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Simple harmonic motion studied on spring-mass system using Phyphox application

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Abstract

Simple harmonic motion experiments have been conducted using a smartphone-based spring-mass system with the Phyphox application. This research aims to investigate the relationship between the mass of an object and the period and frequency of oscillations and determine the spring constant using smartphone-based experimental equipment. The method uses the "spring" feature in the Phyphox application to visualize oscillatory movements in real-time and measure the period and frequency of oscillations. The experimental results show that the spring constant obtained from the smartphone-based experiment is 9.51 N/m, with a difference of 1.25% compared to the Hooke's Law experimental setup with the conventional method. This shows that using a smartphone-based experimental setup can be a better alternative for conducting physics experiments requiring high accuracy.

Keywords: simple harmonic motion, smartphone, Phyphox app, physics experiments, spring constant.

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I. Introduction

The quality physics learning process emphasizes a scientific approach as an effort to understand a physical concept through hand-on activities and mind-on activities. The scientific approach can be realized through demonstration activities and physics experiments. Experiments have a very important role in the physics learning process because students have the opportunity to build their knowledge through direct experience [1], [2]. Experimental-based physics learning allows students to hone high-level cognitive abilities, cultivate scientific attitudes, and practice scientific skills [3]–[5]. Experimental activities lead students to design experiments, classify various experimental variables, observe changes in physical phenomena, measure physical quantities, collect data, make data tabulations, analyze data, make mathematical formulations based on the data obtained, and report experimental results [2], [6], [7]. Experimental activities also encourage students to conduct investigations, appreciate facts, be open-minded, collaborative, and sensitive to the surrounding environment so that it has an impact on increasing conceptual understanding, critical thinking skills, and developing creativity in problem-solving [4], [8]. In addition, physics experiments can increase students' interest and motivation in mastering concepts so that they have a positive impact on learning outcomes [9].

Advances in science and technology nowadays bring a new paradigm to conducting physics experiments. Various digital devices and applications based on Information Technology (IT) have been developed to streamline the learning process in the classroom as well as experimental activities that were previously difficult to do. The use of digital technology in the learning process can make the learning process run continuously without the limits of space and time. One form of digital technology that has developed and has many benefits as a learning medium as well as a physics experimental device is a smartphone. Smartphones are a supporting tool for conducting experiments both in the laboratory and at home with high accuracy [10]. Smartphones have many embedded sensors to measure various physical quantities such as temperature sensors, pressure sensors, light sensors, magnetic sensors, acceleration sensors, gyroscope sensors, sound sensors, and proximity sensors [11]–[13]. Smartphones play an important role in increasing students' interest and motivation toward physics concepts, facilitating various calculations and measurements, reducing data acquisition, and time required to conduct experiments [14]. In addition, the use of smartphones also offers the possibility to implement activities such as laboratories during self-study time and focus students on the problem solving process [15].

Smartphone-based applications have been developed to take advantage of the internal sensors embedded in smartphones. One of the applications developed to utilize the internal sensors in smartphones in conducting various physics experiments is Phyphox. Various advantages obtained from experiments using smartphones, among others: low cost, high accuracy, can be done outside the classroom/anywhere, and open up opportunities for various innovations for users who carry out experiments [16], [17]. The Phyphox application has two advantages in conducting physics experiments, namely providing remote data access and providing analysis data in the form of graphs in real-time [18]. Various physics experiments have been carried out using the Phyphox application, including straight motion [19], free-fall motion [20], circular motion [21], momentum, collision, and energy [22], frictional force on inclined planes [23], the moment of inertia [24], oscillatory motion in a simple pendulum system [25], and sound interference [26]. In addition, Phyphox is ideal for project-oriented learning. The combination of Phyphox and microcontroller/arduino-based sensor modules also offers a unique way to integrate with STEM disciplines [27], [28].

Simple Harmonic Motion (SHM) in a spring-mass system is one of the fundamental topics in physics learning. Improving conceptual understanding of this material requires demonstration and experimentation. Physics experiments are needed to visualize and measure changes in physical quantities during an object experiencing oscillatory motion. However, in the learning process, oscillatory motion experiments are still carried out using manual equipment such as rulers and stopwatches so the measurement accuracy is low [29], [30]. This problem has been overcome through various studies to create an automatic and digital experimental setup by utilizing electronic devices such as sensors, microcontrollers/ arduino, and computers [29], [31]–[33]. In addition, an SHM experimental setup on a spring-mass system has been carried out using a light intensity sensor on a smartphone [34]. However, these experimental setups have two drawbacks, namely: (1) additional knowledge of programming and electronic circuits are required, and (2) additional time and data analysis are required as well as software assistance to determine certain variables in oscillatory motion. In addition, a simple harmonic motion experiment setup on a spring-mass system utilizing the Phyphox application has been carried out [35]. However, the analysis carried out has not provided an overview of the accuracy and precision of the experimental results in determining the value of the spring constant. Therefore, this study was conducted with the objectives of, among others: (1) visualizing the oscillatory motion in a spring-mass system in real-time, (2) investigating the relationship between variables in oscillatory motion, and (3) determining the spring constant and comparing the results obtained by measuring through Hooke's law experimental setup.

The urgency of using this application in simple harmonic motion practicum lies in its ability to increase the precision and accuracy of measurements, which are needed in physics practicum. This helps produce more reliable data and facilitates a better understanding of physics concepts through interactive data visualization.

Hooke's Law

If a spring is placed on a stand then a load is hung as shown in Figure (1). Hanging objects will become a tensile force causing the spring to increase in length. When the spring is pulled by gravity and increases in length, a restoring force acts on the spring which is opposite to the direction of the tensile force. Mathematically the restoring force is written in the form of an equation:

$$F_p = -k\Delta y \tag{1}$$

with F_p is a restoring force (N), k is spring constant (N/m), and Δy is the increase in the length of the spring (m). The minus sign in Equation 1 indicates the direction of the restoring force is opposite to the direction of the tensile forces. Equation 1 is generally known as Hooke's law. If the mass-spring system in Figure 1 is in equilibrium, Newton's first law will apply, namely:

$$\sum F_y = 0$$
$$mg = k\Delta y$$
$$k = \frac{mg}{\Delta y} \quad (2)$$

where m is the mass of the object (kg) and g is the acceleration due to the earth's gravity with a theoretical value of 9.8 m/s^2 [20].

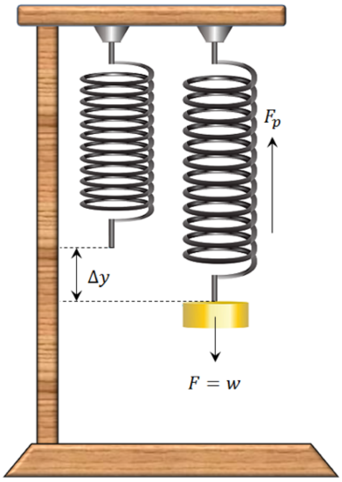

Figure 1. Spring-mass system and the forces acting.

SHM on Spring-Mass System

Suppose the spring-mass system as shown in Figure 1 oscillates so that the displacement of the object is y, then the restoring force is proportional to the force to accelerate the object's motion so that it can be written as:

$$\frac{d^2y}{dt^2} + \frac{k}{m}y = 0 \quad (3)$$

Assuming $\omega^2 = k/m$, then Equation 3 will be rewritten as:

$$\frac{d^2y}{dt^2} + \omega^2 y = 0 \quad (4)$$

The general solution of Equation 4 is obtained by the equation:

$$y = Ae^{i\omega t} + Be^{-i\omega t} \quad (5)$$

By using the concept of complex numbers, Equation 5 is written as:

$$y = c_1 \sin \omega t + c_2 \cos \omega t \quad (6)$$

It is also known that the trigonometric identity $\sin(\omega t + \gamma) = \sin \omega t \cos \gamma + \sin \gamma \cos \omega t$, where γ is a constant, then Equation 6 can be written as:

$$y = c \sin(\omega t + \gamma) \quad (7)$$

In the case of the oscillation of the spring-mass system, the variable c is the maximum deviation (m) and γ is the initial phase, so Equation 7 can be written in the form of a vibration equation that we generally know, namely:

$$y(t) = A \sin(\omega t + \varphi_0) \quad (8)$$

where ω is angular frequency (rad/s), t is oscillation time (s), y is deviation (m), A is maximum deviation or amplitude (m), and φ_0 is the initial phase (rad). It is also known that $\omega^2 = k/m$ and $\omega = 2\pi/T$, where T is the period of oscillation, can be written that:

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{9}$$

While the oscillation frequency *f* will be written in the form of an equation:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{10}$$

From Equations 9 and 10, the relationship between the period and the frequency of oscillations is obtained, which is written in the form of an equation:

$$T = \frac{1}{f} \tag{11}$$

If an SHM experiment is carried out to measure the value of the spring constant, it can be determined from Equation 9 and written in the form of an equation:

$$k = \frac{4\pi^2 m}{T^2} \tag{12}$$

In addition, to state the accuracy of the experimental results by comparing these two measurement results than the state in the form of equation [33]:

$$\%\,\text{Difference} = \frac{|\text{Difference of the two values}|}{\text{Average of two values}} \times 100\% \tag{13}$$

II. Methods

Tools and Materials

The tools and materials used in this experiment include a stand, smartphone, laptop, scales, ruler, paperclip and weights. The smartphone is used as a device to measure period, frequency, and deviation changes with time. The spring used has an initial length of 6.4 cm. Period and frequency were measured with an accuracy of 0.01 s and 0.01 Hz, respectively. The laptop is used as a display to display oscillations in the sinusoidal form in real-time as well as the results of the measurement of the period and frequency of the oscillations. The scale is used to measure the mass of objects with an accuracy of 0.01 gr. Whereas the ruler is used to measure the length of the spring with an accuracy of 0.1 cm.

Experimental Setup

The experimental setup of Hooke's law on a spring-mass system is shown in Figure 2a. This experimental setup consists of a stative, a spring, and a load. The working principle of this experiment is that the mass of the object is varied and the change in the length of the spring is measured using a ruler to determine the spring constant. Measurements are made when the spring-mass system is at rest/static. While the experimental setup of SHM on a smartphone-based spring-mass system using the Phyphox application is shown in Figure 2b. This experimental setup is capable of measuring and visualizing oscillatory motion in real-time. Smartphones are part of the experimental setup, so other devices such as laptops/PC are needed to display the measurement results. In addition, the measurement can be controlled via a laptop so that it does not interfere with the oscillating motion of the system during the measurements. Smartphone and laptop devices can be connected via remote data access by wireless. Data acquisition will be carried out by smartphones using the Phyphox application. This application works by utilizing the accelerometer sensor embedded in the smartphone.

(*a*) (*b*)

Figure 2. SHM experimental setup on a spring-mass system (a) Hooke's law experimental setup (b) smartphone-based experimental setup using the Phyphox application

Data Collection

The variables that were directly measured from these two experiments were the mass of the object, the length of the spring, the period, and the frequency of oscillations. While the variables that are measured indirectly, among others: are gravity, angular frequency, and spring constant. Data collection is done by varying the mass of objects so that it affects changes in spring length, period, and oscillation frequency. The springs used for both experiments are the same. Experimental data that has been collected is presented in tabulated form. In addition, this experiment will visualize the oscillation event in the form of a sinusoidal graph in real-time as shown in Figure 3.

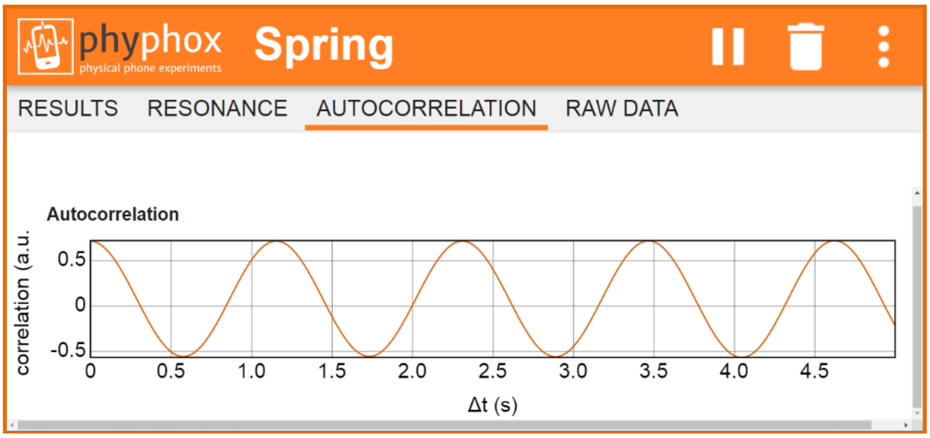

Figure 3. The results of the visualization of oscillating motion on a spring-mass system using Phyphox application

Data analysis

Data analysis in this experiment aims to determine the spring constant, determine the accuracy and precision of the measurement results, and determine the relationship between variables. Determination of the spring constant is done through mathematical calculations. Analysis of the accuracy and precision of the measurement results using an error calculation. While the determination of the relationship between variables was analyzed using regression and presented in the form of a graph.

III. Results and discussion

The results of the GHS experiment on a smartphone-based spring-mass system using the Phyphox application are shown in Figure (4). This experimental setup has several advantages, including: (1) the experimental setup is simple and easy to do by students independently, (2) data acquisition is carried out automatically by smartphones to avoid human error, (3) measurements are carried out in real-time, (4) the measurement results can be accessed by many devices so that they are effective in the learning process, (5) the measurement results are able to visualize the oscillation motion in the form of a sinusoidal graph, (6) the experimental setup is able to measure the period and frequency of oscillations directly, and (7) this experiment can be done anytime and anywhere so as to support project-oriented learning. In addition, real-time visualization of oscillating motion in the form of graphs helps students to understand the relationship between oscillatory events and mathematical formulations. The results of data acquisition presented in the form of a sinusoidal graph can help students to understand the general equations of oscillatory motion. The visualization results also make it easier to understand the parameters in the oscillating motion. This experimental setup also trains students to develop scientific skills based on the STEM approach.

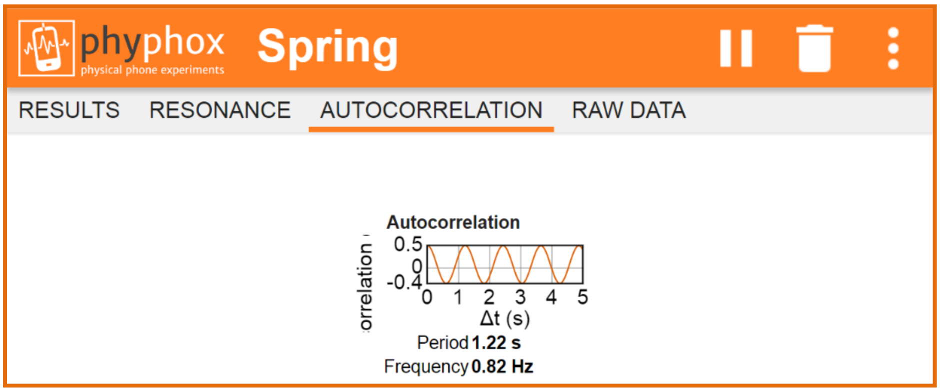

Figure 4. The results of the SHM experiment on a spring-mass system using Phyphox

Tabulation of measurement data using a smartphone-based experimental setup is presented in Table 1. Meanwhile, tabulation of measurement data using Hooke's law experimental setup is presented in Figure 5. The measurement results using a smartphone-based experimental setup show that the spring constant value obtained is 9.51 N/m. Whereas the value of the spring constant obtained from the experimental setup of Hooke's law is 9.63 N/m. The results of the measurement of the spring constant between the two experimental setups showed a difference of 1.25%. These results show that there is no significant difference so that the two measurement results can be accepted. The difference between these two small measurement results shows that the experimental setup using a smartphone and the Phyphox application has high accuracy. These results indicate that smartphones have high accuracy as a measuring tool in conducting physics experiments. In addition, the result of this study is supported by research conducted by Ref [35] who also obtained measurement results with high accuracy for the SHM experimental setup on a spring-mass system using the Phyphox application.

Table 1. SHM experimental results on a smartphone-based spring-mass system

m (kg)	T (s)	f (Hz)	ω (rad/s)	k (N/m)
0.254	1.04	0.96	6.04	9.26
0.312	1.15	0.87	5.46	9.29
0.362	1.23	0.81	5.11	9.43
0.412	1.31	0.76	4.79	9.46
0.462	1.39	0.72	4.52	9.42
0.512	1.45	0.69	4.33	9.60
0.562	1.52	0.66	4.13	9.59
0.612	1.58	0.63	3.97	9.66
0.662	1.64	0.61	3.83	9.70
0.712	1.70	0.59	3.69	9.71
			Average	9.51

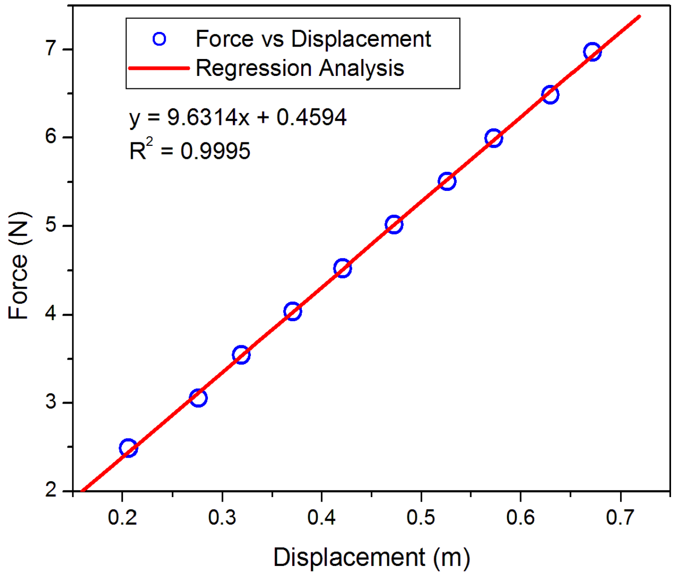

Figure 5. Graph of the relationship between force and displacement

The relationship between variables in simple harmonic motion in the case of a spring-mass system can be investigated using regression analysis. The effect of the object's mass on the period of oscillation is presented in graphical form as shown in Figure 6. The analysis regression of the experiment result is expressed in equation y = $1.9978x^{0.4752}$ with a correlation coefficient of 0.9998. This equation shows y is the period of oscillation and x is the object's mass so that the equation can be rewritten as $T = 1.9978\sqrt{m}$. The results of the regression analysis show that the period of oscillation is directly proportional to the root of the object's mass expressed in the form $T \approx \sqrt{m}$. This result is by the theoretical relationship as stated in Equation 8 that the period of oscillation is proportional to the root of the mass. The results are also supported by a study conducted by Ref [35] which also proved that the square of the period is proportional to the object's mass for SHM in the case of a spring-mass system. In addition, the experiment results of Ref [31] also show that the oscillation period is proportional to the root of the object mass for SHM in a spring-mass system. Regression analysis also shows that the 1.9978 coefficient expresses the $2\pi/\sqrt{k}$ term so that the k value is 9.88 N/m.

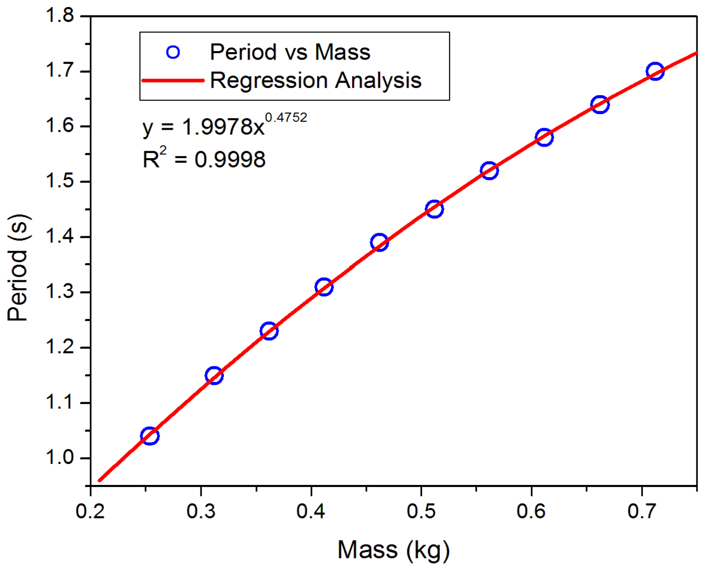

Figure 6. Graph of the effect of mass on the period of oscillation

The effect of object mass on the oscillation frequency in SHM for a spring-mass system is presented in the form of graphs and regression analysis as shown in Figure 7. The results of the regression analysis are expressed in the form of the equation $y = 0.5014x^{-0.472}$ with a correlation coefficient of 0.9997. This equation shows that y is the frequency of oscillation and x is the object's mass, so the equation is rewritten as

$f = 0.5014/\sqrt{m}$. The results of this regression analysis show that the oscillation frequency is inversely proportional to the root of the object's mass expressed in the form $f \approx 1/\sqrt{m}$. This result matches with the theoretical relationship as stated in Equation 9 that the oscillation frequency is inversely proportional to the root of the object's mass. These results are also supported by a study conducted by Ref [31] which also proved that the oscillation frequency is inversely proportional to the root of the object mass for SHM in the case of a spring-mass system. Regression analysis also shows that the coefficient of 0.5014 expresses the $\sqrt{k}/2\pi$ term so that the k value is 9.91 N/m.

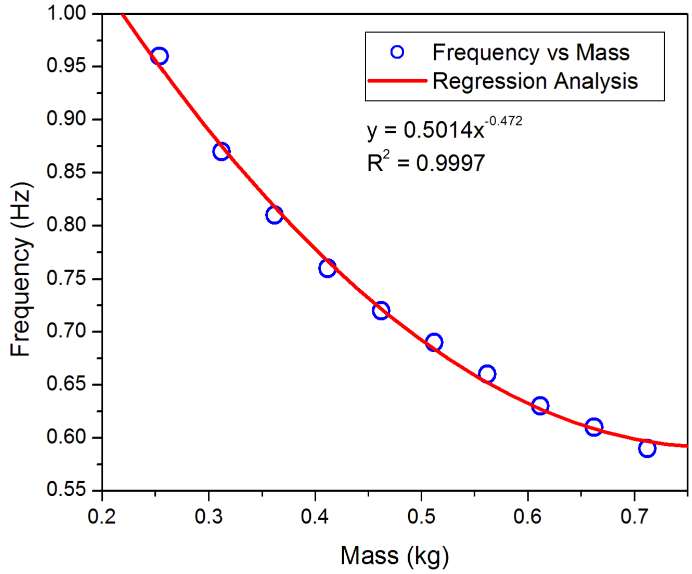

Figure 7. Graph of the influence of mass on the oscillation frequency

The relationship between the period and the frequency of oscillations was determined using regression analysis and presented in Figure (8). The results of the regression analysis are expressed in the form of the equation $y = 0.9974x^{-0.994}$ with a correlation coefficient of 0.9997. This equation shows that y is the frequency of oscillation and x is the period of oscillation so the equation can be rewritten as $f = 1/T$. These results indicate that the oscillation frequency is equal to one per oscillation period or conversely the oscillation period is equal to one per oscillation frequency. This result is in line with the theoretical relationship as stated in Equation 10 that the period of oscillation is equal to one per oscillation frequency or conversely. This result is also supported by the study conducted by Ref [31] who also found that the oscillation period is proportional to one per oscillation frequency or conversely, the oscillation frequency is proportional to one per oscillation period.

The effect of object mass on angular frequency can also be determined in this experiment using regression analysis and shown in Figure (9). The results of the regression analysis are expressed in the form of the equation $y = 3.1435x^{-0.475}$ with a correlation coefficient of 0.9998. This equation shows that y is the angular frequency and x is the object's mass so this equation can be rewritten as $\omega = 3.1435/\sqrt{m}$. This result shows that the angular frequency is inversely proportional to the root of the object's mass expressed in the form $\omega \approx 1/\sqrt{m}$. This result is in line with the theoretical analysis shown by the equation $\omega = \sqrt{k/m}$ that the angular frequency is inversely proportional to the root of the object's mass. This result is also supported by the results of a study by Taneo, *et al* (2021) who found that the angular frequency is proportional to one per mass root of the object. Regression analysis also shows that the coefficient of 3.1435 expresses the $\sqrt{k}$ term so that the k value is also 9.88 N/m.

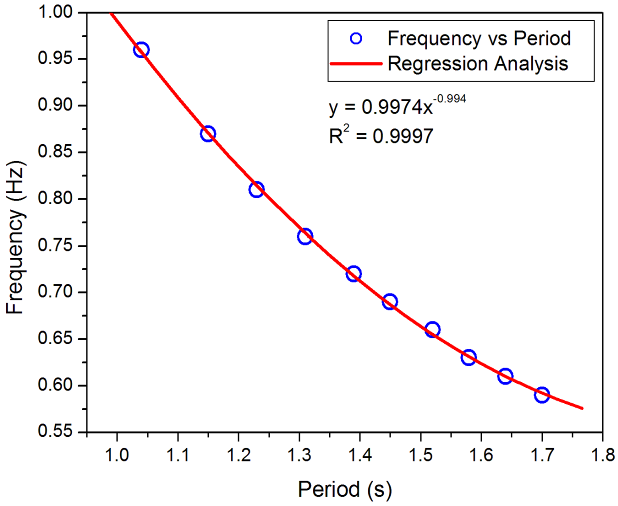

Figure 8. Graph of the relationship between the frequency and the period of oscillations

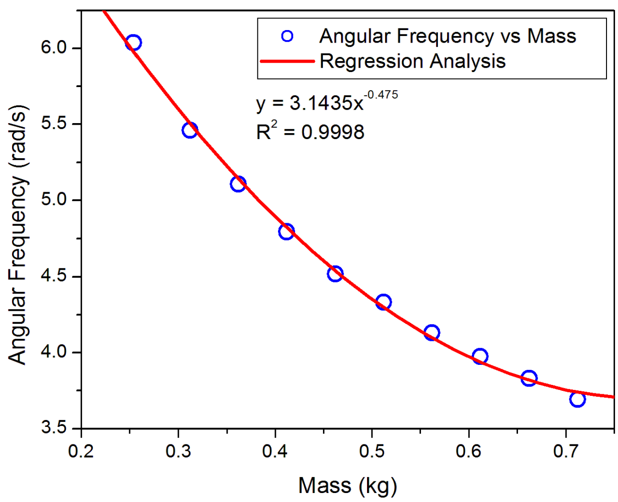

Figure 9. Graph of the effect of mass on the angular frequency of oscillation

Compared with previous research using conventional tools, this research shows several significant improvements. A study by Ref [29], which also studied simple harmonic motion using ping sensors and photodiodes, showed more significant variations in the spring constant, around 3% to 5% of the theoretical value. This shows that using internal smartphone sensors via the Phyphox application can provide higher accuracy than external sensors requiring more complex manual calibration.

Additionally, Ref [31], which uses an Arduino for similar experiments, although providing good control over experimental variables, requires additional knowledge of programming and electronic setup, which can be a barrier for educators and students with minimal technical background. Using the Phyphox app eliminates the need for such technical expertise, making it a more accessible and effective tool for teaching and learning physics.

IV. Conclusions

The use of the Phyphox application in smartphone-based spring-mass system experiments has produced accurate and efficient measurements. A spring constant value of 9.51 N/m was obtained, compared to the conventional Hooke's Law experimental setting, with a difference of only 1.25%. Moreover, the results of this study confirm that the oscillation period is proportional to the square root of the object mass, and the oscillation frequency is inversely proportional to the square root of the object mass, in accordance with the principle of simple harmonic motion. Using smartphone applications in physics experiments offers a more accurate and efficient way to collect and analyze data, which can help students understand physics concepts in more depth. In addition, using applications in physics experiments will improve the quality of the experiments and enrich the student's learning experience.

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