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Analysis of Soil Viability Monitoring System for In-House Plantation Growth Using an Internet of Things Approach

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ABSTRACT

Houseplant cultivation has become increasingly popular, allowing individuals to bring nature into their homes. However, successful indoor gardening requires careful monitoring of soil parameters to ensure optimal plant growth. To address this need, sensor technology and Internet of Things (IoT) devices are utilized to monitor soil temperature and moisture levels, which play crucial roles in plant growth. Various soil factors are sensed and collected using an IoT-based microcontroller, with data transmission facilitated by a Message Queue Telemetry Transport (MQTT) broker. Visualization of the data is achieved through the Node-RED programming tool, simplifying dashboard creation for easy monitoring. Furthermore, the collected data is stored in a MySQL server, enabling further analysis through SQL queries. The day is divided into four quarters with six-hour intervals, allowing for soil data collection using temperature and moisture sensors. The resulting information on the dashboard facilitates informed decision-making to enhance soil conditions for optimal indoor plant growth. Experimentation has revealed a reduction in soil temperature of 3°C during daytime due to air conditioning operation, while soil moisture content remains consistently between 60 to 65% during early mornings and late evenings. Additionally, emphasis is placed on remote management using IoT systems, enabling monitoring of plant

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growth even when access is limited. Overall, monitoring soil factors using IoT technology offers a promising approach to optimizing indoor gardening practices and minimizing environmental resource consumption.

Keywords: In-house plantation, internet of things, MQTT, sensor, soil factors

INTRODUCTION

Farm industries continuously seek ways to improve operational efficiency, fast production, cut costs, and maintain good quality products in today's competitive world. One prominent method is the concept of "in-house forming." This method entails bringing agricultural products or in-house forming rather than growing forma products outside the land, which takes longer, is more expensive, takes more time to reach consumers, and many more. The advantages of in-house forming are numerous. Organizations have more control over every aspect of production by creating and managing forming activities within their facilities. They may tune processes to fulfill precise design specifications, assure product quality, and adapt quickly to changing market demands. In-house forming also provides cost savings by eliminating the requirement for price hikes associated with outsourcing. Further, there is a potential that the amount of water utilized or the time it takes for the water to arrive might be excessive during a conventional method of agriculture, causing the crops to dry up. Real-time temperature and humidity monitoring are critical in many agricultural applications (Prathibha et al., 2017; Kassim, 2020; Bittner et al., 2019).

Recently, researchers have explored agriculture using IoT technology, which has addressed various challenges and proposed different approaches to the faster development of agricultural products (Abbasi et al., 2022; Xu et al., 2022). The key challenges in implementing IoT systems in agriculture include high investment costs, connectivity issues, and needing trained personnel. Also, the main focus is scalability, affordability, and robust models in designing IoT-based agriculture (Dhanaraju et al., 2022). The system requires different assembling units like sensors, controllers, actuators, and software to develop code for appropriate tasks. A few research studies have shown that the IoT-enabled plant watering system uses a different controller and sensors for soil moisture observation (Sheth & Rupani, 2019; Al-Omary et al., 2018). The soil is an important constituent for any growth of agricultural production. Thus, soil-related parameters such as moisture, pH, and temperature were appropriately monitored to boost soil potency (Nguemezi et al., 2020). Also, improving soil productivity is critical for long-term agricultural sustainability and healthy ecosystems. Different sensor technology is used to monitor soil parameters sensibly and accurately. The same concept was adopted in-house forming, which can regularly monitor soil factors and improve the richness of the plant. In-house agriculture can provide a more stable and sustainable source of fresh produce, as well as financial savings, educational possibilities, and environmental advantages. It frequently corresponds to bigger concepts such as urban farming, local food production, and sustainability (Specht et al., 2014).

Pechlivani et al. (2023) have used 3D printing technology to develop an agro toolbox to access the soil parameters using IOT technology. The toolbox is used to integrate the different soil monitoring sensors that are deployed across the farmland. A continuously monitored soil key parameters such as temperature, humidity, intensity of visible light, and other parameters were gathered through IOT technology. Researchers have replaced the manual filed inspection with mobile applications (Ngoc et al., 2023). They have developed embedded technology for monitoring soil nutrients, moisture, organics, Matera, and clay parameters. Different techniques are used to link the sensor located in the diverse places of the farmland. The sensor data were continuously recorded utilizing Wireless Fidelity (Wi-Fi), Low-Power Wide-Area Network (LPWAN), Long Range (LoRa), and Bluetooth before broadcasting to the base station (Nedham & Al-Qurabat, 2023). This method helps lower the agricultural costs related to labor and other expenses.

Jain et al. (2023) studied soil monitoring systems using IoT technology, showing that automatic irrigation is used in agriculture. They have built a system architecture for soil monitoring and controlling irrigation using IoT technique, where the different sensors and actuators like humidity, soil moisture, temperature, and pump are connected with a node microcontroller unit and message queuing telemetry transport (MQTT) protocol for enhancing communication capabilities. The sensor data is displayed on a PC or mobile phone through wireless communication and an IoT cloud platform. Luo and Pu (2024) have used the Underground Internet of Things (UIoT) for soil monitoring using ultra-high-frequency (UHF) radio energy. The UIoT nodes utilize harvested energy to measure soil parameters and transmit data to the Unmanned aerial vehicle (UAV) via the ZigBee protocol. Once the data is collected from the UIoTs, the UAV uploads it to a cloud server for real-time soil quality analysis. Sumarsono et al. (2024) have used an IOT webserver android and machine learning approach to monitor the soil PH factor.

Multiple sensors were used to monitor soil parameters like pH-moisture, Temperature-Humidity, and Sunlight. Arduino Uno microcontroller for serial communication with the ESP 8266 microcontroller for the Wi-Fi module was used for sensor data collection. The collected data was monitored using the web application containing a MySQL database and a local web page. Some of the research has shown that in-house crop monitoring has involved different technologies such as sensor modules, communication, web servers, and controllers, which provide the moisture content and temperature of the soil in hand (Obaideen et al., 2022; Rao & Sridhar, 2018). Based on this monitoring system, an automated watering system and ingredients can be provided to the soil to improve crop growth.

In recent years, Internet of Things (IoT) technologies have developed a system for plants for life, where the automated care of potted plants improves the air quality and makes the indoor environment healthier (Guerrero-Ulloa et al., 2023). Most in-house systems rely on manual temperature and humidity monitoring, which can be inconvenient for personnel who are required to visit the greenhouse daily and manually control it. Riskiawan et al. (2024) have automated the process using the Internet of Things (IoT) and artificial intelligence systems to independently predict and control IoT devices. Also, the intelligent platform based on IoT and low-cost wireless sensors based on radio frequency communication for collecting and sending greenhouse data like temperature, humidity, and soil moisture is used for smart and optimum management of in-house irrigation (Benyezza et al., 2023). Wireless Sensor Network (WSN)--based Internet of Things (IoT) networks are used for clustering methods to optimize energy efficiency while collecting the sensor node data (Mohammed et al., 2022; Nedham & Al-Qurabat, 2022). Furthermore, the author has discussed the agricultural challenges while collecting field data, such as soil conditions and meteorological data locally to accelerate the adoption of appropriate decisions that help the growth of the product (Al-Qurabat et al., 2021; Al-Qurabat et al., 2022). Also, the position of the sensor and the efficient way of collecting the data is another challenging task. Thus, recent studies have shown that it is possible to collect data in an efficient way to improve agriculture environmental conditions using IoT and WSN (Al-Qurabat, 2022).

Nowadays, most plant monitoring systems consider internet-enabled microcontrollers with sensor units leading to soil parameters and crop yield; in one of the recent developments, Message Queue Telemetry Transport (MQTT) protocol was used to transfer the sensor data to a remote server instead of using Hyper Text Transfer Protocol (HTTP). MQTT has been designed to be lightweight and efficient, which makes it ideal for bandwidth-limited real-time applications. Also, it uses the publish-subscribe model, which reduces the data transfer size and makes it ideal for IoT-based applications (Morchid et al., 2024; Min & Park, 2018; Kodali & Sarjerao, 2017).

Further, compared to conventional farming, smart and precision farming produces higher productivity at a lower cost. It requires the proper communication methods and online interfaces for efficient improvement in smart framing systems. Hence, the MQTT is used to communicate with the Node.js server worker. The system directly processes data from numeric image feeds and images. The server would store all received data, including numeric data and live feeds, for future use (Turnip et al., 2023). Also, the author has used monitoring soil properties, like soil pH, electrical conductivity, soil humidity, and temperature, through cloud MQTT (Aarthi & Sivakumar, 2023), which has shown an effective way of communicating with field data.

In addition, IoT systems may have limitations in terms of scalability, making it difficult to deploy them across large agricultural fields or indoor environments with numerous plants. In environments with poor network coverage or interference, such as indoor spaces with thick walls, connectivity issues may arise, leading to data transmission failures or delays. The accuracy and reliability of IoT sensors can vary, leading to discrepancies in the collected data. Factors such as sensor calibration, environmental conditions, and sensor degradation over time can affect data accuracy and reliability. Implementing an IoT-based soil monitoring system requires an initial investment in hardware, software, and infrastructure setup, which may be prohibitive for some users, especially small-scale in-house farming. The in-house plantation data monitoring lacks real-time, comprehensive monitoring systems that can continuously track key soil parameters where the plants are grown in the closed area. Current methods often rely on manual data collection, which can be time-consuming, need continuous observation, and are prone to human error. Additionally, existing monitoring systems may not provide sufficient data granularity or frequency, limiting the ability to detect subtle changes in soil conditions. As a result, there is a need for more advanced, automated monitoring solutions that leverage IoT technology to provide continuous, high-resolution data collection and analysis for optimal plant growth and resource management.

The study investigates soil suitability for indoor plant growth by employing IoT technology as a novel method used to assess real-time soil data. Real-time sensors, including those for temperature and soil moisture, were utilized to monitor soil conditions. Data collected from these sensors was transmitted to an MQTT broker and stored in a MYSQL database. Node-RED was employed to develop a monitoring system with low-code capabilities, enabling analysis of soil parameters for optimal plant growth in an indoor environment. This approach offers a cost-effective solution that can be implemented in farms or homes to enhance crop irrigation efficiency, minimize water usage, and optimize plant growth.

METHODOLOGY

The study was designed to investigate plants' indoor growth using IoT technology. It involved designing an experimental setup where internet-connected devices and technologies could monitor and manage the growth of plants in an indoor environment. The design focused on creating a controlled and automated system that could provide optimal conditions for plant growth, including soil type, pot size, and environmental factors. The study was carried out by setting up an experimental environment where plants could be grown indoors under controlled conditions (i.e., indoor air conditioner room). Various soil types with different grain sizes were used to determine their impact on plant growth. Different pots or containers were also selected to assess their effect on soil moisture retention and plant growth. IoT devices were installed to monitor and collect data on environmental parameters such as temperature, humidity, and soil moisture levels.

The data collected from the IoT devices were analyzed to assess the growth of plants under different soil conditions. Based on these variables, the collected data analyzed the effect of soil and indoor room conditions on plant growth. Additionally, correlations between environmental parameters and plant growth were examined to understand the factors influencing indoor plant growth. Overall, the data analysis aimed to provide insights into the optimal indoor conditions for indoor growing plants using IoT technology.

Layout of Soil

Adopting a systematic and careful approach is necessary to create an environment for controlled plant growth in pots. Based on the plant's requirement and its intention to grow in a controlled environment, they are arranged in such a way as to influence soil factors. It will ensure consistency and fairness in the experiment, which can provide uniform growing conditions for all plants. The pots used in the current process are transparent polyethylene terephthalate (PET) bottles, which can help monitor and easily arrange the sensor per the requirements. Each pot was equipped with equal drainage holes made using identical drill bits. Proper drainage is crucial for preventing waterlogging and root rot. The soil used in the pots was divided into four layers, emphasizing maintaining consistent granule size and volume for each layer in every pot. This standardization helps ensure that each plant has access to the same amount and type of soil. The use of a layering technique in the present work demonstrates a thoughtful approach to replicating natural growing conditions for the proposed plants. With objectives of effective drainage and aeration by prioritizing the primary goal to create a soil structure that would facilitate optimal drainage and aeration for the plants. These factors are crucial for preventing issues like root rot and ensuring that the roots receive sufficient oxygen by dividing the soil into distinct layers based on granule size. This approach allows us to control the characteristics of each layer to meet plants' specific needs by employing a manual multi-level sieving process to separate soil based on its size. This process involved using various sieve sizes one at a time to isolate materials with specific granule sizes.

The paces followed for arranging the pot with sieved soil have four sieved soils. There were 2.36 mm sieves used to filter soil into two layers, and after the sieve, it was left with more prominent granules in the sieve, and the large size granules for the bottom were settled. Mid-size granules were sieved soil and were used for a second from the bottom layer. The soil was sieved again with a sieve size of 1.18 mm, and the soil left in the sieve was used for the third layer from the bottom, and the top layer had fine soil added into the transparent bottle. Four sets with dimensions of 8cm height and 5.6 cm diameter, as well as an overall volume of 217.5 cm size bottles, were used for the experiment. One of the bottles with soil of different granular sizes is displayed in Figure 1.

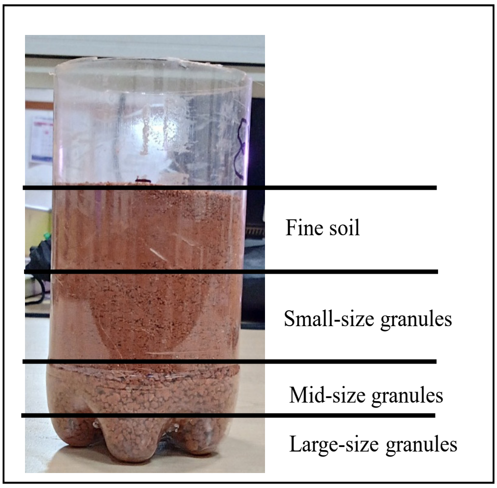
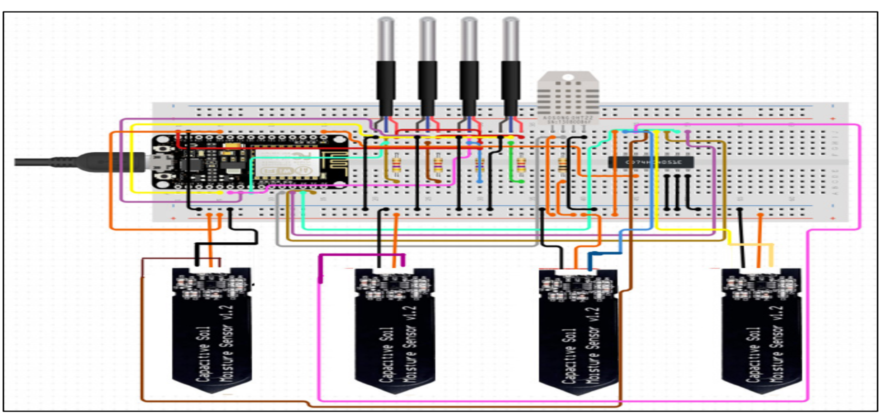


Figure 1. Soil profile after layering

Sensor and IoT Monitoring System

The virtual and real circuit connection for monitoring the soil parameters is shown in Figure 2. Four sets of temperature and moisture sensors connected to an Arduino UNO board could access continuous soil data. The setup consists of four sets of Dallas Semiconductor DS1820b sensors and a Digital Temperature and Humidity Sensor DHT11, which measures the temperature and soil moisture. A resistor is required between the power and data line of the DS1820b sensor for proper functioning, which is why four resistors were used. The four analog capacitive moisture sensors were connected to four pins, with Analogue to Digital Converter (ADC) inputs enabled on the ESP32. In the case of the Arduino UNO board, the analog sensors would be connected to the analog pins, and the DS1820b sensors would be connected to digital pins, respectively.



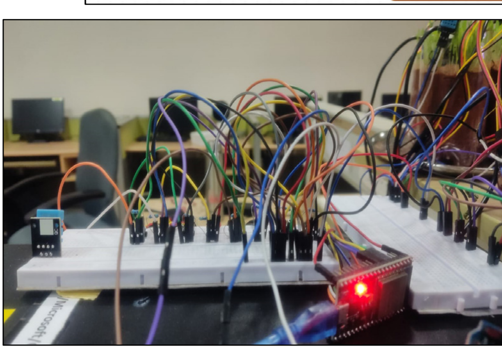


Figure 2. The virtual and real circuit connections are used to monitor the soil parameters.

The overall flowchart of the soil monitoring system is depicted in Figure 3 shows. The data collecting system is assembled with sensors and a controller, integrating the nodes with the database and dashboard. The sensor sends the soil temperature and moisture to the ESP32 controller and then publishes those data through the MQTT protocol. Once sensor data is in the MQTT protocol, which can help push it to any other platform, node-RED is subscribed to access the sensor data. The IP address of the MQTT broker must be provided to the "MQTT-in" node to subscribe to node RED. The values received from these sensors are then connected to "graph" and "gauge" nodes, which allows visualization of these values using the dashboard.

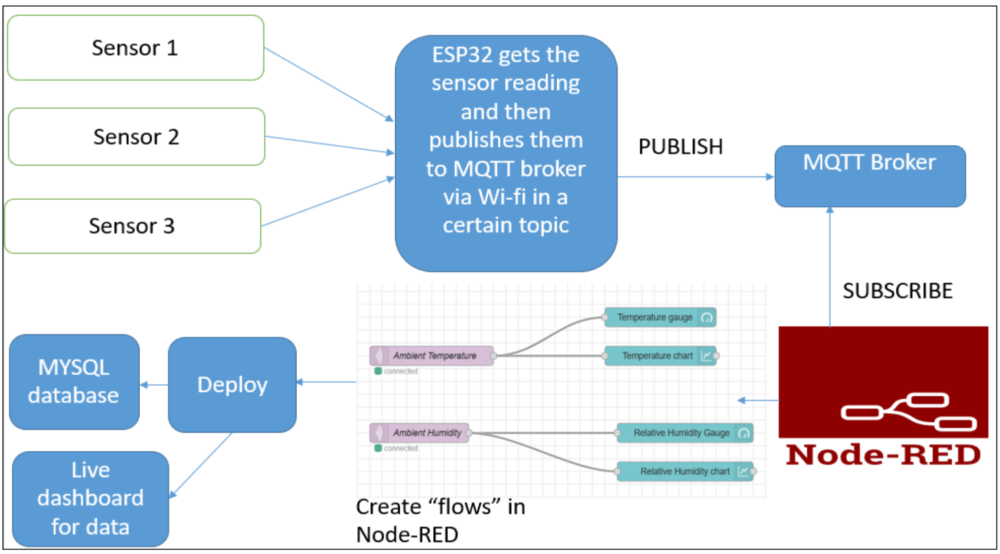


Figure 3. Flowchart used in the soil monitoring system

The nodes used in the Node-RED subscriber are displayed in Figure 4. Additionally, the data from these sensors are combined into a single string separated by a chosen delimiter, a comma mark. The data is joined to send the collected data to a MySQL database, which runs as a service on the computing device. SQL queries must be made in such a way that the entire table must get updated at the same instance to avoid null values in the table.

The data collected at varying times with short delay due to functional programming in Arduino Integrated Development Environment (IDE) is joined into a single string separated by a comma mark using the join node previously configured. This string is then fed into a JavaScript function node, where JavaScript code is written to split the joined data into an array of strings. These strings in the array then become the values to be updated into the columns of the table. The SQL query is then written in the function node and fed into the "MySQL" node in node-RED to update the table. Thus, it ensures that the data collected from the sensors is stored in the table. The debug nodes are used to debug and check queries. The email node is configured along with a JavaScript function node to send an email notifying the soil moisture percentage going below a threshold that can be adjusted by the user in the JavaScript function node. Finally, the accuracy of the sensors should be checked regularly, and any necessary calibrations or replacements should be executed. Ascertain that the IoT system is functioning properly.

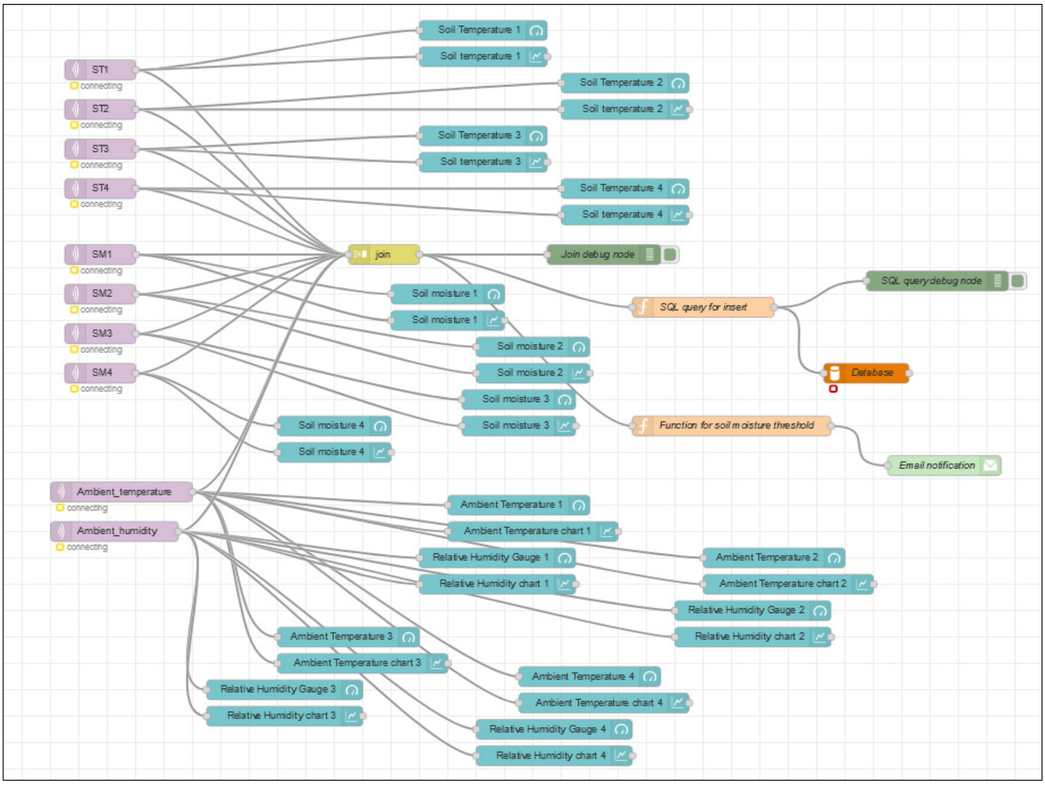


Figure 4. The node-RED flow is used to connect the sensors to the database

RESULTS AND DISCUSSION

The subsequent discussion provides an in-depth exploration of soil health and its profound impact on plant growth. The IoT system adeptly monitored soil moisture levels and temperature throughout four quarters of the day. The output of this monitoring system was meticulously crafted using Node-RED, and it was seamlessly connected to the Mosquitto MQTT broker as a subscriber. Sensors interfaced with the ESP32 microcontroller diligently published the readings acquired from the soil sensors to MQTT topics, meticulously configured within the Arduino code programmed into the microcontroller. These MQTT topics were then subscribed to by Node-RED using specialized "MQTT-in" nodes, configured with precise details, including the MQTT broker's IP address, the port used for connection, and other crucial parameters such as Quality of Service and Transport Layer Security (TLS). Upon reception, the data from these sensors were intelligently amalgamated into a cohesive string, precisely separated by a selected delimiter, typically a comma, leveraging the functionality of the "join" node within Node-RED. The configuration of the join node ensured that the string output was synchronized with the reception of all individual messages, a process facilitated by setting the join node to a "manual" mode within its configuration settings. The chosen delimiter and formatting specifications, such as a string separated by commas, were carefully configured within the "join" node.

Figure 5 vividly demonstrates the culmination of this accurate data processing effort, showcasing the dashboard output of the soil parameters monitoring system. Here, a comprehensive array of data is presented, including soil temperature, moisture levels, ambient temperature, and relative humidity, captured by four distinct sets of sensors housed within different containers. Each container hosts four sensors, transmitting continuous data streams to the dashboard interface for real-time monitoring and analysis.

Figure 5. The dashboard for monitoring the soil parameters

The sensor data is carefully collected column-wise and elegantly displayed through the MySQL node, as showcased in Table 1. The abbreviations "ST" and "SM" in the table aptly denote soil temperature and soil moisture, respectively. Notably, the column designated as the serial number is crucial for the primary key in the MySQL table. Primary keys serve as unique identifiers for individual rows within the table, necessitating that they remain non-null and distinct. Consequently, the serial number column is thoughtfully configured to automatically increment upon data insertion into the table, ensuring the dataset's uniqueness and integrity.With the sensor data seamlessly integrated into the MySQL database, real-time updates are effortlessly captured and reflected as time progresses. A noteworthy observation emerges from the dataset: all four temperature sensors exhibit nearly identical readings for soil temperature, closely mirroring ambient temperature fluctuations. Conversely, the soil humidity readings consistently register marginally higher values compared to ambient humidity levels. This accurate synchronization of sensor data underscores the accuracy and reliability of the recorded information, further reaffirming the seamless functionality of IoT devices in capturing and presenting essential environmental parameters.

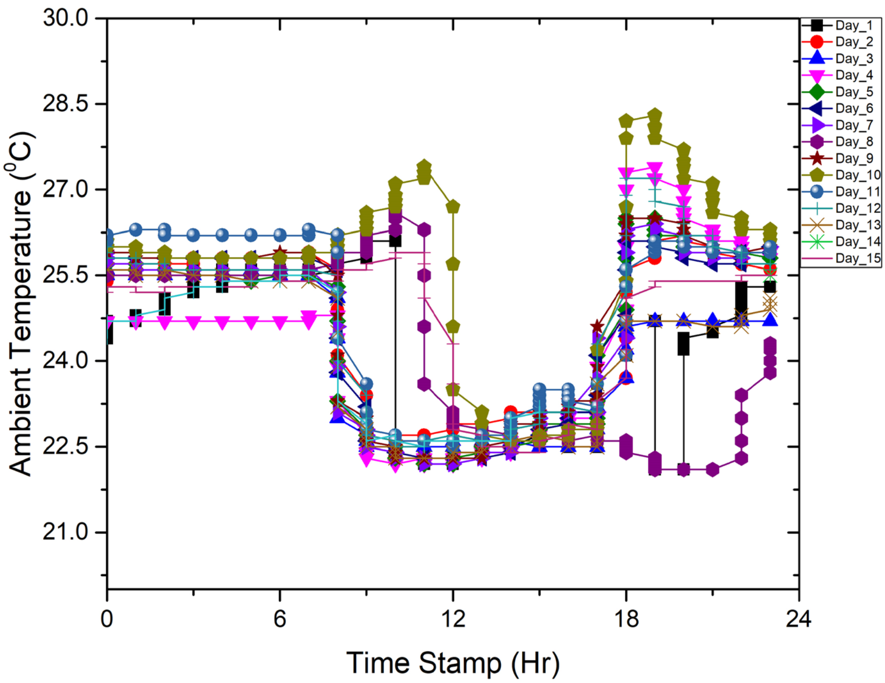
The sensor data is collected column-wise and displayed through the MySQL node displayed in Table 1. ST and SM abbreviations stand for soil temperature and soil moisture, respectively. The serial number column was chosen as the primary key in the MySQL table. Primary keys are used to identify the rows in the table; hence, they cannot be null while also being unique. Hence, the serial number column was chosen to be auto-increased upon data insertion into the table. The sensor data is received and automatically updated in the MySQL database as time passes. It is noticed that all four temperature sensors update soil temperature nearly the same as ambient temperature. At the same time, the humidity of the soil is slightly higher than that of the ambient humidity. It proves that data recorded by sensors and displayed on the dashboard through IoT devices are synchronized properly.

Table 1
MySQL node data collected from sensors

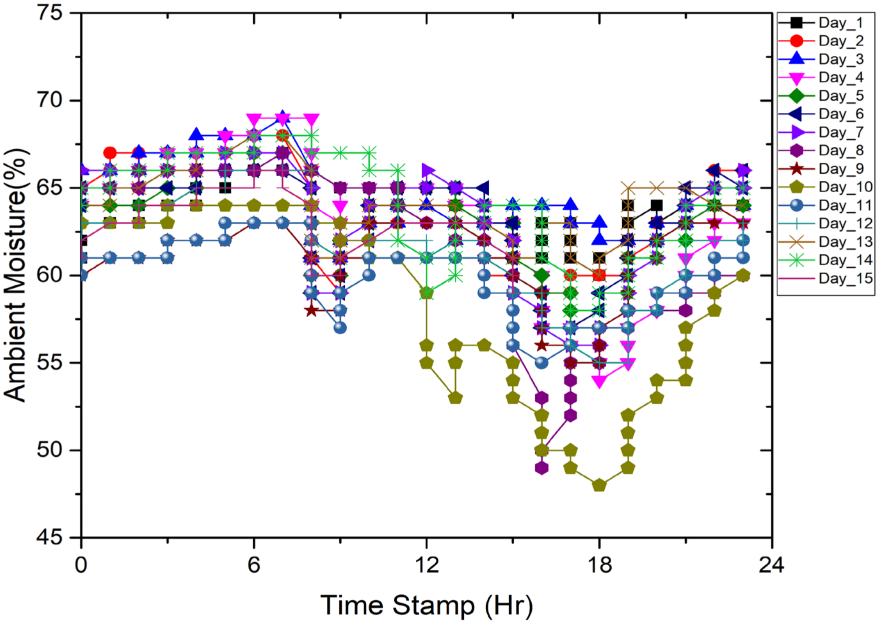
ST1	***ST2***	***ST3***	***ST4***	***SM1***	***SM2***	***SM3***	***SM4***	***AH***	***AT***
22.56	22.69	22.13	20.56	87	69	70	96	65	22.3
22.56	22.69	22.19	20.56	86	69	70	96	65	22.3
22.56	22.69	22.13	20.62	86	69	71	89	65	22.3
22.50	22.69	22.13	20.62	86	70	71	97	65	22.4
22.56	22.69	22.13	20.56	86	70	70	96	65	22.4
22.56	22.69	22.13	20.56	87	69	71	97	65	22.4
22.56	22.69	22.06	20.56	86	69	71	98	65	22.4
22.56	22.69	22.06	20.62	86	69	71	97	65	22.3
22.50	22.69	22.13	20.56	86	69	70	95	65	22.3
22.50	22.69	22.13	20.62	86	69	71	97	65	22.4
22.56	22.69	22.13	20.56	87	69	71	96	65	22.3
22.56	22.69	22.13	20.56	87	69	70	97	65	22.4
22.50	22.69	22.13	20.62	87	68	70	97	65	22.3
22.56	22.69	22.13	20.56	86	69	73	97	65	22.3
22.50	22.69	22.13	20.62	87	69	71	97	64	22.3
22.50	22.69	22.13	20.56	86	68	71	96	65	22.3
22.50	22.69	22.06	20.62	87	69	70	97	64	22.3
22.50	22.69	22.06	20.62	86	69	70	97	64	22.3

The ambient temperature and moisture fluctuations over four quarters across all days are particularly delineated into six-hour intervals, as illustrated in Figures 6(a) and (b). In the first quarter, ambient temperature remains relatively stable, attributed to the cessation of air conditioning within the indoor environment. Subsequently, during the second quarter, a noticeable decline in ambient temperature is observed, coinciding with the activation of the air conditioning system. Quarter 3 unveils an intriguing trend discernible from the graph. On select days, the efficacy of the air conditioning appears diminished, resulting in comparatively elevated temperatures. Notably, a temperature surge is evident around 5 pm, coinciding with the deactivation of the air conditioning system, as depicted in the ambient temperature graph. Moreover, the moisture levels in the environment closely mirror the ambient temperature trend. While the pot remains in the air-conditioned room, the moisture content during early mornings and late evenings hovers between 60% and 65% on varying days. A noteworthy observation emerges from the impact of air conditioning on humidity levels. During the second and third quarters of the day, when the air conditioning is operational, the dry air circulated within the room effectively diminishes heat and humidity. This process entails the refrigerant absorbing heat and moisture from the indoor air, thereby leading to a discernible reduction in room humidity during daytime, as evident in Figure 6(b).

The four pots are equipped with individual soil temperature and moisture sensors, continuously transmitting data throughout a 15-day experimental period. The study reveals that all sensors exhibit closely aligned variations in soil temperature. Soil temperature remains consistent when air conditioning is inactive in the first and fourth quarters. Conversely, a decline in soil temperature is observed during the activation of



(a)



(b)

Figure 6. The variation of (a) Ambient temperature and (b) Ambient Moisture

air conditioning, typically occurring between 9 am and 6 pm. Figure 7 illustrates the comprehensive pattern of soil temperature fluctuations over a full day. Notably, a distinct decrease in soil temperature is evident during quarters two and three, attributed to the cooling effect induced within the soil. Subsequently, as air conditioning ceases in the room, soil temperature stabilizes from the third quarter onwards. This stabilization is followed by a temperature rise in the fourth quarter, aligning with ambient temperature.

The subplot depicted in Figure 7 highlights a three-degree Celsius reduction in soil temperature during quarters two and three over the 15 days. Such temperature variations hold promise for enhancing in-house plant growth.

Additionally, soil moisture plays a crucial role in herb growth. Throughout the day, soil moisture levels exhibit an average increase ranging from 60 to 90% compared to ambient moisture levels. Figure 8(a) provides an overview of the average soil moisture data recorded by all sensors. The consistent maintenance of soil moisture within this range throughout the day is a positive indication that the necessary nutrients for plant growth are evenly distributed. Hourly variations in soil moisture content are depicted in Figures 8(b) and 8(c) subplots. These variations, ranging from 2 to 4%, highlight the need for proactive measures to prevent soil moisture depletion and subsequent plant dryness. Quarters two and three consistently exhibit lower moisture levels compared to other periods of the day.

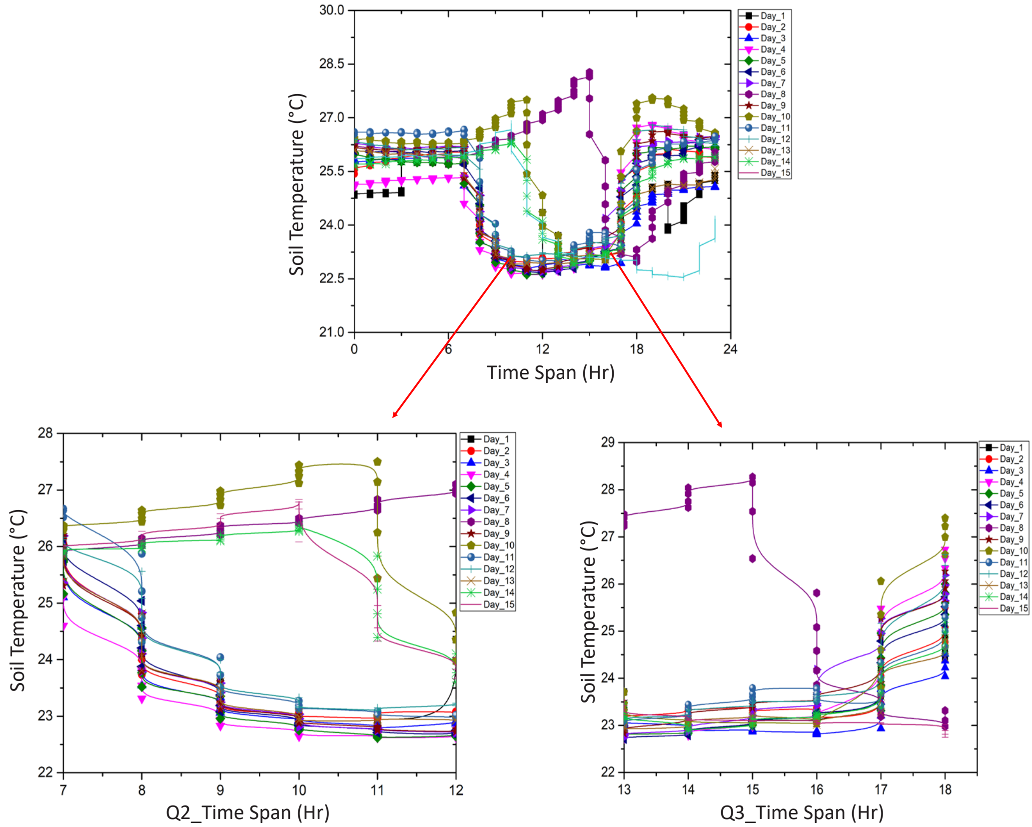
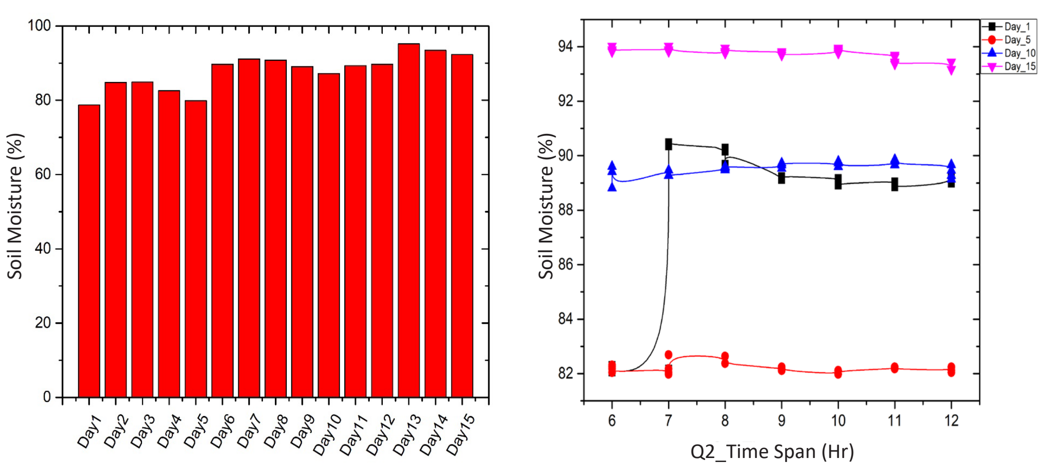
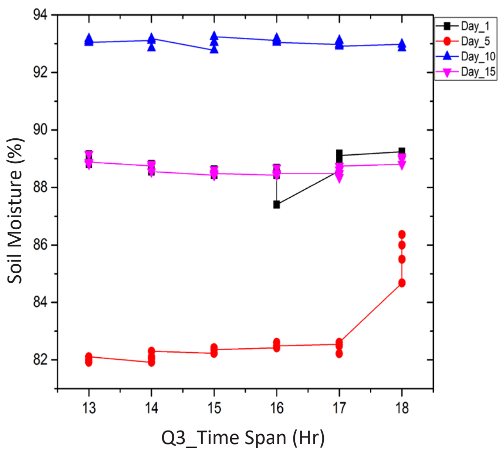


Figure 7. The soil temperature is monitored via a sensor and IoT gateway



(a) (b)



(c)

Figure 8. Illustrates the recoded soil moisture data for all the days

The sensors' consistent detection of soil moisture variations underscores their reliability. Moisture levels within the potting bags remain between approximately 75% and 95%, reflecting the soil's water-holding capacity. Continuously monitoring soil moisture and temperature throughout the day and over extended periods can significantly enhance plant growth potential by optimizing soil conditions.

CONCLUSION

Monitoring soil parameters with IoT technology effectively improves soil health and promotes healthy plant growth. It enables growers and cultivators to make informed decisions that improve soil health, resulting in more successful and long-term in-house plant growth. Assembling recent technology such as ESP32, node–RED, and MQTT protocol to record soil factors leads to estimating in-house plantation. The different grain sizes of soil were considered for monitoring soil temperature and moisture for crop growth. The four sensor data sets were stored in a MySQL table using the "MySQL" through node-RED subscriber. The "email" node was used to send email notifications regarding the soil moisture to a user-specified email address. The temperature and moisture were recorded throughout the day, lasting six hours of four quarters for fifteen days. Also, the study divides the day into quarters, collecting soil data from various layers using temperature and moisture sensors. An in-house experiment showed that the temperature of 3oC was reduced during the day due to air conditioning operation. The soil's moisture has changed to a 50% increment as the day proceeds. Further, soil conditions were displayed continuously through a dashboard, which helped to emphasize remote management via IoT in situations when physical access to plants is limited, promoting efficient resource usage in indoor gardening.

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REFERENCES

Aarthi, R., & Sivakumar, D. (2023). Internet of things based on field soil property prediction system: For optimally monitoring the soil fertility status. In *Internet of Things* (pp. 143-154). Chapman and Hall/CRC.

Abbasi, R., Martinez, P., & Ahmad, R. (2022). The digitization of agricultural industry – A systematic literature review on agriculture 4.0. *Smart Agricultural Technology*, *2*, Article 100042. https://doi.org/10.1016/J.ATECH.2022.100042

Al-Omary, A., Alsabbagh, H. M., & Al-Rizzo, H. (2018). Cloud based IoT for smart garden watering system using Arduino uno. *Smart Cities Symposium*, 1–6. https://doi.org/10.1049/cp.2018.1401

Al-Qurabat, A. K. M. (2022). A lightweight huffman-based differential encoding lossless compression technique in IoT for smart agriculture. *International Journal of Computing and Digital Systems*, *11*(1), 117–127. https://doi.org/10.12785/IJCDS/110109

Al-Qurabat, A. K. M., Mohammed, Z. A., & Hussein, Z. J. (2021). Data traffic management based on compression and MDL techniques for smart agriculture in IoT. *Wireless Personal Communications*, *120*(3), 2227–2258. https://doi.org/10.1007/S11277-021-08563-4

Al-Qurabat, A. K. M., Salman, H. M., & Finjan, A. A. R. (2022). Important extrema points extraction-based data aggregation approach for elongating the WSN lifetime. *International Journal of Computer Applications in Technology*, *68*(4), 357–368. https://doi.org/10.1504/IJCAT.2022.125182

Benyezza, H., Bouhedda, M., Kara, R., & Rebouh, S. (2023). Smart platform based on IoT and WSN for monitoring and control of a greenhouse in the context of precision agriculture. *Internet of Things*, *23*, Article 100830. https://doi.org/10.1016/J.IOT.2023.100830

Bittner, B., Aslan, I., Dang, C. T., & André, E. (2019). Of smarthomes, IoT plants, and implicit interaction design. In *TEI 2019 - Proceedings of the 13th International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 145–154). ACM Publishing. https://doi.org/10.1145/3294109.3295618

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture, 12*(10), Article 1745. https://doi.org/10.3390/AGRICULTURE12101745

Guerrero-Ulloa, G., Méndez-García, A., Torres-Lindao, V., Zamora-Mecías, V., Rodríguez-Domínguez, C., & Hornos, M. J. (2023). Internet of Things (IoT)-based indoor plant care system. *Journal of Ambient Intelligence and Smart Environments*, *15*(1), 47–62. https://doi.org/10.3233/AIS-220483

Jain, R. K., Mukherjee, A., Karmakar, P., Banerjee, A., Akbarov, H., & Hasanov, S. (2023). Experimental performance of soil monitoring system using IoT technique for automatic drip irrigation. *International Journal of Communication Systems*, *36*(18), Article e5617. https://doi.org/10.1002/DAC.5617

Kassim, M. R. M. (2020). IoT applications in smart agriculture: Issues and challenges. In *2020 IEEE conference on open systems (ICOS)* (pp. 19-24). IEEE. https://doi.org/10.1109/ICOS50156.2020.9293672

Kodali, R. K., & Sarjerao, B. S. (2017, July). A low cost smart irrigation system using MQTT protocol. In *2017 IEEE Region 10 Symposium (TENSYMP)* (pp. 1-5). IEEE Publishing. https://doi.org/10.1109/TENCONSpring.2017.8070095

Luo, Y., & Pu, L. (2024). UAV Remotely-powered underground IoT for soil monitoring. *IEEE Transactions on Industrial Informatics*, *20*(1), 972–983. https://doi.org/10.1109/TII.2023.3272016

Min, B., & Park, S. J. (2018). A smart indoor gardening system using IoT technology. *Lecture Notes in Electrical Engineering*, *474*, 683–687. https://doi.org/10.1007/978-981-10-7605-3_110

Mohammed, A., Abdulzahra, K., Kadhum, A., Al-Qurabat, M., Abdulzahra, A. M., Kadhim, A. Q., & Abdulzahra, A. M. K. (2022). A clustering approach based on fuzzy C-means in wireless sensor networks for IoT applications. *Karbala International Journal of Modern Science*, *8*(4), 579–595. https://doi.org/10.33640/2405-609X.3259

Morchid, A., El Alami, R., Raezah, A. A., & Sabbar, Y. (2024). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges. *Ain Shams Engineering Journal*, *15*(3), Article 102509. https://doi.org/10.1016/J.ASEJ.2023.102509

Nedham, W. B., & Al-Qurabat, A. K. M. (2023). A review of current prediction techniques for extending the lifetime of wireless sensor networks. In *International Journal of Computer Applications in Technology* (Vol. 71, Issue 4, pp. 352–362). Inderscience Publishers. https://doi.org/10.1504/IJCAT.2023.132401

Nedham, W. B., & Al-Qurabat, A. K. M. (2022). An improved energy efficient clustering protocol for wireless sensor networks. In *2022 International Conference for Natural and Applied Sciences (ICNAS)* (pp. 23-28). IEEE. https://doi.org/10.1109/ICNAS55512.2022.9944716

Ngoc, T. T. H., Khanh, P. T., & Pramanik, S. (2023). Smart agriculture using a soil monitoring system. In *Handbook of Research on AI-Equipped IoT Applications in High-Tech Agriculture* (p. 21). IGI Global. https://doi.org/10.4018/978-1-6684-9231-4.CH011

Nguemezi, C., Tematio, P., Yemefack, M., Tsozue, D., & Silatsa, T. B. F. (2020). Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon. *Heliyon*, *6*(2), Article e03432. https://doi.org/10.1016/j.heliyon.2020.e03432

Obaideen, K., Yousef, B. A. A., Almallahi, M. N., Chai Tan, Y., Mahmoud, M., Jaber, H., & Ramadan, M. (2022). An overview of smart irrigation systems using IoT. *Energy Nexus*, *7*, Article 100124. https://doi.org/10.1016/j.nexus.2022.100124

Pechlivani, E. M., Papadimitriou, A., Pemas, S., Ntinas, G., & Tzovaras, D. (2023). IoT-based agro-toolbox for soil analysis and environmental monitoring. *Micromachines, 14*(9), Article 1698. https://doi.org/10.3390/MI14091698

Prathibha, S. R., Hongal, A., & Jyothi, M. P. (2017). IOT based monitoring system in smart agriculture. In *2017 International Conference on Recent Advances in Electronics and Communication Technology (ICRAECT)* (pp. 81-84). IEEE Publishing. https://doi.org/10.1109/ICRAECT.2017.52

Rao, R. N., & Sridhar, B. (2018, January). IoT based smart crop-field monitoring and automation irrigation system. In *2018 2nd International Conference on Inventive Systems and Control (ICISC)* (pp. 478-483). IEEE Publishing. https://doi.org/10.1109/ICISC.2018.8399118

Riskiawan, H. Y., Gupta, N., Setyohadi, D. P. S., Anwar, S., Kurniasari, A. A., Hariono, B., Firmansyah, M. H., Yogiswara, Y., Mansur, A. B. F., & Basori, A. H. (2024). Artificial intelligence enabled smart monitoring and controlling of IoT-green house. *Arabian Journal for Science and Engineering*, *49*(3), 3043–3061. https://doi.org/10.1007/S13369-023-07887-6

Sheth, M., & Rupani, P. (2019). Smart gardening automation using IoT with BLYNK App. In *2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI)* (pp. 266-270). IEEE Publishing. https://doi.org/10.1109/ICOEI.2019.8862591

Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., Thomaier, S., Henckel, D., Walk, H., & Dierich, A. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*, *31*, 33–51. https://doi.org/10.1007/s10460-013-9448-4

Sumarsono, Afiatna, F. A. N. F., & Muflihah, N. (2024). The monitoring system of soil pH factor using IoT-webserver-android and machine learning: A case study. *International Journal on Advanced Science, Engineering, and Information Technology*, *14*(1), 118–130. https://doi.org/10.18517/IJASEIT.14.1.18745

Turnip, A., Pebriansyah, F. R., Simarmata, T., Sihombing, P., & Joelianto, E. (2023). Design of smart farming communication and web interface using MQTT and Node.js. *Open Agriculture*, *8*(1), Article 20220159. https://doi.org/10.1515/OPAG-2022-0159

Xu, J., Gu, B., & Tian, G. (2022). Review of agricultural IoT technology. *Artificial Intelligence in Agriculture*, *6*, 10–22. https://doi.org/10.1016/J.AIIA.2022.01.001