Internet of Things based Sensor System for Vertical Farming and Controlled Environment Agriculture

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***Abstract*—The use of internet of things (IoT) technology in vertical farming has the potential to greatly benefit the industry by providing a more efficient and sustainable way to grow plants. IoT-based systems in vertical farming can monitor and control various environmental factors, such as temperature, humidity, and light levels, to optimise growing conditions and increase productivity. These systems can also automate certain aspects of the growing process, such as irrigation and nutrient delivery, saving time and labour costs. Additionally, IoT technology in vertical farming can provide real-time data and analytics, allowing growers to make data-driven decisions and improve the overall efficiency of their operations. This paper presents a working prototype of a sensor system for vertical farming that could easily be integrated with any vertical farming system. The sensor design was based on a thorough study of existing vertical farming systems, considering factors such as cost, power consumption, and suitability for indoor use. The sensors store and display system parameters and send data to a cloud-based server for remote access. The functionality has been confirmed through testing and evaluation of individual components.**

***Index Terms*—Internet of Things, IoT, Vertical farming, Controlled Environment Agriculture**

I. Introduction

According to the United Nations World Food Programme, approximately 768 million people globally are undernourished [1]. It is projected that by 2050, the number of people living in urban areas will increase to over 6 billion, with 90% of them residing in developing countries. This significant population growth requires a corresponding increase in food production, but agricultural land is becoming scarce due to soil degradation and urbanisation. Each year, approximately three million hectares of land are lost due to soil degradation and topsoil erosion. An additional four million hectares are lost due to converting arable land into highways, factories, and other construction [2]. As more land is lost, the gap between food production and the needs of a growing population widens, highlighting the need for new approaches and technologies in food production for sustainable development.

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Vertical farming is the practice of cultivating plants in layers that are stacked vertically, which optimises land consumption because it may be practised indoors. Vertical farming is based on the controlled environment agriculture (CEA) technique, in which all environmental conditions may be managed. Agriculture is vital to the people, and its benefits are readily apparent from the public's perspective. Vertical farming enables areas on the continent to revert to their natural state. Additionally, empty or unused urban spaces in a developed and sophisticated city could be used for vertical farming. It makes it possible to produce food throughout the year. Indoor vertical farming is not only about the vertical plantation on a platform; the irrigation system, room temperature, and plant conditions must be considered. The vertical farms will provide organic minerals and enzymes to support healthy plant growth, and a high mineral intake throughout the crop life cycle [3]. Several approaches for vertical farming and controlled environment agriculture may be taken by evaluating and managing many aspects of the surrounding environment. The lack of proper sunlight, moisture, and heat will harm plant growth. Therefore, it is essential to analyse and control these parameters using modern technologies.

The Internet of Things (IoT) refers to the interconnected network of physical devices, sensors, and actuators embedded with electronics, software, and connectivity, allowing them to collect and exchange data [4]. These devices can be connected to various systems and can be used to monitor and control multiple processes and environments. In vertical farming, the IoT can continuously monitor and optimise growing conditions such as temperature, humidity, light, and nutrient levels. This can improve the health and quality of plants and make horticulture work more productive and efficient. IoT technology can also help reduce the amount of manual labour required, as many tasks can be automated and remotely controlled through sensors and actuators.

In addition, IoT technology in vertical farming can help reduce the environmental impact of horticultural operations by enabling growers to optimise resource use and minimise waste. For example, sensors can monitor and control irrigation systems to ensure that plants receive the right amount of water. LED lighting systems can be programmed to provide optimal light conditions for plant growth while minimising energy consumption [5]. Another potential advantage of these sensor-based systems is their ability to automate certain aspects of the growing process. By continuously monitoring environmental conditions and alerting growers when necessary changes, such as when additional irrigation or CO2 is needed, these sensors can reduce the need for human intervention [6]. This can save time and labour costs while improving the efficiency and sustainability of the growing process. This could save time and labour costs and improve the consistency and reliability of growing conditions. Overall, the use of IoT technology in vertical farming has the potential to revolutionise how we grow plants, leading to more sustainable and efficient horticultural operations.

The current sensors technology does not meet the deployment simplicity and modularity requirements for implementation in any existing horticulture enterprise, regardless of size [7]. Developing sensors with easy deployment and modularity would address this gap in the market, providing a cost-effective and scalable solution that could be easily integrated into horticultural operations of any size. This would make these sensors more widely applicable and benefit the horticultural industry. In this article, we have studied the existing sensors that could be used in the monitoring system and developed an IoT-based sensors monitoring system. The sensors system is a working prototype to measure temperature, humidity, light level and soil moisture. These sensors could be easily integrated into existing operations by providing a flexible and scalable solution without significant modifications.

II. Related Work

An Android-based remote monitoring and control system was developed using a Cyber-physical system (CPS), Arduino ESP32, and sensors set for vertical farming [8]. Experiments were conducted to evaluate the possibility of using a CPS in vertical farming. The evaluation showed that the CPS system could reduce the number of people needed to keep an eye on and control plant growth factors such as light, humidity, temperature, pH level, and CO2 volume. A NodeMCU microcontroller-based greenhouse monitoring system was developed in [9]. Data was collected from the greenhouse's actual environment and was used to control the sudden changes in temperature, sunlight, and humidity using different sensors and actuators. An indoor vertical farming watering system was developed and tested in [10]. Three soil and water level sensors were used to analyse and control the moisture level. The data obtained from sensors was first stored in an Arduino platform and sent to a computer through the ethernet module. The web-based system is then used to control the water flow based on the reading from moisture sensors.

An indoor, automatic vertical hydroponic system independent of external climate conditions was designed and developed in [11]. The system uses a microcontroller as its "brain" to communicate with various sensors and control system parameters, reducing the need for human intervention. A vertical farming monitoring system was proposed to track crop conditions [12]. Different sensors were used to detect current physical conditions and deliver analogue or digital data to BeagleBone Black (BBB) microcontroller. The BBB then uploads the data to Thingspeak Cloud. The system also records equipment positions, making maintenance easier when equipment breaks down. The web-based application lets users turn on/off the irrigation system and LED light remotely.

An IoT-based automated vertical farming system was designed to monitor and control various plant growth parameters using various sensors [13]. The collected data was sent to the ThingSpeak IoT platform and could be accessed through the VertiFarmControl android application. The mobile application could display live data from the sensors and alert the user if the sensor values fell outside the predetermined range. A similar system that uses an android application was proposed for easy remote access to sensor data, control of optimal conditions, and accurate crop yield forecasting [14]. A Wi-Fi module served as a web server from which data was fetched for the mobile application.

III. System Design

In an IoT-based vertical farming system, sensors must be installed within the farm to collect data on various environmental conditions. These sensors could measure temperature, humidity, light levels, and soil moisture. This data are sent to a gateway that bridges the sensors and the internet. A general overview of the IoT for vertical farming is shown in Fig. 1.

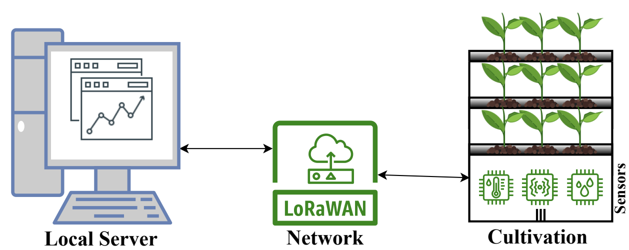


Fig. 1: An overview of IoT-based vertical farming system.

A. Sensors

The sensors are Class A LoRa nodes used to read the sensor data. Using Class A LoRa nodes as sensors in an IoT system for vertical farming provides several benefits. Lora is a long-range radio technology that allows devices to communicate over long distances using low-power signals. This makes it ideal for use in remote or hard-to-reach environments, such as a vertical farm. The Class A designation indicates that the sensors are designed to send data regularly, ensuring they can transmit data efficiently without using too much power.

The schematic design for the sensor was created using KiKad and was initially made for the BotFactory PCB printer. However, the design did not print well, and a second design was made for manufacturing at a PCB facility. The current prototype uses the V0.2 schematic, which has some components only for the prototype. These components, such as the programming header and USB power sections, may not be needed in the final version of the sensor.

B. Gateway

The gateway would be responsible for receiving the data from the sensors, formatting it, and sending it to a local or cloud-based service for storage and analysis. In an IoT system for vertical farming, the gateway plays a crucial role in facilitating communication between the sensors and the cloud-based data storage and analysis service. When the sensors collect data on environmental conditions within the farm, they send it to the gateway using the MQTT protocol. The gateway then receives this data in packets and uses IP (Internet Protocol) communication to forward it to the cloud service.

For the project to rapidly develop an IoT network, raspberry pi is usually used as a gateway for the sensors. A Raspberry Pi is a small, low-cost computer widely used for DIY projects and prototyping. It is a popular gateway in an IoT system for vertical farming because it is affordable, easy to use, and has the necessary processing power and connectivity options to support the sensors. Using a Raspberry Pi as the gateway for the sensors allows the project to rapidly develop the IoT network without the need for complex design work on the gateway itself. This is because the Raspberry Pi is a commercially available, off-the-shelf device that is readily available and easy to use. This means that the project can focus on developing the sensors and the cloud-based data storage and analysis service without spending time and resources on designing and building a custom gateway. In addition, using a Raspberry Pi as a gateway allows for flexibility and scalability. The Raspberry Pi can easily be upgraded or replaced as needed, and additional sensors can be added to the network without requiring changes to the gateway.

Whether to send the data to AWS or a local Chirpstack Server depends on the availability of an internet connection. The data will be sent to AWS for storage and analysis if an internet connection is available. The data will be sent to the local Chirpstack Server if there is no internet connection. This allows the system to continue functioning even if the internet connection is temporarily lost. In addition to receiving data from the sensors and forwarding it to the cloud service, the gateway also receives configuration packets from AWS or the Chirpstack Server. These packets contain instructions for updating the sensors, such as changes to their operating parameters or firmware updates. The gateway then forwards these packets to the sensors, ensuring they are always up-to-date and functioning correctly.

C. Server

A network server is a computer or device that manages communications and data transmission within a network. In this case, the network server is either on Amazon Web Services (AWS) or on a Raspberry Pi, a small, single-board computer. The network server receives packets of data from a gateway, which is a device that connects the network to other networks, such as the internet. The network server stores and presents the data from these packets for users to access. Additionally, the network server can send update packets to the sensors and gateway if there are changes to the network configuration or if firmware updates are needed. This allows the network to remain up-to-date and function properly.

IV. IMPLEMENTATION AND RESULTS

In order to communicate using a LoRaWan network, the Pi requires a hardware accessory called a ”Hat” that provides the necessary communication capabilities. The specific Hat chosen in this case is the Seeed LoRaWan gateway kit. The Seeed LoRaWan gateway kit provides all hardware and software to set up the gateway and host a LoRaWan network. The Table. I below shows the version numbers of all the software programs used for the project.

TABLE I: Software programs along with their versions used.

Software	Purpose	Version Number
Stm32 Cube IDE	Firmware Development	1.3.0
STM Cube Programmer	Programming Seed Modules	2.10.0
KiCad (64-bit)	PCB Development	6.0.4
Chirpstack	Lora Application Server	4.0.0-rc.3
Basic Station	Hardware Communication	2.0.6(rpi/std)
Linux	Pi Operating System	Linux 11

The Seeed LoRaWan Gateway kit comes with software that uses an outdated Semtech UDP application server and Gateway Bridge. This UDP communication between the application server and the hardware is not considered secure. The provided gateway application could set up a local network and demonstrate data being received from a sensor. However, it was based on an outdated version of Linux that is no longer supported. This made installing additional packages, such as python or the AWS command line interface, impossible. An attempt was made to update the operating system while maintaining the current applications, but there were breaking changes in several libraries that prevented the existing applications from functioning correctly. The main application that stopped working was the application server, so a new solution was researched to replace it. Therefore, Chirpstack is used as an application server. Chirpstack is well-supported, has an active community, and is still being maintained. It can be run on a Raspberry Pi and offers the option to use UDP gateway bridge software for communication. Therefore, the Chirpstack framework was implemented on Pi’s most recent version of Linux (Bullseye).

With the gateway set up to work in local mode, the project’s next stage was to get the gateway to report to AWS. Initially, the gateway reported its data to Amazon Web Services (AWS) using a python script and a packet repeater provided by Semtech. The packet repeater, or splitter, would send the hardware’s UDP messages to the local Chirpstack application and a ”Thing” location on AWS. This allowed the data to be accessed and processed locally and on AWS. The setup can be seen in Fig. 2.

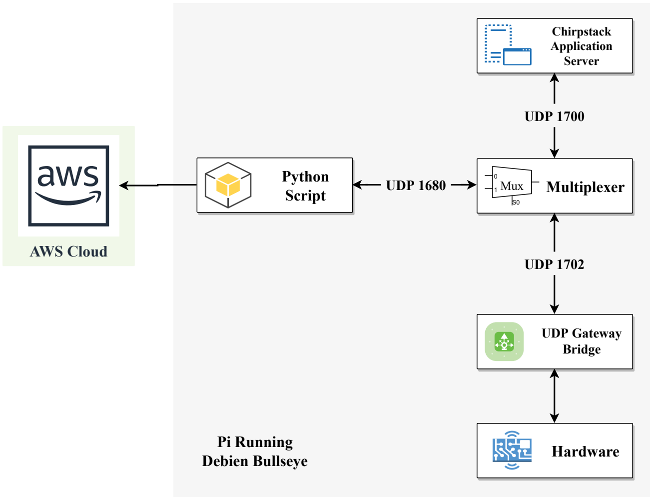


Fig. 2: Initial AWS Communication.

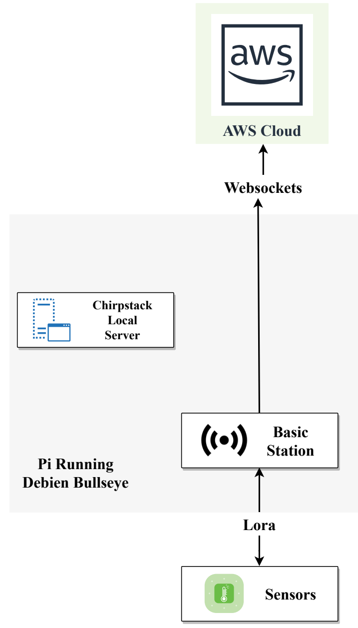
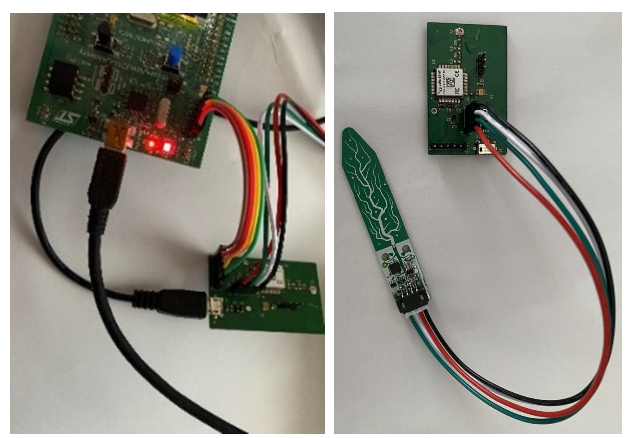


Fig. 3: Basic Station to AWS.

In this configuration, the gateway would receive data packets from the sensors and transmit them to the Chirpstack application on the Raspberry Pi. The Chirpstack application would then process the data and store it locally, while the python script would also send the data to the "Thing" location on AWS. This allowed the data to be accessed and analysed in multiple ways, providing flexibility and redundancy for the network. The main drawbacks of this configuration are that communication from AWS to the gateway is impossible, the connection is direct to the sensor, and the gateway only acts as a passthrough and is not controlled, or even acknowledged, by AWS. For AWS to recognise the gateway, Basic Station was used. The basic station replaces the UDP Packet Forwarder from Semtech and uses a more secure Websockets communication protocol. Once the basic station is installed on the Pi, the LPWAN Devices / Gateways option initiates the gateway on AWS. Adding the gateway gives AWS control over firmware upgrades and sensor registration. Due to the WebSocket communication protocol, it is impossible to report to both AWS and the local Chirpstack simultaneously, as with the python script. There is no multiplexer option for the basic station platform. The communication is outlined in Fig. 3.

If the connection to AWS is lost, the AWS BasicStation service on the Raspberry Pi is stopped, and the local Basic Station to Chirpstack service is started. However, the sensors cannot communicate with either the AWS or Chirpstack application servers unless a join event is registered. Two potential solutions were considered to fix this issue. The first solution was for the sensor to send a join request with every transmission, which increases power consumption but keeps the device awake for longer. The second solution was for the application server or gateway to send a reset command to either restart the sensor firmware or reenable the join functionality in the LoRa stack.

The sensors in this project were developed using development boards and a Seeed Lora-E5 Mini controller. The Lora-E5 Mini modules come with default AT command firmware already installed, but this must be erased before the modules can be used as the controller for the sensor chips. A programmer is required to program the module on the PCB or Lora-E5 Mini. The easiest and cheapest solution is to purchase an STM32 Discovery Board. The board comes with an ST-Link programmer that can be used for external boards by removing two jumper connections, as shown in Fig. 4(a). Jumper wires were then used to connect the ST-Link to the developed board, as shown in Fig. 4(b).



(a) (b)

Fig. 4: (a) STM32 F4 Discovery ST-Link (b) STM Link to Board (C) The developed sensor connected to the board

Once the sensors have collected data on environmental conditions within the farm, they use the MQTT (Message Queuing Telemetry Transport) protocol to pass this information to the gateway. MQTT is a lightweight messaging protocol well-suited to IoT applications because it allows devices to exchange data quickly and efficiently, even over low-bandwidth networks. In this particular setup, the sensors communicate directly with the gateway without requiring repeaters. This is because the sensors and gateway are predicted to be close to one another so that they can communicate directly without any interference. This direct communication allows for faster and more efficient data transfer, improving the overall performance of the IoT system. The sensor's information must be provided to register a sensor on Amazon Web Services (AWS). This information is typically printed to the terminal when the device starts. The specific details required may vary depending on the type of sensor and the AWS service being used. However, information such as the sensor's unique identifier, location, and capabilities are generally provided.

After getting this information, the sensor was registered with AWS. This allows integration of the sensor into the AWS-powered applications and services and access and manages the sensor's data using the AWS platform.In summary, the prototype system developed for this study performed well and has the potential to assist in vertical forming. However, the research team plans to work on the next system version with the functionalities and capabilities described in the future work section. The researchers believe that such systems have the potential to mitigate some of the challenges of lack of agricultural land and more food for the increasing population and can also provide new hobbies to many people, especially those living in the cities.

V. CONCLUSION AND FUTURE WORK

The use of internet of things (IoT) technology in vertical farming has the potential to greatly benefit the industry by providing a more efficient and sustainable way to grow plants. IoT-based systems in vertical farming can monitor and control various environmental factors, such as temperature, humidity, and light levels, to optimise growing conditions and increase productivity. These systems can also automate certain aspects of the growing process, such as irrigation and nutrient delivery, saving time and labour costs. Additionally, IoT technology in vertical farming can provide real-time data and analytics, allowing growers to make data-driven decisions and improve the overall efficiency of their operations. Overall, the use of IoT-based sensor systems in vertical farming has the potential to improve the efficiency and sustainability of the industry significantly. This work presented a prototype based on the low-cost components for vertical farming. A sensor was designed and fabricated to measure temperature, humidity, light, and soil moisture. The sensors for the vertical farming system were initially developed using development boards and a Seeed Lora-E5 Mini for the controller. The sensors can send the measured value to the local gateway and Amazon web services.

Future work on the sensor system for vertical farming includes optimising the frequency of sensor readings for maximum battery life and data accuracy, improving the power consumption of data transmission, implementing a low-power mode, and addressing potential failure cases. These improvements will enhance the effectiveness and reliability of the system. Additionally, the sensor system may require improvements to ensure it can switch between different application servers without losing connectivity. Possible solutions to this issue include having the sensor send a join request on every transmission or sending the application server a sensor reset command.

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