

Autonomous Hydroponic Cultivation

Yashdeep P. Nimje¹, Prof. Chandrahas. C. Handa²

*¹Research Scholar, Department of mechanical engineering, Karmaveer Dadasaheb
Kannamwar College of Engineering Opposite Telephone Exchange, Nandanvan,
Nagpur Maharashtra 440009, India*

*²Professor, Department of mechanical engineering, Karmaveer Dadasaheb Kannamwar
College of Engineering Opposite Telephone Exchange, Nandanvan,
Nagpur Maharashtra 440009, India*

Abstract

Starting almost 2500 years ago, hydroponics has been an old skill. It is a highly productive method of farming that conserves both water and land. In present times, most area of the world is being utilized for agriculture. Unfortunately, the available land for agriculture is becoming unfertile. This is due to most of the land being adapted for industrial evolution. Modern techniques such as farming by soil-less technique also known as hydroponic system. A well-planned hydroponics system provides a new way of an agricultural system that minimizes human involvement. This paper aims to support research towards the marketing of hydroponic solutions by identifying and delivering a detailed study of the necessary parameters in hydroponics. This article focus on various parameter of the automated hydroponics system such as Total dissolved solids present in the water, air circulation required for the plants, temperature of the water and surroundings, Automation history the hydroponics have with it, and the cost management.

Keywords: Automation, Scarcity of water, Hydroponics system

1. INTRODUCTION

At a steady pace, the world's population is climbing while resources continue to steadily diminish. According to research, it is possible for the population to reach 9.5 billion in 2050, which is a significant increase from the current population of six billion.,(Mamta D. sardare et al, 2013). Agriculture without soil, also known as hydroponic farming, involves using mineral solutions to cultivate plants. This scientific approach addresses the growing issue of food demand surpassing available farmland. Although hydroponic farming differs from traditional agriculture, it utilizes similar techniques to create vertical gardens. By using mineral solutions instead of soil, Plants grows efficiently. (Muhammad E H Chowdhury et al,2019). The nutrients are directly absorbed from the water solution so the roots cannot be stressed to search the minerals and go deep in the soil, which results in the main growth will focus on the yield of the plants (Rakshitha M et al, 2018). At various stages of development, researchers have studied the effectiveness of hydroponics. Efficient collaboration between theoretical, numerical, and experimental analysis was implemented. An experiment was conducted using Design Expert software to analyze, compare, and evaluate the effects of the hydroponic system on traditional soil by planting two types of cucumber seeds. Results showed that the hydroponic system promotes faster and healthier



growth of plants compared to traditional soil, as indicated by the ANOVA test. (Raneem Gashgari et al, 2018). To produce a soil-less crop and a soluble synthetic fertilizer, a controlled cultivation system is utilized. Tomatoes are grown under drip irrigation with fertigation as the focus of the researcher. The yielded results indicate a per-plant tomato yield of 2.16 kg and a yield per hectare of 112 t/ha. (Dr. Umesh Barikar et al, 2013). An efficient method of delivering water to plants, particularly fruit trees, is through drip irrigation. Various experiments have been conducted by researchers in this field, resulting in the discovery that the highest fruit yield (126.7 t ha⁻¹) and fruit weight (46.77 g) are obtained through drip irrigation once a day using a base of cocopeat, perlite, and vermiculite in a ratio of 50:25:25, with the water delivery rate set to 100% of pan evaporation. (R. Parameshwarareddy, 2018). In 2019, S. M. Ghatage aimed to evaluate common crops that could operate without depending on the outside climate. Pop-up Agriculture is the farming that enables a modern system to grow outside of its traditional environments. This type of enclosed system is highly adaptable and can be attached to any space or water access point. (Gwynn-Jones et al, 2018). Increasing yields while reducing costs is the biggest advantage of pop-up agriculture. Additionally, farmers have the option to choose from various varieties and adjust their schedules to incorporate the most suitable seasons for the crop. The potential of pop-up agriculture in fulfilling the lack of arable land in Bangladesh is noteworthy. With high space research and development, it has the prospect to meet the needs of growing crops. (N.C. Barman, 2016). A closed feedback loop system is utilized in hydroponics to automate various processes by using sensors. This eliminates the need for manual intervention, and important parameters are decided by the output data. The Android application provides users with the ability to easily monitor the plants and sensor readings.

The data from the output sensor is continuously recorded and displayed on the Android phone, allowing farmers to make informed decisions for better results and maximum profit. Application made on PLC, and the output signals of sensors can be accessed by the user from anywhere with minimal delay. With the Android application, farmers can plot sensor data for several weeks and make the necessary decisions within the stipulated time. The application also allows real-time data to be downloaded from sensors placed in different locations. This enables farmers to supervise their plants effectively and efficiently. (Rakshitha M. 2018). To optimize crop production and improve yields, users can utilize a platform that stores and displays real-time information on crop growth conditions can be easily accessed, allowing for efficient monitoring and adjustment of crop cultivation strategies. (Palande V. et al, 2017). The farm sector is benefiting from the capabilities of wireless sensors and IoT, as highlighted by the work of (Ayaz, M. et.al. 2019). The main part of the work framed AI system which supported the cultivation of medical marijuana, which required attention and tuning of 138 variables. The idea of Ontology was thoroughly examined by me, with a focus on its application in control systems. The ontology of this system has been designed to cater to the needs of control systems in the future. With its adaptability to other systems based on the environment, sensors, and actuators, this control system has proven to be highly versatile (Phutthisathian, A. et. Al. 2011).

2. Limiting Factor for water

In hydroponic systems, various parameters are utilized, and each of them employs different methods of measurement. For instance, pH sensing systems may vary from pH test strips, independent sensors with accompanying LCD screens, to analog sensors that transmit data wirelessly or through wires to control panels.



The design of a dependable, secure, and profitable hydroponic system necessitates the use of automated sensing methods. Researchers have employed (Wel et al. 2019).

2.1 Water

To achieve successful soil-less agriculture, the quality of water plays a crucial role. Referred to as the ‘carrier’ in hydroponic systems, water dissolves nutrients and transports them to plant roots. The quality of water can be easily resolved if properly identified. It is imperative to maintain pH levels, the temperature of the water, and the percentage of dissolved oxygen, and dissolved minerals needed for the plant's survival. (“Lab Water Purification Systems”, 2021).

2.1.1 pH

Hydroponic schemes heavily rely on pH levels as a significant factor that affects plant growth. pH, which stands for the control of hydrogen and pertains to the concentration of hydrogen ions in a solution, is crucial as it affects nutrient absorption. Extremely high or low pH levels can make it difficult for plants to absorb essential nutrients, which ultimately endangers their health. While some plants thrive in acidic water, others prefer an alkaline growing media. In most cases, the superlative pH range for crops fully fledged in soil-less farming is between 5.5 to 6. Fruits and vegetables cultivate best in this range. Fruits like blueberries need a sour solution with a pH value range between 4.0 to 5.0. (Judith, 2019). Similarly in the case of Rhizomes plants like ginger plants the pH value between 6.0 to 8.0. (Fitria Hidayanti et al.,2020). To maintain a healthy growing environment for epiphytes plants the pH level of the fluid needs to hold on within the range of 5.5 to 8.0. (Mamta D. sardare et al., 2013).

2.1.2 Temperature

In the hydroponic system, the role played by water temperature is crucial. For plant life, the water temperature should be maintained between 18 to 26 °C. This temperature maintains the root of the plant showing the best results for dissolved nutrients observed by the plants. It is also recommended by researchers that the nutrient solution and water temperature should be the same to prevent sudden shock to plants' roots, which can cause their death. In cold seasons, aquarium heaters are utilized to maintain the proper temperature of the water, while an aquarium chiller is used in the summer season. (“London Grow” Jan 31, 2020).).

2.1.3 Dissolved oxygen

Oxygenated water in which root are submerged is an essential for the growth of the plant 5mg/L is an Dissolve oxygen require in the water use for soil-less farming else plant will not able to survive. But due to environmental hurdle it is found that temperature of surrounding increases then correspondingly dissolve oxygen in the water decreases. To overcome this hurdle components such as air-pumps, air-stone and oxygen diffuser is used to increase DO levels. (DO sensor hanna instruments, 2015).

2.1.4 Electro-conductivity

Dissolved salt ions in a mixture have varying specific conductivity. The ions used to determine pH values, on the other hand, have a hundred times more specific electrical conductivities. Researchers often attempt to replicate the same EC and solution concentrations for several weeks, but they struggle to recreate the required pH and EC levels for the plant (Hardeep Singh, 2016) If the value of pH remains intact, the method of mixing



nutrients in the hydroponic solution is suggested. The previous nutrient solution can be regenerated with the help of the EC sensor probe. If the EC value falls considerably to 70% of the original value, then the solution becomes unsuitable for the plant and should be replaced with a new one. It has been found that the ideal EC for cultivating ginger hydroponically is 2.5 dS/m. ("How to grow ginger hydroponically (Complete beginner guide)", 2020).

2.1.5 Total Dissolve Solids

Organic and inorganic compounds, as well as minerals, can be dissolved by water, which is why it is often referred to as the universal solvent. Total Dissolve Solids (TDS) is the unit used to determine the quantity of dissolve minerals in water. Calcium, magnesium, and chloride ions are in the middle of the many dissolved minerals and salts institute in all bodies of water. ("Hydroponics vs. Aquaponics – A Complete, and Honest Comparison", 2022). Below 1000ppm are the requirement of the hydroponics solution.(D. Adidrana and N. Surantha, 2019).

3. Circulation of Air

To avoid the leaf burn on the tip (Jun Gu Lee et al., 2013) did the study of the air circulation required for close environment soil-less farming. He concluded that the horizontal flow is more beneficial than the vertical flow. Low velocity of the air, with less intensity of the white LED lights gives the proper growth and also consider as the most feasible for the plants survival. To demonstrate this the researcher also build 3-D model in Computational fluid dynamics using software called as Ansys (Ying Zhang et al., 2016)

4. Automation in soil-less farming

Parameters can be measured differently from system to system. Automation plays a major role in hydroponics by delivering nutrients, and regulating parameter for better health and life of the plant. The relevant data is processed by a microcontroller, such as Arduino Nano, which then generates output signals. Motor pump sets, sprinklers, conveyor belts, and solenoid valves, among other devices, follow these signals to supply nutrients. After certain time intervals with the help of micro-controller the simulation starts automatically. (Soniya Joshi et al., 2018). Aeroponics is an alternative method to traditional farming in the soil-less cultivation domain. Rather than using soil, the system utilizes an atomization nozzle to provide the basic needs of the plant in the moisture form. The system's essential parameters are closely monitored and controlled at regular intervals to ensure plant health. (Imran Ali Lakhia et al, 2018). An automated software has been developed to monitor the electrical conductivity and pH values continuously for 24 hours. The parameter to be control the flow of nutrients in the water can be controlled using solenoid valves. The micro-controller serves as the processing unit, extracting valuable information from the sensor. If the solution fluctuates outside the specified range, the micro-controller corrects the pH, EC, temperature, and other values. The author observed an inverse relationship between temperature and pH while establishing their correlation. In a hydroponic system, the water becomes more acidic, indicated by a decrease in pH, as the water temperature rises. A temperature increase of 100°C results in a pH decrease of 0.06. (Diego S. Domingues et al., 2012) An efficient tool has been designed to maintain pH values within the range of 6.5 to 7.5. The tool is embedded with actuators and a control system which allow for optimal functioning. (Fitria Hidayanti et al, 2020). By utilizing IoT devices, the observation of PH levels and air quality



index becomes possible. If the automated hydroponic system fails to maintain its standard condition, a warning alarm is triggered. In addition to this, an application has been developed for the android operating system that enables researchers to track data from IoT devices. (B S Shubhashree et al, 2020). Utilizing an ultrasonic sensor HC-SR04, the height of nutrient solution can be determined, while a temperature sensor LM35 detects the current temperature. The collected data is wirelessly transmitted to an Arduino Uno microcontroller by means of a wireless transmission and display the same on screen attach to controller. The flow of minerals is regulated through use of the if-else command by the Arduino Uno microcontroller. With the ability to monitor the hydroponic system's data through an Android smartphone, users are granted a comprehensive view of the system's current state. (P Sihombing et al., 2017). An automatic nutrient delivery system is incorporated into the hydroponic model, allowing for a consistent supply of minerals to be provided to the tomato plants. The plants receive a weekly infusion of a water and nutrient mixture that is recycled through a water pump. (Vijendra Sahare et al., 2015). After conducting experiments on selected species comes under the Stonecrop family. The effectiveness and productivity of the artificial lights were tested by subjecting the plants to 16 hours of exposure. The results indicated that this duration was optimal for achieving the desired outcomes. (Sang Yong et al., 2016). In real-time, data importation through an AVR microcontroller board is a primary focus of the work being conducted. The researcher utilizes NI Labview look after the data, and to computerize all of the processes in the system. For various IoT applications, data can be transferred with the assistance of a network. (S. Adhau et al., 2017). Titan Smarphonics, a leading firm in the field of hydroponics, has developed a range of IoT-based solutions for distance monitoring and operating hydroponic systems. Their hardware comprises a variety of sensors and actuators that facilitate the processing of pH, humidity, temperature, and other relevant parameters. Through their cutting-edge applications, these solutions can easily be run and operated on smartphones, providing users with a seamless experience. Furthermore, Titan Smarphonics utilizes Arduinos and Raspberry Pi to develop fully automated hydroponics software, taking the industry to new heights of efficiency and productivity. (Dr. Asawari Dudwadkar et al., 2020)

Through the complete monitoring, the optimal output is continually sought after. The researcher implemented a pest detection system to increase the flexibility of the hydroponic system and connected it with a Wi-Fi module for IoT applications. (Shreya Tembe et al., 2018). An IoT-based system has been developed to transmit data, Various Apps on the mobile devices utilizing this information to inform end-users. The aim is to enhance the accessibility and portability of the information. (Dr.D.Saraswathi et al., 2018)All parameters are displayed on the software platform, an IoT-based system. To control diverse hydroponic system parameters were facilitated by the web interface under the researcher's guidance. A provision was made to send SMS messages to the user's mobile in case of any interruptions in the operation of the automation of hydroponics system. (Muhammad E H Chowdhury et al., 2020). ANOVA, coupled with regression models, was employed for the experimental analysis of phosphorous and potassium concentrations in the shoot. Experiments were conducted with five distinct electrical conductive solutions (0.8dS/m, 1.3dS/m, 1.8dS/m, 2.3dS/m, and 2.8dS/m). The results revealed a quadratic relationship for phosphorus and a linear positive relationship for potassium concentration in the shoot (João Pedro Silvestre et al, 2016). Explicit work on fault detection in the hydroponic system was carried out by a researcher using neural networks, a fuzzy logic control system by operating system for nutrient



injection into the solution. The researcher combines robotic culture with automated soil-less farming to achieve maximum accuracy in the production of yield. (Alejandro Isabel et al., 2019).

Finally simplifying the operating procedure (Miss. Felicia Bernadine Vaz et al. 2016) have mentioned five steps 1) Initiate and set the sensors to optimal values. 2) Examine parameters such as soil moisture, humidity, temperature, pH, and EC. If the specified requirements are met, proceed with the irrigation process. 3) Verify the water level in the tank; initiate irrigation if sufficient, otherwise activate the motor to refill the water tank. 4) Following the completion of the irrigation process, transition to the fertigation tank, combining fertilizer with irrigation water. The fertigation period is pre-programmed for a defined time interval. 5) Present the soil moisture, temperature, pH values, EC values, and humidity values on the LCD.

The system autonomously adjusts to climatic changes, maintains continuous self-rotation, and saves energy. Additionally, it possesses the capability to self-optimize by gaining information from data from different sources. The prediction of data contributes to informed decision-making (Monteiro, J. et al. 2018). Forecasting changes in the root of lettuce, specifically the pH and electrical conductivity (EC) values, is achieved through the utilization of a neural network model algorithm. The algorithm is structured with nine parameters as input (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). Same data points were taken to trained and make set of data points by using the quasi-Newton back-propagation algorithm. The forecast involves predicting the pH and EC values at every 20-minute time step, with intervals of 0.01 pH units and 5 S/cm of EC (K. P. Ferentinos et. al. 2002). The future work in automating hydroponic systems explores the complexities of assessing acidity levels in pH solutions, viscosity, and oxygen levels. The prospective scope involves data collection from the hydroponic environment using sensors, with subsequent processing by AI robots to guide their actions. Researchers also identify potential in amalgamating data from hydroponic systems and AI robots to create standardized systems compatible with other operating systems (Alejandro Isabel et al., 2019). The University of Sakai, Japan introduce the future scope to determine every ion of the minerals. From the obtain data every ion nutrient solution can be controlled automatically by a controlling system (Chapter 1.1 - Theory and Technology to Control the Nutrient Solution of Hydroponics, 2019).

5. Growing of plants in soil-less farming

Less water is utilized in hydroponic systems when compared to traditional farming practices. Vegetables such as tomatoes, peppers, and lettuce hold significant commercial value in the Arabian (Gulf countries) market. The life cycle and growth pattern of plants cultivated through hydroponic systems mirror those of traditional farming. (Sabrina Naz et al., 2021). The success of horticultural crops like strawberries, lettuce, tomatoes, and carnations cultivated through hydroponic systems is elucidated. This system necessitates nominal inorganic elements, complemented by water, oxygen, and sunlight, to make sure the plants' health and energy (Shailesh Solanki et al., 2017). An test was conducted on the nutrient content of vegetables cultivated from side to side hydroponic systems, enlightening a 50% higher attendance of vitamins A, B, C, and E compared to vegetables grown using customary farming methods. The hydroponic system remains unaffected by external environmental variations, and the absence of soil in farming contributes to a reduction in pesticide consumption. (Satya Prakash et al., 2020). Three crops namely radish, beetroot, and Turnip were grown in September 2019, with after 15 days



old sampling were transplanted into the hydroponic system., on the other hand, Colocasia was cultivated within a hydroponics system. The outcomes indicated successful growth of Colocasia under the NFT system, with a 90-day duration for cormlet production. In contrast, Radish, Turnip, and Beetroot required 48-70 days for harvesting. (Agarwal A. et al., 2021). The examination of the impact of various seeds and planting systems involved a 30-day experiment with two distinct types of seeds. The observations were scrutinized using the Design-Expert software, and a variance test (ANOVA) was conducted. In investigating it come to know the growing of the plant is unaffected irrespective of seeds, emphasizing the crucial role played by the planting system. Notably, the hydroponic system exhibited superior plant development compared to traditional farming practices (Raneem Gashgari et al., 2018). New business models, safeguards against security breaches, privacy protection, and data governance were recommended. Additionally, obstacles and limitations in developing a large-scale IoT-based system were identified. (Brewster C. et. Al. 2017).

6. Reward

Hydroponics becomes a preferred choice when conventional or fertile land is unavailable for farming. Farming can be conducted in a more controlled manner, and with immediate data analysis, decisions are made more effectively. Following the initial startup costs, hydroponic farming is approximately 20 percent more cost-effective to operate and maintain than conventional farming. It allows for the planting of more trees in a smaller space, and the controlled growth of roots facilitates efficient nutrient absorption, resulting in shorter root lengths. Maintenance time is significantly reduced in hydroponic indoor farming, and weed growth is minimized. Even in urban areas, hydroponic plants can be cultivated on rooftops, window shelves, corridors, garages, bedrooms, and living rooms. Hydroponic plants can achieve up to 50 percent faster growth, addressing the future population's increasing demand.

7. Disadvantages

The primary disadvantage of hydroponics lies in the requirement for expertise in technical knowledge and a thorough understanding of the principles involved. On a commercial scale, the initial investment is relatively high. Vigilance is necessary in formulating, analyzing data, nutrient mixing procedures, and monitoring plant health.

8. Application

The hydroponics system finds extensive applications in house gardening, indoor gardening, and the cultivation of medicinal plants. The ability to alter nutrient content and modify plant properties eliminates the need for additional spending on pest control. Hydroponic systems can be employed both vertically and horizontally, enabling the cultivation of more plants in limited space. This system is particularly well-suited for countries heavily reliant on imports for basic needs, especially in arid regions.



9. Results

The proposed work demonstrates the efficient automation of hydroponic farming using minimal resources and cost. This system can be easily installed under challenging environmental conditions. Experimental results confirm the performance of the system, showcasing its great stability and control actions.

10. Conclusions

This paper sought to bridge the gap between engineering and agriculture, familiarizing agriculturalists with automation, neural networks, IoT, and SMART applications in hydroponic systems. It provided in-depth knowledge of nutrients and biological activities in hydroponics for Mechanical, Electrical, and Electronics engineers. The paper presented a comprehensive overview of work in the field of hydroponics, aiming to attract attention and encourage contributions from researchers. The fully automated hydroponic system was entirely self-controlled, requiring human involvement only to initiate monitoring parameters. The cultivation with the automated hydroponics system proved to be productive as parameters were effectively controlled. Hydroponics, as proposed, holds good prospects for future sustainable development, meeting the demands of the ever-increasing population.

11. Declaration of competing interest

The authors assert that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

12. References

- [1] "Mamta D. Sardare, Shraddha V. Admane, 2013, "A review on plant without soil– Hydroponics", IJRET: International Journal of Research in Engineering and Technology ISSN: 2319-1163, Volume: 02 Issue: 03 DOI: 10.15623/ijret.2013.0203013
- [2] Muhammad E H Chowdhury , Amith Khandakar, Saba Ahmed , Fatima Al-Khuzaei , Jalaa Hamdalla , Fahmida Haque , Mamun Bin Ibne Reaz , Ahmed Al Shafei , Nasser Al-Emadi, 2020, Design, Construction and Testing of IoT Based Automated Indoor Vertical Hydroponics Farming Test-Bed in Qatar Sensors Published by MDPI, Online ISSN: 1424-8220 20(19):5637, DOI: 10.3390/s20195637
- [3] Rakshitha M. , Shwetha. H. L , Roopa , Tejashwini. R , Anitha S Prasad , 2018, "Automation of Hydroponics System using Android Application and Ubidots Platform "INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) NCESC – 2018 (Volume 6 – Issue 13)
- [4] Raneem Gashgari, Khawlah Alharbi, Khadija Mughrbil, Ajwan Jan, Abeer Glolam, 2018, Comparison between Growing Plants in Hydroponic System and Soil Based System Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering (MCM'18) Madrid, Spain-ICMIE 131, DOI: 10.11159/icmie18.131.
- [5] Dr. Umesh Barihar S. Santhana Bosu K.P. Rema A.R. Murumkar, 2013, "Drip irrigation with fertigation in soil-less media for tomato under controlled cultivation", Journal of Applied Horticulture, 15(3):195-197, DOI: 10.37855/jah.2013.v15i03.38



- [6] R. Parameshwarareddy S.S. Angadi Raveendra H Patil Raveendra H Patil M.S. Biradar, 2018 "Influence of Drip Irrigation Levels and Soilless Media on the Growth, Productivity and Economics of Greenhouse Grown Tomato" International Journal of Current Microbiology and Applied Sciences 7(04):302-308 DOI: 10.20546/ijcmas.2018.704.034
- [7] N.C. Barman, M.M. Hasan, M.R. Islam and N.A. Banu, 2016 "A review on present status and future prospective of hydroponics technique", Plant Environment Development , 5(2):1-7 Print ISSN 1994-1501 Online ISSN 2311-3529
- [8] Gwynn-Jones, Dylan; Dunne, Hannah; Donisson, Iain; Robson, Paul; Sanfratello, Giovanni Marco; Schlarb-Ridley, Beatrix; Hughes, Kevin ; Convey, Peter, 2018, "Can the optimisation of pop-up agriculture in remote communities help feed the world?" Global Food Security, 18. 35-43 DOI:10.1016/j.gfs.2018.07.003
- [9] Dr.D.Saraswathi , P.Manibharathy , R.Gokulnath , E.Sureshkumar , K.Karthikeyan , 2018 " Automation of Hydroponics Green House Farming using IOT" in: 2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN) DOI: 10.1109/ICSCAN.2018.8541251
- [10] Fitria Hidayanti, Fitri Rahmah, Ahmad Sahro , 2020, " Mockup as Internet of Things Application for Hydroponics Plant Monitoring System", Engineering Physics Department, Universitas Nasional, Jakarta, Indonesia ,International Journal of Advanced Science and Technology ,Vol. 29, No. 5, (2020), pp. 5157 - 5164 <http://sersec.org/journals/index.php/IJAST/article/view/14025>
- [11] Domingues D.S., Takahashi H.W., Camara C.A.P. and Nixdorf S.L., 2012, "Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production." Computers and Electronics in Agriculture 84: 53-61. DOI: 10.1016/j.compag.2012.02.006
- [12] Lab Water Purification Systems 2021 [www document] url <https://www.merckmillipore.com/IN/en/water-purification> (accessed on 22 may 2022)
- [13] Judith August 30, 2019 Hydroponics, pH URL [www document] <https://blog.jencoi.com/ph-in-hydroponics-how-to-maintain-the-ph-levels-of-hydroponic-systems>. (accessed on 25 may 2022)
- [14] London Grow Jan 31, 2020 URL [www document] <https://www.londongrow.com/blogs/grow-tips/understanding-optimum-temperature-and-humidity-for-plants>. (accessed on 20 may 2022)
- [15] HANNA INSTRUMENTS, May 2015, DO sensor URL [www] <https://blog.hannainst.com/measuring-dissolved-oxygen-of-hydroponic-nutrient-solutions>. (accessed 21 april 2022)
- [16] Hardeep Singh, Dunn Bruce, 2016, "Electrical Conductivity and pH Guide for Hydroponics", Oklahoma Cooperative Extension Fact Sheets are HLA-6722 also available on website at: <http://osufacts.okstate.edu>
- [17] How To Grow Hydroponic Ginger (Complete Beginners Guide), November 26, 2020 by Soak And Soil, URL [www document] <https://soakandsoil.com/how-to-grow-hydroponic-ginger/> (accessed on 1 may 2022)
- [18] Hydroponics vs. Aquaponics – A Complete, and Honest Comparison by Trees.com Staff - last update on February 10, 2022 URL [www document] <https://www.trees.com/gardening-and-landscaping/hydroponics-vs-aquaponics> (accessed on 23 april 2022)
- [19] D. Adidrana and N. Surantha, "Hydroponic Nutrient Control System based on Internet of Things and K-Nearest Neighbors," 2019 International Conference on Computer, Control, Informatics and its Applications (IC3INA), 2019, pp. 166-171, doi: 10.1109/IC3INA48034.2019.8949585.



- [20] Jun Gu Lee, Chang Sun Choi, Yoon Ah Jang, Suk Woo Jang, Sang Gyu Lee, and Yeong Cheol Um, 2013, "Effects of air temperature and air flow rate control on the tipburn occurrence of leaf lettuce in a closed-type plant factory system" Horticulture, Environment and Biotechnology 54(4):303-310 DOI: 10.1007/s13580-013-0031-0
- [21] Ying Zhang Murat Kacira Murat Kacira Lingling An Lingling An, 2016, "A CFD study on improving air flow uniformity in indoor plant factory system", Biosystems Engineering 147:193-205 DOI: 10.1016/j.biosystemseng.2016.04.012
- [22] Soniya Joshi, Vrushali Gujar, 2018, "Automation in Hydroponic System using Control Circuit", International Journal of Innovative Research in Science, Engineering and Technology ISSN(Online): 2319-8753 ISSN (Print): 2347-6710 Vol. 7, Issue 10, 10891-10897 DOI:10.15680/IJIRSET.2018.0710054.
- [23] Imran Ali Lakhari, Gao Jianmin, Tabinda Naz Syed, Farman Ali Chandio, Noman Ali Buttar, Waqar Ahmed Qureshi, 2018, "Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques: A Review of the Aeroponic System", Journal of Sensors, vol. 2018, Article ID 8672769, 18 pages, DOI: 10.1155/2018/8672769
- [24] B S Shubhashree, Divya D, Harsha Mohan Hiremath, Jyothi T U, Yashonidhi Yajaman, 2020, "Design of Hydroponics System for Remote Automation", INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY, ISSN: 2278-0181 NCCDS - 2020 (VOLUME 8 - ISSUE 13)
- [25] P Sihombing, N A Karina, J T Tarigan and M I Syarif, 2017, "Automated hydroponics nutrition plants systems using arduino uno microcontroller based on android", Journal of Physics: Conference Series, Volume 978 012014, 2nd International Conference on Computing and Applied Informatics 2017 28–30 November 2017, Medan, Indonesia doi:10.1088/1742-6596/978/1/012014
- [26] Vijendra Sahare, Preet Jain, 2015, "Automated Hydroponic System using Psoc4 Prototyping Kit to Deliver Nutrients Solution Directly to Roots of Plants on Time Basis", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. ISSN (Print) : 2320 – 3765 ISSN (Online): 2278 – 8875 4:8765-8770 DOI:10.15662/IJAREEIE.2015.0411032
- [27] Sang Yong Nam Hyun Seok Lee Soon-Yil Soh Raisa Aone Marciales Cabahug Raisa Aone Marciales Cabahug, 2016, "Effects of Supplementary Lighting Intensity and Duration on Hydroponically Grown Crassulaceae Species", Flower Research Journal 24(1):1-9, DOI: 10.11623/frj.2016.24.1.1
- [28] Dr. Asawari Dudwadkar, Tarit Das, Sakshi Suryawanshi, Tejas Kothawade, Rajeshwari Dolas, 2020, "Automated Hydroponics with Remote Monitoring and Control Using IoT", INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT), ISSN (Online) : 2278-0181 Volume 09, Issue 06, DOI: 10.17577/IJERTV9IS060677
- [29] Shreya Tembe, Sahar Khan, Rujuta Acharekar, 2018, "IoT based Automated Hydroponics System", International Journal of Scientific & Engineering Research, Volume 9, issue 2 ISSN 2229-5518
- [30] João Pedro Silvestre, Renan Ribeiro Barzan, 2016, "ELECTRICAL CONDUCTIVITY OF NUTRIENT SOLUTION ON CRISP HEAD LETTUCE FERTIGATED AT SAND" International Journal of Current Research, ISSN: 0975-833X Vol8(Iss10):p:40307-40309



- [31] Alejandro Isabel Luna Maldonado, Julia Mariana Márquez Reyes, Héctor Flores Breceda, Humberto Rodríguez Fuentes, Juan Antonio Vidales Contreras and Urbano Luna Maldonado, 2019, "Automation and Robotics Used in Hydroponic System", journal of Urban Horticulture, DOI: 10.5772/intechopen.90438
- [32] Chapter 1.1 - Theory and Technology to Control the Nutrient Solution of Hydroponics, Plant Factory Using Artificial Light Adapting to Environmental Disruption and Clues to Agricultural Innovation 2019, Pages 5-14 DOI: 10.1016/B978-0-12-813973-8.00001-4