

Designing a Restitution Experiment Using Smartphone Sound Sensor

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Abstract

This study explores the efficiency level of two experimental methods for determining the coefficient of restitution, which have been widely conducted in previous research. Using smartphones as tools in physics experiments, the coefficient of restitution can be determined through visual analysis (camera) and sound sensors to detect collisions. Phyphox is used to record time intervals and the height of the ball after impact based on the sound of the collision with the floor. Additionally, Tracker is employed for visual motion analysis of the object during the collision. The coefficient of restitution calculated using Phyphox yielded a value of 0.894 ± 0.017 , while Tracker provided a value of 0.888 ± 0.014 . The results indicate by reviewing the percentage error between the two methods (0.715%), Phyphox and Tracker can provide accurate data for determining the coefficient of restitution, making them effective and efficient physics experiment-based learning tools in schools.

Keywords: Collision coefficient, Sound sensor, Video analysis, Phyphox, Tracker application, Smartphone

INTRODUCTION

The advancement of technology in the digital era has brought various innovations in the field of education, one of which is the utilization of smart devices such as smartphones. Nowadays, society especially students is highly familiar with smartphone technology (Sari et al., 2020). Using technology in education includes versatility, reliability, and accessibility for students in acquiring learning materials (Chindia & Wawire, 2024). Furthermore, using technology in education can enhance students' learning motivation (Sabron et al., 2020) and enable interactive learning methods (Hadiningrat et al., 2024). Additionally, these devices significantly contribute to improving students' higher-order thinking skills (Kim et al., 2020) and critical thinking skills (Chindia & Wawire, 2024).

Smartphones are ideal tools for use in physics experiments. According to Leong et al., (2021), using smartphones as measurement tools in experiments enhances students' learning experiences, as they can have their measurement tools anytime and anywhere, without the need to share them as with traditional laboratory equipment. With advanced features of smartphone, these are

effective and economical tools for enhancing the quality of learning and research in laboratories (Barro et al., 2023). This study focuses on utilizing the sound sensor feature. This sensor can be applied in various physics experiments, including determining the coefficient of restitution in collisions (Dahnuss et al., 2021; Wijayanti et al., 2022).

Collision is a fundamental topic studied in both high school and undergraduate physics. Topics such as linear momentum conservation and kinetic energy conservation in perfectly elastic and inelastic collisions are challenging concepts for many students. Based on research Singh & Rosengrant (2016), it was found that students often fail to interpret the principles of energy and momentum qualitatively, confusing applying these principles to real-life examples. Additionally, research by Rosa et al. (2018) revealed that 40% of the students studied expressed difficulty distinguishing between momentum and kinetic energy conservation in collisions. Thus, alternative solutions integrating technology into collision-related learning have been widely implemented. One such solution involves using video analysis technology based on cognitive conflict to enhance students' conceptual understanding of momentum (Mufit & Fitri, 2022). Besides, we can also do this by utilizing the sound sensor on

smartphones (Dahnuss et al., 2021).

The experiment on the coefficient of restitution observed in this study involves the collision between a ping-pong ball and the floor. A collision occurs when the ball is dropped from a certain height and collides with the floor. After the ball bounces, its height decreases due to the reduction in kinetic energy after the collision. In the case of a ball colliding with the floor, the collision is inelastic (Freedman, 2014). This is due to the interaction with a hard surface, which reduces part of the ball's kinetic energy. The coefficient of restitution represents the ratio between the ball's velocity before and after the collision (Jewett & Serway, 2014). Partially elastic collisions comply with the law of conservation of momentum, where the coefficient of restitution has a value between 0 and 1 ($0 < e < 1$) (Halliday et al., 2015). As shown in Figure 1, the ball is repeatedly dropped and impacts the floor. Such collisions are typically accompanied by heat and sound generation at the contact surfaces (Douglas C. Giancoli, 2014). This heat and sound originate from the kinetic energy of the objects during the collision. Consequently, the kinetic energy decreases due to friction between the two surfaces.

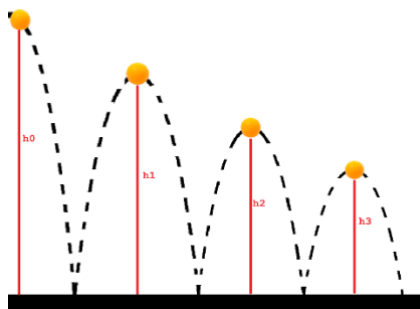


Figure 1. The ball is dropped

This study aims to design an innovative experiment to determine the coefficient of restitution by utilizing the sound sensor and camera on a smartphone. Additionally, we aim to compare the effectiveness of these two methods. The software we used is **Phyphox software**, which employs the smartphone's sound sensor to analyze collision sounds between objects. It provides data on the height of the ball before and after the collision, the time intervals between collisions, and the percentage of kinetic energy dissipation for each collision (see Figure 2a). We also use the **Tracker software** to analyze videos of the object's motion during the collision. This application can analyze time intervals and the distances of moving objects (Cordeiro & Rodrigues, 2020) (see Figure 2b). Previously,

numerous experiments on the coefficient of restitution have utilized Tracker (Mufit & Fitri, 2022; Putri & Saraswati, 2024) dan Phyphox (Dahnuss et al., 2021; Hikmatiar et al., 2019; Wijayanti et al., 2022). Considering the use of sensors available in widely owned devices, especially among students, this approach significantly enhances students' science process skills (Evains et al., 2024) and provides a profound learning experience (Langi et al., 2022; Yasaroh et al., 2021).

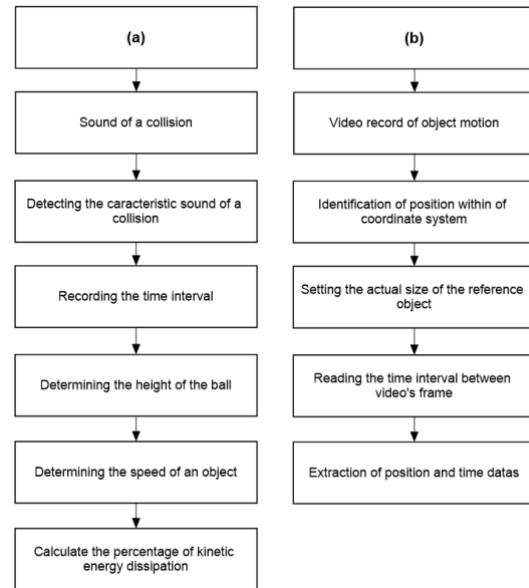


Figure 2. Process Illustration of a. Phyphox Application Work b. Tracker Application Work

Law of Conservation of Momentum

Analysis: Collision between the floor and a ping-pong ball

$$m_B v_{Bi} + m_F v_{Fi} = m_B v_{Bf} + m_F v_{Ff} \quad (1)$$

Since the floor is stationary, the momentum conservation principle applies as follows:

$$v_{Fi} = v_{Ff} = 0$$

$$m_B v_{Bi} = m_B v_{Bf} \quad (2)$$

$$v_{Bi} = v_{Bf} \quad (3)$$

The coefficient of restitution (e) is defined as the ratio of the velocity of the object after the collision to its velocity before the collision.

$$e = -\frac{v_{Bf}}{v_{Bi}} \quad (4)$$

$$v_{Bf} = -e \cdot v_{Bi} \quad (5)$$

$$|v_{Bf}| = e \cdot |v_{Bi}| \quad (6)$$

Equation of Free-Fall Motion

$$v_f^2 = v_i^2 + 2gh \quad (7)$$

$$v_f = \sqrt{2gh} \quad (8)$$

Equation of Relative Velocity Rasio

$$e = \frac{v_{Bf}}{v_{Bi}} \quad (9)$$

By combining the equations of free-fall motion and the coefficient of restitution based on the relative velocity ratio, the equation for the coefficient of restitution in this experiment is given by:

$$e = \frac{v_{Bf}}{v_{Bi}} = \frac{\sqrt{2gh_{Bf}}}{\sqrt{2gh_{Bi}}} = \sqrt{\frac{h_{Bf}}{h_{Bi}}} \quad (10)$$

METHOD

Materials

The tools and materials used in this research are relatively simple. They include a ping-pong ball, a stand, a ruler, a tripod, two smartphones, and a PC (the experimental setup is illustrated in Figure 3). In this study, we used a Realme 8 Android smartphone to utilize its sensor for detecting the collision sound between the ball and the tile. The application used was Phyphox version 1.1.16 (latest version), which can be downloaded for free from the Play Store or App Store. In addition to utilizing the smartphone's sound sensor, this study also made use of its camera feature. The device employed was a Redmi Note 11 Android smartphone, capable of recording videos in 720P quality with a resolution of 1280 x 720 pixels and a frame rate of 30 frames per second (fps).

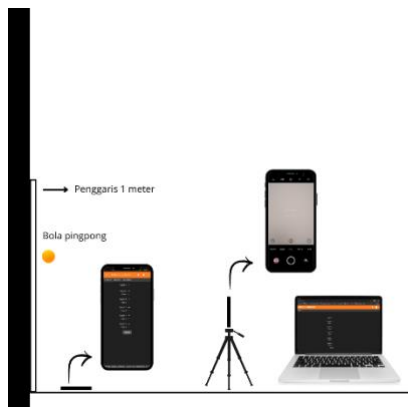


Figure 3. Experimental tools and materials set

Experimental Setup

The Phyphox application enable remote access on the smartphone connected to the PC via the same Wi-Fi network or through tethering (see Figure 6). The Phyphox application provides a private IP address that can be

entered into the PC browser, allowing remote access to connect to the mobile device (see Figure 5).

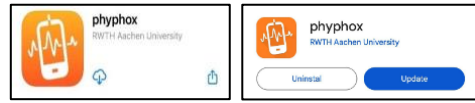


Figure 4. Phyphox in a. the AppStore b. The Play Store

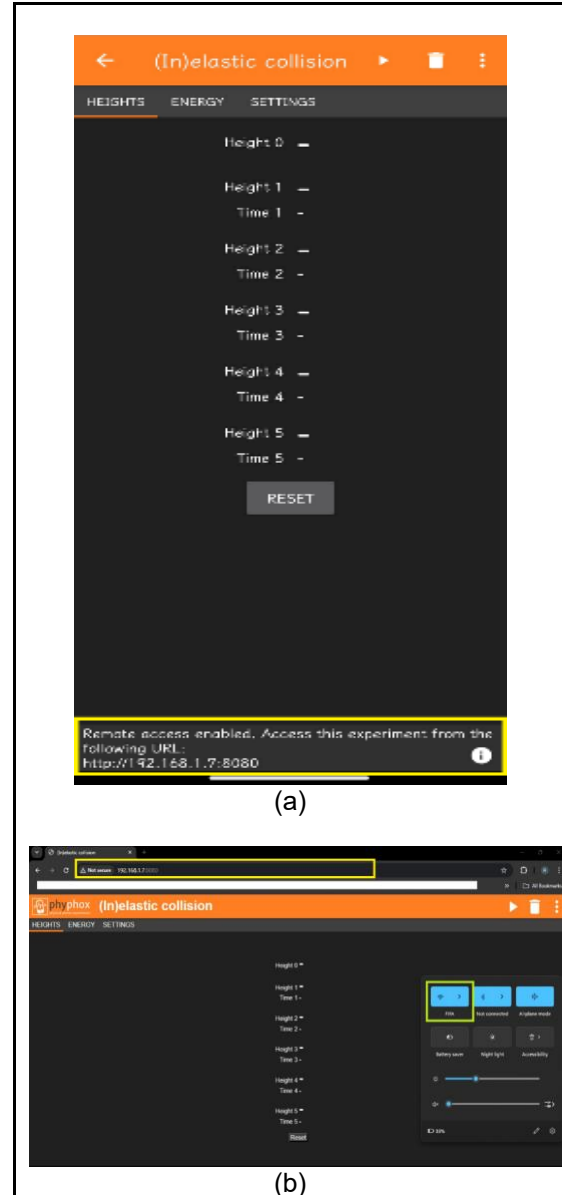


Figure 5. Connecting the Phyphox application to a PC via a URL address (a) Smartphone display (b) PC display

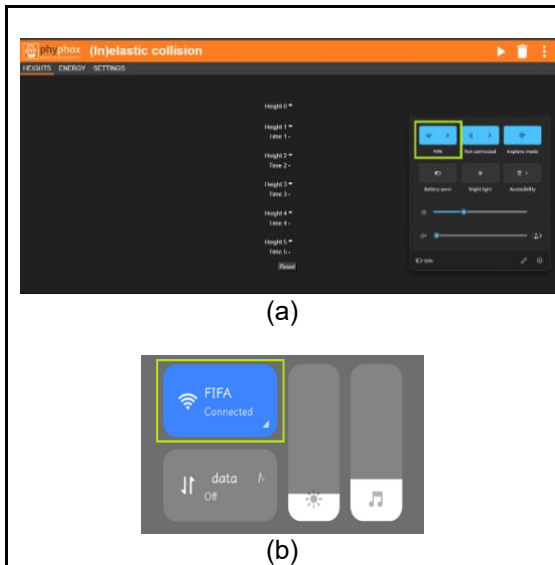


Figure 6. Connecting the Phyphox application to a PC on the same internet network (a) PC display (b) Smartphone display

In addition to using the smartphone's sound sensor, the experimental data will be analyzed using the Tracker application for video analysis of the ball's motion during the drop. The camera position must be carefully adjusted to ensure it is perpendicular to the frame of the object's motion being captured (see Figure 7).

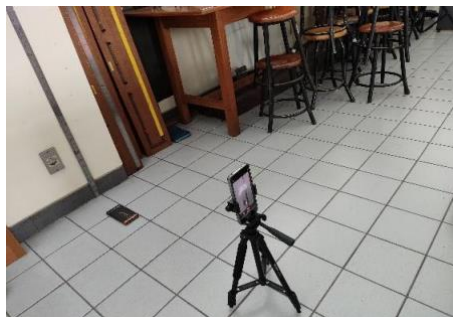


Figure 7. Camera setup for recording the ball's motion

Data Collection

The experimental data collection involves releasing the ball from a certain height, where the sound sensor on the smartphone records the sound of the ball colliding with the floor. The Phyphox application automatically records the height, time, and percentage of kinetic energy retained after the collision (see Figure 8).

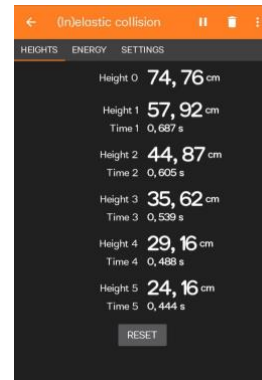


Figure 8. Phyphox application interface. a. Height data and time intervals b. Kinetic energy percentage

As the ball is freely dropped from a certain height, it is recorded. The camera captures the ball's trajectory until it stops bouncing. The video is then analyzed to determine the ball's peak positions when it is initially dropped and after each collision. (see Figure 9).

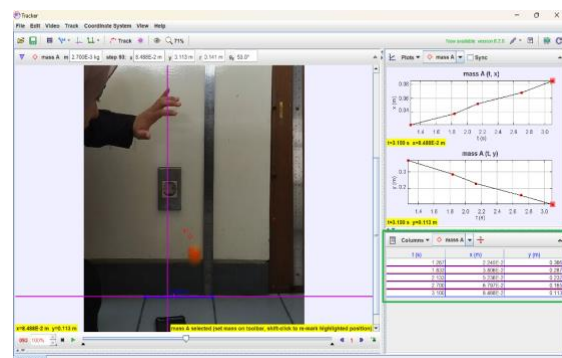


Figure 9. Video motion analysis using the Tracker application

Data Analysis

The data collection process in this experiment involves five repetitions for each data set and eight variations of initial heights as optimal repetition. The initial heights range from 30 to 100 cm, with 10 cm intervals. Data extraction from the Phyphox is performed directly without any specialized data extraction procedures. Data analysis is conducted using statistical methods (mean) and graphing with Microsoft Excel to determine the relationship and effectiveness between the two methods employed. The flow of the data research process can be seen in Figure 10.

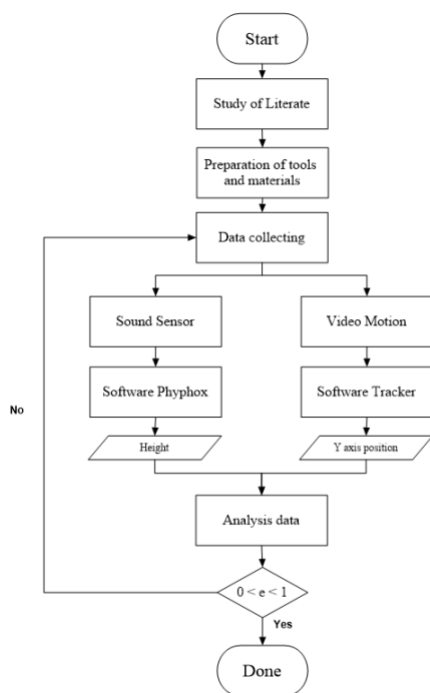


Figure 10. Research Flowchart

Error Calculation

After data analysis, the next step is to test the error value in the Phyphox data analysis results, referring to the efficiency of using the Tracker method. Use the following error percentage formula:

$$\% \text{ error} = \frac{\text{approximate} - \text{exact}}{\text{exact}} \times 100 \quad (11)$$

$$\% \text{ error} = \frac{e_{\text{phyphox}} - e_{\text{tracker}}}{e_{\text{tracker}}} \times 100 \quad (12)$$

The error percentage will indicate the level of effectiveness of the tested method (Phyphox) compared to the method that has been widely used (Tracker) (Helmenstine, 2024).

RESULT AND DISCUSSION

Result

The data collected from the smartphone is analyzed to determine the coefficient of restitution. Video recordings of the ball's free-fall motion are analyzed using the Tracker application to identify the initial height and the height after each collision by applying Equation 10. At the same time, the sound generator during the ball-floor collision will analyze using Phyphox ((in) elastic collision tools). The results from five repeated measurements are processed statistically to obtain the average coefficient of restitution for a specific initial height. Data obtained from Phyphox at a certain initial height, based on five repetitions, are presented in Table 1. These data are compared

with Tracker's results (Table 2).

In Table 1, the initial height values are not identical to the heights measured using a ruler. That caused by Phyphox sensor, which determines the height indirectly by analyzing the time intervals between collision sounds. On the other hand, the initial heights in Table 2 match the ruler measurements, cause the data can manually input into the Tracker. Nevertheless, the differences in initial height do not significantly affect the result, since the data analysis relies on the ratio of height each rebound

Based on the data from Tables 1 and Table 2, the average coefficient of restitution values between Tracker and Phyphox show no significant difference, with a difference of data $e = 0,006497 \pm 0,000101$. This very small difference is also supported by the minimal standard deviation of both data sets, which is 0,000101 This indicates that both applications provide highly consistent results, and the observed difference can be considered statistically insignificant.

After all the data have been analyzed and the average values calculated, we compared the coefficient of restitution values for each different initial height. Table 3 shows that the coefficient of restitution of the freely dropped ball slightly decreases as the initial height of the ball increases. This could be due to the effect of air friction, which was neglected by the researcher due to its relatively small impact (Zakwandi et al., 2021). Based on Table 3, the collision between the ping-pong ball and the tile shows that the collision is partially inelastic (Tipler & Mosca, 2007).

Discussion

To observe the relationship between the average coefficient of restitution values for each height variation, the following graph (Figure 11) shows the relationship between the coefficient of restitution values for each method and the variation in initial height.

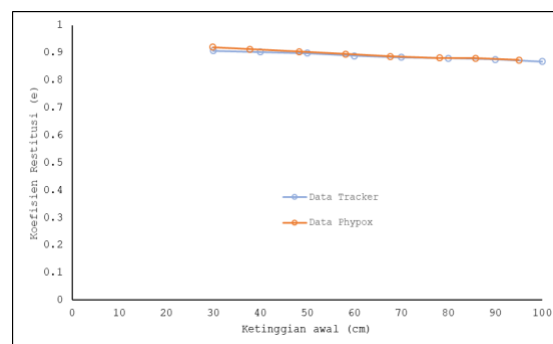


Figure 11. Graphic Relationship Between Coefficient of Restitution and Initial Height for Tracker and Phyphox Method

It can be seen that the relationship graph (Figure 11) for the two different methods overlaps due to their nearly identical values. Although the relationship line slightly shows a decrease as the initial height of the ball increases. The line still tends to remain straight. This demonstrates show that the accuracy of the data obtained from different method and different technologies is essentially similar.

against the visual analysis method using the Tracker. We can use the Error Percentage Equation based on Equation 11. By using Equation 12, the obtained error percentage is 0.715%. Since the error percentage is less than 1%. it can be concluded that the Phyphox application is quite effective as an alternative method alongside the visual analysis method using Tracker. which has been widely used in previous studies.

Error Percentage

To test the effectiveness of the smartphone sensor method using the Phyphox

Table 1. Data Processing for an Initial Height of 100 cm from Phyphox

No.	h_0	h_1	h_2	h_3	e_1	e_2	\bar{e}
1	0.9685175	0.7295243	0.5495055	0.429968	0.867893	0.88457	0.876231 ± 0.011792
2	0.9523034	0.7188444	0.5426182	0.403522	0.86882	0.862355	0.865588 ± 0.004571
3	0.9390262	0.7082043	0.5341208	0.413548	0.868441	0.87992	0.874181 ± 0.008117
4	0.9390438	0.7096417	0.5362811	0.419235	0.869314	0.884163	0.876739 ± 0.0105
5	0.951149	0.714899	0.537329	0.421748	0.866958	0.885944	0.876451 ± 0.013426
MEAN							0.873838 ± 0.004721

Table 2. Data Processing for an Initial Height of 100 cm from Tracker

No.	h_0	h_1	h_2	h_3	e_1	e_2	\bar{e}
1	100	74.6	55.3	40.9	0.86098	0.860001	0.860491 ± 0.000692
2	100	77	57.7	43.7	0.86565	0.870268	0.867959 ± 0.003265
3	100	73	55.4	41	0.871151	0.860274	0.865713 ± 0.007691
4	100	73.1	55.2	42.6	0.868982	0.878487	0.873734 ± 0.006721
5	100	75.3	56.1	42.9	0.863145	0.874475	0.86881 ± 0.008011
MEAN							0.867341 ± 0.004822

Table 3. Coefficient of Restitution Data for Each Initial Height

Tracker		Phyphox	
Initial Height (cm)	$\bar{e} \pm \Delta e$	Initial Height (cm)	$\bar{e} \pm \Delta e$
30	0.907 ± 0.016	29.918340	0.919917 ± 0.000633
40	0.903 ± 0.016	37.794341	0.912892 ± 0.007897
50	0.898 ± 0.008	48.230337	0.903862 ± 0.00078
60	0.888 ± 0.005	58.113856	0.895358 ± 0.002096
70	0.883 ± 0.004	67.668486	0.886451 ± 0.006647
80	0.879 ± 0.004	78.072120	0.880430 ± 0.004596
90	0.876 ± 0.002	85.741878	0.880065 ± 0.000917
100	0.867 ± 0.005	95.000802	0.873838 ± 0.004721
0.888 ± 0.014		0.894102 ± 0.016774	

CONCLUSION

Based on the explanation above, this study has positive implications for physics education in schools. The use of Phyphox as an accessible and affordable practicum tool can enhance student engangemet in understanding the concepts of collisions and the coefficient of restitution in a more practical and interactive way. Through this method, teachers can utilize the smartphone already available to student to support experimental learning without the need for expensive laboratory equipment.

Furthermore, both method—Phyphox

and Tracker—are equally effective. Phyphox analized collision by detecting, while Tracker performs frame-by-frame visual analysis. The average coefficient of restitution obtained from the Tracker application analysis is $e = 0.888 \pm 0.014$, while the Phyphox analysis yields $e = 0.894 \pm 0.017$. The Tracker method shows great accuracy, as indicated by its smaller standard deviation (0.014) compared to the Phyphox method (0.017). However, the results from the Phyphox method remain sufficiently precise and effective, with a percentage error of only 0.715%.

Several considerations for this experiment; are 1) ensure that the surface

where the ball bounces is solid and flat. It is recommended to bounce the ball on the same tile to maintain consistent density. 2) activate the sensor immediately after dropping the ball. 3) beforehand check whether the height detected by the smartphone's sound sensor closely matches the height. 4) ensure the data collection area is quiet and away from objects that absorb sound.

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