European Journal of Applied Sciences – Vol. 13, No. 03
Publication Date: June 24, 2025
DOI:10.14738/aivp.1303.18981.
Chaudhary, V., Singh, I., & SIngh, N. (2025). Refining Gravity Estimation in the Simple Pendulum Experiment using Microcontroller. *European Journal of Applied Sciences*, Vol - 13(03). 435-443.

Refining Gravity Estimation in the Simple Pendulum Experiment using Microcontroller

Varsha Chaudhary
Department of Electronics, SGTB Khalsa College,
University of Delhi, Delhi – 110007

Inderpreet Singh*
Department of Electronics, SGTB Khalsa College,
University of Delhi, Delhi – 110007

Nimmi Singh
Department of Physics, SGTB Khalsa College,
University of Delhi, Delhi - 110007

ABSTRACT

The simple pendulum is a basic experiment performed in undergraduate laboratory to determine the value of acceleration due to gravity 'g' by studying simple harmonic motion. The experiment requires continuous monitoring of the pendulum oscillations to measure its time-period with the help of a stop watch. This task, though simple, becomes cumbersome when the students are asked to take several numbers of readings to decrease random error. In this work, we have automated this experiment with the help of a light dependent resistor (LDR), laser light and microcontroller, Arduino. For this purpose, a voltage divider circuit is designed using LDR (with aperture pointed by a laser light). This setup is kept across the pendulum bob so that bob can block the light from laser to reach LDR. The LDR is then connected to analog pin of the Arduino to record voltage across it. When the pendulum begins oscillations, the laser beam is blocked by the bob at regular intervals of time and voltage across the LDR also varies with it. By measuring this change in voltage, the controller is programmed to measure the time-period of the oscillations. By programming, we have been able to take large number of readings. The readings obtained by this setup are observed to be more accurate and precise as compared to the manual readings. Manually the value of 'g' is found to be 10.31 ± 1.03 m/s^2 but with Arduino setup it was observed to be 9.77 ± 0.006 m/s^2.

Keywords: Pendulum, Sensors, Automation, Microcontrollers.

INTRODUCTION

A simple pendulum is a setup where a weight is suspended from a shaft, kept at some height, with the help of a massless string (Fig 1). The arrangement is such that the mass (henceforth called bob) is able to swing freely in the air when displaced from its resting equilibrium position. Under this condition, the only force acting on the bob is the force exerted by the acceleration due to gravity 'g'. Under the influence of restoring force exerted by gravity, the bob swings back and forth about the mean position. Time taken by the bob to swing from extreme left position to the extreme right and then back to the left position is known as the time period (T) of the pendulum. In this situation, the pendulum is known to set in an oscillatory harmonic motion. The time period of this harmonic motion depends upon length of the string (L), acceleration due to gravity (g) at that place and upon the maximum angle that the pendulum swings away from the mean position [1]. However, the dependence on the angle diminishes if the initial displacement is made at small angles [2]. In our earlier work [3], we have shown that below 12°, the pendulum exhibits simple harmonic motion independent of the angle of displacement. Thus, time period of the pendulum is solely determined by length of the string and acceleration due to gravity. This property makes pendulum useful in time keeping applications [4]. Also, if the value string length is known then the experiment can be used to compute the value of acceleration due to gravity at a surface.

The simple pendulum is introduced to undergraduate students, as a basic experiment, in Physics laboratory to determine the value of acceleration due to gravity. The students need to set the pendulum in oscillatory motion and then record the time period of the pendulum using a stop watch. The expression for the oscillatory pendulum motion can be derived from motion of equation as follows

The equation of motion is given by

$$F = m.a \tag{1}$$

where 'F' is the exerted force, 'm' is mass of the object and 'a' is acceleration produced. In the present case, net force exerted on the bob is $mg\ sin(\theta)$, where 'θ' is the angle between extreme and equilibrium positions of the thread and the acceleration is in the angle. The acceleration in our case is in the arc exerted by the angle 'θ'. The arc can be approximated by Lθ, where L is the length of the pendulum. The expression (1), thus, reduces to

$$-mg\ \sin(\theta) = mL\frac{d^2\theta}{dt^2} \tag{2}$$

For small angles $sin(\theta) \approx \theta$ and the equation (2) reduces to

$$mL\frac{d^2\theta}{dt^2} = -mg\theta \tag{3}$$

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\theta = 0 \tag{4}$$

Comparing this equation with second order differential equation for simple harmonic motion.

$$\frac{d^2\theta}{dt^2} + w^2\theta = 0 \tag{5}$$

where 'w' is the frequency of the oscillatory motion. The value of 'g' can be calculated using the following relation

$$T = 2\pi\sqrt{\frac{L}{g}} \quad (6)$$

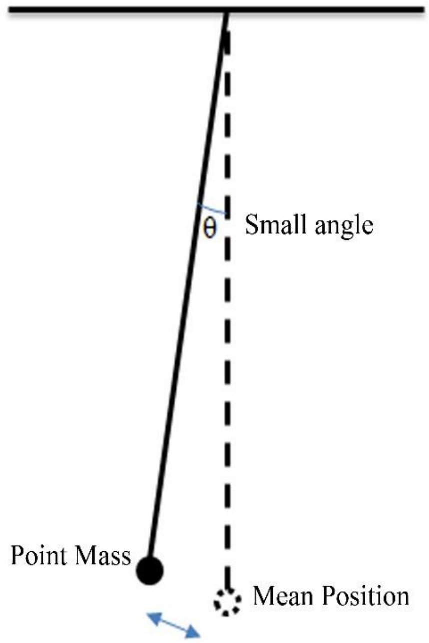

Fig 1: A simple pendulum.

The two most important requirements for this experiment to work properly are (a) point mass and (b) small angle of oscillation. The dimension of the bob suspended from a support using string should be much smaller than the length of the string to satisfy the condition of point mass. If this condition is not satisfied then the value of 'g' obtained by the experiment will not be in agreement with the true value i.e. 9.8 m/s^2. For setting the pendulum in oscillatory motion, the bob of the pendulum should be held at a position slightly away from the rest position so that the angle of displacement is very small. This is due to the fact that only at small angles the arc of the circle can be approximated by a straight line and thus the motion of pendulum can be approximated as linear motion.

Even after careful consideration of these two requirements, the value of 'g' obtained by the students performing the experiment in laboratory is not accurate. Even the precision in the values of 'g' determined by taking multiple values of time period is not good and the standard deviation in the data is substantial. This is due to the random errors which are attributed to the incapability of humans in pressing the stop watch switch exactly at the time as the bob crosses the equilibrium position. The person observing the pendulum motion should be steady and fully focused on the motion of bob. But there are limitations on how much a person can focus on the motion of bob and press the stop watch timer together. In addition to this, the least count of the stop watch available in undergraduate physics laboratories also determines the accuracy in the estimation of the value of acceleration due to gravity.

Therefore, there will always be an error in the value of 'g' obtained by this experiment.

To eliminate the human error, we have automated this experiment with the help of microcontroller Arduino Uno and sensors. For this purpose, a setup comprising of light dependent resistance (LDR) and laser is made. The microcontrollers operate at high frequencies using precise timing mechanisms and are, thus, capable of producing consistent and highly reliable results. The setups based on controllers are ideal for applications where high accuracy and minimum uncertainty is required.

EXPERIMENTAL SETUP

Arduino Uno

Arduino Uno is an open source micro controller board comprising of processor ATmega328P (Fig 2) [5]. It is an 8-bit processor and the board can be easily used for controlling and sensing external electronic devices. Arduino Uno board functions at an operating voltage of 5V and can be easily connected to a programming computer via USB connector. It works at a clock frequency of 16 MHz and is capable of designing a large number of embedded systems. The key reason for its popularity among the enthusiasts is its ease of use and accessibility. The Arduino Uno board is equipped with both digital and analog input/output (I/O) pins. It has 14 digital I/O pins which can be used individually or in groups to exchange (read or write) data with the external world. And for reading analog data from the external world, it includes 6 analog input pins. It also includes a 32 KB of memory for storing program code uploaded by the user. It can be programmed using open source Arduino IDE, which is freely available at the Arduino website [5]. The IDE supports, widely used, C language and includes a large collection of built in libraries for interfacing a variety of sensors, motors and display devices. It also provides on board 5V and ground pins that can be employed to power external circuits.

Arduino IDE, also, provides a built in feature called serial monitor that can be used to send and receive data between Arduino Uno and the connected computer. This tool is very useful in debugging program errors, monitoring sensor values and interacting with the controller in real time. Using the built in library for serial monitor, a separate window can be opened on the connected computer that displays real time readings. In addition to this a serial plotter is also available in Arduino IDE that can be used to visualize the numeric values of the data with time in graphical format.

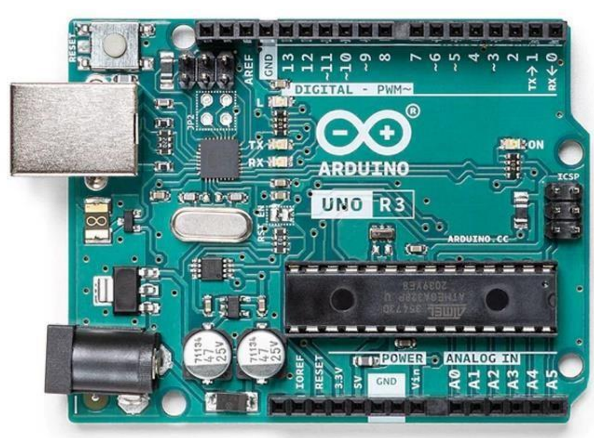

Fig 2: Atypical image of Arduin Uno Microcontroller board [5].

In the present work, we have used analog pin A0 of the Arduino Uno to read the value of voltage from an external circuit. The change in the values of voltage read by the analog pin were used to determine the time period of the pendulum and the same were displayed on the serial monitor at regular intervals of time. The data obtained from the serial monitor was then copied to the MS Excel files for further analysis.

Laser

A laser is an electronic device that emits light in the form of a focused beam. Unlike LEDs or light bulbs it is monochromatic, directional and coherent [6]. The narrow beam of light produced by laser is useful in many instruments and technologies. It is used for precise sensing and reading when integrated in systems like laser printers, barcode scanners and medical instruments. Laser provides an accurate, directional and non contact means of communication within a system, thus, is useful in developing micro controller based projects.

In our research work, we have utilized laser as a key component of the experimental setup designed to study the simple harmonic motion of the pendulum. The laser beam is strategically positioned to point at the mean or equilibrium position of the pendulum bob. This placement ensures that the laser serves as a precise reference point for detecting the motion of the bob as it oscillates back and forth.

Light Dependent Resistor (LDR)

LDR is a variable resistance that has the ability to change its resistance depending upon the intensity or amount of light falling on its aperture. Thus, it can control the current flowing through an electronic circuit depending upon the light illuminated upon its aperture. This property is very useful in determining the light and dark conditions of a system. The LDRs are widely used in manufacturing of automatic night lamps and other similar applications.

In our work, we have employed LDR to detect the presence or absence of the laser beam on the other side of the pendulum bob. As soon as the oscillating bob reaches its mean position it blocks the laser beam from falling on the LDR leading to a rapid increase in its resistance value. And when the bob is away from the mean position, the laser beam falls on the LDR aperture. In this situation, the value of LDR resistance is considerably reduced. This variation in the value of resistance with time is used to determine the time period of the pendulum harmonic motion.

Experimental Setup

The materials required for the setup namely resistors, LDR, laser and Arduino Uno microcontroller were taken from the Electronics Laboratory of our college. A potential divider circuit is designed on bread board by connecting a standard 10 K ohm resistor and LDR in series. To read the voltage across the 10 K ohm resistor, it is connected to the A0 analog pin of the board. The circuit is powered through 5V and ground pins of the Arduino Uno. The circuit diagram designed is as shown in Fig 3. The laser light is then pointed at the LDR aperture due to which, the resistance of the LDR changes. This, in turn, results in the change in voltage across the10 K ohm resistor in the potential divider circuit. Thus, the presence and absence of laser light on the LDR aperture can be observed by the change in voltage at the A0 analog pin of the Arduino Uno board.

The laser and LDR setup is kept across the pendulum bob so that bob can block the light emitted by laser to reach LDR. As the bob is set in harmonic motion it tends to oscillate about the mean position. When the bob is away from the mean position laser light points to the LDR and its resistance decreases. This decrease in LDR resistance is reflected by an increase in voltage across the 10 K ohm resistor of the potential divider. A corresponding change in the value of voltage at A0 analog pin reflects this change to the Arduino Uno. A schematic diagram of the experimental setup is shown in Fig. 4. During oscillations, the laser beam is blocked by the bob at regular intervals of time and voltage across the LDR also varies with it. By measuring this change in voltage, the controller is programmed to measure the time-period of the oscillations and in turn, the value of 'g' is calculated.

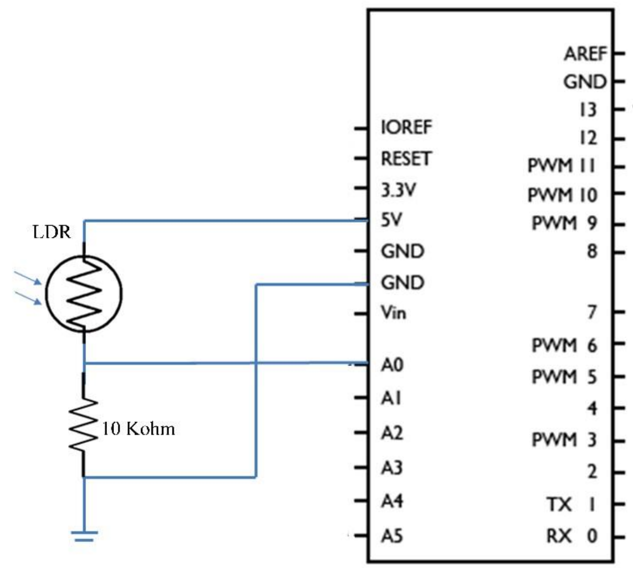

Fig 3: Circuit diagram of the setup.

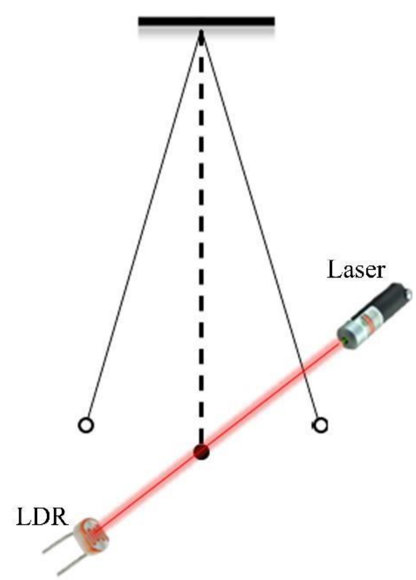

Fig 4: Schematic diagram of the experimental setup.

For comparison, the value of ‘g’ has been calculated using two different methods: a manual approach and an automated approach utilizing the Arduino Uno based experimental setup. The goal of this comparison is to analyse the accuracy and precision of each method and to determine the extent of errors involved in manual calculations versus those obtained using the microcontroller-based system. The variation in the values of ‘g’ obtained from 30 different sets of readings in both cases is illustrated in Fig. 5. The data used in the figure is shown in Tables 1 and 2. The graphical representation provides insight into the nature of errors introduced by human intervention while measuring the time period of the pendulum’s oscillations.

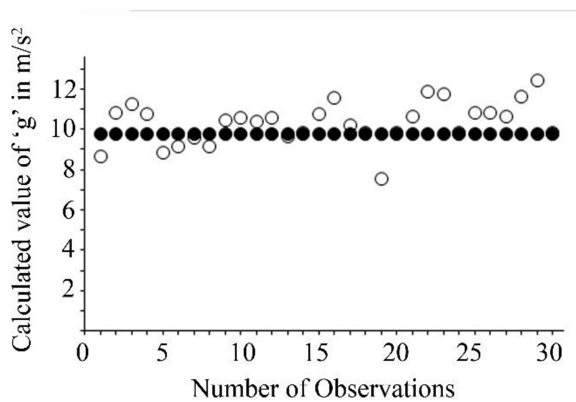

Fig 5: Variation in value of ‘g’ obtained manually (hollow circles) and using Arduino (solid circles).

Table 1: First 30 sets of the recorded values of Time Period and the corresponding value of ‘g’ determined manually using stop watch, and automatically using Arduino Uno.

S No	Manually using Stop Watch		Automatically using Arduino Uno	
	Time Period (in sec)	g (m/s^2)	Time Period (in milli sec)	g (m/s^2)
1	2.34	10.01	2370	9.76
2	2.34	10.01	2368	9.78
3	2.39	9.60	2369	9.77
4	2.16	11.75	2367	9.78
5	2.26	10.73	2369	9.77
6	2.30	10.36	2369	9.77
7	2.26	10.73	2368	9.78
8	2.34	10.01	2368	9.78
9	2.34	10.01	2369	9.77
10	2.19	11.43	2368	9.78
11	2.26	10.73	2368	9.78
12	2.23	11.02	2368	9.78
13	2.24	10.93	2369	9.77
14	2.30	10.36	2367	9.78
15	2.40	9.52	2370	9.76
16	2.36	9.84	2368	9.78
17	2.27	10.64	2368	9.78
18	2.43	9.28	2368	9.78
19	2.25	10.83	2369	9.77

20	2.04	13.17	2368	9.78
21	2.25	10.83	2368	9.78
22	2.23	11.02	2368	9.78
23	2.27	10.64	2368	9.78
24	2.47	8.99	2368	9.78
25	2.65	7.81	2368	9.78
26	2.45	9.13	2368	9.78
27	2.25	10.83	2369	9.77
28	2.43	9.28	2367	9.78
29	2.54	8.50	2369	9.77
30	2.18	11.54	2367	9.78

The variation in the recorded values, observed in manual readings, is due to the human reaction time and the inherent limitations of manually operated devices. The spread in the manually obtained values of 'g' indicates the presence of random errors, which are attributed to the inconsistency in starting and stopping the stopwatch precisely at the right moments. Such errors arise due to variations in human response time and hand-eye coordination, which can lead to discrepancies in measurements. Consequently, the average value of 'g' determined through the manual method is 10.31 ± 1.03 m/s^2. The significant standard deviation suggests that the manual method introduces considerable uncertainty into the measurements.

Additionally, the presence of an absolute error of approximately 0.5 m/s^2 (10.3 – 9.8) in the manually obtained value of 'g' further highlights the limitations of human-dependent measurements. This absolute error is a direct consequence of human limitations in timing accuracy and precision, as well as possible parallax errors while observing oscillations. Since random errors are unavoidable in manual experiments, the results obtained using this approach lack consistency, leading to relatively lower reliability when compared to automated systems. On the other hand, when the Arrduino Uno based setup was employed for measuring the time period of the pendulum, a significant improvement in precision was observed. The value of 'g' determined using the microcontroller-based setup is found to be 9.77 ± 0.006 m/s^2. In contrast to the manually obtained results, the standard deviation in this case is extremely small, indicating minimal fluctuations in recorded values. The absolute error associated with the Arduino-based measurements is only about 0.03 m/s^2 (9.8 – 9.77), which is significantly lower than the error present in the manual method. This remarkable reduction in error underscores the advantage of using automated systems over manual techniques for precise scientific measurements.

Table 2: Comparison of values obtained in manual and automated setups.

	Acceleration due to gravity 'g'	**Absolute Error**	**Standard Deviation**
Manual setup	10.31	0.51	1.03
Automated setup	9.77	0.03	0.006

The key advantage of employing microcontrollers in physics experiments, such as the Arduino Uno, is their ability to eliminate random errors, which are common in human-operated experiments. The implementation of an Arduino Uno based setup for studying simple harmonic motion has additional benefits. It provides an affordable and efficient alternative to traditional manual methods, making it a valuable tool for educational and research purposes. The use of sensors and microcontrollers allows real-time data collection and analysis, reducing the time required for experiments while increasing the accuracy of results. This approach can be extended to other physics experiments, offering students and researchers a reliable means of studying various phenomena with improved precision.

CONCLUSIONS

A simple yet effective experimental setup has been designed and implemented to study the simple harmonic motion of a pendulum. The setup primarily comprises of an Arduino Uno microcontroller, which serves as the central processing unit to record and analyze the oscillatory motion of the pendulum. A Laser and LDR have been employed as sensing components to accurately measure the time period of the pendulum's oscillations. The system functions by detecting the periodic interruptions of the laser beam caused by the motion of the pendulum, thereby allowing precise determination of the time interval between successive oscillations. The experimental results obtained using this setup have been analyzed and compared with manually recorded values to assess the accuracy and reliability of the system. The value of the acceleration due to gravity ('g') determined using the Arduino-based setup is found to be 9.77 ± 0.006 m/s^2, which demonstrates a high degree of accuracy and precision. In contrast, the manually obtained value of 'g' is 10.31 ± 1.03 m/s^2, indicating a relatively larger uncertainty and deviation from the expected theoretical value. The comparison suggests that the automated setup significantly improves measurement accuracy while minimizing human errors.

Overall, the present work highlights the effectiveness of using an Arduino-based system for studying simple harmonic motion. The proposed setup not only provides a cost-effective and user-friendly approach to measuring the time period of a pendulum but also offers a more reliable method for determining the value of 'g' with greater precision. Such an experimental arrangement can be widely adopted in educational and research environments to enhance the understanding of fundamental physics concepts related to oscillatory motion.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Kleppner, D., Kolenkow, R.: An Introduction to Mechanics. 2nd edn. Cambridge University Press, London (2014).
2. Poynting, J., Thompson, J.: Textbook of Physics. Vol. I Charles Griffin and Co., London (1907).
3. Singh, I., Arun, P., Lima, F.: Fourier analysis of nonlinear pendulum oscillations. Revista Brasileira de Ensino de Fisica 40(1), e1305 (1-4) (2018).
4. Agnew, D.: Time and tide: pendulum clocks and gravity tides. History of Geo and Space Sciences 11, 215224 (2020).
5. Arduino Homepage, https://www.arduino.cc, last accessed 2025/03/05.
6. Ghatak, A., Thayagarajan, K.: Optical Electronics. Cambridge University Press, London (1989).
7. Electronics For You, https://www.electronicsforu.com/technology-trends/learn-electronics/ldr-lightdependent-resistors-basics, last accessed 2025/03/05.