Fuzzy-based automated nutrient solution control for a hydroponic tower system

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Abstract. Hydroponic farming is gaining significant interests in the field of agriculture due to its many advantages. Its design is modular thereby allowing it to be installed in limited spaces and urban applications. Also, the trend of controlled environment agriculture (CEA) is now prevalent in the study of hydroponics. This ensures that hydroponic setups are invulnerable to plant diseases, infestations, and variable weather systems. One of the challenges in its operation, however, is in the efficient and accurate maintenance of the nutrient solution. Sudden changes in the growth parameters such as ambient temperature, relative humidity, electrical conductivity (EC), and pH level negatively impact the growth of hydroponic plants. Several studies have proposed systems which can control the distribution of the nutrient solution and maintain the optimal levels of growth parameters. This paper discusses a proposed control framework for nutrient solution management in a hydroponic system. Moreover, this system is based on fuzzy logic and designed for the adjustment of the pH level and electrical conductivity (EC) of the mixture. Additionally, the complexities in the process and maintenance of the system were made simple to facilitate easy adaptation and familiarization that even non-educated growers can easily acclimate to the proposed system. Also, dedicated sensor modules were used for monitoring the growth environment. Four treatment solutions were administered using dosing pumps to correct parameter values that went beyond the desired setpoint ranges. This system is applied on a nutrient film technique (NFT) hydroponic tower farm to assess its performance on an actual physical setting.

1. Introduction

Hydroponics pertains to the technique developed by William Frederick Gericke in which plants are grown using nutrient solution instead of soil [1]. Given that its design can be scaled into vertical farms, it can produce greater yield per area as compared with horizontal farms [2]. However, the main challenge in its implementation is in the control of the nutrient solution. Regular monitoring of the parameters is necessary since sudden increase or drop in the pH value and electrical conductivity (EC) have adverse effects on plant health [3].

Several studies proposed methods on how to regulate the nutrient solution. Eridani et al. designed a prototype of an automated nutrient feeding system [4]. The system was able to detect changes in the parameter values and can correct the nutrient concentration back to normal. A similar approach was conducted by Sihombing et al. wherein an automated irrigation for a hydroponic system was developed [5]. Artificial intelligence, particularly fuzzy logic, was also involved in some works which attempted to control the nutrient solution. For example, Yolanda et al. proposed a nutrient adjustment system using fuzzy inference in which the system architecture is based on wireless sensor network [6]. Also,
Fuangthong and Pramokchon involved fuzzy logic in the decision-making process in nutrient solution adjustment [7]. The study also used HSV histogram to generate setpoint values for the sensors. However, some of these studies used experimental setups that were not entirely automated or intelligent. Moreover, in order to determine whether the control systems can manage the nutrient distribution system, there is a need for it to be applied in an actual physical farm. Lastly, the use of multiple stock solutions and treatment agents introduces further complexities in the control process.

This study, on the other hand, proposes an automated nutrient solution control based on fuzzy inference systems. This system is designed to manage the deployment of solution for a nutrient film technique (NFT) hydroponic tower growing cos lettuce. In this study, the complex operation and maintenance of the system were simplified so that even non-educated farmers can easily adapt to the proposed system which is user friendly. Moreover, the rest of the paper proceeds as follows. The related works are discussed in the next section. This is followed by the theoretical framework, proposed experimental setup and lastly, the conclusion.

2. Related Works
A hydroponic tower was developed by Tagle et al. for urban farming application [8]. It was installed with various sensor modules to monitor the growth parameters such as water temperature and level, ambient temperature, relative humidity, total dissolved solids, and light intensity. A subsequent study has seen the inclusion of an automated data acquisition system (DAQ) [9]. The DAQ program was written using Arduino software and was designed to gather and store data from 6 hydroponic parameters.

Another study used wireless sensor networks to detect the parameters in a greenhouse type hydroponic farm [10]. Moreover, the data from the sensor network was sent to cloud storage. Remote farm maintenance was also possible through the use of smartphones. In addition, a system was designed to cultivate plants in a hydroponic environment with minimal human intervention [11]. It also used the concept of Internet of Things to allow remote monitoring and control.

![Figure 1. The basic setup of an NFT hydroponic system [12].](image-url)

3. Theory
3.1. The irrigation system
Irrigation systems, often called as hydroponic setup, refer to the way the nutrient solution is administered to the crops. Currently, there are 6 general setups in hydroponic farming, namely: ebb and flow, deep water culture, wick system, drip system, aeroponics, and nutrient film technique.

Ebb and flow system and deep water culture are popular among home growers for its efficient use of resources and low start-up cost. The main difference between the two, however, is in its operation. While ebb and flow setup involve the ‘flooding’ and ‘draining’ of the plant roots, the deep water culture allows the roots to be fully submerged in the nutrient solution at all times. Wick system, on the other hand, is a passive system for it doesn’t require the use of pumps to administer the nutrient solution. This setup uses the principle of capillary action to soak up the solution, which in turn dampens the growing medium where the plant roots are located. Moreover, the drip system administers the nutrients into the growing
tray in slow, regular trickles and is ideal for plants with large roots. Meanwhile, aeroponics is a unique type of hydroponic setup for it doesn’t require growing media. Plants are thereby cultivated in a mist-like environment where nozzles spray droplets of nutrient solution towards the exposed roots.

The nutrient film technique (NFT) is one of the frequently employed irrigation setups for growing leaf plants in hydroponics. This method is best suited for small, quick-growing plants. Since the hydroponic plant used in this study is lettuce – a fast-growing, vegetative plant, the NFT system is the most ideal setup.

Furthermore, its operation involves the flowing of a shallow stream of nutrient solution in growing channels where the roots of plants are exposed. As depicted in Figure 1, the nutrient solution is typically stored in a mixing tank just below the channels. A water pump drives the mixture from the tank to the top side of the NFT channel. Moreover, the flowing solution creates a shallow film or stream of fluid within reach of the plant roots exposed in the planting media. The plant roots absorb the nutrition from this continuous flow of nutrient-enriched water. On the other hand, the leftover solution is drained back to the tank to be recirculated again by the pump.

Table 1. The optimum range of pH and electrical conductivity (EC) for some hydroponic crops [13].

| Plants | Electrical Conductivity \[in micro Siemens per cm (\text{mS/cm})\] | pH |
|--------|-------------------------------------------------|-----|
| Cabbage | 2.5 – 3.0                                      | 6.5 – 7.0 |
| Celery  | 1.8 – 2.4                                      | 6.5   |
| Cucumber| 1.7 – 2.0                                      | 5.0 – 5.5 |
| Eggplant| 2.5 – 3.5                                      | 6     |
| Lettuce | 1.2 – 1.8                                      | 6.0 – 7.0 |

3.2. Control framework

The challenge in the maintenance of the nutrient solution lies in the accurate control of the electrical conductivity (EC) and the pH level, particularly that pH level frequently changes due to the ion absorption of plant roots [14] and EC is easily affected by dissolved solids in the water. This usually creates complexity and fuzziness in the control process. Conventional control can be employed yet it will encounter issues in dealing with fuzziness, while advanced controls such as PIDs involve a more complex control system [15].

Fuzzy logic is one ideal method in solving this problem. While traditional control can only represent true and false value, fuzzy logic handles the concept of partially acceptable truths. This is vital in designing the control parameters for the EC and pH values.

In addition, different plants grow best at different pH and EC values that are suitable for their development. As shown in Table 1, there are various recommended ranges of electrical conductivity and pH for hydroponic plants. These ranges are used as setpoint values for the control system.

The proposed approach can be visualized as a closed-loop system, as depicted in Figure 2. The setpoint values were the input or reference for the fuzzy-based control system and were the standard from which the actual or real values read by the sensors were compared. This comparison from actual to setpoint will generate an error value. The error value is directly proportional to the runtime of treatment pumps for the nutrient control system. Hence, the higher the error value, the longer the pumping time and vice versa. The actual values were read again by the sensors installed in the NFT hydroponic tower and fed back to the fuzzy inference system. This loop continues until the error value is within the desired range.
4. Experimental setup

Shown in Figure 3 is the diagram of the proposed nutrient solution control system. The microcontroller processes the runtime of the dosing pumps for the treatment solutions as well as the main pump to recirculate the nutrient solution throughout the growing channels of the NFT hydroponic tower. The sensors were used to read and feed data into the control system. The EC and pH sensor were installed in the mixing tank. A temperature sensor, light sensor, and relative humidity (RH) sensor also monitored the conditions in the NFT tower. The data gathered by these sensors were sent into data storage.

4.1. Treatment solutions

In order to regulate the nutrient solution parameters within the setpoint ranges, four (4) treatment solutions were used, namely: water, AB mix solution, acid solution, and alkaline solution. Depending upon which parameter is in need of correction, these solutions were administered via dosing pumps into the mixing tank.

4.2. Sensors

For sensing the pH level, pH meter Pro Analog Sensor was used. It has a measuring range of 0 – 14 pH with an accuracy of ± 0.1 pH at standard temperature and pressure. In addition, it can measure the pH value of fluids within 0 – 60 °C temperature range in under 1-minute response time. On the other hand,
the electrical conductivity (EC) was measured using DFRobot Gravity Analog Electrical Conductivity Meter. It can detect EC within the range of 0 – 20 mS/cm at 0 – 60 °C temperature range with ± 5% F.S. measurement accuracy.

A DHT11 sensor was used to detect the temperature and humidity in the NFT hydroponic tower. The module can read relative humidity from 20 – 80% range at 5% accuracy. Meanwhile, the support temperature range is from 0 – 50 °C with ± 2 °C accuracy. Other supplementary sensors for light intensity, water level, and water temperature were interfaced using Analog and Digital Output Light Sensor, HC-SR04 Ultrasonic Sensor, and DS18B20 Water Temperature Sensor, respectively.

4.3. Development board

The development board used in this study is Arduino Mega 2560. Its microcontroller is ATmega2560. It has 4 serial ports and 16 pins designed for analog input. Also, it holds 54 digital I/O pins; 15 of which provide pulse width modulation (PWM) function.

The program for the fuzzy inference system was written using Arduino Integrated Development Environment (IDE). The latest version of which can be downloaded in its dedicated website [16].

5. Conclusion

A proposed automated control system for nutrient solution of a hydroponic farm was discussed in this paper. Its framework is grounded on fuzzy logic to manage the adjustment of parameters of nutrient solution in a hydroponic tower system. Dedicated sensor modules were used to detect changes in the pH level and electrical conductivity of the solution. Moreover, 4 treatment solutions were used to correct the solution parameters back to ideal should its values go out of the desired ranges. This system was implemented in an actual NFT hydroponic tower to assess its performance.

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