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Automated monitoring and controlling pH levels for hydroponics cultivation technique

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ABSTRACT

A hydroponics plant can grow healthily with sufficient nutrient, temperature, light, humidity as well as pH level that is indeed vital in ensuring the plants will absorb maximum nutrient elements required. This paper presents automated monitoring and controlling pH levels for the hydroponic cultivation technique. In this study, automated monitoring and controlling of pH levels are developed specifically for the hydroponic cultivation technique. There are three main methods that involved in the development of the system namely hardware, programming and functionality test. Firstly, users need to set the maximum and minimum pH levels as required by the plant. Then, the pH sensor will monitor the real-time pH level of the water. A syringe pump that contains a pH up solution (alkaline) and a pH down solution (acid) will drip the solutions to neutralize the water content if the water pH level is not within the stated ranges as set by the user. Results showed that the automated monitoring and controlling pH levels were successfully developed and functionality was tested and confirmed as desired. The syringe pumps responded perfectly upon changes of the water pH value based on the validation done that showed 100% accuracy of the syringe pump responds.

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1. INTRODUCTION

In the hydroponics cultivation technique, plants are cultivated without soil. There are many types of hydroponics techniques such as deep-water culture, aeroponic system, drip system, EBB and flow (food and drink) system, N.F.T (Nutrient Film Technique) and wick system [1-3]. Water replaced soil as a medium to supply nutrients to the plant through its roots. The nutrient is essential to increase the quality of plant growth [4, 5]. Temperature, pH water, light, and humidity are also necessary to optimize the plants healthy. Each type of plant needs a specific pH level of water because the plant's growth and health will be jeopardized if the pH level of water is not in the required pH ranges [6, 7].

Recall that pH is a measure of the hydrogen ion concentration of a solution. An acidic solution has a higher relative number of hydrogen ions which its substances dissociated to release hydrogen ions or react with water to form hydrogen ions while the alkaline solutions have the higher corresponding number of hydroxyl ions which its elements dissociated release hydroxyl ions or react with water to hydroxyl ions [8-10].

The standard range of pH level value is between 0 to 14 in which pH 7 reacted as a neutral value (pure water). The pH value is acidic at a range of 0 to 6.9 and alkaline at a range of pH 7.1 to 14 [11, 12]. The water pH value would become acid or alkaline if it mixed with more acidic or alkaline solutions. Here, it is indeed vital to understand that different plants required a different pH level. The differences in pH level range between these plants are too small which is between 0.5 to 1. This means that the pH level is significant and to be ensured to be in the exact range and hence need to be monitored and controlled appropriately [13]. For instance, a conventional method has used litmus paper and a pH meter to measure the pH level. The pH level must continuously be measured manually for monitoring purposes. This is because pH is essential to make sure the plant receives the maximum absorption of nutrients elements as required by the plant. The plant will lose its ability to absorb some of the nutrients elements needed if the pH is not in the proper range [14]. Thus, pH values need to be adjusted so that the plant meets the correct amount. As an example, a suitable value of pH levels for plants was different; cabbage (pH 6.6-7.0), broccoli (pH 6.0-6.5), carrot (pH 5.8-6.3), cucumber (pH 5.5-6.0) and etc [15].

Previous researchers have developed a system to monitor and control pH levels for hydroponics. As discussed in [16] that proposed hydroponic cultivation by implementing the integration of different varieties of crops. Here, the researchers' implemented monitoring and controlling pH for the hydroponics plant by releasing a nutrient to vary the pH value. But this system can be improved by replacing a method that only used nutrients to vary the pH value with acidity and alkaline solution (pH Up and pH Down solution) that can be more efficient to change a pH value. Further, B.Siregar et.al. [17] developed a remote monitoring system for hydroponics. Next as reported in [18], an automated system for hydroponic farming using various sensor networks was proposed. The researchers claimed that the system was able to assist in monitoring and controlling water pH level, EC, water temperature and humidity but upon reviewing their article, only monitoring data was discussed and not about the control part.

Since the pH value can give effect to the photosynthetic activity of the plant, the pH level in water solution should be controlled to avoid the plant will be damaged [19]. The pH of the plant root environment is an important factor affecting the uptake of many nutrients [20, 21]. Nutrient solution pH usually controlled by adding either dilute acid or base to maintain the desired value. It is known as pH up and pH down solutions [22]. Conventionally, the hydroponics cultivation technique is not equipped with an automatic system that able to maintain the pH level in water solution, and the user needs to adjust the pH level in water solution manually. The pH values need to be checked and maintained from time to time as required by the plant. In the market, pH solution that contains acid or alkaline is used to control pH values. There are two types of pH solution, which is pH up (alkaline) and pH down (acid). An accurate pH solution must be added to gain the required pH values of plants.

Hence, in this study, we deem further to develop a system for measuring and monitoring pH levels for the hydroponic cultivation technique. As mentioned earlier, the user must insert the required minimum and maximum pH levels. Next, a pH sensor will measure the pH level of water in the tank and monitor the pH level as well. If the measured pH level is below the minimum value, a syringe pump will drop alkaline solution to increase the water pH value and vice versa, the other syringe pump will drip an acid solution to reduce the water pH value. The proposed system will monitor the pH levels automatically as well as control and neutralize according to the pH level required by the plants.

2. RESEARCH METHOD

In this section, the research method is described that comprised of three sections specifically hardware development, programming development, and functionality test.

2.1. Hardware Development for Automated Monitoring and Controlling pH Value

As explained earlier, the relationship between input, micro-controller, and output of the system is illustrated as in Figure 1. There are three components as inputs to the system; the input buttons, pH sensor, and water level sensor. Input buttons are used for the user to set the range of pH levels as required by the plants. Users need to key-in the two values of pH levels the lowest and highest and these values will be stored in the internal memory of the system. For instance, the required pH level for chilli plants is 5.5-6.8 hence the user must set the lowest pH value as 5.5 and the highest pH value as 6.8.

Further, a pH sensor is placed in a water container filled with water that measured the pH value in every second. These values will be transmitted to the microcontroller. The pH sensor used in this project is an industrial electrode type with an accuracy of ±0.1pH. The container can store water up to 20 litres and this amount will be monitored by the water level sensor.

The water level sensor is placed on the upper side of the container for monitoring the maximum water level. If the water level in the container is lower than the position of the sensor, a water pump will be activated to enable water to be filled in the container from the supply pipeline.

The output section of this project consists of five components; the syringe pump mechanism for acid and alkaline solution, stirrer pump, LCD display, water pump for supplying the water from the tank to hydroponics tray and the water pump for supplying water from the pipeline to the tank. The submersible water pump is used as a stirrer mechanism to stir the water. This type of pump is used because it can be operated gently and suitable for long-lasting underwater. The water pump for supplying the water from the pipeline to the container will be activated if the water level sensor failed to detect the water level in the container. This pump will stop supplying water to the container until the water level sensor detected the set water level. This is to ensure that the container stored enough water prior to watering the plant. For instance, the water pump for supplying the water from the container to the hydroponics tray will activate for one minute. Next, this pump will activate again every two hours depending on the required amount of water by the plant. The user can monitor the information on the current values namely the pH, time and syringe pump status that is displayed on the LCD.

Further, two syringe pump mechanism is used to store and drip acid (pH down) or alkaline (pH up solution) to the main container. Stepper motor is connected with a lead screw rod that holds the syringe. The stepper motor will rotate the lead screw rod that moves in linear and will push the syringe pump. The basic concept design for the syringe pump is as shown in Figure 2. In general, each acid and alkaline solution are stored in two different syringes and a stepper motor is used to push the syringe for dripping the solutions into the water container. The stepper motor is also able to rotate in the opposite direction for the purpose of pulling the syringe back to the origin position. Since the stepper motor has a suitable torque and small step angle, the syringe pump movement can easily be controlled accurately. The amount of acid and alkaline dripped to the plant from syringe depended on the number of stepper motor rotation and the number of rotations is programmed accordingly.

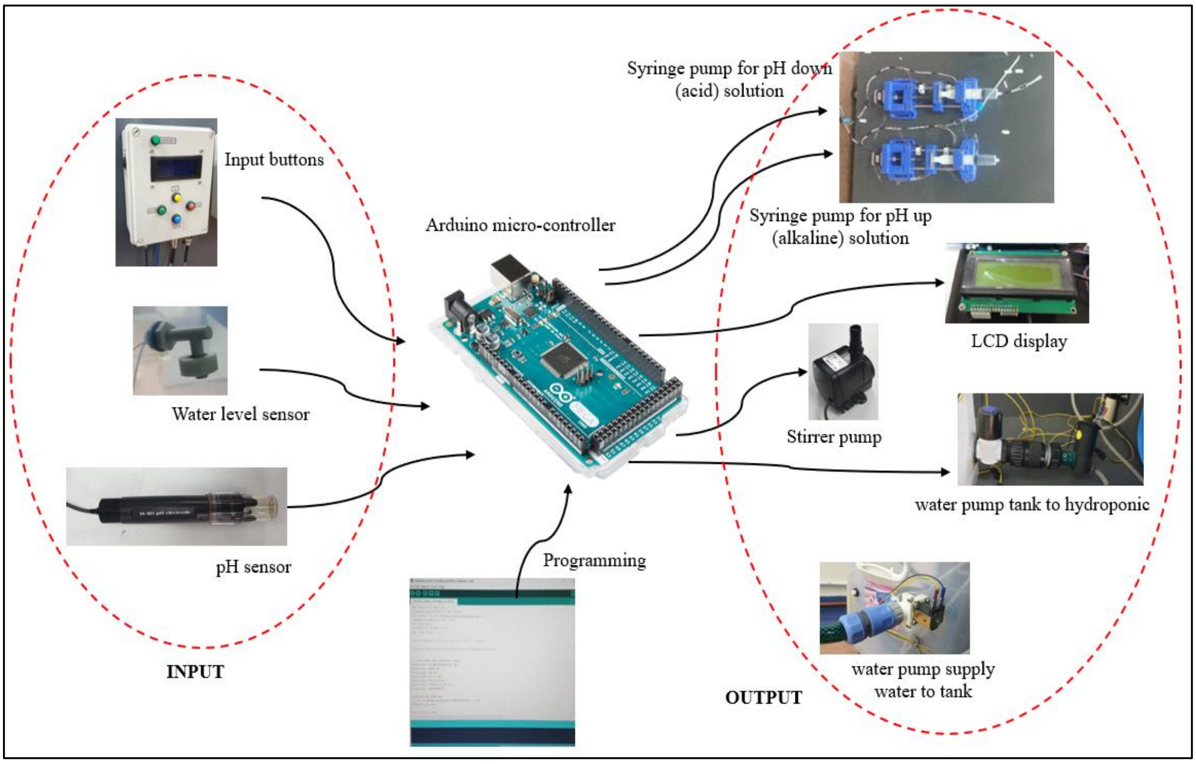


Figure 1. A diagram of automated monitoring and controlling pH value

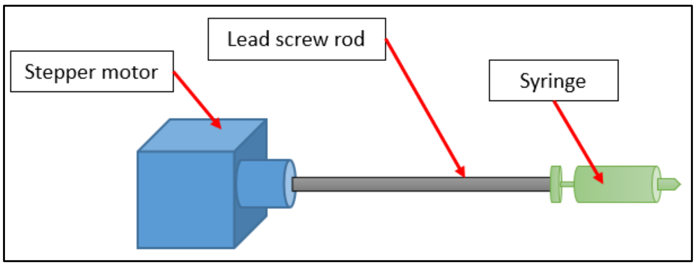


Figure 2. Basic concept design for syringe pump

In this system, the microcontroller functioned is as a 'brain'. Microcontroller received all information from the inputs and simulated it in sequence as programmed and then sent it to the output to execute specific tasks [23, 24]. This project used an Arduino Mega because it has a sufficient number for digital/analogue input/output pin, memory and compatible with most Arduino shields [25].

After the hardware components are entirely assembled, the command to execute a specific task is developed using the Arduino programming. The overall process of the system is as shown in Figure 3.

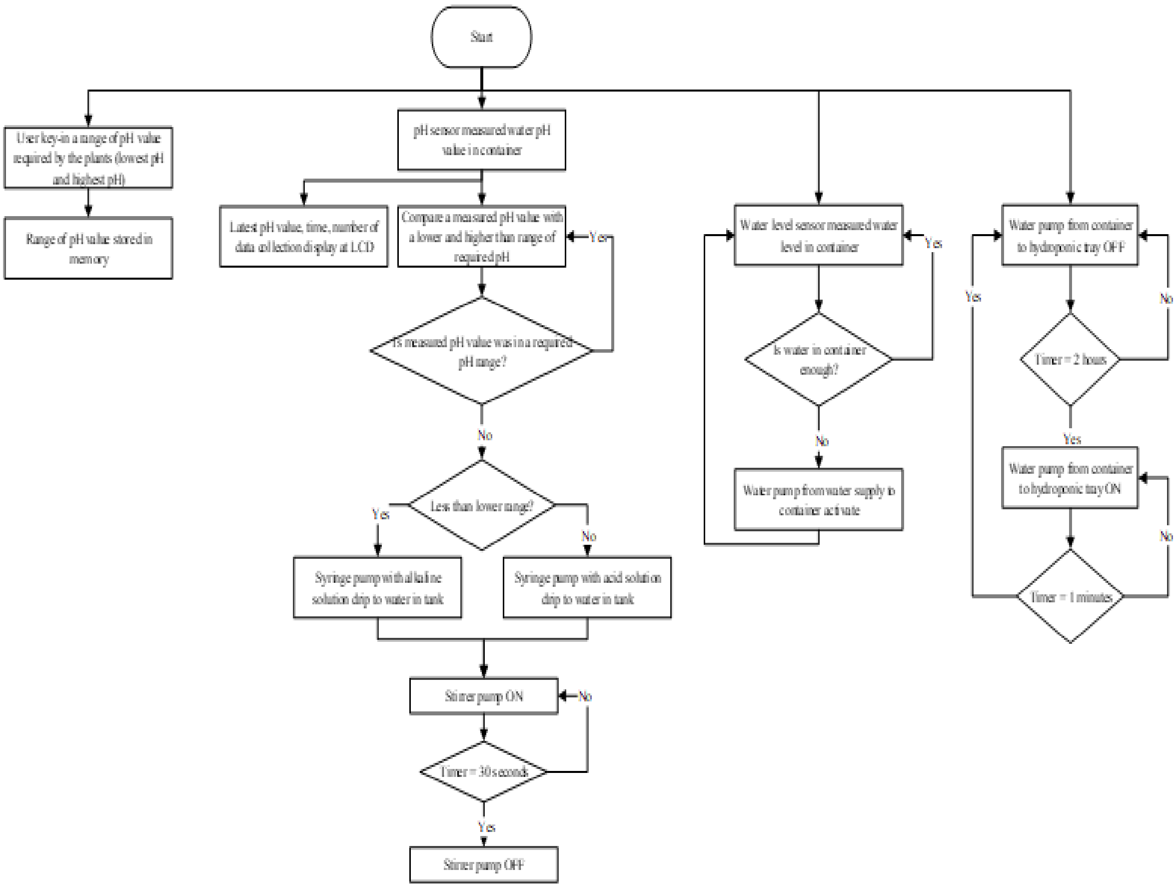


Figure 3. The overall operational process of automated monitoring and controlling pH value

The process started after a user inserted the required pH value by the plants. A user only needs to set the lowest and highest pH value through the buttons at the input panel. Then, the pH values will be stored in the Arduino memory. At the same time, a pH sensor that is located in the container filled with water will measure the pH values for every second and sent it to the microcontroller. Then, the latest measured pH value will be compared with the required pH value. If the measured pH value is less than the lowest pH value, the signal will be sent to the alkaline syringe pump to drip 1ml of alkaline to the water in the container. The water stirrer will stir the water for 30 seconds and then the water pH value will be measured again. If the measured pH value is more than the required value, the acid solution will be applied. If the measured pH value was in the needed range, therefore no action from the syringe pump. As stated earlier, a 20 litres container filled with water along with a water level sensor is used in ensuring the consistency of the water.

2.2. Programming Development for Automated Monitoring and Controlling Ph Value

The development of programming is important to execute the tasks for this system. This stage started after the completion of hardware development. Once the system activated, three parallel processes will run; read analogue pH value from pH sensor, read digital water level value and saved input data insert by the user. The signal will be sent to the water inlet valve to enable the water flow to the container if the water level sensor triggered a reduction of water. At the same time, the pH values that are inserted by the user is saved into the system memory. The pH values data is then read by the sensor that converted into array and further saved into the memory. This measured value has continued to read and saved when the measured pH value in the required range. In the programming, the lowest pH value insert by the user is used as a reference for comparison with the measured pH value. Then, decision will be made to execute the syringe pump programmed as either acid or alkaline. This project used a 1.8 degrees/step stepper motor that needs 200 steps to complete 360 degrees (one rotation). A lead screw rod that is connected to the stepper motor is also rotating together with the rotation of the stepper motor. Based on the lead screw sizes, a syringe dripped a 1ml solution upon two rotations. The rotations of stepper are set in the programming. After both or either stepper is activated, the program will enable the water stirrer to execute and the timer is used to activate the stirrer for 30 seconds.

2.3. Functionality Test

This section will detail the evaluation and validation of the developed system.

2.3.1. Syringe Pump Mechanism Development and Overall System Functionality Test

The main component in the syringe pump mechanism is the stepper motor, syringe, and lead screw rod. However, several holders are developed using the 3D printer to hold the three main components. The result of the syringe pump mechanism development will be discussed in detail in Section 3. Three fix holders will be used to hold the stepper motor and syringe. One moving holder will be attached to the syringe handle to push and pull the syringe. This moving holder can be moved by the rotation of the lead screw rod.

2.3.2. Syringe Pump Responded Based on A Changing of Water pH Value

The objective of this test to analyse the respond of the once the water pH value is not in the required range. A random acid and alkaline solution are consistently added to the water container. The additional solution will change the water pH value and both the syringe pump will response to stabilize the pH value to the desired range. For every response by the syringe pump, the acid or alkaline solution of 1ml each is dripped. The amount of 1ml for each drip is chosen because this amount is sufficient to change the water pH value. In this test, the required range of pH value is set between 5.5 to 6.5.

3. EXPERIMENTAL ANALYSIS AND RESULTS

The results of the integration for each component as one complete system are discussed in this section. Two syringe pumps are developed and tested. The syringe pump is integrated with all input and output and the functionality of the overall system is evaluated and validated. The results for the syringe pump response due to the changed pH level are also discussed here.

3.1. Syringe Pump Mechanism Development and Overall System Functionality Test

The developed syringe pump mechanism for this research is as shown in Figure 4. The permanent holder that holds the syringe can be adjusted that allows the different sizes of the syringe to be used. The syringe with a diameter of 3cm and volume of 60 ml capacity is used. After the integration between the syringe pump and programming, the movement of the stepper motor to push the syringe is tested and proven successfully function to drip the solution. The syringe pump moved forward and backward accordingly once the stepper motor activated.

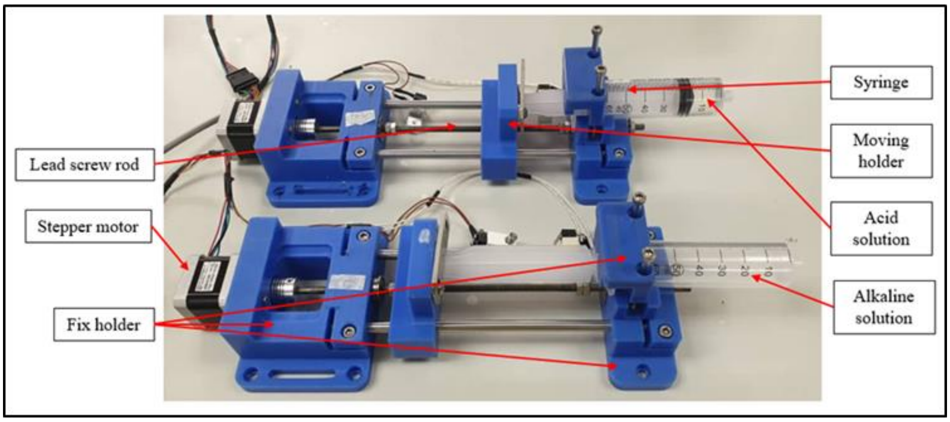
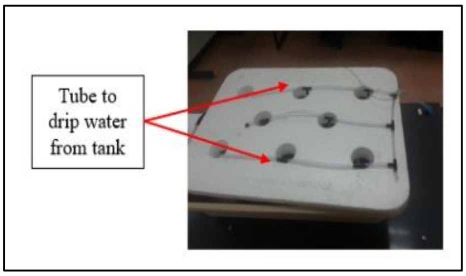
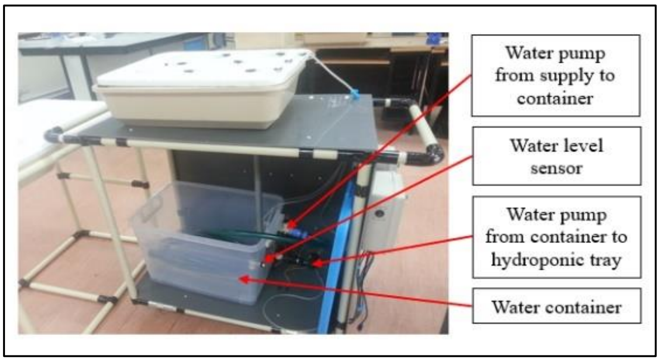


Figure 4. Syringe pump mechanism

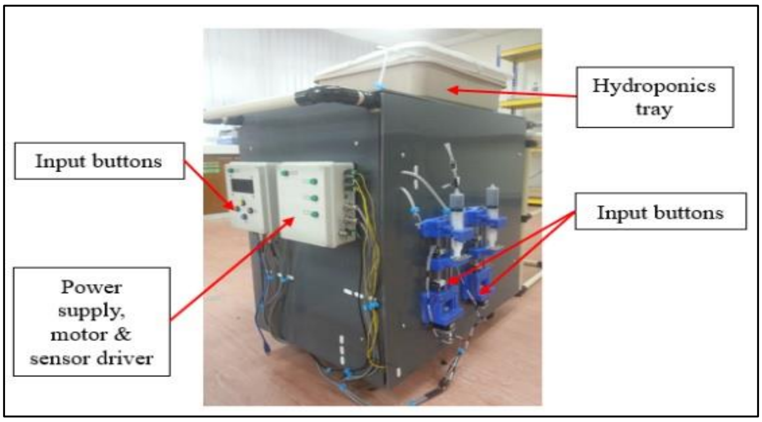
The integration of all inputs and outputs components, namely the automated monitoring and controlling pH value for hydroponic drip is as shown in Figure 5. Figure 5 (a) showed the drip process to supply water from containers to hydroponic plants. Next, Figure 5 (b) showed the container at the downside position under the hydroponic tray. The water pump is used to pump water from the container to the hydroponic tray. The other water pump is used to enable water flow from the water supply to the container. The water level sensor is placed in the container at the upper side position to limit the water volume to a maximum of 20 litres. Further, Figure 5 (c) depicted the acid and alkaline syringe pump mechanism at the vertical position. Here, tube is installed at both syringes and connected to the container to drip either acid or alkaline solution for neutralizing the pH value. The input button and LCD display are placed on the other side for the user to insert the required pH ranges for the desired plant. Users can also monitor each activity that includes the real-time pH value from the LCD display.



(a)



(b)



(c)

Figure 5. (a) Drip technique for hydroponic tray, (b) Back view of the system, (c) Front view of the system

3.2. Syringe Pump Response Based on A Changing of Water pH Value

The syringe pump responds due to the pH value of water if the pH ranges are not within the range is evaluated. Once the syringe pump responds, the data is recorded as ‘1’ (one) and ‘0’ (zero). Further, the selected sample data from the overall data collection showed the syringe pump feedback as tabulated in Table 1.

Firstly, the evaluation started with the initial pH level in the container that is more than 6.5. From the sample data in Table 1, the syringe pump was drip acid solution after the measured pH value was at 9.90. The pH value drops to 9.68 and the syringe pump dripped acid solution again. The syringe pump was stopped drip after the measured pH value at 6.48 because it was in the required pH ranges of 5.5 to 6.5. The same method was repeated, but the initial pH level was less than 5.5. From Table 1, the syringe pump was dripped alkaline solution when water pH value as at 3.71. The syringe pump continued dripped alkaline solution until water pH value rise to 5.51 and then stopped because the pH value was in the required pH ranges.

Table 1. Syringe Pump Response for pH Level Not in the Required Ranges

Water pH value	Syringe pump for acid solution	Syringe pump for alkaline solution	Water pH value	Syringe pump for acid solution	Syringe pump for alkaline solution
9.9	1	0	3.71	0	1
9.68	1	0	3.86	0	1
9.31	1	0	3.97	0	1
8.71	1	0	4.15	0	1
8.47	1	0	4.34	0	1
7.90	1	0	4.52	0	1
7.53	1	0	4.73	0	1
7.39	1	0	4.90	0	1
7.17	1	0	5.08	0	1
6.93	1	0	5.23	0	1
6.87	1	0	5.4	0	1
6.55	1	0	5.48	0	1
6.48	0	0	5.51	0	0

4. CONCLUSION

The automated monitoring and controlling pH levels for hydroponic drip techniques are successfully developed. The proposed method is able to neutralize the pH level once the present pH level is detected not within the desired range. This is achieved via the proposed system developed. The sensor used is of industrial-type pH sensor along with the Arduino microcontroller for measuring and monitoring the water pH levels. Further, the syringe pump mechanism applied for controlling the two stepper motor is capable of drip both acid and alkaline solution as required. The accuracy of the proposed system is also proven specifically 100% response through the experimental analysis and testing conducted for both the syringe pump. Future work includes other factors in optimizing the plant growth namely the electrical conductivity (EC), temperature and lighting environment.

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