Automation and Control System of EC and pH for Indoor Hydroponics System

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Abstract: Automation and control systems play a vital role in modern lifestyle which aim to provide enhanced performance when applied to a system. This paper presents a locally designed automation and control system for indoor hydroponics system. Hydroponics is soil-less agriculture technique in which crops are grown under controlled environment using nutrient solution as source of nutrition. Electrical Conductivity (EC) and pH of nutrient solution are the major factors in hydroponics system which need to be continuously controlled and monitored. In this proposed control system, the sensing network, data acquisition and the decision making is done by Arduino Mega. EC and pH values of nutrient solution are recorded by using DF-Robot EC and industrial DF-Robot pH probes respectively. Recorded EC and pH values are fed to Arduino Mega which adjusts the values, if required, through actuators. The recorded values are, simultaneously, sent to Raspberry-Pi for data logging using CAN Bus protocol. The proposed system successfully monitors electrical conductivity (EC) and pH and automatically balances these factors. It is applicable in indoor hydroponics systems and maintains reliability and sustainability. CAN Bus protocol makes the system easily scalable and cost effective. This paper focuses on design of automation and control system of electrical conductivity (EC) and pH in hydroponics system, however, the study of nutrients, nutrient solution strength and composition remains out of the scope.

Keywords: Hydroponics, Electrical Conductivity (EC), pH, Automation and Control, CAN Bus Protocol

1. INTRODUCTION

Hydroponics is a technique to grow plants without using soil. In this technique, nutrients required by plants are supplied through composition of certain organic nutrients in solution form called nutrient solution. The nutrient solution is continuously flooded through the roots of the plants and roots absorb the nutrients as required. Hydroponics technology enhances crop growth rate and yield. For maximum growth and production of crops, the nutrient concentration in nutrient solution is very important [1]. There are certain environmental factors that should be taken under consideration while using hydroponics, that are oxygenation, pH and conductivity of nutrient solution, light, temperature, photosynthesis period and air humidity [2]. The traditional technique of growing crops needs labor to provide control required to plant where everything is manually monitored [3].

EC and pH are basic parameters which need to be monitored and controlled so as to increase accuracy and ideal conditions for plant growth. Electrical Conductivity (EC) indicates the salt concentration in nutrient solution. It shows the concentration of nutrients retained in the solution as well as the nutrients absorbed by the plants. Low EC values result in low production while increase in EC value increases the yield [1]. Table 1 shows optimal EC ranges of different plants grown in hydroponics system.

Table 1: Optimal EC ranges in Hydroponic System

Vegetable	Optimal EC Range
CAULIFLOWER	0.5-2.0
LETTUCE	0.8-1.2
CUCUMBER	1.7-2.5
EGGPLANT	2.5-3.5
PEPPERS	2.0-3.0
TOMATO	2.0-5.0

Photosynthesis process of a plant can be affected by change in pH value. pH level of nutrient solution should be controlled to avoid chance of plant damage [2]. In Table 2, optimum pH ranges of different plant types are given. These values indicate the ranges of pH in which plants will yield maximum.

Table 2: Optimal pH Ranges in Hydroponics System

Vegetable	Optimal pH Range
CAULIFLOWER	6.0-6.5
LETTUCE	6.0-7.0
CUCUMBER	5.5-6.5
EGGPLANT	5.5-7.5
PEPPERS	5.5-6.5
TOMATO	5.5-6.5

This paper presents a control and automation system for hydroponics using Arduino Mega as microcontroller along with CAN Shield and Raspberry-Pi to maintain the parameters within the optimum range. Moreover, it does not limit the design to small system but the extension at large scale requires just the addition of sensing and actuating devices. Electrical conductivity and pH are discussed in the paper which are controlled and monitored.

2. ELECTRICAL CONDUCTIVITY (EC) OF NUTRIENT SOLUTION

The conductivity is the measure of ability of nutrient solution to conduct electric current. Electrical conductivity (EC) measures the concentration of nutrients in nutrient solution. It is measured in PPM (Parts per Million) or in milliSiemen (mS). At different stages of plant growth, different nutrient concentration is required accordingly. The required EC level of nutrient solution is determined through feedback of plant growth [4]. High nutrient concentration causes nutrient uptake blockage due to increased osmotic pressure, while low concentration may deteriorate plant growth and health. The low uptake rate of water is linearly correlated to electrical conductivity. Optimum range of Electrical Conductivity (EC) in a hydroponics system is between 1.5 and 2.5 mS/cm. Nutrient solution or water is added if EC values are not in optimum range. Also, in some cases nutrient solution needs to be entirely replaced [5].

Each type of crop requires its own nutrient concentration ranges or levels. For maximum growth and yield, optimum nutrient concentration is ensured. Researchers have shown that EC values need to be adjusted before adjusting pH level of nutrient solution as EC indicates nutrient strength [6].

This research proposes a design to automatically balance the EC level of nutrient solution. Using gravity based design with solenoid valve to inject nutrient solution in desired proportion which balances the EC value in required range which is optimal for the plants. The EC values are obtained using DF-Robot EC Sensor in milliSiemens (mS) and (µS). Fig. 01 illustrates the practical function of the EC balancing procedure.

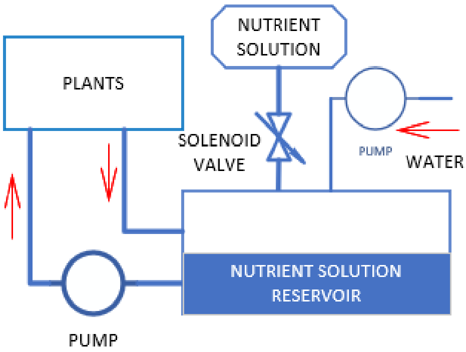

Fig 01: EC Control System

The measured values are sent to Arduino Mega acting as main microcontroller for comparison and analysis. The recorded values indicate that if EC of nutrient solution is high or low. If EC is lower than the specified range, nutrient solution in a proportion with the main tank/reservoir is injected automatically by signaling N/C solenoid valve to open for certain time. If EC is high, water is pumped into the tank to balance EC level.

The decision making is done by Arduino Mega through logic implementation. Fig. 02 shows the program logic flow diagram to balance the EC in nutrient solution tank.

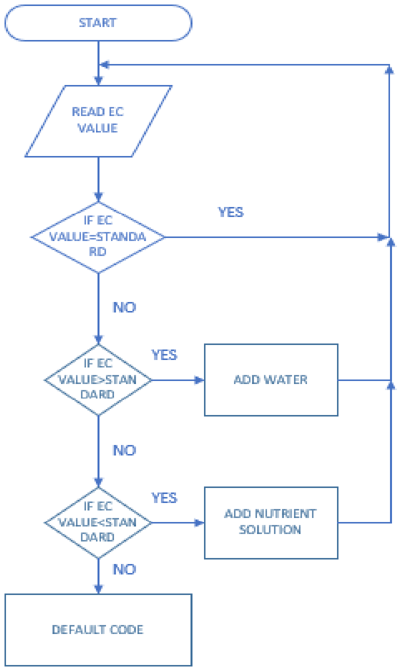

Fig 02: EC Balancing Program Logic

3. POTENTIAL OF HYDROGEN (PH) OF NUTRIENT SOLUTION

Potential of hydrogen (pH) is an important parameter for plant growth. pH is a parameter that determines the acidity or alkalinity of a solution. pH value effects the photosynthesis process in plant, pH level in water solution needs to be controlled in order to protect plant damage [2]. When pH is out of optimum range, phosphoric or nitric acid and potassium hydroxide are used to lower or raise pH respectively to make pH level in perfect range [5]. pH values may vary for different crops but the optimum pH range for most of the crops is 5.5 to 6.5 in hydroponics system [4]. Value of pH varies due to nutrient intake by plant. The ideal values of pH in hydroponic system are between 5.8 and 6.5 which need to be maintained [5]. pH levels in hydroponics change consistently with the plant growth. Change of lesser than 0.1 in pH is not considerable [7]. In hydroponics, for most of the plants 5.5 to 6.5 is the optimal pH range and this range varies with different species as many species can, also, grow well beyond or beneath this range [7].

Both low and high values may cause harm for the plant. Plant roots can be damaged instantly if exposed to low pH nutrient solution such as pH range of 2-3 for just few moments [4]. The proposed design to monitor and control pH of nutrient solution is to use solenoid valves as actuator to inject pH adjuster solution in main nutrient solution tank. Sensing the pH value is done by DF-Robot pH Probe which provides continuous pH values of the nutrient solution. Microcontroller receives the pH values and compares the data to make decision accordingly. It further signals to open the normally closed (N/C) solenoid valve to balance the pH level. The balancing of pH level is then verified by measuring the pH level of the main nutrient solution tank.

Physical installation of pH control system is illustrated in Fig. 03.

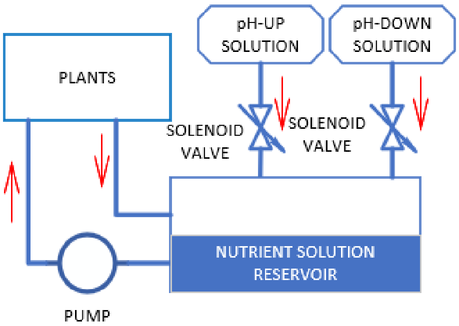

Fig 03: pH Control System

Microcontroller compares the pH values recorded by the pH sensor and consequently actuators are automatically activated through designed logic. The values are compared and analyzed. Program logic to control and balance pH of nutrient solution is shown in Fig. 04.

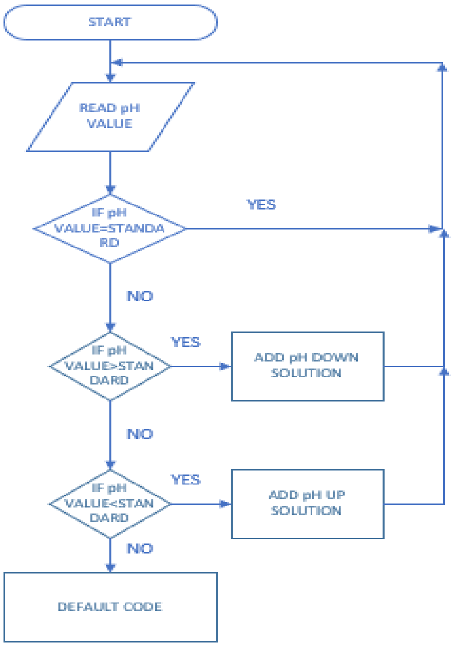

Fig 04: pH Balancing Program Logic

4. COMMUNICATION BLOCK

Communication system in the proposed control system is designed in such a way that it can easily withstand the physical expansion of the system. All the sensors are integrated with Arduino Mega board which performs the task of data acquisition, decision making and signaling the actuators. Furthermore, the data is sent to Raspberry-pi through CAN Bus protocol which acts as a data logging and monitoring unit and stores the parameters of the system. The values are logged in a file and can be accessed. In Fig. 05, communication block for EC and pH control is illustrated.

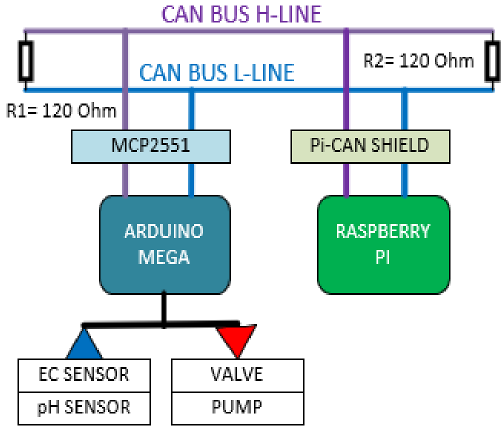

Fig 05: Communication Block of Proposed System

At large scale level there are multiple processing units acting as nodes that are interfaced with the central monitoring unit in the following topology in Fig. 06.

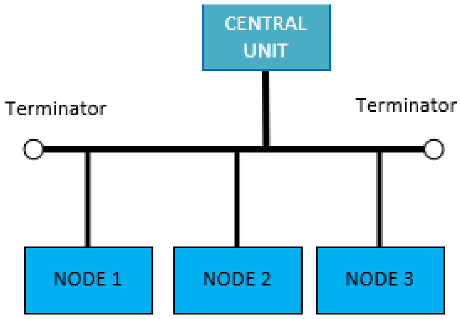

Fig 06: Topology of Proposed System Expansion

4.1 Can Bus Protocol

CAN protocol has advantages over several other communication protocol as it has, for instance, really good price/performance ratio. Moreover, it also has capability to transfer data as fast as up to 1Mb/sec and it is quite capable to be used in real time systems [8]

CAN is flexible, reliable, robust and standardized protocol with real time capabilities [9]. Major communication networks have four categories, specifically:

- IP Core Network/Internet
- Wireless LAN
- 3G/4G Cellular Network
- Controller Area Network

A fast serial bus serves as the basic support of the Controller Area Network (CAN) for the purpose to give a proficient and cost effective connection between sensors and actuators. CAN consist of twisted-pair link to communicate at speeds up to 1 Mbits/sec, with up to 40 devices. CAN was basically designed to simplify the wiring in automobiles [10]. For reception (broadcast), every CAN node has a CAN message available. Using CAN in real-time control environment makes it attractive due to the feature of allocating priority to data messages in identifier [9].

Signaling is differential which is where CAN derives its robust noise immunity and fault tolerance. Balanced differential signaling reduces noise coupling and allows for high signaling rates over twisted-pair cable. Balanced means that the current flowing in each signal line is equal but opposite in direction, resulting in a field-canceling effect that is a key to low noise emissions. The use of balanced differential receivers and twisted-pair cabling enhance the common-mode rejection and high noise immunity of a CAN bus. Fig. 07 shows the CAN Bus protocol in the proposed system.

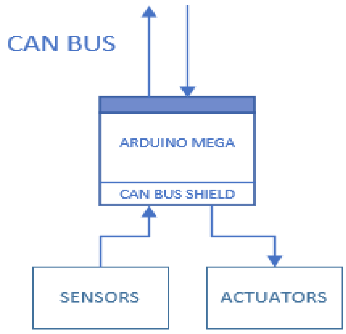

Fig 07: CAN-Bus

Raspberry-Pi performs the task of data logging and monitoring. Data logging is important part of the system which helps to create an ability to automatically collect data on 24-hour basis without using manual work. Purpose and function of Raspberry-Pi is indicated in Fig. 08.

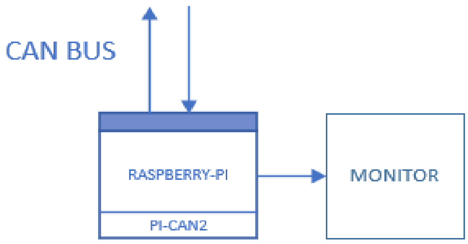

Fig 08: Raspberry-Pi in Proposed System

5. EFFECTS OF HYDROPONICS TECHNIQUE ON PLANT GROWTH

Greenhouse (controlled) Hydroponics has capacity to improve production as well as vegetable quality under sub-optimal environment [11]. In [7] comparison between crops grown in hydroponics system (controlled system) and conventional agricultural system (uncontrolled, soil system) shows notable difference among the yields under both systems. Hydroponics provides optimal conditions for maximum growth and in conventional system, conditions are dependent upon climate and fertilizers. Table 03 shows the study of [7] which indicates significant difference in crop yield of different vegetables grown in hydroponics system and conventional agricultural system.

Table 03: Crop Yield of Hydroponics vs Agricultural

Crop	**Production under Hydroponics System**	**Production in Agricultural System**
TOMATO	180 Tones	5-10 Tones
PEAS	14,000 lbs.	2,000 lbs.
CAULI-FLOWER	30,000 lbs.	10-15,000 lbs.
LETTUCE	21,000 lbs.	9,000 lbs.
CUCUMBER	28,000 lbs.	7,000 lbs.

6. RESULTS AND DISCUSSION

EC and pH, being very important factors in hydroponics need to be controlled and monitored very carefully. In this system, pH and EC control of nutrient solution was carried out while study of nutrient solution remained out of scope. As low EC values effect plant growth and high EC values are responsible for nutrient uptake blockage [5]. This system maintained aforementioned parameters within the suitable range.

Electrical Conductivity of the nutrient solution, in this study was tested and the system itself maintained the required level within a short period of time. Fig. 09 shows the graph of electrical conductivity (EC) in and the action by the designed control system to maintain the range. Highly concentrated nutrition solution was added in proportion of 2ml/liter in 25L reservoir to balance when EC is less than the suitable range.

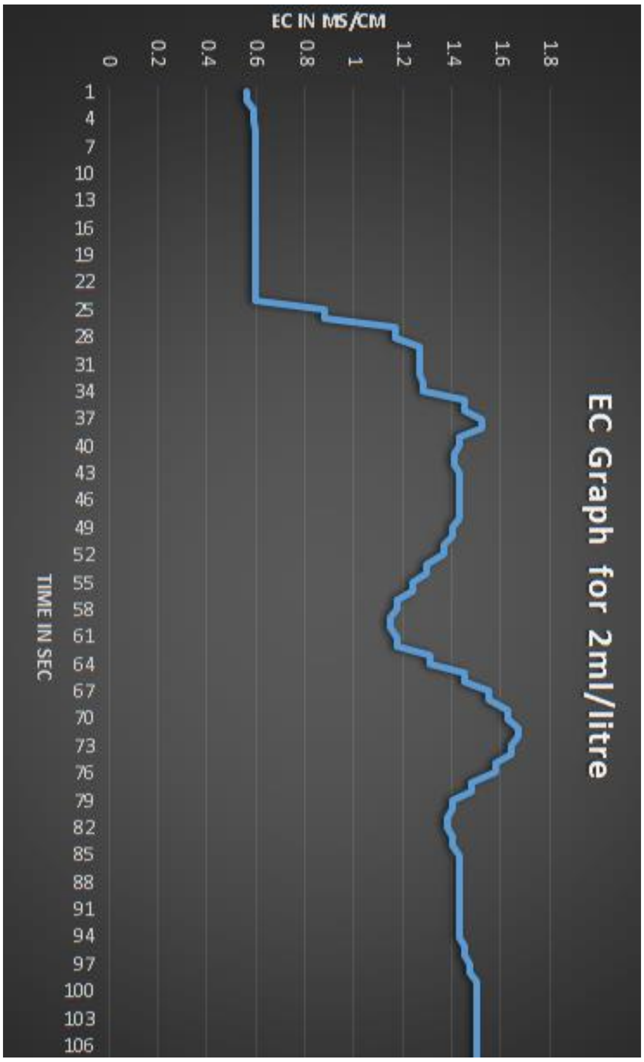

Fig 09: Graph of EC Stability in System

Balancing from 0.6 mS/cm to 1.5 mS/cm in a running system, it stabilizes EC value within 75 seconds when 2ml of highly concentrated nutrient solution is added to 1 liter of nutrient solution having low EC value. At start, when highly concentrated nutrient solution is just injected, graph shows a non-uniform disturbance in EC level and after few seconds these values are stabilized and are within range. After stabilizing values, the program logic runs to check whether system is stabilized or not. Fig. 10 shows program logic flow after adding highly concentrated solution each time. It checks that if EC values are stable or not, if not then it adds more nutrients and same logic runs for high EC values.

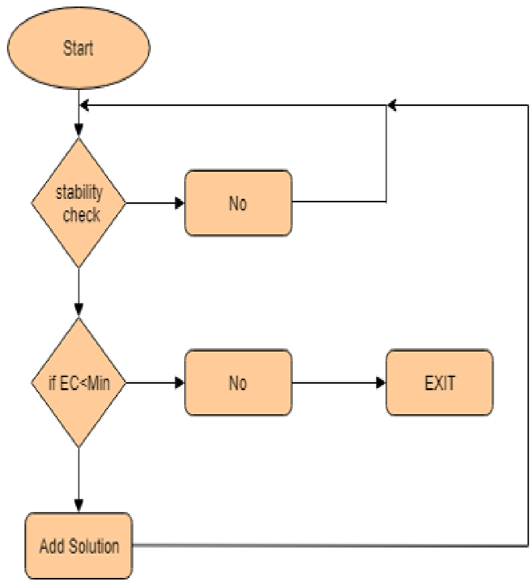

Fig. 11: Program Logic Flow of EC Stability Check

pH values of nutrient solution determine the alkalinity or acidity of nutrient solution. It can either slow down the photosynthesis process or burn the roots of plants. The proposed control system showed ability to maintain pH levels automatically. When pH level is high, a pH-Down solution is injected in reservoir to decrease pH level and pH-Up solution in vice versa case. Fig. 12 shows a graph of pH stability in the system, when pH of nutrient solution is disturbed and exceeds the required range then system automatically takes action to maintain pH level. In this case, similar as in EC, pH level of nutrient solution in reservoir shows sudden reaction to the injected pH-down solution. After 15 seconds, pH level is stabilized within range as shown in Fig. 12.

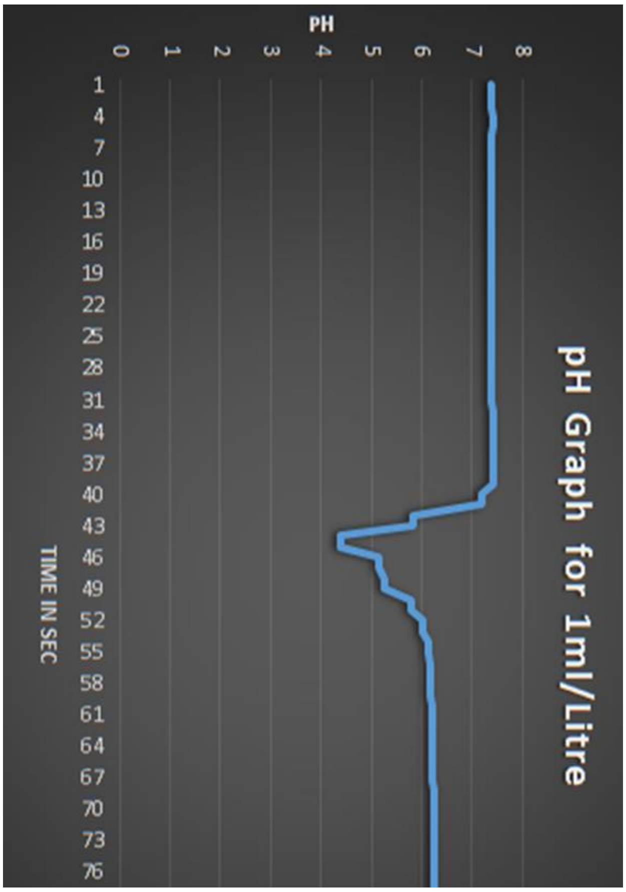

Fig 12: Graph of pH Stability in Hydroponics System

After stabilizing pH level within the range, control system checks if pH is within range or not. If yes, then system report regarding pH is alright, but in other case solution will be again injected and the system will go under same procedure again, automatically. Fig. 13 shows the program logic flow of pH stability check.

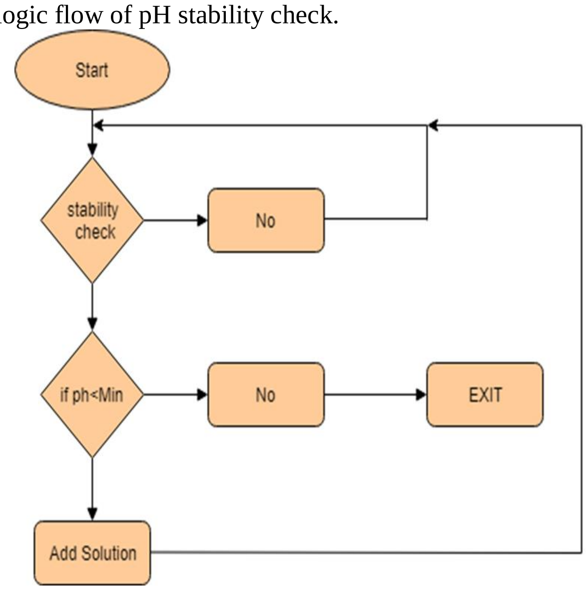

Fig 13: Program Logic Flow of pH stability Check

Results showed the sustainability and reliability of the proposed automatic control and monitoring system for Ebb & Flow hydroponics system. pH and EC balancing maintains the nutrient solution level in the main tank. Proposed system was tested at prototype level and the design shows compatibility and reliability at large scale and hence reducing the scaling cost of the system. The pH and EC sensors are reliable with less error factor.

In [5] the designed control system consists of Arduino Uno ATMEGA 328 microcontroller as heart of the system which shows inflexibility and unreliability of the system. With many controlling parameters in hydroponics system, Arduino becomes unreliable and inflexible. [12] shows a complete design of hydroponics system based on IoT (Internet of Things), using Raspberry-Pi as heart of the system. In [6], control system of pH and EC in hydroponics system is designed using fuzzy logic and results show that control system is able to maintain the EC and pH ranges automatically. However, in [6] and [12] flexibility towards large scale system remains questionable as these systems has no central processing for large scale implementation. Extension in network will prove costly. In this proposed system, CAN Bus protocol provides an advantage over aforementioned systems. Through CAN Bus protocol, there is only need to add nodes and each node can be a standalone indoor hydroponics system. So, it proves to be low cost in terms of ability of extension. Data logging is done by Raspberry-Pi for all nodes and that data is saved which might help to study behavior of plants afterwards. Stored data can be presented through developing GUI and mobile app to access data from anywhere anytime.

As the agricultural aspects and factors were out of scope and the time to stable EC and pH depends upon the respective solution's concentration and strength. The scope of the paper and focus was to develop a sustainable and reliable automated design. It also becomes a cause of energy savings, reduction in labor costs, and controlling the amount of fertilizer, which are some major advantages while adopting automated techniques.

7. CONCLUSION

The experimental research showed that the proposed solution is sustainable and reliable. The control system was able to balance the pH and EC values of the nutrient solution being fed to the roots of the plants. The proposed design can be implemented as indoor hydroponics farming and more parameters can be added just as adding nodes to the CAN-Bus. Light intensity, temperature and humidity are the factors which can be automated. Furthermore, the system is low cost at large scale implementation. The recorded values can be monitored by developing mobile application and GUI to give more obvious control and information to user.

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