Comparison of Illuminance Measurements Using a Photoresistor and a Standard Lux Meter

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ABSTRACT
Light is an essential needs for living organisms, especially humans. Human activities depend on adequate lighting to ensure clear and effective visual perception when performing various tasks. Illuminance measurement instruments are used to determine and assess the level of illumination needed for specific applications, with the lux meter serving as the standard measuring device. In this experiment, a photoresistor will be utilized as a light sensor, and its measurements will be compared with those obtained from a standard lux meter. The experiment will also employ calibration methods and several analytical approaches to determine the most accurate measurement model. The results of the experiment will be used to evaluate whether a photoresistor is sufficiently effective as a simple instrument for measuring light illuminance.

ABSTRAK
Cahaya telah menjadi hal yang dibutuhkan sebagai makhluk hidup, terutama manusia. Aktivitas manusia mengandalkan cahaya agar visualisasi saat melakukan sesuatu menjadi mudah dan jelas. Alat ukur iluminansi cahaya digunakan untuk mengetahui dan menentukan tingkat iluminansi cahaya yang diperlukan sesuai kebutuhannya dan menggunakan lux meter. Dalam eksperimen ini, fotoresistor akan digunakan sebagai sensor cahaya dan akan dibandingkan dengan nilai lux meter standar. Eksperimen ini juga akan menggunakan metode kalibrasi dan akan menggunakan beberapa pendekatan untuk menentukan pengukuran terbaik. Hasil eksperimen akan menentukan apakah penggunaan fotoresistor cukup efektif sebagai alat ukur iluminansi cahaya secara sederhana.

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INTRODUCTION

Light is a basic necessity for all living organism, particularly human. It offers numerous benefits for humans. Human activities heavily rely on light to facilitate clear visualization, for instance, nocturnal fishing utilizes the physics principles of light to improve catch efficiency (Rosyidah et al., 2009). Furthermore, light applications are found in indoor lighting systems designed to meet specific standards, such as SNI 03-6575-2001, to ensure optimal functionality (Andryadi & Nugraha, 2021). In fact, lighting systems significantly influence the work environment, affecting worker comfort and enhancing productivity (Gucci et al., 2025). These examples demonstrate that light is indispensable for providing the necessary illumination to support various human activities.

Light is electromagnetic radiation that propagates through a vacuum (Ningrum, 2017). Furthermore, radiometry introduces the term irradiance, which is defined as the radiant flux density per unit area incident upon, transmitted through, or emitted from a specific surface point. Radiometry is closely related to photometry; the former is a system used to measure the propagation of electromagnetic radiation, while the latter shares a similar definition but focuses specifically on the response of the human eye. The radiometric equivalent of irradiance is illuminance (McCluney, 2014). Irradiance is measured in W/m^2 whereas illuminance is quantified lm

$(lumen)/m^2$ or lux.

The measuring instrument used to determine illuminance levels is called a lux meter. In assessing lighting quality, the lux meter remains the primary benchmark due to its certified data accuracy (Lumembang & Kolibu, 2024).

However, this standard instrument presents practical constraints, particularly high procurement costs that limit device accessibility across academic institutions and small enterprises.

Various sensors are used for light illuminance detection, including photodiodes, photoresistors, and the BH1750, each possessing distinct advantages and limitations. Several experiments indicate that photoresistor sensors offer satisfactory accuracy, closely approximating the values of a standard lux meter. A photoresistor, also commonly referred to as a light-dependent resistor (LDR), is a specific type of light sensor and electronic resistor whose resistance value depends on light illuminance. The resistance of a photoresistor remains high under dark conditions and decreases upon exposure to light, with these fluctuations in resistance being proportional to the amount of light received (Nurhayati & Maisura, 2021). The material typically used to fabricate these sensors is cadmium sulfide (CdS), a semiconductor material whose electrical resistance varies depending on the amount of light striking its surface (Kusuma et al., 2023).

The resulting data demonstrate a linear relationship between photoresistor-based illuminance measurements and the standard lux meter (Manik et al., 2020). Integrating an photoresistor with an Arduino Uno microcontroller offers great potential as a cost-effective alternative for light intensity measurement, where accuracy can be further optimized through proper calibration and mathematical regression techniques (Sahara et al., 2024). Nevertheless, the physical performance of an photoresistor is heavily influenced by device dimensions and environmental stability parameters. Different sensor diameters (such as 5 mm and 10 mm variations) have been shown to yield distinct measurement characteristics (Kusuma et al., 2023). Beyond sensor dimensions, ambient temperature fluctuations serve as a critical parameter that can shift output values due to increased conductivity in the Cadmium Sulfide (CdS) base material, necessitating stable environmental temperatures to achieve ideal testing results (Román-Raya et al., 2020).

Research evaluating different mathematical models has compared linear, quadratic, exponential, and logarithmic regressions. Khotimah et al. (2022) found that exponential curves yield significantly lower error rates. Concurrently, optimizing accuracy through a power-law model to map the non-linear relationship between photoresistor resistance and light intensity has also proven highly effective, showing strong agreement with experimental data (Ambrosio et al., 2022).

Although various mathematical approaches, such as exponential and power-law models, have been reported to enhance alternative sensor performance, a distinct gap remains regarding a comprehensive comparative evaluation of all five regression methods within a single, isolated experimental environment. Most prior studies assume that photoresistor sensors perform uniformly across all lighting conditions without explicitly mapping the effectiveness thresholds and physical error fluctuations of 5 mm photoresistor sensors against changes in distance and indoor illumination intensity. Therefore, an empirical verification comparing multi-regression linearity (linear, polynomial, exponential, logarithmic, and power-law) is highly necessary. This study is crucial to examine the extent to which the accuracy of a low-cost, Arduino Uno R3-based device can be optimized to approximate the reliability of a standard Sanfix GM1010 lux meter.

METHODS

This experiment utilized an Arduino Uno as the primary microcontroller, with a solderless breadboard serving as the base for assembling all electronic components. Supporting hardware included a 5 mm photoresistor (photoresistor) sensor, a 10 kΩ resistor, jumper wires, a Sanfix SP-305E power supply, and a Mitsuyama MS-7310DC 12 V lamp acting as the instrument's light source. A Sanfix GM1010 lux meter was employed as the calibration reference and standard for comparing illuminance levels. The measuring device was designed by integrating the photoresistor sensor into the analog input pin of the microcontroller via a voltage divider circuit utilizing a 10 kΩ fixed resistor ($Rfix$). The circuit schematic of the photoresistor-based lux meter is shown in Fig. 1.

According to Ohm's law, fluctuations in the intensity of light incident upon the surface of the Cadmium Sulfide (CdS) semiconductor in the photoresistor will alter its resistance value $R_{\text{photoresistor}}$, which automatically changes the analog output voltage V_{out}, as expressed in Eq. 1:

$$V_{out} = V_{CC} \times \frac{R_{fix}}{R_{fix} + R_{photoresistor}}$$

Where $R_{photoresistor}$ represents the resistance of the photoresistor sensor, V_{CC} is the input voltage, and R_{fix} of the fixed resistor (Sarasook and Thongchaisuratkrul, 2018). This analog voltage is subsequently read by 10-bit Analog-to-Digital Converter (ADC) on the Arduino Uno. The digital data obtained have an interval value of 0–1023 ($2^n - 1$). The physical resistance value of the photoresistor at each change in light intensity is thereafter calculated in real-time by the microcontroller by substituting the digital reading value into Eq. 2

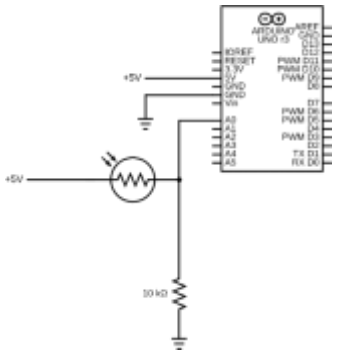


Figure 1. Circuit schematic of photoresistor

$$R_{photoresistor} = R_{fix} \left(\frac{1023}{\text{Data ADC}} - 1 \right)$$

The linear, quadratic, exponential, logarithmic, and power-law regression equation models for calibration are as follows in Table 1:

Table 1. Regression model for calibration

Regression model	Equation
Linear	$E = aR + b$
Second-order Polynomial	$E = aR^2 + bR + c$
Exponential	$E = ae^{bR}$
Logarithmic	$E = a \ln R + b$
Power-law	$E = aR^b$

The illuminance data collection procedure was conducted directly inside a closed room without external light intervention. This light isolation was strictly applied to eliminate ambient light interference that could act as stray light noise, given that the photoresistor semiconductor material possesses a spectral response sensitivity that absorbs all photons falling onto its surface regardless of the light source's origin. Meanwhile, direct data collection aimed to ensure that both the photoresistor sensor and the standard lux meter received the light flux under identical temporal conditions, thereby avoiding measurement errors due to physical voltage instability fluctuations from the lamp light source.

Measurements were performed by periodically varying the distance of the lamp relative to the positions of the sensor and the standard lux meter, ranging from 10 cm to 150 cm with a 10 cm increment for each subsequent measurement. At each distance interval, the reference illuminance parameter value $E_{lux\ meter}$ and $R_{photoresistor}$ were recorded. Instrument accuracy was optimized by mapping the sensor characteristics using five distinct calibration curve techniques: linear, second-order polynomial, exponential, logarithmic, and power-law regressions. The final phase of the experiment focused on data analysis by conducting linearity tests through the graphical interpretation of the relationship between the calculated photoresistor illuminance value and the actual data from the standard lux meter. The precision of the system was quantitatively evaluated by calculating the

percentage error of each tested mathematical regression model.

RESULTS AND DISCUSSIONS

The illumination from the lamp was gradually dimmed by reducing the voltage supplied to the device. While maintaining a constant distance, the voltage was decreased to achieve specific reference lux values on the standard lux meter. Subsequently, the corresponding resistance values were determined based on the standard lux meter readings and converted into digital data by the Arduino Uno. These resistance values were monitored via the Arduino IDE software, ultimately yielding the paired resistance and standard lux values presented in Table 2.

Table 2. Measurement of illuminance of standard lux meter and resistance of photoresistor for calibration

Illuminance of Standard Lux Meter (lx)	Resistance of Photoresistor (Ω)
10	21189.03
20	12834.82
50	6715.69
80	4847.60
100	4188.63
150	3132.22
200	2708.07
300	2092.20
500	1520.27
750	1254.13
1000	1059.46
1500	825.40
2000	678.50

Based on the resistance values obtained and presented in Table 2, the regression coefficients for each model were determined. The coefficients obtained are as follows: for the linear model, $a = -0.0562$ and $b = 784.75$; for the second-order polynomial model, $a = 1.023 \times 10^{-5}$, $b = -0.2662$; and $c = 1230.555$; for the exponential model, $a = 643.5$ and $b = -2.4113 \times 10^{-4}$; for the logarithmic model, $a = -493.3993$ and $b = -4433.743$ and for the power-law model, $a = 4.921 \times 10^{7}$ and $b = -1.562$. These regression models were subsequently applied, and the corresponding measurement results are compiled in Table 3. Table 3 presents the varied distances, which were measured at 10 cm intervals. Furthermore, the ADC value, output voltage, and photoresistor resistance are also documented to demonstrate the variations in illuminance values for each regression model derived from the resistance readings of the Arduino Uno.

Table 3. Results of measurement with applied calibration

Distance (cm)	Illuminance of Standard Lux Meter	ADC Number	V_{output}	Resistance of Photoresistor (Ω)	Regression Model				
					Power	Log	Exp	SOP	Linear
10	3200	979	4.785	449.4	3537.1	418.04	922.4	670.8	573.3
20	1730	956	4.673	700.8	1767.1	393.8	780.0	680.4	555.2
30	988	929	4.541	1011.8	995.8	365.7	662.2	691.6	537.4
40	636	899	4.394	1379.3	613.8	335.1	563.0	704.2	513.9
50	450	867	4.238	1799.3	405.2	303.3	477.8	717.7	487.1
60	334	837	4.091	2222.2	291.4	274.3	410.1	730.6	460.1
70	261	805	3.935	2708.1	214	244.4	346.8	744.7	429.1
80	209	777	3.798	3166.0	167.6	219.1	296.7	757.2	399.9

90	171	750	3.666	3640.0	134.8	195.8	252	769.7	369.7
100	142	724	3.539	4129.8	110.7	174.3	211.5	782.0	337.4
110	115	692	3.382	4783.2	88	149.2	164.4	797.8	296.7
120	99	669	3.270	5291.5	75.2	132.2	132.1	809.5	264.3
130	87	647	3.162	5811.4	64.9	118.8	102.0	821.0	231.1
140	75	624	3.050	6349.2	55.9	101.7	71.4	833.6	193.9
150	66	604	2.952	6937.1	49.2	89.4	45.3	844.8	159.3

Based on Table 3, the lux values derived from the power-law regression exhibit a proportional relationship with those from the standard lux meter across varying distances. This power-law regression model yields nearly comparable illuminance values and displays a graphical trend that closely resembles the illuminance profile obtained from the lux meter across varying distances, as it shown in Fig. 2. In alternative studies, measurements are typically based on modeling resistance as a function of illuminance. However, to determine the illuminance values from the photoresistor sensor response, the current modeling instead establishes illuminance as a function of photoresistor resistance. Ambrosio et al. (2022) and Kumar et al. (2026) established the definitive relationship of resistance as a function of illuminance through the utilization of power-law regression. In this investigation, illuminance is treated as a function of resistance. The results demonstrated by this model indicate that the most optimal calibration between the photoresistor sensor and light illuminance is achieved through the power-law model. This power-law model can serve as a foundational step toward a more refined calibration technique between photoresistor resistance and light illuminance. Nevertheless, further development of more accurate and precise methods to obtain optimal and comparable values remains necessary to enhance, or at least characterize, this photoresistor sensor, thereby maximizing the measurement outcomes.

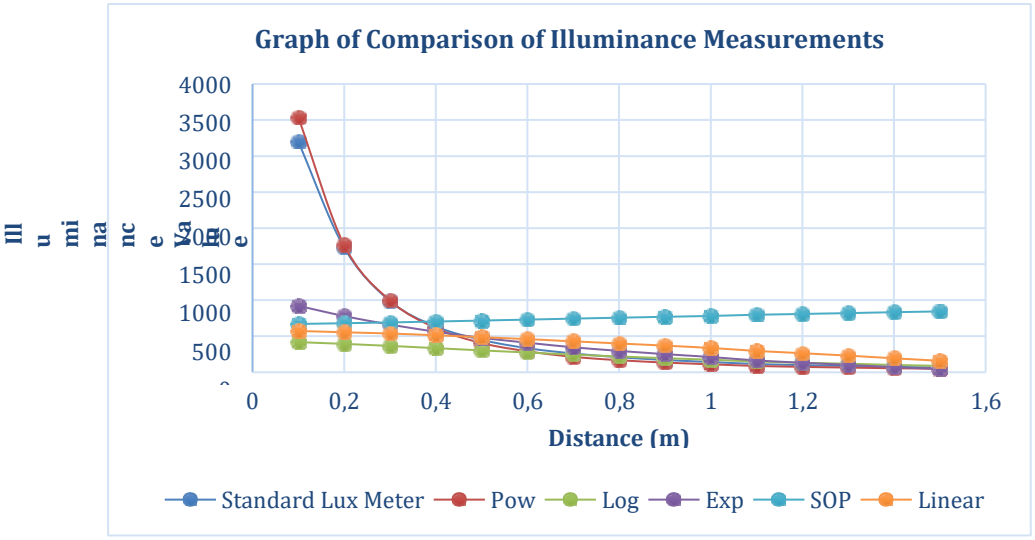


Figure 2. Graph of comparison of illuminance measurements, with the illuminance as a function of distance

CONCLUSIONS

Based on the evaluation of the five regression models, the power-law model emerged as the most optimal choice due to its superior curve-fitting alignment in representing the relationship between photoresistor resistance and illuminance. This power-law relationship aligns with existing literature, despite an inversion in the calibrated parameters, where prior studies predominantly modeled resistance as a function of illuminance to analyze fundamental sensor characteristics. Nevertheless, the long-term effectiveness of utilizing a photoresistor as a standard illuminance meter warrants further investigation, particularly through comparative performance analyses with alternative sensors, such as photodiodes. Future sensor characterization requires deeper empirical study, and the regression models selected for calibration must carefully account for appropriate operational parameters as well as the underlying physical properties of the sensor's response.

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