm motors for the sowing platform and (d) two gearmotors for the rotational joint of the sowing and unloading platforms. The hydraulic system supplied the nutrients and the flow of water in the system and consisted of

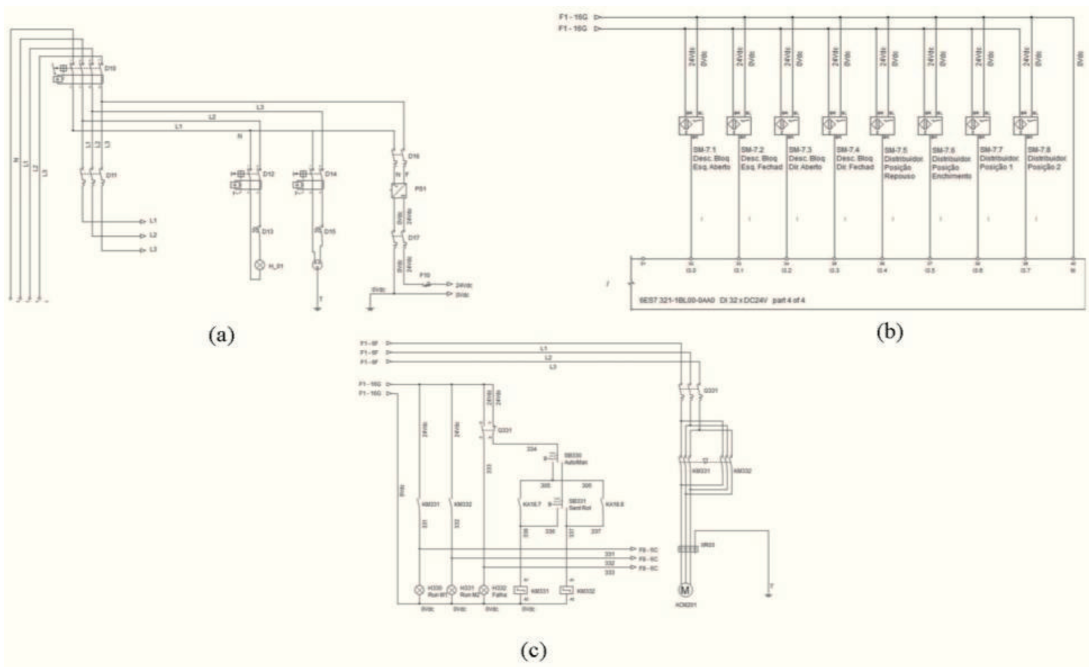


**Figure 16.**
*Power circuit (a), sensor circuit for the unloading part (b) and actuator circuit for the elevator one (c).*

two irrigation pumps to generate redundancy. The hydraulic circuit comprised the valves, nutrients and water reservoirs, the six storeys pipeline with the irrigation micro-jets, and the 2 $m^3$ water return reservoir with the two redundant pumps. The chosen microspray jets operate at 1 bar and have the capacity of 1 L $h^{-1}$, with 0.8 m maximum spray diameter area. The pipeline structure consisted of six storeys and watering pumps performed system irrigation three times. The system controls the actuators of the mechanical structure. The nutrient solution control is also performed in the PLC, to control the pH and electric conductivity, while mixing the nutrients and the control sequence of the trays in the hydroponic system.

This sequence definition is a high-level control task, while the low-level actuator control is performed in inner loops and is programmed directly on the motor drives. The system starts when the first storey is filled with trays. When the seeds are placed in the tray, in the first storey near a first elevator, the next step is to elevate the tray and push it to the structure in the second storey. On the other side of the structure, a second elevator, receives a tray that was pushed as consequence of the previous movement. This tray is then elevated to the next storey. This process is repeated until the tray reaches the end. When this happens, the elevator number two descends to the first storey and unloads the produced fodder to the conveyor. After unloading this tray, it is pushed to the first level for washing, and the next 6 days cycle then starts, to produce new trays full of fodder. This system was simulated in Matlab SimMechanics, showing its proper operation for the mechanical and electrical parts. The development phase of the fodder was tested, and validated, which benefits the agricultural holding [12].

### 2.5 Expert system-based automation system (HES)

HES was developed to minimize the labor force used in the process of hydroponics, the total amount of time spent in agricultural process, human-based errors, as well as, the control of hydroponics greenhouse plant production. All these processes are conducted by a computer unit where the relevant programs are loaded. The system defined the values that belong to the input parameters by using the output parameters that are used by the user (**Figure 17**). The input

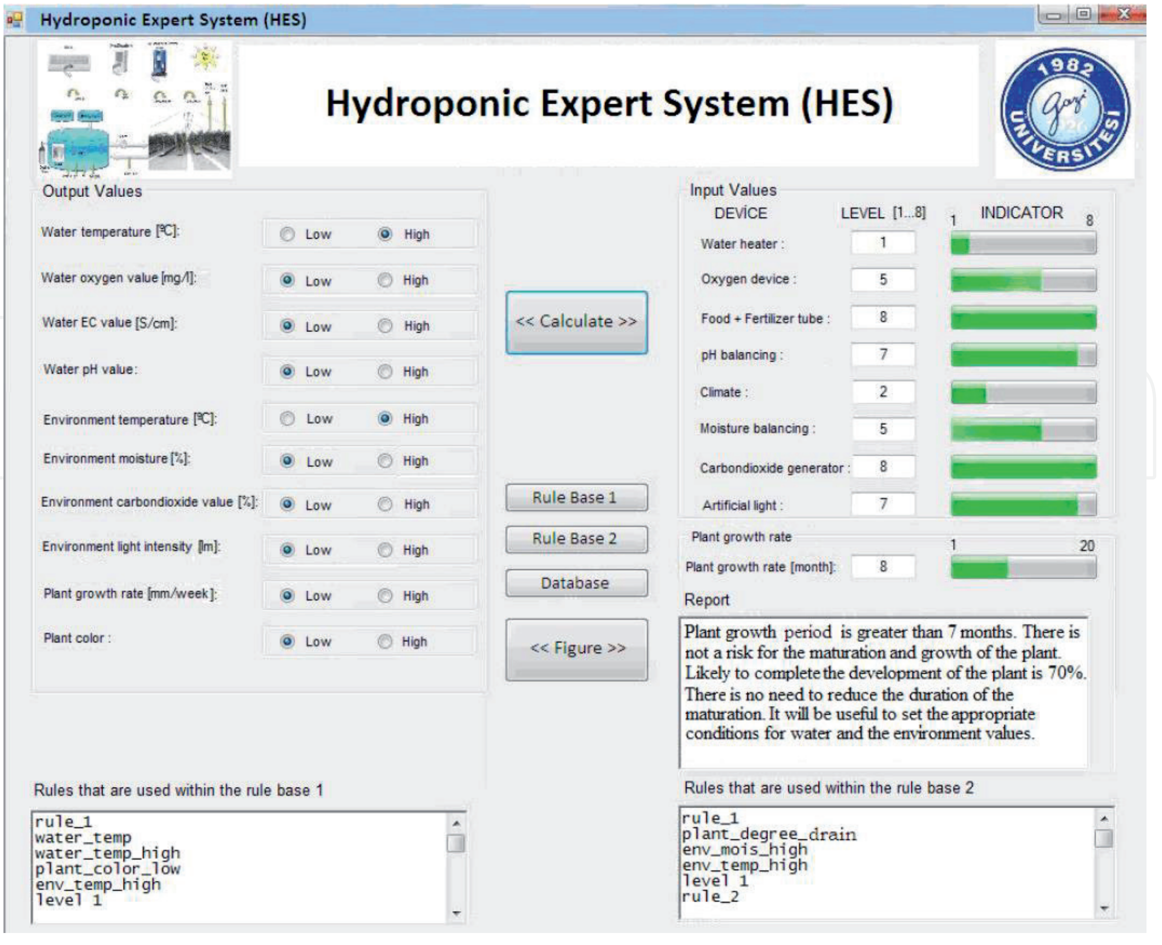


**Figure 17.**
*Graphic user interface of HES.*

parameters prepared the optimum growth environment for the plants. User interface controlled the knowledge base of the expert system and entered data and realize operations. All parameters were taken in to consideration in order to create controlled environment exactly. Knowledge base is continuously in a process of improvement and human experts would add new knowledge to knowledge base or modify the existing knowledge heuristics when new situations occurs. The data base was made up of real conditions that summarize the current situation of the problem and quality-value pairs. By all these output parameters level management, the total level grade can be attained, and this can determine the development period of the plant.

This system had two rule bases. The first one was the rule base that constitutes the input parameters and the second one was the rule base that determines the growth period of the plant. The growth period of the plant is determined by adding the values of plant drain degree, plant nutrition degree, plant deterioration degree, plant photosynthesis degree and plant growth degree. The inference engine, had the function to produce the results that the system needs by using the data in the knowledge base and by interpreting the rules of the system as follows; the user interface of the HES software and the relevant output values taken from the greenhouse system and the sensors are interpreted and translated into linguistic expressions such as low-high. When the system finds a rule that matches the related values in the rule base, it attributes this level value as the level value. It is used for all parameters temperatures, oxygen device, nutrition and the operating levels for water heater, fertilizer tube, pH balance, conditioner, moisture balance, carbon dioxide producer and artificial light are attuned, creating the appropriate conditions for the greenhouse system (**Figure 18**). Plant growth period is attained from

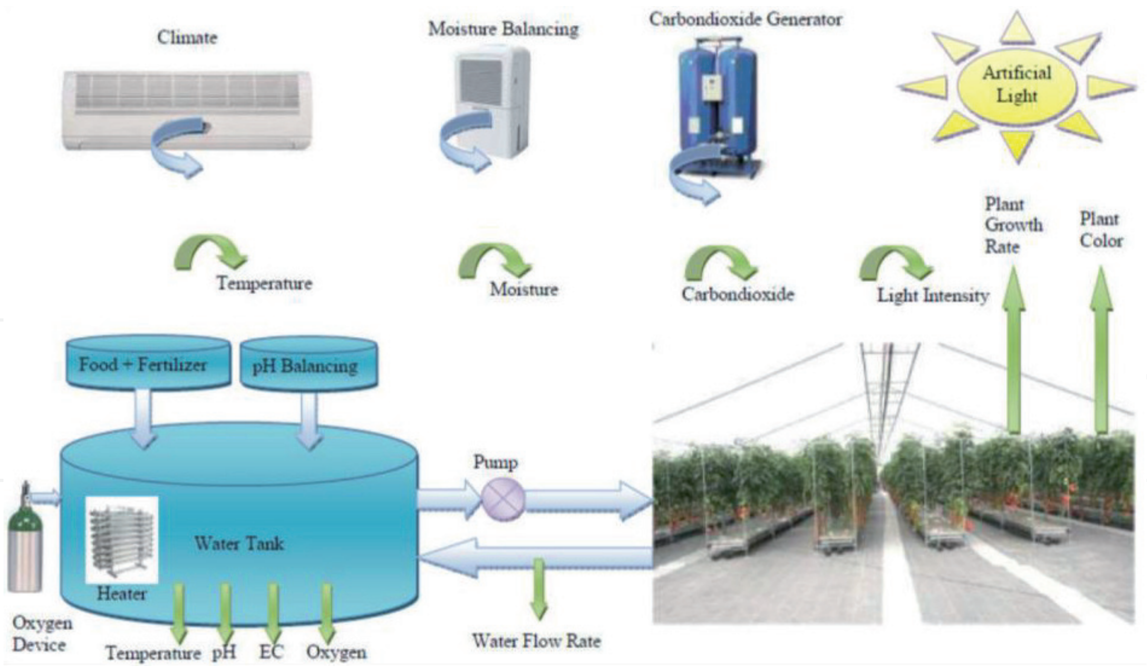


**Figure 18.**
*Hydroponic system setup.*

the total of plant drain degree, plant nutrition degree, plant deterioration degree, plant photosynthesis degree and plant growth degree parameters. After all these processes are completed, reports were produced by the system, based on the plant growth period [13].

### 2.6 Automated hydroponics nutrition plant systems (AHNPS)

AHNPS was placed in a special chamber or vessel and the nutrients were supplied directly to the hydroponic roots at any given time (**Figure 19**). Microcontroller (Arduino Uno) will control the flow of nutrient solution on the vessel automatically, and the microcontroller can be controlled from Android smartphone. This system had an embedded program module. The microcontroller worked in real time to setup the alarms on nutrient pumps. If alarm is enabled, a relay will be also activated, and then the pump will drain the nutrition solution on the plant. If alarm is deactivated, the relay will be turned off and the pump will stop supplying. Moreover, it has been designed a virtuino application on Android smartphone that serves to check the water level and temperature around the plants. Before starting the design of a virtuino application, it first provides the data storage using the features of thingspeak.com.

The hydroponic flow system starts from the detection of a proximity sensor and a temperature sensor (**Figure 20**). The sensor will detect the water level in the hydroponic tube and the temperature sensor to detect the room temperature. The detection sensor was connected to a relay that in turn was attached to the microcontroller port. When the relay port pin is lower than the specified height, the water flow will be run on the water pump to irrigate the plant. If the relay of port pin is turned on, it means the water level is above of the specified height, and then the water pump will stop being water, in that manner the water flow was regular. Time and date were displayed at any time of the process in an LCD screen. The pumps are used not only to increase water but also to add nutrients to the hydroponic tube. The water pumps were used for water recirculation and relays used to control both nutrient solution as well drain pumps. The system mechanism worked as follows: HC-SR04 ultrasonic sensor detected the height value of

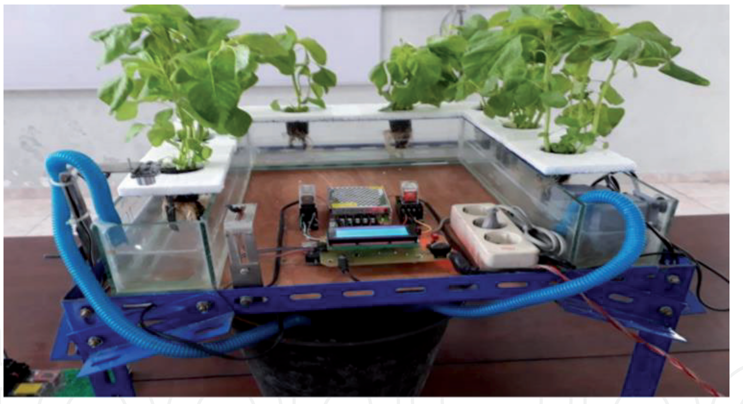

**Figure 19.**
*Experimental hydroponic system configuration.*

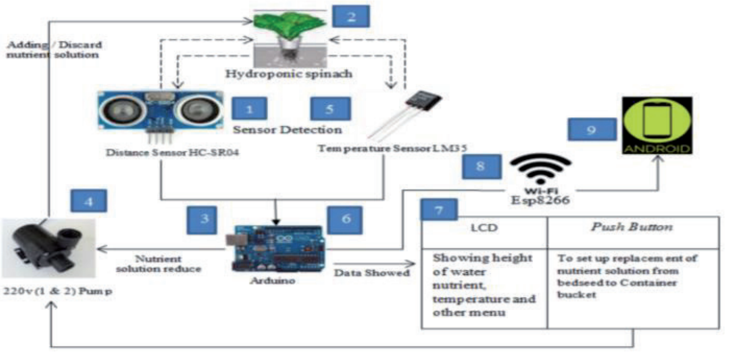


**Figure 20.**
*Automated hydroponics nutrition plant system.*

nutrient solution in hydroponic plants by the parameter of the high of water (in cm) unit and the temperature. The LM-35 sensor detected the temperature in Celsius degrees.

The ultrasonic sensors measured the distance of water based on ultrasonic wave. The difference between the transmission time and the reception time became the water distance. The system started working by using of sensors connected to the electrode. The output of this electrode will be forwarded to the microcontroller as an entry point to be processed by the microcontroller. The microcontroller received this voltage signal and compared it with the previous value and decided based on that input signal. Based on this voltage the microcontroller decided whether to drain the water at the pump or not. All the commands on microcontroller (Arduino Uno) can be controlled from a smartphone-based Android. It was observed that this hydroponic plant grows well with proper water and nutrient usage because it is controlled by the microcontroller. The rate of hydroponic plant growth was faster when compared with plants with soil-grown systems. The WiFi module sent the water level information and the temperature values of the plants area. This value was compared to the value in LCD microcontroller and on Android smartphone application. This value is directly obtained from the sensor and sent to the Arduino. After the water level 5 cm in the nutrient tube then the pump stops, and water did not flow anymore. The average temperature for five tests was 28.43°C. The relationship of water height in the nutrient tube with time is recorded continuously by the ultrasonic sensor on several measurements. The maximum level of water was 6 cm in the hydroponic tube. The sensor detected if the water level decrease in hydroponic nutrition tube. If the water level has decreased, then the sensor will perceive what occurs and automatically the water pump will be turned on to increase the water level on the hydroponic nutrient tube [14].

### 2.7 Hydroponic management and monitoring system for an IOT-based NFT farm using web technology (Hommons)

It was created a hydroponic farm management system that could monitor water temperature, water level, higher densities of nutrient solution and the acidity of a nutrient solution using sensors are related and connected to the microcontroller via a website. Hommons used a 20 W solar system, which consisted of a solar cell panel, controllers, battery and DC to AC inverters. The ESP8266 module was used as a communication medium through a wireless network to the internet and integrated with objects that have connection to the internet. Systems can be accessed through the web page using browser based on the server address. The core material of the PVC pipe tool with 3 in. of diameter as his planting medium and ¾ in. of diameter PVC to flow the nutrient solution. The plastic box reservoir served to accommodate any mix of nutrient solution in water. Hommons hardware design relationship of the NFT consisted of sensors, actuator, microcontroller, ESP8266, wi-fi access point, microcomputer (Raspberry Pi) and power supply. In addition, some Raspberry Pi 2 microcomputers served to accommodate the webserver and brokers. Communication technologies on this system using 802.11 or better known as Wi-Fi by using the internet (**Figure 21**).

The power supply using voltage 5 DCV and 2A. Various environmental sensors had been installed to detect any change in the physical or chemical environments and sensors became the input to the process management of NFT. After the user successfully performs the login process so the system redirected the user to the main page heading. There were two buttons on the sidebar navigation. On the main content there were four columns that display data from the sensors-sensors on the NFT hydroponic farming tools, such as nutrient levels, nutrient pH levels, temperature, nutrient and nutrient EC and parts per million (ppm) level. In the navbar a notification function button displayed the alarm or warning to the user while the settings button function settled the system (restart and shutdown) and logout of the system. Automation settings pages were divided into two parts: first part with its own set of pH and ppm values are desirable way entering the value in the textbox. The second automation page contained a selection of plants type which pH and ppm value have been set before, so farmers only need to choose the type of plants that they maintained to grown. After the hardware and sensors on the hydroponic NFT management system were integrated, the sensors (ultrasonic sensors, pH, temperature and EC) needed to be tested to quantify the level of accuracy. The system testing used the

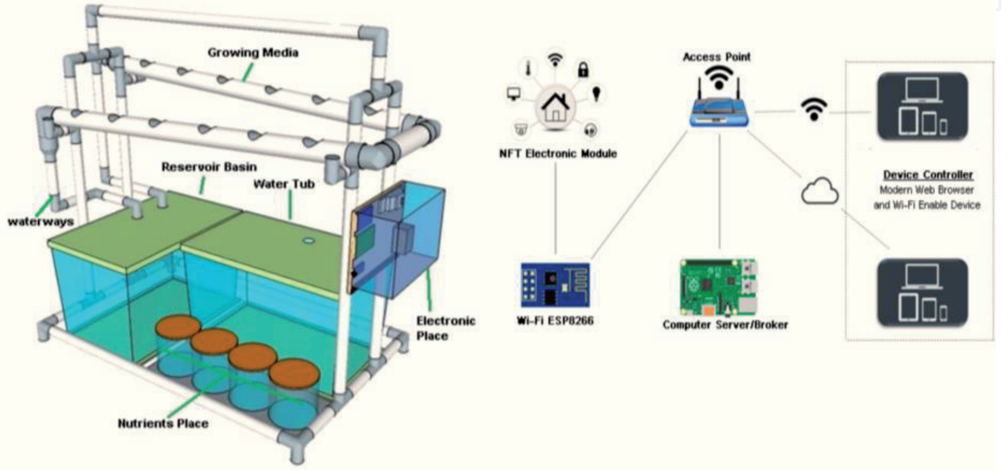


**Figure 21.**
*Hommons hydroponic system.*

original plant samples to find out if the plant is growing well. The plants used in this test are pokchoy, lettuce and kale at the teen age period (after nursery). Plant growth was observed by taking pictures of the plant for a few days [15].

### 2.8 Neural network-based fault detection in hydroponics

It was developed a fault detection model for hydroponic systems, with a feed-forward neural network. Mechanical, sensor and biological faults were considered: a preliminary detection system detected the existence of any faulty situations. Finally, the developed network, only considered two first kinds, mechanical and sensor faults. Biological faults, because of their particularities, were treated separately [16].

Other model based on a feedforward neural network predicted pH and EC changes in the root zone of *Lactuca sativa* cv. Vivaldi grown in a deep–trough hydroponic system. The neural net had inputs as follows: pH, EC, nutrient solution temperature, air temperature, relative humidity, light intensity, plant age, amount of added acid and amount of added base and two outputs: pH and EC. A combination of network architecture and training method was one hidden layer with nine hidden nodes, trained with the quasi–Newton backpropagation algorithm which was the most suitable and accurate (**Figure 22**). The model was capable of predicting pH at the next 20–min time step within 0.01 pH units and EC within 5 μS $cm^{-1}$. Simpler prediction methods, such as linear extrapolation and the lazy man prediction, value of the previous time step, gave comparable accuracy much of the time, though, they performed poorly in situations where the control actions of the system had been activated and resulted rapid changes in the predicted parameters. In those cases, the neural network model did not encounter any difficulties predicting the rapid changes. Thus, the developed model successfully identified dynamic processes in the root zone of the hydroponic system and accurately predicted one–step–ahead values of pH and EC [17].

### 2.9 IoT-based intelligent hydroponic system

An IoT-based intelligent hydroponic plant factory solution called PlantTalk was developed. PlantTalk intelligence could be built through an arbitrary smartphone. PlantTalk was flexibly to configure the connections of various plant sensors and actuators through a smartphone. Python programs for plant care intelligence through the smart phone were convenient (**Figure 23**). Automatic LED lighting, water spray, water pump and so on were included in the developed plant-care intelligence included and so on. For instance, it was showed that the PlantTalk

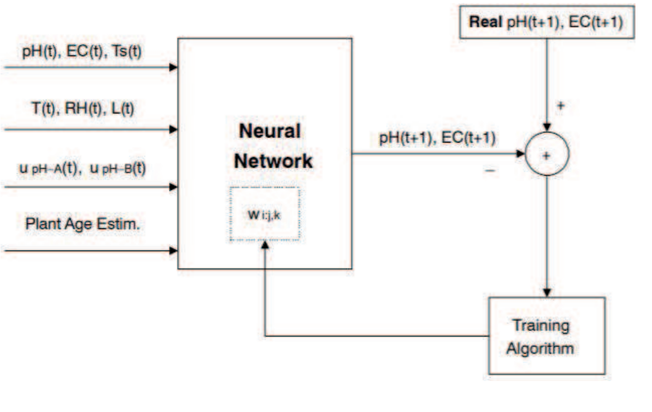


**Figure 22.**
*Neural network model inputs and outputs and training process.*

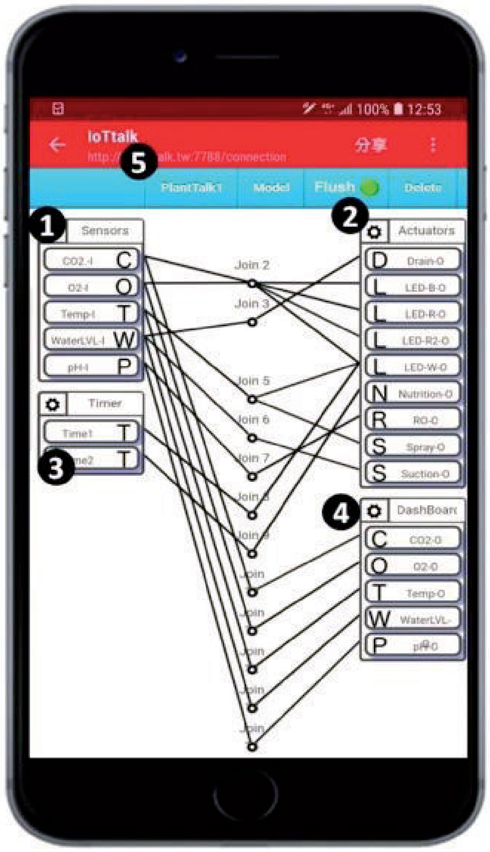


**Figure 23.**
*PlantTalk in a smart phone.*

intelligence effectively lowers the $CO_2$ concentration, and the reduction speed is 53% faster than a traditional plant system. AgriTalk for a plant factory is an extension of PlantTalk [18].

### 2.10 Other technologies used in hydroponic systems

It was applied ultrasound and dissolved oxygen supersaturation as external for controlling the growth rate of plants in hydroponics as well as maintaining the product quality. In the case of the leaf lettuce growth in hydroponics with exposure to 28-kHz ultrasound and dissolved oxygen supersaturation up to 36 mg $L^{-1}$ at 20°C and peak-to-peak pressure at 20 kPa or larger worked as the growth inhibitor of the leaves and the roots; in addition, oxygen supersaturation became a growth promoter, without any degradation of chlorophyll in the leaves [19].

On the other hand, liquid separated reactor and a high voltage power supply based on a 20 kHz inverter neon-transformer were developed to archive the treatment with high energy efficiency, a low initial cost and a low running cost. The performance of the system on bacteria inactivation in the nutrient solution was evaluated in a continuous treatment system operation and the results showed that the standard plate count for background microflora and *R. solanacearum* is drastically reduced by the plasma treatment and is not detected after 8 days treatment. The nutrient solution was decontaminated by 4 log cycle with plasma treatment under the continuous operation condition [20].

Other researchers applied electro-degradation (ED) to the culture solution in order to degrade their root exudates and improve growth, yield and quality of strawberry. They used four types of nutrient viz. renewed, non-renewed, non-renewed with direct current electrodegradation (DC-ED) and non-renewed with alternative current electro-degradation (AC-ED). Fresh 25% standard Enshi nutrient solution were changed every 3 weeks interval, with in renewed treatment, while DC- and AC-ED treatment were applied in non-renewed solutions. Significantly greater fruit yield (225.9 g plant$^{-1}$) was obtained from renewed nutrient solution, which was statistically similar to fruit yield in non-renewed solution with AC-ED application. Compared to renewed solution, fruit yield was decreased to about half (114.0 g plant$^{-1}$) in non-renewed solution while non-renewed with DC-ED produced intermediate yield between non-renewed and renewed solution or non-renewed with AC-ED. It was concluded that growth performance was greater in renewed solution followed by non-renewed with AC-ED, while it was decreased significantly in nonrenewed solution with DC-ED similar to non-renewed solution. It was also observed a similar trend in vitamin C content while brix and citric acidity was not varied. Calcium and iron concentration in the culture solution were significantly decreased in DC-ED, consequently their contents were also found lower in crowns and roots compared to other solutions used. The strawberry yield and quality can be improved through application of AC-ED in non-renewed solution [21].

## 3. Robotics in hydroponic systems

### 3.1 Robot with position-based visual feedback (RPBVF)

RPBVF was developed to act and observe the crop in NFT hydroponic systems. The focus is on the implementation of a position-based visual feedback (PBVF) algorithm in combination with a Microsoft Kinect. AmHydro 612 NFT production unit was 1.8 m × 3.65 m × 0.9 m production unit that stored 144 plants and 144 seedlings and used a closed loop water system. Above the NFT system were placed artificial lights to improve the lettuce growth. The gullies laid on an inclined table, which angle was θ, so that water flows passively to the end of the gullies. Water was collected at the end of the gullies and directed to the water reservoir, where a water pump propelled water to the top of the gullies. To manipulate the plants, the robot (**Figure 24**) was designed as a gantry with four v-groved wheels running on two inverted angle iron tracks (x-axis). On top of the gantry was a carriage that can move back and forth over the gantry (y-axis), this was perpendicular to the x-axis. On the carriage was a mechanism to move an arm up and down (z-axis), down being the negative direction. At the end of the arm was placed a two degrees of freedom gripper which opened, closed and rotated around the y-axis.

The structure is made primarily from aluminum that allows the robot to be adjusted to accommodate different sizes of NFT hydroponic systems. The x-axis was driven by a stepper motor and a chain. A timing belt transmitted the power from the carriage on the gantry to the stepper motor. The arm on the carriage was balanced by a counterweight and was driven by a stepper motor and a chain. Two linear actuators were used to open and close the gripper and the other linear actuator was used to rotate the gripper around the y-axis. All three linear actuators were driven by a 12 DCV relay board that communicates with a Phidgets interface board, which was connected to the main computer, which was running Ubuntu Server 11.04 × 64. The Kinect vision system was mounted on the carriage so that the optical axis was along the negative z-axis. All software was programmed in C++. Every hardware component communicated with its own ROS (Robotic Operating System) node. The main hardware nodes were stepper motor node, gripper node, interface board node, position node and Kinect node. The position node keeps track of the x, y and z-position of the robot and a graphic user interface was designed to provide low level control of the system. A Microsoft Kinect camera was added to the system, which produced

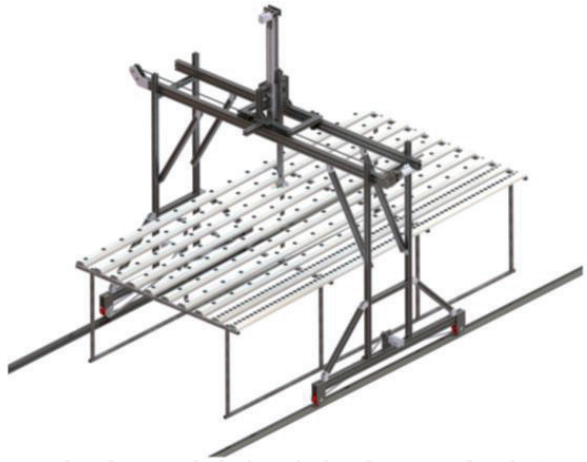

**Figure 24.**
*Robot manipulator arm.*

two kinds of images, a 640 × 480-pixel RGB color image and a 640 × 480 pixel 11-bit (0–2047) gray scale depth image that was provided by an Infra-Red (IR) sensor. The extraction of the plants required combining classical 2D image analysis techniques and IR-based depth measurement the 3D position. The computer language used was C++ using the Open Computer Vision library. The Kinect was placed on the carriage and is facing downwards (negative z-axis) to ensure the plants in its field of view are at a maximum distance of 1.5 m, because the accuracy of the Kinect decreases quadratically with distance. Up to 1.5 m the accuracy was 10 mm and the precision of the Kinect was 1 mm. The field of view was of 0.8 m × 1.15 m in x and y-direction. It was used a RPBVF algorithm was used to detect plants on the hydroponic system and placed the robot to manipulate plants (**Figure 25**).

In the algorithm, first were detected the gullies, because the plants are only located on them. All gullies are oriented along the x-axis and are straight. A probabilistic Hough Transform was used for straight line detection. By filtering the detected lines, the edges of the gullies were identified. After the identification of the edges, the lines were grouped, resulting in a segmentation of the gullies. After filtering, the coordinates of the plants in the image frame were known. Point was defined as the top left corner of the image. The depth information was extracted from the depth image by getting the value at point. The OpenNI driver transforms the IR sensor values into distances in meters by using a fitting function. To reduce the noise, multiple consecutive frames were averaged to calculate the plant coordinates. The plant coordinates form the control input for the robot. The output only depends on the current state and the control input. The open loop control algorithm was used. To be able to pick up a plant, the image frame coordinates had to be transformed to gantry coordinates. To transform the image frame coordinates to gantry coordinates a Garstka and Peters modified transformation was used. Because the Kinect is not located on the gripper, all coordinates have to be offset. These offsets are dependent on the position of the Kinect relative to the gripper. The z-coordinate has to be offset by an extra value, because the NFT table is under an angle of 2.2°. In this transformation, the point is the principal point in pixels of the depth sensor and the focal lengths in pixels were calculated. The values were quantified by calibrating the Kinect. The position bias was removed by a linear scaling of the x and y-coordinates. To evaluate the performance of the positioning and control algorithm, the x, y and z-position error between the final position of the gripper and the plant coordinate was measured. The final position of the gripper was defined as 20 mm above the center of the cup. On the top of the cup a cross-hair is drawn to mark the center. The initial position of the gripper is defined as the middle between the

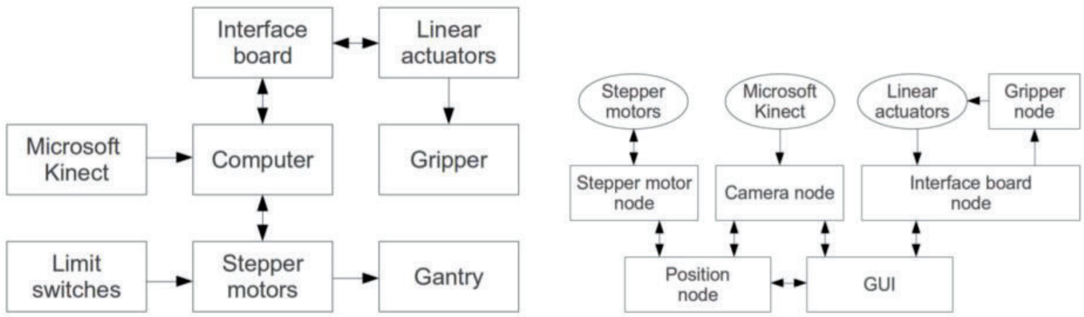


**Figure 25.**
*Hardware layout of the robot (a) and software layout of the robot (b).*

points of the gripper so the x, y and z-position error can be measured. Each image was analyzed to detect the plants. With these coordinates the robot is heading to the plant. The position error was measured with a ruler at the final stopping position and robot then returned to the same starting position. The gripper must be ±15 mm in x-direction, ±20 mm in y-direction and ±10 mm in z-direction from the center of the cup to allow the robot to pick up the plant. From the images with detected plants the gantry coordinates of the plants were calculated and inputted for the positioning algorithm so that the robot can be positioned to pick up the plants. There were 25 samples evaluated. The performance of the system is within the requirements and the plants could be manipulated on an NFT system [22].

## 4. Conclusions

It is expected that future developers can to detect acidity levels of pH solution, viscosity, oxygen and other variables. The future work will be collecting environmental data, which are obtained from sensors and implanting an artificial intelligence in robots and in hydroponics systems.

It is also expected that in future research make the hydroponics systems and robots able to make information panel with other operating systems that can be used as a standard system.

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## References

[1] Alexandratos N, Bruinsma J. World Agriculture Towards 2030/2050: The 2012 Revision. USA: University of Minnesota; 2012

[2] Resh HM. Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower. Boca Raton, Florida, USA: CRC Press; 2016

[3] Sheikh BA. Hydroponics: Key to sustain agriculture in water stressed and urban environment. Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences. 2006;**22**:53-57

[4] Kozai T, Niu G, Takagaki M, editors. Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production. Editorial Elsevier, London, England: Academic Press; 2015

[5] Mehra M, Saxena S, Sankaranarayanan S, Tom RJ, Veeramanikandan M. IoT based hydroponics system using deep neural networks. Computers and Electronics in Agriculture. 2018;**155**:473-486

[6] Fonteno WC. Growing media: Types and physical/chemical properties. In: Reed DW, editor. Water, Media and Nutrient for Green House Crops. Batavia, IL: Ball Publishing; 1996. pp. 93-122

[7] Alipio MI, Cruz AEMD, Doria JDA, Fruto RMS. On the design of nutrient film technique hydroponics farm for smart agriculture. Journal of Engineering in Agriculture, Environment and Food. 2019;**12**:315-324

[8] Trejo-Téllez LI, Gómez-Merino FC. Nutrient solutions for hydroponic systems. In: Hydroponics—A Standard Methodology for Plant Biological Researches. London, England: IntechOpen; 2012. pp. 1-22

[9] Atmadja W, Liawatimena S, Lukas J, Nata EPL, Alexander I. Hydroponic system design with real time OS based on ARM Cortex-M microcontroller. In: IOP Conference Series: Earth and Environmental Science, Vol. 109(1). IOP Publishing; 2017. p. 012017

[10] Suhardiyanto H, Seminar KB, Chadirin Y, Setiawan BI. Development of a pH control system for nutrient solution in ebb and flow hydroponic culture based on fuzzy logic. IFAC Proceedings Volumes. 2001;**34**(11):87-90

[11] Yildirim M, Dardeniz A, Kaya S, Ali B. An automated hydroponics system used in a greenhouse. Scientific Papers, Series E, Land Reclamation, Earth Observation & Surveying Environmental Engineering. 2016;**5**:63-66

[12] Matos J, Gonçalves PJ, Torres PM. An automatic mechanical system for hydroponics fodder production. Romanian Review Precision Mechanics, Optics and Mechatronics. 2015;**47**:63

[13] Şahin İ, Calp MH, Özkan A. An expert system design and application for hydroponics greenhouse systems. Gazi University Journal of Science. 2014;**27**(2):809-822

[14] Sihombing P, Karina NA, Tarigan JT, Syarif MI. Automated hydroponics nutrition plants systems using arduino uno microcontroller based on android. Journal of Physics: Conference Series. 2018;**978**(1):012014

[15] Crisnapati PN, Wardana INK, Aryanto IKAA, Hermawan A. Hommons: Hydroponic management and monitoring system for an IOT based NFT farm using web technology. In: 5th International Conference on Cyber and IT Service Management (CITSM); IEEE. 2017. pp. 1-6

[16] Ferentinos KP, Albright LD, Selman B. Neural network based

fault detection in hydroponics. IFAC Proceedings Volumes. 2001;**34**(26):37-42

[17] Ferentinos KP, Albright LD. Predictive neural network modeling of pH and electrical conductivity in deep–trough hydroponics. Transactions of ASAE. 2002;**45**(6):2007

[18] Van LD, Lin YB, Wu TH, Lin YW, Peng SR, Kao LH, et al. PlantTalk: A smartphone-based intelligent hydroponic plant box. Sensors. 2019;**19**(8):1763

[19] Kurashina Y, Yamashita T, Kurabayashi S, Takemura K, Ando K. Growth control of leaf lettuce with exposure to underwater ultrasound and dissolved oxygen supersaturation. Ultrasonics Sonochemistry. 2019;**51**:292-297

[20] Takahashi K, Saito Y, Oikawa R, Okumura T, Takaki K, Fujio T. Development of automatically controlled corona plasma system for inactivation of pathogen in hydroponic cultivation medium of tomato. Journal of Electrostatics. 2018;**91**:61-69

[21] Talukder MR, Asaduzzaman M, Tanaka H, Asao T. Electro-degradation of culture solution improves growth, yield and quality of strawberry plants grown in closed hydroponics. Scientia Horticulturae. 2019;**243**:243-251

[22] Tanke NF, Long GA, Agrawal D, Valada A, Kantor GA. Automation of hydroponic installations using a robot with position based visual feedback. In: Proceedings of the International Conference of Agricultural Engineering CIGR-AgEng. 2012. p. C1429