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Measurement of spring constant by means of arduino: A STEM teaching proposal

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Abstract: This study advances a STEM teaching proposal and aims to determine spring constant of a spring pendulum by means of an Arduino microprocessor. The measurements are managed by simply letting the spring pendulum to oscillate freely and recording the distance perceived by the distance sensor-Arduino system as a function of time. The mean periods are estimated by using displacement-time plots of the harmonic motion and the results are used to estimate the spring constant. The spring constant is also determined conventionally by employing Hooke's law a number of times. The relative error rate between the two results is found to be about % 6.00 which is pretty acceptable. This approach is important in the sense that it is inexpensive and also encourages students to learn how to use the Arduino microprocessor. The approach adds to physics education efforts due to creating an enjoyable and beneficial teaching-learning environment.
Keywords: physics education; arduino; STEM; harmonic motion; spring constant

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Introduction

Physics is a fundamental science based on observations and experimental measurements associated to understanding the natural phenomena in our universe (Serway and Jewett, 2018). The natural phenomena is generally complicated and comprehend problematic concepts and conceptual interrelations. Physics courses obviously aim to properly teach those natural phenomena with complete comprehension and ability to resolve entire concepts and topics both experimentally and theoretically (Aalst, 2000). Physics Education Research (PER) focuses on challenging and problematic concepts and laws of physics and tries to develop alternative or novel teaching materials, approaches and methods to overcome teaching difficulties (Bao and Koening, 2019; Kanim and Cid, 2020). Hence, it is obviously important to advance teaching materials and methods in accordance with the technological developments in order to improve the teaching-learning facilities.

In this context, Arduino microcontrollers emerge as an easily accessible and inexpensive electronic data collection tool that is presented by today's technologies (Erol and Oğur, 2023; Çoban and Erol, 2021). Arduino microprocessors allow the science and physics educators to design and propose almost any experiment that can measure and teach countless concepts based on available appropriate sensors. Experimental design spectrums can literally be as wide as educators' imagination due to freely availability of the required electronics connections and coding (Chaudry, 2020). According to a study conducted by Petry et al. it is both more instructive and more fun for students to study in a technology-supported environment with Arduino compared to traditional laboratory teaching approaches, specifically, 94 % of the students found it interesting to integrate the Arduino into the laboratories (Petry, Pacheco and Lohmann, 2016). In a recent study, it is also found that trying to teach physics to high school students with Arduino can change the way students view engineering and basic sciences. Accordingly, students studying with Arduino have started to develop an interest in these branches and Arduino makes physics out of the ordinary and makes it fun, interesting and instructive. (Martin-Ramos et al, 2016)

Simple harmonic motion, on the other hand, is a very special type of motion relentlessly realised within countless natural phenomena and accordingly it is very fundamental and important subject of physics (Serway and Jewett, 2018). Hence, teaching harmonic motion and relating concepts are central and ought to be designed and tackled properly. Evidently, there are numerous studies indicating student learning difficulties and misconceptions. (Tumanggor et al., 2020; Dimas et al., 2018) The spring pendulum is, on the other hand, a very simple and accessible apparatus to study and resolve the harmonic motion and has been recently resolved in a variety of methods, namely smart phones and Arduino microprocessors (Kuhn & Vogt, 2012; Çoban and Çoban, 2020; Erol, Hocaoğlu and Kaya, 2020; Pili, 2018). However, based on the previous research, it is detected that students' understanding of harmonic motion is still low and there are some misconceptions and certain teaching-learning difficulties (Wardani, 2020; Somroob & Wattanakasiwich, 2017; Janah & Mindyarto, 2021; Nugraha, Cari, Suparmi & Sunarno, 2019).

Introducing Arduino microprocessors as a part of STEM education approach is very popular and beneficial in a variety of ways and ought to be employed in teaching the harmonic motion and relating concepts. Accordingly, in this study, it is aimed to resolve the simple harmonic motion and the Hooke's law by measuring the spring constant for a spring pendulum based on a STEM teaching proposal.

Method

Experimental Setup

The objective of this work is to resolve the simple harmonic motion and to quantify the spring constant of a spring pendulum by means of an Arduino Uno microprocessor. The experimental setup mainly consists of an ordinary computer with appropriate distance sensor code loaded, an ordinary spring pendulum with different masses, an Arduino Uno microprocessor, a HC-SR04 distance sensor, a breadboard, an Arduino Uno-computer communication cable and connecting cables. The experimental set up containing all the equipment is shown in Figure 1.

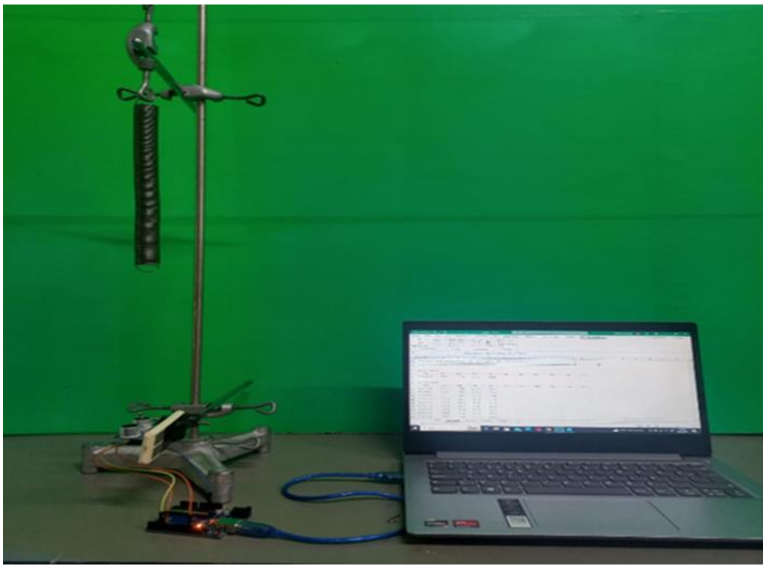

Figure 1. The photography of experimental setup showing all parts of the equipment employed to carry out the measurements

The schematic representation of the actual connections between the HC-SR04 distance sensor and the Arduino Uno is also shown in the Figure 2. The HC-SR04 distance sensor is held by a mechanical arm to keep it stable. Briefly, the HC-SR04 distance sensor provides an ultrasonic sound emission at a frequency of 40 kHz from the Trig pin and when this sound wave hits any object and returns to the sensor, the Echo pin becomes active. Arduino Uno microprocessor determines the distance of the object from the sensor.

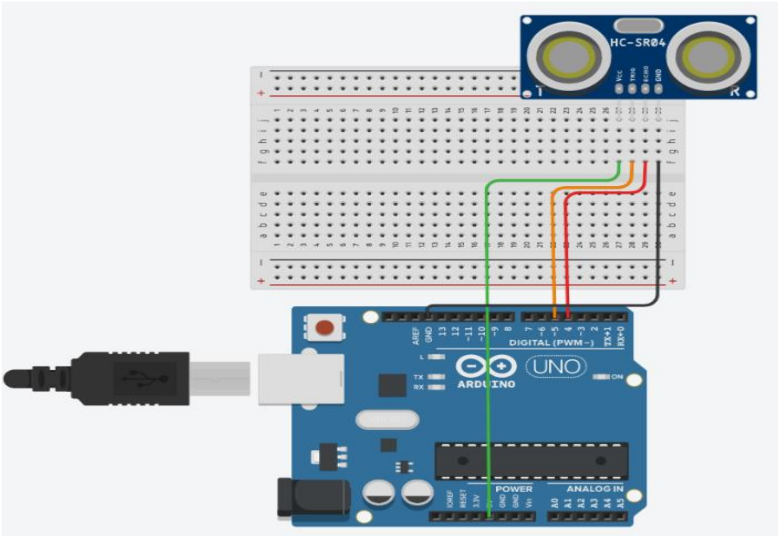

Figure 2. The schematic representation of the actual connections and wiring of the distance sensor and the Arduino Uno

Arduino Uno and the Distance Sensor

The Arduino Uno microprocessor can obviously be used for countless applications by an appropriate sensors and codes to run the system. In this case, the code is obviously and specially prepared for the HC-SR04 distance sensor. The photography of the actual wiring between the HC-SR04 distance sensor, the computer and the Arduino Uno is shown in Figure 3.

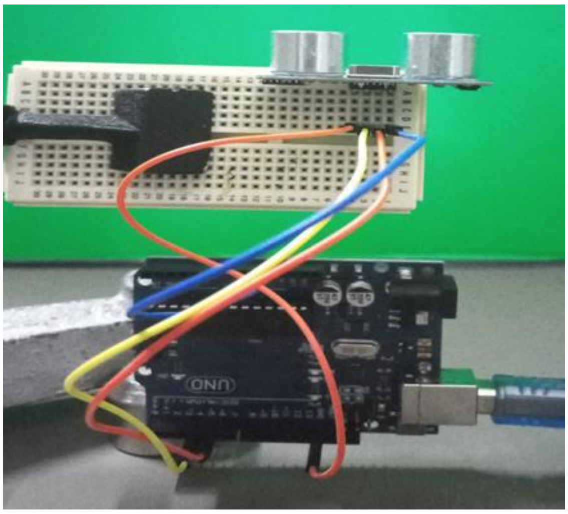

Figure 3. The photography of the actual wiring of Arduino Uno, the distance sensor and the computer

The HC-SR04 Distance Sensor Code

The actual HC-SR04 distance sensor code to run the system is prepared by the authors however it can obtained from the Arduino library (https://www.arduino.cc/reference/en/libraries/) and can be used for any Arduino project. The code is fully presented below.

```
#define trigPin 5
#define echoPin 4
longsure;
float t = millis()/1000.00;
float mesafe, a, b;
void setup () {
Serial.begin(9600);
pinMode(trigPin, OUTPUT);
pinMode(echoPin, INPUT);
Serial.println("CLEARDATA");
Serial.println("LABEL,t1,mesafe"); }
void loop() {
unsigned long t1 =millis();
digitalWrite(trigPin, LOW);
delayMicroseconds(3);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
sure =pulseIn(echoPin, HIGH);
mesafe =(sure/2)*0.0343;
b =t1;
a =b/1000;
Serial.print("DATA, TIME,");
Serial.print(a);
Serial.print(",");
Serial.println(mesafe,3); }
```

Theoretical Resolution to Measure the Spring Constant

The spring pendulum is an appropriate and simple instrument to demonstrate and teach the simple harmonic motion. The simple harmonic motion can easily be managed when a mass of m is attached to the bottom of a vertically mounted spring and if the mass is displayed from the equilibrium position by an amount of x and released then the mass of the system starts to harmonic motion ceaselessly, of course neglecting the air and contact frictions. Resolution of the motion or the oscillations is straightforward, assuming that the actual spring stays within the limits of the flexibility and also assuming the Hooke's law is obeyed, then the reciprocal force is given by Hooke's law,

$F = -kx$ and the oscillations ought to simply obey to the Newton's second law, that is, (Serway & Jewett, 2018)

$$m\frac{d^2x}{dt^2} = -kx \tag{1}$$

Knowing that the harmonic motion is described by the basic equation of,

$$\frac{d^2x}{dt^2} = -w^2x \tag{2}$$

The solution of this fundamental second order differential equation leads to the simple harmonic motion which is expressed by,

$$x(t) = A\cos(wt - \varphi) \tag{3}$$

where A denotes the amplitude of the oscillation, ω denotes the angular frequency and φ denotes the phase angle. Comparing the two fundamental equations of (1) and (2) leads to the equation of

$w^2 = \frac{k}{m}$ which now can be used to formulate the period of the oscillations that can be expressed by,

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

These expressions are obviously valid in an ideal case, in other words, the spring oscillates within the limits of the flexibility and the contact and air friction effects are negligibly small. One can smoothly resolve and test these theoretical equations by experimentally determining the actual oscillation periods and estimating the spring constants of various spring-mass systems.

Results and Discussion

Spring Constant Determined by Hooke's Law

The spring pendulum, shown in Figure 1, is sequentially equipped with the masses of 100, 150, 200, 250, and 300 grams and freely suspended from the pivot. The amount of displacement of the mass attached to the spring is carefully measured by a ruler and noted. The free length of the spring was measured as 20.0 cm and the variation of the spring elongation amount, x, as a function of the mass is given in Table 1.

Table 1. The Elongation Amounts of the Spring are Given as a Function of the Masses Attached at the Bottom of the Spring

Measurement No	m(kg)	x(cm)
1	0.10	3.9
2	0.15	5.8
3	0.20	8.0
4	0.25	9.8
5	0.30	11.8

The spring constants are calculated for each case as a function of the suspended mass and based on the values of the amount of extension of the spring. The spring constant was calculated in accordance with the Hooke's law, $\boldsymbol{F} = -\boldsymbol{kx}$, for each mass which leads to the equation (1) as the equation of motion. The results are shown in Table 2.

Table 2. The Spring Constants Calculated Based on the Elongation Amounts of the Spring

Measurement No	m(kg)	x(cm)	k (N/m)
1	0.10	3.9	25.1
2	0.15	5.8	25,3
3	0.20	8.0	24.5
4	0.25	9.8	25.0
5	0.30	11.8	24.9

Based on the values in the Table 2, the average value of the spring constant is calculated to be, $\boldsymbol{k_{av}}$= 24.96 N/m. There are some recent studies on Hooke's law resolving the harmonic motion (Menezes de Souza Lima, Venceslau & Nunes, 2002; Park & Huh, 2020; Kääntä, Kasper & Piirainen-Marsh, 2018).

Spring Constant Determined by Arduino Uno Microprocessor

Experimentally the spring pendulum, shown in Figure 1, is equipped to observe the simple harmonic motion and also to measure the spring constant of the selected spring. The spring pendulum is basically attached stiffly at the top and also suspended at bottom with the masses of 100, 150, 200, 250 and 300 grams. The displacement versus time data is obtained by means of HC-SR04 distance sensor fixed appropriately at the bottom of the spring and connected to the Arduino Uno microprocessor. The recorded data are then used to plot the displacement-time graphs for each mass case by using the EXCEL and displayed directly by the computer. The graphs are shown in the figures from 4 to 8.

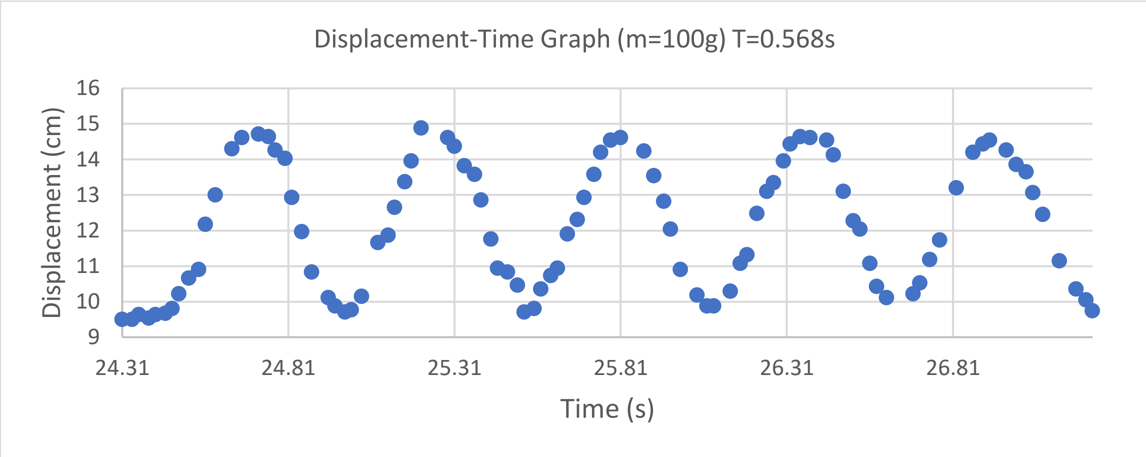

Figure 4. Displacement Versus Time Graph of the Spring-mass System Clearly Showing Simple Harmonic Motion With a Mass of m=100 g

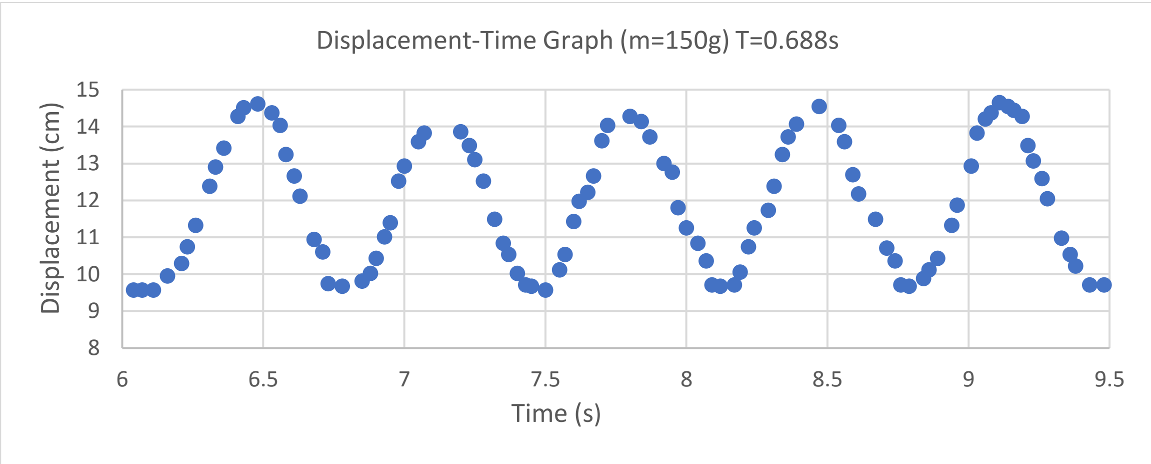

Figure 5. Displacement Versus Time Graph of the Spring-Mass System Clearly Showing Simple Harmonic Motion With a Mass of m=150 g

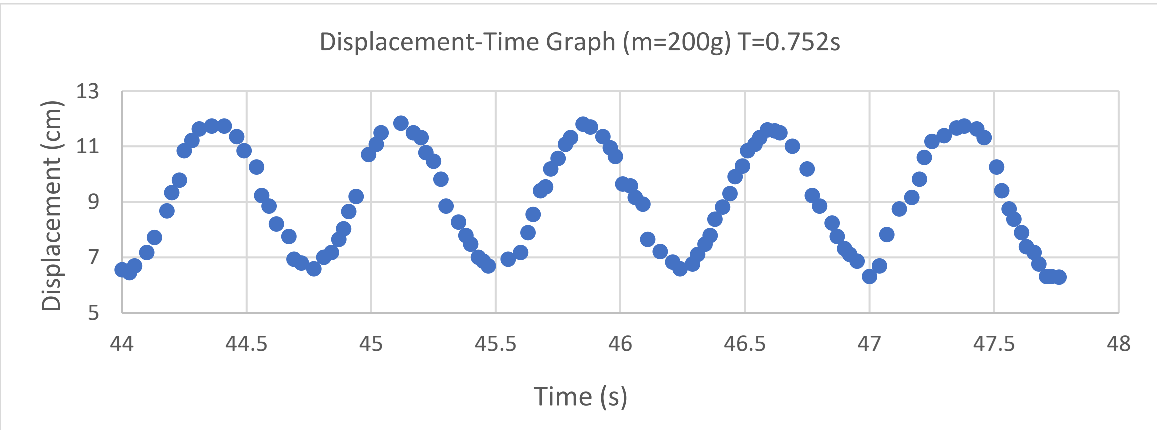

Figure 6. Displacement Versus Time Graph of the Spring-Mass System Clearly Showing Simple Harmonic Motion With a Mass of m=200 g

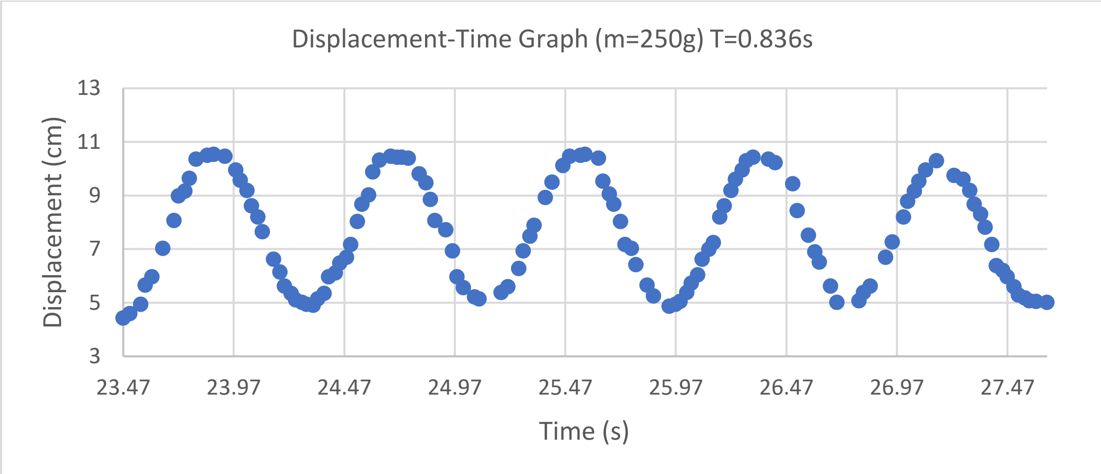

Figure 7. Displacement Versus Time Graph of the Spring-Mass System Clearly Showing Simple Harmonic Motion With a Mass of m=250 g

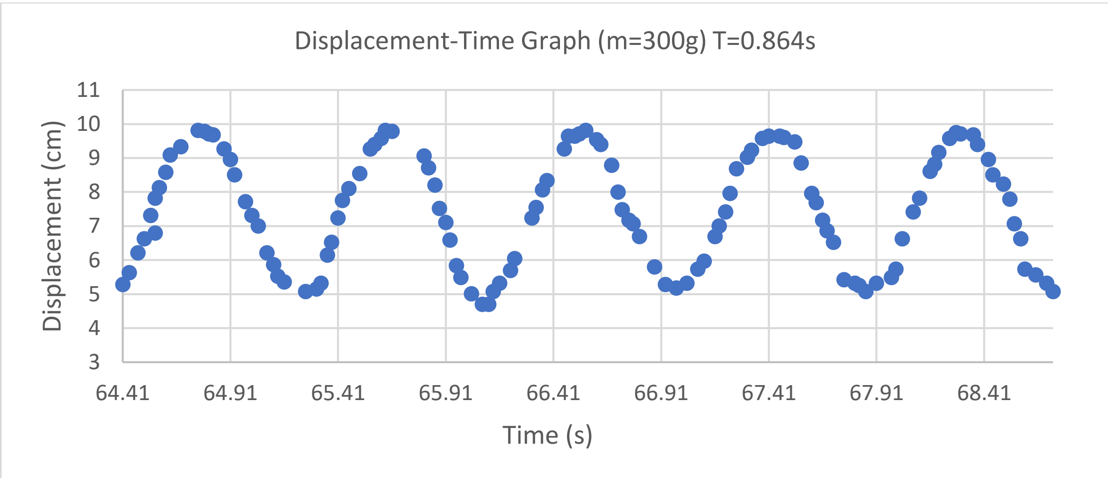

Figure 8. Displacement Versus Time Graph of the Spring-Mass System Clearly Showing Simple Harmonic Motion With a Mass of m=300 g

The average period of the harmonic motion, $\boldsymbol{T_0}$, is determined directly from these graphs, basically by reading the overall time for 5 oscillations, Δt, from the graphs and dividing the total elapsed time by the number of periods. Experimental data and calculated period values are given in Table 3.

Charts and tables must be centered. Each table or figure must be numbered. The inclusion of the table or figure must be mentioned in the sentence. The text in the table uses single spaced or single space. The table only uses horizontal lines.

Table 3. The Outcomes of the Spring Mass System, Showing the Masses, The Measurement Time Intervals for Five Oscillations and the Average Oscillation Periods

Measurement No	m(kg)	$\Delta t=5T_0$(s)	T_0(s)
1	0.10	2.84	0.568
2	0.15	3.44	0.688
3	0.20	3.76	0.752
4	0.25	4.18	0.836
5	0.30	4.32	0.864

The displacement versus time graphs are nicely demonstrating the full agreement with the equation (2) and the spring constant is then estimated based on the values of the oscillation periods and oscillation masses and in accordance with the period relation of $\boldsymbol{T = 2\pi\sqrt{\frac{m}{k}}}$. In order to find the final result of the spring constant more accurately T versus √m graph is drawn. The spring constant was found by using the slope of this graph. The T-√m graph is shown in Figure 9.

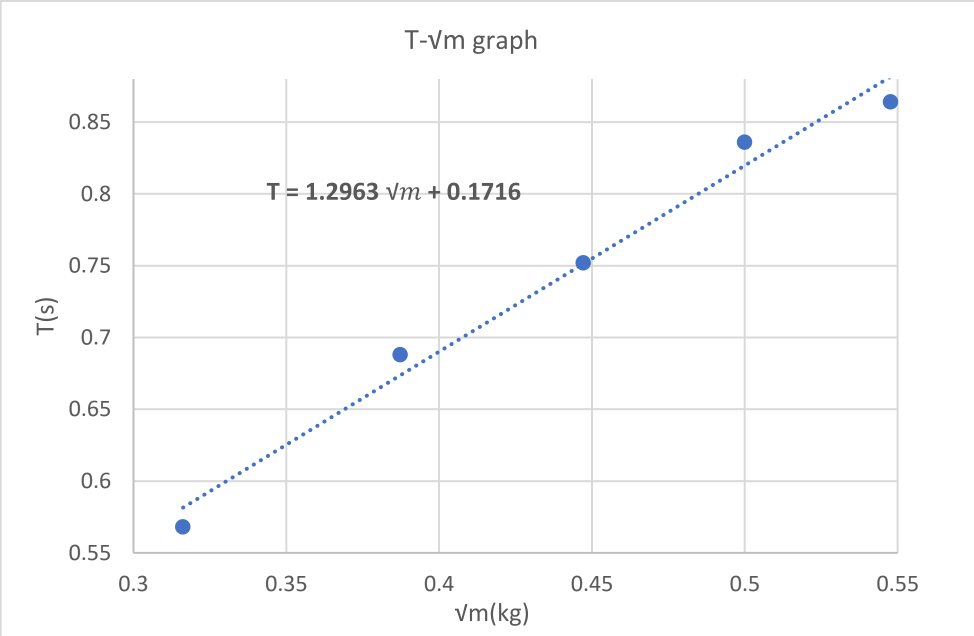

Figure 9. The Graph of Period as a Function of √m , Obviously the Slope Leads to the Spring Constant

The standard curve-fit application to the graph leads to the equation of T= 1.2963 √m+ 0.1716. Hence, it is obvious that the slope of the linear relation is found to be 1.2963. It is also obvious based on the relation of $T=2\pi\sqrt{\frac{m}{k}}$ the slope is equal to $\frac{2\pi}{\sqrt{k}}$ which leads to the final result of k= 23.46 N/m. The relative error rate between the result of the conventional method, k= 24.96 N/m, and the Arduino Uno based STEM method, k= 23.46 N/m, is about % 6.00 which is reasonable. The literature has some similar studies for the validation and resolution of the simple harmonic motion (Galeriu, Edwards & Esper, 2014; Tong-on, Saphet & Thepnurat, 2017; Buachoom, Thedsakhulwong & Wuttiprom, 2019).

Conclusion

In this study, a simple and easily accessible Arduino based STEM teaching tool has been developed and proposed in order to resolve the simple harmonic motion as well as to measure the spring constant of a spring pendulum. The approach basically employs an Arduino Uno microprocessor with a Hc-SR04 distance sensor and the Hooke's law. The measurements have clearly shown the character of the simple harmonic motion which is surely beneficial for the students. The actual data are obtained by recording the instantaneous displacement values as a function of time for various mass values. The Linear graph between the period, T, and √m is then curve fitted and the mathematical relation is estimated as, T= 1.2963 √m+ 0.1716, which straightforwardly lead to a spring constant of k= 23.46 N/m. The measurement managed by Arduino Uno is compared with the data found from Hooke's law, k= 24.96 N/m, and a very good agreement is obtained with a relative error rate of about %6.00. This approach is beneficial for physics students and teachers due to being uncomplicated and easily accessible tool in addition of providing an enjoyable educational environment.

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