DESIGN AND IMPLEMENTATION OF A CYBER PHYSICAL SYSTEM OF A AUTOMATED WHEATHER STATION AND AGRICULTURAL NODE IN SMART FARMING

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***Abstract**. This research focuses on the development of a Cyber-Physical System (CPS) for Smart Farming by integrating an automated weather station with an agricultural node. The automated weather station collects crucial meteorological data, including temperature, humidity, rainfall, wind speed, and solar radiation, while the agricultural node monitors soil conditions, nutrient levels, and pest presence. Through seamless wireless communication and cloud-based analytics, the system provides real-time insights to farmers, enabling informed decision-making regarding irrigation, fertilization, and pest control. Field trials have demonstrated improved crop yield, resource optimization, and reduced environmental impact, showcasing the potential of this CPS to revolutionize modern agriculture and contribute to sustainable and efficient farming practices. The Agricultural Node, on the other hand, incorporates various sensors and actuators to monitor and control essential factors such as soil moisture, nutrient levels, and pest presence.*

***Keywords:** Cyber-Physical System (CPS), Smart Farming, Automated Weather Station, Agricultural Node, Internet of Things (IoT).*

Abstrak. Penelitian ini berfokus pada pengembangan Sistem *Cyber-Physical* (CPS) untuk Pertanian Cerdas dengan mengintegrasikan stasiun cuaca otomatis dengan simpul pertanian. Stasiun cuaca otomatis mengumpulkan data meteorologi penting, termasuk suhu, kelembaban, curah hujan, kecepatan angin, dan radiasi matahari, sementara simpul pertanian memantau kondisi tanah, tingkat nutrisi, dan kehadiran hama. Melalui komunikasi nirkabel yang lancar dan analitika berbasis awan, sistem ini memberikan wawasan waktu nyata kepada petani, memungkinkan pengambilan keputusan yang terinformasi mengenai irigasi, pemupukan, dan pengendalian hama. Uji lapangan telah menunjukkan peningkatan hasil panen, optimalisasi sumber daya, dan berkurangnya dampak lingkungan, menunjukkan potensi CPS ini untuk merevolusi pertanian modern dan berkontribusi pada praktik pertanian yang berkelanjutan dan efisien. Di sisi lain, *Agriculture Node* menggabungkan berbagai sensor dan aktuator untuk memantau dan mengontrol faktor-faktor penting seperti kelembapan tanah, tingkat nutrisi, dan keberadaan hama.

Kata kunci: Sistem *Cyber-Physical System (CPS)*, Pertanian Cerdas, Stasiun Cuaca Otomatis, *Agricultural Node*.

I. INTRODUCTION

Smart farming, as a modern agricultural paradigm, has emerged as an innovative approach to improving crop production. In this context, agricultural productivity is closely related to the dynamic atmospheric conditions specific to each location and time. Basic parameters such as wind speed, temperature, humidity, and precipitation must be continuously monitored. Nevertheless, traditional farming methods used in Indonesia are often inefficient, require significant resources, and are primarily rudimentary based on observation of natural phenomena, especially wind and cloud patterns. It features unpredictable harvest results due to unpredictable weather forecasts. This highlights the urgent need for more sophisticated systems that can provide accurate real-time weather data.

Agriculture plays a central role in meeting society's diverse demands, including basic needs such as nutrition, industrial raw materials, energy resources, and environmental protection [1]. However, the agricultural sector faces major challenges from climate change, which is leading to inaccurate weather forecasts. As a result, farmers are faced with the difficult task of making strategic decisions to reduce the negative effects of capricious weather conditions. Traditional weather monitoring techniques are often limited in scope, accuracy, and timeliness and have proven inadequate to effectively address this challenge [2]. Given that weather conditions directly affect crop growth and yield, the accuracy and timeliness of weather monitoring is paramount to healthy agricultural management.

Although weather remains a natural phenomenon that cannot be controlled, it can be systematically observed and analyzed through the practice of weather monitoring.

In this context, it is essential to develop systems that can monitor important meteorological parameters such as temperature, humidity, wind direction, and wind speed. One such example is his AWS weather monitoring node operated at Gambung Tea Estate and Quinine Farm (PPTK). It is based on the NRF24L01 wireless communication protocol [3]. The system integrates multiple sensors for comprehensive data collection, providing accurate and timely insights on temperature, humidity, precipitation, soil moisture, wind speed and direction, and ambient light levels. These systems have proven to be essential tools for providing farmers with real-time data, enabling informed decision-making, and promoting sustainable agricultural practices in the face of climate change.

II. METHODOLOGY

This research was conducted in several stages. Broadly speaking, this research starts from making tools, making programmes, and testing tools, as well as data analysis where the flow chart can clearly be seen in the figure.

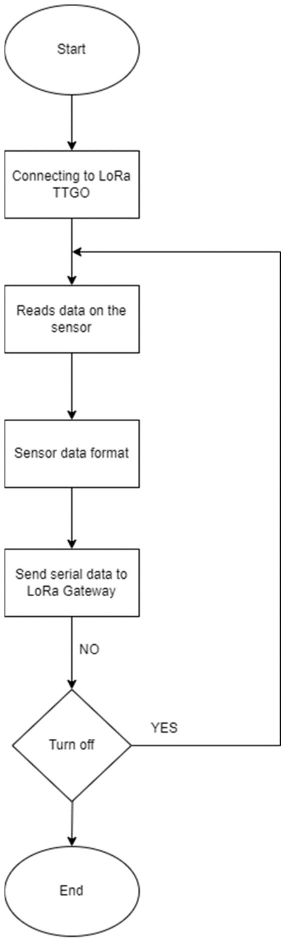

Figure 1 Flowchart Node Sensor AWS

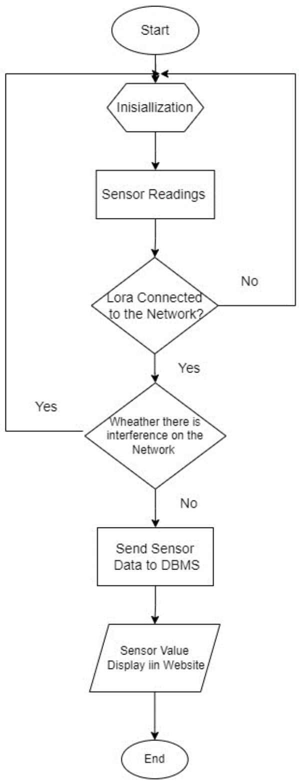

Figure 2 Flowchart Sistem Monitoring

Figure 2 is a flowchart on this device. This system has several system stages as a Weather Station Monitoring System. The following stages:

1. Starting with the initialization of the sensors used in the weather station and LoRa devices.
2. After initializing the Temperature and Humidity Sensor, Air Pressure Sensor, UV Light Intensity, Light Intensity Sensor, Wind Speed Sensor, Wind Direction Sensor, Rainfall Sensor, Soil Moisture, Soil Temperature, Electrical Conductivity, Soil PH and NPK will take readings to get the value of each sensor. Then the value of the sensor will be sent to the Database Management System.
3. Before sending the system will check whether LoRa is connected to the network, and in this process there are 2 possibilities. Possibility 1, if LoRa is connected to the network then LoRa will continue checking. But if it is not sent then possibility 2, LoRa will return to taking sensor readings
4. After checking if there is interference. If there is no interference then LoRa will send sensor data to the DBMS and if there is interference then the system returns to reading the sensor.
5. After the data is sent to the DBMS, the DBMS will store the sent data. The website becomes an interface that will display the value and graph of the sensor data to the user.

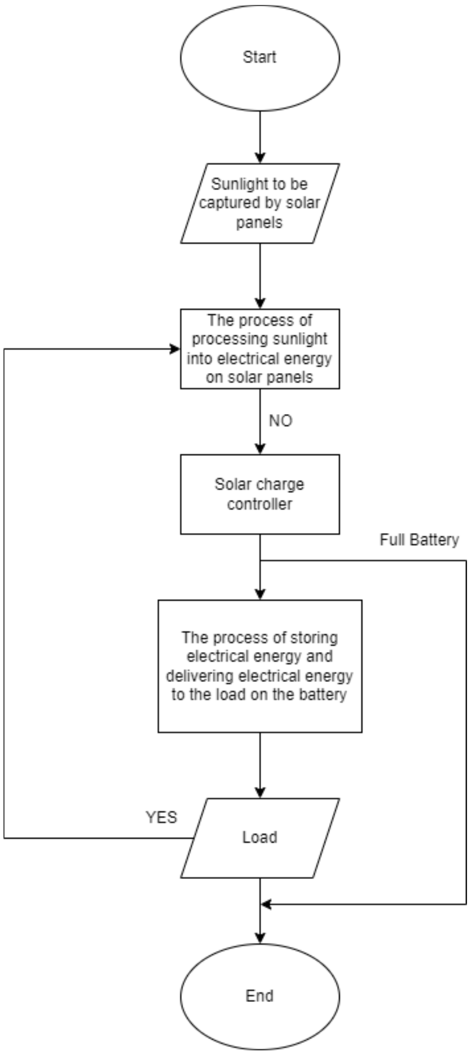

Figure 3 Flowchart Hardware System Power Supply

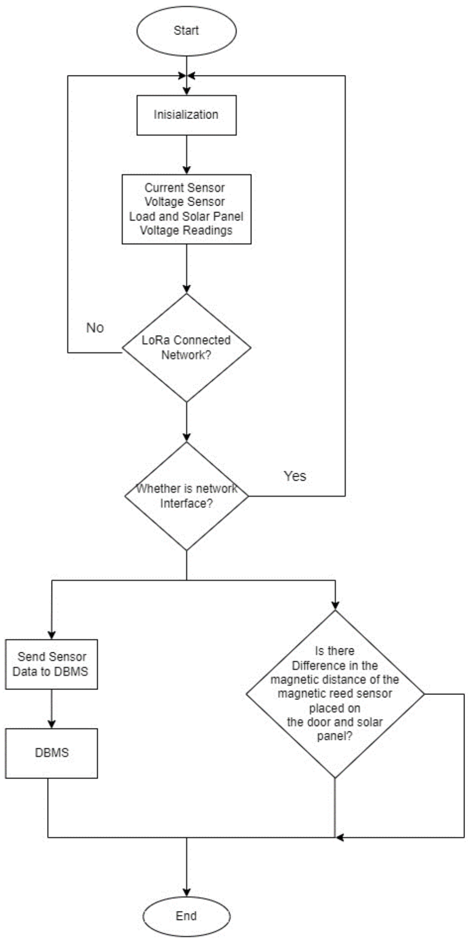

Figure 4 Flowchart Hardware System Power Supply

Figure 3 & 4 is a flow chart of this device. This system has several stages of power supply monitoring system software and security systems. The following are the stages:

1. Sunlight will enter the solar cell module
2. From the solar module will be processed to the battery through the Solar Charge Controller.
3. The battery connected to the Solar Charge Controller will activate the weather station and LoRa system as a load monitoring system and security system then wait for the network connection to connect to the internet.
4. When it is connected to the internet network, LoRa will measure the load parameters on the Weather Station which will be sent to the DBMS.
5. Website will display data from all load measurements on the Weather Station system
6. When the cell module or door is opened in the weather station box, an alert will sound and a notification will appear on the UI.

III. RESULTS AND DISCUSSION

The testing and analysis process of the developed Node Sensor device is carried out with the aim of ensuring that the sensor data received by the Node can be successfully read and transmitted. This testing encompasses the verification stage of the microcontroller's ability to read sensor data and subsequently transmit it through the LoRa TTGO communication module. The testing process is designed to ensure that the data received by the microcontroller, after being processed by the Arduino Mega, accurately reflects the actual values from the installed sensors.

The testing process involves placing the receiving device in a fixed position, while the transmitting device moves away from the receiving device using predefined distance parameters. This process is designed to evaluate the communication capabilities and system performance in handling varying distances between the transmitter and receiver according to the specified parameters.

The power testing focuses on measuring the current used by the Node device, and battery usage is terminated when the battery capacity decreases to a specific threshold. The primary objective of this testing is to ensure that the batteries can maintain adequate endurance, allowing the Node device to operate for a specified period. This is accomplished by referring to the following formula:

$$Battery\ Duration = \frac{Battery\ Capacity}{Current} \quad (1.1)$$

To obtain accuracy values and calculate error values for each experiment conducted, all of them are based on the established mathematical equations. These equations are used as the basis for calculations that allow the determination of how closely the experimental results approach the expected values. Accuracy results and error values are crucial components in the overall evaluation of the system's performance that has been developed as follows:

$$Accuracy = 100\% - \%error$$

With

$$\%error = \frac{Measurement\ Values - True\ Values}{True\ Values} \times 100\% \quad (1.2)$$

1. Battery
The battery in the remote weather monitoring device functions as an electrical power source that provides energy for operations/using battery cells that can store electrical energy. Because the battery used is rechargeable type, the weather monitoring tool will be equipped with a charging system using solar panels to recharge the battery. The tool is equipped with a power management system designed to optimise battery usage which involves monitoring the battery level, regulating the power used by various components of the tool and disconnecting power when not required to extend battery life. The battery will provide power to the weather sensor and communication module so that the sensor can detect weather parameters.

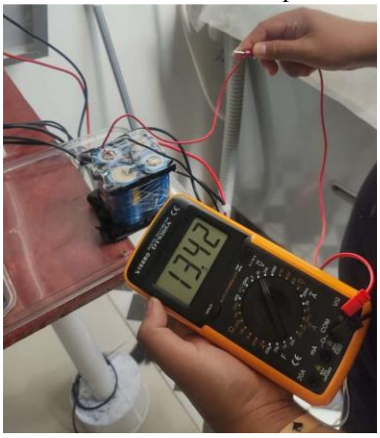

Figure 5 Battery Testing

Table 1 Battery Test Tables

Date	I (A)	4 Battery	Daya	Voltage
9/16/2023	2.3	9.2	198	13.35
9/22/2023	2.4	9.6	275.32	13.2
9/28/2023	2	8	262.08	13
10/4/2023	2	8	113.4	13.1
10/10/2023	2.2	8.8	386.32	12.89
10/16/2023	2.2	8.8	106.52	12.88
10/22/2023	2.1	8.4	145.28	12.88
10/28/2023	2.2	8.8	307.96	12.87
11/3/2023	2.3	9.2	359.8	12.82
11/9/2023	2.1	8.4	276.44	12.81
11/15/2023	2.4	9.6	230.32	12.79
11/21/2023	2.3	9.2	358.32	12.78
11/27/2023	2.2	8.8	275.8	12.68
12/2/2023	2.19	8.76	338.96	12.68
12/8/2023	2.15	8.6	359.92	12.59
12/14/2023	2.1	8.4	275.8	12.43
12/20/2023	2.08	8.32	338.96	12.31
12/26/2023	2.08	8.32	358.32	12.27
1/1/2024	2.32	9.28	326.64	12.11
1/7/2024	2.21	8.84	443.84	11.96

In this Capstone Design, the total capacity of the implemented battery reaches 24,000 mAh, according to equation 1.1. During the operational period involving a period of 121 days or equivalent to 4 months and 3 days, the battery is able to provide 2,925 hours of operational power.

2. Solar Panel
Solar panels consist of photovoltaic cells that absorb sunlight energy. When sunlight hits the photovoltaic cell, the sunlight energy is converted into electrical energy through the photovoltaic effect. The energy produced by photovoltaic cells is in the form of direct current (DC). These panels are usually connected in series or parallel to achieve the desired voltage and power. The power generated by solar panels varies depending on the intensity of sunlight and the angle of sunlight.

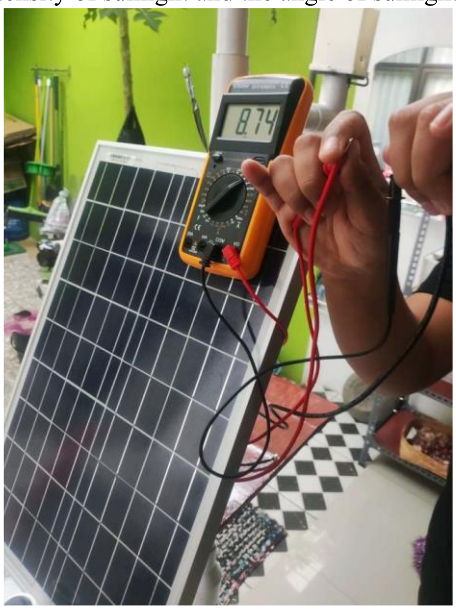

Figure 6 Solar Panel Testing

Table 2 No Load Test Tables

Time	Multimeter	Voltage (V)	Error (%)
08.30	21.20	21.27	0.33
09.00	21.58	21.66	0.37
09.25	20.19	20.26	0.35
09.45	20.72	20.83	0.53

10.10	19.83	19.97	0.66
10.45	19.56	19.63	0.36
11.25	20.34	20.41	0.34
11.50	19.73	19.88	0.76
12.15	19.87	19.95	0.40
13.10	19.39	19.53	0.72
13.35	18.27	18.36	0.49
13.50	17.60	17.68	0.45
14.15	17.15	17.26	0.64
14.30	14.05	14.11	0.43
14.45	12.84	12.96	0.9
Average			0.53

Table 3 Load Test Tables

Time	Current (A)	Voltage (V)	Power (Watt)
08.30	19.6	0.8	15.68
09.00	19.8	0.8	15.84
09.25	18.8	0.6	11.28
09.45	19.2	0.7	13.44
10.10	18.7	0.6	11.22
10.45	18.5	0.5	9.25
11.25	18.9	0.6	11.34
11.50	18.7	0.6	11.22
12.15	18.7	0.6	11.22
13.10	18.6	0.5	9.3
13.35	16.4	0.3	4.92
13.50	15.8	0.2	3.16
14.15	15.6	0.2	3.12
14.30	13.2	0.1	1.32
14.45	12.4	0	0

In order to test the performance of solar panels with a capacity of 20 WP, voltage readings were taken using a multimeter. Testing was carried out in the span of time from 08.30 to 14.45 WIB, with one test. In no-load conditions, the solar panel module operates optimally, supported by sunny weather conditions. The test results showed a maximum voltage value of 21.66 V at a certain time, while the minimum voltage was recorded at 12.96 V at 14.45.

3. SHT21

The SHT21 temperature sensor is a digital temperature and humidity sensor that operates based on the change in resistance of a semiconductor material as temperature changes. This sensor utilizes special semiconductor materials that have sensitive resistance characteristics to temperature. To read the temperature, an automatic weather station will send a command to the SHT21 sensor to initiate temperature measurement.

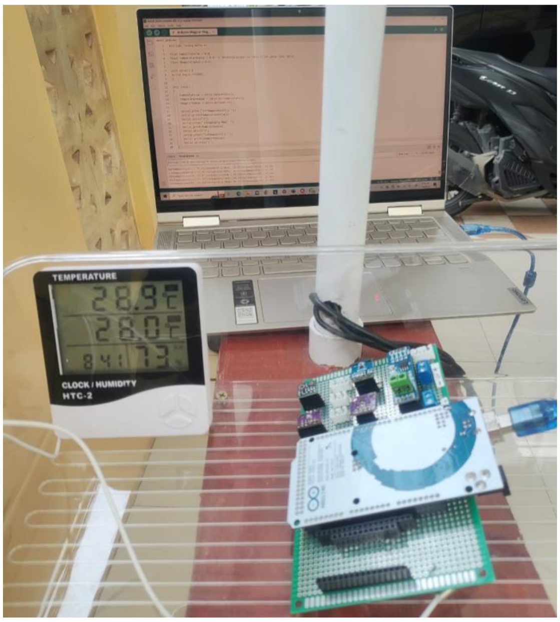

Figure 7 SHT21 Testing

Table 4 SHT21 Test Temperature Table

Pengujian Sensor Suhu (°C) selama 3 menit				
Data to -	SHT21 (°C)	MISOL (°C)	Selisih (°C)	Error (%)
1	30.99	31.5	0.51	0.02
2	31.14	31.7	0.56	0.02
3	31.06	32.4	1.34	0.04
4	30.83	32.5	1.67	0.05
5	30.75	32.9	2.15	0.07
6	30.74	33.8	3.06	0.10
7	30.7	32.8	2.1	0.07
8	31.04	32.05	1.01	0.03
9	31.05	32.2	1.15	0.04
10	31	32.3	1.3	0.04
11	30.99	32.7	1.71	0.06

12	30.99	31.5	0.51	0.02
13	31	32.5	1.5	0.05
14	31.01	32.3	1.29	0.04
15	31.02	31.8	0.78	0.03
16	31.04	32.5	1.46	0.05
17	31.04	32.1	1.06	0.03
18	31.08	32.4	1.32	0.04
19	30.89	31.15	0.26	0.01
20	31.07	32.22	1.15	0.04
Rata-rata %Error				0.04
Accuracy				96%

Table 5 SHT21 Test Humidity Table

Pengujian Sensor Kelembaban (%RH) selama 3 menit				
Data to -	SHT21 (%RH)	MISOL (%RH)	Selisih (%RH)	Error (%)
1	52.90	65.00	12.10	0.23
2	53.42	60.00	6.58	0.12
3	49.24	51.00	1.76	0.04
4	44.64	53.00	8.36	0.19
5	44.85	52.30	7.45	0.17
6	44.77	54.27	9.50	0.21
7	44.82	50.80	5.98	0.13
8	41.97	50.00	8.03	0.19
9	41.42	48.00	6.58	0.16
10	40.21	49.00	8.79	0.22
11	40.26	51.00	10.74	0.27
12	40.80	48.00	7.20	0.18
13	40.31	46.00	5.69	0.14
14	40.76	45.00	4.24	0.10
15	41.15	43.00	1.85	0.04
16	41.06	47.00	5.94	0.14
17	40.98	48.00	7.02	0.17
18	40.33	44.00	3.67	0.09
19	41.77	43.69	1.92	0.05
20	48.50	50.25	1.75	0.04
Rata-rata %Error				0.14
Accuracy				86%

Based on the comparative testing of temperature and humidity parameters that have been conducted, it can be concluded that both sensors, the SHT21 temperature and humidity sensor implemented in the Capstone Design, and the MISOL device used as a reference, exhibit good levels of accuracy. Calculate the recorded temperature values to determine the error and accuracy of the SHT21 sensor. This approach is crucial for measuring the reliability and suitability of the sensor and validating its ability to achieve the required accuracy level according to formula 1.2. The average error values in temperature measurements reached 0.8%, and humidity measurements reached 0.8%. This testing serves a highly relevant purpose, considering that high temperatures can affect plant growth in various ways, such as in photosynthesis and respiration processes.

4. BMP280

   The BMP280 sensor is a digital air pressure and temperature sensor that can be used in an automated weather station (AWS) to measure air pressure, which is one of the crucial parameters in weather monitoring. The BMP280 sensor operates based on the principle of changes in air pressure with altitude.

Figure 8 BMP280 Testing

Table 6 BMP280 Air Pressure Test Table

Data to -	Pressure BMP280 (Pa)	Pressure Barometer (Pa)	Selisih (Pa)	Approxe Altitude (m)	Error (%)
1	93873.52	101450	7576.48	639.72	0.08
2	93874.58	101380	7505.42	639.63	0.08
3	93882.03	101420	7537.97	638.97	0.08
4	93878.02	101290	7411.98	639.32	0.08
5	93849	101350	7501	641.9	0.08
6	93677.91	101200	7522.09	657.06	0.08
7	93673.42	101270	7596.58	657.46	0.08
8	93671.91	101050	7378.09	657.6	0.08
9	93661.4	101320	7658.6	658.53	0.08
10	93662.6	101360	7697.4	658.42	0.08
11	93657.85	101470	7812.15	658.84	0.08
12	93658.78	101230	7571.22	658.76	0.08
13	93657.63	101340	7682.37	659.32	0.08
14	93649.41	101360	7710.59	658.86	0.08
15	93945.68	101290	7344.32	659.59	0.08
16	93945.68	101310	7364.32	633.33	0.08
17	93822.41	101327	7504.59	644.25	0.08
18	93821.89	101304	7482.11	644.3	0.08
19	93824.89	101277	7452.11	644.03	0.08
20	93825.8	101285	7459.2	643.95	0.08
Rata-rata %Error					0.08
Accuracy					99%

Based on the comparison tests of air pressure parameters that have been carried out, it can be concluded that the BMP280 air pressure sensor implemented in Capstone Design, and the application device used as a reference, shows a good level of accuracy. This approach is crucial for measuring the reliability and suitability of the sensor and validating its ability to achieve the required accuracy level according to formula 1.2. The average error value of the air pressure measurement reached 0.7%. This test has a very relevant purpose, given that air pressure can affect the movement of air masses in any given unit area, the force that moves the air masses presses in the direction of the Earth's gravitational force.

5. BH1750
The BH1750 sensor is a digital light sensor that measures the intensity of light. It is commonly used in various applications where light levels need to be monitored, such as in Autometed Weather Stations (AWS). An Autometed Weather Station (AWS) is a set of weather monitoring instruments that are designed to operate without human intervention. These stations are equipped with various sensors to measure parameters like temperature, humidity, atmospheric pressure, wind speed and direction, rainfall, and sometimes even solar radiation.

Figure 9 BH1750 Testing

Table 7 BH1750 Indoor Test Table

Data to -	BH1750 (Lux)	Lux Meter (Lux)	Selisih (Lux)	Error (%)
1	126.67	130	3.33	0.03
2	217.5	210	-7.5	-0.03
3	200	200	0	0.00
4	162.5	160	-2.5	-0.02
5	174.17	165	-9.17	-0.05
6	23	26	3	0.13
7	25	25	0	0.00
8	32.5	31	-1.5	-0.05
9	30.83	33	2.17	0.07
10	37.5	39	1.5	0.04
Rata-rata %Error				0.01
Accuracy				99%

Table 8 BH1750 Outdoor Test Table

Data to -	BH1750 (Lux)	Lux Meter (Lux)	Selisih (Lux)	Error (%)
1	1200	1195	-5	0.00
2	1323	1323	0	0.00
3	1315.25	1310	-5.25	0.00
4	1154	1423	269	0.23
5	1129	1125	-4	0.00
6	1142.5	1141	-1.5	0.00
7	1222	1250	28	0.02
8	1245	1290	45	0.04
9	1297	1292	-5	0.00
10	1305.16	1400	94.84	0.07
Rata-rata %Error				0.03
Accuracy				97%

Based on the light intensity parameter comparison tests that have been carried out, it can be concluded that the BH1750 light intensity sensor implemented on the Capstone Design, and the Sunche Light Meter device used as a reference, show a good level of accuracy. This approach is crucial for measuring the reliability and suitability of the sensor and validating its ability to achieve the required accuracy level according to formula 1.2. The average error value of the light intensity measurement is 0.8%. This test has a very relative purpose, as light levels can affect plant growth in various ways, such as in the processes of photosynthesis and respiration.

6. GYML8511
   The ML8511 ultraviolet sensor is an easy-to-use sensor for measuring ultraviolet waves. This UV sensor has a signal output in the form of an analog signal according to the size of the wave being read. This wave reading is useful for knowing the weather conditions at the time of reading. The ML8511 ultraviolet sensor most effectively detects light from 280-390nm which is part of the UVB light spectrum and most of the UVA light spectrum.

Figure 10 GYML8511 Testing

Table 9 GYML8511 Test Table

Data to -	ML8511 (mW/cm²)
1	968
2	1072
3	1006
4	968
5	1008
6	1011
7	997
8	994
9	988
10	967
11	933
12	928
13	936
14	978
15	944
16	959
17	963
18	969
19	889
20	862

Based on the comparative testing of UV light intensity parameters, it can be concluded that the UV light intensity sensor implemented in Capstone Design, and the manual device used as
a reference, show a good level of accuracy. This test has a very relative purpose, given that light levels in UV rays can affect plant growth in various ways, such as in the photosynthesis process.

7. TIPPING BUCKET
   A tipping bucket is a type of rain gauge used to measure precipitation. It consists of a funnel that directs rainwater into a small bucket with a pivot at its center. The bucket is balanced in such a way that when it reaches a tip of the bucket represents a specific amount of precipitation, often in increments of 0.01 inches (0.25 millimeters) or other chosen units. The tips are counted electronically, providing a record of the amount of rainfall over a given period of time.

Figure 11 Tipping Bucket Testing

Table 10 Tipping Bucket Test Table

Data to -	Volume (ml)	Tipping Bucket (mm)	Manual (mm)	Jumlah Tip (kali)	V	T	Error (%)
1	50	11.9	11.9	17	2.9	0.08	0.0
2	50	21.7	21.7	31	1.6	0.05	0.0
3	50	23.1	23.1	33	1.5	0.04	0.0
4	50	25.9	25.9	37	1.4	0.04	0.0
5	50	24.55	24.55	35	1.4	0.04	0.0
6	100	33.6	33.6	48	2.1	0.06	0.0
7	100	37.1	37.1	53	1.9	0.05	0.0
8	100	39.2	39.2	56	1.8	0.05	0.0
9	100	40.6	40.6	58	1.7	0.05	0.0
10	100	41.3	41.3	59	1.7	0.05	0.0
11	150	57.4	57.4	82	1.8	0.05	0.0
12	150	68.6	68.6	98	1.5	0.04	0.0
13	150	70.7	70.7	101	1.5	0.04	0.0
14	150	77	77	110	1.4	0.04	0.0
15	150	81.2	81.2	116	1.3	0.04	0.0
16	200	100.1	100.1	143	1.4	0.04	0.0
17	200	102.9	102.9	147	1.4	0.04	0.0
18	200	109.9	109.9	157	1.3	0.04	0.0
19	200	113.4	113.4	162	1.2	0.04	0.0
20	200	123.2	123.2	176	1.1	0.03	0.0
Rata-rata %Error							0.0
Accuracy							100%

Based on the comparative testing of the rainfall sensor parameters that have been carried out, it can be concluded that the Tipping Bucket rainfall sensor implemented on the Capstone Design, and the device with water spraying or taken from rainwater used as a reference, shows a good level of accuracy. The average error value of the rainfall measurement is 0.8%. This test has a very relevant purpose, given that rainfall levels can affect plant growth in various ways, such as in the process of making water reserves for plants throughout the day, so that plants will be able to better deal with the heat of the sun.

8. ANEMOMETER

Anemometer is a device for measuring wind speed and for measuring wind direction. Anemometer is one of the instruments often used by the Meteorology, Climatology and Geophysics Agency (BMKG). The word anemometer comes from the Greek anemos which means wind, wind is air that moves in all directions, the wind moves from one place to another.

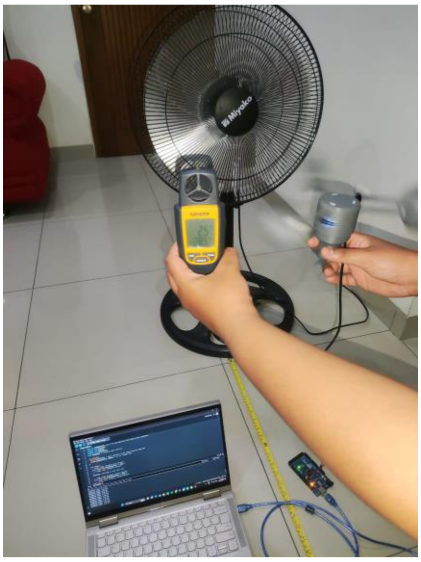

Figure 12 Anemometer Testing

Table 11 Anemometer Test Table

Data to -	Jarak (cm)	Anemometer (m/s)	Edison (m/s)	Selisih (m/s)	Error (%)
1	40	3.69	3.7	0.01	0.00
2	80	3.16	3.2	0.04	0.01
3	120	2.47	2.6	0.13	0.05
4	160	1.13	1.4	0.27	0.24
1	40	4.53	4.7	0.17	0.04
2	80	3.57	3.8	0.23	0.06
3	120	2.59	2.8	0.21	0.08
4	160	1.65	1.7	0.05	0.03
1	40	5.74	5.9	0.16	0.03
2	80	5.18	5.2	0.02	0.00
3	120	3.16	3.4	0.24	0.08
4	160	2.37	2.5	0.13	0.05
Rata-rata %Error					0.06
Accuracy					94%

Based on the comparison tests of wind speed sensor parameters that have been carried out, it can be concluded that the Anemometer wind speed sensor implemented in Capstone Design, and the EDISON device used as a reference, show a good level of accuracy. The average error value of the wind speed measurement reached 0.7%. This test has a very relevant purpose, given that wind can help in supplying carbon dioxide for plant growth, but it also affects soil temperature and moisture. Strong winds can cause large evaporation.

9. WIND VANE DIRECTION
wind vane sensor, also known as a weather vane sensor, is a device used to measure the direction from which the wind is blowing. It is a common instrument in meteorology and is often used in various applications, including weather monitoring stations, environmental monitoring, and industrial settings.

Figure 13 Wind Vane Direction Testing

Table 12 Wind Vane Direction Test Table

Wind Source	The direction of the wind source read by the sensor	Wind Speed (m/s)	Description
North	North	3.8	Suitable
Northeast	Northeast	3.6	Suitable
East	East	3.6	Suitable
Southeast	Southeast	3.7	Suitable
South	South	3.6	Suitable
Southwest	Southwest	3.7	Suitable
West	West	3.5	Suitable
Northwest	Northwest	3.8	Suitable

Based on the wind direction sensor parameter comparison tests that have been conducted, it can be concluded that the Wind Vane Direction wind direction sensor implemented on the Capstone Design, and the Edison device used as a reference, show a good level of accuracy. The average error value of the wind direction measurement is 0.8%. This test serves a very relevant purpose, given that the wind moves around the low-pressure regions of the southern hemisphere in a clockwise direction. Conversely, winds move counterclockwise around low-pressure regions in the northern hemisphere.

10. SOIL 7 IN 1
The soil NPK sensor is suitable for detecting the content of nitrogen, phosphorus, and potassium in the soil. It helps in determining the fertility of the soil thereby facilitating the systematic assessment of the soil condition. The sensor can be buried in the soil for a long time. It has a High-quality probe, rust resistance, electrolytic resistance, salt & alkali corrosion resistance, to ensure the long-term operation of the probe part.

Figure 14 Soil 7 in 1 Testing

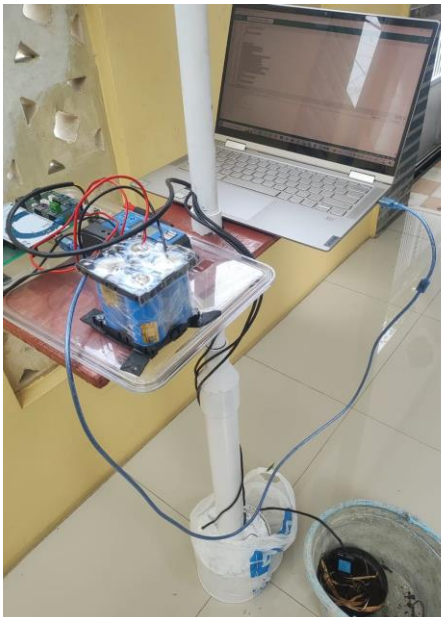

Table 13 Soil 7 in 1 NPK Test Table

Data to -	Sensor Nitrogen (mg/kg)	Sensor Phosporus (mg/kg)	Sensor Potassium (mg/kg)
1	15	84	77
2	42	81	184
3	48	92	160

4	51	99	152
5	42	105	140
6	48	113	182
7	48	112	189
8	105	113	172
9	109	149	163
10	110	138	166
11	115	135	122
12	112	139	138
13	110	144	140
14	93	52	83
15	90	20	96
16	85	35	110
17	88	39	127
18	82	39	103
19	82	47	118
20	81	51	129

Table 14 Soil 7 in 1 Soil Test Table

Data to -	Sensor Soil pH (pH)	Sensor Soil Moisture (%)	Sensor Temperature (°C)	Sensor Electrical Conductivity (mS/m)
1	3	145	13.6	3
2	5.2	142	15	9
3	4	144	28	27
4	4.9	140	26	31
5	3.2	100	29	37
6	3.7	133	42	63
7	6.2	139	33	77
8	6	121	37	89
9	5.4	119	31	113
10	5.1	119	40.3	106
11	5	136	29.8	128
12	5.74	125	43	135
13	6.01	119	31.1	162
14	6.12	97	50.9	174
15	6.33	93	47.4	163
16	7.2	90	52.2	185
17	7.9	90	49.5	190
18	7.9	96	48.4	183
19	8.13	88	39.1	156
20	8.04	83	32.2	141

Based on the comparative testing of the agricultural node sensor parameters that have been carried out, it can be concluded that the Soil 7 in 1 agricultural node sensor implemented on the Capstone Design, and the manual device used as a reference, show a good level of accuracy. The average error value of the wind direction measurement reached 0.7%. This test has a very relevant purpose, in that fertilizer selection must be tailored to the type of crop, growth phase, and environmental conditions, keeping in mind temperature, humidity, nitrogen, phospor, potassium, soil moisture and soil pH which can affect plant growth.

- Design a weather monitoring tool that incorporates a remote communication module for accurate wireless data transmission.
  1. Testing Step
     Testing is done by testing all sensors can run at one time, can work for 24 hours and can work in all weather. The following is testing Specification 1: Put all the sensors together and then put all the source code together and make sure there are no errors when running.
     - Firstly by uniting or wiring all sensors, Communication Module, and Power Supply connected to the PV Load that has been calibrated before;
     - Next, integrate all sensor and communication module source code in the Arduino IDE;
     - Run the source code and the readings of all sensors will be displayed on the serial monitor;
     - After the system can read all sensors, system testing will be carried out for 24 hours non-stop with the results of the average hourly reading data;
     - Finally, the AWS System was tested for weather resistance such as being able to work in the heat of the day, during heavy rain and at night.
  2. Testing Result

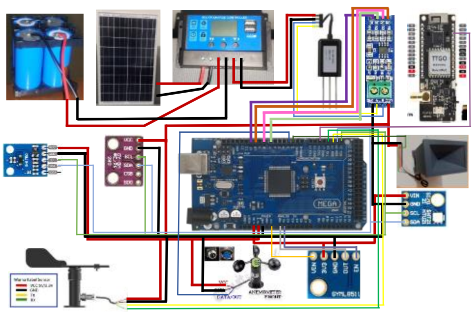

Figure 15 hardware design or wiring system on the AWS system

Figure 16 is the result of testing standards for AWS systems that can be performed as a whole. Automated Weather Stations (AWS) collect data from a variety of weather sensors and monitor atmospheric conditions such as temperature, humidity, barometric pressure, wind speed and direction, light intensity, precipitation, ultraviolet light, and surrounding ground conditions. Each sensor connected to AWS measures specific weather parameters. For example:

- SHT21: Air temperature and humidity sensor.
- BMP280: Air pressure sensor.
- BH1750: Light intensity sensor.
- GYML8511: UV radiation sensor.
- Anemometer and Wind Vane: Wind speed and direction sensors.
- Tipping Bucket: Rainfall sensor.
- Soil 7 in 1: Soil moisture and temperature sensor.

Each sensor generates an electrical signal depending on the parameter being measured. There is also data processing where electrical signals from the sensors are recorded with a microcontroller connected to his AWS. With this program, the Arduino IDE uses signals from sensors and converts them into understandable values such as temperature in degrees Celsius, wind speed in miles per hour/km/h, etc. You can save the collected weather data for distribution. It may be stored locally on your AWS device or transmitted via your internet connection to an online server or platform for further analysis.

Data transfer can take place over the Internet using a Wi-Fi connection or other technologies, depending on the connectivity available at your location. Powering and charging AWS is typically supported by solar power systems, especially in remote locations or locations where grid access is difficult. Solar panels collect energy from the sun and charge the battery as a backup power source. A solar charge controller, on the other hand, regulates battery charging through the solar panel and prevents overcharging and damaging the battery. AWS monitors the gateways to which sensor nodes are connected, so regular maintenance is required to ensure reliable operation. This includes regular checks of sensors, connections, solar power systems, and other hardware. The software that runs your system should also be updated or repaired as necessary.

3. Testing Analysis

In this sensor test, some of the factors that affect the acquisition of AWS sensor readings are temperature, humidity, air pressure, light intensity, ultraviolet radiation, wind speed, wind direction, precipitation, nitrogen, phosphorus, potassium, soil pH, soil moisture, soil temperature, electrical conductivity. This measurement is very different from measurements made by regularly monitoring the performance of this AWS system to detect problems or failures that may occur over a period of time. According to the tests conducted, the overall system sensor value at this location was 98%.

Data transfer for all sensors went very well, and data from AWS was compared with other meteorological data sources that are considered standard or reference, confirming the reliability of the data obtained. Sensor connectivity and data transmission are well integrated and no data is lost.

IV. CONCLUSION

1. The results of a number of tests conducted in experiments pertaining to the transmission distance of sensor data indicate that the achievable performance will decrease with increasing transmission distance and the presence of interference or obstacles. The BH1750 light intensity sensor is functioning well, with an accuracy of 99.99% indoors and 99.85% outdoors, while the SHT21 temperature and humidity sensor test results are operating well with an accuracy of 99.6% and 99.86%. The BMP280 air pressure sensor can operate with an accuracy of 99.90%, the GYML8511 UVA/UVB sensor can operate with a value of 99.90% accuracy, and the rainfall sensor can operate with a 100% accuracy. According to the goal of this capstone design, the wind direction sensor can measure eight cardinal directions with variations in wind direction readings with speeds below 1.3 m/s. It operates well over the speed of 3.6 m/s. The utilized gadget performs poorly. Sensors for pH, NPK, Electrical Conductivity, Soil Humidity, and soil Temperature can all function properly on the tested soil samples.
2. T-Beam was used in the design of the gateway system, and testing revealed that 2.8 km was the maximum distance at which the system could function properly. Up to 378 sensor nodes were used in the data reception test, which was conducted both stationary and in a mobile testing position in the field. The test was deemed successful when the sensor data was successfully received by the gateway, and this occurred from a distance of 0 to 2.8 km. While mobile testing was conducted in the field by walking successively in the range of

zero to 800m distance, an average RSSI value of -124 dBm and an average delay value of 850s were obtained, although the RSSI value obtained was quite far from zero. Data reception of sensor nodes carried out in a stationary manner obtained a comparison of the time of data sent by the node and the data received by obtaining an RSSI of -56 dBm and an average delay of 500s. However, throughout the test no data failed and was not sent by the sensor node.

3. The weather may be closely monitored using the system. In order to measure and record meteorological parameters automatically, the measured weather variables have an accuracy level of 99%. The best time to measure is between 09.00 and 13.30 WIB, and the accuracy value obtained is 98% with a node error rate and a lattitude and longitude error rate on the T-Beam of 0.004. Measurements may be done with a 100% success rate since data transmission employing nodes and a gateway linked to LoRa can successfully cover 1.2 km with 0% packet loss. Weather data may be displayed in real time on websites with good functionality. After confirming that the data delivered by the server to the dashboard is accurate in terms of data, visuals, date, and time, the website can function properly. Loading time testing with an overall average test of 1.4 s and an overall average of beta testing website testing of 91.5% indicates that the website-based IoT platform development results of calculations made using a Likert scale for beta testing are workable and capable of monitoring agriculture.
4. By comparing the sensor data with each sensor's measurement device, the calibration findings of each employed sensor have already given the weather station system a fair level of accuracy. In order to monitor the outcomes of environmental parameter data readings from weather stations, such as temperature, humidity, temperature, and other factors, in real time, the system may show weather data. Furthermore, weather data for the following 30 days will be shown on this page. The data will be recorded and stored in a database and made available for download in the form of Excel files at 5-second intervals. Data transmission tests to Wireshark were successfully completed and were tracked in real time. The parameters include a very excellent category: the necessary delay is 0.066 m/s, the throughput is 413.66 bytes, the packet loss is 0%, and the jitter is 0.00643.

OVERVIEW

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