Development of an Automation System for Nutrient Film Technique Hydroponic Environment

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ABSTRACT

Hydroponic is one of the plant cultivation systems known for its high-quality products. The growth of the plant depends on the composition of nutrient solution and the plant environment. Due to its nutrient absorption process, nutrient solution composition continuously varies in the Hydroponics nutrient solution irrigation system. An automation system is necessary to control and monitor the composition of nutrient solutions. This paper presents the development of an automation system for nutrient film technique (NFT) Hydroponic system. The proposed system control and monitor the pH level, Electrical conductivity (EC), Dissolved Oxygen (DO), water temperature, water flow rate, and water level of the nutrient solution in the Hydroponics nutrient solution irrigation system suited for a specific plant. The main system is composed of sensors, microcontrollers, actuators, and data loggers. It was verified by the testing of sensors and actuators functionality, and also a field experiment. The experiment result revealed that the developed system works properly to monitor and control the environment nutrient solution parameters of Hydroponic. The field experiment also shows that the vegetable plant sample grew well during cultivation and showed good quality crop yield with a harvest-time is of around 3.5 weeks.

Keywords: *Hydroponic, Automatic, Harvest-time, Nutrient sensor, NFT.*

1. INTRODUCTION

Nowadays, the agriculture industry is characterized by its technological advance and capital-intensive. It has achieved great growth both in quantity and quality and has become a considerable industry with a big potential market both in domestic and overseas demands [1].

One of the plant production systems known for its high-quality products is Hydroponic system. Hydroponic is a type of hydro-culture plant cultivation. It cultivates the plant with less soil and uses mineral nutrient solution in water [2 - 4]. The plants grow with their roots either in nutrient solution or in an inert medium (gravel, perlite, or mineral wool). There are six types of hydroponic systems, namely nutrient film technique (NFT), drip system, water culture, ebb & flow, geoponics, and wick. Water/moisture, nutrients, and Oxygen are the common parameters needed by plant roots. The six types of Hydroponic system differ from each other based on how they deliver these basic parameters needed by the plant to grow. The parameters to be considered in a Hydroponics system are the nutrient solution, pH of the nutrient solution, electrical conductivity (EC) of the nutrient solution, the temperature of the solution, dissolved oxygen (DO) of the solution, and air temperature [5 - 7].

Since the plant quality and harvest-time become important issues in optimizing productivity [8, 9], a reliable and precise environment control system of Hydroponic is critical to achieving this goal. The Hydroponics environmental control system has to monitor and control the nutrient solution variables (pH, electrical conductivity, dissolved oxygen, and temperature) accurately [6]. Today's embedded system and digital controls are becoming more common in controlling and monitoring Hydroponics operations. It substitutes many independent sensors and controllers that frequently work against each other and inflates the operational cost. A farmer can set all growth parameters using the automated system device according to the plant needed going to grow. Therefore, the hydroponic system can be executed efficiently and timely. Thus, the result is better quality plants with less cost, effort, and time-consuming [9, 10].

This paper aims to describe the development of an automated system that is capable to control and monitor the nutrient solution variables (pH, electrical conductivity, dissolved oxygen water temperature, water flow, and water level) during the whole cycle of the NFT Hydroponic system.

2. MATERIALS AND METHODS

2.1. Hydroponics

Hydroponics is the concept of soil less gardening. It is a method of growing plants in water with the needed nutrients. In this way, water must be delivered directly to the roots of the cultured plants. The plants that grow with the roots are slightly soaked in the nutrient solution [11 - 13]. There are different techniques on how to deliver water to the roots. One of these is the nutrient film technique system. In this method, water is continuously channelled within a tray. With this system, water can be typically recycled. Using Hydroponics, the growth rate of the plant is 30- 50 percent faster than soil plants. This method can also help plants get the nutrients needed without searching unlike in soil gardening. Hydroponic gardening uses less water than soil gardening because water can be recycled [14, 15].

The NFT system is basically popular for home hydroponic plants such as lettuce, tomatoes, peppers, cucumber, some herbs, etc. This is because of its simple orientation as shown in Figure 1. Therefore, NFT systems are most commonly used for quick-growing small plants.
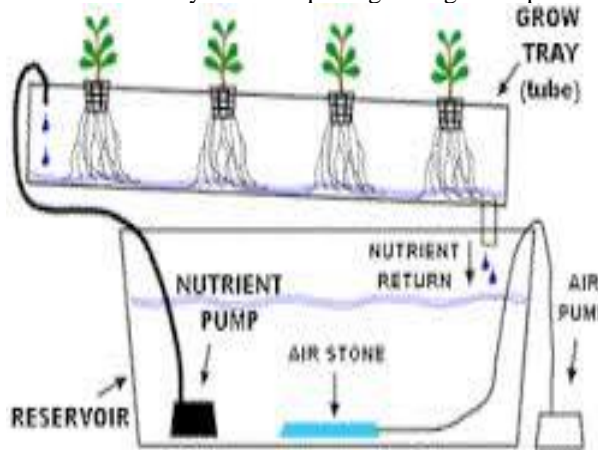

Figure 1 The NFT Hydroponic system.

The parameters to be considered in a hydroponics system are the nutrient solution, the nutrient solution pH, the nutrient solution EC, the solution temperature, air temperature, and Oxygen concentration [16, 17].

2.2. System Design

The proposed system is a part of the SmartHydroFarm system that is an automatic controlling

and monitoring system platform for water culture Hydroponic cultivation. It is namely onsite terminal as shown in Figure 2.

The general objective of this research is to design a device that will mix automatically the nutrient solution to achieve a balanced hydroponics system. While the water temperature, pH level, EC level, DO percentage, water flow, and water level are the targeted parameters to be monitored and controlled.

Figure 2 Architecture of SmartHydroFarm systems.

The block diagram of the Hydroponic control and monitoring system is shown in Figure 3. pH level, electrical conductivity level, water temperature, and water level are monitored using a pH sensor, EC sensor, water temperature sensor, and water level sensor respectively placed on the mixing tank. The pH sensor automatically adjusts the acidity and basicity of the balanced nutrient solution according to the plant's pH need. While the EC sensor will adjust automatically the amount of nutrients are needed by the crop. The pH sensor and EC sensor adjust the pH and amount of nutrients the plant needed by activating the nutrient pumps.
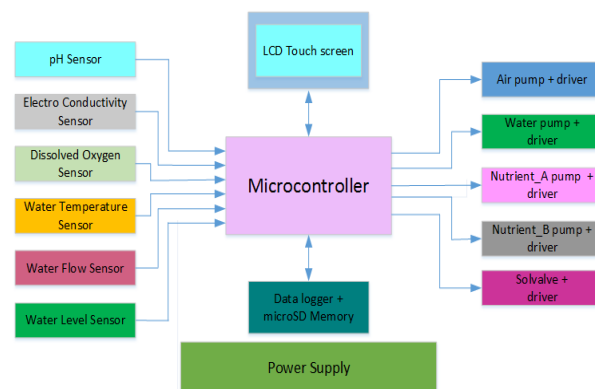

Figure 3 Block diagram of Hydroponic control & monitoring system.

The system also controls the water temperature and dissolved oxygen level of the nutrient solution. The water temperature sensor and DO sensor on the mixing tank are used for the activation of the oxygen pump. While the water flow sensor is placed on the growing tray to know the water flow speed in the growing tray, and the water level sensor on the mixing tank to control the level of the nutrient solution in the mixing tank. A touch screen LCD is incorporated into the system to display monitored nutrient environment variables, and to manually encode the pH, EC, DO, and water temperature needs of the crop to be planted on the hydroponic system. All monitored nutrient environment variables also are recorded in a MicroSD card by the data logger module.

The proposed algorithm for Hydroponic control and monitoring system is described as follows:

1 : select the hydroponic nutrient environment parameters control modes either manual or automatic,

2 : turn on the water pump,

3 : read the hydroponic nutrient environment parameters,

4 : display the actual Hydroponic nutrient environment parameters on LCD,

5 : record the actual Hydroponic nutrient environment parameters in data logger,

6 : compare between the hydroponic nutrient environment parameters set-point and actual parameters (sensors reading),

7 : if the parameters don't match, modifying the EC, DO, pH, water temperature, and water level of the nutrient solution by controlling the air pump, nutrient pump, and solenoid valve,

8 : control water flow,

9 : loop back to step 3,

10 : else stop control action.

3. RESULTS AND DISCUSSION

3.1. System Implementation

The developed system was built according to the block diagram in Fig 3. The system is composed of sensors, microcontrollers, actuators, LCD, data logger, and power supply as shown in the integration of the component system in Fig 4.

The pH sensor, EC sensor, and DO sensor from Atlas Scientific are chosen to measure pH level, electrical conductivity level, and dissolved oxygen level respectively. The pH sensor has ±0.1 pH (25°C) accuracy, 0–14 pH measuring range, and 5V DC operating voltage. The EC sensor has also 5V DC operating voltage, < ±10% F.S accuracy, 1- 20ms/cm measuring range, and 5–40°C operating temperature. While DO sensor has 0–20 mg/L measuring range, 50°Cmax probe temperature, 690 kPa (100PSI) max probe working pressure, ±0.1full range DO readings, two

significant figures (XX.XX mg/L)accuracy and 5V DC operating voltage.

Figure 4 The integration of sensors and actuators.

DS18B20 temperature sensor (waterproof) from Dallas Semiconductor is used to measure the water temperature. The sensor has-55°C to +125°C temperature range, 3.0–5.5V input voltage, ±0.5°C accuracy from -10°C to +85°C, and 1 Wire interface

The nutrient solution flow rate circulation is measured by a hall-effect water flow sensor model FS200A. It has 4.5–24V DC working voltage, 0–1.2Mpa working pressure, 0.5–30L/min flow range, and1% accuracy.

The water level sensor from Funduino is chosen to measure the level of nutrient solution in the mixing tank. It has 5V DC working voltage, <20mA working current, 10–30°C working temperature, low power consumption, high sensitivity, and 0–4.2V DC output voltage signal.

The processing unit uses Arduino Mega 2560.The module applied the ATmega2560 chip, which has 54 digital I/O pins (15 pins can be used as PWM outputs), 16 analogue inputs, 4 UARTs, a 16 MHz crystal oscillator, a USB connection, and an ICSP header.

The data logger module from Deek robot is used for the data logging and storage. It has an SD card interface for either FAT16 or FAT32 formatted cards, a 3.3V level shifter circuitry that prevents damage to the SD card, a real-time clock (RTC), and a battery backup that lasts for years.

A 3.6" TFT LCD is used to display the result of data processing by a microcontroller. It has a color arrangement: RGB Stripe, 65K color with 320 × 240 resolutions. The controller of this LCD module is SSD1289; it supports a 16-bit data interface with a 4 wire control interface. This module includes the touch screen and SD card socket.

The nutrient circulation in the growing tray and the supply water in the mixing tank is controlled by a mini water pump and solenoid valve. The mini water pump has
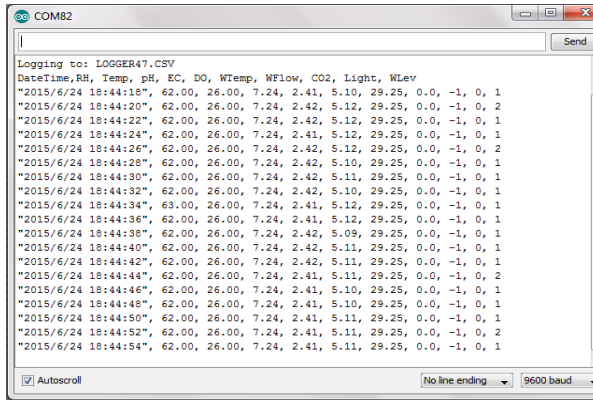
12VDC 300mA working power, 10×4 cm size, and 5000–10000Pa rated pressure. While the solenoid valve operates with a minimum pressure of 3 PSI, flow rate of 3 L/min, and working voltage of 12V DC.

The microcontroller interfaces the actuator using a driver module. The driver module was built based on the simple Darlington transistor amplifier configuration. It uses the TIP120 Darlington transistor.

The final implementation of the Hydroponic control and monitoring system is shown in Fig 5.

(a)   (b)

Figure 5 The final system implementation: (a) the Hydroponic control and monitoring system device; (b) actuator driver

The Hydroponic control and monitoring system algorithm were implemented by writing C code using Arduino IDE software as shown in Fig 6.

Figure 6 The IDE programming tool.

3.2. Functionality test configuration

The testing was conducted to verify the developed device's functionality. The pH sensor, DO sensor, EC sensor, water temperature sensor, water level sensor, and water flow sensor were connected to the control and monitoring device. While the mini water pumps and solenoid valve were connected to the driver module device. The testing configuration is shown in Fig 7.

(a)   (b)

Figure 7 The testing configuration: (a) the Hydroponic control and monitoring system integrated with actuator driver; (b) sensors in the test environment.

3.3. System integration and experiment setup

The sensors and actuators are installed in the NFT Hydroponic irrigation system. The NFT Hydroponic irrigation system was placed inside the open type greenhouse as shown in Fig 8(a).While the developed Hydroponic control and monitoring system device was placed on the growing support of the NFT Hydroponic irrigation system as shown in Fig 8(b).

(a)   (b)

Figure 8 The integrated SmartHydroFarm system: (a) NFT Hydroponic system in a greenhouse; (b) Hydroponic control & monitoring device.

A field experiment was setup to examine the performance of developed Hydroponic control and monitoring system using the configuration as presented in Fig 8. In the field experiment, the Chinese cabbage plant was chosen for the cultivated plant.

3.4. Discussion

The functionality test results show all sensors could work properly to acquire the Hydroponic environment parameters. The parameters data were recorded in the data logger as shown in Fig. 9.

Figure 9 The data logger acquisition.

The functionality test results also revealed that all actuators could respond to the triggering signal from the controller. The testing result was summarized in Table 1.

Table 1. The pumps and solenoid functionality test result.

Input signal from microcontroller	Water pump Status	Air Pump Status	Nutrient_A pump Status	Nutrient_B pump Status	Solenoid Valve Status
HIGH	Running	Running	Running	Running	Running
LOW	Stop	Stop	Stop	Stop	Stop
HIGH	Running	Running	Running	Running	Running
LOW	Stop	Stop	Stop	Stop	Stop

In the field experiment, Chinese cabbage plants were cultivated in the Hydroponic grow tray for four weeks. All growth parameters need for Chinese cabbage plants were maintained by the developed device and recorded in the data logger. The charts of recorded growth parameters data trends are shown in Figs 10 to 12.
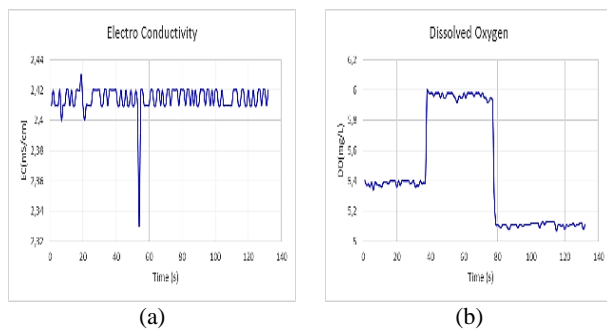
Figure 10 (a) Acquired EC data; (b) Acquired DO data.
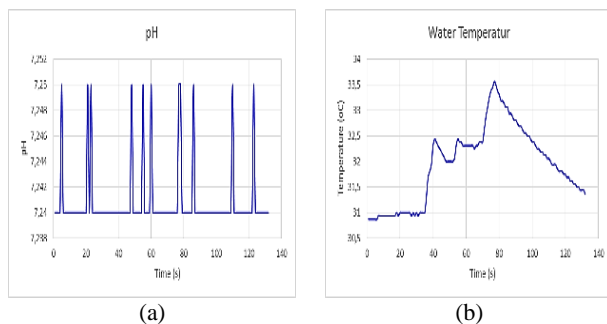
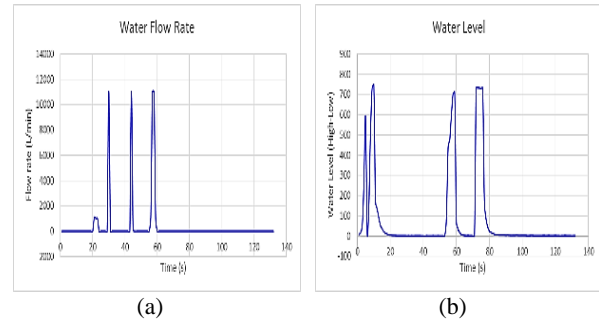**Figure 11** (a) AcquiredpH data; (b) Acquired water temperature data.

Figure 12 (a) Acquired water flow data; (b) Acquired water level data.

The recorded data revealed that the developed control and monitor system could maintain the Hydroponic nutrient solution parameters at defined value, although they fluctuate because of the nutrient absorption process.

The field experiment results also show that uncontrollable Hydroponic nutrient parameters have an awful impact to plant growth as shown in Fig 13.
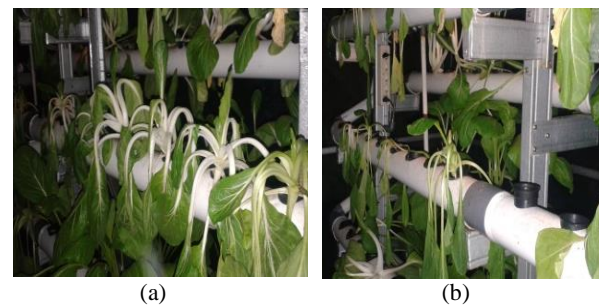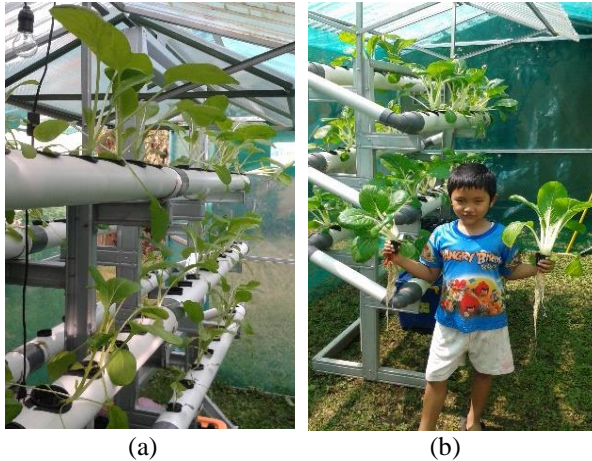

Figure 13 Uncontrollable of Hydroponic plant cultivation: (a) one day; (b) two days.

The uncontrollable nutrient solution in one day caused the plant withered as shown in Fig 13(a), and in two days caused the plant to decay as shown in Fig 13(b).

The field experiment results in Fig 14 show the cultivation was controlled by the developed system. The Chinese cabbages look fresh, healthy, and high-yielding. The developed control and monitoring system improved the Chinese cabbages' quality and harvest time. The conventional cultivation system needs around 5 weeks for harvesting, while the controllable Hydroponic system needs around 3.5 weeks.

(a)   (b)

Figure 14 Controllable of Hydroponic plant cultivation: (a) 1.5 weeks cultivation; (b) harvesting.

4. CONCLUSIONS

The first design of the Hydroponic control and monitoring system has been already implemented and installed at the laboratory scale of the NFT Hydroponic irrigation system. The laboratory experiment shows that the developed system works properly and reliably to maintain the Hydroponic nutrient solution parameters for cultivated plants.

The field experiment with Chinese cabbages targeted plant reveals that the performance of developed system produces fresh, healthy, and high-yielding plants in shorter harvest-time. The harvest-time is around 3.5 weeks.

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