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Performance Analysis of LDR, Photodiode, and BH1750 Sensors for Sunlight Intensity Measurement in Open Areas

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ABSTRACT

Light, as an electromagnetic phenomenon, can be elucidated as both a wave and a particle. The wave-particle duality portrays light as an electromagnetic wave and discrete particles known as photons. The spectrum of light represents the wavelength in a visual array of colors. Optics, a vital field in physics, delves into the characteristics of light. Light, an electromagnetic wave with a wavelength of 380-750 nm, exhibits dual nature as both a wave and a particle. Light intensity is measured in lumens or lux, indicating the strength of a light source in a specific direction per unit angle. The human eye, sensitive to the visible light spectrum, holds significance in optics and photometry. Light sensors such as LDR, Photodiode, and BH1750 sensor transform light information into electronic signals for electronic devices like the Arduino Uno microcontroller. The research was methods by measuring light intensity for 5 days at 3 different times (morning, noon and afternoon) simultaneously and open area. The parameters that form the basis of the comparison include error values, stability in the calibration process, light intensity measurement range, and sensor price. Data was collected at the same time during the day to ensure consistent test conditions. Based on the research findings, the BH1750 sensor was selected as the most effective among the three sensors used, exhibiting the smallest average error value of 0.755%. It is easily calibrated, has a wide intensity measurement range (0-65535 lux), and comes at a relatively affordable price.

1. Introduction

Light is an electromagnetic phenomenon that exhibits both wave-like and particle-like properties, as described by the wave-particle duality theory [1]-[3]. It is perceived as an electromagnetic wave with various wavelengths and as discrete particles known as photons [4], [5]. The spectrum of light, seen as color by the human eye, visually represents differences in wavelength [6]. [7]. The scientific study of light, known as optics, is a significant field within modern physics [8], [9].

Light manifests as energy in electromagnetic waves with wavelengths typically ranging from 380 to 750 nanometers [10]-[12]. The wave-particle duality explains that light possesses properties of both waves and particles [13]. Light intensity, denoted as I, measures the strength of a light source in a specific direction per unit solid angle [14]. The SI units for light intensity are lumen (lm) or lux [15],

[16]. The human eye's sensitivity to specific wavelengths within the visible spectrum is crucial in optics and photometry [17].

Sensors convert specific quantities into analog or digital signals readable by electronic devices [18], [19]. This study aims to evaluate the sensitivity variations of light sensors, ranging from low-cost to high-end, regarding their calibration characteristics. Data acquisition for light sensors was conducted using three systems: Light Dependent Resistor (LDR), photodiode, and BH1750 sensor, utilizing a lux meter measurement system.

An LDR is a resistor whose resistance varies with the intensity of the light it receives, making it commonly used as a light sensor. The resistance of an LDR is significantly influenced by the light intensity it receives. A photodiode, a type of photodetector, produces a current linearly proportional to the light intensity it receives. The BH1750 sensor, an IC sensor, measures changes in light intensity in lux units using the I2C communication protocol.

A lux meter measures the level of illumination or light intensity. The lighting requirements for each location vary depending on weather conditions and system design. The calibration system is designed to accommodate these differences. Measurements are taken with varying light sources to observe changes in the illuminance received by the sensor. By investigating the performance of these sensors, this study aims to provide insights into their suitability for various applications, highlighting their advantages and limitations to aid in the selection of appropriate sensors for specific tasks.

2. Methods

2.1. Light Intensity

Light intensity is an important parameter in optical studies that describes the amount of energy received by an observing surface from a light source [20], [21]. Defined as light power per unit area and measured in watts per square meter (W/m^2) [22], light intensity is affected by the strength of the light source [23], the distance between the source and the observing surface [24], and the optical characteristics of the medium [25]. A luxmeter sensor measures light intensity in lux (lx), which corresponds to the perception of the human eye.

The main factors that affect light intensity include the power of the light source, which varies depending on technology such as incandescent or LED lamps, and the surface area being illuminated, where intensity decreases with increasing surface area [26]. The distance between the light source and the observer is also significant, following the inverse square law, which states that intensity decreases quadratically with an increase in distance [27]. The optical characteristics of the medium, such as the refractive index, affect light intensity when light propagates through different mediums, with changes governed by Snellius' law that describes refraction at the interface of different mediums.

2.2. Linear Regression

Linear regression is a statistical method used to analyze and identify the relationship between one or more independent variables and one dependent variable [28]. Its main advantage lies in its ability to visualize the relationship in detail, taking into account the degree of change of one variable on another [29]. The linear regression equation is shown in equation (1).

$$y = ax + b \tag{1}$$

Based on equation (1), a commonly used formula to evaluate the relationship between variables X (independent variable) and Y (dependent variable) is the linear equation $y = ax + b$. Where y is the predicted dependent variable, x is the independent variable from the sensor, a is the coefficient describing the change in the dependent variable with respect to the independent variable, and b is the intercept value, indicating the intersection point with the y-axis when $x=0$. In the use of sensors, the value received from the sensor (x) represents the independent variable, while the predicted or expected value (y) can be estimated using this formula, taking into account the coefficient a and the intercept value b.

2.3. System Design

In this sub section, the tool design process carried out through the Solid Works application is explained. Solid Works application. The initial design is done to ensure that the structure and functionality of the tool can be optimized during the assembly process. The main objective of of this design stage is to minimize the possibility of malfunction in each light measurement component. The results of the design generated using the Solid Works application is illustrated in Fig. 1.

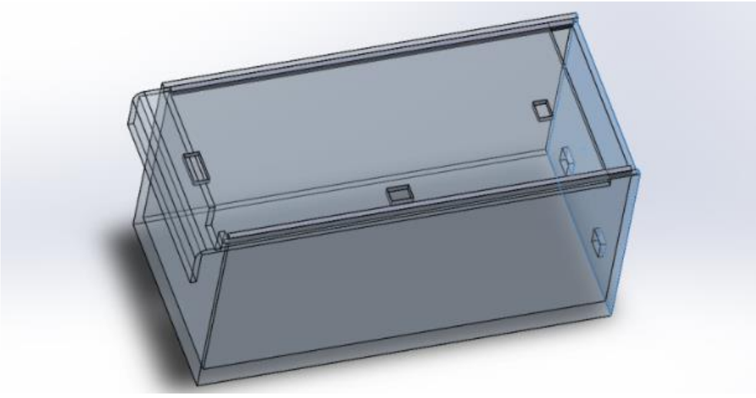

Fig. 1. Device Design

The device design in Fig. 1 shows three holes at the top where the three sensors will be placed. Inside the box, a support is provided to place the Arduino and LCD components. The dimensions of the box are 20.5 cm long, 10 cm high, and 10 cm wide. These sizes are considered sufficient to form a simple tool for comparing light sensors.

2.4. Wiring Diagram

This sub section discusses the use of wiring diagrams that visualize the configuration of connections between components in this research system. A wiring diagram is a graphical representation that illustrates the way each component in the system is connected to each other through wires or connection paths. In the context of this research, the wiring diagram provides a detailed explanation of the interconnections and interactions between the components. By utilizing the wiring diagram, it is easier to understand the physical configuration and cable connections required in the operationalization of the system. Fig. 2 shows the wiring diagram of the system, while Table 1 provides information on the pin usage of the components used in this study.

Table 1. Use of pins for each component

Initial Device		Destination Device	
Device Name	**PIN**	**Device Name**	**PIN**
Arduino Uno	GND	LCD_I2C	GND
Arduino Uno	5V	LCD_I2C	VCC
Arduino Uno	A4	LCD_I2C	SDA
Arduino Uno	A5	LCD_I2C	SCL
Arduino Uno	GND	BH1750 Sensors	GND
Arduino Uno	5V	BH1750 Sensors	VCC
Arduino Uno	A4	BH1750 Sensors	SDA
Arduino Uno	A5	BH1750 Sensors	SCL
Arduino Uno	A1	LDR Sensors	OUT
Arduino Uno	5V	LDR Sensors	VCC
Arduino Uno	GND	LDR Sensors	GND
Arduino Uno	A2	Photodiode Sensors	OUT
Arduino Uno	5V	Photodiode Sensors	VCC
Arduino Uno	GND	Photodiode Sensors	GND

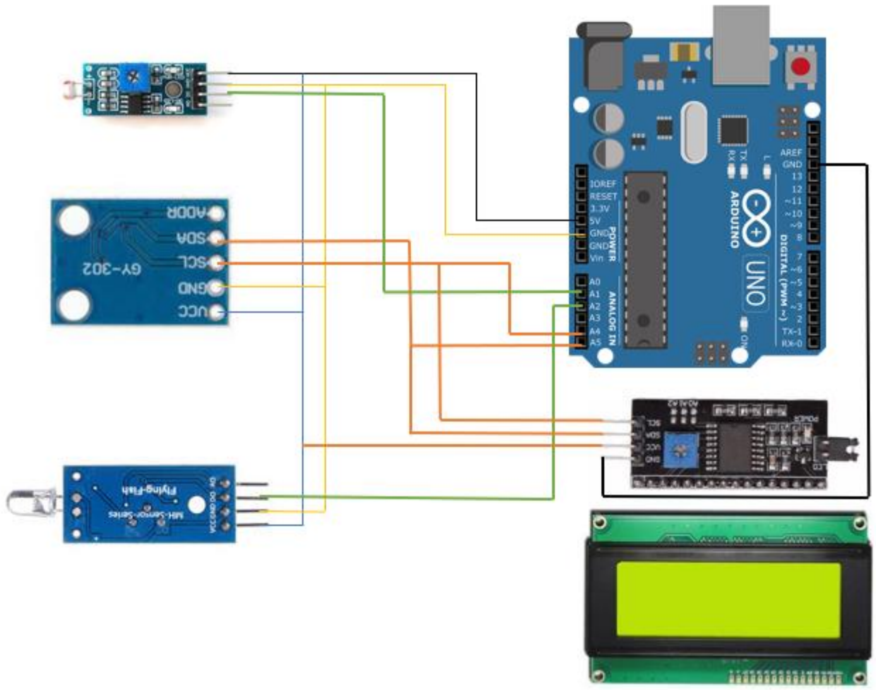

Fig. 2. Wiring Diagram

2.5. Flowchaty System

This sub section discusses the system flow diagram used in this research to illustrate the sequence of steps in the system operation. The system flow diagram is a visual representation that shows the relationship between the components. In this research, the system flow diagram is used to explain in detail how the system works, starting from initialization to setting the watering interval based on temperature and humidity data. Fig. 3 shows the system flow diagram.

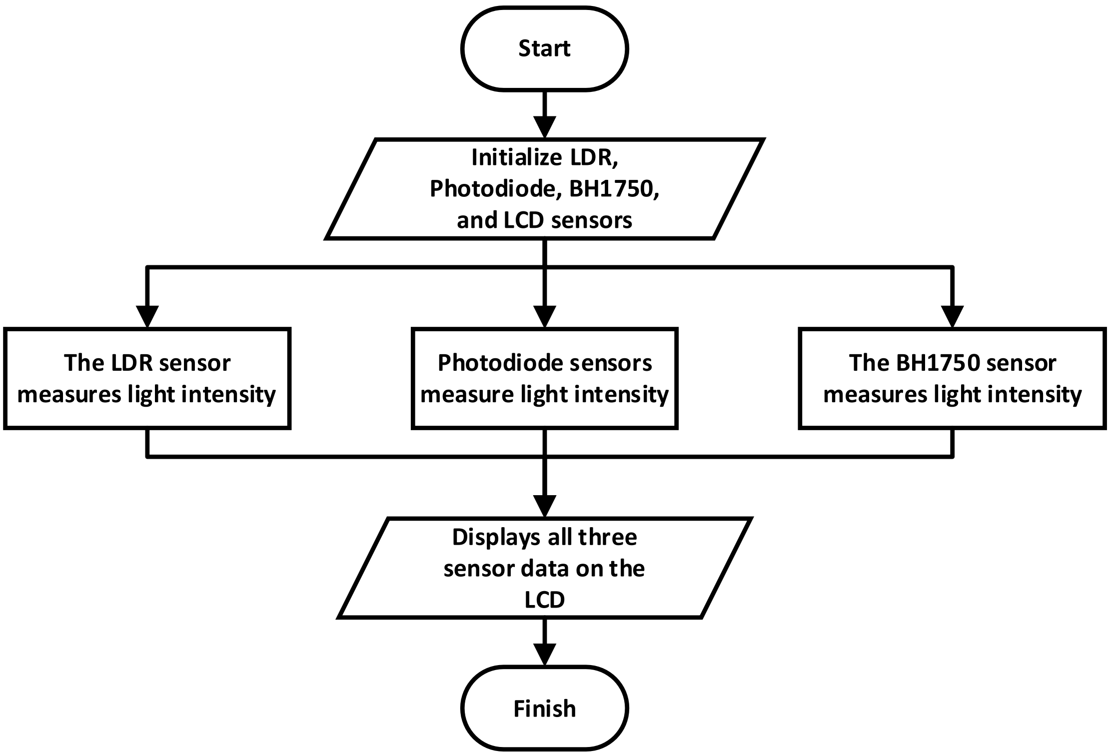

Fig. 3. Flowchart System

Fig. 3 illustrates a series of steps in the system operation. The process begins with the initialization of the LDR, Photodiode, and BH1750 sensors, as well as the initial settings on the LCD screen. The next step involves the measurement of light intensity by these three sensors in an outdoor environment, where each sensor collects data related to light intensity. This step is the foundation for obtaining precise information regarding the sensor's response to changes in light intensity in a given environment. The light intensity measurement results of the three sensors are presented on the LCD screen as a visual indicator, allowing users to directly monitor and evaluate changes in the measured light intensity. This process provides a comprehensive overview of how the system responds to changes in the environment and enables quick and efficient visual monitoring of the measured light conditions.

2.6. System Testing

At this stage, an evaluation is carried out to assess the optimal performance level of the developed tool. The tool testing process is carried out in two steps as follows:

1. Light intensity measurement testing using LDR, Photodiode, and BH1750 sensors.

Tests were conducted on the three sensors to evaluate changes in sensor resistance in relation to variations in light intensity. The testing process involved characterizing the LDR Sensor, Photodiode Sensor, and BH1750 Sensor. The characterization steps of the three sensors were carried out as follows:

   a. Setting up the necessary tools outdoors (open area).
   b. Placing the Lux meter and the three sensors with parallel height.
   c. Measuring the change in light intensity every 15 minutes.
   d. Recording the data in the table, then comparing with the measurement on the Lux meter.

2. System calibration

At this stage, the initial test data has been obtained, then the calibration process is carried out to obtain more accurate measurement results. The system calibration steps are carried out as follows:

   a. Analyzing the data that has been obtained with the Lux meter comparison using the linear regression method.
   b. After obtaining the linear regression results, the regression equation is used on each sensor.

3. Data retrieval stage

This stage is carried out to take system output data that has been calibrated. Data collection is carried out with the following steps:

   a. Prepare an outdoor light intensity measuring device (open area) boarding house.
   b. Light intensity measurements were taken at three different times, namely in the morning (05.45-08.00), afternoon (10.00-12.15), and evening (16.00-18.15) for 5 days.
   c. Light intensity measurements were taken simultaneously using three different sensors.
   d. Recording the observation data after calibration displayed on the 20x4 LCD and Lux meter as a comparison.
   e. Analyzing the data by comparing the three sensors with the Lux meter, as well as comparing with the system if it is not calibrated.

3. Results and Discussion

This sub section describes the results of the tool design using Solid Works software. The implementation of the tool in this study involves a transparent acrylic base with all the planned components and materials installed in sequence. The tool design reflects the physical representation of the previous concept, featuring clear visualization and the application of transparent acrylic material for a brightly lit structure. Fig. 4 illustrates the implementation details of the tool design, showing the systematic connection of each component, and meeting the specifications of this study.

3.1. Device Implementation

This sub section describes the results of the tool design using Solid Works software. The implementation of the tool in this study involves a transparent acrylic base with all the planned components and materials installed in sequence. The tool design reflects the physical representation of the previous concept, featuring clear visualization and the application of transparent acrylic material for a brightly lit structure. Fig. 4 illustrates the implementation details of the tool design, showing the systematic connection of each component, and meeting the specifications of this study.

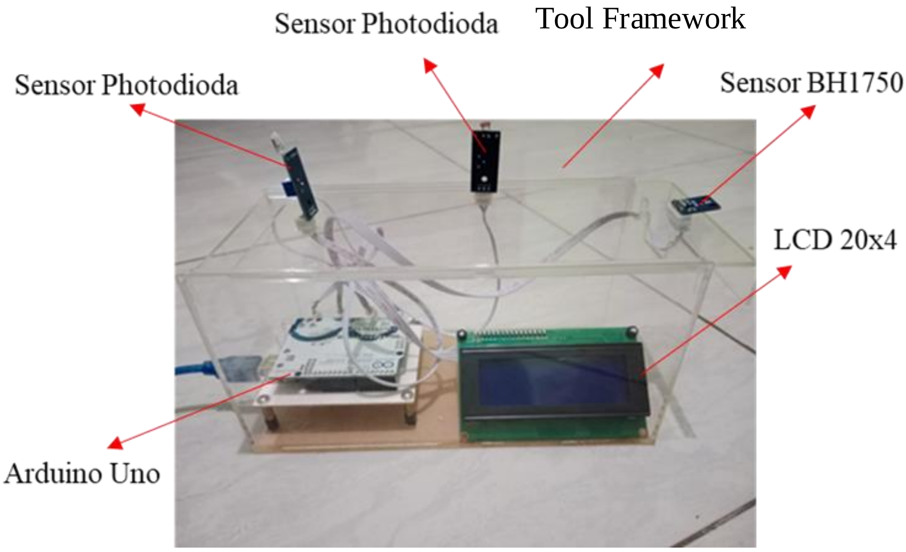

Fig. 4. Device Implementation

3.2. Sensor Measurement Experiments

In this section, the intensity measurement results obtained from the three sensors simultaneously according to the planned schedule are described. Light intensity measurements were taken in parallel from the three sensors tested, with the lux meter used as a reference value. This aims to compare the results of light intensity measurements from the three sensors with the reference value provided by the lux meter.

The validity of the light intensity value is compared to the value produced by the lux meter so that the sensor that has a value close to the lux meter is considered the most optimal sensor. Table 2 displays the converted measurement results of the LDR, Photodiode, BH1750, and Lux meter sensors in the morning. Table 3 displays the measurement results at noon, and Table 4 displays the measurement results in the afternoon. These intensity measurements have not been calibrated and will be used for calibration data.

Table 2, Table 3, and Table 4 show the results of light intensity measurements in the morning, afternoon, and evening, respectively. Measurements were taken at the planned times using LDR, Photodiode, and BH1750 sensors, with lux meter as the reference value. In the morning, there is a difference between the measurement results of the three sensors and the value measured by the lux meter. The average significant error occurs in the LDR sensor of 9.169%, in the Photodiode sensor of 11.388%, and in the BH1750 sensor of 4.234%. During the day, the sensor measurement results also show a significant difference with the value of the lux meter. The average errors on the LDR, Photodiode, and BH1750 sensors are 12.835%, 13.089%, and 4.310%, respectively. Meanwhile, in the afternoon, the sensor measurement results also show a difference with the value of the lux meter. The average errors on the LDR, Photodiode, and BH1750 sensors are 10.082%, 11.699%, and 4.700%, respectively.

Based on the analysis of the measurement results of each sensor outdoors (open area) shows the measurement results of the light sensor value in lux units compared to the value measured by the lux meter as a reference standard. This data provides a comparative picture between the values generated by the sensor and the values measured by the lux meter as a reference benchmark. Percentage error recorded in each sensor test. Based on measurements, the average error per day for each sensor is as follows: LDR sensor of 10.704%, Photodiode sensor of 12.057%, and BH1750 sensor of 4.415%. This shows that the most accurate measurement is obtained from the BH1750 sensor. The calibration process also managed to significantly improve the measurement accuracy of all sensors, as seen from the decrease in average error.

Table 2. Measurement results of light intensity in the morning

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	05.45	19	19	16	17
2	06.00	29	30	26	27
3	06.15	62	64	59	60
4	06.30	83	85	81	80
5	06.45	133	134	129	130
6	07.00	227	229	224	222
7	07.15	379	377	381	384
8	07.30	519	518	511	514
9	07.45	648	649	643	645
10	08.00	824	820	814	816
Average Error (%)		9.169	11.388	4.234	-

Table 3. Measurement results of light intensity during the day

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	10.00	1027	1021	1221	1320
2	10.15	1268	1258	1356	1382
3	10.30	1209	1205	1335	1368
4	10.45	1193	1192	1262	1323
5	11.00	1216	1218	1385	1440
6	11.15	1314	1311	1408	1455
7	11.30	1376	1375	1417	1489
8	11.45	1124	1121	1312	1402
9	12.00	1373	1363	1484	1542
10	12.15	1393	1393	1524	1598
Average Error (%)		12.835	13.089	4.310	-

Table 4. Measurement results of light intensity in the afternoon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	16.00	721	712	772	802
2	16.15	679	670	740	798
3	16.30	661	657	717	754
4	16.45	338	335	352	375
5	17.00	272	267	274	290
6	17.15	168	165	172	180
7	17.30	118	120	136	130
8	17.45	73	72	77	80
9	18.00	47	45	51	53
10	18.15	31	29	34	35
Average Error *(%)*		10.082	11.699	4.700	-

3.3. Calibration Sensors

Sensor calibration is done using data that has been taken from previous measurements, the calibration method used in this study is linear regression in equation (1). Fig. 5 (a) displays the calibration results of the LDR sensor, Fig. 5 (b) displays the calibration results of the Photodiode sensor, and Fig. 5 (c) displays the calibration results of the BH1750 sensor.

3.4. Sensor Experiments After Calibration

3.4.1. Experiments Day 1

In this sub section, light intensity measurements were taken on the first day. Measurements were taken simultaneously from all three sensors along with lux meter measurements. The measurement results were then recorded in Table 5 for the morning, Table 6 for the afternoon, and Table 7 for the afternoon.

Table 5. Sensor measurement results on day 1 in the morning

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	05.45	19	19	16	17
2	06.00	29	30	26	27
3	06.15	62	64	59	60
4	06.30	83	85	81	80
5	06.45	133	134	129	130
6	07.00	227	229	224	222
7	07.15	379	377	381	384
8	07.30	519	518	511	514
9	07.45	648	649	643	645
10	08.00	824	820	814	816
Rata-Rata *Error (%)*		3.453	4.573	1.609	-

Table 6. Sensor measurement results on day 1 at noon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	10.00	1111	1166	1061	1091
2	10.15	1182	1192	1124	1132
3	10.30	1242	1255	1202	1206
4	10.45	1284	1318	1226	1230
5	11.00	1351	1311	1250	1256
6	11.15	1315	1308	1272	1268
7	11.30	1374	1412	1348	1354
8	11.45	1454	1437	1370	1375
9	12.00	1562	1534	1480	1487
10	12.15	1677	1659	1570	1590
Rata-Rata *Error (%)*		4.263	4.722	0.744	-

Table 1. Sensor measurement results on day 1 in the afternoon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	16.00	812	811	820	822
2	16.15	803	801	810	813
3	16.30	772	768	781	783
4	16.45	375	370	385	387
5	17.00	317	314	324	325
6	17.15	175	179	184	187
7	17.30	149	146	154	156
8	17.45	86	88	89	92
9	18.00	53	52	57	59
10	18.15	38	38	41	42
Rata-Rata *Error (%)*		4.653	4.893	1.361	-

In Table 5, it can be seen that the sensor measurement results in the morning show a significant difference with the value measured by the lux meter as a reference. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.453%, 4.573%, and 1.609% respectively. Table 6 also illustrates the significant difference between the sensor measurement results during the day and the value from the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.263%, 4.722%, and 0.744%. Meanwhile, in Table 7, the sensor measurement results in the afternoon also show a significant difference with the value of the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.653%, 4.893%, and 1.361%. Based on measurements on day 1, the average error per day for each sensor is as follows: LDR sensor of 4.123%, Photodiode sensor of 4.729%, and BH1750 sensor of 1.238%. This shows that the most accurate measurement is obtained from the BH1750 sensor. The calibration process also succeeded in significantly improving the measurement accuracy of all sensors, as seen from the decrease in average error.

3.4.2. Experiments Day 2

In this subchapter, light intensity measurements were taken on the first day. Measurements were taken simultaneously from all three sensors along with lux meter measurements. The measurement results were then recorded in Table 8 for the morning, 9 for the afternoon, and Table 10 for the afternoon.

Table 8. Sensor measurement results on day 2 in the morning

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	05.45	27	27	25	26
2	06.00	47	48	44	45
3	06.15	84	85	88	89
4	06.30	95	95	100	102
5	06.45	145	144	149	153
6	07.00	250	249	245	246
7	07.15	375	377	381	380
8	07.30	524	523	518	520
9	07.45	685	687	691	692
10	08.00	840	839	848	849
Rata-Rata *Error (%)*		3.178	3.224	1.308	-

Table 9. Sensor measurement results on day 2 at noon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	10.00	1213	1216	1164	1167
2	10.15	1295	1298	1254	1249
3	10.30	1341	1344	1305	1295
4	10.45	1368	1371	1338	1322
5	11.00	1416	1419	1359	1370
6	11.15	1484	1487	1452	1438
7	11.30	1540	1543	1504	1494
8	11.45	1608	1611	1559	1562
9	12.00	1682	1685	1633	1636
10	12.15	1741	1744	1705	1695
Rata-Rata *Error (%)*		3.276	3.490	0.605	-

Table 10. Sensor measurement results on day 2 in the afternoon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	16.00	826	822	820	818
2	16.15	821	819	813	811
3	16.30	770	773	768	764
4	16.45	394	395	394	390
5	17.00	306	307	302	297
6	17.15	203	202	203	198
7	17.30	153	154	154	149
8	17.45	102	100	98	96
9	18.00	68	72	65	63
10	18.15	63	59	55	53
Rata-Rata *Error (%)*		4.532	4.245	1.864	-

In Table 8, it can be seen that the sensor measurement results in the morning show a significant difference with the value measured by the lux meter as a reference. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.178%, 3.224%, and 1.308% respectively. Table 9 also illustrates the significant difference between the sensor measurement results during the day and the value from the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.276%, 3.490%, and 0.605%. Meanwhile, in Table 10, the sensor measurement results in the afternoon also show a significant difference with the value of the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.532%, 4.245%, and 1.864%. Based on measurements on day 2, the average error per day for each sensor is as follows: LDR sensor of 3.662%, Photodiode sensor of 3.653%, and BH1750 sensor of 1.259%. This shows that the most accurate measurement is obtained from the BH1750 sensor. The calibration process also succeeded in significantly improving the measurement accuracy of all sensors, as seen from the decrease in average error.

3.4.3. Experiments Day 3

In this sub section, light intensity measurements were taken on the first day. Measurements were taken simultaneously from all three sensors along with lux meter measurements. The measurement results were then recorded in Table 11 for the morning, Table 12 for the afternoon, and Table 13 for the afternoon.

Table 11. Sensor measurement results on day 3 in the morning

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	05.45	39	35	43	45
2	06.00	60	61	61	63
3	06.15	79	78	80	81
4	06.30	108	113	114	115
5	06.45	155	153	157	159
6	07.00	242	243	245	248
7	07.15	426	422	425	428
8	07.30	547	542	547	549
9	07.45	682	682	685	686
10	08.00	853	852	857	859
Rata-Rata *Error (%)*		3.370	4.070	1.363	-

Table 12. Sensor measurement results on day 3 at noon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	10.00	1207	1205	1169	1158
2	10.15	1225	1242	1194	1186
3	10.30	1323	1327	1286	1276
4	10.45	1348	1353	1310	1299
5	11.00	1365	1378	1334	1327
6	11.15	1356	1371	1337	1325
7	11.30	1471	1460	1433	1423
8	11.45	1497	1490	1460	1449
9	12.00	1593	1599	1555	1550
10	12.15	1683	1691	1642	1637
Rata-Rata *Error (%)*		3.245	3.614	0.678	-

Table 13. Sensor measurement results on day 3 in the afternoon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	16.00	819	823	817	815
2	16.15	816	815	810	807
3	16.30	767	770	763	761
4	16.45	392	394	390	387
5	17.00	317	312	310	307
6	17.15	200	199	197	195
7	17.30	142	144	140	137
8	17.45	101	103	95	93
9	18.00	79	78	74	71
10	18.15	60	62	55	53
Rata-Rata *Error (%)*		4.623	5.135	1.600	-

In Table 11, it can be seen that the sensor measurement results in the morning show a significant difference with the value measured by the lux meter as a reference. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.370%, 4.070%, and 1.363% respectively. Table 12 also illustrates the significant difference between the sensor measurement results during the day and the value from the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.245%, 3.614%, and 0.678%. Meanwhile, in Table 13, the sensor measurement results in the afternoon also show a significant difference with the value of the lux meter.

The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.632%, 5.135%, and 1.600%. Based on measurements on day 3, the average error per day for each sensor is as follows: LDR sensor by 3.662%, Photodiode sensor by 4.273%, and BH1750 sensor by 1.213%. This shows that the most accurate measurement is obtained from the BH1750 sensor. The calibration process also managed to significantly improve the measurement accuracy of all sensors, as seen from the decrease in average error.

3.4.4. Experiments Day 4

In this subchapter, light intensity measurements were taken on the first day. Measurements were taken simultaneously from all three sensors along with lux meter measurements. The measurement results were then recorded in Table 14 for the morning, Table 15 for the afternoon, and Table 16 for the afternoon. In Table 14, it can be seen that the sensor measurement results in the morning show a significant difference with the value measured by the lux meter as a reference. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 2.822%, 3.338%, and 1.562% respectively. Table 15 also illustrates the significant difference between the sensor measurement results during the day and the value from the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.101%, 3.462%, and 0.705%.

Table 14. Sensor measurement results on day 4 in the morning

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	05.45	48	48	51	54
2	06.00	72	72	73	75
3	06.15	92	88	93	95
4	06.30	101	101	101	104
5	06.45	166	169	172	173
6	07.00	268	265	268	270
7	07.15	422	417	423	424
8	07.30	558	555	559	561
9	07.45	688	689	691	692
10	08.00	853	853	856	859
Rata-Rata *Error (%)*		2.822	3.338	1.562	-

Table 15. Sensor measurement results on day 4 at noon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	10.00	1212	1221	1174	1163
2	10.15	1229	1229	1196	1190
3	10.30	1299	1284	1256	1249
4	10.45	1303	1313	1276	1264
5	11.00	1353	1354	1320	1308
6	11.15	1374	1394	1345	1336
7	11.30	1441	1442	1412	1399
8	11.45	1465	1471	1436	1428
9	12.00	1572	1577	1540	1532
10	12.15	1675	1689	1651	1643
Rata-Rata *Error (%)*		3.102	3.462	0.705	-

Table 16. Sensor measurement results on day 4 in the afternoon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	16.00	824	824	821	818
2	16.15	815	816	811	808
3	16.30	769	770	764	761
4	16.45	397	392	391	388
5	17.00	309	308	303	300
6	17.15	197	197	194	191
7	17.30	148	147	142	139
8	17.45	94	97	91	89
9	18.00	74	73	70	67
10	18.15	50	51	48	46
Rata-Rata *Error (%)*		4.235	4.431	1.771	-

Meanwhile, in Table 16, the sensor measurement results in the afternoon also show a significant difference with the value of the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.325%, 4.431%, and 1.771%. Based on measurements on day 3, the average error per day for each sensor is as follows: LDR sensor of 3.662%, Photodiode sensor of 3.743%, and BH1750 sensor of 1.346%. This shows that the most accurate measurement is obtained from the BH1750 sensor. The calibration process also managed to significantly improve the measurement accuracy of all sensors, as seen from the decrease in average error.

3.4.5. Experiments Day 5

In this sub section, light intensity measurements were taken on the first day. Measurements were taken simultaneously from all three sensors along with lux meter measurements. The measurement results were then recorded in Table 17 for the morning, Table 18 for the afternoon, and Table 19 for the afternoon.

Table 17. Sensor measurement results on day 5 in the morning

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	05.45	39	41	48	49
2	06.00	70	68	69	72
3	06.15	100	100	102	106
4	06.30	97	96	101	102
5	06.45	169	170	168	172
6	07.00	256	257	260	262
7	07.15	423	425	426	430
8	07.30	532	531	533	534
9	07.45	659	660	663	666
10	08.00	841	842	843	844
Rata-Rata *Error (%)*		4.119	3.936	1.574	-

Table 18. Sensor measurement results on day 5 at noon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	10.00	1201	1205	1173	1160
2	10.15	1223	1248	1195	1189
3	10.30	1296	1296	1261	1250
4	10.45	1342	1350	1305	1298
5	11.00	1358	1378	1337	1327
6	11.15	1343	1338	1303	1298
7	11.30	1436	1435	1393	1386
8	11.45	1493	1497	1452	1445
9	12.00	1593	1603	1552	1544
10	12.15	1718	1723	1675	1668
Rata-Rata *Error (%)*		3.237	3.771	0.611	-

Table 19. Sensor measurement results on day 5 in the afternoon

No	Time	LDR (lux)	*Photodiode* (lux)	BH1750 (lux)	Lux meter (lux)
1	16.00	817	816	812	809
2	16.15	813	818	812	809
3	16.30	769	769	765	762
4	16.45	388	392	384	382
5	17.00	310	308	306	304
6	17.15	204	202	198	196
7	17.30	152	151	148	145
8	17.45	91	92	89	87
9	18.00	68	68	64	62
10	18.15	61	63	57	55
Rata-Rata *Error (%)*		4.004	4.399	1.457	-

In Table 17, it can be seen that the sensor measurement results in the morning show a significant difference with the value measured by the lux meter as a reference. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.119%, 3.936%, and 1.574% respectively. Table 18 also illustrates the significant difference between the sensor measurement results during the day and the value from the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 3.237%, 3.771%, and 0.611%. Meanwhile, in Table 19, the sensor measurement results in the afternoon also show a significant difference with the value of the lux meter. The average errors recorded for the LDR, Photodiode, and BH1750 sensors are 4.004%, 4.399%, and 1.457%. Based on measurements on day 3, the average error per day for each sensor is as follows: LDR sensor of 3.786%, Photodiode sensor of 4.035%, and BH1750 sensor of 1.214%. This shows that the most accurate measurement was obtained from the BH1750 sensor. The calibration process also succeeded in significantly improving measurement accuracy on all sensors, as seen from the decrease in average error.

Based on the measurement results that have been carried out, it can be further analyzed for the effectiveness of the three light intensity sensors used in this study by looking at the minimal error rate, calibration, light intensity measurement interval, and prices in the Indonesian market. Table. 20 shows the comparison of the three sensors with the parameters mentioned.

Table 20. Sensor comparison with several parameters

Parameter	LDR	*Photodiode*	BH1750
Average error without calibration (%)	10.704	12.057	4.415
Average error with calibration (%)	3.829	4.087	1.254
Measurement interval	Calibration-dependent measurement	Calibration-dependent measurement	0-65535
Sensor type	Analog	Analog	16-bit digital

Based on Table 20, the BH1750 sensor excels as a more effective choice for light intensity measurement compared to the LDR and Photodiode sensors. One of the main advantages of the BH1750 sensor lies in its lower average error after calibration, which is only 1.254%. This is much better than the average error of the LDR (3.829%) and Photodiode (4.087%) sensors, indicating a higher level of accuracy in light intensity measurement. In addition, the BH1750 sensor also has another advantage in terms of a wider measurement interval of 0-65535, while LDR and Photodiode sensors rely on calibration to determine the measurement interval. The BH1750 sensor is also favored because it is a 16-bit digital sensor, which provides more accurate and stable measurement results compared to analog sensors. Although its price is higher compared to LDR and Photodiode sensors, its effectiveness in light intensity measurement makes it a better choice for applications that require high accuracy in light intensity measurement.

4. Conclusions

The conclusion of this research shows that the BH1750 sensor has a lower average error after calibration, which is 1.254%, which is much better than the average error of the LDR sensor of 3.829% and Photodiode of 4.087%. This indicates that the BH1750 sensor has a higher level of accuracy in measuring light intensity and that the calibration method used is effective in improving the accuracy. In addition, the BH1750 sensor has a wider measurement interval of 0-65535, which provides greater flexibility compared to the LDR and photodiode sensors that require calibration to determine their measurement interval. By using an Arduino to process data from these three types of sensors, it was found that the BH1750 sensor not only provides more accurate and stable results, but also offers greater flexibility in light intensity measurement applications. This advantage is reinforced by the BH1750's ability to provide more accurate and stable measurement results than analog sensors, making it a superior choice for various light intensity measurement needs in open-air environments. Suggestions for future research include the implementation of light intensity sensors in smart home automation, which can enable the system to automatically respond to changes in lighting, thereby improving occupant comfort and optimizing energy use. This technology forms the basis for the development of adaptive and environmentally friendly intelligent systems in the context of smart homes. In addition, the use of analog-to-digital converter (ADC) modules in analog sensor applications is proposed to improve measurement accuracy and set light intensity measurement intervals. ADCs are capable of converting analog signals to digital form with high precision, thus enabling more accurate and optimal data acquisition, ensuring that the information obtained more accurately reflects the lighting conditions.

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