Measurement of Speed of Sound using Smartphone and Phyphox Application

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Abstract: ***The absence of an experiment to measure the speed of sound in the air causes the students' scientific process skills to be low in studying the topic of sound waves. This study aims to develop a smartphone-based experimental setup using the phyphox application to measure the speed of sound in the air. The measurement method used in this experiment is Time of Flight (ToF) in the case of free fall motion. Tools and materials used in this experiment include: ruler, smartphone, thermometer, stative, iron ball, and various electronic components such as adapters, switches, voltage regulator modules, push buttons, buzzers, 5V relay modules, and magnetic induction. The smartphone functions as an acoustic stopwatch to measure the time of wave propagation, which is controlled by the sound generated from the buzzer and the ball's collision with the plane's surface. Determination of the speed of sound in air is carried out through regression analysis. The speed of sound obtained in this experiment is 340.7 m/s at a temperature of 25.4 ^{0}C with an error percentage of 1.25 % when compared to the theoretical value of 345 m/s.***

Keywords: sound waves, Time of Flight, smartphone, phyphox

1. Introduction

The speed of sound is one of the essential properties that need to be analyzed in studying sound waves. The speed of sound in the air can be determined by the method of resonance [1][2] and Time of Flight (ToF) [3][4]. The ToF method is a method that has been widely developed to measure the speed of sound in the air because it is simple and only requires a measuring instrument to measure the time of sound propagation from the source to the receiver. Many studies have been conducted to measure the speed of sound propagation using the ToF method combined with various electronic devices and computer software. Arduino and sensors are electronic devices that can be used to measure the speed of sound in the air [5][6]. In addition, devices such as tone generators, speakers, microphones, and computers can also be used to measure the speed of sound in the air [7]. However, for experimental setups that use computers, additional Audacity software is required to perform data analysis and measure time [3][4][8].

The development of mobile applications has a positive impact on simplifying and facilitating the rapid measurement of the propagation of sound in the air using the ToF method. One of the mobile applications that can be used is phyphox. This application works by utilizing the smartphone's internal sensors to be used as a measuring tool for physics experiments [9][10][11]. The phyphox application also provides a time measurement tool in the form of an acoustic stopwatch that uses the microphone on the smartphone as a sensor. The phyhox application provides an acoustic stopwatch feature that functions to measure time by using sound as a trigger to control the timer. The speed of sound can be measured easily through a simple experimental setup using an acoustic stopwatch. In general, the measurement of the speed of sound propagation uses two smartphones to measure the time difference between two sound sources that are generated at a certain distance. However, in this study, measurement variations were carried out using one smartphone and two sound sources in the case of free fall motion [12]. The advantage of this experimental setup is that time is measured directly and variations in measurement with distance can be carried out easily.

2. Theoretical Background

An object falls freely from a height of h as shown in Figure 1. A smartphone is also placed at a height of H to measure time using an acoustic stopwatch. If the time counted by the stopwatch is the travel time of the object along h and the speed of sound traveling along H, it can be written in the form of an equation:

$$t = t_h + t_H \tag{1}$$

$$t_H = t - t_h \tag{2}$$

where t is the time counted by the stopwatch, t_h is the time the object is in free fall along h, and t_H is the time for sound to travel along H. Since sound travels through air at a constant speed, t_H is written in the equation:

$$v = \frac{H}{t_H} \tag{3}$$

$$t_H = \frac{H}{v} \tag{4}$$

where H is the height of the smartphone from the plane surface and v is the speed of sound in air expressed in (m/s). If the object in free fall from a height h takes time to reach the surface of the plane is t_h, then it can be written in the form of the equation:

$$h = \frac{1}{2} g t_h{}^2 \tag{5}$$

$$t_h = \sqrt{\frac{2h}{g}} \tag{6}$$

where g is the acceleration due to the gravity of the earth which has a theoretical value of 9.8 m/s^2. If equations (4) and (6) are substituted into equation (1), we get:

$$t = \sqrt{\frac{2h}{g}} + \frac{H}{v} \quad (7)$$

While the error in the measurement of the speed of sound is determined by the equation:

$$\%\ error = \left| \frac{v_{experiment} - v_{theory}}{v_{theory}} \right| \times 100\% \quad (8)$$

with the value of the theoretical speed of sound propagation at a temperature of 24 ^{0}C is 345 m/s [1].

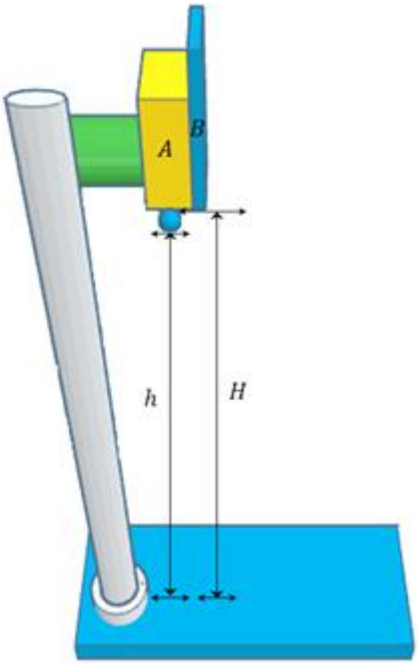

Figure 1: The principle of measuring the speed of sound in air in the case of free fall

3. Experimental Setup

The tools and materials used in this experiment include a ruler, smartphone, thermometer, stative, and iron ball. The ruler is used to measure height with an accuracy of 1 mm. A smartphone is used as an acoustic stopwatch by utilizing the phyphox application. The stopwatch used in this experiment has an accuracy of 0.001 s. A thermometer is used to measure the room temperature with an accuracy of 0.01 C. While the stative is a mechanical system that serves to make variations in measurements by changing the height of objects. The experimental setup developed is shown in Figure 2. The working principle of this experimental setup is that there are two sound sources that are generated to trigger the measurement of time using an acoustic stopwatch. The first sound is to start the measurement and the second sound is to stop the measurement. The first sound is generated at the same point as the stopwatch so the time it takes for the sound to propagate to the stopwatch is negligible. Whereas the second sound is generated at a certain distance so that it takes time to propagate to the stopwatch. If time and distance can be measured, the speed of sound in the air can be determined. In this experimental setup, the time measured by the stopwatch is the time it takes for the object to fall freely from a certain height and the time it takes for the sound to propagate from the second sound source to the stopwatch.

Figure 2: Experimental setup to determine the speed of sound in air

The experimental setup developed must trigger the stopwatch to start measuring using a sound and at the same time, the object is in free fall. To realize this, a hardware system is designed as shown in Figure 3. The hardware components consist of adapters, switches, voltage regulator modules, push buttons, buzzers, 5V relay modules, and magnetic induction (coils and iron). This system works on the principle that when the push button is pressed the buzzer will sound and the current flowing in the coil will disappear so that the object falls and time measurement begins. Meanwhile, to stop the measurement of time, a falling object will strike a stative surface made of iron so that it generates a sound that triggers the stopwatch to stop the measurement. The variables measured in this experiment, among others: were the height of the object, the height of the smartphone, time, and room temperature. Data collection is done by varying the height of objects and smartphones and then measuring the time. The variable that is calculated in this experiment is the speed of sound in the air. The speed of sound in the air was determined using linear regression analysis.

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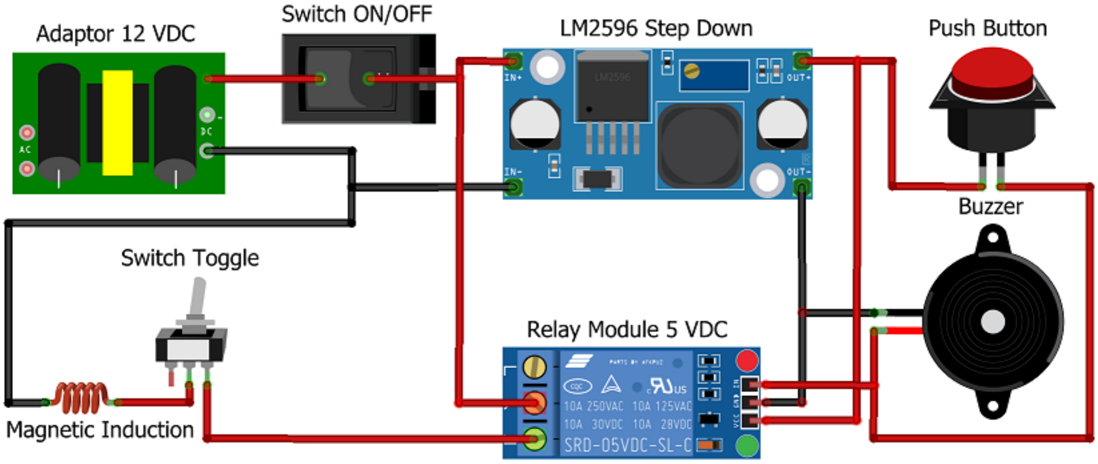

Figure 3: Experimental setup hardware diagram

4. Results and Discussion

The method used to measure the speed of sound in this experiment is ToF, which measures the time it takes for sound to propagate from the source to the receiver. Determination of the speed of sound in air in this experiment utilizes an acoustic stopwatch on the phyphox application as a timer to measure time automatically. The results of measuring time using an acoustic stopwatch in this experiment are shown in Figure 4. The time measured is a combination of the time it takes for an object to fall freely from a certain height and the time it takes the sound to propagate to the stopwatch. Data collection to determine the speed of sound propagation is done by varying the height of objects from 0.5 m to 1.5 m. The advantages of this experimental setup are (1) it is simple and low-cost, (2) it does not require the help of certain software for further analysis, and (3) it can be done anytime easily so that it can be extended to in-house investigation activities. One of the factors that affect the speed of sound in air is temperature, so in this experiment, the measurements were carried out at a room temperature of 25.4^{0}C. The tabulation of the measurement data is presented in Table 1. The time required for an object to fall freely is calculated using equation (6), while The speed of sound propagation is determined using equation (2).

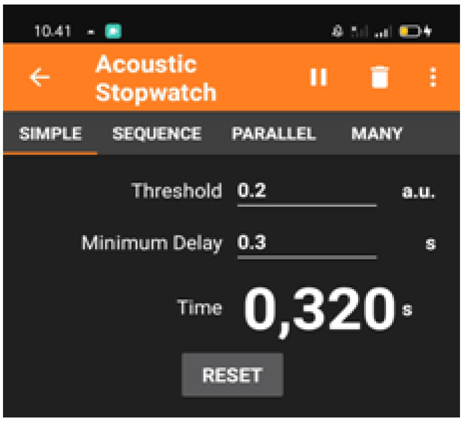

Figure 4: Sample of results measurement using the acoustic stopwatch on phyphox application.

Table 1: Tabulation of experimental data

h (*m*)	*H* (*m*)	t (s)	t_h (*s*)	t_H (*s*)
0.50	0.52	0.3209	0.319438	0.0015
0.60	0.62	0.3517	0.349927	0.0018
0.70	0.72	0.3801	0.377964	0.0021
0.80	0.82	0.4063	0.404061	0.0022
0.90	0.92	0.4312	0.428571	0.0026
1.00	1.02	0.4547	0.451754	0.0029
1.10	1.12	0.4770	0.473804	0.0032
1.20	1.22	0.4985	0.494872	0.0036
1.30	1.32	0.5190	0.515079	0.0039
1.40	1.42	0.5385	0.534522	0.0040
1.50	1.52	0.5577	0.553283	0.0044

The speed of sound in air is determined through regression analysis as presented in Figure 5. The results of the regression analysis between the distance traveled and the time of sound wave propagation is expressed by the equation $y = 340.7x + 0.02268$ with a correlation coefficient of 0.99711. This equation shows that y is the distance traveled and x is the time for sound to travel. The gradient of this equation states the speed of propagation in the air is 340.7 m/s. The results obtained have an error percentage of 1.25% when compared to the theoretical value of 345 m/s. The results of this experiment are supported by a study conducted by Coban & Coban (2020) in measuring the speed of sound in air with an error tolerance of 1.42% [2]. A study conducted by Astuti (2016) also obtained a measurement of the speed of sound in air with a relative error proportion of 1.3% [3], while a study conducted by Boimau, et al (2019) obtained the speed of sound in air with a percentage relative error of 2.29% [6]. In addition, a study conducted by Hahn, et al (2019) obtained a measurement of the speed of sound in air with a relative error percentage of less than 1% [5]. The results of the regression analysis also think that the speed of sound in air is constant at the same temperature.

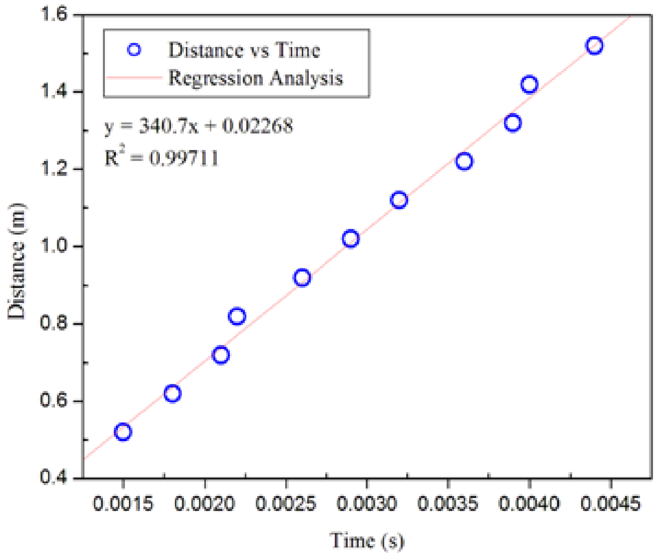

Figure 5: Graph of distance and time propagation of sound in air

5. Conclusion

A smartphone-based physics experiment to measure the speed of sound in the air using the Time of Flight (ToF) method has been carried out in the case of free fall motion. Smartphones can be used as stopwatches by utilizing the phyphox application so that the measurement of sound propagation time can be controlled using sound input. The determination of speed of sound propagation in air was determined using regression analysis and obtained a value of 340.7 m/s at a temperature of 25.4 ^{0}C. The measurement of the speed of sound propagation obtained had a relative error percentage of 1.25% when compared to the theoretical value of 345 m/s.

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