Design and Development an IoT Based Real-Time Agriculture Plant Monitoring System

Nasir Uddin^{1✉}, Dipta Barua¹, Md. Aminul Islam^{2✉}

¹School of Science Engineering and Technology, East Delta University, Abdullah Al Noman Road, Noman Society, East Nasirabad, Khulshi, Chattogram 4209, Bangladesh

²Department of Materials Science and Engineering, Rajshahi University of Engineering and Technology, Rajshahi 6204, Bangladesh

Received: May 30, 2021

Revised: December 04, 2021

Accepted: December 07, 2021

Keywords

IoT

Agriculture

Monitoring

ESP8266

Cloud

Thing Speak

Abstract: The agricultural sector plays an important role in Bangladesh that contributing 19.6 % to the national GDP and providing employment to 63 % of the population. So, it is needed to digitalize this sector to make it more productive and effective. Therefore, it is essential to monitor and analyze the real-time agriculture condition data for future improvement. In this project, we have used different sensors such as temperature sensor and humidity sensor soil moisture sensor and pH sensor to monitor the ambient temperature, humidity, moisture content in soil and pH level of water respectively. Node MCU ESP8266 and ThinSpeak have been used as microcontroller and web servers respectively. Using these sensors, it can be monitored the real-time data on the server and controlled from a remote location. This system also has an option to store data in a convenient place. The water pump turns on and off automatically depending on moisture level.

© 2021 The authors. Published by EDU Journal of Computer and Electrical Engineering. This is an open access article under the CC BY NC license.

1. INTRODUCTION

Agriculture plays an important role in feeding the world in a healthy way. In recent decades, the agro-food sector has already realized big achievements in meeting critical challenges [1]. Day by day, the population increase rapidly, while agricultural land decrease due to industrialization and climate change. It has been predicted that a 70% increase in agricultural food production will be required by 2050 [2]. Therefore, technology-aided smart agriculture practice is essential for high highly efficient and sustainable food production [3]. Globally, the market of the smart agriculture system is in an increasing trend and it is expected to reach \$15.3 Billion by the end of 2025 [4]. So precise monitoring and control of the agriculture process is necessary to increase the efficiency and productivity of the system. Recently internet of things (IoT) has been introduced in the agriculture system, which increases agriculture yield and production [5]. IoT comprises smart web interface objects with sensing, identifying and remotely controlling capacity [6-8]. The basic architecture of IoT is shown in Figure 1. There are four significant layers (i) physical layer consists of different sensors, transducer, actuator or other physical devices [9] (ii) communication layer: consist of

different networking system used to transfer accurate and secure data to different computing devices. There are some common technologies used such as Wi-Fi, WiMAX, Ethernet, Zigbee, Long-range wide area network (LoRaWAN), Radiofrequency Identification (RFID) and Bluetooth low energy (BLE) etc. [10-13] (iii) cloud layer: consists of database, big data processing and different computing technologies to receive, store and analyze data collected in physical layer [14] (iv) service layer consists of web/mobile interfaces which enable users to view the processed data in different visual forms (graphs, chart or spreadsheet etc.) and control the connected devices in IoT system [15]. The agricultural plant monitoring system is needed to check temperature monitoring, control water pH level, and soil moisture level etc. The success of agriculture plants is highly dependent on climate and environmental factors such as soil moisture, water condition, the temperature of the growth environment, and humidity [16]. All these parameters are required to maintain an optimum level to ensure better crop quality. In addition, the utilization of an IoT-based monitoring system enables the optimal use of the resources. The advantages of IoT in agriculture are water conservation, real-time data,

✉Corresponding author. E-mail address: nasirmohammadbd@gmail.com (Nasir Uddin), aminulmse@gmail.com (Md. Aminul Islam)

This work is licensed under a Creative Commons Attribution 4.0. License (CC BY NC 4.0)

Available online at <http://edu-journals.com/index.php/ejee>

<https://doi.org/10.46603/ejee.v2i1.26>

lowered operation costs, increased quality of production, remote monitoring.

Figure 1. Structure of Internet of Things (IoT) [8].

Moreover, various stakeholders such as contractors, veterinarians, agronomists, suppliers, and inspection companies, etc., also benefited from IoT-based agriculture systems. Numerous works on IoT-based agriculture systems have been found in the literature. Alipio et al. [17] developed a smart hydroponic system in automating the growing process of the crops using Bayesian Network (BN) techniques, sensors, and actuators installed at the agriculture field to control pH, the acidity of the soil, water temperature and humidity. They managed to increase productivity 66.67% higher than using manual control. Kamilaris et al. [18] also proposed an adaptive IoT framework for smart farming, called Agri-IoT, which can support various IoT devices. Online information source is available and also possible to stream on the web. Akkas et al. [19] present a system that monitors environmental parameters related to the greenhouse with the help of IoT and is also possible to control from mobile phones and computers. Hassan et al. [20] developed an irrigation system that detects moisture, then watering automatically that controlled by a smartphone with IoT functionality. Gautam et al. [21] made a system that set up irrigation time based on temperature and humidity using GSM. A Bluetooth module was used that sent field data within a limited range. Mathurkar et al. [22] developed a monitoring system based on a smart sensor using field programmable gate array with a display element. A microcontroller with Bluetooth module transmits and receives data from various sensors using serial communication and data was displayed on an LCD unit. However, the application of IoT in agriculture is challenging, especially because of the high uncertainty of business processes. The main objective of this project is to focus on the design and development of the prototype of an agriculture monitoring system with cloud-server based remote monitoring. In the work presented below, a microcontroller with Wi-Fi module collects data through temperature and humidity sensors, soil moisture sensor and pH level sensor. This data is sent to the cloud-server named 'ThingSpeak', which shows real-time data and users can monitor the data from remote location.

2. ARCHITECTURE OF PROPOSED SYSTEM

Block diagram of the proposed system is shown in Figure 2. Node MCU ESP8266 is used as a microcontroller that collects input data through Temperature and Humidity sensors, Moisture sensor and pH sensor. Then, send this data to the cloud server through Wi-Fi module. And relay module turns on and off the motor depending on soil moisture level. The ESP8266 is a low cost MCU widely used to build different IoT-based intelligent agro-tech systems [23, 24].

Figure 2. Block Diagram of Proposed System.

The hardware setup of the proposed system is shown in Figure 3 and the different components such as buck converter, pH level module, relay module, moisture sensor module and ESP8266, etc., are marked in the picture.

Figure 3. Complete hardware setup of the project.

2.1 Power Unit

A power adapter has been used that converts 220 volts to 12 volts, and a buck converter that changes 12 volts to 5 volts and current 3A with excellent line and load regulation. These devices are likewise accessible in fixed yield voltages of 3.3 V, 5 V, 12 V, and

an adjustable output version. The LM2596 arrangement works at a switching frequency of 150 kHz, consequently permitting more modest estimated channel parts than what might be needed with lower frequency switching controllers. A solar panel can be used to increase the efficiency of the project by reducing grid power consumption.

2.2 Microcontroller unit

ESP8266 has been used as a microcontroller, as shown in Figure 4. It has 16 GPIO pins that take the input signal from the temperature sensor, soil moisture sensor, pH sensor and process the data. It also has a built-in Wi-Fi module that helps communication with the cloud server, and users can easily monitor the real-time data from a remote location. The range of the Wi-Fi module was 300m in line of sight outdoors and in indoor 10m, where the signal has to pass 2 or 3 walls. The Controller board used in this system is Node MCU. Node MCU is an open-source IoT platform. It includes firmware that runs on the ESP8266 Wi-Fi. The feature of Node MCU is shown in Table 1 [25].

Figure 4. Micro controller unit (ESP8266).

Table 1. Features of Node MCU.

Features	Description
Microcontroller	ESP8266
Communication	UART-CH340
Operating voltage (logic label)	3.3V
Digital I/O pins	16
Analog Input pins	1
Flash memory	4 Mega Bytes
Clock Speed	80MHz
EEPROM	512 KB
Dimensions	2.54mm

2.3 Temperature & Humidity Sensor

Both temperature and moisture monitoring are very crucial for agricultural yields. In the presence of high humidity, crops are more vulnerable to various diseases, fungi, and parasites that flourish in moist conditions. Furthermore, high temperature has similar effects regarding affecting the stomata. However, it can have a contrary impact. So that, Temperature & Humidity sensors monitoring is very important. Using sensors, a person can monitor the temperature and humidity level and take preventive measures to suppress the problems. DHT11 sensor has been used to monitor temperature and humidity as shown in Figure 5. The

sensor can measure temperature from 0°C to 50°C and humidity from 20% to 90% with an accuracy of $\pm 1^\circ\text{C}$ and $\pm 1\%$.

Figure 5. DHT11 Temperature Sensor.

2.4 Soil Moisture Sensor

Soil moisture is the water stored in the soil and is influenced by precipitation, temperature, and soil attributes. The health of crops depends upon a sufficient stockpile of moisture and soil supplements. As moisture accessibility decreases, the ordinary capacity and development of plants are disturbed, and crop yields are diminished. A resistive moisture sensor has been used in this system, as shown in Figure 6, to determine the moisture level of the soil. It gives a digital signal depending on the soil moisture level. According to the results, the pump turns on and off. Here, a DC motor pump has been used that turns ON and OFF according to the feedback of the soil moisture sensor. In a real case, a two-horsepower (HP) pump provides sufficient water in a 10000 square meter plant in 30 minutes.

Figure 6. Soil Moisture Sensor.

2.5 pH Level Monitoring Sensor

A pH sensor as shown in Figure 7, has been used to measure pH level of water (concentration of hydrogen ions (H^+) in water. Generally, the plants flourish within a pH level of 5.5 to 6.5. Below that, water is acidic and above that alkaline or basic in nature. The pH level above or underneath these limits brings less lively development and supplement lacks for the agriculture plants. Using this sensor, it can monitor the value of pH in water within a range from 0 to 14. By measuring the pH value, a person takes action. Such as adding lime, wood debris, or a specially formulated solution to the water to raise the pH or add sulphur, phosphoric acid, or a pH bringing arrangement down to bring down the pH level.

Figure 7. pH Level Monitoring Sensor.

2.6 ThingSpeak

ThingSpeak is an open-source Internet of Things (IoT) application and API to store and recover information from things utilizing the HTTP and MQTT protocol over the internet or through a Local Area Network. ThingSpeak empowers the formation of sensor logging applications, area following applications, and an interpersonal organization of things with notices [26]. The “Thingspeak” has been used as a cloud server in this project. Advantages of this server are (i) it is possible to monitor real-time data from a remote location, (ii) the site provides free services with limited applications. Clients of the free alternative will be restricted to sending close to 3 million messages every year to the ThingSpeak administration. Clients of the free permit will also be limited to 4 channels. Each channel stores up to 8 fields of data.

2.7 Relay Module

Relay is used to control the circuit by separate low power signal [27]. The relay used in this system was a 5 V relay to drive a higher output voltage, as shown in Figure 8. The features with a description of the individual pin of the relay are shown in Table 2.

Figure 8. 5-Volt Relay Module.

Table 2. Physical parameters for Cadmium Telluride structure.

Pin Number	Pin Name	Description
1	Coil end 1	To trigger the relay. One end is connected to 5v and the other to the ground
2	Coil end 2	To trigger the relay. One end is connected to 5 V
3	COM	and the other to the ground
4	NC	Connected to one end that needs to be controlled
5	NO	If the other end is connected to NC, the load remains connected before the trigger

3. WORKING PROCEDURE

A flow chart of the working procedure of this project is presented in Figure 9. After getting power, ESP8266 and all sensors are initiated. The temperature and humidity sensor starts to check the temperature and humidity of the plant and then sends data to the cloud server. Same way, the moisture sensor senses the soil moisture and then sends the data to the cloud. If the moisture level is low, it initiates the pump. When the moisture level is high, the pump will be off automatically. Finally, the pH sensor checks the pH level of water and sends the data to the cloud. Finally, cloud servers show all data in numerical and graphical views that will help to monitor real-time data.

Figure 9. System Flow Chart.

4. OUTPUT RESULTS

In this study, different sensors have been used to monitor the agriculture firm’s environmental conditions such as ambient temperature, humidity, feedwater pH level and soil moisture, etc. The output results of these sensors can be monitored from a remote area on the ThingSpeak web page.

4.1 Temperature Monitoring

Figure 10 represents the graphical representation of temperatures with respect to varying time (a) and the instantaneous value of temperature (b) in the ThingSpeak web page. Temperature is one of the major factors affecting plant development and productivity [28]. The most temperature sensitive stage is the pollination for almost all species [29]. Optimum temperatures for growth and yield of different agriculture crops were reported in the literature [30-32]. Figure 11 shows the effect of temperature on the growth of broccoli and maize. It has been reported that maize yield rate reduces to 80-90% due to the impact of warmer temperature compared to normal temperature [29]. By monitoring ambient temperature, farmers can decide the suitable time period for the cultivation of a specific crop. And also can control the temperature within a greenhouse chamber.

4.2 Humidity Monitoring

The measured value of humidity in % with respect to time and instantaneous values are shown in Figure 11 (a) and (b), respectively. Humidity is also an essential factor for agriculture plant growth and development [33]. In greenhouses or plastic tunnels, it is crucial to monitor and maintain the optimum humidity for particular crops [34]. Humidity Higher the

optimum level leads to plant water stress and reduces the plant growth and development, and higher the optimum level causes diseases infection [35, 36].

4.3 Soil Moisture and Water Pump

The moisture content in soil has been measured by a resistive type soil moisture sensor. The soil resistance is inversely

proportional to the moisture content in the soil. The sensor produces an output voltage according to the resistance of soil which indicates the moisture level in the soil. With the increase of moisture level, the soil resistance decreases; as a result, the output voltage also increases and vice versa [37].

Figure 10. Temperature monitoring in (a) Graphical View (b) numerical value.

Figure 11. Growth response of Broccoli and Maize in different temperature range [29].

Figure 12. Humidity monitoring in (a) Graphical View (b) numerical value.

The output voltage readings from the device were obtained by following Equation number (1).

$$V_o = (ADC / 1023) \times V_{in} \quad (1)$$

Where V_o is output voltage, ADC is the analog read values and V_{in} is the input voltage equal to 5V. The output voltage for dry soil was found 1.4 V corresponds to 300 ADC value. This value was taken as a threshold to turn ON the motor. Near about 15wt% water has been added to soil to wet enough. The output voltage of wetted soil was 3.4V corresponding to 700 ADC value. Figure 12 shows the moisture condition of the soil. The zero states indicate the dry condition and “1” state means the wet condition of the soil. If the moisture level is zero condition, the pump will be started automatically, and when soil becomes wetted, then the water pump stops. Figure 13 shows the pump condition where green presents for running and red presents for off conditions. Automated pump control system where water pump on and off automatically depends on the moisture level in soil has a significant impact on the total water needed in different agricultural systems. Table 3 shows the impact of an automated irrigation system in reducing the amount of water required during the cultivation of different crops in India. Maximum 38.5% water can be saved in the wheat cultivation per hectare by using an automated irrigation system compared to a conventional irrigation system.

Table 3. Water saving in automated irrigation system [38].

Crops	Water savings per hectare (%)
Wheat	25-38.5
Rice	0-20
Potato	20-28.5
Sugarcane	26.5-6-28

4.4 pH Monitoring

Figure 14 represents the graphical representation of pH level of water with respect to varying time (a) and the instantaneous value (b) on the ThingSpeak web page. By monitoring the temperature, pH and humidity values, farmer can take action to maintain these parameters within an optimum level. For example, soil pH can be controlled by adding appropriate fertilizer.

Figure 13. Moisture monitoring in Graphical View (0 means dry, 1 means wet).

Figure 14. Pump indication.

Massive researches have been reported in the literature to make the agriculture sector more intelligent and smart by integrating IoT [39-42]. The researcher proposed installing intelligent devices in the agriculture field to constantly monitor ambient conditions, plant diseases, soil fertility, moisture conditions, etc., in these IoT-based agriculture systems. The most widely used processors are Arduino ARM and Raspberry PI-based. Comparative evaluation of this project with other proposed reports in the literature has been depicted in Table 3.

Figure 15. Feed water pH level monitoring in (a) Graphical View (b) numerical view.

Table 4. Comparative view of this work with research works published in the literature.

Ref.	Sensors Used	Microcontroller or Board	Communication Technologies
[43]	Soil moisture sensor	Arduino	WiFi, ZigBee, LoRa WAN
[44]	Temperature, RH, WS, WD, PM 2.5, PM 10	Microcontroller based (STM32L011)	LoRa
[45]	DHT22, Soil moisture sensor	Arduino	ZigBee
[46]	DHT11, TGS813, SO ₂ gas, PIR motion, pH	Microcontroller based Arduino	RF (nRF24201)
This work	DHT11, Soil moisture sensor, pH,	Microcontroller unit (ESP8266)	WIFI

Many companies like Cropin [47] provide the digitalizing infrastructure for the agriculture sector. They provide continuous monitoring facilities for crop growing conditions and send to the farmers with an approximate annual cost of 6.6 USD to 13.3 USD per hectare [38]. The cost breakdown of this project is depicted in Table 5. The total cost of this project was 6675 BDT.

Table 5. Cost breakdown of the project.

Component	Price (BDT)
Micro controller unit (ESP8266)	445
DHT11 Temperature Sensor	180
Soil Moisture Sensor	100
pH Level Monitoring Sensor	3000
Buck Converter	100
5-volt Relay Module	300
12V 5A AC Power Adapter	450
Dc Motor	600
Wire and others materials	1500
Total	6675

5. CONCLUSIONS

An IoT-based smart agriculture plant monitoring system has been developed. Different physical conditions such as temperature, humidity, dryness of the soil, pH condition of irrigated water etc., can be monitored from any place by avail of internet. This project gives a more gainful way to deal with agribusiness robotization, which is completed using Node MCU ESP8266. By using sensors, appropriate inspection about varying moisture, temperature, and humidity levels will be made conscious to the farmers. Node MCU and ThingSpeak act as the server system. Users can monitor the conditions of the firms. Once the low level of moisture on the soil is detected, the water pump turns on automatically and turns off when it detects a sufficient level of moisture. In the ThingSpeak web server, the level of moisture and pump running conditions are monitored.

REFERENCES

- [1] C. Verdouw, H. Sundmaeker, B. Tekinerdogan, D. Conzon, T. J. C. Montanaro, and E. i. Agriculture, "Architecture framework of IoT-based food and farm systems: A multiple case study," vol. 165, p. 104939, 2019.
- [2] M. M. Syeed, M. A. Islam, and K. Fatema, "Precision Agriculture in Bangladesh: Need and Opportunities," *Precision Agriculture*, vol. 29, no. 04, pp. 6782-6800, 2020.
- [3] A. Tzounis, N. Katsoulas, T. Bartzanas, and C. Kittas, "Internet of Things in agriculture, recent advances and future challenges," *Biosystems Engineering*, vol. 164, pp. 31-48, 2017.
- [4] M. A. Ferrag, L. Shu, X. Yang, A. Derhab, and L. Maglaras, "Security and Privacy for Green IoT-Based Agriculture: Review, Blockchain Solutions, and Challenges," *IEEE Access*, vol. 8, pp. 32031-32053, 2020. doi: 10.1109/ACCESS.2020.2973178.
- [5] M. Farooq, S. Riaz, A. Abid, K. Abid, and M. Naeem, "A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming" *IEEE Access*, vol. 7, pp. 156237-156271, 2019.
- [6] M. S. Farooq, S. Riaz, A. Abid, T. Umer, and Y. B. Zikria, "Role of IoT Technology in Agriculture: A Systematic Literature Review," *Electronics*, vol. 9, p. 319, 2020.
- [7] J. Wang, M. K. Lim, C. Wang, and M.-L. Tseng, "The evolution of the Internet of Things (IoT) over the past 20 years," *Computers & Industrial Engineering*, vol. 155, p. 107174, 2021.
- [8] K. Lawal and H. N. Rafsanjani, "Trends, Benefits, Risks, and Challenges of IoT Implementation in Residential and Commercial Buildings," *Energy and Built Environment*, 2021. doi.org/10.1016/j.enbenv.2021.01.009.
- [9] P. Sethi and S. R. Sarangi, "Internet of Things: Architectures, Protocols, and Applications," *Journal of Electrical and Computer Engineering*, vol. 2017, p. 9324035, 2017.
- [10] P. P. Ray, "A survey on Internet of Things architectures," *Journal of King Saud University - Computer and Information Sciences*, vol. 30, no. 3, pp. 291-319, 2018.
- [11] B. Sidhu, H. Singh, and A. Chhabra, "Emerging wireless standards-wifi, zigbee and wimax " *World Academy of Science, Engineering Technology*, vol. 25, pp. 308-313, 2007.
- [12] M. Burhan, R. A. Rehman, B. Khan, and B.-S. Kim, "IoT Elements, Layered Architectures and Security Issues: A Comprehensive Survey," *Sensors*, vol. 18, no. 9, p. 2796, 2018.
- [13] E. Park, M.-S. Lee, H.-S. Kim, and S. Bahk, "AdaptaBLE: Adaptive control of data rate, transmission power, and connection interval in bluetooth low energy," *Computer Networks*, vol. 181, p. 107520, 2020.
- [14] A.-R. Al-Ali, I. A. Zualkernan, M. Rashid, R. Gupta, and M. Alikarar, "A smart home energy management system using IoT and big data analytics approach," *J IEEE Transactions on Consumer Electronics*, vol. 63, no. 4, pp. 426-434, 2017.
- [15] R. Yugha and S. Chithra, "A survey on technologies and security protocols: Reference for future generation IoT," *Journal of Network and Computer Applications*, vol. 169, p. 102763, 2020.
- [16] E. R. Kaburuan and R. Jayadi, "A design of iot-based monitoring system for intelligence indoor micro-climate horticulture farming in indonesia," *Procedia Computer Science*, vol. 157, pp. 459-464, 2019.
- [17] M. I. Alipio, A. E. M. D. Cruz, J. D. A. Doria, and R. M. S. Fruto, "A smart hydroponics farming system using exact inference in Bayesian network," in *6th Global Conference on Consumer Electronics (GCCE)*, pp. 1-5: IEEE.
- [18] A. Kamilaris, F. Gao, F. X. Prenafeta-Boldu, and M. I. Ali, "Agri-IoT: A semantic framework for Internet of Things-enabled smart farming applications," in *3rd World Forum on Internet of Things (WF-IoT)*, 2016, pp. 442-447: IEEE.
- [19] M. A. Akkas and R. Sokullu, "An IoT-based greenhouse monitoring system with Micaz motes," *Procedia computer science*, vol. 113, pp. 603-608, 2017.
- [20] O. A. Hassan, S. A. Zulkifli, R. Norjali, S. Y. Sim, and H. Y. Lam, "Iot Based Smart Irrigation Control And Monitoring System," *Advances in Computing Intelligent System*, vol. 2, no. 2, pp. 1-7, 2020.
- [21] I. Gautam and S. R. N. Reddy, "Innovative GSM bluetooth based remote controlled embedded system for irrigation," *International Journal of Computer Applications*, vol. 47, no. 13, 2012.
- [22] S. S. Mathurkar, N. R. Patel, R. B. Lanjewar, and R. S. Somkuwar, "Smart sensors based monitoring system for agriculture using field programmable

- gate array," in International Conference on Circuits, Power and Computing Technologies [ICCPCT-2014], 2014, pp. 339-344: IEEE.
- [23] A. Podder et al., "IoT based Smart AgroTech System for Verification of Urban Farming Parameters," *Microprocessors and Microsystems*, vol. 82, p. 104025, 2021.
- [24] D. Parida, A. Behera, J. K. Naik, S. Pattanaik, and R. S. Nanda, "Real-time environment monitoring system using ESP8266 and ThingSpeak on internet of things platform," in 2019 International Conference on Intelligent Computing and Control Systems (ICCS), 2019, pp. 225-229: IEEE.
- [25] V. S. R., "IoT-Enabled Smart Agriculture Powered By Microcontroller: A Review," *International Journal of Innovative Research in Science, Engineering and Technology* vol. 10, no. 6, pp. 7242-7248, 2021.
- [26] M. S. Mekala and P. Viswanathan, "CLAY-MIST: IoT-cloud enabled CMM index for smart agriculture monitoring system," *Measurement*, vol. 134, pp. 236-244, 2019/02/01/ 2019.
- [27] K. J. Vanaja, A. Suresh, S. Srilatha, K. V. Kumar, M. J. I. R. J. o. E. Bharath, and Technology, "IOT based agriculture system using node MCU," vol. 5, no. 3, pp. 3025-3028, 2018.
- [28] J. L. Hatfield et al., "Climate Impacts on Agriculture: Implications for Crop Production," *Agronomy Journal*, vol. 103, no. 2, pp. 351-370, 2011.
- [29] J. L. Hatfield and J. H. Prueger, "Temperature extremes: Effect on plant growth and development," *Weather and Climate Extremes*, vol. 10, pp. 4-10, 2015.
- [30] P. V. V. Prasad, P. Q. Craufurd, V. G. Kakani, T. R. Wheeler, and K. Boote, "Influence of high temperature during pre-and post-anthesis stages of floral development on fruit-set and pollen germination in peanut," *Functional Plant Biology*, vol. 28, no. 3, pp. 233-240, 2001.
- [31] P. V. V. Prasad, K. J. Boote, L. H. Allen Jr, and J. M. G. Thomas, "Effects of elevated temperature and carbon dioxide on seed-set and yield of kidney bean (*Phaseolus vulgaris* L.)," *Global Change Biology*, vol. 8, no. 8, pp. 710-721, 2002.
- [32] P. V. Prasad, S. Pisipati, Z. Ristic, U. Bukovnik, and A. Fritz, "Impact of nighttime temperature on physiology and growth of spring wheat," *Crop science*, vol. 48, no. 6, pp. 2372-2380, 2008.
- [33] Z. M. Sawan, "Climatic variables: Evaporation, sunshine, relative humidity, soil and air temperature and its adverse effects on cotton production," *Information Processing in Agriculture*, vol. 5, no. 1, pp. 134-148, 2018.
- [34] B. Amin, M. J. Atif, X. Wang, H. Meng, M. I. Ghani, M. Ali, Y. Ding, X. Li, and Z. Cheng, "Effect of low temperature and high humidity stress on physiology of cucumber at different leaf stages," *Plant biology*, vol. 23, no. 5, pp. 785-796, 2021.
- [35] R. I. Grange and D. W. Hand, "A review of the effects of atmospheric humidity on the growth of horticultural crops," *Journal of Horticultural Science*, vol. 62, no. 2, pp. 125-134, 1987.
- [36] M. Cheng, H. Wang, J. Fan, X. Wang, X. Sun, L. Yang, S. Zhang, Y. Xiang, and F. Zhang, "Crop yield and water productivity under salty water irrigation: A global meta-analysis," *Agricultural Water Management*, vol. 256, p. 107105, 2021.
- [37] M. Saleh, I. H. Elhajj, D. Asmar, I. Bashour, and S. Kidess, "Experimental evaluation of low-cost resistive soil moisture sensors," in 2016 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET), 2016, pp. 179-184: IEEE.
- [38] D. Gangwar, S. Tyagi, and S. Soni, "A techno-economic analysis of digital agriculture services: an ecological approach toward green growth," *International Journal of Environmental Science Technology*, pp. 1-12, 2021.
- [39] G. Babu Loganathan, "Smart Agriculture System With E-Cabbage Using Iot," *International Journal of Modern Agriculture*, vol. 10, no. 1, pp. 928-931, 2021.
- [40] G. Delnevo, R. Girau, C. Ceccarini, and C. Prandi, "A Deep Learning and Social IoT approach for Plants Disease Prediction toward a Sustainable Agriculture," *IEEE Internet of Things Journal*, pp. 1-1, 2021.
- [41] P. Wang, B. A. Hafshejani, and D. Wang, "An improved multilayer perceptron approach for detecting sugarcane yield production in IoT based smart agriculture," *Microprocessors Microsystems*, vol. 82, p. 103822, 2021.
- [42] R. Morais, J. Mendes, R. Silva, N. Silva, J. J. Sousa, and E. Peres, "A versatile, low-power and low-cost IoT device for field data gathering in precision agriculture practices," *Agriculture*, vol. 11, no. 7, p. 619, 2021.
- [43] S. Sadowski and P. Spachos, "Wireless technologies for smart agricultural monitoring using internet of things devices with energy harvesting capabilities," *Computers and Electronics in Agriculture*, vol. 172, p. 105338, 2020.
- [44] D. Wang, H. Hu, H. Yang, and K. Zheng, "A Real-time LoRa-based IoT System for Intelligent Meteorological Monitoring," in 2020 IEEE 6th International Conference on Computer and Communications (ICCC), 2020, pp. 921-925.
- [45] S. Sadowski and P. Spachos, "Solar-powered smart agricultural monitoring system using internet of things devices," in 2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2018, pp. 18-23: IEEE.
- [46] N. Karimi, A. Arabhosseini, M. Karimi, and M. H. Kianmehr, "Web-based monitoring system using Wireless Sensor Networks for traditional vineyards and grape drying buildings," *Computers and Electronics in Agriculture*, vol. 144, pp. 269-283, 2018.
- [47] Cropin. (2021, 10-10-2021). Digitizing farms: delivering cutting-edge solutions for every stakeholder in the ecosystem. Available: <https://www.cropin.com/>