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Effectiveness of Various Light Sensors for Indoor Use

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ABSTRACT

A light sensor is a type of electronic device that can produce changes in visible light energy or infrared light into electrical energy by utilizing the electrical current and resistance that enters the light sensor. This research objective is to design the light sensor circuit and program that can have a light sensor sensitivity to the light intensity in the room and test the success of indoor light sensors from the cheapest to the most expensive sensors. The sensors used are LDR, BH1750, and Photodiode. The research stage carried out was to prepare the equipment in a boarding room with dimensions of 3x3. The light intensity of windows and lamps for 10 days with three different sessions in the morning, afternoon, and evening are measured. Linear regression calibration is used to obtain more accurate results. The results of the light sensor used are compared with a digital lux meter. The cheapest sensor, namely the LDR, has the slowest response to light and is less accurate with an error value of 23.74%. An affordable sensor, namely a Photodiode sensor, has a fast response to light, but the results are less stable with an error value of 18.20%. The more expensive sensor is the BH1750 with the highest accuracy and stability with an error value of 7.53%..

1. Introduction

The development of science and technology is the result of human observation and experimentation in various fields to gain better experiences. This progress provides numerous benefits to society, facilitates daily tasks, and contributes to research on technological quality. Thus, people can be more educated in assessing whether more expensive tools have better quality compared to cheaper ones [1].

Various studies have been conducted to improve the accuracy of light intensity measurement and monitoring using different sensors. Research related to the BH1750 sensor was conducted by [2] with an IoT-based solar tracking system that resulted in low measurement error. Research [3] developed a smart lighting system based on a wireless sensor network using the BH1750 sensor, which can save up to 50% of energy. Research [4] studied a telemonitoring system for light intensity in semi-indoor spaces using the BH1750 sensor, in [5] designed an IoT-based weather monitoring system that transmits real-time data. Research [6] used the BH1750 sensor to measure sunlight intensity to improve solar energy efficiency, while in [7] monitored lighting in workspaces using the same sensor.

Several other studies have focused on the LDR sensor. Research [8] investigated LDR sensor calibration to enhance light intensity measurement accuracy. Research [9] applied a Kalman Filter to stabilize LDR sensor data in a smart home system. Research [10] and [11] examined the accuracy of the LDR sensor in detecting light intensity, while [12] compared LDR sensor measurement results with a standard lux meter. Research [13] designed an automatic lighting system based on LDR and PIR sensors that adjusts lighting according to human presence.

Besides the BH1750 and LDR sensors, research has also been conducted using other light sensors. Research [14] developed a photodiode-based colorimeter to detect food dyes. Research [15] studied the characteristics of the LDR sensor in light intensity measurement, while [16] developed a light measurement device using the BH1750 and HC-SR04 sensors to ensure compliance with lighting standards.

Based on the previously explained background, this study examines the effectiveness of three light sensors LDR, photodiode, and BH1750 through testing conducted in a 3x3 meter boarding room.

2. Methods

2.1. Linear Regression

Calibration is the process of determining accurate results [17] by comparing the measurements of three sensors LDR, BH1750, and Photodiode with a standard reference instrument for measuring light intensity, such as a digital lux meter, to achieve more precise results.

The calibration process is carried out by comparing the measurement results of the three light sensors, which act as readers, with the digital lux meter as the standard reference value. The purpose of this calibration is to obtain more precise and accurate results from the three light sensors. The linear regression equation is shown in Equation (1).

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

Equation (1) represents a relationship between two variables, where y is the dependent variable and x is the independent variable. a is the gradient, which determines the magnitude of change in y when x changes by one unit, defining the slope of the line. b is the intercept, indicating the point where the line crosses the y-axis when x = 0 [18].

2.2. Error Rate Formula

The measurement results obtained from the LDR, BH1750, and Photodiode sensors can be compared with the digital lux meter measurements using the Mean Absolute Percentage Error (MAPE) [19] Equation (2) as follows.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right| \times 100\% \tag{2}$$

In Equation (2), the variable F_i represents the predicted value, A_i represents the actual value, and n is the total number of data points used. After calculating the error value, the average error of the three light sensors can be compared, where the sensor with the lowest average error is considered to produce the most accurate results [20].

2.3. System Design

Fig. 1 represents the device design created using the SolidWorks application. Fig. 1 shows the device design: (a) the side view with a length of 15.5 cm and a height of 5 cm, (b) the top view with a length of 15.5 cm and a width of 11 cm, featuring a lid that can be opened upwards, and (c) the side view with a width of 11 cm and a height of 5 cm. Inside the device, there is a bolt section to secure the components, ensuring they remain firmly in place.

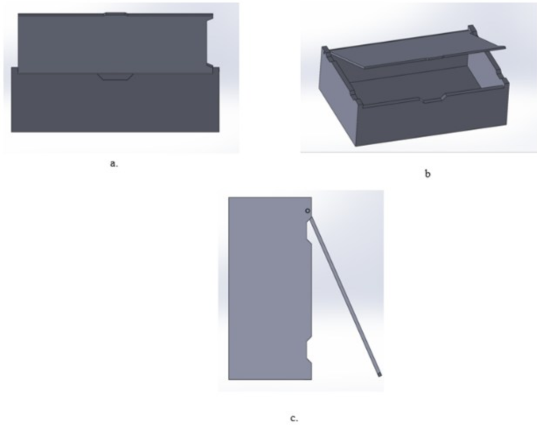

Fig. 1. Device design

2.4. Wiring Diagram

The following is a wiring diagram that connects the components of the constructed device. Fig. 2 illustrates the wiring diagram used to connect all the required components in the device. The detection of light intensity in the boarding room utilizes LDR, BH1750, and Photodiode sensors as inputs, which are processed by the Arduino Uno. The Arduino Uno then executes commands to process all the data obtained from these three light sensors, and the output is displayed on the LCD. The measurement of light intensity is conducted within the boarding room. Table 1 shows the pin diagram for the wiring of the components used in this study.

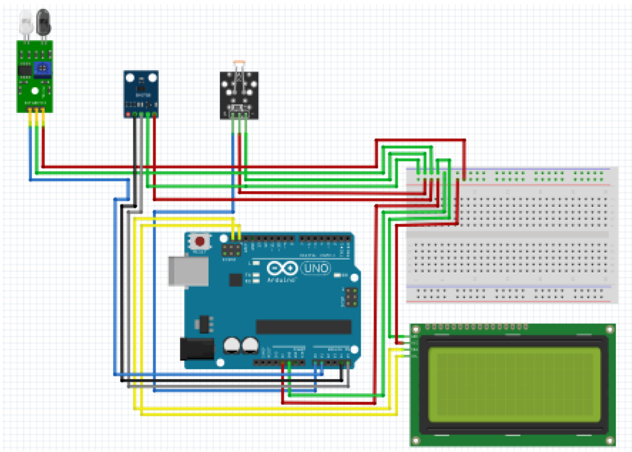

Fig. 2. Wiring Diagram

Table 1. Component wiring pins

Component	PIN	Component	PIN
Arduino Uno	GND	LDR	GND
Arduino Uno	5V	LDR	VCC
Arduino Uno	A1	LDR	A0
Arduino Uno	5V	BH1750	VCC
Arduino Uno	GND	BH1750	GND
Arduino Uno	A5	BH1750	SCL
Arduino Uno	A4	BH1750	SDA
Arduino Uno	5V	Photodiode	VCC
Arduino Uno	GND	Photodiode	GND
Arduino Uno	A0	Photodiode	A0
Arduino Uno	5V	LCD_I2C	VCC
Arduino Uno	GND	LCD_I2C	GND
Arduino Uno	A4	LCD_I2C	SDA

2.5. Flowchart

A flowchart is a part where the processing flow in the relationship between processing (commands) and other processing in a program is depicted in symbols. The flowchart in this research is used to detect light intensity in a room which will be processed using an Arduino Uno to obtain light intensity data, so a flowchart like Fig. 3 is needed. Fig. 3 is a diagram that illustrates the steps in the operational system. The first step begins with program initialization processing, then the LDR, Photodiode, and BH1750 sensors will detect the light intensity in the room. The LCD will display the results of measuring light intensity information obtained by the LDR, Photodiode and BH1750 sensors.

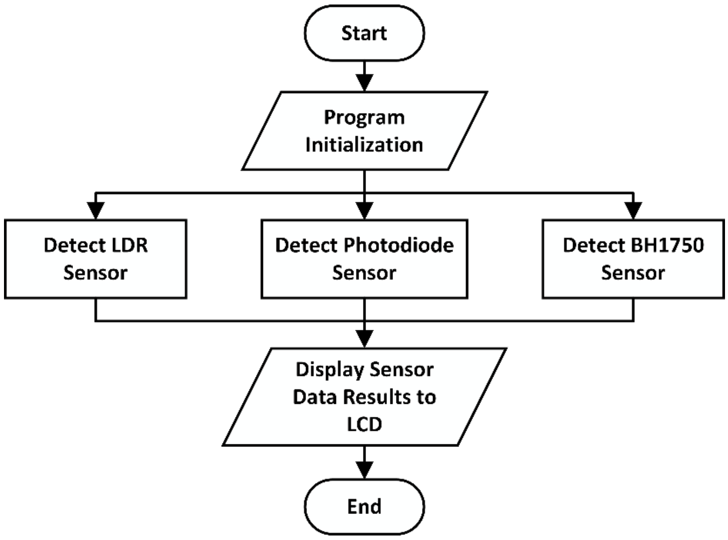

Fig. 3. System flowchart

2.6. System Testing

System testing can be conducted once the device design is complete to evaluate its performance. The testing process follows these steps:

- Testing of LDR, BH1750, and Photodiode Sensors Using Indoor Light Sources
  a. Prepare the equipment required for measuring indoor light intensity.
  b. Set up a digital lux meter (AS803) as a reference for comparing the three light sensors.
  c. Measure indoor light intensity using natural window light every 10 minutes in three data collection sessions: morning, noon, and afternoon.
  d. Measure indoor light intensity using artificial lighting with different lamp brands and wattages.
  e. Record the measurement results from the three sensors and compare them with the digital lux meter readings.
- Calibration System

The collected test data is then calibrated to obtain accurate measurement results. Calibration is performed by analysing the recorded measurements against the reference values from the AS803 digital lux meter. The calibration process uses the linear regression method, and the calculated regression results are applied to the LDR, BH1750, and Photodiode sensors.

3. Results and Discussion

3.1. Tool Design Results

This research has succeeded in designing a tool that can compare the effectiveness of the LDR, BH1750, and Photodiode light sensors with the standard digital lux meter AS803 as in Fig. 4. Fig. 4 is a tool that has been successfully made with several components that have been installed according to the design. The box is made of clear acrylic material so that all components can be seen clearly.

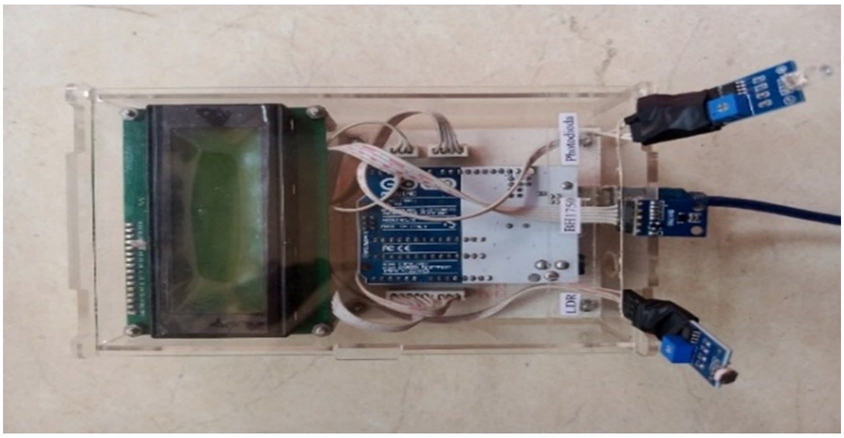

Fig. 4. Design tools

3.2. Window Light Intensity Measurement

In measuring window light intensity, there are three sessions for measuring window light intensity, where the first session is the morning session which is carried out from 07.00 to 10.10, then the second session is the afternoon session which is carried out from 10.30 to 13.40, and the third session is carried out in the afternoon from 14.00 to 17.10. The results of measurements of the three light sensors used will be recorded as in Table 2.

Table 2. Morning window light intensity

No	Time	LDR (Lux)	BH1750 (Lux)	Photodiode (Lux)	Digital Lux Meter (Lux)
1	07.00	14	15	14	17
2	07.10	17	16	16	18
3	07.20	20	17	16	19
4	07.30	19	17	17	19
5	07.40	22	19	20	20
6	07.50	26	21	24	22
7	08.00	29	23	27	24
8	08.10	29	23	26	24
9	08.20	34	24	29	25
10	08.30	34	26	31	27
11	08.40	32	26	27	26
12	08.50	32	26	29	27
13	09.00	34	27	30	27
14	09.10	41	32	36	31
15	09.20	44	34	39	33
16	09.30	45	36	40	34
17	09.40	50	39	38	36
18	09.50	50	39	43	37
19	10.00	53	43	45	39
20	10.10	54	44	46	40
Average of error (%)		**23.53**	**5.97**	**12.14**	**-**

Table 2 shows the result of measuring the intensity of window light in the morning, where the measurement results obtained significant data from the three sensors used. The average error value for the LDR sensor is 23.53%, the BH1750 sensor is 5.97%, and the Photodiode sensor is 12.14%. So the closest result to a digital luxmeter is the BH1750 sensor with an average error of 5.97%. Table 3 shows the result of measuring the intensity of window light during the day, where the measurement results obtained significant data from the three sensors used. The average error value for the LDR sensor is 20.24%, the BH1750 sensor is 7.69%, and the Photodiode sensor is 9.42%. The closest result to a digital luxmeter is the BH1750 sensor with an average error of 7.69%. Table 4 is the result of measuring the intensity of window light in the afternoon, where the measurement results obtained significant data from the three sensors used. The average error value for the LDR sensor is 21.73%, the BH1750 sensor is 10.84%, and the Photodiode sensor is 19.72%. The closest result to a digital luxmeter is the BH1750 sensor with an average error of 10.84%.

Table 3. Daytime window light intensity

No	Time	LDR (Lux)	BH1750 (Lux)	Photodiode (Lux)	Digital Lux Meter (Lux)
1	10.30	56	44	44	42
2	10.40	59	48	51	44
3	10.50	63	51	54	48
4	11.00	69	57	60	52
5	11.10	67	56	55	52
6	11.20	75	64	66	59
7	11.30	77	67	68	61
8	11.40	80	71	71	65
9	11.50	85	77	75	71
10	12.00	93	89	83	80
11	12.10	98	94	83	83
12	12.20	108	115	102	103
13	12.30	117	123	112	116
14	12.40	95	85	64	82
15	12.50	104	106	91	90
16	13.00	95	86	68	80
17	13.10	91	80	65	79
18	13.20	97	81	71	82
19	13.30	99	83	79	89
20	13.40	92	81	78	81
Average of error (%)		**20.24**	**7.69**	**9.24**	**-**

Table 4. Window light intensity in the afternoon

No	Time	LDR (Lux)	BH1750 (Lux)	Photodiode (Lux)	Digital Lux Meter (Lux)
1	14.00	112	110	106	114
2	14.10	98	96	88	96
3	14.20	80	61	63	74
4	14.30	53	46	30	47
5	14.40	136	220	189	221
6	14.50	129	140	129	140
7	15.00	135	134	132	137
8	15.10	118	124	117	128
9	15.20	136	129	123	137
10	15.30	89	73	66	71
11	15.40	64	57	50	54
12	15.50	64	56	49	55
13	16.00	63	54	49	50
14	16.10	55	40	38	47
15	16.20	59	39	36	43
16	16.30	45	36	27	39
17	16.40	37	20	20	28
18	16.50	19	15	16	18
19	17.00	4	8	5	10
20	17.10	0	1	0	3
Average of error (%)		**21.73**	**10.84**	**19.72**	**-**

3.3. Lamp Light Intensity Measurement

Measurement of the light intensity of the lamp using the Luby brand with a power of 18 watts. This measurement was divided into three sessions measuring the light intensity, where the first session was the morning session which was carried out from 07.00 to 10.10, then the second session was the afternoon session carried out from 10.30 to 13.40, and the third session was carried out in the afternoon from 14.00 to 17.10. The results of measurements of the three light sensors used will be recorded as in Table 5.

Table 5. Light intensity of morning lights

No	Time	LDR (Lux)	BH1750 (Lux)	Photodiode (Lux)	Digital Lux Meter (Lux)
1	07.00	118	134	112	130
2	07.10	119	134	111	130
3	07.20	117	134	112	130
4	07.30	118	135	111	130
5	07.40	115	133	110	129
6	07.50	114	133	111	129
7	08.00	114	134	110	129
8	08.10	113	133	113	127
9	08.20	112	131	112	126
10	08.30	111	121	112	126
11	08.40	111	120	111	125
12	08.50	111	120	111	124
13	09.00	110	120	110	124
14	09.10	110	120	109	123
15	09.20	110	121	109	123
16	09.30	109	121	108	120
17	09.40	109	123	108	120
18	09.50	106	123	108	120
19	10.00	104	122	112	118
20	10.10	104	122	112	119
Average of error (%)		**10.69**	**3.10**	**11.51**	**-**

Table 5. is the result of measuring the intensity of light in the morning, where the measurement results obtained significant data from the three sensors used. The average error value for the LDR sensor is 10.69%, the BH1750 sensor is 3.10%, and the Photodiode sensor is 11.51%. The closest result to a digital lux meter is the BH1750 sensor with an average error of 3.103%. Table 6 shows the result of measuring the intensity of light during the day, where the measurement results obtained significant data from the three sensors used. The average error value for the LDR sensor is 10.17%, the BH1750 sensor is 6.90%, and the Photodiode sensor is 7.37%. So, the closest result to a digital luxmeter is the BH1750 sensor with an average error of 6.90%. Table 7 shows the result of measuring the intensity of light in the afternoon, where the measurement results obtained significant data from the three sensors used. The average error value for the LDR sensor is 9.03%, the BH1750 sensor is 3.65%, and the Photodiode sensor is 5.35%. So, the closest result to a digital luxmeter is the BH1750 sensor with an average error of 3.65%.

Table 6. Daytime light intensity

No	Time	LDR (Lux)	BH1750 (Lux)	Photodiode (Lux)	Digital Lux Meter (Lux)
1	10.30	117	116	112	111
2	10.40	116	115	111	110
3	10.50	116	114	111	109
4	11.00	116	113	111	108
5	11.10	116	112	111	107
6	11.20	115	111	111	106
7	11.30	114	110	111	105
8	11.40	115	112	111	109
9	11.50	114	113	111	104
10	12.00	114	116	111	103
11	12.10	114	112	113	102
12	12.20	114	113	113	102
13	12.30	113	110	111	101
14	12.40	113	109	111	100
15	12.50	113	108	111	100
16	13.00	113	107	111	100
17	13.10	113	108	111	100
18	13.20	113	106	111	100
19	13.30	113	105	111	100
20	13.40	114	109	113	100
Average of error (%)		**10.17**	**6.90**	**7.37**	**-**

Table 7. Intensity of light in the afternoon

No	Time	LDR (Lux)	BH1750 (Lux)	Photodiode (Lux)	Digital Lux Meter (Lux)
1	14.00	118	116	111	116
2	14.10	117	114	110	113
3	14.20	116	112	110	110
4	14.30	115	111	110	109
5	14.40	115	110	110	107
6	14.50	114	109	109	106
7	15.00	114	108	109	104
8	15.10	113	107	109	103
9	15.20	113	107	109	102
10	15.30	113	106	109	102
11	15.40	113	105	109	102
12	15.50	113	106	109	102
13	16.00	113	107	109	102
14	16.10	113	107	109	102
15	16.20	112	106	108	101
16	16.30	112	106	108	101
17	16.40	112	106	108	101
18	16.50	112	106	108	101
19	17.00	112	106	108	101
20	17.10	112	106	108	101
Average of error (%)		**9.03**	**3.65**	**5.35**	**-**

3.4. Comparison of the Three Light Sensors Used

After measuring the light intensity, a comparative analysis of the three light sensors used in this research can be carried out by looking at several points in the written parameters. As in Table 8. Based on Table 8 it shows the comparison results of the three light sensors used, where the comparison of the average errors shows that the calibration results succeeded in increasing the accuracy of each sensor. The results that show the most accurate accuracy value are the BH1750 sensor with an average error of 7.53%, so it can be said to be a better sensor than the LDR sensor at 23.74% and the Photodiode sensor at 18.20%.

Table 8. Comparison of three light sensors

Parameter	**LDR (before calibration)**	**LDR (after calibration)**	**BH1750 (before calibration)**	**BH1750 (after calibration)**	**Photodiode (before calibration)**	**Photodiode (after calibration)**
Average *error*	224.72%	23.74%	23.83%	7.53%	145.40%	18.20%
Accuracy	Not accurate	Accurate (smaller error)	Accuracy (±15%)	Accuracy (10%)	Accuracy	Very accurate and stable
Operating voltage	5V		5V		5V	
Sensor type	Analog		Analog		16-bit digital	

4. Conclusion

After designing the tool and analysing the testing of the LDR sensor, BH1750 sensor, and Photodiode sensor, we can provide the following conclusions, LDR sensors can be assembled and programmed for simple applications. Photodiode sensors can be assembled and programmed, very suitable for applications that require a sensitive response to light. Meanwhile, the BH1750 sensor obtains lux data directly via I2C, is easier to use and suitable for applications that require high accuracy values. Effectiveness of the LDR sensor at a cheaper market price, the Photodiode sensor at an affordable price and the BH1750 sensor at an expensive price. These light sensors have different results regarding light intensity, the LDR sensor has a slower light response and less accurate results, the Photodiode Sensor has the fastest response to light intensity and is more accurate than the LDR sensor, the BH1750 sensor has more accurate and stable results regarding light intensity. The BH1750 sensor has a lower average error after calibration of 7.536%, compared to the average error of the LDR sensor of 23.744% and the Photodiode sensor of 18.206%, so that calibration of the three sensors used can increase the accuracy of measuring light intensity more precisely and effectively.

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