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Design Of Data Acquisition And Environmental Parameter Monitoring System For Smart Greenhouse

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Abstract*—Indonesia is the largest agricultural country in the world. The agriculture potential is tremendous because Indonesia can produce various types of plants. This causes the addition of farming methods developed to produce optimal products. One method that is widely used is a greenhouse. Greenhouse can be defined as buildings that function to manipulate the environment to create the desired environment following the needs of the plants in it. But for now, general arrangements in the greenhouse still use the manual method such as room temperature measurements using a thermometer, air humidity measurements using a hygrometer, and soil moisture and soil pH measurements using a soil pH meter. Therefore we need to develop a greenhouse to maintain environmental conditions without having to use human assistance directly. This integrated system that we designed is what we call a smart greenhouse. We design a data acquisition system and environmental parameter monitoring system in this smart greenhouse. The system provides filtering with EWMA. Furthermore, as a result, we were able to make a designed air temperature reading with an average error of 0.48. Air humidity reading with an average error of 5.33. Soil moisture parameters with an accuracy of 91.66 percent. The wi-fi module ESP-32S successfully sends data to the Thingspeak website server with a delay of 30 seconds.*

Keywords—data acquisition; monitoring system; greenhouse;

1. INTRODUCTION

Indonesia is the largest archipelagic country in the world, with a land area of around 190 million hectares, of which about 28.94 percent or about 55 million hectares are agricultural lands [1]. As the fourth most populous country globally, the 2010 population census recorded Indonesia's population of 238 million, with a growth rate of 1.49% in the 2000-2010 period. The total population of Indonesia is expected to increase to 288 million by 2050 [2]. With a large population and extensive agricultural land, Indonesia can produce various types of plants that are consumed by Indonesian citizens or exported abroad. A greenhouse or greenhouse is a building framed or made in the shape of a bubble, covered with transparent, clear, or a material that can continue light optimally to produce and protect plants from climatic conditions that can adversely affect plant growth and development processes. The advantages of the greenhouse are developing control strategies for increased efficiency, high compatibility, easy operation, and low cost, especially for energy savings in greenhouses [3].

In previous research, [4] proposed to control the greenhouse based on the Internet of Things with the Atmel SAM3X8E ARM Cortex-M3 CPU microcontroller, and the sensor data sent in real-time to the Adafruit.io website. There was a monitoring system and controlling plant watering using the Fuzzy Logic method with the Internet of Things approach. The next research proposes to control the greenhouse based on the AT89S52 microcontroller, and the sensor data is displayed on a real-time 128 x 64 LCD [5]. Moreover, another research proposed an automatic plant watering and lighting system by comparing three factors: temperature, light intensity, and soil moisture. As a result, the automation system in the greenhouse (water alarm, automatic watering, automatic lighting) can work well. Subsequent research in 2016 proposed controlling a greenhouse to achieve optimal temperature and humidity conditions using the Bayesian Network method [6].

Furthermore, we designed a data acquisition system and a monitoring system for environmental parameters with the MQTT protocol in a greenhouse, which we call a smart greenhouse. This smart greenhouse design uses a 12V power supply to supply all components in the system. In this study, a system was designed to transmit data on air temperature, humidity, soil pH, and soil moisture in real-time. The four climate parameters can be determined using three sensors: the DHT22 sensor, soil pH sensor, and SEN0193 sensor. This system is designed based on Internet of Things (IoT) to detect and monitor the greenhouse environment parameters remotely via the website.

2. SYSTEM DESIGN

2.1 Hardware Design

The design of hardware (hardware) in this study uses the following components:

1. Arduino Due microcontroller

2. A DHT22 sensor
3. A soil pH sensor
4. A SEN0193 sensor
5. Adapter 12V
6. DC-DC Buck converter
7. OLED 128 x 64
8. Wi-Fi NodeMCU ESP-32S module
9. Data logging board

All these components are assembled into a block diagram, as shown in Figure 1.

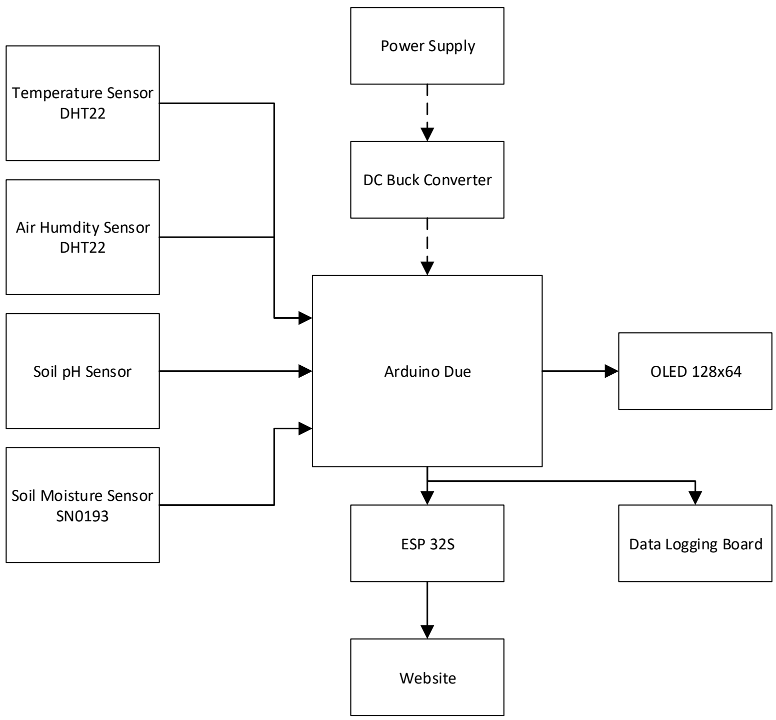

Fig. 1. *System block diagram*

2.2 Data Processing Design

Arduino Due is utilized to read the DHT2 sensor input, soil pH sensor, and SEN0193 sensor. Arduino Due is also used to generate sensor reading data displayed on a 128 x 64 OLED and stored on the SD Card via the data logging board. Besides, Arduino Due also sends sensor data to the Thingspeak website via the ESP-32S NodeMCU Wi-Fi Module Figure 2 displays the pin configuration on the Arduino Due.

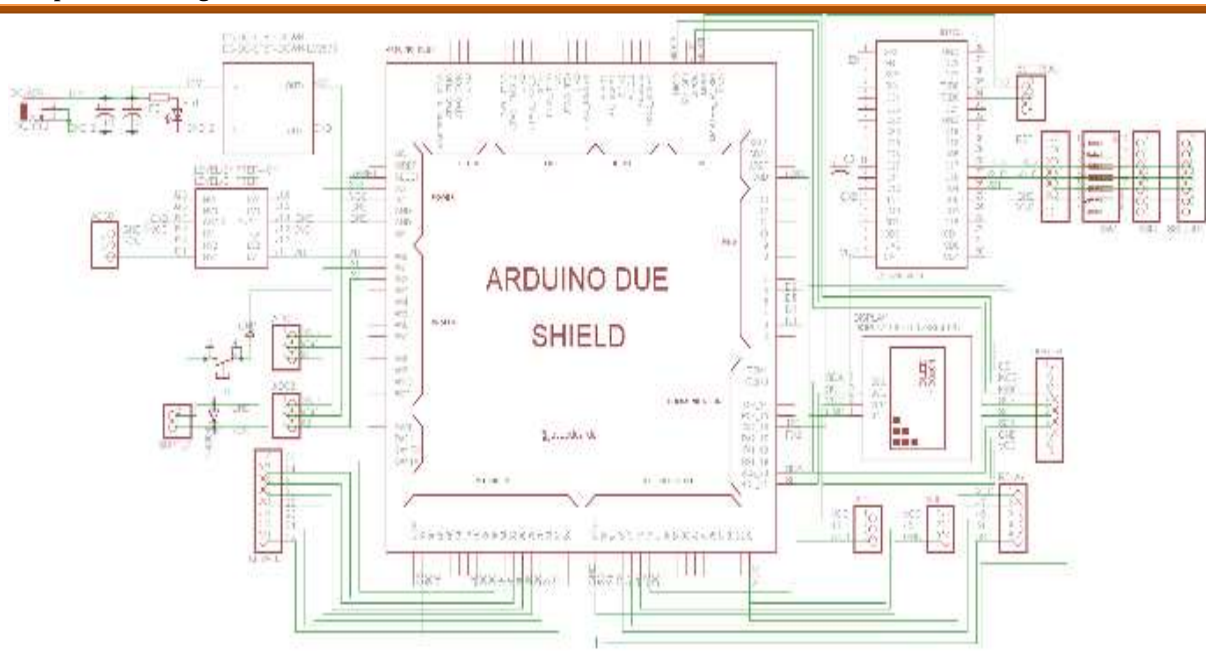

Fig. 2. *Pin Configuration on Arduino Due*

2.3 Exponentially Weight Moving Average

EWMA or Exponentially-Weighted Moving Average is a filter used to smooth the reading of a series of data. EWMA filter has now become a popular control method for implementing Run-to-Run (RtR) process control. Unlike the history buffer method, which calculates the average of the last N reads, this method on this filter uses less memory and can run faster. This filter provides an additional EwmaT template that allows restrictions on certain data types, such as uint32_t, to avoid floating-point arithmetic and can significantly reduce code footprint [10].

3. Testing and Analysis

3.1 DHT22 Air Temperature Sensor Testing

DHT22 Air Temperature sensor testing is done by comparing the air temperature read by the sensor via a microcontroller with the air temperature read by a digital thermometer. Table 1 shows the comparison of the DHT22 sensor air temperature readings with a digital thermometer.

Table 1: Comparison of Sensor Air Temperature Readings DHT22 with Digital Thermometer

No	Air Temperature (digital thermometer)	Air Temperature (DHT22)	|Error|	|%Error|
1.	25.30	24.64	0.66	2.61%
2.	25.30	24.58	0.72	2.85%
3.	25.10	24.48	0.62	2.47%
4.	24.60	24.20	0.40	1.63%
5.	24.50	24.10	0.40	1.63%
6.	24.00	24.10	0.10	0.42%
7.	24.80	24.40	0.40	1.61%
8.	28.70	28.33	0.37	1.29%
9.	33.50	33.85	0.35	1.04%
10.	36.80	37.49	0.69	1.88%
11.	36.50	36.88	0.38	1.04%
12.	35.30	35.98	0.68	1.93%
	Average		0.48	1.70%

Based on Table 1, it is found that the temperature with an average error of 0.48 and an average error percentage of 1.70%. This error because of differences in sampling time and differences in response to sensor readings with a digital thermometer and the placement between the DHT22 sensor and the digital thermometer. Fig. 3 shows a graph comparing the air temperature reading of the DHT22 sensor to a digital thermometer. Table 2 shows the calculation of statistical regression comparing the air temperature reading of the DHT22 sensor to a digital thermometer.

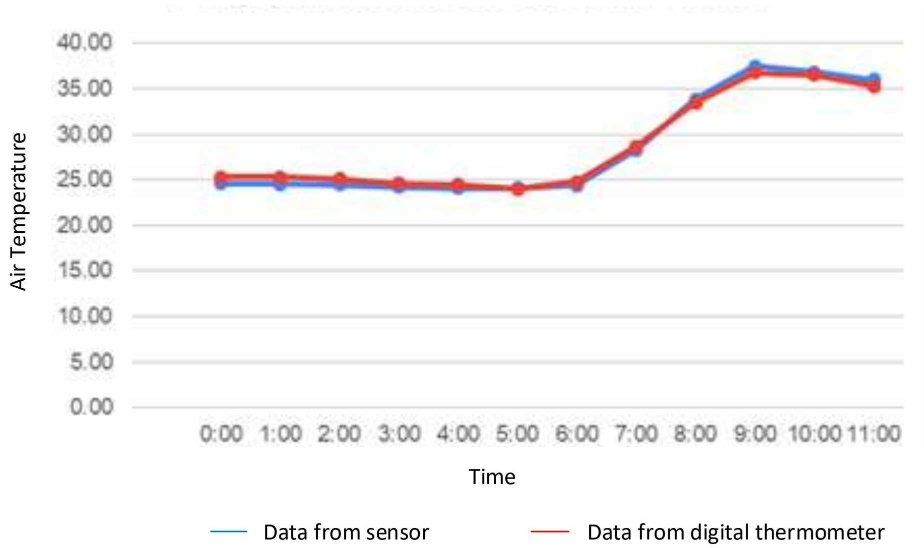

Fig. 3. *Comparison of DHT22 air temperature sensor to digital thermometer readings*

Table 2: Calculation of statistical regression comparison of DHT22 air temperature sensor to digital thermometer readings

Statistical Regression	
Multiple R	0.998987649
R Square	**0.997976323**
Adjusted R Square	0.99775147
Standard Error	0.254594114
Observations	11

The statistical regression calculations in Table 2 obtain the value of R2, or R Square is 0.9977, where R2 shows the accuracy of the measurement tools made of 99.77%.

3.2 The DHT22 Air Humidity Sensor Testing

Testing of the DHT22 air humidity sensor is performed by comparing the air humidity read by the sensor through the microcontroller with the air humidity read by a digital thermometer. Table 3 shows the comparison of the DHT22 sensor air humidity reading with a digital thermometer.

Based on Table 3, air humidity is obtained with an average error of 5.33 and an average error percentage of 6.23%. This error because the measuring instrument has a very high sensitivity in scanning changes in air humidity compared to the humidity reading by the DHT22 sensor. Fig. 4 shows a graph comparing the moisture of the DHT22 sensor reading with a digital thermometer. Table 4 shows the statistical calculation of comparing the air humidity of the DHT22 sensor reading with a digital thermometer.

Table 3: Comparison of DHT22 air temperature sensor to digital thermometer readings

No	Air Humidity (*Thermometer* Digital)	Air Humidity (DHT22)	|Error|	|%Error|
1.	99.00	95.21	3.79	3.83%
2.	99.00	95.71	3.29	3.32%
3.	87.00	93.06	6.06	6.97%
4.	78.00	91.81	13.81	17.71%
5.	83.00	92.22	9.22	11.11%
6.	84.00	93.27	9.27	11.04%
7.	85.00	93.16	8.16	9.60%
8.	89.00	95.10	6.10	6.85%
9.	99.00	97.09	1.91	1.93%
10.	99.00	98.56	0.44	0.44%
11.	99.00	98.60	0.40	0.40%
12.	99.00	97.46	1.54	1.56%
	Average		5.33	6.23%

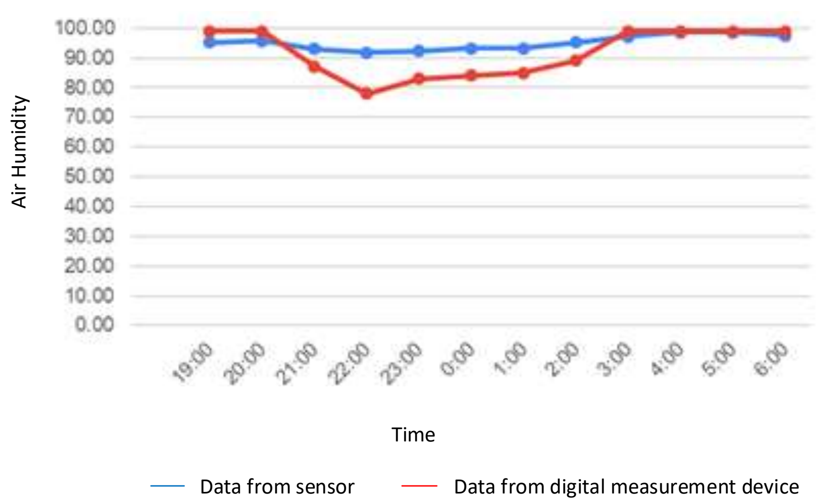

Fig. 4. *Comparison of DHT22 air temperature sensor to digital thermometer readings*

Table 4: Statistical regression comparison of DHT22 air humidity sensor with digital thermometer reading

Statistical Regression	
Multiple R	0.94050994
R Square	**0.884558947**
Adjusted R Square	0.871732163
Standard Error	2.905171886
Observations	11

Based on the statistical regression calculations in Table 4, it provides the value of R2 or R Square is 0.8845, where R2 shows the accuracy of the measurement tools made of 88.45%.

3.3 The SEN0193 Sensor Soil Moisture Testing

The SEN0193 sensor testing is done by comparing the soil moisture read by the sensor via a microcontroller with the soil moisture read by a digital soil moisture meter. The value read by a digital soil moisture meter is in the form of an indicator, amounting to 5. We divide the five indicators in the range of 0-100% in Table 5.

Table 5: Distribution of soil moisture meter range on soil moisture meter

The indicator on a digital soil moisture meter	Soil moisture range
DRY+	0-20%
DRY	21-40%
NOR	41-60%
WET	61-80%
WET+	81-100%

From Table 5, a description of the soil moisture test can be made based on its true value. Table 6 shows the comparison of the SEN0193 soil moisture sensor reading with a digital soil moisture meter.

Table 6: Comparison of SEN0193 soil moisture sensor with digital soil moisture meter reading

No	Soil moisture meter	Soil moisture range	Soil moisture (SEN0193)	The value of truth
1.	WET	61-80%	78%	TRUE
2.	WET +	81-100%	79%	FALSE
3.	WET	61-80%	79%	TRUE
4.	WET	61-80%	79%	TRUE
5.	WET	61-80%	79%	TRUE
6.	WET	61-80%	79%	TRUE
7.	WET	61-80%	80%	TRUE
8.	WET	61-80%	80%	TRUE
9.	WET	61-80%	79%	TRUE
10.	WET	61-80%	75%	TRUE
11.	WET	61-80%	73%	TRUE
12.	WET	61-80%	72%	TRUE
		Data Accuracy		91,66%

Based on Table 6, the average percentage accuracy is 91.66%, where there are 11 times the accurate data from 12 times data collection. The error in reading the data can be caused by differences in sampling time and differences in the response of the sensor readings with a digital soil moisture meter and the placement between the SEN0193 sensor and the digital soil moisture meter.

3.4 The EWMA Filter on the DHT22 Sensor Testing

A. Testing the EWMA Filter on the air temperature reading

Testing of the EWMA filter at air temperature is carried out by comparing the air temperature readings added by the EWMA filter with the air temperature readings that are not added by the EWMA filter. Table 7 shows a comparison of the DHT22 sensor air temperature readings with filter and without EWMA filter.

Based on testing the effect of the EWMA filter on the DHT22 air temperature sensor in Table 7, it can be seen that the accuracy of the DHT22 sensor readings reaches 0.01oC when the EWMA filter is added. In contrast, when the EWMA filter is not added, the sensor sensitivity only gets 0.1oC. So it can be concluded that the addition of an EWMA filter can increase the accuracy

Table 7: Testing the effect of the EWMA filter on the DHT22 air temperature sensor

Time	Air Temperature without Filter	Air Temperature with Filter
10.00	37.30	34.12
11.00	34.00	33.92
12.00	35.20	35.00
13.00	34.70	33.00
14.00	35.00	31.21
15.00	35.30	28.10
16.00	32.30	26.75

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17.00	29.20	25.92
18.00	26.50	24.85
19.00	25.50	24.50
20.00	24.80	23.81
21.00	24.20	23.81

Fig. 5 shows a graph comparing the readings of the DHT22 air temperature sensor with the EWMA filter.

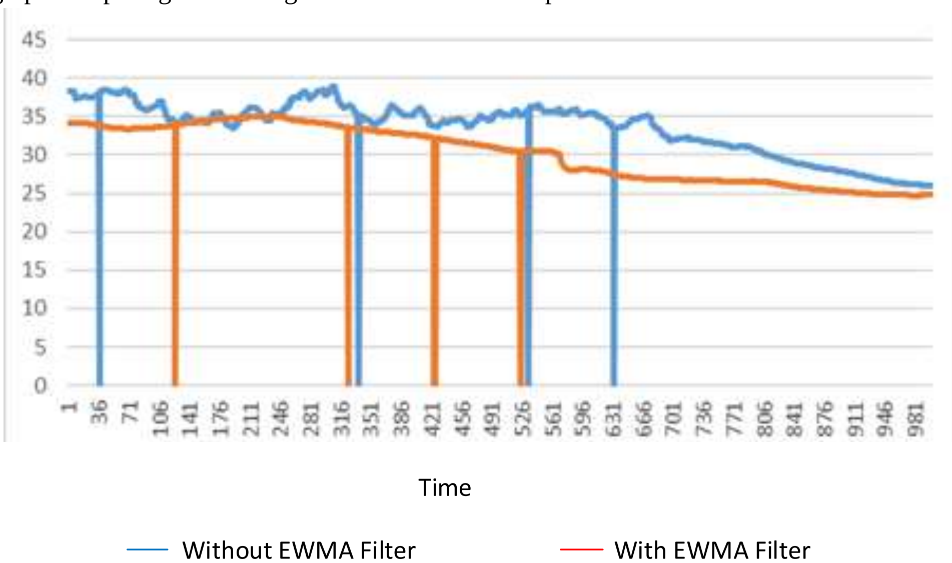

Fig. 5. *Comparison graph of EWMA filter effect on air temperature DHT22 sensor reading*

Based on the graph of the comparison of the effect of the EWMA filter in Fig. 5, it can be seen that the graphic form of the sensor readings becomes smoother when an EWMA filter is added. Meanwhile, when the EWMA filter is not added, the chart has a lot of up or down overshoot. So it can be concluded that the addition of an EWMA filter can smooth the reading of the graph.

B. Testing the EWMA Filter on the air humidity reading

Testing the EWMA filter on air humidity is carried out by comparing the reading of air humidity added by the EWMA filter with the reading of air humidity that is not added by the EWMA filter. Table 8 compares the air humidity reading of the DHT22 sensor with an EWMA filter and without an EWMA filter. From the results of the data experiment, it can be concluded that the average data sending and receiving data in the investigation is appropriate, and there is only a slight difference due to delivery delay.

Table 8: Testing the effect of the EWMA filter on the air humidity DHT22 sensor

Time	Air Humidity without Filter	Air Humidity with Filter
10.00	44.4	57.82
11.00	54.5	58.23
12.00	52.3	55.2
13.00	51.5	59.73
14.00	53.2	66.19
15.00	54.5	90.34
16.00	59.1	91.63
17.00	72	92.46
18.00	88.5	96.8
19.00	90.8	96.35
20.00	93	97.31
21.00	96.5	98.32

Fig. 6 shows a graph comparing the DHT22 air humidity sensor readings with the EWMA filter

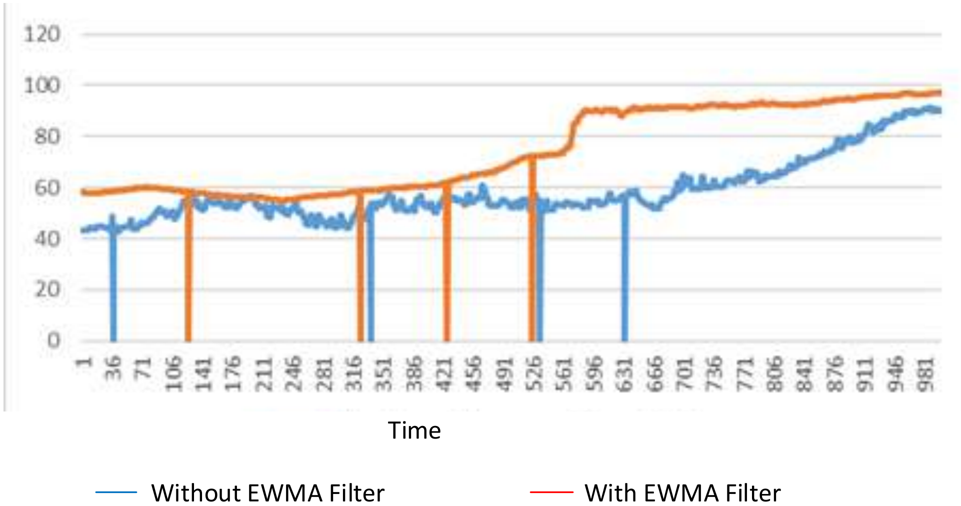

Fig. 6. *Comparison graph of EWMA filter effect on air humidity DHT22 sensor reading*

3.5 The ESP-32S Testing

Testing the ESP-32S Wi-Fi module is by comparing the reading of the sensor value with the value received by the website. Table 9 shows the tests for the ESP-32S Wi-Fi module.

Table 9: Testing of the ESP-32S Wi-Fi Module

Testing	Sensor reading value			Time of receiving data	Value received by Website		
	DHT22 Air Temperature (^{0}C)	DHT22 Air Humidity (%)	SEN0193 Soil Humidity sensor		DHT22 Air Temperature (^{0}C)	DHT22 Air Humidity (%)	SEN0193 Soil Humidity sensor
1.	24.35	98.48	80.00	06:10	24.32	98.54	81.00
2.	28.35	91.12	80.00	07:02	28.27	91.06	82.00
3.	29.07	78.00	92.00	08:00	29.03	77.91	91.00
4.	30.13	74.85	93.00	09:02	30.13	74.85	93.00
5.	35.18	56.47	92.00	10:02	35.08	56.56	91.00
6.	37.00	49.65	91.00	11:05	37.00	49.78	90.00
7.	37.84	50.00	90.00	12:07	37.83	50.26	89.00
8.	36.92	52.47	42.00	13:16	36.95	52.09	42.00
9.	36.57	52.73	69.00	14:02	36.59	52.21	70.00
10.	34.66	58.54	74.00	14:59	34.09	59.84	79.00
11.	29.62	76.39	86.00	16:03	29.62	76.38	86.00
12.	28.00	84.26	85.00	17:03	28.00	84.18	84.00

3.6 Submission of Microcontroller Data via the ESP-32S to the Website

Communication on the microcontroller uses the ESP-32S using a Telkomsel Flash USB modem via a TP-Link wireless router. Website address https://thingspeak.com/channels/1205088. Fig. 7, Fig. 8, and Fig. 9 display monitoring readings of air temperature, air humidity, and soil moisture, respectively.

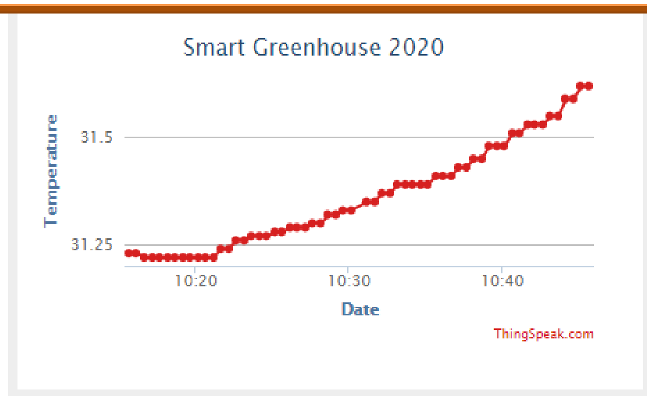

Fig. 7. *Website inteface of air temperature condition*

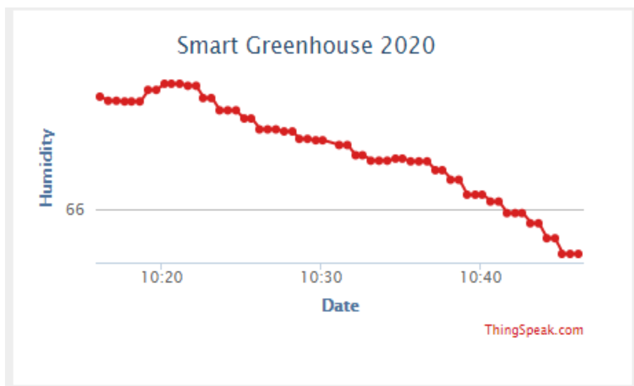

Fig. 8. *Website inteface of air humidity condition*

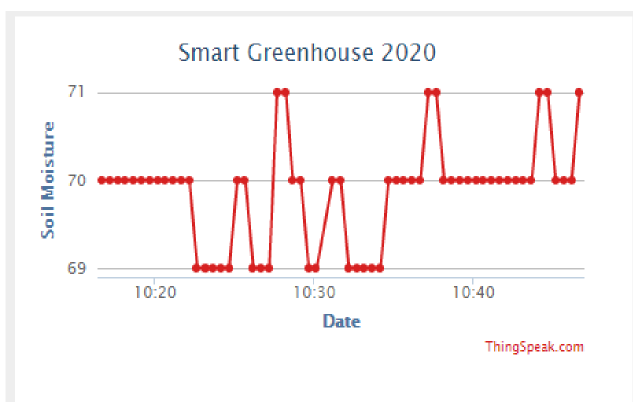

Fig. 9. *Website inteface of soil moisture condition*

3.7 Testing and Analysis of Environmental Monitoring Systems

Testing and analysis of the environmental parameter monitoring system are carried out by observing the time delay of sending DHT22 values of air temperature, DHT22 air humidity, SEN0193 soil moisture, and soil pH sensor from the Microcontroller via ESP-32S to the website Thingspeak. Table 12 shows the test time delay for the environmental parameter monitoring system.

Table 10: Testing of Time Delay for Environmental Parameter Monitoring System

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Test	Value on website				
	DHT22 Air temperature (^{0}C)	**DHT22 air humidity (%)**	**Soil pH Sensor**	**SEN0193 soil humidity sensor**	**Time Delay (ms)**
1.	31.53	65.95	3.00	70	30105
2.	31.53	65.95	3.00	70	29595
3.	31.53	65.95	3.00	70	28751
4.	31.55	65.80	3.00	70	30272
5.	31.55	65.80	3.00	70	30539
6.	31.59	65.58	3.00	71	29810
7.	31.59	65.58	3.00	71	30571
8.	31.62	65.35	3.00	70	29225
9.	31.62	65.35	3.00	70	30401
10.	31.62	65.35	3.00	70	29464

From Table 10, it can be seen that the value sent by the microcontroller to the Thingspeak website database is well received. Time testing using the website www.estopwatch.net. Delivery time takes 28500 - 31500 milliseconds. It can be concluded that the system is designed to work well in the real-time observation area as a monitoring system for smart greenhouse environmental parameters.

3.8 Testing of Data Logging Board

The data logging board containing the SD card is used as a storage for sensor data and as a time saver. This data logging board test is carried out to find out whether the SD card used can store sensor data and time. Fig. 10 shows the data logging board test when input has been given.

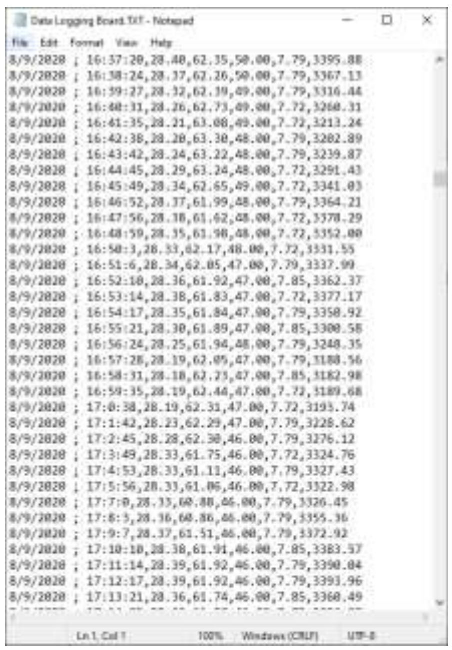

Fig. 10. *Testing of the logging board data when it has been given input*

4. CONCLUSIONS

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- In testing the air temperature parameters, it was obtained 12 times the reading of the DHT22 sensor reading data and the digital thermometer obtained the temperature with an average error of 0.48 and an average error percentage of 1.70%. And can show the accuracy of the measurement tools made of 99.77%. In testing the air humidity parameter, it was obtained 12 times the reading data of the DHT22 sensor with a digital thermometer, obtained air humidity with an average error of 5.33 and an average error percentage of 6.23%. And can show the accuracy of the measurement tools made of 88.45%. In testing the Wi-Fi module the ESP-32S has successfully sent data from the Arduino Mega (Microcontroller) to the website database with a delay of about 30 seconds.

- In testing the effect of the EWMA filter on the DHT22 sensor, the temperature and humidity showed that the accuracy of the DHT22 sensor reached 0.01oC and 0.01% when the EWMA filter was added. In addition, the shape of the sensor reading graph becomes smoother when an EWMA filter is added.

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