International Journal on Advanced Science Engineering Information Technology

Vol.14 (2024) No. 1
ISSN: 2088-5334

Monitoring and Controlling System of Smart Mini Greenhouse Based on Internet of Things (IoT) for Spinach Plant (*Amaranthus sp.)*

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***Abstract*— Greenhouses, often composed of plastic or glass structures, play a fundamental role in optimizing the environmental conditions essential for successful plant cultivation, ultimately resulting in higher-quality crop yields. The study aims to develop a real-time monitoring and control system for a smart mini greenhouse utilizing the Internet of Things (IoT), with a specific focus on cultivating spinach. The monitoring system is constructed around an ESP32 microcontroller, complemented by a DHT22 sensor for accurate air temperature and humidity measurements, and an RTC DS3231 timer for scheduling tasks. The DHT22 sensor's set point values trigger the fan and misting system operations. The fan activates when the air temperature reaches 32°C, while the misting system turns on when humidity levels (RH) reach 55%. The ESP32 is the central processing unit, enabling internet connectivity through Wi-Fi for real-time data monitoring via the Blynk application. Sensor calibration confirms the system's precision, with regression analyses producing impressive R^2 values of 0.989 and 0.952. The shading net control system operates four hours daily, from 11:00 to 15:00 WIB (Western Indonesian Time), optimizing the greenhouse environment. This well-executed system leads to the robust growth of spinach plants, reaching a height of 23.02 cm, sprouting nine leaves, and attaining a weight of 10 grams. The findings from this study highlight the efficiency and effectiveness of the smart mini greenhouse's monitoring and control system, offering promising applications in broader greenhouse management and crop cultivation practices.**

***Keywords*— Smart mini greenhouse; monitoring and control system; internet of things; smart agriculture.**

Manuscript received 13 Nov. 2022; revised 31 Oct. 2023; accepted 24 Dec. 2023. Date of publication 29 Feb. 2024.

I. Introduction

Agriculture is a critical field for the economic development of any country [1]. The development of agriculture is based on both the improvement in productivity and the restrictions of the era, and the progress of science and technology drives the revolution of agriculture [2]. The rapid climate change, population explosion, and reduction of arable lands are calling for new approaches to ensure sustainable agriculture and food supply for the future [3]. Climate change has already proven its terrible effect on agriculture [4]. Agricultural researchers have developed various agricultural technologies and methods as part of climate change adaptation and mitigation activities [5]. an Efficient one-man farming solution that can combat climatic disturbances to yield a good harvest [6].

The introduction of Information and Communication Technology (ICT) in the agricultural field is currently experiencing momentum, as digitization has a large potential to benefit producers and consumers [7]. The developments of modern information technologies and wireless communication technologies are the foundations for the realization of precision agriculture [8]. With the profound combination of modern information technology and traditional agriculture, the era of agriculture 4.0, which takes the form of smart agriculture, has come [9]. Agricultural IoT is a key technology in smart agriculture that makes it possible to quantify the environmental factors, crop growth, and agricultural production process by automatic processing, analysis, and access [10].

The Internet of Things has drawn the attention of academicians, governments, and engineers from various sectors [11]. Recently, it has made revolutionary changes in human life [12]. Such revolutionary changes are shaking the existing agriculture methods, creating new opportunities and challenges [13]. The Internet of Things (IoT) has recently played a significant role in the agricultural industry by supporting farmers [14]. IoT is quite helpful in uplifting living standards by transforming conventional technology into smart systems [15]. The Internet of Things (IoT) concept was designed to change people's everyday lives via multiple forms of computing and easy deployment of applications [16].

IoT-based smart farming techniques have come up as one of the solutions to tackle the effects of climate change[17]. Many farmers cannot make a reasonable sum from greenhouses because they cannot control two critical factors: productivity and plant growth [18]. The environment is a crucial factor in the greenhouse system [19]. The potential of the Internet of Things (IoT) in greenhouse farming and leading to smart agriculture [20]. In the greenhouse sector, these technologies help farmers increase their profits and crop yields while minimizing production costs, producing in a more environmentally friendly way, and mitigating the risks caused by climate change [21].

A multi-objective integrated optimization framework is proposed to manipulate the whole operation of the smart greenhouse [22]. automation using the Internet of Things (IoT) in a greenhouse environment [23]. Such plant life can be monitored regularly to increase the yield with high quality and quantity[24]. The smart device installed in the greenhouse has many sensors that measure environmental parameters, such as temperature and air humidity [25]. The temperature sensor and humidity sensors are present to control and monitor [26].

Greenhouse design considers greenhouse structures, ventilation, and lighting systems [27]. Wireless Sensor Networks have been often used in the context of Greenhouse architectures. This architecture is IoT-based and built on top of switched Ethernet and Wi-Fi [28]. An effective and efficient sensor network is essential to an automated urban greenhouse [29]. The remote monitoring of different control functions of greenhouses remains mandatory [30]. The possibility of improving the accuracy of climate monitoring in greenhouse cultivation by way of model-based filtering was explored [31]. The design of the smart mini greenhouse systems aims to develop the use of technology in spinach cultivation activities that can monitor and control the microclimate in real-time conditions for growing spinach plants, which is integrated with the internet network.

II. Materials and Method

A. Control System

A control system is a system that works together to achieve the goal of controlling, ordering, or writing the state of a system. The control system has three components: input, process, and output. The control system can unify the parameters at any time following the ordered set point. Networked control systems are spatially distributed systems in which the communication between sensors, actuators, and controllers occurs through a shared band-limited digital communication network[32].

The ESP32 is a low-cost, low-power system on a chip series of microcontrollers with Wi-Fi and Bluetooth capabilities and a highly integrated structure powered by a dual-core Tensilica Xtensa LX6 microprocessor[33]. the DHT22 sensor measured the humidity and temperature values[34]. The DS3231 is a low-cost, extremely accurate I2C real-time clock (RTC) with an integrated temperature-compensated crystal oscillator (TCXO) and crystal. The RTC maintains seconds, minutes, hours, day, date, month, and year information [35]. A relay is a device that drives a contactor or a magnetic switch that can be controlled from an electronic circuit. A DC gearbox motor is a machine that can convert direct current (DC) electrical energy into rotational mechanical motion energy.

B. Internet of Things (IoT)

The Internet of Things (IoT) is a data transmission activity not involving user-to-user or user-to-computer interaction. The IoT concept has three main components: physical objects in the form of sensor modules, internet connections, and data centers on servers that store data and information from physical objects. Blynk is one of the server service platforms used to support the Internet of Things project. Blynk is a digital dashboard with graphical interface facilities for making projects. There are three main components of Blynk: Blynk Apps, Blynk Cloud Server, and Blynk Library [36].

C. System Design

The prototype of the smart mini greenhouse is made of land for farming in urban farming, which will be manufactured with 140 cm × 80 cm × 150 cm made of mild steel, and the entire surface of the smart greenhouse is covered with 14% UV plastic. The design of the smart mini greenhouse prototype is shown in Fig. 1.

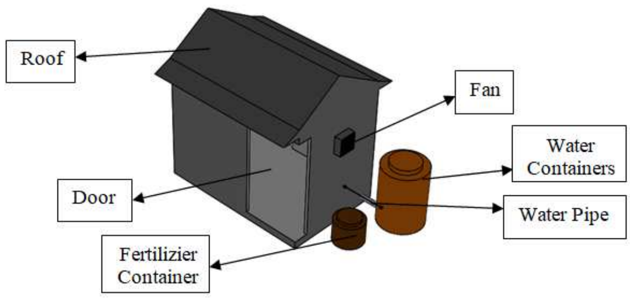


Fig. 1 Prototype Smart Mini Greenhouse

The components of the DHT 22 and RTC DS3231 sensors are placed in a place that can detect the maximum observation parameters. Fans, misting, and shading nets are placed in a place that can reach all spaces in the smart mini greenhouse. The scheme for placing sensors and actuators (top view) on a smart mini greenhouse is shown in Fig. 2.

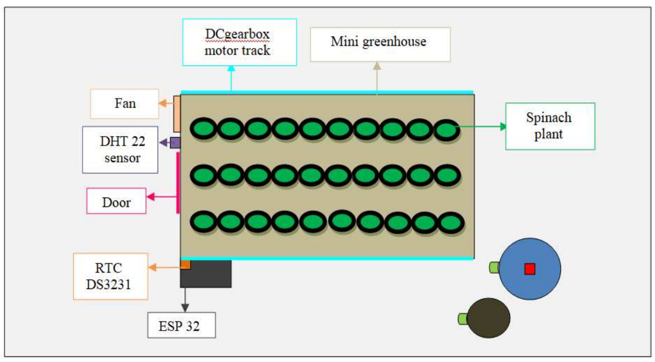


Fig. 2 The Scheme for Placing Sensors and Actuators (Top View) on A Smart Mini Greenhouse

The working value of the sensor serves to drive the fan and misting which is connected to the relay. the set point value of the DHT 22 sensor is at air temperature 32°C to drive the fan control system and stop when the temperature is 30°C and the humidity at RH 55% turns on misting and stops when RH is 60%. This control can control the air conditioner in the smart mini greenhouse. The flow diagram of the DHT22 sensor system is shown in Fig. 3.

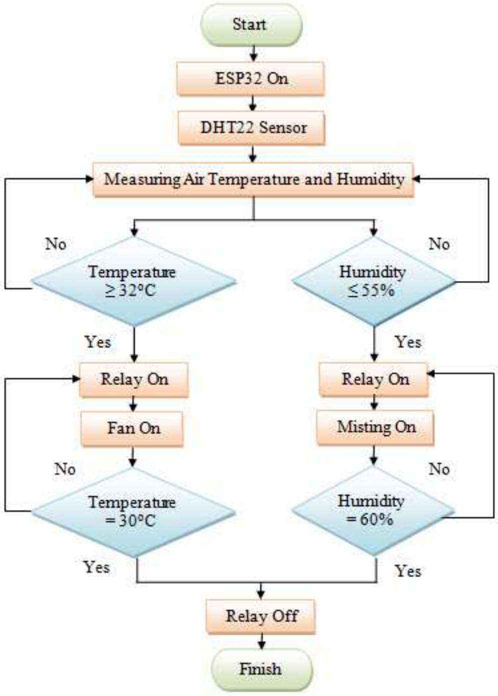


Fig. 3 The Flow Diagram of The DHT22 Sensor System

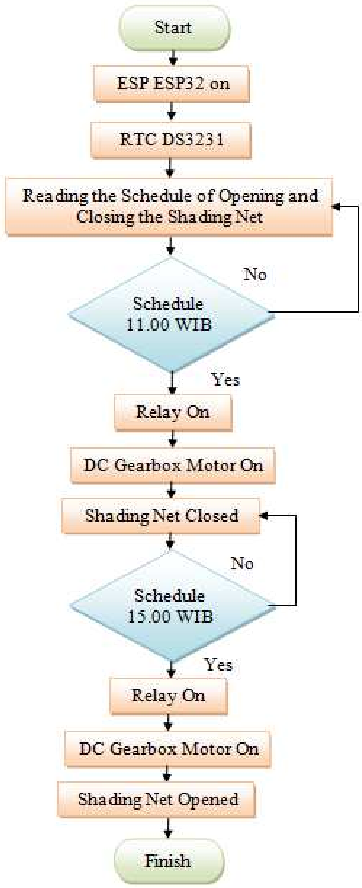


Fig. 4 The Flow Diagram of The RTC DS3231System

The shade level of 0% – 25% causes the light intensity received by plants to range from 20,181.81 to 42,771.81 lux. The working value of the RTC DS3231 is determined based on the schedule of moving the shading net with a density of 25% connected to the relay. The set point value for setting the light intensity in the smart mini greenhouse is set at a working limit of 20,000 lux at 11.00 – 15.00 WIB. The flow diagram of the RTC DS3231 system is shown in Fig. 4.

III. Results and Discussion

A. Calibration

The calibration of the DHT22 sensor was carried out to determine the ability of the sensor to read the temperature and humidity values by comparing the sensor reading value with the measurement results of the thermo hyygrometer. DHT22 Sensor Calibration Graph with thermo hyygrometer is shown in Fig. 5.

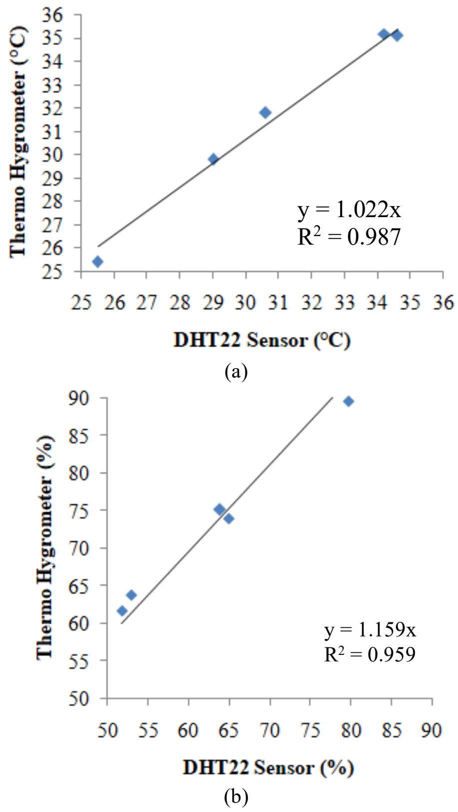


Fig. 5 DHT22 Sensor Calibration with Thermo Hygrometer (a) Air Temperature, (b) Air Humidity

The results of the calibration of the sensor and thermos hygrometer readings obtained an R2 value for an air temperature of 0.987 and an R2 value for an air humidity of 0.959. The results of R2 obtained in the calibration process show that the temperature and humidity readings by the DHT 22 sensor are almost close to value 1. It is concluded that the sensor readings are accurate and ready to be used as a reference for the control system to turn on or turn off the fan and misting [37, 38].

B. Control System Test

The testing process for the smart mini greenhouse control system aims to determine whether the performance of the sensor and actuator readings have worked according to the program order or not. The results of the tests carried out can be seen in Table I.

TABLE I
SMART MINI GREENHOUSE CONTROL SYSTEM TEST

No	Sensor	Parameter	Time	Value	*Relay*
1	DHT22 Sensor	Air temperature	07:00:00	26.5°C	*OFF*
			10:40:00	32.1°C	*ON*
			16:17:00	29.9°C	*OFF*
		Air humidity	07:00:00	86.4%	*OFF*
			12:16:30	54.9%	*ON*
			12:18:59	60.1%	*OFF*
2	RTC DS3231	Light intensity	11:00:00	Closed schedule	*ON*
			11:00:18	Closed schedule	*OFF*
			15:00:00	Opened schedule	*ON*
			15:00:18	Opened schedule	*OFF*

The results on the performance of the DHT 22 sensor indicate that the fan and misting have worked well based on the programmed set point value. The reading of the RTC DS3231 schedule against the shading networks according to the program ordered.

C. *Connection to Blynk App*

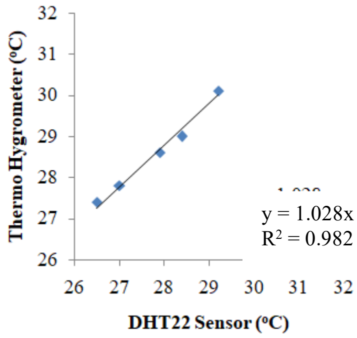
Blynk application can be connected to the ESP 32 Wi-Fi module used via the auth token code. ESP 32 must be connected to the internet network via a router or a hotspot connection that is connected through programming in the Arduino IDE application. The programming of the ESP 32 connection with the Blynk application is shown in Fig. 6.

```
#define BLYNK_PRINT Serial
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
char auth[]="w0uFmL6XGnzKEjpTNbAdCiLRWJ4nkVDy";
char ssid[]="Pikaspong";
char pass[]="alexthefox";
```

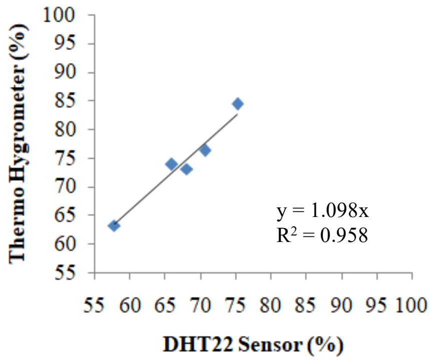
Fig. 6 ESP32 Connection Programming with Blynk App

D. *Sensor Reading Accuracy*

The results of the accuracy of reading the air temperature sensor DHT 22 obtained an R2 value of 0.982 and air humidity with an R2 value of 0.958. The results of R2 obtained show the reading of air conditions by the DHT 22 sensor, which is almost close to the value of 1. So, it can be concluded that the sensor's reading of air temperature during research activities still functions correctly. The graph of the accuracy of the DHT 22 sensor readings is shown in Fig. 7.



(a)

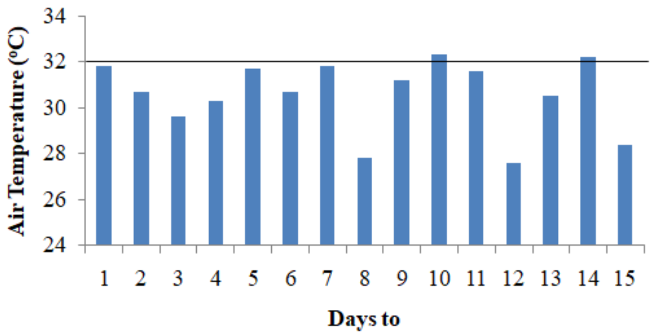


(b)

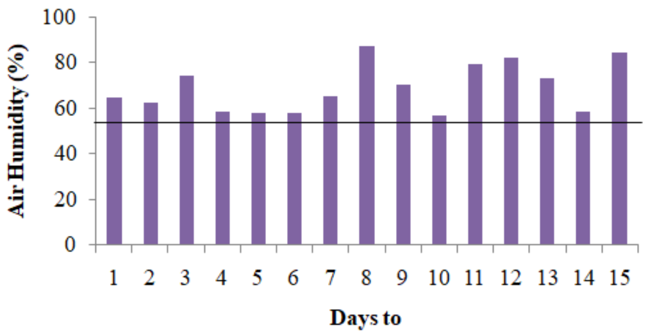
Fig. 7 The Graph of the Accuracy of the DHT22 sensor Readings (a) Air Temperature, (b) Air Humidity

E. *Control System Monitoring*

During the observation of the air temperature in the smart mini greenhouse, there were two days the value reached the set point, which was >32°C which occurred on the 10th and 14th observation days, and for the humidity of the air in the smart mini greenhouse, no one reached the set point value, which was <55% or the humidity was in normal conditions. The fixed values of air temperature and air humidity are depicted by a straight line in Fig.8. The graph of the observation of the DHT22 sensor is shown in Fig. 8.



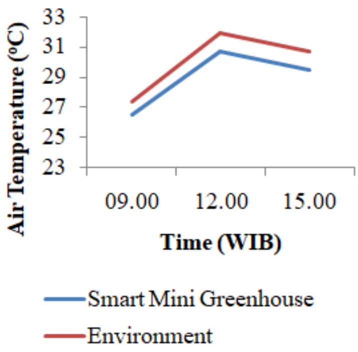
(a)



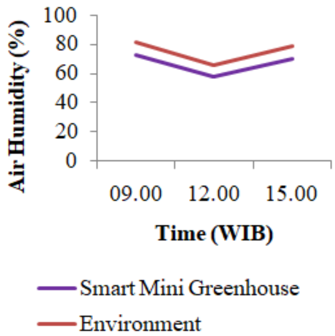
(b)

Fig. 8 The Graph of The Observation of The DHT22 Sensor (a) Air Temperature, (b) Air Humidity

Weather conditions at the time of observation changed, such as scorching heat or rain, which affected the temperature and humidity in the smart mini greenhouse. In addition, observations were made on the smart mini greenhouse's air conditioning with the environment's air temperature conditions. The results of comparing air conditions in the smart mini greenhouse with the environment are shown in Fig. 9.



(a)



(b)

Fig. 9 The Results of The Comparison of Air Conditions in The Smart Mini Greenhouse with The Environment (a) Air Temperature, (b) Air Humidity

The air temperature in the smart mini greenhouse is lower than the air temperature in the surrounding environment. The intensity of the incoming light can influence the air temperature in the smart mini greenhouse, and the air temperature in the environment is influenced by weather and wind conditions [39]. The humidity in the smart mini greenhouse can be affected by the air temperature in the smart mini greenhouse, so the humidity in the smart mini greenhouse is lower than the surrounding environment.

F. Control System

The fan turn-on time is set when the sensor reads the air temperature as more than 32°C and turns off when the temperature is 30°C. To lower the temperature by 2°C, the time required by the fan is 5 hours 37 minutes. Then, controlling the humidity in the smart mini greenhouse is set at 55% to turn on the misting and stop working when the humidity has reached 60%. The time misting required to increase the humidity by 5% in the smart mini greenhouse is 157 seconds or 2 minutes 29 seconds.

The closing time for the shading net is scheduled for 4 hours every day during research observations starting at 11.00 WIB and will reopen at 15.00 WIB. This schedule is determined based on the observation of the set point in which the light intensity results are 20.000 lux. This light intensity control is carried out at 11.00 WIB to close the shading net driven by the DC gearbox motor and at 15.00 WIB to open the shading net.

G. Spinach Plant Growth

Observations on the growth of spinach plants in the form of stem height, number of leaves, and plant weight. The stem height of the spinach plant was 23.02 cm. The number of leaves of spinach plants is 9 strands, and the weight of spinach plants is 10 grams.

IV. Conclusion

The smart mini greenhouse control system is controlled by an ESP 32 microcontroller, which uses a DHT 22 sensor to measure temperature and humidity parameters and RTC DS3231 to set the light intensity control schedule. The control system works well according to the set point value ordered to drive the actuator as a fan, misting, and shading net with a DC gearbox motor drive. Observation of the working system can be done remotely using the Blynk application connected to the internet network. The designed smart mini greenhouse can work well in controlling the microclimate in the form of air temperature, air humidity, and light intensity according to the conditions for growing spinach plants. The mechanism of this work system can be further applied to large-scale greenhouses. In addition, the automation of watering and fertilizer application for spinach plants can also be added.

V. ACKNOWLEDGMENT

We thank Andalas University Grant number T/12/UN.16.17/PP.PanganOUT-KRP2GB-Unand/2022 for providing financial support or this project.

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