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Design of IoT-based Greenhouse Temperature and Humidity Monitoring System

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ABSTRAK

Penelitian ini bertujuan mengembangkan sistem pemantauan temperatur dan kelembaban udara di Smart Greenhouse Lembang Agri. Sistem ini terdiri dari beberapa perangkat yang saling terhubung untuk mengukur temperatur dan kelembapan secara nirkabel. Data pengukuran dikumpulkan lalu dikirim ke internet. Setiap perangkat memiliki sumber daya mandiri yang berasal dari baterai dan dapat dihubungkan ke sistem panel surya. Penelitian ini menggunakan mikrokontroller WEMOS D1 Mini dan memanfaatkan protokol ESP-NOW untuk transmisi data nirkabel. Sensor yang digunakan adalah DHT21 dengan performa lebih unggul dibandingkan sensor DHT11 atau DHT22. Tampilan website menggunakan PHP untuk menerima, memvalidasi, dan menyimpan data di Firebase Real-time Database. Website dilengkapi fitur agar pengguna dapat mengakses data real-time dan historis untuk setiap perangkat.

Kata kunci*: smart farming, ESP-NOW, ESP8266, gateway, panel surya, portabel*

ABSTRACT

This study aimed to develop a monitoring system for air temperature and humidity in the Lembang Agri Smart Greenhouse. This system consists of multiple interconnected devices that can wirelessly measure temperature and humidity. Measurement data is collected and then sent to the internet. Each device has an independent power source derived from the battery and can connect to a photovoltaic system. This study uses the WEMOS D1 Mini microcontroller and enabling wireless data transmission through the ESP-NOW protocol. The sensor employed in this study is the DHT21, known for its superior performance compared to the DHT11 or DHT22 sensors. The website dashboard utilises PHP to receive, validate, and store the data in the Firebase Real-time Database. The Website features allow users to access real-time and historical data for each device.

Keywords*: smart farming, ESP-NOW, ESP8266, gateway, Photo Voltaic, portable*

1. INTRODUCTION

In 2021, Indonesian government has launched a national priority program, "making Indonesia 4.0" **(Rachmawati, 2021)**. The agricultural community in Lembang Bandung, Indonesia, known as "Gapoktan Lembang Agri," has constructed an intelligent greenhouse that utilises advanced farming techniques, including an automated sprinkler system powered by Arduino IoT Cloud **(Hartawan et al., 2023)**. This greenhouse serves as a pilot project in the West Bandung District.

The greenhouse climate control system in modern technology can create an optimal environment for plant growth, thereby reducing production costs associated with the impacts of the microclimate environment. Alterations in temperature frequently impact the physiological processes of plants **(Wang & Wang, 2020)**. The greenhouse microclimate is influenced by input variables, primarily temperature and humidity, and output variables, primarily the weather conditions outside **(Gruber et al., 2011)**.

The optimal conditions for a greenhouse necessitate an equilibrium of multiple factors, including air temperature, humidity, and light **(Salazar-Moreno et al., 2018)**. The device is called the HOBO station, positioned inside and outside the greenhouse, as depicted in Figure 1. The temperature is a crucial determinant in the greenhouse environment **(Weaver et al., 2019)**. The temperature can significantly impact the movement of air **(Pawlowski et al., 2011)**.

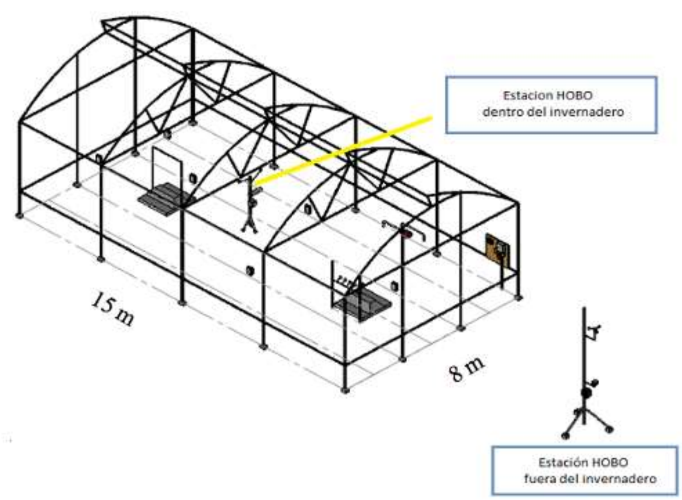


Figure 1. Location of the HOBO stations in the zenithal-type greenhouse (8 m wide by 15 m long) with natural ventilation, located at the Universidad Autónoma Chapingo, Mexico (Salazar-Moreno et al., 2018).

Figure 2 displays the state variable, which includes air temperature (T_a), as well as the inputs: heat gain from solar radiation (Q_{sol}) and heat gain from water vapour condensation on the roof (Q_{cond}). The system outputs consist of four components of heat loss: Q_{cub}, which represents heat loss through the cover; Q_{vent}, which represents heat loss due to ventilation; Q_{trans}, which represents heat loss through crop transpiration; and Q_{suelo}, which represents heat loss through the soil.

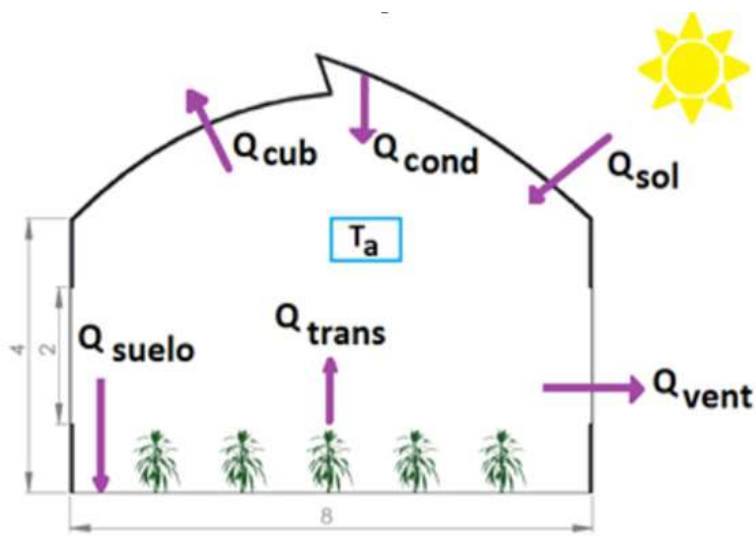


Figure 2. Energy transfers occur within a greenhouse (Salazar-Moreno et al., 2018).

Zhang, H. and Xue, H. have developed a system for monitoring and predicting greenhouse environmental parameters using the Web or the Internet. The system is designed to provide greenhouse managers with highly accurate data on changes in greenhouse environmental parameters. The system has the capability for remote monitoring and prediction through the use of the Web. The system is illustrated in Figure 3, which is displayed in the flow chart.

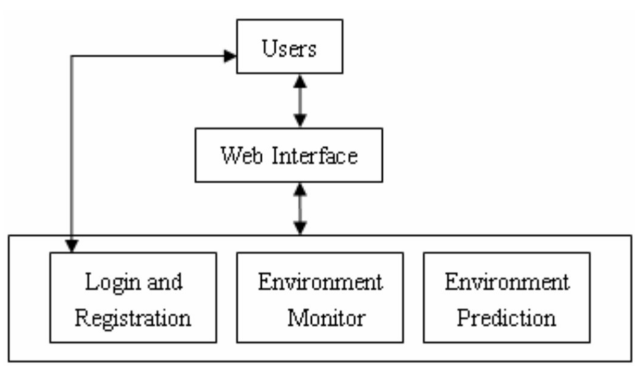


Figure 3. System flow chart (Li et al., 2011).

The concept of IoT can be implemented in various domains, including construction monitoring, smart homes, and smart agriculture **(Asghari et al., 2019)**. Qiu, Xiao and Zhou introduced an IoT intelligent monitoring platform for agricultural environments. This platform is comprised of four layers, as depicted in Figure 4. (1) The sensor layer collects environmental data in agriculture. (2) The transmission layer uses internet technology to send the environmental data. (3) The control layer analyses the data and monitors agricultural production tasks. (4) The application layer provides an interactive interface representing agriculture's business logic **(Qiu et al., 2013)**. The IoT technology can monitor various environmental parameters in agricultural production, including soil moisture, soil nutrients, pH levels, precipitation, temperature, humidity, air pressure, light intensity, and CO_2 concentration. Scientific evidence can be used to precisely regulate and optimise the growth environment of crops in a greenhouse.

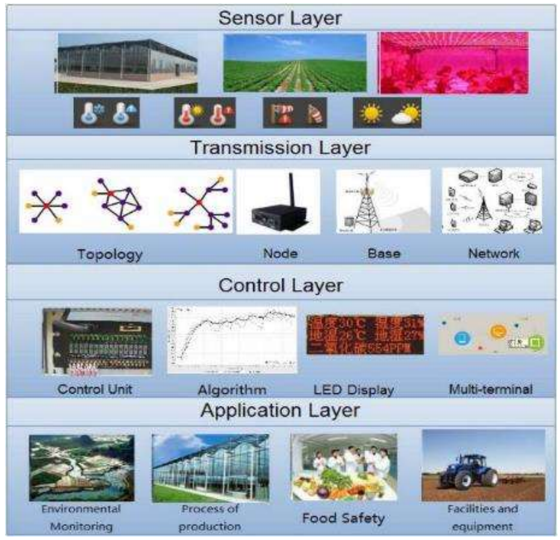


Figure 4. Platform Framework (Qiu et al., 2013)

Multiple wireless technologies are accessible as the transmission layer in IoT projects. Prior studies have utilised the nRF24L01 module to enhance the communication range of automatic sprinkler systems **(Hartawan et al., 2024)**. However, the outcome is unsatisfactory because of the module's orientation. ESP-NOW is a wireless communication protocol developed by Espressif Systems, a semiconductor manufacturer. It is specifically designed for their low-power Internet of Things devices, which are enabled with IEEE 802.11 technology. ESP-NOW can theoretically run on any IoT device with an IEEE802.11 transceiver. Nevertheless, the long-range mode of the protocol is exclusively compatible with ESP32 and ESP8266 formats.

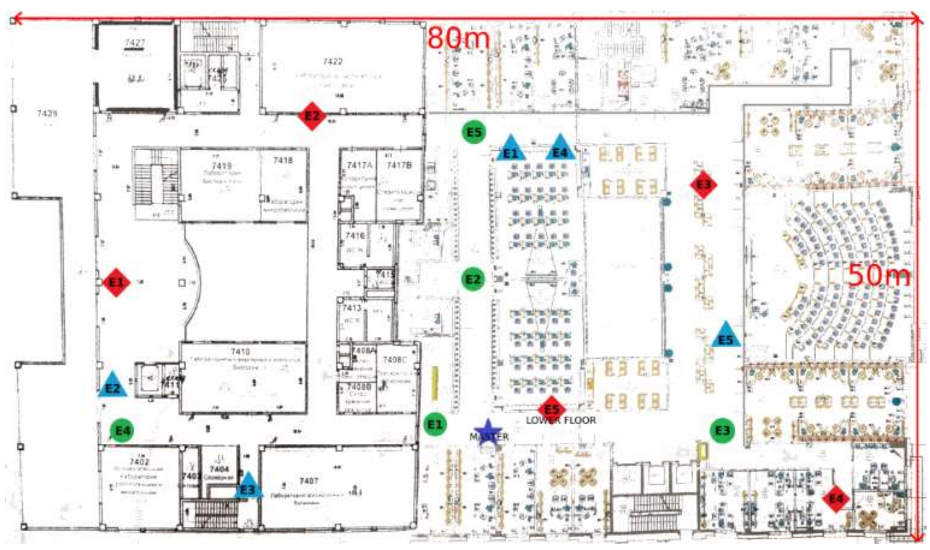


Figure 5. Map of the floor where experiments were conducted. Primary device: star, Secondary devices: circles (Experiment A), triangles (Experiment B), diamonds (Experiment C) (Urazayev et al., 2023).

The experiments conducted by Urazayev demonstrate that ESP-NOW can achieve a marginally greater distance compared to the conventional TCP WiFi method when faced with numerous obstacles. The experiment comprised three conditions, as depicted in Figure 5. Experiment A involved positioning secondary devices at different distances (ranging from 5 to 55 meters) from a primary device, ensuring a clear line of sight between them. Experiment B involved positioning secondary devices at varying distances from the primary device, without a direct line of sight, but with numerous obstacles obstructing the path between them. Experiment C involved placing secondary devices far from the primary device, without a Line of Sight (LoS) between them **(Urazayev et al., 2023)**. Given these findings, the ESP8266 formats will be applied in this study.

Wicaksono and Rahmatya conducted a study that integrated the ESP-NOW protocol with IoT. Their research aimed to develop a cluster housing monitoring system, as depicted in Figure 6. The research employed a methodology that involved utilising four primary components for the system: ESP-NOW Sender, ESP-NOW Receiver, Gateway Module, and Server. Ten ESP-NOW Senders are installed throughout the house to collect data, while the ESP-NOW Receiver receives data from all the ESP-NOW Senders. The data from the ESP-NOW Receiver is sequentially transmitted to the Gateway Module. Subsequently, the Gateway Module forwards all the messages to the online server **(Wicaksono & Rahmatya, 2022)**.

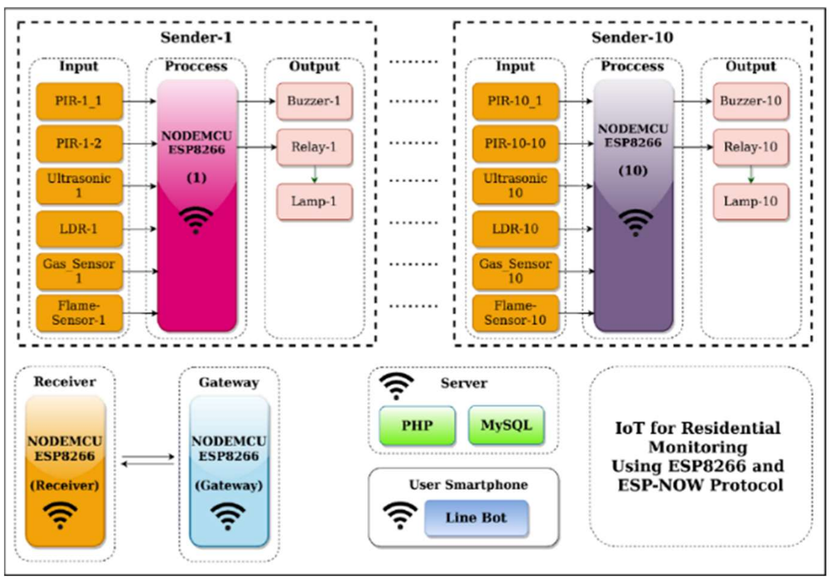


Figure 6. IoT & ESP-NOW House Monitoring Block Diagram (Wicaksono&Rahmatya,2022).

Air humidity is an indicator that quantifies the quantity of water vapour present in the atmosphere. The humidity level in the air is directly proportional to the amount of water vapour it contains, as measured by a percentage. The results of comparing the quality of humidity sensors using Arduino UNO indicate that the average error rates for DHT-type sensors are 38.84% for DHT11, 7.42% for DHT21, and 8.96% for DHT22 **(Utama et al., 2019)**. Given these findings, the DHT21 will be employed in this study. Currently, Arduino-based sensors are being utilised in agricultural production. These sensors exhibit a mean difference considered acceptable compared to industrial measurement devices **(Hartawan, Rusirawan, et al., 2023)**. The ESP32 and ESP8266 formats have low power consumption, which makes them suitable for utilising small photovoltaic systems as power sources in agricultural applications **(Anggraeni et al., 2022)**. The purpose of the Control Layer in this research is to monitor data. The data can be monitored via the Website and through mobile applications.

2. MATERIALS AND METHODS

Lembang Agri Smart Greenhouse size is 16 x 35 x 6 m (w x l x t) as seen in Figure 7. It is located at an altitude of 1,312 - 2,084 meters above sea level with an average rainfall of 20 mm/day and an average temperature between 23 °C – 25 °C with an average humidity of 74 – 82 % per year.

Figure 7. Lembang Agri Smart Greenhouse.

The monitoring device, combining the Wemos D1 Mini and the DHT21 sensor, will be strategically positioned at multiple locations within the greenhouse to accurately measure the temperature and humidity levels in each specific area (Figure 8). The data transmission from each monitoring device utilises the ESP-NOW protocol, which establishes a sequential connection starting from the monitoring device (acting as the transmitter), located far away from Internet access and connects to the nearest device.

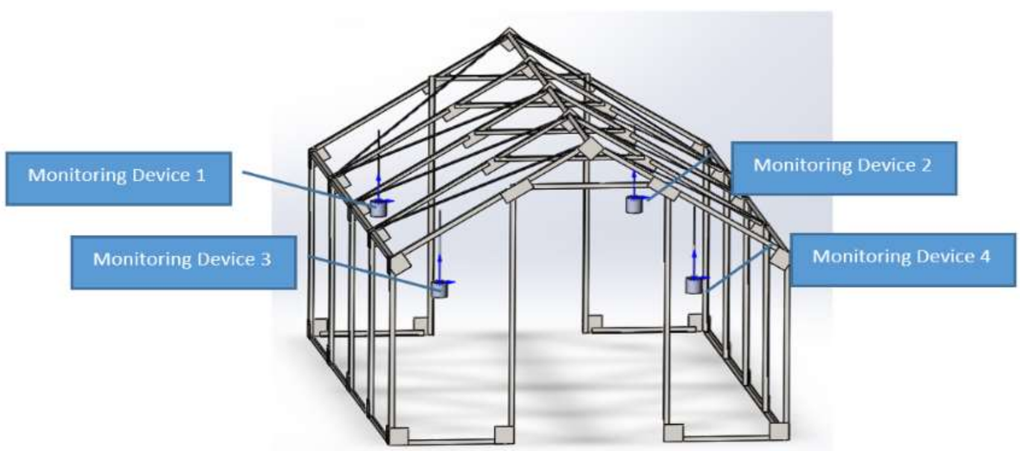


Figure 8. Sample Placement of Monitoring Device.

The data is transmitted to the Website through the Internet until all the data is gathered in the microcontroller acting as a receiver (master), as depicted in Figure 9. Every transmitter has a battery that supplies power and replenishes the module. The device can be recharged using a USB connection or a photovoltaic (PV) panel.

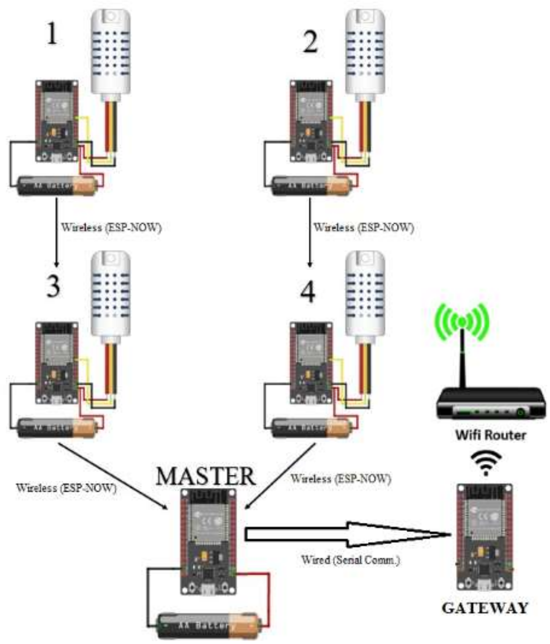


Figure 9. Data transmission methods.

To fulfil this condition regarding power and transmission methods, the system utilises the components listed in Table 1.

Table 1. Components for IoT-based Greenhouse Temperature and Humidity Monitoring System.

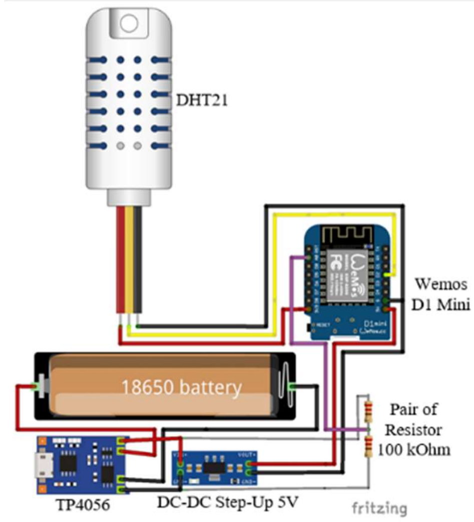
No	Electrical Components	Specification
Transmitter		
1	Microcontroller	Wemos D1 Mini
2	Temperature & Humidity sensor	DHT21
3	Power Supply/Battery	18650
4	Charging Module	TP4056
5	Step-Up	DC Boost Converter 1-5V to 5V (DC-DC 5V OUT)
6	Resistors	100 kOhm (2 pieces)
Master (Receiver)		
1	Microcontroller as receiver	Wemos D1 Mini
2	Microcontroller as Gateway	Wemos D1 Mini
3	USB Adaptor	5V; 0.5 - 1 Amp.

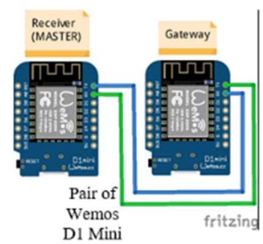
The Website and mobile apps will incorporate temperature, humidity, and battery voltage data from each monitoring device (transmitter) for surveillance.

3. RESULT AND DISCUSSION

The IoT temperature and humidity monitoring system is designed using the ESP-NOW protocol. It comprises a monitoring device as the sender, placed in multiple areas within the greenhouse. The receiver device consists of two microcontrollers, one for receiving data and another as a gateway to transmit the data to the Internet. The Wemos D1 Mini, which utilises the ESP8266 format, enables the utilisation of the ESP-NOW protocol without the need for any supplementary components.

Figure 10 displays the components and wiring diagram of the monitor (transmitter) and receiver (primary) created during the monitoring system's design.





(a) **(b)**

Figure 10. (a) Wiring diagram for monitoring device (transmitter) (b)receiver (Master)

Alternatively, a photovoltaic system can power the monitoring device (transmitter), as depicted in Figure 11. Typically, the photovoltaic system generates an output voltage ranging from 9 V to 12 V. To obtain a voltage of 5 V, the photovoltaic system will incorporate a DC to DC step-down module.

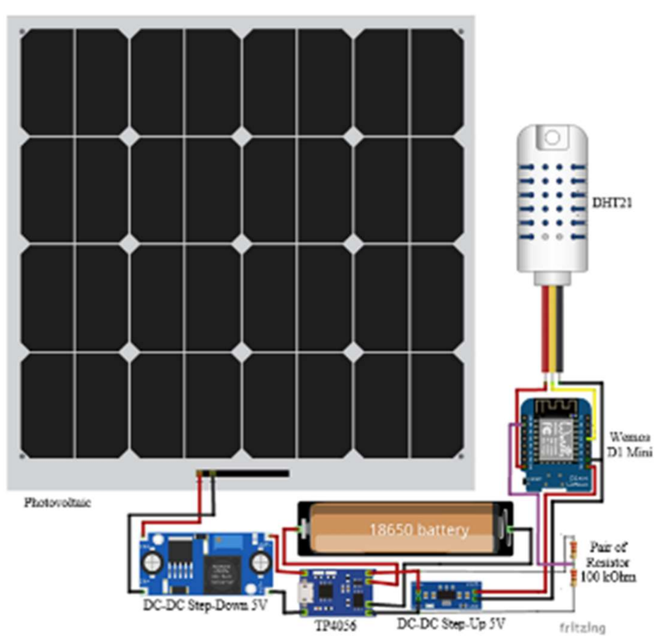
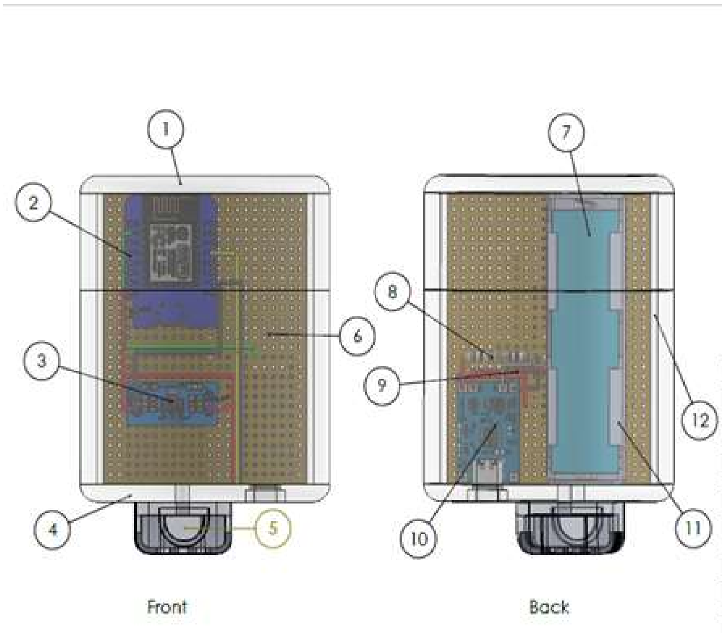


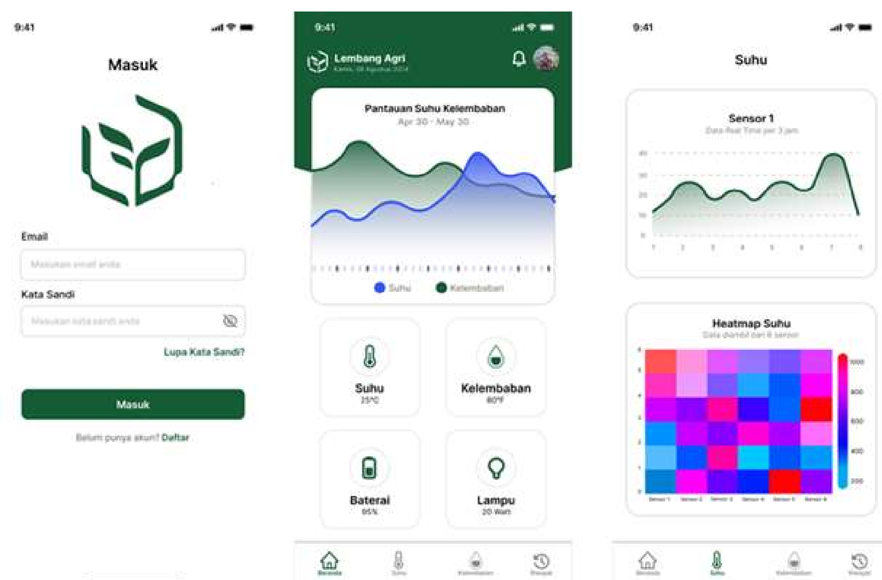
Figure 11. Wiring diagram for monitoring device (transmitter) with Photovoltaic.

The concept of a construction monitoring system is illustrated in Figure 12. The monitoring system is to be installed within a PVC container. The container utilises 2-inch PVC pipe and two caps of 2-inch PVC pipe. The PVC pipe has a length of 8.5 cm, and one of the dop (used as a front cover) will be cut until only 3.5 cm remains. The receiver (master) is positioned close to the WiFi router, ensuring it has access to a power source. Usually, the WiFi router is placed in a strategic location, so the receiver does not require any specific design.



NO.	Components	QTY.
1	Front Cover	1
2	WEMOS D1 MINI (8266)	1
3	STEP-UP 5V	1
4	Back Cover	1
5	DHT 21	1
6	PCB	1
7	Battery 18650	1
8	RESISTOR 100K	2
9	Cable (1 SET)	1
10	TP 4056	1
11	Battery Holder	1
12	PVC Pipe 2"	1

Figure 12. The design of the construction monitoring system (transmitter).



(a) **(b)** **(c)**

Figure 13. The design of the mobile application Temperature and Humidity Monitoring System (a) Sign in, (b) Dashboard indicator, (c) History & Heatmap.

The Website and mobile applications were created using JavaScript. The data collected by the Website will be used to analyse historical trends for future enhancement, such as prediction or control. To meet the screen resolution requirements of smartphones, the mobile apps provide real-time monitoring and the option to download historical data upon request (manually). Figure 13 displays the dashboard of the mobile apps. The measured values are presented not only in numerical form but also in visual form as images.

4. CONCLUSION

Based on the IoT, the Greenhouse Temperature and Humidity Monitoring System developed in this study signifies a notable progression in smart farming technology. The system effectively monitors and transmits environmental data using the WEMOS D1 Mini microcontroller and the ESP-NOW protocol, eliminating the need for expensive or complicated components. This efficient approach improves the precision and dependability of data gathering and simplifies the implementation process, making it more easily usable for a wider range of agricultural applications. Adding a photovoltaic system to power the monitoring devices highlights the system's sustainability and ability to be used for an extended period. This study provides valuable insights into utilising IoT technology in the agricultural sector, specifically enhancing greenhouse conditions to maximise crop productivity. Implementing advanced predictive analytics and automation controls in the future could enhance the system's functionality, resulting in increased efficiencies in greenhouse management. The effective implementation of this system in the Lembang Agri Smart Greenhouse establishes a favourable example for the broader integration of intelligent agricultural technologies throughout Indonesia and beyond.

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