Semiconductor Optoelectronics, *Vol. 43 No. 1 (2024), 206-238*
https://bdtgd.cn/

Semiconductor Optoelectronics
ISSN: 1001-5868

A COMPREHENSIVE REVIEW OF HYDROPONIC FARMING IN INDIAN CONTEXT

Pradnya Kulkarni [0000-0001-6855-2707]1, Dr. Vinaya Gohokar [0000-0002-7386-0234]1, Kunal Kulkarni [0009-0006-1143-253X] 1

[1]MIT World Peace University, Pune, Maharashtra, India

Abstract Worldwide population is anticipated around 9 billion till 2050. Therefore traditional farming has limitations to fulfill the food demands. Alternate solutions are necessary for farming that can use modern technologies. Growing the crops in different regions of the world is a challenge due to environmental conditions. Hydroponics has become popular for the last few years as it can produce better quality crops using minimum resources. Being scalable to use in greenhouse, poly house or indoor set up, hydroponics is a sustainable solution for smart agriculture. It is a method of growing plants without using soil. Nutrients dissolved in water are given to plants. This paper presents a review of various hydroponic methods mainly used in India; technologies used in IoT based hydroponic farming and communication protocols used in data transfer. Various types of plants like leafy, tuber and fruit plants are cultivated using suitable hydroponic methods. The work presents the plant nutritional requirements. Parameters such as pH, temperature etc. required for plant growth are discussed. Technologies like Internet of Things, Machine Learning etc. are widely used for monitoring the parameters and to get better quality yield. Wireless Sensor Network collects the information from the field to make a data repository about temperature, humidity etc. Data is processed and sent using networks. Image processing helps collect plant images for monitoring, disease tracking as per requirement. Network technologies like LoRa, ZigBee, etc. help exchange the information from field to control station. The overall work done by researchers worldwide is showcased for all these aspects. Open issues and challenges are discussed for future work in hydroponics.

Keywords: Communication, Hydroponics, IoT Technology, Agriculture, Sensors

1 Introduction

Hydroponic farming is soilless farming. It is done using the nutrients dissolved in water. It is a type of controlled environment agriculture as the nutrients and environmental parameters can be controlled externally. This is done using green houses or poly houses. It is also called precision farming because all the nutrients are provided to plants in very précised quantities. Macro nutrients like nitrogen, phosphorus and potassium (N, P, K) and micronutrients like chlorine, calcium etc. are dissolved in water and this water is given to plants for their growth**.** It also includes the other nutrients namely iron, zinc, phosphorus, manganese, copper, boron, magnesium and molybdenum. All these nutrients are dissolved in water in a reservoir and circulated through the roots of plants. Instead of soil, different media is chosen, perlite, coco peat, sand, Rockwool, to name a few. Special arrangements called the hydroponic set up are designed for crop cultivation.

In the agriculture sector, because of dependency on environmental parameters, there are many challenges before farmers to increase the crop yield and to maintain the crop quality. Farmers may have to eliminate weeds, manage pathogens and diseases, and add more fertilizer, more water; manage larger land areas and so on. Arable land is getting decreased and most of the population will be in urban areas. Hydroponics can partly address these issues of open traditional agriculture. Due to antiquated and unethical practices, there has been a significant increase in CO_2 emissions. This is affecting crop quality. Nowadays people are becoming health conscious and getting quality, nutritious food is an important requirement. Achieving the sustainability of all essential human activities—agriculture included—is the first step in ensuring that human nutritional requirements are met in 2050. Hydroponics stands out as a suitable and sustainable alternative for urban and peri-urban settlements to the current inherently non-ecological method of outdoor agriculture, helping to achieve Sustainable Development Goal (SDG) 11: Sustainable Communities and Cities, part of the United Nations 2030 Agenda for Sustainable Development.

Moreover, hydroponics is now the future in farming because as said earlier, it is suitable for urban settlements where most of the population would be living. Industry 4.0 has brought the paradigm shift in many industries like manufacturing, medicine, supply chain, and agriculture as well. Using technology platforms is giving better results in each of the sectors.

Objectives of this work are - i) Review the technical architectures of the on-field set up like cloud based, edge based etc., that includes sensor network, hardware boards, database server etc. ii) Study the different communication gateways used by researchers. iii) Review the system set ups for small and medium scale utilization that will work in urban settlements.

This paper is an attempt to review various technologies essential for hydroponic farming. Figure 1 explains the flow of paper. The need of hydroponics is presented in section 1, which also includes objectives and scope of this review work. In countries like India, what is the current status of hydroponics is presented. Section 2 elaborates current status of hydroponics in the Indian region with some examples and state of the art setups. Literature review is also presented in the same section that uncovers the worldwide work done in the field of hydroponics. In section 3, the work discusses hydroponic methods and tools which are chosen worldwide also, considering the type of crops, available resources etc. It presents a comparative analysis for different hydroponic methods. Currently, hydroponics is opted for plant crops/ vegetables and fruits rather than grain crops. Crop requirements like pH values, nutrition quantity are discussed in section 4. On the technological front in section 5, this work goes through the automation done in hydroponics. Many technological platforms are used to make farming more productive in terms of quality and quantity. This work takes a brief review of cloud based and edge based architecture. Also, it includes wireless sensor networks and data transfer protocols that belong to embedded systems architecture. Machine learning, deep learning , and image processing provides the information about the crop conditions, thus making decisions about harvesting or to detect the diseases. It’s been observed that the hydroponic system is set in big polyhouses or green houses. But considering urban settlements, it becomes necessary to design the infrastructure that would be suitable for small or medium scale. Section 6 enlightens the integration of more than one technology done in such setups. Wireless sensor networks, communication channels, smart cameras to capture plant images and other devices can be integrated to set up the system. Different types of sensors like pH, moisture, humidity; actuators suitable for pumping the nutrient solution are presented in this paper in section 7. The data transfer protocols that are widely used in automation and auto dosing systems in hydroponics. These are discussed in section 8. All the circuit parameters are controlled by a microcontroller. Researchers have used Arduino, Raspberry Pi, NodeMCU and other controllers as the central controlling device of the complete setup. This is reviewed and a comparative analysis is presented in section 9. Artificial Intelligence (AI) along with machine learning (ML) has introduced a new dimension in agriculture. Disease detection, prediction of diseases using the parameters data help farmers to take corrective actions at an earlier stage and potential loss can be avoided. Role of AI and ML is discussed in section 10.

Every advancement comes with its own benefits and limitations. Hydroponics is also not the exception. Last section, the conclusions, discuss the current issues and limitations in setup faced by scholars.

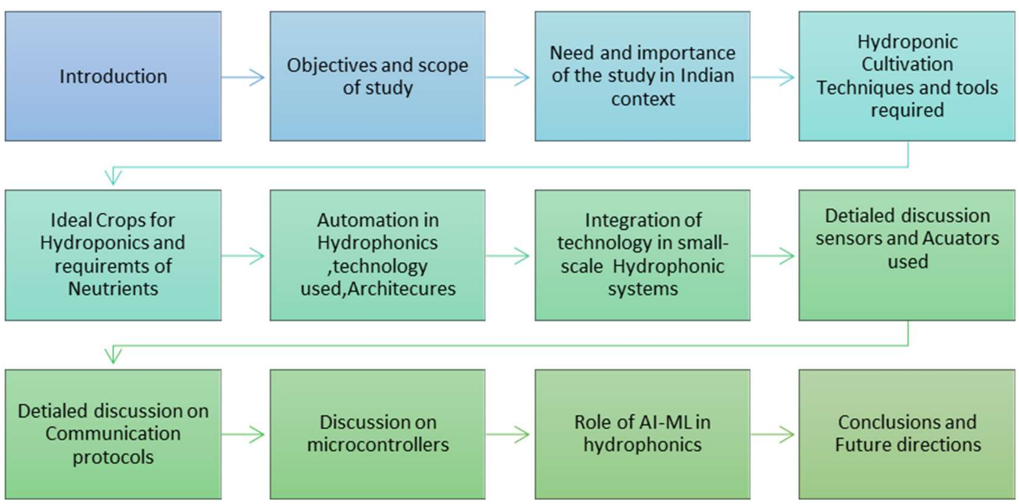


Fig1 Scope and Flow of the Paper

Following research questions are answered in the detailed review

1. How to decide the hydroponic cultivation techniques and components for a crop?
2. What are different architectures available for automation of Hydroponic Plant?
3. What are different parameters to be sensed and controlled and how to select a sensor?
4. How to decide the microcontroller for the application?
5. What are the parameters to select communication technology? Can 5G be used?
6. What are various applications available and what can be done by these apps?
7. What is the role of AI-ML?

2 Related Work

2.1 State of the art - Indian Region

CDAC is the Centre for Development in Advanced Computing, in India. CDAC, Mohali

(India) has developed a Continuous Flow Automated Hydroponic System with support from MeitY, Govt. of India. The system named ‘Jalkrishi’ is a closed loop control system with programmability and graphical interface [36].

In a five-layered mixing tank, there is a calculated flow of water and nutrients. Pumping the fluid into the gullies allows for the growth of plants in the proper supporting cups. Plants directly absorb water and minerals through their roots. The excess solution is gathered in the recycle tank and fed back to the mixing tank for further use. For control, the solution's conductivity, pH, and temperature can be measured simultaneously. The automation makes it possible to monitor the system in different ways and to regulate the timing with a simple graphical user interface. The system can be scaled to accommodate the addition of additional features.

The hydroponic farming consultancy, ‘Aqua Farms’, in Chennai, India, is growing many greens from exotic Italian basil to carom, mint, spinach etc. using PVC pipes in hydroponic setup [37]. This system is set in an 80 sq ft area and grows over 6000 plants.

One of the successful hydroponic farmers from Hyderabad, India, Mr. Harishchandra Reddy shares his experience in [38]. He is earning up to 3 crores per year from hydroponic farming. NFT, both linear and vertical systems, DWC systems are used in his farm to grow greens like mint.

Amit Kumar and Abhay Singh, both IIT-Bombay graduates, founded the Kota-based startup Eeki Foods to grow high-quality, residue-free vegetables [39]. Arugula, lettuce, kale, and other exotic leafy vegetables are not primarily grown by Eeki Foods. They specialize in traditional Indian food. Furthermore, no coco-peat (husk) or other growing medium is used by the startup. As an alternative, they use a technology called an IoT-enabled, medium-less growing chamber. This startup has developed its soon-to-be-patented 'Growing Chambers' in order to facilitate the scaling-up process. The chambers reportedly offer better control over taste and nutrition value than hydroponic companies using coco-peat.

Adding one more success story from hydroponics in India, is - Taking up hydroponics and growing saffron in shipping containers, Nashik resident Shailesh Modak is earning lakhs[40]. Indian spices are worth wars, as history has proven. Saffron, or 'Red Gold', which comes from the flower of Crocus sativus, is one of the country's specialties. Kashmir's spice production is confined to a small area, despite its immense popularity. Nevertheless, software engineer Shailesh Modak has made it possible in Pune to grow it, where the weather conditions are very much different than Kashmir. At first, a total of 875 grams were grown, which were sold for Rs 500 a gram. It has taken him a year to earn Rs 5 lakh after investing Rs 10 lakh for setting up the laboratory and conducting research.

2.2 Literature Review

Several studies and comprehensive reviews are reported in literature for designing and implementation of hydroponic systems. Authors in [1] and [3] Propose a hydroponic system for plant growth using IoT. Wireless sensor networks are used to sense various parameters. [2] Proposes an automation for tomato plant disease detection. Diseases are detected using image processing and feature extraction methods. Researchers in [4] propose a system that works for resource optimization in smart farming. The framework consists of data storage, image processing, event managing, decision making and irrigation scheduling etc. Irrigation and

water supply is the very crucial part in farming. Considering this, one more text [5] presents the robust smart irrigation system that uses a combination of data science and IoT. THe work is done using an ARM processor. Data analysis has given a wide scope in farming to store and analyze the data received from many sensors and users can use the results for better yield. This is presented in [6]. Agriculture is highly dependent on weather conditions. It has to manage the uncertainties and authors propose a system to manage these conditions using data science.
The final produce in farming, the plants/ crops should be fresh and detecting the freshness is presented in work done in [7]. The images of fresh and withered veggies are captured. Samples taken for every 10 minutes for 7 continuous days make a large data set and 80/20 model helps detect the fresh veggies with the accuracy up to 99% for shortlisted 21 parameters, as per authors. Work done in [8] uses machine learning methods for automatic dosing. EC and pH values are monitored before managing the nutrition dose. Artificial neural networks are used for auto dosing. Scholars in [9] present an automatic hydroponic drip irrigation system using big data. In combination with IoT/ Raspberry Pi, this work gives a solution for drip irrigation management. Technology platforms are helping agriculture to make things easy with lesser labor. Cloud and edge computing approach is proposed in [10] to control the concentration of nutrient solution in hydroponic systems. Considering the contribution of researchers worldwide, literature survey is continued in table 1.

Table 19(a) Literature Survey

Ref No	Title, Authors	Information	Description
11	Design and Implementation of Irrigation Water Saving Control System Based on WSND. Qiong and P. Hao	2021 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), Xi'an, China, 2021, pp. 75-78, doi: 10.1109/ICITBS53129.2021.00027.	Water saving control system based on WSN using Zigbee protocol, STM32F103C8T6 for medium to large systems
12	Energy-Efficient Edge-Fog-Cloud Architecture for IoT-Based Smart Agriculture Environment H. A. Alharbi	IEEE Access, vol. 9, pp. 110480-110492, 2021, doi: 10.1109/ACCESS.2021.3101397.	Design energy efficient architecture using edge-cloud-fog layers in smart agriculture. To be used in any wireless sensor network with microcontroller based IoT system for

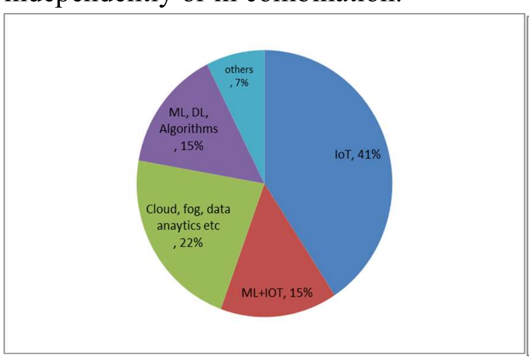
	and M. Aldossary		medium to large scale systems
13	IoT based hydroponic system with supplementary LED light for smart home farming of lettuce T. Namgyel et al.	2018 15th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Chiang Rai, Thailand, 2018, pp. 221-224, doi: 10.1109/ECTICon.2018.8619983.	Measurement of solar energy, LED light supplementary arrangement, plant physiology and chlorophyll for lettuce plant, using Arduino Mega2560, RTC, NOdeMCU for large green houses
14	Microfluidic Soil Nutrient Detection System: Integrating Nitrite, pH, and Electrical Conductivity Detection S. Dudala, S. K. Dubey and S. Goel	IEEE Sensors Journal, vol. 20, no. 8, pp. 4504-4511, 15 April 15, 2020, doi: 10.1109/JSEN.2020.2964174.	Design a system using microfluidic based soil nutrition detection unit for measuring pH, EC and nitrate contents in soil using Arduino Atmega. Large systems
15	Renewable Energy Integration Into Cloud & IoT-Based Smart Agriculture E. -T. Bouali, M. R. Abid, E. -M. Boufounas, T. A. Hamed and D. Benhaddou	IEEE Access, vol. 10, pp. 1175-1191, 2022, doi: 10.1109/ACCESS.2021.3138160.	Design a cost effective system for renewable energy, water management using various transfer protocols, IoT, actuators, motion sensor etc using arduino nao and various protocols like Bluetooth, Zigbee, LoRa, Z-Wave, SigFox, WiFi, GPRS, 4G, 5G

16	Disposable pH sensor on paper using screen-printed graphene-carbon ink modified zinc oxide nanoparticles Aliyana, A. K., Ganguly, P., Beniwal, A., Kumar, S.K. N. and Dahiya, R. (2022)	IEEE Sensors Journal, 22(21), pp. 21049-21056	Fabrication and manufacturing of pH sensing mechanism on paper using NodeMCU
17	Design and Implementation of Smart Hydroponics Farming Using IoT-Based AI Controller with Mobile Application System S. V. S. R Raju, B Dappuri, P. R K Varma, M Yachamaneni, D. M G V, M K Mishra	Journal of Nanomaterials, vol. 2022, Article ID 4435591, 12 pages, 2022. https://doi.org/10.1155/2022/4435591	Mobile Application System developed using raspberry Pi, CNN, IoT Cloud Server
18	Design of a Shallow-Aero Ebb and Flow Hydroponics System and Associated Educational Module for Tri Cycle Farms Halveland, J.	Undergraduate Honors Theses Retrieved from https://scholarworks.uark.edu/baeguht/76	EBB and Flow system is developed using vertical hydroponic planter with the help of sensors

19	Design, Construction and Testing of IoT Based Automated Indoor Vertical Hydroponics Farming Test-Bed in Qatar M E. H. Chowdhury, A Khandakar, S Ahmed, F Al-Khuzaei J Hamdalla, F H, M B I Reaz , A Al Shafei, N Al-Emadi	www.mdpi.com/journal/sensors Sensors 2020, 20, 5637; doi:10.3390/s20195637	Test bed developed for indoor farming using wireless sensor networks and microcontrollers
20	Fully Automated Hydroponic System for Indoor Plant Growth V Palande, A Zaheera, K Georgea	Procedia Computer Science, Volume 129, 2018, Pages 482-488, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2018.03.028.	Automation is achieved using Raspberry Pi for EC, pH and other parameters
21	Predictive Control on Lettuce NFT-based Hydroponic IoT using Deep Neural Network E. D. Nugroho, A. G. Putrada and A. Rakhmatsyah	2021 International Symposium on Electronics and Smart Devices (ISESD), Bandung, Indonesia, 2021, pp. 1-6, doi: 10.1109/ISESD53023.2021.9501402.	Deep Neural Network is used for predictive control using Node MCU, Raspberry Pi and Arduino for humidity and water level.

22	Indoor Hydroponic System Using IoT-Based LED W Atmadja, I Alexander S Dewanto, A C Nugraha, S Gokparulian	Wiedjaja Atmadja et al 2022 IOP Conf. Ser.: Earth Environ. Sci. 998 012048	System developed using LED lights, ESP32 and sensor DHT 11,

Researchers are presenting the review and surveys in the field of hydroponic farming. [23-26] presents the utilization of various modern technologies like IoT, ML, cloud, edge and fog computing in hydroponics. Also, communication protocols are discussed in different reviews [23], [24], [29], [31]. Variety of microcontrollers, sensors are used and considered in hydroponics and showcased by authors in [25-28]. Large greenhouses are nowadays shifting their farming methods into hydroponics. this is presented in [30], [35]. Artificial Intelligence, machine learning, IoT help the argo sector for predictions, accurate measurement of parameters and get better yield. This is presented in surveys [31-34].
Summarizing this as a pie chart as shown in fig 2 a&b, it can be observed that IoT is the most widely used technology in hydroponics. It can be used independently for complete setup or can be combined with other platforms like ML, big data etc.
Also, for data transfer, protocols like LoRa, LoRaWAN, LPWAN, Zigbee etc are used either independently or in combination.



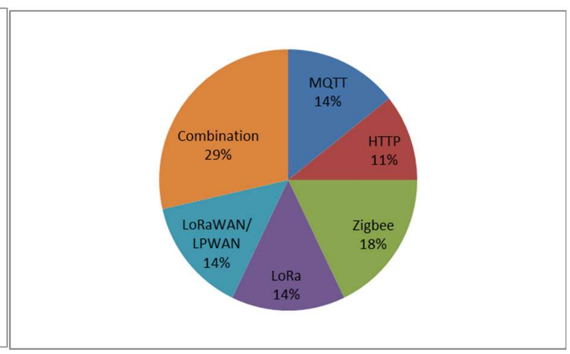


Fig 2 (a) Technology Platforms used in Hydroponics Fig 2(b) Transfer Protocols Used in Hydroponics

3 Hydroponic Methods and Tools

The goal of this review work is to bridge up the knowledge gap between the two disciplines by going deeper into the basics of hydroponics as a crucial step for technicians to assimilate the requirements of small and medium-scale operations, which is essential for achieving the SDG 11. Technology has started changing the face of farming using precision farming/ smart farming**.** Hydroponic farming is a method of growing plants using mineral solutions dissolved in water, without using soil. It has been observed that plants can grow without using soil. The photosynthesis process is expressed as a chemical reaction:

$$6CO2 \quad + \quad 6H2O \xrightarrow[\text{Sunlight}]{} C6H12O6 + 6O2 \qquad (1)$$

It means, carbon dioxide + water → Glucose + Oxygen

We have seen that hydroponics does not require land to produce food. In this method, plants are grown on a substrate made of natural materials or synthetic materials, and the roots of the plants can readily draw nutrients from a prepared nutrient solution. The majority of systems comprise an aerator and a holding tank for nutrient solution. Various types of hydroponic systems are nutrient film technique (NFT), wick system, deep water culture (DWC), EBB and Flow, aeroponic method and drip system. Fig. 3 explains about these methods. Each method has its own benefits and limitations. These are also discussed in table 2, comparative analysis of hydroponic methods. The comparison is done on the basis of initial cost, water management, ease of maintenance, space required.

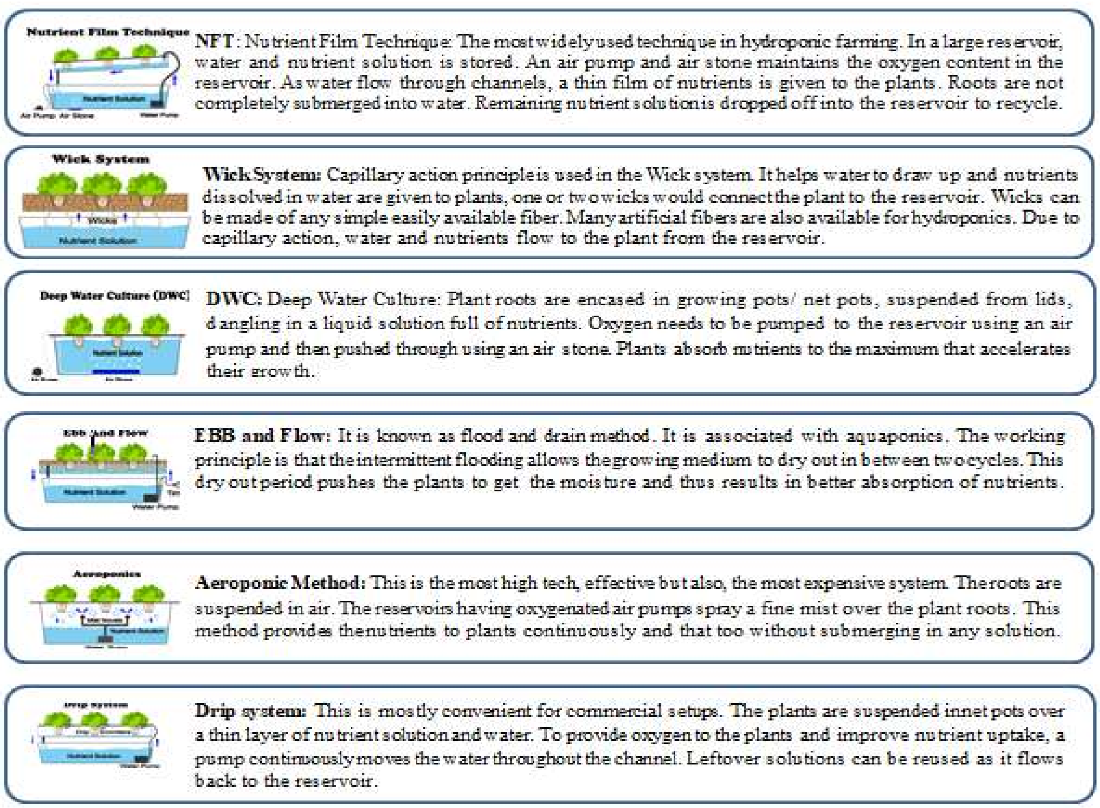


Fig. 3. Types of Hydroponic Systems

Table 2 Hydroponic Methods Comparative Analysis

Sr. No.	**Hydroponic Method**	**Initial Cost**	**Water Management**	**Ease of maintenance**	**Benefits**	**Limitations**
1	NFT	Low cost	Water is recycled,	Low maintenance	Easy to monitor	Continuous water flow is must, else roots would

			less wastage		roots and overall growth	get dried out Roots may block the channels when grown
2	DWC	moderately expensive	Plants are submerged in water, not much fertilizers are required,	Lesser maintenance	Faster plant growth	Plants will rapidly decline if air pump stops working Fluctuation in nutrient contents
3	Wick System	Low cost requirement	capillary action is the key less water required	Wicks are required to monitor to avoid clogging	Easy to set up and use	Wicks can get clogged or saturated with water affecting plant growth More prone to pests, diseases Needs periodic monitoring
4	EBB and Flow	Low cost	More water required	Needs proper monitoring to maintain the flow	Easy to build and use	Initially needs washing and sterilization Contamination may occur due to pathogens developed in flood tray
5	Aeroponics	Expensive initial set up	Lesser need of nutrients and water	Lesser maintenance	Fast plant growth	Needs high pressure pumps, timers and sprinklers, so dependency of system Technical knowledge is needed Regular cleaning of root chamber is needed High cost
6	Drip Irrigation	Low cost	Efficiency in terms of water and nutrient consumption	Monitoring is required	Simple to set up Versatile for small and large settlements	Dependency on electricity pH and nutrient fluctuations are frequent drip emitters tend to clog resulting into algae formation

It can be seen that hydroponic setup does not need exclusive components. The components required in system are discussed below:

1. PVC Pipes - Most of the methods need PVC pipes as the main frame of the structure. For NFT, PVC pipes are arranged one near another in a flatbed system or one above the other in a vertical layered structure. The wick system also used PVC pipes to keep the wicks submerged in water.
2. Net pots/ planters - Plant roots are submerged in water and so, net pots are used to sow the seeds.
3. Water tank/ reservoir - Nutrients dissolved in water are continuously flowing through pipes. excess water is recycled to avoid wastage. So, a water tank that is suitable for the system is required for water management.
4. Motor/ Actuator - To maintain the water supply, actuators are a must to have components in a hydroponic set up. Actuators are selected as per the design of the setup. Details about actuators are discussed in the upcoming section.
5. Substrate/ media - The physical support for plants that holds them up to the stem and maintains them in good growing circumstances by offering a sterile environment with adequate oxygenation and nutrient flow is known as substrate.
6. Nutrient Solution - With the exception of hydrogen, carbon and oxygen, which are carried in the air in hydroponics, all necessary nutrients are delivered to the plant through the fertilizer solution. With the exception of iron, this is introduced as iron chelates to increase its availability, inorganic fertilizers are used as sources of nutrients. Depending on the crop and plant state, the nutrient solution's chemical composition varies. Ammonium nitrate (NH4NO3), calcium nitrate (5Ca(NO3)22H2O] NH4NO3), phosphoric acid (H3PO4), nitric acid (HNO3), and others are among the liquid fertilizers used in hydroponics.

4 Crops Cultivated using Hydroponics

A variety of crops are cultivated worldwide using hydroponic methods. Leafy vegetables, root vegetables; fruit vegetables are preferred for hydroponic farming in small and medium scale cultivation. Each crop has its own requirements of water, humidity, pH level, temperature requirement etc. Table 3 given below describes the plant variety and the cultivation techniques preferred. Some plants are discussed here.

Tomato: traditional as well as cherry tomato plants can be cultivated using drip irrigation hydroponics or NFT. It gives results in all seasons.

Lettuce: Very popular salad leaf, especially among diet and health cautious people, is the highly grown leafy crop in hydroponics. Beginners may start their garden farming with lettuce as this crop gives a high yield in a controlled environment.

Cucumber: Environmental friendly highly demanded plant that can be cultivated at commercial level. It requires enough light and temperature. Drip irrigation or NFT gives a high quality yield.

Beans: most productive because of lesser germination time. Harvesting can be started in 3-4 weeks. Also requires less maintenance.

Table 3 Crop Variety with required parameters

Plant Type	Plant Name	Hydroponic Technique	pH requirement / TDS (ppm)	EC Value
Bulb Vegetables	Garlic	Drip Irrigation	6 to 6.5 /980-1260	1.4 to 1.8
	Onion	Drip Irrigation/ NFT	6 to 6.7	1.4 to 1.8
Leafy Vegetables	Lettuce	NFT, DWC	6 to 7/ 560-840	0.8 to 1.2
	Cabbage	NFT, DWC	6.5 to 7 /1750-2100	2.5 to 3.0
	Celery	NFT, DWC	6.5/ 1260-1680	1.8 to 2.4
	Parsley	NFT, DWC	6 to 6.5/ 560-1260	0.8 to 1.8
	Spinach	NFT, DWC	6 to 7 /1260-1610	1.8 to 2.3
	Mustard	NFT, DWC	5.5 to 6.5 / 600-1200	1.2 to 2.4
	Coriander	NFT, DWC, Drip Irrigation	5.5 to 6.7/ 600-800	1.2 to 1.8
Root Vegetables	Beet Root	Drip irrigation, Aeroponic	6 to 6.5/ 1260-3500	0.8 to 5
	Turnip	NTF	6 to 6.5/ 1260-1680	1.8 to 2.4
	Carrot	Drip irrigation, Aeroponic	5.8 to 6.3 /1120-1400	1.6 to 2.0
Tuber Vegetables	Potato	Drip Irrigation	5.8 to 6.2/ 1400-1750	2.0 to 2.5
	Sweet Potato	Drip Irrigation	5.8 to 6/ / 1400-1750	2.0 to 2.5
Fruit Vegetables	Cucumber	Drip Irrigation, NFT	5 to 5.5 /1190-1750	1.7 to 2.5
	Tomato	Drip Irrigation, NFT	6 to 6.5/ 1400-3500	2.0 to 5.0
	Eggplant	Drip Irrigation	6/ 1750-2450	2.5 to 3.5
Pulse Vegetables	Beans	Drip Irrigation	6/ 1400-2800	2 to 4
	Sweet Corn	Drip Irrigation	6 to 7/ 840-1680	1.6 to 2.4
	Pea	Drip Irrigation	6 to 7/ 980-1260	0.8 to 1.8

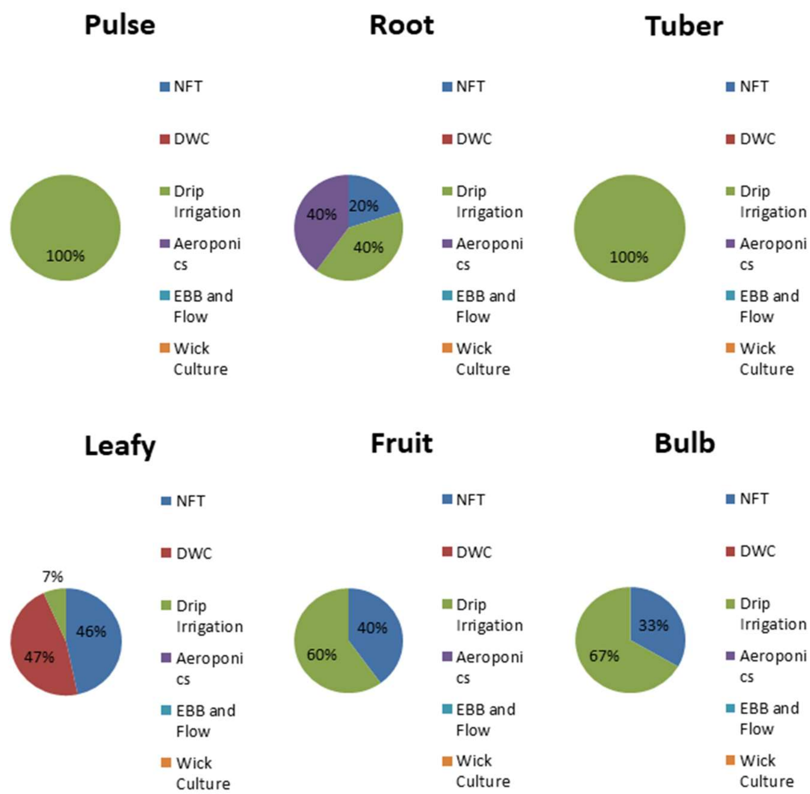


Fig 4 Pie Chart showing highly used hydroponic Methods

Fig. 4 shows the highly utilized system for crop cultivation is NFT and DWC according to the data taken from table 3. These methods can be used as independent methods or in combination with each other.

It can be seen from table 3 that most of the plants need a pH level around 6 to 7. However, at pH levels above 7, Fe and H2PO4 become less soluble, which causes Ca and Mg to deposit and other molecular reactions between the nutrient solution's constituents that prevent the absorption of Fe, B, Cu, Zn, or Mn. On the other hand, the adsorption of nitrogen, phosphorus, potassium, calcium, magnesium, and molybdenum is prevented if the pH is lower than 5. So to maintain the pH value is the important part in hydroponics. Fig. 5 shows the relation between pH value and nutrient contents in the soil. The consumption of certain micronutrients, such as manganese, can occasionally result in harmful pollution. Also, TDS value differs for each plant during each phase of cultivation. The approximate range at the time of harvesting is around 800 ppm. EC is the electrical conductivity which is around 1.8 to 2.

Maintaining all these parameter values is a tedious task. Monitoring the values and controlling the parameters is achieved using various technologies like IoT, machine learning, big data etc.

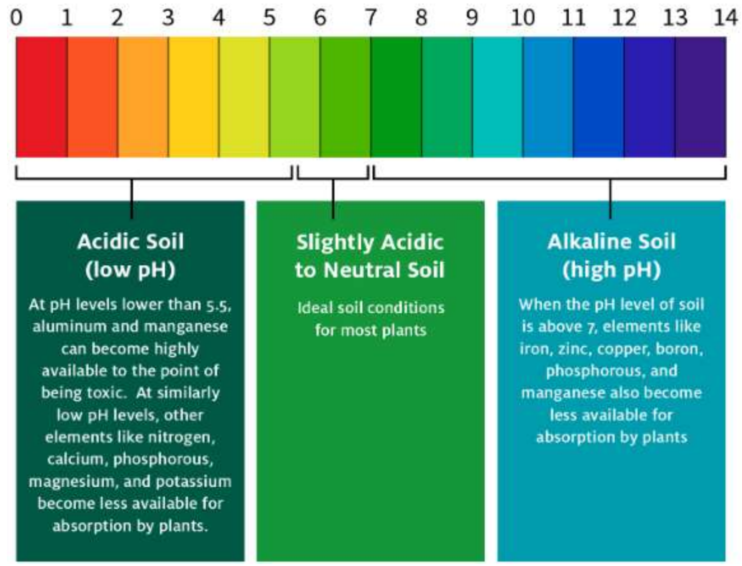


Fig 5 Relation between pH value and soil nutrients

5 Technologies in Hydroponics

5.1 IoT Architecture in Hydroponics

In current technology platforms, IoT is the most widely used solution for hydroponic farming. Because of its flexibility and scalability in terms of hardware and software, it gives a wide range of solutions in the agriculture sector. Researchers are coming up with set ups that include microcontrollers, sensors and communication gateways. Fig 4 shows the general architecture for hydroponic set up. Fig 6 shows the general architecture using IoT. Input sensors would sense the change in parameters like pH, air temperature and humidity, water temperature, flow meter to check the water flow, EC meter to check the electrical conductivity, TDS sensor to check the total dissolved solids in the solution, camera to capture the images, mainly for disease detection and other sensor as per design requirements. All the sensed and captured data is given to the microcontroller using data transfer protocols. Actuator is controlled using a microcontroller. The data is also stored to the IoT server where data is processed according to the needs. Android mobile app developed specifically for hydroponic setup would be used by end users or farmers to control and monitor the overall system.

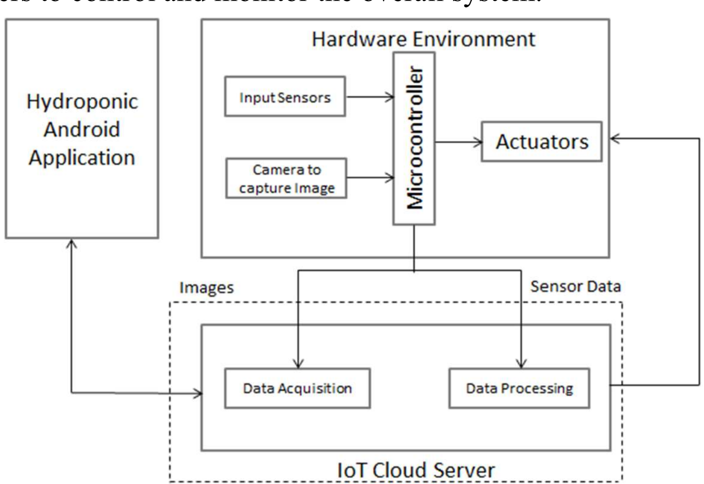


Fig 6 IoT Based General Hydroponic System Architecture

Sensors continuously sense the values of pH, EC, TDS etc. In real time systems, it is not a time critical system, so it is not really mandatory to sense the values every minute. The sampling time can be 10 minutes also. Accordingly, samples can be taken, recorded and stored to the IoT server.

Automation becomes more hassle-free using IoT architecture. Microcontrollers nowadays are compatible with data transfer methods using wireless communication gateways. Therefore a system that consists of a wireless sensor network, controller, motor and an IoT server makes the pathway for automation also.

5.2 Cloud Based Architecture in Hydroponics

Cloud based architecture consists of network layers as shown in Fig 7. Physical and sensing layer consists of the sensors, actuators, microcontroller and other hardware components. Data is collected by sensors and monitored, controlled using microcontrollers. The main aim of using a cloud based system would be to ensure the security of the data being processed. The sampling time would be nearly 10 mins for every parameter, so it would make a large database from the setup. Managing the data is a very crucial step in automation. Cloud provides the required security to manage the data. The dashboard provides the data of earlier readings taken from sensors. This is necessary for analysis like what values were recorded for the last harvest cycle, are any changes required in the upcoming harvest cycle etc. To make these decisions, older data needs to be maintained with the server. Dashboard provides the current data repository and older data storage as well.

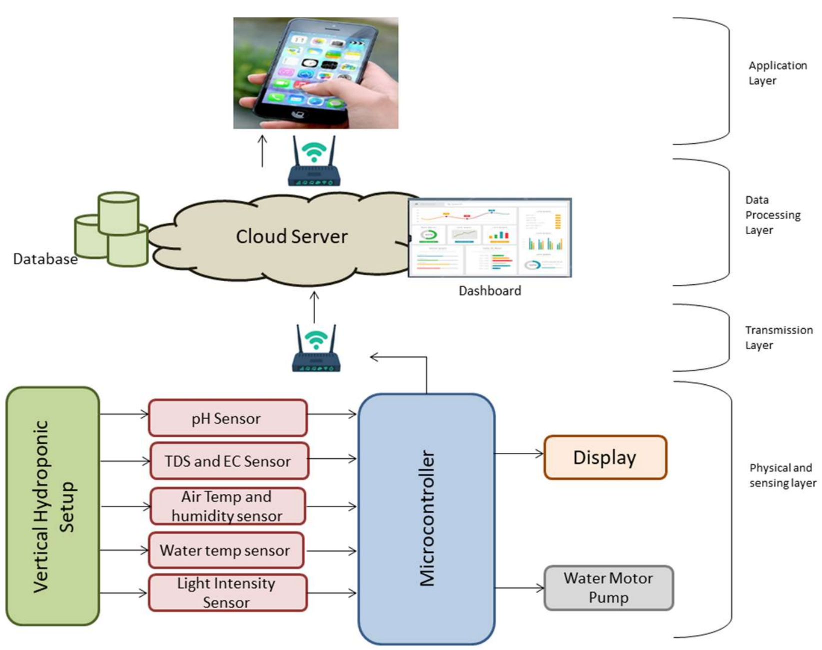


Fig 7 Cloud Layer Architecture

Along with cloud, edge based architecture is also used for hydroponics.

5.3 Edge Based Architecture

Edge computing is a new type of computing that uses sensors and actuators at the network's edge to compute data. Using this idea, a few applications and services that don't need a lot of processing power can be handled at the edge layer, near to the data source, eliminating the need for the fog or cloud to travel the network to process them. Edge computing can thereby enhance data transmission efficiency, guarantee real-time processing and lower the computational load as well as the volume of data sent to and from fog or cloud data centers.

5.4 Fog Based Architecture

In order to extend the capabilities of cloud computing to the edge of the communications network, Cisco first suggested the fog computing concept in 2014. In this instance, IoT sensor data must be processed and analyzed by the fog layer in order to reduce latency for agricultural applications and services. Additionally, the fog layer is better than the edge layer at processing and analyzing complex data. Between the sensor layer and the cloud layer, fog and edge both have the ability to offer computing, networking, and storage services. It implies that the fog and edge layers can process and analyze agricultural data locally in place of carrying out complete processing at the cloud layer.

Considering the hydroponic requirements, it can be said that the system is not time critical. It is time tolerant. One more structure that uses embedded systems and wireless sensor networks is also proposed by many researchers. Nowadays, a combination of technologies like IoT with cloud/ edge/ fog computing etc. is preferred over to have an individual technology platform. Communication gateways are also used in combinations. The following structure in fig 8 shows the combination of technologies.

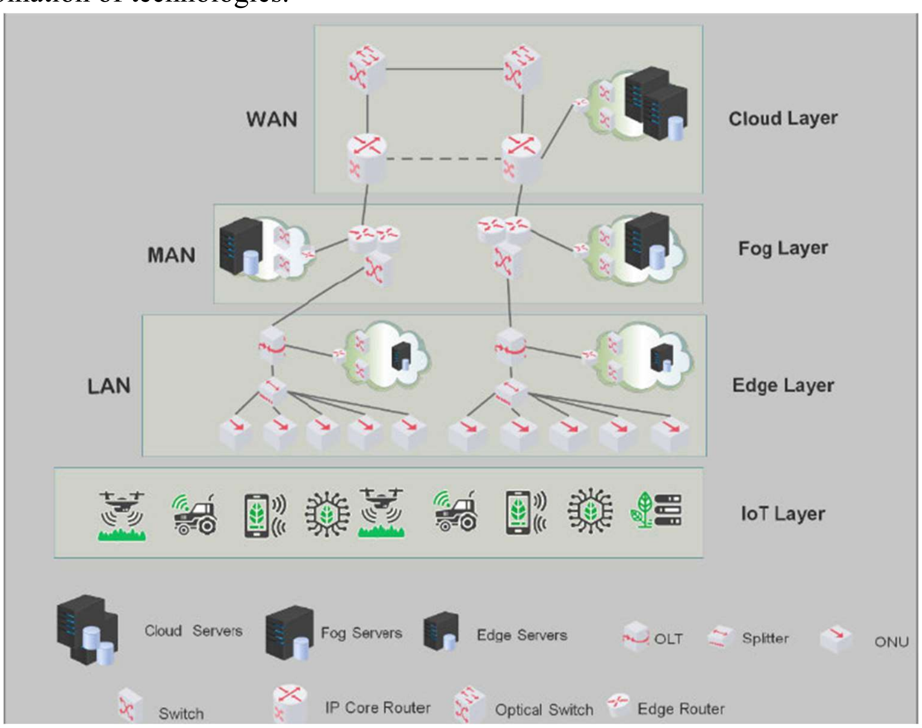


Fig 8 IoT and Edge-Cloud-Fog based Layered Architecture

This architecture proposes the energy efficient system and discusses the carbon emission which can be defined as the carbon emission intensity per unit of energy consumption.

5.5 Automation in Hydroponic System

All the technology platforms that reduce the farmer's efforts lead to automation in farming. This is known as smart farming, Agri 4.0 - a part of Industry 4.0. Automation is achieved using IoT, different architecture, and machine learning approaches. Machine learning (ML) approach includes data analytics and big data also. Artificial Neural Network (ANN), Deep Neural Network (DNN) are the different methods in (ML) that are widely used in training and testing. Sensor values taken from different sensors like pH, EC, light intensity (LDR/ Lux meter value), TDS, plant images etc are stored in the database. Whenever the values change in actual setup, sensors will sense the values and using networks and control methods, the changes would be noticed as server end. In such cases, the end user has to tune the system of nutrient solution to maintain the solution parameters within the range. This is the dosing process. Auto dosing is possible by automation. The training data is available as a reference and actual values are testing data.

ML is very useful in early disease detection. Healthy plant images are stored in a database and then by continuously monitoring the plants, diseased plants are identified. This is done by camera and the other circuit components. Early stage disease detection avoids the potential losses in farming.

This is also applicable for change in light intensity. As hydroponics is mostly indoor farming, keeping the light intensity as per the plant requirement is very necessary. LED light arrangement is done in most of the indoor setups. This is shown in fig 9. At any instance when light intensity gets changed, it is recorded in the database and discrepancy is identified. Automation helps in this process and manual intervention can be partially avoided. End user, if provides the automatic light intensity regulator, then it can be called as fully automated light sensing.

In case of other values like EC, pH; the changed value would be recorded in the database and for nutrient solution tuning, the dosing material would be poured into the water tank using motor control. Microcontroller programming is the main part in automation.

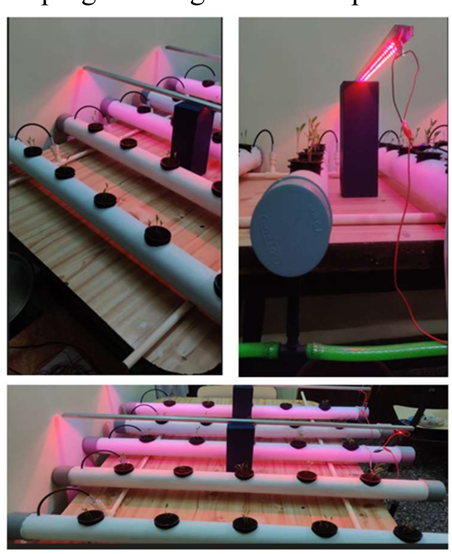


Fig 9 LED Light for Indoor Hydroponics

6 Integration of Technology in Small and Medium Scale Hydroponic System

As this is about indoor, urban farming, it is to be decided by the end users whether the setup is to be utilized at domestic level or commercial level. Once this is answered, the technological structures can be thought of. Elaborating on this, if any user wishes to grow the crops for domestic purposes, the partially automated systems would be a better solution. This is because in small spaces, one can adjust the nutrient solutions, light intensity and other values by manual dosing. The automation part would be useful to get the changed values of parameters, getting the notification about diseased plants etc. Fig 10 discusses integration of technologies.

If a user can accommodate a small greenhouse in a slightly bigger area where natural light is available for 6-7 hours, light adjustment would not be the part of automation. In such cases, nutrient solution is required to be monitored for all its parameters and auto dosing would be required.

For medium scale setup which can be called a semi-commercial setup, the user has to have an appropriate initial investment for selection of sensors, hardware boards that include microcontrollers, actuators and processing elements. Weather conditions in particular areas play a key role in selection of sensors for air temperature sensing, humidity sensing. Water temperature needs to be monitored. Depending on the area, water can be hard water or soft water. So the water temperature sensor is again one of the important components.

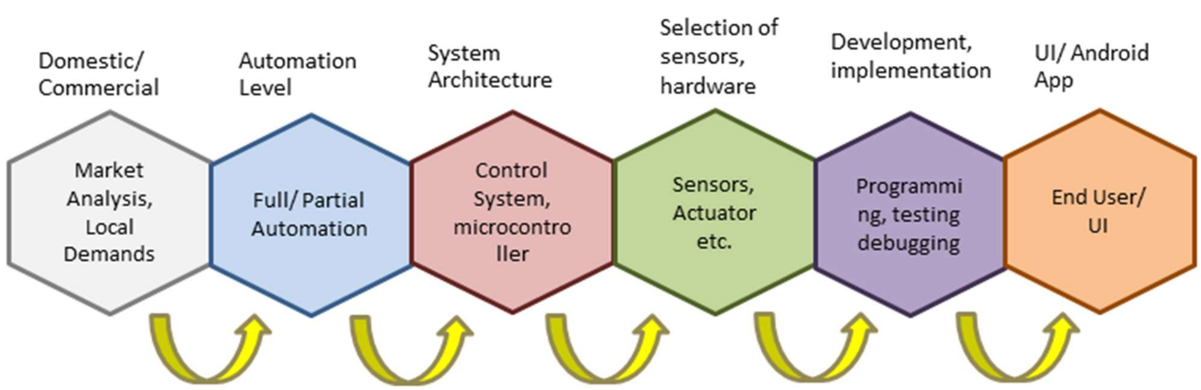


Fig 10 Integration of Technologies for Small and Medium Scale Hydroponic Setups

A combination of controllers like Arduino Uno and Nano, Raspberry Pi, NodeMCU is preferred for moderately large setup. This is because there are many sensors, actuators and other components. SOmetimes, for better outputs, data fusion method is used where multiple sensors are fitted to measure the same parameter. It gives a big set of values among which more accurate values can be chosen using averaging techniques. This requires a high degree of accuracy which is achieved by combination of controllers.

When the system becomes more complex, machine learning algorithms help get better results. Classification algorithms for sensors, prediction algorithms in disease detection etc. are implemented by many researchers. Many control techniques such as fuzzy logic, PID controllers are implemented in hydroponics.

At User Interface (UI) level, where users can actually send signals to control motor pumps, control the dosing in nutrient solution, light intensity tuning, increasing or decreasing the temperature; HMI - Human-Machine-Interface interaction comes into picture. User applications, websites enable users to make any decision in case of any deviations, system failure or any unwanted changes.

7 Sensors and Actuators in Hydroponics

Sensors are the initial components in hydroponic systems. In industry 4.0 Agriculture, IoT has brought a paradigm shift in farming. Traditional farming methods are now getting replaced by modern farming methods, improving crop quality and yield also. This section discusses sensors and actuators used in hydroponic farming. Sensors, actuators and other components are IoT enabled to make automation easier.

1. pH and EC Sensor - pH is the main parameter for any plant to grow well. Nutritional requirements are already discussed in the earlier section. There are four types of pH sensors viz. differential sensors, combination sensors, laboratory sensors and process sensors.

   Combination sensor uses a reference electrode and a measuring electrode to generate the electric signal from the difference and to calculate pH from it. Mostly, hydroponic setups use this type of pH sensor.

   Differential sensor uses a similar structure with a third metal grounding electrode. This is to maintain the accuracy of pH value in case of contamination.

   Laboratory sensor is an improved one to measure temperature and pH values for commercial and research purposes.

   Process pH sensors are robust in nature, they have process connections and are ideal for large scale setups.

   Sensor in Hydroponic setup -

   A glass membrane or glass bulb fused to the end of a glass tube serves as the pH-sensitive electrode. A known pH potassium chloride buffer solution (electrolyte) is used to fill the electrode. (usually pH 7). The electrical connection is made using a silver wire that is covered in silver chloride. All of this results in an environment on the inside of the glass membrane where H+ ions are always bound, while the outside is exposed to a sample where the number of H+ ions is varied.

   The electrical potential of the pH-detecting half-cell is determined by the activity of hydrogen (H+) ions in the sample solution. A potassium chloride solution is contained in the reference system, which is housed in the outer glass tube and has a silver wire coated with silver chloride. A constant electrical potential is maintained by the reference electrode, which is unaffected by the sample's composition or temperature.

   Without cutting off the electrical connection, a junction shields the reference system from the test solution. Testers, portable meters, desktop meters, and inline meters are the four different kinds of pH meters. Hobbyists and small scale growers most frequently use testers and handheld meters. Inline meters for IoT detect pH in your nutrition line immediately. For the purpose of tracking the pH and EC of nutrient solutions that are applied to and removed from crops, inline sensors are mounted in irrigation pipes or reservoir tanks. Fig 11(a) shows pH meter with probe. Fig 11(b) shows the connection with the microcontroller.

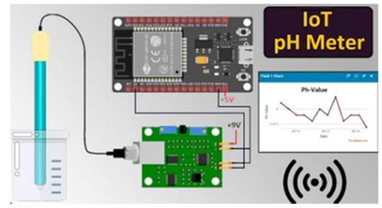


Fig 11 (a) pH sensor with WiFi module Fig 11 (b) Connectivity
with microcontroller

2. TDS/ EC meter - A TDS meter is a tiny, portable instrument used to measure the amount of total dissolved solids (TDS) in a solution, often water. Due to the fact that dissolved ionized particles, such as salts and minerals, enhance a solution's conductivity, a TDS meter measures the solution's conductivity and infers the TDS from that value. More dissolved minerals equal a higher EC when using an EC meter to measure how much electricity is flowing from one electrode to the other. The concentration of conductive minerals in your water is measured by EC, or electrical conductivity, and is expressed in Siemens-per-meter (or S/m). The concentration of all minerals in water is measured by TDS (or total dissolved solids), which is expressed in PPM. (or Parts Per Million). For automation and smart farming, the TDS is as shown in fig 12 (a & b).

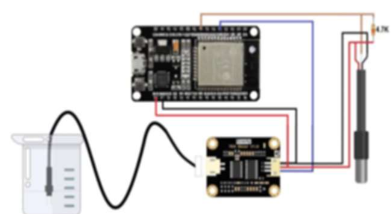


Fig 12 (a) TDS Sensor Probe and Module Fig 12(b) Connectivity
with Microcontroller

3. Temperature Sensor - The DS18B20 temperature sensor on hydroponic plants functions by detecting the temperature in the storage container to maintain a proper temperature. This is used for water temperature measurement. Air temperature and humidity measurement can be done by different sensors. DHT11, DHT22 are to name a few. Considering IoT requirements, compatibility with microcontrollers and automation, temperature sensors should be selected. Unforeseen climate changes affect the air temperature, humidity and water temperature in reservoirs. COntinuous monitoring is very much required to maintain the temperature of the surrounding and also of the water. Sensor selection is a key part in automation. Accuracy of the sensor must be higher to ensure that the readings taken are correct. Following table 4 gives the comparison between different temperature sensors. This would give the idea which sensor can be selected.

Table 4 Comparison between Temperature Sensors

Sensor	**DHT11**	**DHT22(AM2302)**	**LM35**	**DS18B22**
Measures	Temperature Humidity	Temperature Humidity	Temperature	Temperature
communication protocol	One-wire	One-wire	Analog	One-wire
Supply voltage	3 to 5.5V DC	3 to 6V DC	4 to 30 V DC	3 to 5.5V DC
Temperature range	0 to 50ºC	-40 to 80ºC	-55 to 150ºC	-55 to 125ºC
Accuracy	+/- 2ºC (at 0 to 50ºC)	+/- 0.5ºC (at -40 to 80ºC)	+/-0.5ºC (at 25ºC)	+/-0.5ºC (at -10 to 85ºC)

Actuators

Actuators, the devices that actuate the motor, are used in hydroponics for circulation of nutrient solution. In any hydroponics methods like DWC, NFT, Wick culture etc., nutrient solution is circulated throughout the setup. The proportion of this solution is monitored and controlled by end users, manually or by automation.

Hydroponic structure can be vertical or horizontal. The selection of actuator or motor with pump depends on the structure of the system. For vertical systems, space available is lesser and thus, layered pipe structure is preferred. It is the requirement of the system to make the solution reach up to the topmost layer with the same quantity as that of the bottom layer.

Motor and pump have a key role in this arrangement. 'Head max' number is the maximum height up to which a pump can circulate the water. Considering the structure of the vertical setup, the motor power requirement is calculated. The pump is selected such that it should be compatible with motor power.

When used in a small area, the setup should not consume more space and so a submersible pump is preferred, as shown in fig 13 (a & b).

Fig. 13(a) Motor for Hydroponics Fig. 14(b) Submersible Arrangement

So the pump and motor should be selected considering following parameters:

1. Consumption - For how many days/ hours - For hydroponics, it will be 24 hours
2. Height up to which it should pump the water - For flatbed setup, it will be approximately 2 ft, for vertical height approximately up to 2.5 meters.

3. Submersible or not
4. Water circulation per minute or per hour.
5. Revolutions Per Minute - RPM

8 Communication Protocols for Data Transfer

Monitoring and control of the system is provided with the help of IoT and wireless communication. In smart farming, the things which are manually monitored, or can be said as 'necessary to keep an eye on' are now getting replaced by automation. Devices are getting connected to each other for better functionality and performance. By 2050, the number of IoT connected devices is anticipated to reach up to 2000 billion. Communication is now the most important aspect of IoT, that deploys mainly wireless communication methods like WiFi, WiMax, Bluetooth, to name a few. Fig 14 presents the classification chart of wireless communication technologies based on communication range.

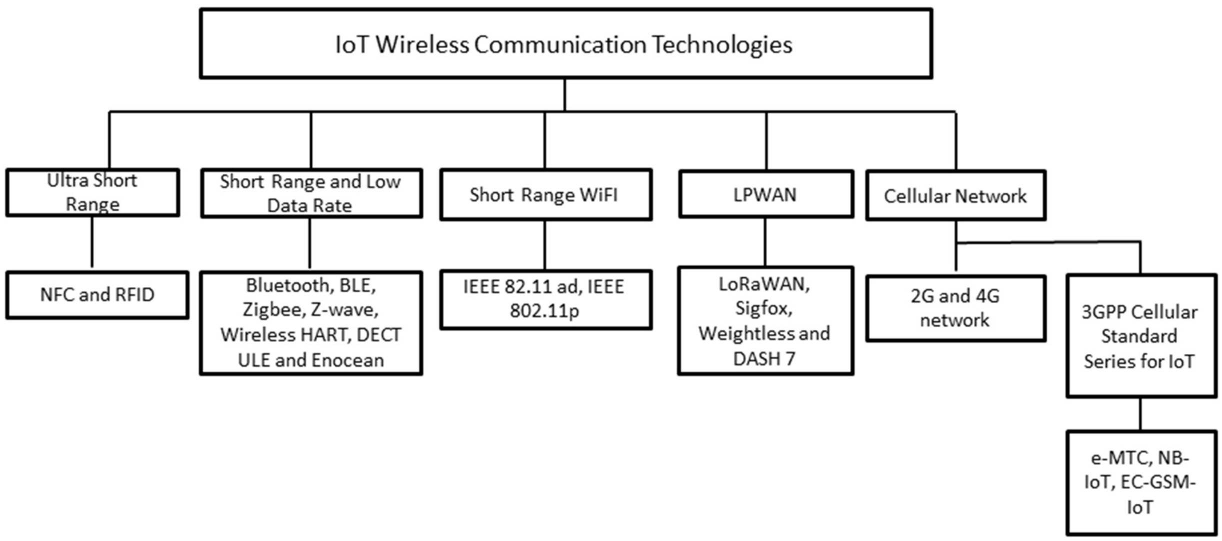


Fig. 14 Wireless Communication Technologies Classified Based on Communication Range

Apart from communication range, the other factors are also considered before selecting protocol for IoT enabled hydroponics setup. Table 5 gives the comparison of these protocols considering the data rate, power consumption and other factors.

Table 5 IoT Transmission Protocol Comparison

Parameter	Standard	Data Rate	Frequency Band	Power	Transmission Range	Cost
Wi-Fi	IEEE 802.11 a/c/b/d/g/n	1 mbps to 6.75 gbps	5 to 60 GHz	High	20 to 100 m	Large

LoRaWAN	LoRaWAN R1.0	0.3 to 50 kbps	868 to 90 MHz	Very Low	<30 km	Large
RFID	ISO-18000 6C	40 to 160 kbps	860 to 960 MHz	Low	1 to 5 m	Small
MQTT	OASIS	250 kbps	2.4 GHz	Low	-	Small
SigFox	SigFox	100 to 600 bits/s	200KHz	Low	30 to 50 km	Small
WiMax	IEEE 802.16	1 mbps to 1 gbps (fixed) 50 to 100 gbps (mobile)	2 to 66 GHz	Medium	<50 km	Large
Bluetooth	IEEE802.15.1	1 to 24 mbps	2.4 GHz	Very Low	8 to 10 m	Small
ZigBee	IEEE802.15.4	40 to 250 kbps	2.4 Hz	Low	10 to 20 m	Small

The comparison of different protocols based on transmission range, power consumption and other parameters enables one to decide on which protocol can be selected for any particular setup. ZigBee is preferred by most users where range is not the constraint. It is short range, low cost technology. However, if long range is the constraint, then LoRa or cellular network NB-IoT can be the better option. The limitations of LoRa are that it works on unlicensed frequency and NB-IoT has a higher cost.

When the application layer is considered which is actually the UI part in the system, CoAP is best followed by MQTT. In descending order of power consumption the IoT protocol sequence can be given as HTTP, AMQP, MQTT and CoAP. In terms of latency, regardless of quality of service, MQTT has higher latency than CoAP. For simple, small scale applications, REST and MQTT are preferred. For medium and large scale setups, MQTT, CoAP, REST are used and if required, MQTT-CoAP combination can also be implemented.

As end users are using smartphones nowadays with 5G connectivity, WiFi is also preferred for short range transmission in small scale systems, especially established in urban areas for domestic purposes.

9 Discussions on Microcontrollers

Smart hydroponic systems are installed in small and moderate settlements and can be monitored using microcontrollers. Varieties of controllers are available for smart farming. Being the central controlling element in the system, microcontroller receives the data collected from sensors and as per the need, converts it to digital format using ADC - analog to digital converter. Then the data is transferred to the central database, a server. It is stored in a repository over the server and can be accessed using a dashboard. With the help of an android application, data can be accessed by the end user. Any change in any parameter would be notified to the end user. Using control functions in the app, the user will monitor and control the field. the user commands will be transmitted and automation will be done without manual interference. The selection of microcontroller depends on the scale of the system as small/ medium/ large. IoT provides the connectivity between devices and a variety of controllers such as Arduino Uno, Arduino Nano, Arduino Mega, Raspberry Pi, NodeMCU etc. Some parameters are discussed here upon which controller can be selected.Processing Power - It is a very important criteria. Raspberry Pi comes with a clock speed of 133 MHz, ESP32 comes with 240 MHz. Both of them have dual core CPU and have capacity to run multi processes at the same time. However, ESP32 processing is faster than Raspberry Pi.

The Arduino controller family works on an even lower clock speed of 16 MHz. one more powerful processor is available with a PIC microcontroller, 25 MHz core speed. ARM controllers can be clocked up to 600 MHz.

1. Processor Memory - Performance of processor also depends upon the memory capacity. Arduino has a flash memory from 32kb to 256 kb for different variants. For Raspberry Pi, on-board RAM ranges from 256 MB to 8 GB. For ESP32, on chip flash memory is 4/ 8/ 16 MB. Fro AR controller LPC 2128, on-chip flash memory is 32kb-512 kb, SRAM is 8kb-40kb

2. Networking and Connectivity - ESP32 is proved to be the better option for connectivity in IoT systems, especially in the agriculture sector as it includes both WiFi and Bluetooth connectivity. Raspberry Pi Pico W has been launched in June 2022, it comes with WiFI connectivity but no bluetooth functionality is included.

3. Power Consumption - All the advanced controllers come with power saving technologies. Raspberry Pi Pico, according to datasheets, consumes 91 mA during the pop-corn test with disabled power saving mode. It provides two modes- dormant mode and sleep mode. The power consumption in dormant mode is lesser, but needs an external trigger to wake. ESP32 has six power modes - active, light-sleep, modem-sleep, deep-sleep, hibernation and power-off. Active mode with fully running functionalities can consume up to 240 mA current at a time. The hibernation consumes 5 μA. ESP32 can be woken up from any stage without external triggering.

It has been observed that most of the small scale settlements prefer Raspberry Pi or ESP32. So a comparison between these two is given in table 6.

It can be seen that ESP32 is more scalable. It has more RAM, flash memory, higher clock speed, wider operating temperature range. Bluetooth, ethernet and WiFi connectivity is offered by ESP32 than in Raspberry Pi Pico. Other interfaces are more scalable than in Raspberry Pi Pico, and it can accommodate more sensor handling. So, for small or medium scale operation in hydroponic systems, ESP32 can be a better option.

Table 6 Comparison between Raspberry Pi Pico and ESP32

	Raspberry Pi Pico	ESP32
Processor	ARM Cortex-MO+ Dual Core	Tensilica Xtensa LX6 32 bit Dual COre
RAM	264 KB	520 KB
Clock Speed	133MHz	80/160/240MHz
Operating Voltage	1.8-5.5 V	2.2-3.6 V
Operating Temperature	-20^0C to $+85^0$C	-40^0C to $+125^0$C
Flash	2MB	4MB
External Flash Support	16MB	16MB
RTC Memory	Not Specified	16 KB
WiFi	No	802.11 b/g/n
Bluetooth	No	Bluetooth 4.2, BLE
Ethernet	No	10/100 Mbps
Other Interfaces	2 x UART, 2 x I2C, 2 x SPI, 16 x PWM	2 x I2S, 2 x I2C, 3 x UART, 4 x SPI, 16 x PWM
Sensors	Temperature	Touch, Temperature, Hall Effect
GPIO	26, plus 3 analog pins	34 programmable pins

10 Role of AI-ML in Hydroponics

While going through the review, it can be seen that many setups are offering automation in hydroponics, partial or full system automation is done by many researchers. When it comes to advancements, Artificial Intelligence (AI) and Machine Learning (ML) are the buzzwords in modern technologies.

Through a combination of hardware configuration and a software application that can simulate a plant's growth trajectory, AI-driven "Smart Hydroponics" may calculate the best possible growth for a given plant. Data gathered by hardware sensors, or insights, are produced.

Each of the three categories of sensing equipment is thoughtfully positioned somewhere in the hydroponics farm. They gather information regarding the crop vitals, pH levels, electrical conductivity levels, and nutrient delivery while seated close to the plant roots. Additionally, they measure temperature, humidity, and light density. A visual camera examines the coloration of the developing plants as well and transmits the information to the AI software. On the other hand, machine learning produces insights on the precise nature and requirements of the items.

In India, artificial intelligence in hydroponics may still remain in its infancy. The promise of AI-driven Hydroponics farming is still not well known, despite the fact that a few prosperous hydroponics firms have been able to raise money and innovate using AI.

A few young "agripreneurs" who are trying to use innovation through AI to turn Indian agriculture into a niche industry are currently the only ones using AI in hydroponics.

These firms have developed to the point where the farmer may remotely monitor and manage the hydroponics farm using AI-driven automation devices and farm management software. As a result, hydroponic farms are becoming increasingly popular everywhere, not only in India.

Contribution of AI - In a hydroponics farm, germination of the seeds is the first step and is very essential for plant growth. The usual medium for germination is specialized soil, like coco peat. The seeds are repotted into a vertical soilless structure once they have grown and reached the desired height. It differs from plant to plant. At this stage, AI can be assigned to classify seeds in order to identify which plants will have the best germination rate.

Plant nutrition: In a hydroponics farm, the saplings must be carefully and precisely provided with nutrients in the right amounts. This measurement of the ideal nutrient level based on the crop profile can be delegated to AI.

AI Greenhouses: Proper and ideal conditions within the greenhouse are essential. The challenge of keeping the greenhouse's temperature consistent appears to be one that AI can handle. AI can automate greenhouse temperature control, which can then be managed using software. Intelligent farmers can equip themselves to control the greenhouse atmosphere based on the crops they are growing.

Proposed Work

Authors propose a hydroponic system with some research objectives. For a small garden or balcony area, the proposed set up can be implemented. Let us assume the area 7ft*3ft in a small terrace garden. Referring to the hydroponics cultivation methods, it can be seen that vertical farming would be a better option for small areas. NFT is available in flat bed structure and vertical half ‘A’ shape structure. In a given area, flatbed structure is not advisable. So a vertical NFT structure is proposed. With reference to table 3, NFT is better to cultivate green vegetables. This setup is proposed for domestic purposes, so market demands are not considered. In commercial cases, considering market demands, if the crop is finalized prior then hydroponic setup can be selected accordingly.

After finalizing the method, components are to be discussed. For NFT, PVC pipe structure is required. For vertical setup, the number of PVC pipes, planter holes needs to be calculated. For beginners or experimental analysis in a research perspective, one can opt for nearly 40 to 50 plants to analyze. This is the optimum number so that sufficient data is collected from plants and the system will be simple. As per experts opinion, for this type of half ‘A’ structure, the optimum height should not go beyond 2.5 meters. So there should be 6 channels, with the space between them around 8”.

Mathematically, the set-up is designed as follows:

*No of planters = No of channels * No. of openings in each channel* (2)

For 2 meters height, maintaining approximately 4” space between openings, 6 channels are ideal, each with 7 openings. Thus, *No of planters= 6 channels * 7 openings in each channel = 42* (3)

Fig 15 presents the proposed set up.

Fig 15 Proposed Hydroponic Setup Using Vertical Half 'A' Shape NFT

To push the water up to the top most channels, the motor speed should be calculated. For motors, H-max count is measured which is the measure of the height up to which the motor can pump the water upwards. For hydroponic requirements, considering 2.4 to 2.5 as H-max count, a 35W motor is preferred[32]. To push the water, a pump is required that is compatible with a 35 W motor. So, considering this, This motor can pump 40 liters of water per minute. Thus 42 planters set up with a motor of 2.4 H-max, 35W would be selected for small scale farming.

Nutrient tank is filled with nutrient water. All the essential nutrients are dissolved in water and with the help of a motor, this solution is pumped up to the top most channel of the system. Valves help collect the excess water. Sensors are attached to the channels to check the pH level of solution, Total Dissolved Solids (TDS) in the solution and Electrical Conductivity (EC) of the solution. Water temperature, air temperature and humidity can also be checked using sensors. These sensors are connected to a microcontroller and data is stored to the web server. The transfer of data is done using communication protocols. Web server data can be accessed by remote users and parameters can be monitored and controlled using this data.

Open Issues and Challenges

Farmers are very much used to the traditional ways of farming. They are more comfortable with methods that are used for years. Making them friendly with new technology is a major concern. Selection of hydroponic techniques may need some experimentation, especially at the initial stage. Also, selection of proper crop seed type (stem crop/ root crop/ leafy crop) also takes some time.

Technically, installation of hardware is a crucial task. Sensors would be continuously in touch with moisture/ water flow pipes etc. So to gather data from sensors without fail is a tedious task to do. Hydroponic farming needs more technical knowledge than that of traditional soil farming. Beginners can acquire it from various videos, review and research papers and mostly from experience. As it can be seen that the precise level of dissolved nutrients, pH, and temperature are the most important parameters, one has to take care of the quantity of these parameters. These are the factors that may affect the crop:

a) Leakage: Due to various reasons, set up may face leakage problems, especially NFT systems. When a root mass clogs the NFT system, it causes the water to back it up and spill.

Also, if the reservoir is not able to store all of the nutrient solution in the system, it may leak. Power outage, pump failure may cause the overflow. In such issues, one has to test the system thoroughly, tighten the valves and check all the connections. Further, root overgrowth, clogged drains are to be checked regularly. Reservoir needs to be selected such that it should comfortably contain all the required nutrient solutions in the system. Various IoT enabled sensors would help to observe the set up continuously. Automation reduces human interference also. [22, 23]

b) Nutrient deficiency and Toxicity: A little more experience will help find out the reasons behind deficiency and toxicity. In general, change in the values of pH, electrical conductivity or proportion of dissolved solids causes the deficiency or toxicity. Continuous observation on these values will be effective to maintain the quality of nutrient solution. To overcome this issue, the nutrient solution should be made precisely. Water used for this purpose should not be too strong. In such cases, distilled water or reverse osmosis processed water can be used to make the required solution. Activated carbon filter is one of the solutions to make the water usable for hydroponic set up. Change in the color of plant root or other parts of plants, fruits etc. can be captured and compared with the database. This is done nowadays using image processing, machine learning and data science. These platforms help detect the abnormalities or diseases in plants at the very initial stage and reduce the potential losses in crop yield. [19, 20]

c) Infestation: Even if the plants are grown under controlled environment, infestation cannot be completely avoided. The main factor to cause the infestation is algae. It can absorb the nutrient solution and stop the plant growth. This can be reduced by painting the reservoir tank in black color. Also, reducing the sunlight exposure helps to decrease the algae development. Overwatering the plants increases algae so water supply should be just enough. [23-26]

All these challenges can be overcome using artificial intelligence (AI), automation and data science. Changes in growing media parameters, the appearance of plants etc. can be tracked and monitored by sensors, image processing. Using a database of healthy as well as infected plants, the abnormalities can be traced. This reduces human efforts up to a great extent. In traditional methods, all these procedures required a human being to check, keep track and take necessary actions. Automation and a combination of AI-ML would surely help take earlier actions.

At the end, when it comes to the initial investment, return on investment is a challenge initially for small and medium scale farming..

Despite various challenges, efficient use of technology would be helpful for modern farming. IoT enabled sensors and smart systems would reduce human efforts and increase crop production. Using cellular technology, users can control their field from their smartphones. For small scale farmers, short range data transfer channels would be more useful. Furthermore, adding Artificial Intelligence (AI) into farming would reduce the chances of loss of crops. Prediction and detection of pest attacks, reduced level of nutrients, disease detection in crops and climate changes can easily be achieved by AI resulting in better quality and quantity of crops.

Conclusions

This work presents the current deployments in Hydroponics farming. Among the six types of hydroponic farming, any one type can be selected as per the crop variety. Crop variety depends on the land availability. One can go with the beginners set up that starts with easy-to-grow crops and basic infrastructure. For further advancements, many technologies can be implemented like IoT, Cloud Computing, and Machine Learning etc. According to the range of wireless communication, appropriate communication gateway can be selected. Appropriate hardware and sensor network gives the accurate values. Continuous monitoring would help get better produce. With some limitations in cost effectiveness and other challenges, hydroponics is a future in smart farming. To achieve the sustainable development growth target, traditional practices have to be gradually replaced by modern advancements.

References

1. K. A. Jani and N. K. Chaubey, "A Novel Model for Optimization of Resource Utilization in Smart Agriculture System Using IoT (SMAIoT)," in IEEE Internet of Things Journal, vol. 9, no. 13, pp. 11275-11282, 1 July1, 2022, doi: 10.1109/JIOT.2021.
2. T. A. M., R. U. G. K. L. P. S., M. F. A. Sakee, I. M. M. M, H. Mahaadikara and S. Wellalage, "Fully Automatic Hydroponic Cultivation Growth System," 2021 3rd International Conference on Advancements in Computing (ICAC), Colombo, Sri Lanka, 2021, pp. 205-209, doi: 10.1109/ICAC54203.2021.9671167.
3. R. S. Al-Gharibi, "IoT-Based Hydroponic System," 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-6, doi: 10.1109/ICSCAN53069.2021.9526391.
4. 3128161N. Bakhtar, V. Chhabria, I. Chougle, H. Vidhrani and R. Hande, "IoT based Hydroponic Farm," 2018 International Conference on Smart Systems and Inventive Technology (ICSSIT), Tirunelveli, India, 2018, pp. 205-209, doi: 10.1109/ICSSIT.2018.8748447.
6. P. P. V, S. S M and S. S. C, "Robust Smart Irrigation System using Hydroponic Farming based on Data Science and IoT," 2020 IEEE Bangalore Humanitarian Technology Conference (B-HTC), 2020, pp. 1-4, doi: 10.1109/B-HTC50970.2020.9297842.
7. G. Manogaran, M. Alazab, K. Muhammad and V. H. C. de Albuquerque, "Smart Sensing Based Functional Control for Reducing Uncertainties in Agricultural Farm Data Analysis," in IEEE Sensors Journal, vol. 21, no. 16, pp. 17469-17478, 15 Aug.15, 2021, doi: 10.1109/JSEN.2021.3054561.
8. K. Wongpatikaseree, N. Hnoohom and S. Yuenyong, "Machine Learning Methods for Assessing Freshness in Hydroponic Produce," 2018 International Joint Symposium on Artificial Intelligence and Natural Language Processing (iSAI-NLP), Pattaya, Thailand, 2018, pp. 1-4, doi: 10.1109/iSAI-NLP.2018.8692883.
9. U. Arora, S. Shetty, R. Shah and D. K. Sinha, "Automated Dosing System in Hydroponics with Machine Learning," 2021 International Conference on Communication information and Computing Technology (ICCICT), Mumbai, India, 2021, pp. 1-6, doi: 10.1109/ICCICT50803.2021.9510115.
10. A. Ani and P. Gopalakirishnan, "Automated Hydroponic Drip Irrigation Using Big Data," 2020 Second International Conference on Inventive Research in Computing

Applications (ICIRCA), Coimbatore, India, 2020, pp. 370-375, doi: 10.1109/ICIRCA48905.2020.9182908.

11. Helmy, E. U. Sari, T. A. Setyawan, A. Nursyahid, K. A. Enriko and S. Widodo, "Automatic Control of Hydroponic Nutrient Solution Concentration Based on Edge and Cloud Computing Using Message Queuing Telemetry Transport (MQTT) Protocol," 2021 8th International Conference on Information Technology, Computer and Electrical Engineering (ICITACEE), 2021, pp. 207-212, doi: 10.1109/ICITACEE53184.2021.9617513.
12. Qiong and P Hao, "Design and Implementation of Irrigation Water Saving Control System Based on WSND", 2021 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), Xi'an, China, 2021, pp. 75-78, doi: 10.1109/ICITBS53129.2021.00027.
13. H. A. Alharbi and M. Aldossary, "Energy-Efficient Edge-Fog-Cloud Architecture for IoT-Based Smart Agriculture Environment," in IEEE Access, vol. 9, pp. 110480-110492, 2021, doi: 10.1109/ACCESS.2021.3101397.
14. T. Namgyel et al., "IoT based hydroponic system with supplementary LED light for smart home farming of lettuce," 2018 15th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Chiang Rai, Thailand, 2018, pp. 221-224, doi: 10.1109/ECTICon.2018.8619983.
15. S. Dudala, S. K. Dubey and S. Goel, "Microfluidic Soil Nutrient Detection System: Integrating Nitrite, pH, and Electrical Conductivity Detection," in IEEE Sensors Journal, vol. 20, no. 8, pp. 4504-4511, 15 April15, 2020, doi: 10.1109/JSEN.2020.2964174.
16. E. -T. Bouali, M. R. Abid, E. -M. Boufounas, T. A. Hamed and D. Benhaddou, "Renewable Energy Integration Into Cloud & IoT-Based Smart Agriculture," in IEEE Access, vol. 10, pp. 1175-1191, 2022, doi: 10.1109/ACCESS.2021.3138160.
17. A. K. Aliyana, P. Ganguly, A. Beniwal, S. K. N. Kumar and R. Dahiya, "Disposable pH Sensor on Paper Using Screen-Printed Graphene-Carbon Ink Modified Zinc Oxide Nanoparticles," in IEEE Sensors Journal, vol. 22, no. 21, pp. 21049-21056, 1 Nov.1, 2022, doi: 10.1109/JSEN.2022.3206212.
18. S. V. S. Ramakrishnam Raju, Bhasker Dappuri, P. Ravi Kiran Varma, Murali Yachamaneni, D. Marlene Grace Verghese, and Manoj Kumar Mishra, "Design and Implementation of Smart Hydroponics Farming Using IoT-Based AI Controller with Mobile Application System
1. ", Vol 2022 Article ID 4435591 https://doi.org/10.1155/2022/4435591
19. Halveland, J. (2020). Design of a Shallow-Aero Ebb and Flow Hydroponics System and Associated Educational Module for Tri Cycle Farms. Biological and Agricultural Engineering Undergraduate Honors Theses Retrieved from https://scholarworks.uark.edu/baeguht/76
20. Chowdhury, M.E.H.; Khandakar, A.; Ahmed, S.; Al-Khuzaei, F.; Hamdalla, J.; Haque, F.; Reaz, M.B.I.; Al Shafei, A.; Al-Emadi, N. Design, Construction and Testing of IoT Based Automated Indoor Vertical Hydroponics Farming Test-Bed in Qatar. *Sensors* **2020**, *20*, 5637. https://doi.org/10.3390/s20195637

21. V Palandea, A Zaheera, and K Georgea "Fully Automated Hydroponic System for Indoor Plant Growth", 2017 International Conference on Identification, Information and Knowledge in the Internet of Things https://doi.org/10.1016/j.procs.2018.03.028
22. E. D. Nugroho, A. G. Putrada and A. Rakhmatsyah, "Predictive Control on Lettuce NFT-based Hydroponic IoT using Deep Neural Network," 2021 International Symposium on Electronics and Smart Devices (ISESD), Bandung, Indonesia, 2021, pp. 1-6, doi: 10.1109/ISESD53023.2021.9501402.
23. Wiedjaja Atmadja et al, "Indoor Hydroponic System Using IoT-Based LED", 2022 IOP Conf. Ser.: Earth Environ. Sci. 998 012048
24. D. K. Singh and R. Sobti, "Wireless Communication Technologies for Internet of Things and Precision Agriculture: A Review," 2021 6th International Conference on Signal Processing, Computing and Control (ISPCC), Solan, India, 2021, pp. 765-769, doi: 10.1109/ISPCC53510.2021.9609421.
25. Velazquez-Gonzalez, R.S.; Garcia-Garcia, A.L.; Ventura-Zapata, E.; Barceinas-Sanchez, J.D.O.; Sosa-Savedra, J.C. A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations. *Agriculture* 2022, *12*, 646. https://doi.org/10.3390/agriculture12050646
26. F. Modu, A. Adam, F. Aliyu, A. Mabu, Mahdi Musa "A Survey of Smart Hydroponic Systems", Advances in Science, Technology and Engineering Systems Journal, vol. 5, no. 1, pp. 233-248 (2020).
27. A. Pagano, D. Croce, I. Tinnirello and G. Vitale, "A Survey on LoRa for Smart Agriculture: Current Trends and Future Perspectives," in IEEE Internet of Things Journal, vol. 10, no. 4, pp. 3664-3679, 15 Feb.15, 2023, doi: 10.1109/JIOT.2022.3230505.
28. N. ElBeheiry and R. S. Balog, "Technologies Driving the Shift to Smart Farming: A Review," in IEEE Sensors Journal, vol. 23, no. 3, pp. 1752-1769, 1 Feb.1, 2023, doi: 10.1109/JSEN.2022.3225183.
29. Seerat Jan, Zahida Rashid, Tanveer Ahmad Ahngar, Sadaf Iqbal, M. Abbass Naikoo, Shabina Majeed, Tauseef Ahmad Bhat, Razia Gul1 and Insha Nazir, " Hydroponics – A Review" International Journal of Current Microbiology and Applied Sciences 9(8):1779-1787
30. B. Almadani and S. M. Mostafa, "IIoT Based Multimodal Communication Model for Agriculture and Agro-Industries," in IEEE Access, vol. 9, pp. 10070-10088, 2021, doi: 10.1109/ACCESS.2021.3050391.
31. M. S. Farooq, S. Riaz, M. A. Helou, F. S. Khan, A. Abid and A. Alvi, "Internet of Things in Greenhouse Agriculture: A Survey on Enabling Technologies, Applications, and Protocols," in IEEE Access, vol. 10, pp. 53374-53397, 2022, doi: 10.1109/ACCESS.2022.3166634.
32. T. Ojha, S. Misra and N. S. Raghuwanshi, "Internet of Things for Agricultural Applications: The State of the Art," in IEEE Internet of Things Journal, vol. 8, no. 14, pp. 10973-10997, 15 July15, 2021, doi: 10.1109/JIOT.2021.3051418.
33. S. Qazi, B. A. Khawaja and Q. U. Farooq, "IoT-Equipped and AI-Enabled Next Generation Smart Agriculture: A Critical Review, Current Challenges and Future

Trends," in IEEE Access, vol. 10, pp. 21219-21235, 2022, doi: 10.1109/ACCESS.2022.3152544.

34. V. P. Kour and S. Arora, "Recent Developments of the Internet of Things in Agriculture: A Survey," in IEEE Access, vol. 8, pp. 129924-129957, 2020, doi: 10.1109/ACCESS.2020.3009298.
35. M. Ayaz, M. Ammad-Uddin, Z. Sharif, A. Mansour and E. -H. M. Aggoune, "Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk," in IEEE Access, vol. 7, pp. 129551-129583, 2019, doi: 10.1109/ACCESS.2019.2932609.
36. M. S. Farooq, R. Javid, S. Riaz and Z. Atal, "IoT Based Smart Greenhouse Framework and Control Strategies for Sustainable Agriculture," in IEEE Access, vol. 10, pp. 99394-99420, 2022, doi: 10.1109/ACCESS.2022.3204066.
37. https://www.cdac.in/index.aspx?id=pe_awcs_HydroponicsSystemImg
38. https://www.acquafarms.org/
39. https://www.agrifarming.in/earning-up-to-3-crores-per-year-from-soilless-farming-a-success-story-of-a-hydroponic-farmer-in-india
40. https://www.eeki.com/
41. https://www.thebetterindia.com/311587/nashik-engineer-quit-job-to-grow-saffron-in-shipping-container-hyroponics-earn-lakhs/