An Arduino board with ultrasonic sensor investigation of simple harmonic motion

A Buachoom¹, A Thedsakhulwong¹ and S Wuttiprom¹,²*
¹ Department of Physics, Faculty of Science, Ubon Ratchathani University, Ubon Ratchathani, 34190, Thailand
² Thailand Center of Excellence in Physics, Commission on Higher Education, Bangkok 10400, Thailand

* E-mail: sura.w@ubu.ac.th

Abstract. An Arduino, one of the most popular microcontroller platforms, is widely used in teaching and learning STEM. It is really open source software and hardware, huge community, low cost boards and peripherals, and simple programming language. This research aims to develop an Arduino-based physics investigation of the simple harmonic motion (SHM) of mass on a spring. This rich cross curricular STEM activity integrates electronics, computer programming, physics, and mathematics in a way that is both experimentally exciting and intellectually rewarding. The experimental data are collected with the help of an HC-SR04 ultrasonic distance sensor and an Arduino Uno board. The data are then graphed and analysed using Microsoft Excel in real-time. The experiment data can be used to investigate Hooke’s law. The elastic constant of the spring, \( k = 16.54 \text{ N/m} \), is very close to the value determined from the period of the SHM. This Arduino-based investigation of SHM can be helped the students to improve both their experimental and theoretical skills.

1. Introduction
The experimental investigation of SHM is fundamental importance to the study of physics. While the classical experiment is done using a ruler and a stopwatch, this procedure is tedious and prone to human errors. We have developed an Arduino-based physics investigation of the SHM of a mass on a spring. The experimental data are collected with the help of an HC-SR04 ultrasonic distance sensor and an Arduino Uno board. The data were collected and then graphed real-time using the Parallax Data Acquisition tool (PLX-DAQ). In order to find the SHM equation, the GeoGebra program were used [1]. Because of the inexpensive, flexible and easily implementable character, schools in general and physics instructors in particular have also realized the advantages of using Arduino boards as low-cost data acquisition systems for lab experiments. Students at schools are usually excited by physics labs based on an Arduino, this engagement is a key task for the success of learning [2].

2. Experimental setup
The experimental setup for our investigation of SHM consists of a stand, a spring, a brass weight, and an HC-SR04 ultrasonic distance sensor, as shown in figure 1(a). Pulling the brass weight down a little bit, and then releasing it, will start the oscillation. Due to very small frictional forces, the amplitude of
the observed SHM will slowly decrease in time, but we can neglect this effect when we analyze just a few cycles. We have also used a brass weight holder with a base diameter of 3.2 cm and brass slotted weights. The computerized data collection was done with the help of an HC-SR04 ultrasonic distance sensor, an Arduino Uno microcontroller board, a USB cable, and four male-to-female breadboard jumper wires. We have repeated the SHM with a variety of springs and masses with excellent results. The data reported in this article were obtained with the spring using a total mass of 250 g and using the HC-SR04 ultrasonic distance sensor [3].

![Figure 1](image1.png)

**Figure 1.** (a) Picture of the experimental setup. (b) Sketch of the circuit with the Arduino.

The HC-SR04 ultrasonic distance sensor (transmitter and receiver) has four pins: 5 V (power supply), 0 V (ground), trigger pulse input, and echo pulse output. It has an operating range of 2 cm to 5 m, with a resolution of 0.3 cm. The transmitter emits a short ultrasonic signal, consisting of eight pulses at 40 kHz, which is reflected on the measurement object and is received back in the form of the echo. The echo is changed from 40 kHz because of the Doppler effect. However, in this case, it is very small because the moving spring is not very fast. After the receiver detects the echo signal from the travel time of the sound, the sensor calculates an analog output signal proportional to the distance [4].

3. **Arduino programming code**

The HC-SR04 sensor is connected to the Arduino Uno board with the help of four male-to-female breadboard jumper wires. The Arduino Uno board supplies the voltage to the HC-SR04 sensor. The Vcc pin of the sensor is connected to the 5 V pin of the Arduino board, and the GND pin of the sensor is connected to a GND pin of the Arduino board. The Trig pin of the sensor is connected to the Arduino digital pin 7, and the Echo pin of the sensor is connected to the Arduino digital pin 8, shown in figure 1(b). A short piece of Arduino programming code is needed to collect the experimental data. The computer first compiles this program and then sends it to the Arduino board through the USB cable. The Arduino board will execute the code and will repeatedly send back to the computer the two experimental measurements, the internal clock time, and the distance to the brass weight. The measurements are repeated every 10 ms.

The Arduino board is measuring the echo time with the help of the pulseIn() function, which in this case measures the total time (in ms) during which the HC-SR04 sensor keeps the Echo pin at 5 V. The result of multiplying this echo time and the speed of sound in air at room temperature (343 m/s) gives the total distance travelled by the ultrasonic pulse. When the HCSR04 sensor is placed under the brass weight, this total distance is the sum of two identical sides of length d each in an isosceles triangle. The height in this triangle is the distance to the brass weight, which is the position x that we need. The distance of 2.6 cm between the transmitter and the receiver of the HC-SR04 sensor allows us to calculate the distance x by using the Pythagorean’s theorem.
4. Data analysis
The Arduino Uno board collected distance and time data. Data were transferred to the Excel program by using the PLX-DAQ. A graph was drawn simultaneously with the data collection process. The Excel file containing the PLX-DAQ is opened after the codes are loaded into the Arduino. In the opened window, the port number and the baud rate are chosen. The port number must be the same as the number that the Arduino is connected to, and the baud rate must match with the number that’s in the “Serial.begin” command. Finally, the “Reset on Connect” button is disabled and the “Connect” button is clicked [5]. Thus, the connection between Arduino and Excel is provided. A graph can be added to see real-time plotting, as shown in figure 2. The graph produced in real time is still very useful because it reveals the qualitative behaviour of the SHM [6].

![Figure 2. The SHM data shown in real time.](image)

The experimental data were analysed by the GeoGebra program in order to fit the curve of the SHM. The selected experimental data copied from Excel and pasted into the GeoGebra program. The sinusoidal curve fitting function were used. The general form of this function is \( y = A \sin(2\pi/T+\phi) + M \). For this experiment, the amplitude \( A \) is 7.45 cm, the period \( T \) is 0.77 s, the initial phase is 3.54 rad, and the midline (equilibrium position) \( M \) is 43.46 cm. The value of the period can be used to calculate the elastic constant of the spring: \( k = 16.48 \text{ N/m} \), as shown in figure 3.

![Figure 3. The SHM data analysis done using the GeoGebra program.](image)

In order to confirm that the experimental results of the SHM obtained from Arduino Uno board are consistent with other experiments. We compared with Hooke’s law method because it is easy to set up,
validity result in terms of measuring data with statics masses [7]. The same experimental setup can be used to investigate Hooke’s law. This will produce an independent measurement of the elastic constant of the spring. The total masses were used from 100 g to 450 g.

![Hooke's law graph](image)

Figure 4. Experimental investigation of Hooke’s law.

The graph of the applied force as a function of displacement displays the anticipated linear behaviour. The slope of the line of best fit shows the elastic constant. The elastic constant value obtained 16.54 N/m, as shown in figure 4. It is very close to the value determined from the period of the SHM.

5. Conclusion
This research has developed the SHM of a mass on a spring by using an Arduino Uno board and an HC-SR04 ultrasonic distance sensor. It is very important physics experiment. It is low cost experiment. The data were collected and graphed in real time. It can be help students to improve both their experimental and theoretical skills, and supporting STEM activity [8].

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