Simple Harmonics Motion experiment based on LabVIEW interface for Arduino

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Abstract. In this work, we developed an affordable modern innovative physics lab apparatus. The ultrasonic sensor is used to measure the position of a mass attached on a spring as a function of time. The data acquisition system and control device were developed based on LabVIEW interface for Arduino UNO R3. The experiment was designed to explain wave propagation which is modeled by simple harmonic motion. The simple harmonic system (mass and spring) was observed and the motion can be realized using curve fitting to the wave equation in Mathematica. We found that the spring constants provided by Hooke's law and the wave equation fit are 9.9402 and 9.1706 N/m, respectively.

1. Introduction

Technology has now become very important in education for students and educators. The all in one system is needed for physics apparatus to interface with computer that provide data processing, data acquisition, control and visualization. Arduino is one of excellent microcontrollers that offer much more than a tool for making interactive projects. It is a cheap open-source electronic platform based on easy-to-use hardware and software [1]. To encourage students to understand the theory of physics, the visualized data collected during experiments can help imagine and enable them to understand the lesson [2]. For this purpose, we developed an innovative physic lab apparatus that is modern, cheap and simple to explain Simple Harmonic Motion (SHM), the spring constant (k) represented by Hooke's law and the wave equation [3]. For the case of wave equation, the position of a mass attached on a spring is presented as a function of time. A force as weight of mass is also proportional to the position. Both cases are measured using the ultrasonic sensor that shows real time data on the front panel of LabVIEW. There are many different open-source programs to visualize graphical output and perform curve fitting solution of a raw data (text) file. Then, the data must be interpreted in order to utilize meaningful information [4]. We use the Mathematica 10 for graphical visualization and curve fitting.

2. Basic concepts of spring-mass system

The oscillatory motion is a motion of an object which returns to a given position after a fixed time interval. The basic concepts of SHM are well explained in most physics textbooks [4]. The main topic of this work, we presented the method to find the spring constant, using Hooke's law and wave equation.

2.1. Hooke's law

Figure 1(a) shows the basic concept of spring-mass system given by Hooke's law. The system consists of a mass (m) attached to one end of a spring which has spring constant (k). The other end of the spring is mounted to a rigid support. The spring is stretched by a restoring force that is proportional to the position (x), therefore Hooke's law can be applied in this situation [3]. The restoring force of the SHM can be written as

$$F_s = -kx \tag{1}$$

The restoring force is a gravity force in this case, then

$$mg = -kx \tag{2}$$

2.2. Wave equation

The SHM is likely related to circular motion that can be explained by wave equation. From the equation 2, the accelerator of motion is written as the second derivative of the position with respect to time, according to

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x \tag{3}$$

In this case, we denote the constant of ratio k/m with the symbol ω^2, then

$$\frac{d^2x}{dt^2} = -\omega^2 x \tag{4}$$

The solution of displacement is a function of $x(t)$ that satisfies this second-order differential equation, and is a mathematical representation of the position of an object as a function of time. The following cosine function solution can be written as

$$x(t) = A cos(\omega t + \emptyset) \tag{5}$$

$$k = m\omega^2 = m(\frac{2\pi}{T})^2 \tag{6}$$

The constant angle ($\emptyset$) is called phase constant. (A) represents an amplitude. The displacement as a function of time graph for an object undergoing SHM is shown in figure 1(b). The experiment apparatus is designed to monitor under the both basic concepts. The spring constant will be investigated by curve fitting using Hooke's law and the wave equation.
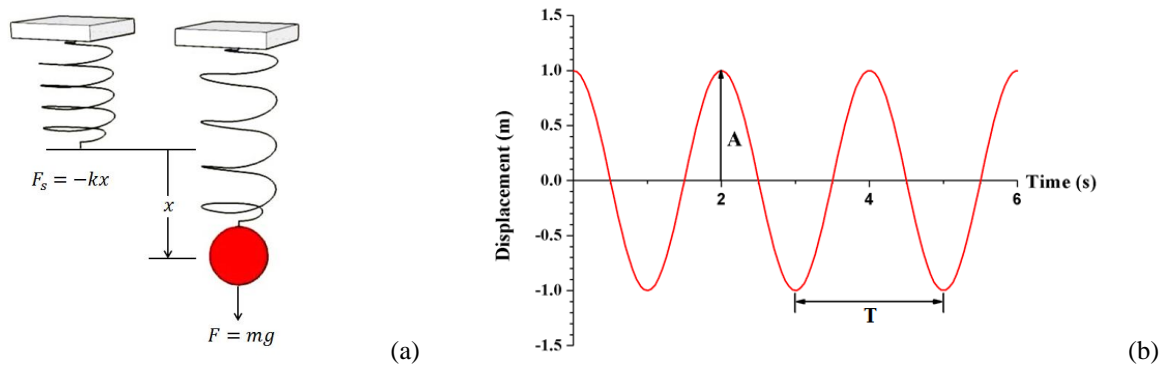
(a)

(b)

Figure 1. The basic concept of spring-mass system (a) Hooke's law (b) The displacement as a function of time graph for an object undergoing SHM (wave equation).

3. Hardware and Software preparation

3.1. Hardware

The experimental apparatus includes a microcontroller system (MCS), an ultrasonic sensor system (USS) and a spring-mass system (SMS). The MCS is a control system which consists of a 220 to 9 VAC power supply, a 9 VAC to 9 VDC circuit, a 9V cooling fan and Arduino Uno R3. In figure 2, the features are an 8-bit, 16 MHz board, a USB connection, a 9V power jack, 14 digital input/output pins (orange box) and 6 analogue input pins (green box). The Simple Harmonic Motion MCS box is shown in figure 2.

Figure 2. The microcontroller system (MCS) unit.

Figure 3. The ultrasonic system (USS) unit.

The USS, shown in figure 3, is a sensor system which consists of a HC-SR04 ultrasonic sensor containing 4 pins of 5VDC (working voltage, VCC pin, ground (GND pin), trig (Trig pin) and echo (Echo pin)). To generate eight pulses of a 40 kHz ultrasound, the trig pin is set for a high state of 10 μs and it will be received in the echo pin. After the echo signal is detected, the echo pin is reset to 0 V. The USS box is shown in figure 3. The SMS, shown in figure 4, consists of a spring, masses (made from 38.1 mm diameter cylindrical brass with two thicknesses of 0.2 and 0.4 mm related to the estimated weight of 0.017 and 0.034 kg, respectively) and a stand with clamp.
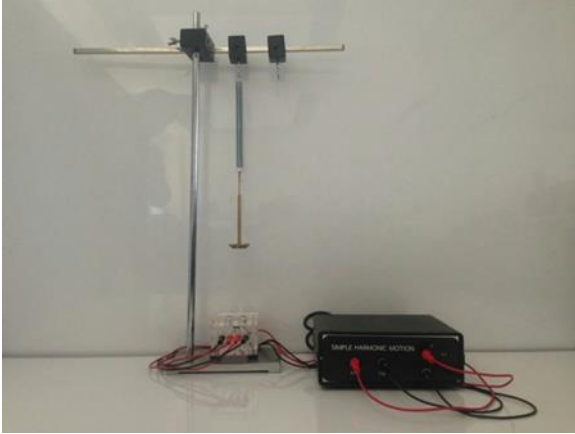

Figure 4. The experimental apparatus set up including the SMS unit.

3.2. Software

The software has been developed using LabVIEW for user interface. To communicate the HC-SR04 ultrasonic sensor with Arduino Uno R3, an easy to use add-on called LabVIEW VIs is provided by LINX for interfacing with the controller board with common embedded platforms like Arduino. The built in sensor VIs is used to access devices through the digital I/O, analog I/O, PWM, SPI, I2C, UART [5].
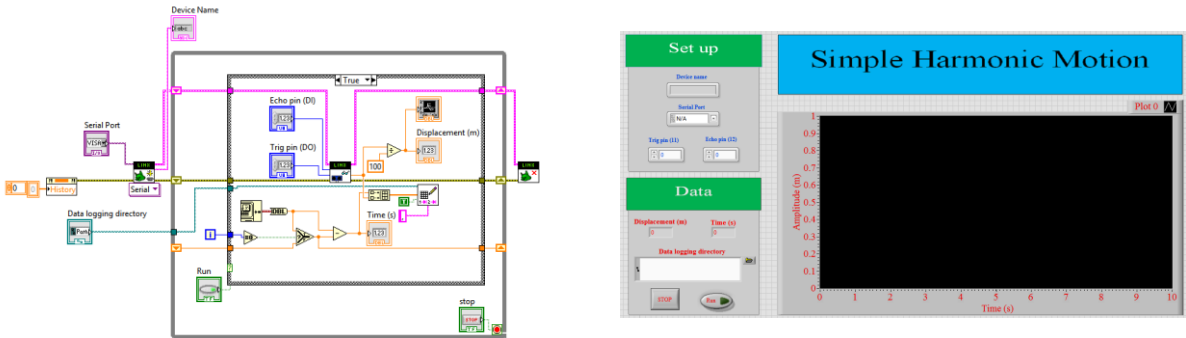

Figure 5. The LabVIEW program is designed to measure the position of a mass attached on a spring as a function of time.

The SHM LabVIEW code is shown in figure 5. When the program is executed, the trig and echo pin have to be set to the pin number of 11 and 12, respectively. The program will measure the distance to the brass weight as a function of time after the run button is clicked. The stop button is clicked after 10 seconds. Finally, the raw data of the distance to the brass weight is saved as a function of time.

4. Experimental results

The raw data of the distance to the brass weight as a function of time is imported to Mathematica 10 for data analysis. The Mathematica 10 is useful software for scientific calculation. The nonlinear model fit is used for curve fitting. A model is defined in the form of $A * \text{Cos}[2 * \text{Pi} * (t - tc)/T] + y_0$. In this case, the equilibrium position of the brass weight (y_0) is 0.124540 ± 0.000092 m, the initial phase amplitude ($2 * Pi * tc$) is -1.231550 ± 0.011874 rad, the amplitude (A) is 0.016370 ± 0.000130 m and the period (T) is 0.700280 ± 0.000216 s. The R^2 value is 0.97386, implying that the curve fitting, which is the sinusoidal model, can be used to describe the experimental data.
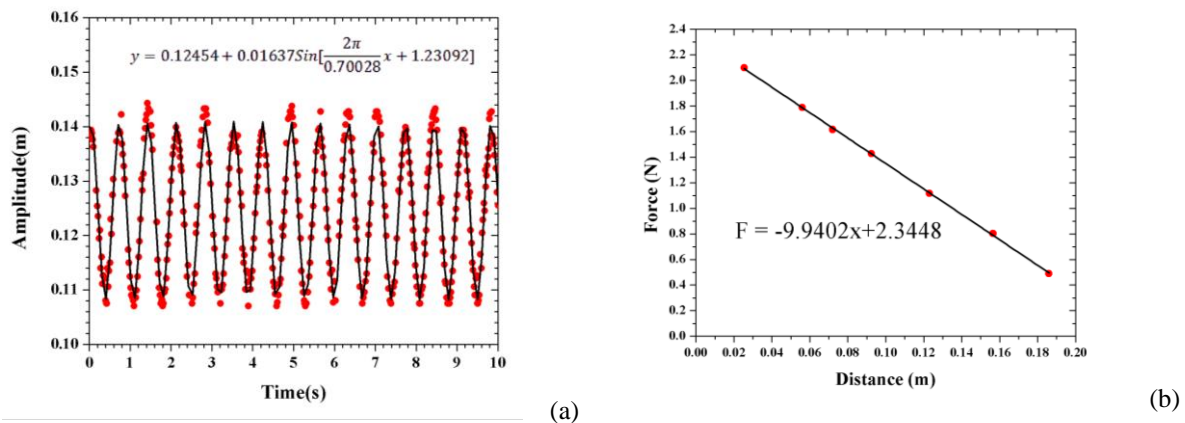

Figure 6. The data curve fitting using Mathematica 10 and represented by Origin 8 (red dots are raw data and black line is curve fitting) (a) wave equation (b) Hooke's law.

Figure 6(a) shows the value of the period received from the data curve fitting can be used to calculate the spring constant using equation 6. The spring constant (k) is 9.1706 N/m while the brass weight is 0.114 kg. To compare the spring constant with different experiments, the second experiment setup similar to the same experiment can be used to investigate Hooke's law. In this case, the brass weights used vary from 0.051 to 0.214 kg. The result shows that the displacement of spring (x) is an anticipated linear behavior with the gravity force (mg) same as equation 2. The linear fitting, shown in figure 6(b), gives the slope value which is the spring constant (k) of 9.9402 N/m.

5. Conclusions

The spring-mass system which is the Simple Harmonic Motion, based on LabVIEW interface for Arduino has been developed to perform an innovative physics lab apparatus that are modern, cheap and simple. The HC-SR04 ultrasonic sensor is used to measure the position of a mass attached on a spring as a function of time. The experimental data and the theoretical model are in good agreement. The most important aspect is our students have used the STEM activity in order to integrate Science (physics concept), Technology (electronic circuit design and computer programming), Engineering (design and build apparatus) and Mathematics (investigate data using Mathematica).

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