Evaluating the Accuracy of Smartphone Light Sensors in a Uniformly Accelerated Motion Experiment

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Abstract.
***Background**: The accuracy of a smartphone's ambient light sensor via Phyphox for measuring acceleration in a uniformly accelerated motion experiment was evaluated.*
***Aims**: This study evaluates the accuracy of a smartphone's ambient light sensor via Phyphox for measuring acceleration in a uniformly accelerated motion experiment.*
***Methods**: A dynamics cart mounted with a smartphone was released along a 1° inclined rail, with an LED strip acting as fixed light markers to record illuminance peaks as the cart moved.*
***Results**: Across three trials, the experimental acceleration ranged from 0.127 to 0.128 m/s², with a standard deviation of 0.000242, indicating high precision and repeatability. However, this value differed from the theoretical acceleration of 0.1712 m/s² (for a frictionless incline) by approximately 25%. This discrepancy stems from rolling friction, which becomes significant at low inclination angles, and the sensor's limited sampling rate (4–5 data points per second), so peak-illuminance timing was not always captured precisely.*
***Conclusion**: Despite this accuracy gap, the setup's high precision and low-cost, contactless design make it a viable instructional tool for demonstrating uniformly accelerated motion. Future work should explore higher-sampling-rate sensors and reduced-friction tracks to improve accuracy.*

***Keywords**: inclined plane; light sensor; linear motion; lux meter; phyphox.*

Abstrak.
Latar Belakang: Akurasi sensor cahaya smartphone melalui Phyphox untuk mengukur percepatan pada eksperimen gerak lurus berubah beraturan (GLBB) dievaluasi dalam penelitian ini.
Tujuan: Penelitian ini mengevaluasi akurasi sensor cahaya smartphone melalui Phyphox untuk mengukur percepatan pada eksperimen gerak lurus berubah beraturan (GLBB).
Metode: Kereta dinamika yang dilengkapi smartphone dilepaskan pada rel yang dimiringkan 1°, dengan strip LED sebagai sumber cahaya tetap untuk merekam puncak intensitas cahaya seiring pergerakan kereta.
Hasil: Dari tiga kali percobaan, diperoleh percepatan berkisar 0,127–0,128 m/s² dengan standar deviasi 0,000242, menunjukkan presisi dan konsistensi pengukuran yang tinggi. Namun, nilai ini berbeda dari percepatan teoretis sebesar 0,1712 m/s² (bidang miring tanpa gesekan) dengan *error* sekitar 25%. Perbedaan ini disebabkan oleh gesekan pada roda, yang berpengaruh besar pada sudut kemiringan kecil, dan keterbatasan laju pengambilan data sensor cahaya (4–5 data per detik), sehingga waktu puncak intensitas cahaya tidak selalu terekam secara presisi.

Kesimpulan: Meski demikian, presisi tinggi serta desain yang murah dan tanpa kontak menjadikan metode ini alat yang layak untuk mendemonstrasikan GLBB. Penelitian selanjutnya disarankan mengeksplorasi sensor dengan laju pengambilan data lebih tinggi serta lintasan dengan gesekan lebih rendah untuk meningkatkan akurasi.

Kata kunci: bidang miring; sensor cahaya; gerak lurus; luxmeter; phyphox.

INTRODUCTION

Uniformly accelerated linear motion (GLBB) refers to the motion of an object along a straight path whose velocity changes at a constant rate over time, producing a constant, non-zero acceleration. Accurately measuring its kinematic variables requires either costly digital acquisition systems, such as photogates, or low-cost mechanical tools like ticker timers, the latter of which introduce friction that can distort data, especially at low incline angles where the driving force is minimal. A contactless measurement approach would minimize such disruptions and enable more reliable data acquisition.

As technology advances, built-in smartphone sensors—such as the ambient light sensor accessed via Phyphox—have emerged as a cost-effective, accessible alternative for modernizing data collection in standard physics setups. Smartphone-based experiments have been shown to enhance students' conceptual understanding, motivation, and engagement [1,2], and specifically to empower creative thinking through interactive inclined plane practicums [3]. Beyond kinematics, Phyphox's sound sensor has also been used to accurately measure the Doppler effect and the coefficient of restitution in partially elastic collisions, both with error rates under 4% [4,5].

Before applying this contactless sensing method to the inclined plane experiment, it is necessary to review the governing kinematic equations of GLBB. The fundamental kinematic equations describing GLBB are presented in **Equation 1-3.**

$$\mathbf{v} = \mathbf{v}_0 + \mathbf{a}t \tag{1}$$

$$\mathbf{s} = \mathbf{v}_o t + \frac{1}{2}\mathbf{a}t^2 \tag{2}$$

$$\mathbf{v} \cdot \mathbf{v} = \mathbf{v}_0 \cdot \mathbf{v}_0 + 2\mathbf{a} \cdot \mathbf{s} \Rightarrow v^2 = v_0^2 + 2as \tag{3}$$

To generate a controlled, reproducible instance of GLBB suitable for experimentation, an inclined plane is commonly used, since Newton's second law provides a deterministic framework for predicting an object's acceleration from its mass and the net force acting on it [6]. Specifically, when a block slides down an incline, the net force acting along the plane is the component of gravitational force parallel to the incline, where m is the mass of the object and g is the acceleration due to gravity; this force component determines the object's resulting acceleration [7]

The forces acting on an object on an inclined plane include the gravitational force and the normal force, which can be resolved into two components: one parallel to the inclined plane (along the x-axis) and one perpendicular to it (along the y-axis), as illustrated in **Figure 1**. Additionally, resistance forces, such as friction, must be considered, as they oppose the applied force, necessitating a greater force to achieve the desired acceleration [8]. In this experiment, the rail is assumed to be a frictionless track so the frictional force was not analyzed.

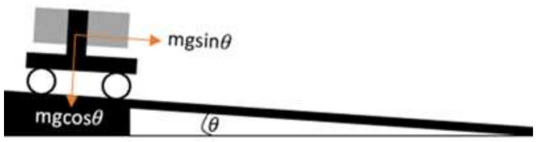

Figure 1. Force diagram for an object on the inclined plane

By applying Newton's Second Law to an inclined plane, we get the acceleration and gravity relationship in **Equation 6**.

$$\sum \mathbf{F} = m\mathbf{a} \quad (4)$$

$$m\mathbf{g}\sin\theta = m\mathbf{a} \quad (5)$$

$$\mathbf{a} = \mathbf{g}\sin\theta \quad (6)$$

In previous research, Pierratos & Polatoglou [9] explored experiments on uniformly accelerated and decelerated motion using Christmas lights as position markers, with a spacing of 10 cm between each light, and concluded that the data collected was both valid and reliable. Other studies have further explored smartphone-based kinematics experiments more broadly: Imtinan & Kuswanto [10] examined the broader use of Phyphox in physics experiments, while Namchantra & Putthagrusa [11] that used LED gates for measuring kinematic parameters using the ambient light sensor of a smartphone.

Despite these advantages, existing literature predominantly focuses on the practicality and motivational benefits of smartphone-based tools, with limited rigorous evaluation of their quantitative measurement accuracy. Pierratos & Polatoglou [9], concluded their LED-based setup was valid for qualitative classroom presentations, but did not quantify error margins against theoretical kinematic calculations, nor address how the light sensor's low sampling rate affects measurement accuracy.

This study aims to bridge that gap by rigorously evaluating how accurately a smartphone's light sensor can measure acceleration in a GLBB experiment, using fixed LED markers that function as a low-cost, contactless photogate array. In doing so, this research provides a critical, quantitative evaluation of the light sensor's accuracy and limitations, establishing a foundation for its reliability as a high-precision instructional tool in physics education.

RESEARCH METHODS

Design Experiment

In this experiment, LED lights were used as position markers to accurately monitor an object's movement. By placing LED lights at fixed intervals along the inclined plane, students can observe changes in the object's position at consistent time intervals. Each time the object passes an LED light, the light can serve as an indicator of time and position. The data obtained can then be used to calculate speed and acceleration using uniformly accelerated motion equations. In addition to LED lights, phyphox's measurement of illuminance were used to examine the time needed for the cart to move between lights.

The app's design ensures accessibility on both Android and iOS platforms, enabling seamless data collection even when the smartphone is not directly accessible during experiments [12]. Phyphox also serves as a versatile tool that not only enhances practical skills but also prepares students for a technologically advanced educational landscape [13]. The application also supports contextual learning by enabling experiments anywhere, which fosters meaningful engagement with scientific concepts and promotes interactive learning experiences in diverse educational contexts [14, 15].

The experimental setup consisted of a 1.2-meter rail acting as an inclined plane. A smartphone was securely mounted on a dynamics cart, while a customized LED strip served as a series of fixed light markers positioned along an optical bench (see **Figure 2** and **Figure 3**).

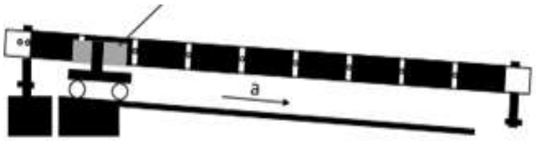

Figure 2. Experimental design for uniformly accelerated motion using phyphox

Figure 3. Experimental setup for uniformly accelerated motion using phyphox

To ensure quantitative rigor, specific experimental conditions and variables were strictly defined. The independent variable was the fixed distance between the exposed LED lights (x), set at 10.5 cm intervals. The dependent variable was the time (t) recorded at the peak illuminance, which was subsequently used to determine the cart's velocity and acceleration. Control variables included maintaining a constant rail inclination of 1° and keeping the total mass of the moving system (cart and smartphone) constant throughout the trials. Furthermore, the experimental design planned for three repeated iterations of the same setup to evaluate the precision, reliability, and standard deviation of the collected data.

Data Collection

The inclination angle of the rail was strictly controlled at 1° using the "inclination" feature in Phyphox. This specific angle was strategically chosen to accommodate the operational boundaries of the smartphone's ambient light sensor. Preliminary observations indicated that typical smartphone light sensors possess a limited temporal resolution. A steeper inclination would result in a higher terminal velocity of the dynamics cart, causing the exposure time beneath each LED to fall below the sensor's sampling interval. By maintaining a 1° incline, the cart's velocity was restricted to a measurable range, ensuring the sensor had adequate time to accurately capture the peak illuminance at each distance interval without missing data points. Next, a 10V DC-powered LED strip was activated as the light source, and the dynamics cart was positioned at the top of the rail.

During the experiment, it can be physically difficult to start, stop, or observe the process without disrupting the experimental setup [15]. To maintain the integrity of the uniformly accelerated motion and strictly control external variables, the smartphone was operated entirely via Phyphox's remote access feature from a connected laptop [17,18]. As highlighted by Staacks et al. [12], physically interacting with the device during a sensitive experiment introduces significant mechanical noise and alters the physical initial conditions. By utilizing remote access, data acquisition can be controlled wirelessly, eliminating direct human interference on the moving object.

The data recording was initiated by clicking the play button on the laptop interface simultaneously with the release of the cart. Once the cart reached the bottom of the rail, the recording was halted remotely. This entire data collection procedure was conducted through three repeated iterations to ensure the reliability and repeatability of the measurements. The diagram in **Figure 4** shows the overall data collection scheme.

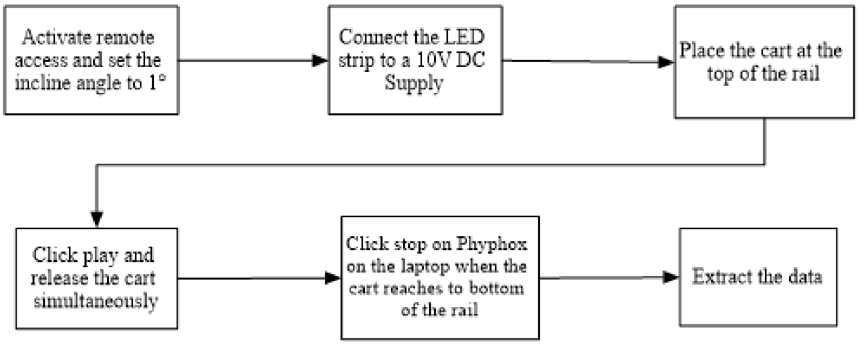

Figure 4. Data collection setup

Data Extraction

The next step was to extract the data for further analysis. Since the app supports various data export formats, its utility for subsequent analysis has been enhanced [17]. The data file was exported to Microsoft Excel for pre-processing. To address the fundamental challenge of converting light intensity data into precise kinematic variables, a peak identification method was employed. (see **Figure 5**). As the smartphone's sensor passed directly beneath each exposed LED light along the track, it registered a maximum light intensity. By highlighting these specific illuminance peaks in the dataset, the exact timestamps (*t*) of the cart's passage were extracted (see **Table 1**). Because the physical distance between each exposed LED was fixed and known (x_n), each extracted timestamp (t_n) could be directly paired with a specific positional coordinate. This process explicitly converts the raw light intensity signals into standardized position-time (*x*-*t*) data.

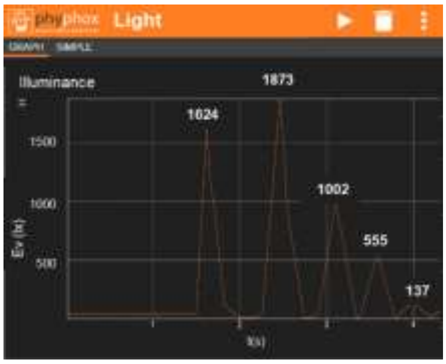

Figure 5. Timestamp extraction

Table 1. Extracted data from Phyphox app

Time (s)	Illuminance (lx)
…	…
1.500586	41
1.620548	1624
…	…
2.263207	46
2.464528	1873
…	…
2.905744	42
3.106516	1002
3.347479	6
3.387639	19
3.588441	555
3.789244	5
3.990016	137

Following this conversion, the velocity ($\vec{v}$) of the cart between any two successive LED markers was calculated using the formula in **Equation 7**.

$$\mathbf{v} = \frac{\mathbf{x}_2 - \mathbf{x}_1}{t_2 - t_1} \tag{7}$$

These calculated velocity values were then plotted against the cumulative time to generate a velocity-time (*v-t*) graph while Through linear regression analysis of this graph, the equation of the line was established. The slope (gradient) of this linear equation represents the experimental acceleration ($\mathbf{a}_{\exp}$) of the dynamics cart.

Finally, to evaluate the accuracy of the smartphone sensor, the experimental acceleration was quantitatively compared to the theoretical acceleration $\mathbf{a}_{theory} = \mathbf{g}\sin\theta$ derived from Newton's Second Law for an object on a frictionless inclined plane. The deviation between these values was assessed using a standard percentage error calculation. The overall data analysis procedure is summarized in the **Figure 6**.

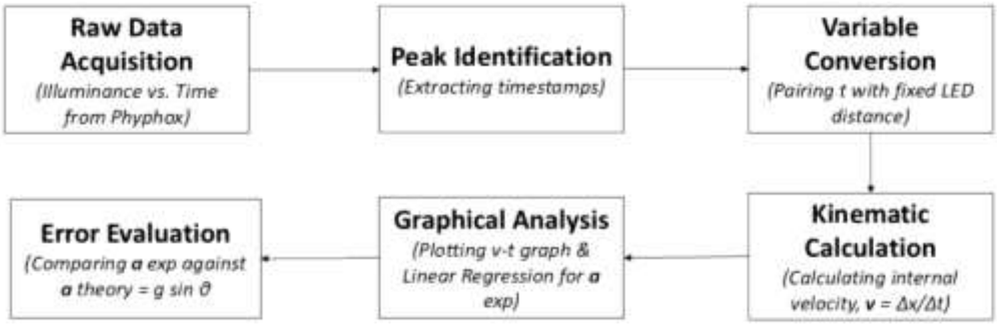

Figure 6. Data extraction setup

Error Calculation

Error percentage were calculated by comparing values we got from the experiment and those from the theory. Percent error, also known as percentage error, measures the difference between an experimental or predicted value and an accepted or theoretical value, expressed as a percentage. It plays a significant role in validating experimental results, testing hypotheses, and ensuring quality control in various scientific and industrial applications. In some contexts, the sign of the error indicates whether the measured values exceed or fall short of expectations (see equation 8).

$$\%Error = \frac{\left|x_{mesured} - x_{theory}\right|}{x_{theory}} \times 100 \tag{8}$$

This provides a clear and standardized way to interpret the magnitude of deviations. Percent error is extensively used in education, manufacturing, and research to assess deviations and refine processes, emphasizing its universal applicability in science and engineering [18].

RESULTS AND DISCUSSION

Results

Three repeated experiments with the same slope angle and LED spacing were conducted. First, the value of velocity across three trials were calculated by using the velocity equation from linear motion as in **Equation 7.**

Which Δx is the spacing between visible LED and Δt is the time between the light peak as shown earlier in **Figure 5**. From these experiments, we obtained acceleration values ranging from 0.127 to 0.128 m/s², which is the gradient we obtained by plotting velocity vs time graph. This result is shown in the velocity-time graph from the three experiments in **Figure 7**. The trend observed indicates that the dynamics cart exhibits uniformly accelerated linear motion with increasing velocity over time intervals as shown in **Table 2.**

Additionally, the consistent acceleration pattern across trials indicates reliability in the initial experimental setup and the accuracy of the measuring tools used. Minor differences in linear regression values may be attributed to external factors such as friction. Nonetheless, the overall trend confirms that the object's motion aligns with the theoretical model of uniformly accelerated motion.

Table 2. Experimental data

No	Iteration 1			Iteration 2			Iteration 3		
	t (s)	*x* (m)	*v* (m/s)	*t* (s)	*x* (m)	*v* (m/s)	*t* (s)	*x* (m)	*v* (m/s)
1.	1.31	0.006	0.005	1.46	0.006	0.004	1.62	0.006	0.003
2.	2.59	0.293	0.208	2.82	0.293	0.194	3.11	0.293	0.182
3.	3.44	0.528	0.294	3.26	0.41	0.265	3.59	0.41	0.243
4.	4.12	0.76	0.367	4.31	0.642	0.355	3.99	0.528	0.296
5.	4.40	0.876	0.413	4.59	0.76	0.420	4.31	0.642	0.355

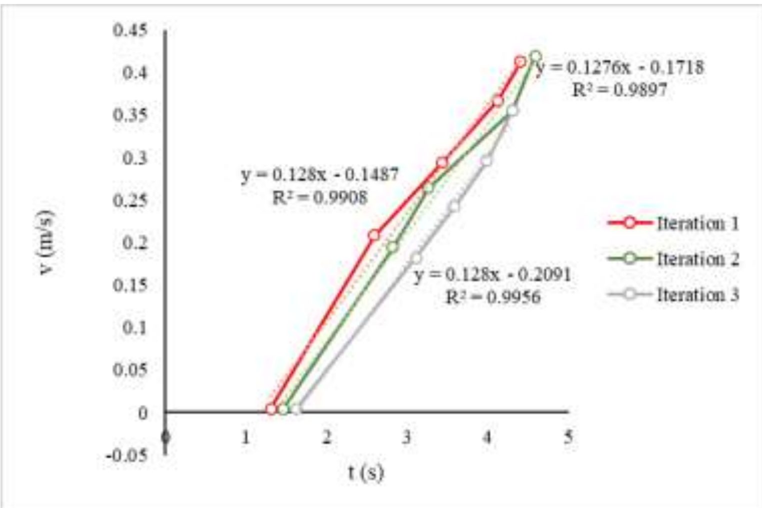

Figure 7. Graphic relationship between velocity and time across multiple trials

Based on the experiments conducted, the calculation of the acceleration value was carried out by applying Newton's Second Law on an inclined plane, yielding results in the range of 0.1275 to 0.1279 m/s². When compared to the theoretical value, the acceleration should be approximately 0.1712 m/s². The difference between the theoretical and experimental results indicates that there were still some errors in the experiment. The detailed results of these calculations are presented in the **Table 3** below.

Table 3. Error percentage of acceleration measurement compared to theory

Iteration	a based on experiment	a based on theory	% error
1	0.12797 ± 0.007	0.17120	25,25%
2	0.12755 ± 0.007		25,49%
3	0.12797 ± 0.004		25,25%
Std. Dev	0.000242 ± 0.0017		

Discussion

The experimental results yielded acceleration values ranging from 0.127 to 0.128 m/s², demonstrating an exceptionally low standard deviation of 0.000242. This negligible variance indicates a high level of precision and repeatability in the smartphone's data acquisition capabilities. However, when compared to the theoretical acceleration of a frictionless inclined plane where $\mathbf{a} = \mathbf{g}\sin\theta \approx 0.1712\, m/s^2$, the experimental data exhibits a percentage error of approximately 25%. Rather than undermining the reliability of the method, this systematic deviation highlights the operational realities of both the physical setup and the smartphone hardware.

The primary contributor to this error margin is the presence of mechanical friction, which the theoretical model assumes to be zero ($\mu = 0$). At a severely restricted inclination angle of 1°, the driving force component of gravity ($m\mathbf{g}\sin 1°$) is exceedingly small. Consequently, even the minimal rolling friction of the dynamics cart wheels exerts a highly disproportionate retarding effect on the cart's acceleration. While this rolling friction is inevitable, the contactless nature of the Phyphox measurement prevents the introduction of additional external drag, such as the paper tape friction inherent in traditional ticker-timer experiments, thereby keeping the error systematic rather than chaotic.

A secondary factor contributing to the error lies in the temporal resolution limit of the smartphone's ambient light sensor. Preliminary testing showed that standard smartphones operate at a sampling rate of approximately 4 to 5 data points per second. This low frequency can create micro-delays in capturing the exact instantaneous peak illuminance as the cart passes beneath the LED, accumulating minor timing discrepancies (Δt) that slightly distort the velocity calculations.

Compared to previous literature by Pierratos & Polatoglou [9], which advances the discourse by quantifying these exact limitations. While previous studies often bypass error margin calculations against pure theory, this 25% deviation establishes a realistic, quantitative baseline for the accuracy of low-cost, contactless data acquisition. Ultimately, because the error is systematic and the precision remains exceptionally high, this method is reliable as an instructional tool to demonstrate the core principles of uniformly accelerated motion.

While previous studies utilizing smartphone sound sensors for acoustic experiments—such as the Doppler effect and collisions—reported minimal error rates below 5% [4,5], the 25% error observed in this light-sensor experiment highlights the distinct operational boundaries of different built-in hardware. Furthermore, explicitly quantifying and analyzing this 25% uncertainty is academically vital. As Zakwandi et al. emphasize, cultivating a positive perception and deep understanding of experimental uncertainty significantly enhances students' overall experimental abilities and scientific reasoning [19].

CONCLUSION

Based on the experiment, the motion of a dynamics cart on a 1° inclined plane can be effectively monitored using a smartphone's light sensor and the Phyphox application. The experimental results yielded acceleration values ranging from 0.127 m/s² to 0.128 m/s² with a very high level of precision, as evidenced by a low standard deviation of 0.000242. Although a systematic error of approximately 25% was observed compared to theoretical calculations, this discrepancy is primarily attributed to the influence of rolling friction at low inclination angles and the sensor's limited temporal sampling rate. To optimize the results in future implementations, it is recommended to use smartphones with higher sensor sampling rates, minimize track friction, and adjust the LED spacing to ensure adequate data capture.

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