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*Article*

# Multi-Sensor Based on Internet of Thing (IoT) in Determining the Accuracy of Sensors for Air Temperature, Air Humidity, and Light Intensity

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**Abstract.** Multi-sensor technology based on the Internet of Things (IoT) is implemented in determining the accuracy of sensors for air temperature, air humidity, and light intensity. The multi-sensor based on IoT consists of a DHT11 sensor to detect air temperature and humidity, and a BH1750 sensor to detect light intensity was implemented using the NodeMCU ESP8266 microcontroller, monitored via the IoT on the Blynk application on the smartphone. Data Sensor validation by comparing data from the SNI measuring instrument to determine the sensor accuracy. The results of testing the sensors for air temperature, air humidity, and light intensity produced average accuracies of 99.899%, 100%, and 99.895%, respectively. All sensor errors remain within the specified tolerance limit of <5%. The low error sensor results in a high accuracy value. These sensors are suitable for various monitoring needs, both in automation systems and environmental research.



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## 1. Introduction

The environment is a spatial entity encompassing living things, non-living components, and interconnected physical and chemical conditions that influence the continuity of life. The creation of a balanced ecosystem, clean air, fertile soil, and adequate water availability demonstrates a good quality environment [1-2]. One of the crucial steps in environmental management is regularly measuring and monitoring environmental parameters to determine current conditions and detect changes that could cause negative impacts [3-4]. Environmental parameters are physical, chemical, or biological quantities used to describe the quality of an environment [5-6]. Some frequently monitored physical parameters include air temperature, air humidity, and light intensity [7-8]. Air temperature influences thermal comfort, organism activity, and physical and chemical processes in the environment [9-10]. Air humidity affects health, plant growth, and the risk of mold and bacterial growth [11-12]. Light intensity plays a crucial role in photosynthesis, building energy efficiency, and human productivity indoors [13-14]. Monitoring air temperature is crucial because extreme temperature fluctuations can trigger health problems, such as dehydration and heat stress, and affect ecosystem stability [15-16]. Excessive or insufficient air humidity can also cause discomfort, material damage, and respiratory health problems [17-18]. Meanwhile, measuring light intensity is necessary to ensure optimal lighting in workspaces, greenhouses, and automated lighting systems, thereby increasing energy efficiency and productivity [19-20].

Along with technological advancements, environmental monitoring systems are increasingly being developed using multi-sensor technology based on the Internet of Things (IoT) [21-22]. Temperature, humidity, and light intensity sensors can be integrated with microcontrollers and internet networks to transmit data in real time to web-based monitoring platforms or applications [23]. Several researchers have created microcontroller-based prototypes to measure air temperature and humidity in greenhouse areas. This test only determines errors and shows data transmission within a certain range [24-25]. The application of Arduino-based temperature and humidity sensors in greenhouse environmental monitoring yields measurements that are inversely proportional to temperature and humidity [26-27]. Another physical parameter in the environment is the use of sensors based on microcontroller to measure light intensity. This measurement is carried out to determine the average light intensity in a certain area [28-29].

Some weaknesses of previous research include: the prototype is not multi-sensor based, the measurement results are not IoT-based, and the sensors used do not determine the sensor accuracy. These weaknesses can lead to errors and reduced measurement accuracy in the development of IoT-based systems. Therefore, this study aims to develop and evaluate the accuracy of a multi-sensor system based on IoT for measuring air temperature, humidity, and light intensity. This multi-sensor system is expected to provide an IoT-based measurement solution with high sensor accuracy, supporting smarter, more responsive, and sustainable environmental monitoring.

## 2. Experimental Section

The application of multi-sensors based on IoT in determine sensor accuracy for air temperature, air humidity, and light intensity was implemented using the NodeMCU ESP8266 microcontroller as the main controller. The multi-sensor based on IoT consists of a DHT11 sensor to detect air temperature and humidity, and a BH1750 sensor to detect light intensity. This design is also equipped with a laptop, smartphone, and Blynk application for remote monitoring based IoT, as shown in Figure 1.

Multi-sensor based on IoT testing was carried out in an environment area under the hot sun. This testing was carried out in conjunction with conventional measuring instruments in accordance with Indonesian national standards (*Standar Nasional Indonesia* = SNI), namely a digital thermometer for measuring air temperature, a hygrometer for measuring air humidity, and a luxmeter for measuring light intensity. Measurement data are collected simultaneously by the SNI measuring instrument and the multi-sensor instrument from 07:00 WITA to 17:00 WITA (Central Indonesian

Time), with a 1-hour data collection interval, and are monitored via the IoT on the Blynk application on the smartphone. The data from multi-sensors based on IoT is then analyzed by comparing it with data from SNI measuring instruments to determine the sensor error and accuracy.

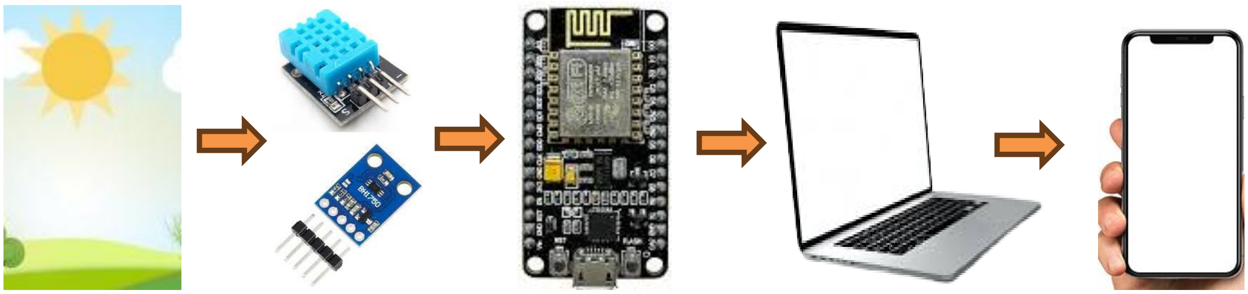


**Figure 1**. Multi-sensor based on IoT design

## 3. Results and Discussion

### 3.1. Air Temperature Sensor

Multi-sensor based on IoT testing to determine changes in air temperature was conducted by periodically collecting data from 07:00 WITA to 17:00 WITA using a DHT11 sensor installed in the system and a digital thermometer as a benchmark. The measurement data were then presented in graphical form in Figure 2.

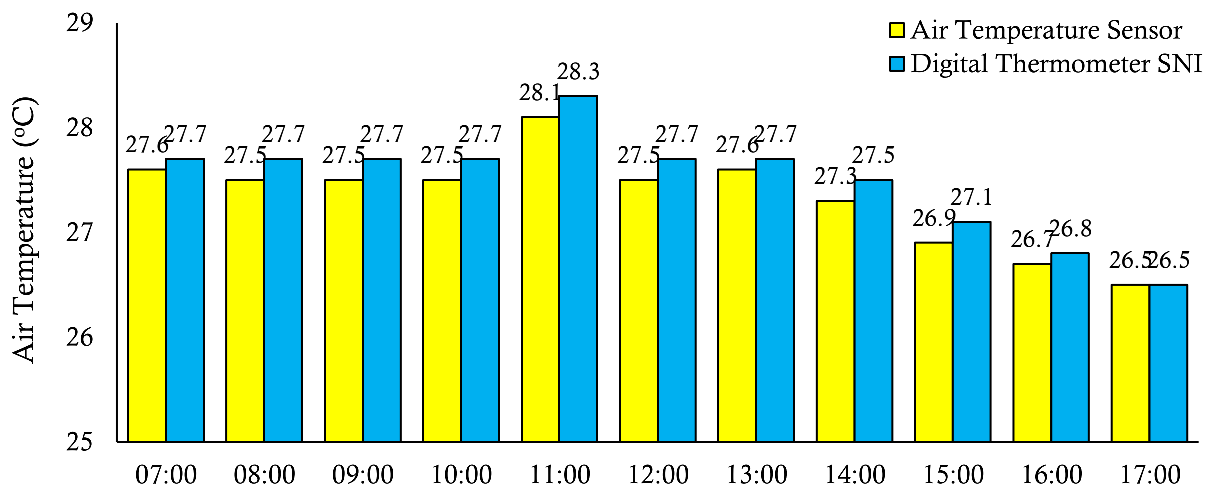


**Figure 2.** Comparison of DHT11 Air Temperature Sensor and Digital Thermometer

Based on Figure 2, air temperature measurements using the DHT11 sensor were obtained by comparing its readings with those of a digital thermometer. Observations were made every hour from 07:00 WITA to 17:00 WITA to assess the sensor's accuracy and its ability to track changes in ambient temperature. Overall, the measurement graph shows that both devices exhibit similar temperature change patterns, with very small differences within the sensor's tolerance limits.

During the initial observation period in 07:00 WITA to 10:00 WITA, the air temperature ranged from 27.6°C to 27.7°C. This range indicates that the air temperature gradually increased as sunlight intensity increased throughout the morning [30]. The difference in readings between the DHT11 sensor and the Digital Thermometer was very small, around 0.1°C, confirming that the sensor performs well under stable temperature conditions [31]. At 11:00 WITA, there was a significant increase in temperature, with the Digital Thermometer SNI recording a peak temperature of 28.3°C, while the DHT11 sensor recorded 28.1°C. This condition is a common daily temperature peak in tropical climates, when solar radiation is at its maximum intensity near noon. The difference in readings between the two devices remained small, demonstrating the DHT11 sensor's ability to capture temperature increases accurately [32].

Between 12:00 WITA and 14:00 WITA, the air temperature began to decrease again to around 27.7°C–27.6°C. This decrease was influenced by the increasingly even distribution of heat in the atmosphere and by evaporation from the ground surface and vegetation, which also reduced temperatures around the observation location [33]. The DHT11 sensor continued to show readings that accurately followed this temperature change pattern. In the afternoon, from 15:00 WITA to 17:00 WITA, the temperature decreased to around 27.1°C–26.5°C. This decrease is a normal response to reduced sunlight at the end of the day [34]. Air temperatures rise during the day as solar intensity increases, and vice versa. The higher the intensity of sunlight received by an area, the higher the air temperature. This occurs because Earth's surface absorbs a large amount of solar radiation, which is then converted into heat. Conversely, if solar intensity is low, the air temperature tends to be lower.

Both measuring instruments still showed a very small difference in values, thus maintaining consistency between the sensor and the Digital Thermometer. The pattern of air temperature changes recorded during the observations showed a reasonable trend and was in accordance with actual environmental conditions. The consistency of data between the DHT11 sensor and the comparison tool, namely the Digital Thermometer, indicates that the sensor has a good level of accuracy and is reliable for use in environmental temperature monitoring. A comparison of the DHT11 air temperature sensor readings with the digital thermometer used to determine the sensor's accuracy is shown in Table 1.

**Table 1.** Determining the Accuracy of Air Temperature Sensor

| Time (WITA) | Air Temperature Sensor (°C) | Digital Thermometer SNI (°C) | Error (%) | Accuracy (%) |
|---|---|---|---|---|
| 07:00 | 27.6 | 27.7 | 0.361 | 99.273 |
| 08:00 | 27.5 | 27.7 | 0.722 | 99.273 |
| 09:00 | 27.5 | 27.7 | 0.722 | 99.273 |
| 10:00 | 27.5 | 27.7 | 0.722 | 99.273 |
| 11:00 | 28.1 | 28.3 | 0.706 | 99.294 |
| 12:00 | 27.5 | 27.7 | 0.722 | 99.273 |
| 13:00 | 27.6 | 27.7 | 0.361 | 99.639 |
| 14:00 | 27.3 | 27.5 | 0.727 | 99.273 |
| 15:00 | 26.9 | 27.1 | 0.738 | 99.262 |
| 16:00 | 26.7 | 26.8 | 0.373 | 99.627 |
| 17:00 | 26.5 | 26.5 | 0.000 | 100.000 |
| Average | | | 0.101 | 99.899 |

Table 1 shows the determination of the air temperature sensor's accuracy by comparing DHT11 sensor readings with a digital thermometer as a reference. The purpose of this test was to determine the sensor's accuracy, the stability of the resulting data, and its ability to track changes in air temperature throughout the day. The data collection process took place from 07:00 WITA to 17:00 WITA to describe the overall daily temperature variation. The DHT11 sensor is characterized by its ability to detect changes in the surrounding air temperature using a thermistor. When the ambient temperature changes, the thermistor's resistance changes, which is then converted by the internal circuitry into digital temperature data that the microcontroller can read. Based on the measurement results, the DHT11 sensor performed excellently, with an average error of 0.101% and an average accuracy of 99.899%. In the same parameters, this error value is lower than the error value of 0.92%, and still lower than the specified error tolerance limit of <5% [25, 35]. The findings of this study are in line with research [36], which supports this finding, indicating that the DHT11 sensor has an average measurement deviation of 0.3°C to 0.5°C with an accuracy of 99.8%. This shows that the DHT11 sensor has a good balance between accuracy, power efficiency, and price, making it suitable for use in a NodeMCU ESP8266-based air temperature monitoring system.

Overall, the DHT11 sensor has also proven stable in reading air temperature throughout the day. The difference in readings between measuring instruments is relatively small and does not show a significant deviation pattern. This stability makes the DHT11 sensor the right choice for daily temperature monitoring needs in both research and automation applications. With consistent performance and very low error rates, this sensor can support decision-making based on accurate, reliable environmental temperature data. Test results show that the DHT11 sensor has excellent capabilities in measuring air temperature accurately and stably throughout the day. An average accuracy of 99.899% demonstrates that this sensor is reliable for various temperature-monitoring applications, especially in IoT-based systems that require real-time data readings.

### 3.2. Air Humidity Sensor

A multi-sensor based on IoT was used to measure changes in air humidity during testing. Data was collected periodically using a DHT11 sensor and a hygrometer, an SNI benchmark. The measurement results are presented graphically in Figure 3.

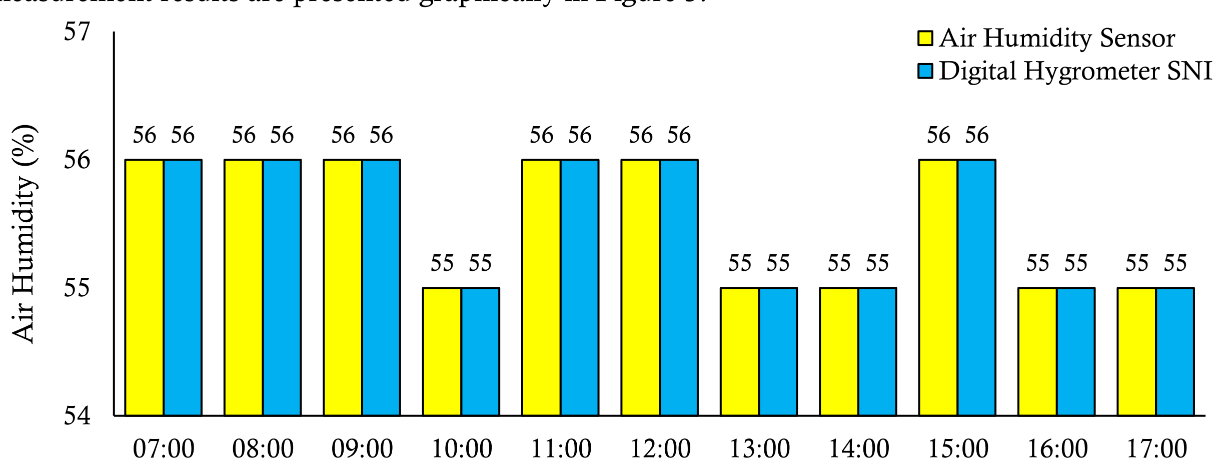


**Figure 3.** Comparison of DHT11 Air Humidity Sensor and Hygrometer

Figure 3 compares humidity readings from the DHT11 sensor with those of a digital hygrometer, serving as a reference device, between 07:00 WITA and 17:00 WITA. In general, both devices produced nearly identical measurements, with a maximum difference of only about 1% at some observation times. This indicates that the DHT11 sensor has good capability to detect humidity in the research environment [31]. During the initial observation period, from 07:00 WITA to 09:00 WITA, the humidity readings were stable at 56% for both devices. This stability reflects the morning air conditions, which tend to be humid due to low sunlight intensity, which prevents optimal evaporation. Around 10:00 WITA, humidity decreased slightly to 55% for both the DHT11 sensor and the SNI reference device [37]. This decrease indicates an increase in solar radiation, which begins to trigger evaporation, thereby reducing relative humidity [38]. From 11:00 WITA to 12:00 WITA, the humidity value rose again to 56%. Furthermore, from 13:00 WITA to 17:00 WITA, the humidity fluctuated slightly between 55% and 56%. The decrease from 13:00 WITA–14:00 WITA and the subsequent increase at 15:00 WITA are natural responses to changes in sunlight intensity, airflow, and vegetation activity. By the end of the observation, from 16:00 WITA–17:00 WITA, the humidity value had stabilised again at 55%, in line with the decrease in sunlight intensity in the afternoon. This phenomenon is caused by the intensity of sunlight received in a region, which increases air temperature, and vice versa. Air temperature has an inverse relationship with relative humidity. As the temperature increases, the air's capacity to hold water vapor also increases. Consequently, relative humidity tends to decrease if the amount of water vapor remains constant. Conversely, as temperature decreases, the air has a smaller capacity to hold water vapor, increasing relative humidity.

Based on the overall measurement pattern, the DHT11 sensor shows very high agreement with the benchmark. The small measurement deviation indicates that the sensor can produce consistent, reliable data, especially for environmental monitoring. This finding aligns with other research, which reported that the DHT11 sensor has a high coefficient of determination when calibrated against a thermohygrometer ($R^2 > 0.94$ for temperature and $> 0.96$ for humidity), making it suitable for use in environmental measurement applications [36]. Sensors can experience drift or deviations in readings due to changes in environmental conditions, so periodic calibration is necessary, especially when the sensor is used in continuous monitoring systems, such as irrigation automation or climate control in greenhouses [31].

Thus, the results of the air humidity graph not only demonstrate the consistency between the sensor and the SNI measuring instrument, but also confirm that the measurement environment during the study was relatively stable. The consistency of the values from morning to evening shows that the DHT11 sensor can provide readings representative of actual conditions. A comparison of the DHT11 air temperature sensor readings with those from the hygrometer used to determine the sensor's accuracy is shown in Table 2.

**Table 2.** Determining the Accuracy of Air Humidity Sensor

| **Time (WITA)** | **Air Humidity Sensor (%)** | **Digital Hygrometer SNI (%)** | **Error (%)** | **Accuracy (%)** |
|---|---|---|---|---|
| 07:00 | 56 | 56 | 0 | 100 |
| 08:00 | 56 | 56 | 0 | 100 |
| 09:00 | 56 | 56 | 0 | 100 |
| 10:00 | 55 | 55 | 0 | 100 |
| 11:00 | 56 | 56 | 0 | 100 |
| 12:00 | 56 | 56 | 0 | 100 |
| 13:00 | 55 | 55 | 0 | 100 |
| 14:00 | 55 | 55 | 0 | 100 |
| 15:00 | 56 | 56 | 0 | 100 |
| 16:00 | 55 | 55 | 0 | 100 |
| 17:00 | 55 | 55 | 0 | 100 |
| | Average | | 0 | 100 |

Based on Table 2, the DHT11 air humidity sensor was tested to evaluate its accuracy, stability, and responsiveness to changes in environmental humidity. Sensor readings were compared with a reference measuring instrument, a digital hygrometer, between 07:00 WITA and 17:00 WITA. The DHT11 sensor uses a capacitive humidity sensor to measure air humidity. This sensor detects changes in capacitance caused by variations in the amount of water vapor in the air. When air humidity increases or decreases, the sensor's capacitance changes, which is then processed by the internal circuitry into digital data that the microcontroller can read. The test results showed that all values generated by the DHT11 were identical to those measured by the digital hygrometer. This similarity resulted in a 0% error and 100% accuracy across all measurement sessions [31]. The 0% error value produced by the sensor is due to a precise and accurate calibration process. Correct calibration will produce measurement values identical to those of the SNI standard reference measuring instrument. Within the same parameters, the 0% error was lower than the 3.1% error, and both remained within the specified error tolerance limit of <5% [25, 35]. This indicates that the sensor has good sensitivity to small changes in humidity [31].

The findings of this study are also consistent with previous studies. The DHT11 sensor has a very high accuracy rate of around 99.9%, with a difference of only 1%–2% compared to a standard hygrometer [29]. The DHT11 sensor has an average error value of 0.02% compared to a digital hygrometer, with optimal performance in the humidity range of 40%–80% [39]. Meanwhile, the DHT11 sensor has a fast response, high stability, and measurement deviation below 1% after calibration [31]. Thus, this test demonstrates that the DHT11 sensor is highly reliable and can serve as a primary component in an air humidity monitoring system. The consistency of readings across all time intervals indicates that the research environment is relatively stable and supports the sensor's ability to provide accurate and reliable data.

### 3.3. Light Intensity Sensor

A multi-sensor based on IoT system periodically collects data on changes in light intensity using the BH1750 sensor installed in the system and a luxmeter, a SNI-certified comparison tool. The measurement results are presented in Figure 4.

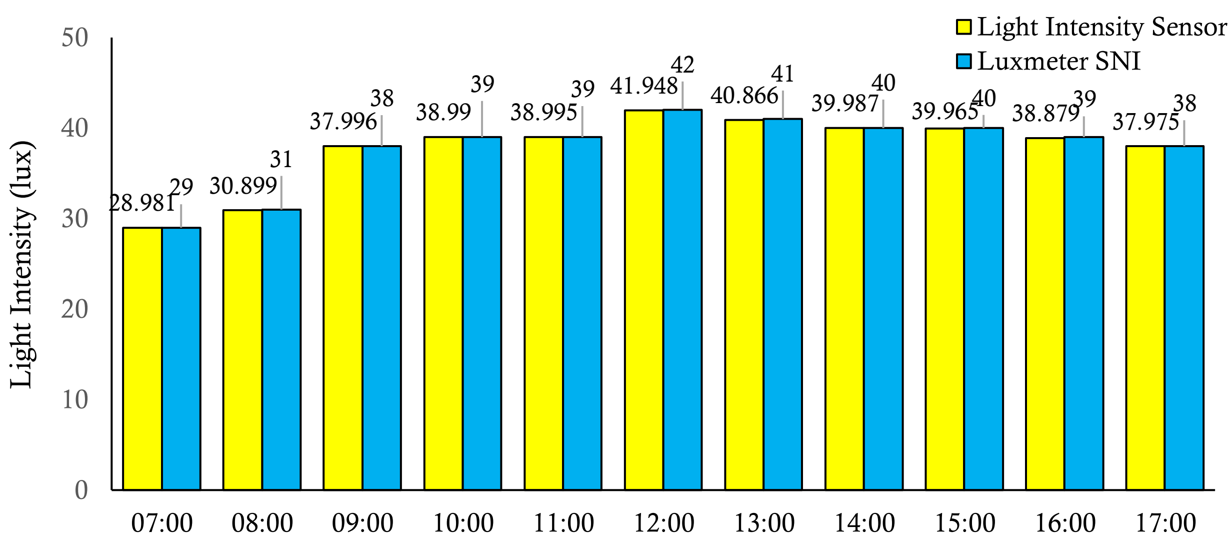


**Figure 4.** Comparison of BH1750 Light Intensity Sensor and luxmeter

Based on Figure 4, the BH1750 light intensity sensor was tested by comparing its readings to a standard Lux Meter between 07:00 WITA and 17:00 WITA. This test aimed to determine the sensor's accuracy, reading consistency, and ability to track changes in natural light intensity throughout the day. Overall, the observations indicated that the pattern of changes in light intensity recorded by the BH1750 sensor closely matched that of the Lux Meter used as a comparison tool. At the start of the measurement 07:00 WITA, the detected light intensity was still low, at 28.981 lux on the BH1750 sensor and 29 lux on the Lux Meter. This value reflects the weak morning lighting conditions because the sun had not yet fully illuminated. From 08:00 WITA until midday, light intensity increased significantly. Peak illumination occurred at 12:00 WITA, with values of 41.948 lux on the BH1750 sensor and 42 lux on the Lux Meter. This condition shows that the sensor can accurately record light intensity when solar radiation is at its maximum, when the light received by the Earth's surface is highest. As the afternoon progresses, from 13:00 WITA to 17:00 WITA, light intensity gradually decreases. At 17:00 WITA, the light intensity recorded was 37.975 lux on the BH1750 and 38 lux on the Lux Meter. This decrease occurs because the sun's elevation angle is decreasing, reducing the amount of light reaching the sensor. The intensity of the sun's radiation significantly influences the brightness of light in the environment. The higher the intensity of solar radiation, the brighter the light received. If the intensity decreases, the light received will decrease as well. Despite the fairly dynamic changes in light intensity during this time period, the BH1750 sensor still provides stable readings close to the reference value.

Overall, the difference in readings between the BH1750 and the Lux Meter is in the range of 0.01 lux–0.05 lux, indicating that the sensor has excellent accuracy for use in light intensity monitoring applications. This consistency aligns with research findings [28], which indicate that the BH1750 can detect changes in light intensity with very small deviations. This sensor has high linearity and a high coefficient of determination, making it suitable for use in field light measurement applications. The research findings are also relevant to the test results [40], which show that the BH1750 consistently follows light change patterns. The data from the light intensity sensor and luxmeter readings to determine sensor accuracy are shown in Table 3.

**Table 3.** Determining the Accuracy of Light Intensity Sensor

| Time (WITA) | Light Intensity Sensor (lux) | Luxmeter SNI (lux) | Error (%) | Accuracy (%) |
|---|---|---|---|---|
| 07:00 | 28.981 | 29 | 0.065 | 99.935 |
| 08:00 | 30.899 | 31 | 0.101 | 99.899 |
| 09:00 | 37.996 | 38 | 0.010 | 99.990 |
| 10:00 | 38.990 | 39 | 0.025 | 99.975 |
| 11:00 | 38.995 | 39 | 0.012 | 99.988 |
| 12:00 | 41.948 | 42 | 0.123 | 99.877 |
| 13:00 | 40.866 | 41 | 0.326 | 99.674 |
| 14:00 | 39.987 | 40 | 0.032 | 99.968 |
| 15:00 | 39.965 | 40 | 0.087 | 99.913 |
| 16:00 | 38.879 | 39 | 0.310 | 99.690 |
| 17:00 | 37.975 | 38 | 0.065 | 99.935 |
| | Average | | 0.105 | 99.895 |

Table 3 shows the results of sunlight intensity testing using the BH1750 sensor compared to a reference measuring instrument, a digital lux meter. Measurements were conducted hourly from 07:00 WITA to 17:00 WITA to obtain a comprehensive overview of sensor performance under natural lighting conditions. The parameters analysed included the BH1750 sensor readings, the reference value from the lux meter, the error percentage, and the sensor's accuracy level compared to the standard instrument. The BH1750 sensor features a digital light sensor that uses a photodiode to measure light intensity in the environment. When light hits the sensor surface, the photodiode converts the light energy into an electrical signal, which is then processed by internal circuitry and converted into a light intensity value in lux. Overall, the BH1750 sensor demonstrated excellent measurement performance. The sensor's light intensity readings were nearly identical to the lux meter measurements. This is evident from the error values, which ranged from 0.010% to 0.326%, with an average error of only 0.105%. This value is still lower than the established error tolerance limit of <5% [35]. This very small difference indicates that the sensor's performance is not significantly different from that of the reference measuring instrument, making the resulting data reliable for light-intensity monitoring. The sensor accuracy level is in the range of 99.674% to 99.990%, with an average accuracy reaching 99.895%, which indicates that the sensor is in the very high accuracy category.

However, the overall error value is still within very low limits, so it does not affect the validity of the measurement results. The measurement pattern shows that the BH1750 sensor can follow the daily light change curve, characterised by an increase in intensity until near midday and a decrease in the afternoon. The reliability of the BH1750 sensor in detecting light intensity is also in line with several previous research findings [41], explaining that the BH1750 has high sensitivity and can provide stable readings under various illumination conditions, especially when the light intensity is at its maximum point around the sun's zenith position. Research [40] also confirms that the BH1750 exhibits good linearity over a wide range of illuminations, so the difference in readings between the sensor and a lux meter is relatively small. In addition, the BH1750 sensor exhibits a fast, stable response to changes in illumination, making it suitable for use in real-time data acquisition systems. The findings of this study strengthen the measurement results, showing that the BH1750 sensor provided accurate, stable values throughout the observation period. With its high level of accuracy, very small error, and consistent readings that align with natural lighting patterns, the BH1750 sensor can be considered an efficient and reliable device for measuring light intensity. This sensor is suitable for various IoT-based monitoring needs in automation systems and environmental research.

The IoT system acts as a link between sensor devices and users via an internet network. Data from sensors, such as air temperature, air humidity, or light intensity, will be sent by a microcontroller to a server or application platform via a communication network, such as Wi-Fi or a cellular network. The stability of the network connection is crucial to ensure that sensor data can be sent continuously and without interruption. This connection stability ensures that data sent from the sensor to the server or application remains consistent and uninterrupted, resulting in more accurate monitoring results. Furthermore, IoT can perform real-time monitoring. Data from sensors can be displayed directly in an application or dashboard accessible via a smartphone or computer. Thus, users can monitor environmental conditions directly, anytime and anywhere as long as they are connected to the internet. With IoT, data transmission can be automated, quick, and without manual measurements. The use of IoT-based sensors in this study is a strategic solution for real-time, high-reliability monitoring of illumination conditions.

## 4. Conclusion

Multi-sensor testing to determine sensor accuracy was conducted based on IoT. Based on the measurement results, the air temperature sensor produced an average error of 0.101% and an average accuracy of 99.899%. The air humidity sensor produced an average error of 0% and an accuracy of 100%. Meanwhile, the light intensity sensor produced an average error of 0.105% and an average accuracy of 99.895%. The values of all sensor errors remain within the specified error tolerance limit of <5%. The low error value results in a high accuracy value. These sensors are suitable for various monitoring needs, both in automation systems and environmental research. The use of this sensor in this study is a strategic solution for real-time, high-accuracy, high-reliability monitoring of illumination conditions.

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