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# A Study of Tracker Software-assisted Spring Coupled Pendulum Oscillation

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**ABSTRACT**

Oscillatory motions are an essential part of our physical world. These motions need to be studied and learned by students. However, complicated oscillatory motions, e.g.: spring coupled pendulum, are rarely taught to students because their analytical solutions (if they exist) are complicated Here, we use the Tracker software to bridge between the actual coupled pendulum oscillation and its analytical solution. This study aimed to determine the period and frequency of Tracker software-assisted spring coupled pendulum oscillations. The displacement of the pendulum is divided into in-phase and out-of-phase motions. Data collection was carried out by recording the oscillatory motions up to 10 oscillations. The data were obtained from the pendulum position with respect to time. The data analysis techniques in this study used two methods, namely: i) Tracker software and ii) analytical calculations. The results showed that the period and frequency obtained via the Tracker software were in accordance with the analytical calculations. The periods of the in-phase motion and analytical calculation were 1.42 s and 1.54 s, respectively. The periods of the out-of-phase motions and analytical calculation were 0.7 s and 0.55 s, respectively. The frequencies of the in-phase motion and analytical calculation were 0.70 Hz and 0.65 Hz, respectively. The frequencies of the out-of-phase motions and analytical calculation were 1.50 Hz and 1.83 Hz, respectively. The uncertainty values of the results were 7% to 22%. Hence, the spring coupled pendulum oscillations became tractable and can be compared to the analytical solution.



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## I. Introduction

Oscillatory motion is a physical phenomenon that is often encountered in everyday life. One of the characteristics of oscillatory motion is periodic or repetitive motion [1]. The repeated back and forth motion of an object and then returning to its equilibrium position is called oscillation. All objects that have mass and elasticity can potentially vibrate given external forces acting upon the objects. The characteristics of vibration include frequency, amplitude, and waveform [2].

A popular example of oscillation is the motion of a pendulum. A simple pendulum consists of a string and a pendulum [3]. A simple pendulum is a basic physics experiment for observing harmonic oscillatory motion. An example of other than a simple pendulum oscillation is the oscillation of two coupled pendulums connected by a spring [4]. A spring as well as a pendulum is an object that can return to its original state when given an external force. If the two pendulums, which are connected by a spring, are given a small deflection then they will move periodically. This may be referred to as a coupled oscillation.

The coupled oscillations occur when two or more oscillating systems are linked in such a way that energy can be transferred between them. In coupled oscillations, the magnitude of the force is proportional to the magnitude of the displacement from the equilibrium position [5]. The coupled oscillation simulation uses two pendulums of the same mass connected by a spring. Coupled oscillations correspond to the motion of oscillating bodies within the same system. Experiments on spring coupled oscillatory motion are rarely carried out either in schools or universities. This is because such experiments are complicated to study [6]. The experimental activity of a spring coupled pendulum oscillation requires data interpretation in the form of tables and graphs.

The oscillatory motion of a coupled pendulum via a spring or spring coupled pendulum is divided into in-phase and out-of-phase oscillatory motions. The oscillation of a spring coupled pendulum occurs in quite complex dynamics, so to obtain data on the motion of the pendulum, a device is needed that is able of recording the event with high accuracy. To overcome this problem, in this study, the observations of spring coupled pendulum oscillations are carried out using video, which are then analysed using the Tracker software.

Tracker software is appropriate for learning and physics experiments. However, so far, physics experiments in the laboratory have been carried out conventionally or still use an analytical data collection system, so the experimental data obtained are less accurate. Moreover, the Tracker software has been used for distance learning in the Advanced Physics Experiment course [7]. In simple terms, a tracker has the ability to track the motion of an object so that various information can be obtained that is needed in the analysis of the motion event [8]. By recording motion phenomena using a video recorder, the results of these recordings can be processed using the Tracker software. The data can be conveniently interpreted in order to analyse the phenomenon, especially for the spring coupled oscillatory motion. The coupled system using a spring can be studied from the data on the pendulums' positions with respect to time. The spring coupled pendulum system has been studied using the Tracker software in [9]. However, their investigation was focused on the beats produced by the system [9]. Moreover, their system consisted of a rigid pendulum, whereas ours use a string attached to two spherical pendulums. Based on the description above, the purpose of this study is to determine the period and frequency of the Tracker software-assisted spring coupled pendulum oscillation.

## II. Theory

### Coupled Pendulum Oscillation

Oscillations occur when a system is disturbed from its stable equilibrium position. The most well-known characteristic of oscillatory motion is its periodic or repetitive nature [10]. The spring coupled pendulum system acquires data on the pendulums' position relative to time. In the coupled oscillations, two identical pendulums with mass *m* are connected by a spring with a spring constant *k*. The length of the spring is *l*, stretched between the two pendulums in the equilibrium condition with zero displacement [1]. Both pendulums move with the equation of motions, i.e. [11]:

$$m\ddot{x} = -mg\frac{x}{l} - k(x-y) \qquad (1)$$

$$m\ddot{y} = -mg\frac{y}{l} - k(y-x) \qquad (2)$$

where *g* is the acceleration due to gravity, *x* and *y* are the positions of the first and second pendulums, respectively. Here, the spring coupled pendulum oscillatory motion is divided into two, namely in-phase and out-of-phase oscillatory motions. This can be observed in Figure 1.

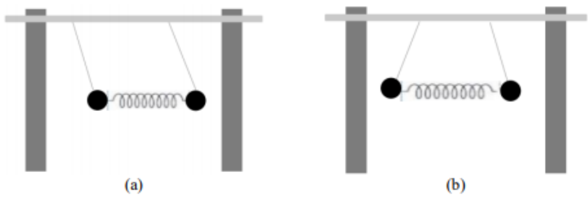

**Figure 1.** Spring coupled pendulum oscillatory with (a) in-phase and (b) out-of-phase motions.

Solving the differential equations (1) and (2) produces frequencies for the in-phase and out-of-phase oscillatory motions. The frequency for the in-phase oscillation is given as follows:

$${\omega_1}^2 = \frac{g}{l} \qquad (3)$$

Moreover, for out-of-phase oscillatory motion, the frequency can be determined using the equation:

$${\omega_2}^2 = \frac{g}{l} + \frac{2k}{m} \qquad (4)$$

### Spring

Spring is an elastic object that is used to store mechanical energy [12]. Springs come in several forms, namely: leaf, spiral, and disc. Springs are widely used in vehicle suspensions because springs have the ability to return to their equilibrium position when given an external force so that they can keep the vehicle wheels in their normal position [13]. The spring coupled pendulum is composed of objects that have masses and are connected to springs. This system can be used to study wave propagation behaviour in physical systems [14].

Springs are usually represented by a constant, i.e., known as *k*. *k* is a constant of proportion between the


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value of the force $F$ exerted on the spring and the value of the increase in length $\Delta x$ of the spring. This statement is called the Hooke's law, which can be expressed as [15]:

$$k = \frac{F}{\Delta x} \tag{5}$$

The value of $k$ is also a measure of the stiffness of the spring where the greater the value of $k$, the stiffer the spring is [16].

### Tracker Software

Tracker software is a video analysis and modelling tool built on open-source physics with the Java framework [17,18]. Tracker software can be freely downloaded and utilized using a computer device [19]. Tracker software can analyse videos about natural phenomena, especially those related to the motion of an object, such as speed, velocity, acceleration, force, gravitational field, and energy conservation [20]. Tracker software is designed for physics learning and can be used easily [21]. Tracker has the ability to provide users with many ways of representing data, as well as providing tools for multi-representation of experimental data [22]. Video tracking analysis using the Tracker software is used to train multi-representational skills in the context of physics [23]. In addition, the ability to read tracks of object movements using the Tracker software can display results in the form of images, tables, and graphs with good precision [8]. In general, the tracker defines two basic types of particle models, namely: analytical and dynamic. The dynamic particle model can be expressed in terms of Cartesian, polar, or two-body systems that experiences internal and external forces. All physical models studied using the Tracker software provide control for defining various parameters, initial conditions, and positions [24].

## III. Method

This was an experimental study, which was equipped with confirmation from the theory of spring coupled pendulum system. There were five experimental stages in this study, namely: (i) preparing a spring-coupled pendulum oscillation experiment, (ii) recording the experiments for in-phase and out-of-phase oscillations (see Figure 3), (iii) video analysis using the Tracker software, (iv) calculating the period and frequency of the in-phase and out-of-phase oscillatory motions, and (v) comparing the experimental (Tracker) and analytical (theoretical) results for the period and frequency values. The design of the system in this experiment can be observed in Figure 2.

The tools and materials used in this study were: i) two identical pendulums with a mass of 100 grams, ii) one spring, iii) one roll of nylon thread, iv) one 30 cm ruler, v) one 100 cm ruler, vi) an Ohauss analytical balance, vii) one protractor, x) a smartphone, and xi) a laptop.

The data obtained were from the Tracker software and analytical calculations as a comparison. The experiments of the oscillatory motion of the spring coupled pendulum were carried out using a variation of five oscillatory motions, namely: in-phase, inward out-of-phase, outgoing out-of-phase, pendulum (A) fixed and pendulum (B) stretched, and pendulum (A) stretched and pendulum (B) fixed. The data obtained from the Tracker was the period $T$, where $T$ is the time for one oscillation, so the equation for determining the period was as follows:

$$T = t_2 - t_1 \tag{6}$$

where $t_1$ and $t_2$ were the start and end time of the pendulum oscillation (s). In addition, $f$ was the number of oscillations in one second. The connection between $f$ and $T$ was given by:

$$f = \frac{1}{T} \tag{7}$$

Furthermore, to determine the propagation of error (uncertainty) for $f$ the following equation was used:

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial T}\Delta T\right)^2} \tag{8}$$

where $\Delta f$ was the uncertainty of $f$ and $\Delta T$ was the uncertainty of $T$.

In addition to data analysis using the Tracker software, this study used analytical (theoretical) calculation analysis. In this study there were two kinds of motion, namely in-phase and out-of-phase oscillatory motions with different equations. The oscillating motion of a spring coupled pendulum was influenced by $m$, $g$, $l$, and $k$. For the in-phase oscillatory motion, the value of the frequency $f_1$ can be calculated based on Equation (3), namely:

$$\omega_1^2 = \frac{g}{l},$$

or

$$\omega_1 = \sqrt{\frac{g}{l}},$$

or

$$2\pi f_1 = \sqrt{\frac{g}{l}},$$

or

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \tag{9}$$

Meanwhile, for the out-of-phase oscillatory motion, the value of the frequency $f_2$ can be calculated using Equation (4), namely:


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$$\omega_2^2 = \frac{g}{l} + \frac{2k}{m},$$

or

$$\omega_2 = \sqrt{\frac{g}{l} + \frac{2k}{m}},$$

or

$$2\pi f_2 = \sqrt{\frac{g}{l} + \frac{2k}{m}},$$

or

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{g}{l} + \frac{2k}{m}} \quad (10)$$

Finally, the period of the oscillatory motion of a spring coupled pendulum can be determined using Equation (7).

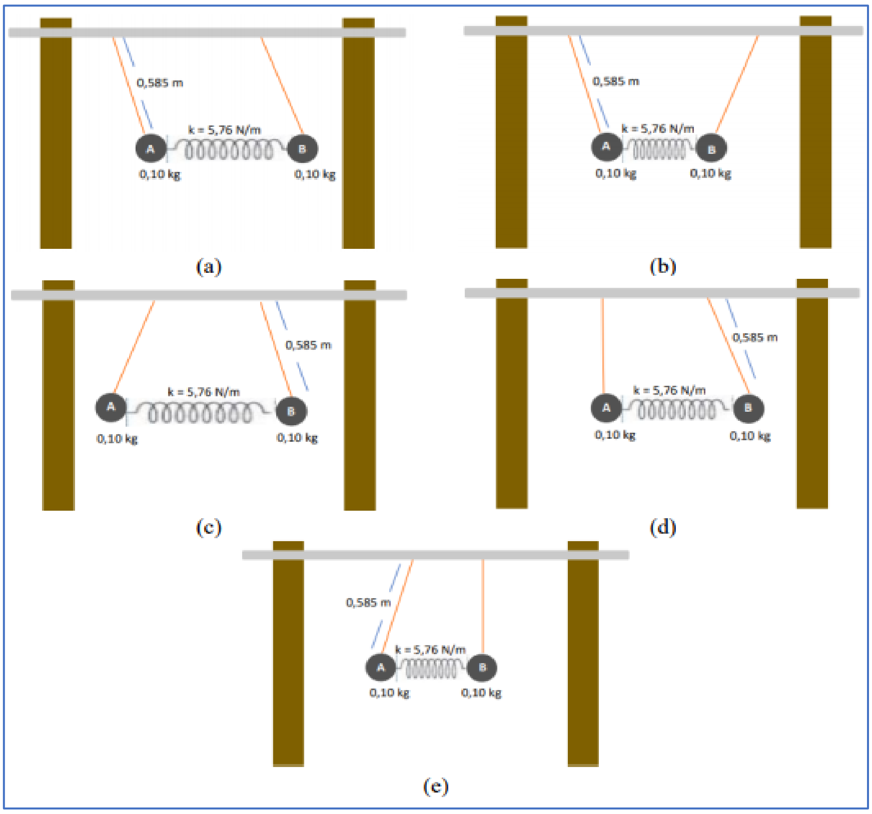


**Figure 2.** Experimental design of the spring coupled pendulum system with (a) in-phase oscillatory motion; (b) inward out-of-phase motion; (c) outward out-of-phase oscillatory motion; (d) out-of-phase oscillation of pendulum (A) fixed and pendulum (B) stretched; and (e) out-of-phase oscillation of pendulum (A) stretched and pendulum B fixed.

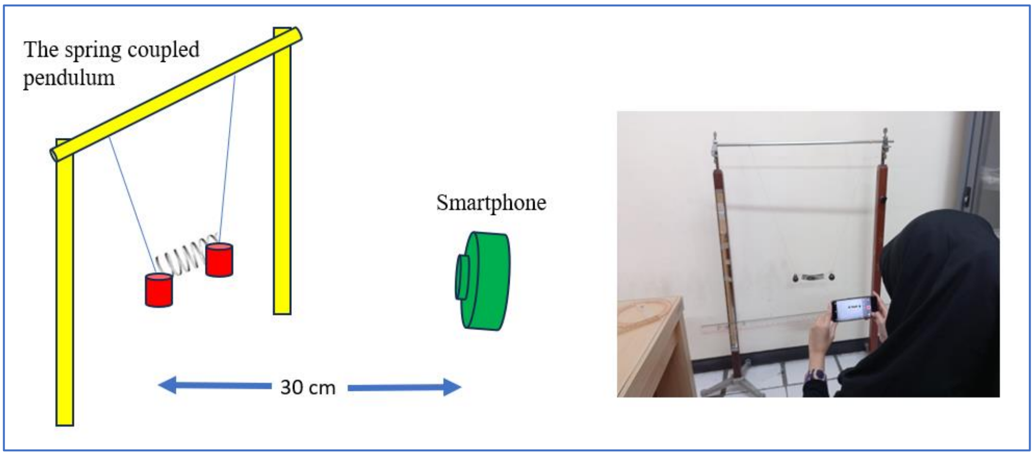


**Figure 3**. The experiment recording set-up.


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## IV. Results and Discussion

The observation data obtained after recording and analysing the video using the Tracker software can be seen in Table 3 in the Appendix section. The oscillations comprise of in-phase and out-of-phase motions of the doubled pendulum. In order to satisfy the condition of the analytical solution, a small angle of deviation is used in the initial set-up of the pendulums, i.e.: of 5°. Moreover, the rope length is 0.585 m for all variations of the oscillatory motions.

The Tracker analysis in this study produces the $T$ data of the pendulums during oscillations. The data collection is carried out until the pendulums experienced 10 oscillations. This is conducted to produce a consistent value of $T$. The value of $T$ can be used to determine the value of $f$ using Equations (6) and (7).

For the analytical analysis, the data needed first is $k$. It is known that $m$ is the mass of the load (0.0923 kg), $g$ is the earth's accelaration of gravity (9.8 m/s$^2$), $x_0$ is the initial length of the spring (7.3 cm), and $x_1$ is the final length of the spring after being loaded (23 cm). Based on Equation (5), $k$ is obtained, namely: 5.76 N/m. The coupled oscillatory with in-phase motion uses Equation (3), while the coupled oscillatory of the out-of-phase motion uses Equation (4).

A comparison of the results of the experimental data with Tracker and analytical analysis can be observed in Table 1. Inaccuracies in the research of coupled spring oscillatory motion can be determined by comparing the Tracker software and analytical results. Research inaccuracies can be observed in Table 2. The uncertainties of $f$ and $T$ are given by Equation (8) and the standard deviation, respectively.

This study aims to determine the period and frequency of the Tracker-assisted spring coupled pendulum oscillation. First, we need to know the value of the spring constant connected to the two pendulums. Determination of the value of the spring constant in this study uses manual analysis. Based on the arithmetic analysis using Hooke's law, the spring constant value is obtained, namely: 5.76 N/m. This constant value is used in all oscillatory motions.

**Table 1.** Comparison of Tracker software and analytical calculation results.

| Oscillatory Motion | | Experiment $T$ (s) | Experiment $f$ (Hz) | Theory $T$ (s) | Theory $f$ (Hz) |
|---|---|---|---|---|---|
| In-phase | Pendulum A | $1.42 \pm 0.05$ | $0.70 \pm 0.03$ | 1.54 | 0.65 |
| | Pendulum B | $1.42 \pm 0.02$ | $0.70 \pm 0.01$ | | |
| Inward Out-of-phase | Pendulum A | $0.67 \pm 0.04$ | $1.5 \pm 0.1$ | 0.55 | 1.83 |
| | Pendulum B | $0.66 \pm 0.06$ | $1.5 \pm 0.1$ | | |
| Outward Out-of-phase | Pendulum A | $0.7 \pm 0.1$ | $1.5 \pm 0.3$ | 0.55 | 1.83 |
| | Pendulum B | $0.7 \pm 0.1$ | $1.5 \pm 0.3$ | | |
| Out-of-phase of Pendulum A Fixed and Pendulum B Displaced | Pendulum A | $0.7 \pm 0.1$ | $1.5 \pm 0.3$ | 0.55 | 1.83 |
| | Pendulum B | $0.7 \pm 0.1$ | $1.5 \pm 0.3$ | | |
| Out-of-phase of Pendulum A Displaced and Pendulum B Fixed | Pendulum A | $0.67 \pm 0.08$ | $1.5 \pm 0.2$ | 0.55 | 1.83 |
| | Pendulum B | $0.7 \pm 0.1$ | $1.5 \pm 0.3$ | | |

**Table 2.** Uncertainties of Tracker software and analytical calculation.

| Oscillatory Motion | | $f_{tracker}$ (Hz) | $f_{count}$ (Hz) | Uncertainty (%) | $T_{tracker}$ (s) | $T_{count}$ (s) | Uncertainty (%) |
|---|---|---|---|---|---|---|---|
| In-phase | Pendulum A | 0.70 | 0.65 | 7 | 1.42 | 1.54 | 8 |
| | Pendulum B | 0.70 | 0.65 | 7 | 1.42 | 1.54 | 8 |
| Inward Out-of-phase | Pendulum A | 1.50 | 1.83 | 22 | 0.67 | 0.55 | 18 |
| | Pendulum B | 1.51 | 1.83 | 21 | 0.66 | 0.55 | 17 |
| Outward Out-of-phase | Pendulum A | 1.51 | 1.83 | 21 | 0.66 | 0.55 | 17 |
| | Pendulum B | 1.52 | 1.83 | 20 | 0.66 | 0.55 | 17 |
| Out-of-phase of Pendulum A Fixed and Pendulum B Displaced | Pendulum A | 1.52 | 1.83 | 20 | 0.66 | 0.55 | 17 |
| | Pendulum B | 1.51 | 1.83 | 21 | 0.66 | 0.55 | 17 |
| Out-of-phase of Pendulum A Displaced and Pendulum B Fixed | Pendulum A | 1.50 | 1.83 | 22 | 0.67 | 0.55 | 18 |
| | Pendulum B | 1.50 | 1.83 | 22 | 0.67 | 0.55 | 18 |


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In this study, we took two types of oscillations, namely: in-phase and out-of-phase motions. Based on the data analysis that has been done, the two types of oscillatory motions show that the results obtained are different. The factors that affect the oscillatory motion are the earth's acceleration of gravity (*g*) and the length of the rope (*l*). It can be seen in the in-phase motion that both pendulums move in the same direction. Meanwhile, the factors that influence the out-of-phase motion are the earth's gravity (*g*), the length of the rope (*l*), the spring constant (*k*), and the mass of the pendulum (*m*). It can be seen that in the experiment the two pendulums move in different directions. Thus, in the out-of-phase motion, it is possible to transfer energy between pendulums to one another, so that *m* and *k* affect or determine the value of *T* and *f*. Therefore, the out-of-phase oscillatory motion is faster than the in-phase oscillatory motion.

In this study, experiments on the oscillatory motion of a spring-coupled pendulum are carried out using a variation of five oscillatory motions, namely (see Figure 2): in-phase, inward out-of-phase, outward-out-of-phase, out-of-phase with pendulum A fixed and pendulum B displaced, and out-of-phase with pendulum A displaced and pendulum fixed B. The data analysis uses the Tracker software and the results are compared with the analytical calculation.

In the analysis using the Tracker software, data tables and graphs are obtained. The coupled system using a spring is obtained from data on the pendulums' position with respect to time. From the time data, it can be seen that the value of *T* is then used to determine the value of *f*. Meanwhile, analytical calculation is obtained using the equations of oscillatory motion. From this equation, *f* is obtained and then used to determine *T*. The results of *T* and *f* from the data analysis using the Tracker software and analytical calculation can be observed in Table 2.

Based on the results obtained from the analysis using the Tracker software and analytical calculation, it can be observed that there are differences in the results of *T* and *f* obtained. However, the difference between the experimental results and analytical calculations (theory) is not too different. The uncertainty of the results of this study is 7% to 22%, which can be interpreted that 78% to 93% of the data obtained in the spring coupled pendulum oscillation experiment are accurate. The uncertainty of the research results is obtained because of the difference between the results obtained using the Tracker software and analytical calculations. Some of the influencing factors include air friction and the mass of the string, which affect the pendulum's oscillatory motion, as well as the researchers' inaccuracy in measuring the time of the pendulum's oscillation. In the analytical solution, it is assumed that the air friction can be neglected. However, in the actual experiment, the air friction may affect the pendulums' oscillatory motion. Moreover, time tracking for determining *T* of the pendulums using the Tracker software depends upon the interpretation of the video by the researcher. This may lead to subjective decision making due to the uncertainty in determining the exact position of the pendulums in order to be counted as one period of oscillation.

## V. Conclusion

Based on the results of the research that has been conducted, it can be concluded that the period of the spring coupled pendulum oscillation analysed using the Tracker software is 1.42 s for the in-phase oscillation motion, while for the out-of-phase oscillation motions the period 0.7 s. These values are close to the period calculated analytically, namely: 1.54 s for the in-phase oscillation and 0.55 s for out-of-phase oscillation. The frequency of the spring coupled pendulum oscillations analysed using the Tracker software is 0.70 Hz for the in-phase oscillation, while for the out-of-phase oscillations the frequency is 1.50. These frequencies are close to the analytical calculations, namely: 0.65 Hz dan 1.83 Hz for the in-phase and out-of-phase oscillations, respectively. The differences in the period and frequency values between the Tracker software and analytical calcuations are caused by the limitations of this study. Various factors including air friction and masses of the string and pendulum may affect the values of the period and frequency. The limitation of the human hands in manually tracking the motion of the pendulum may play a role as well. Hence, recommendations for further studies include using the automatic tracking feature of the Tracker software, conducting the experiment in a condition with less air frition or larger pendulum mass, and using a reliable spring. On the other hand, introducing these limiations to students is an appropriate and/or arguably the best way to analyze the uncertainty that may occur in the experiment, hence providing students with the knowledge of experiment limitations and its uncertainty.

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## References

[1] A. M. Habib and Y. Pramudya, "Penentuan Frekuensi Osilasi pada Dua Pendulum Terkopel Menggunakan Arduino Uno dengan Sensor Ultrasonik," *J. Fis. Unand*, vol. 10, no. 1, pp. 15–21, Feb. 2021, doi: 10.25077/jfu.10.1.15-21.2021.

[2] D. Nurhadiyanto, *Getaran struktur*. Yogyakarta: K-Media, 2015.

[3] M. Rosales-Vera, "The simple pendulum motion by considering the mass of the string: Asymptotic corrections," *Phys. Scr.*, vol. 99, no. 4, p. 045236, Apr. 2024, doi: 10.1088/1402-4896/ad314f.

[4] M. C. de Sousa, F. A. Marcus, I. L. Caldas, and R. L. Viana, "Energy distribution in intrinsically coupled

systems: The spring pendulum paradigm," *Phys. A Stat. Mech. its Appl.*, vol. 509, pp. 1110–1119, Nov. 2018, doi: 10.1016/j.physa.2018.06.089.
[5] A. Kusumadjati *et al.*, "Simulasi 1D gerak osilasi terkopel di sumbu vertikal untuk menentukan amplitude maksimum benda terbawah," in *Prosiding SNIPS*, 2017, pp. 184–190.
[6] R. Espíndola *et al.*, "The Double Pendulum of Variable Mass: Numerical Study for different cases.," *J. Phys. Conf. Ser.*, vol. 1221, no. 1, p. 012049, Jun. 2019, doi: 10.1088/1742-6596/1221/1/012049.
[7] E. Pratidhina, D. Rosana, and H. Kuswanto, "Implementation of a Tracker-Assisted Modeling Activity in an Online Advanced Physics Experiment Course," *J. Educ. e-Learning Res.*, vol. 8, no. 2, pp. 222–229, 2021, doi: 10.20448/journal.509.2021.82.222.229.
[8] M. Campbell *et al.*, "A computer vision approach to monitor activity in commercial broiler chickens using trajectory-based clustering analysis," *Comput. Electron. Agric.*, vol. 217, p. 108591, Feb. 2024, doi: 10.1016/j.compag.2023.108591.
[9] S. Trocaru, C. Berlic, C. Miron, and V. Barna, "Using Tracker as video analysis and augmented reality tool for investigation of the oscillations for coupled pendula," *Rom. Reports Phys.*, vol. 72, p. 902, 2020, [Online]. Available: https://rrp.nipne.ro/2020/AN72902.pdf
[10] H. M. Saeed, "Wave motion in continuous mono-coupled locally periodic structures," *Wave Motion*, vol. 127, p. 103290, Jun. 2024, doi: 10.1016/j.wavemoti.2024.103290.
[11] H. J. Pain, *The Physics of Vibrations and Waves*. John Wiley and Sons, 2015.
[12] R. N. Jazar and H. Marzbani, "Springs," in *Vehicle Vibrations*, Cham: Springer International Publishing, 2024, pp. 3–14. doi: 10.1007/978-3-031-43486-0_1.
[13] T. Ranjan Pradhan, D. Aniket Sunil, and A. Shrivastava, "Static Structural Analysis of Suspension System," *J. Mater. Eng.*, vol. 2, no. 1, pp. 28–34, Jan. 2024, doi: 10.61552/JME.2024.01.003.
[14] W. Feng *et al.*, "A Contactless Coupled Pendulum and Piezoelectric Wave Energy Harvester: Model and Experiment," *Energies*, vol. 17, no. 4, p. 876, Feb. 2024, doi: 10.3390/en17040876.
[15] R. A. Serway and J. W. Jewett, *Physics for Scientists and Engineers with Modern Physics*. Thomson-Brooks/Cole, 2014.
[16] A. Mirbakhsh, J. Lee, and D. Besenski, "Spring–Mass–Damper-Based Platooning Logic for Automated Vehicles," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2677, no. 5, pp. 1264–1274, May 2023, doi: 10.1177/03611981221143121.
[17] D. Brown and A. J. Cox, "Innovative Uses of Video Analysis," *Phys. Teach.*, vol. 47, no. 3, pp. 145–150, Mar. 2009, doi: 10.1119/1.3081296.
[18] L. K. Wee, K. K. Tan, T. K. Leong, and C. Tan, "Using Tracker to understand 'toss up' and free fall motion: a case study," *Phys. Educ.*, vol. 50, no. 4, pp. 436–442, Jul. 2015, doi: 10.1088/0031-9120/50/4/436.
[19] T. Firdaus, W. Setiawan, and I. Hamidah, "The Kinematic Learning Model using Video and Interfaces Analysis," *J. Phys. Conf. Ser.*, vol. 895, p. 012108, Sep. 2017, doi: 10.1088/1742-6596/895/1/012108.
[20] W. S. B. Dwandaru, D. F. Zulaikha, R. W. M. Sulaindra, D. G. SL, and E. S. Ayu Listari, "Measuring the refraction index of luminescent carbon nanodots forming Gaussian beam using the tracker software," *Rev. Mex. Física E*, vol. 21, no. 1, p. 010207, Jan. 2024, doi: 10.31349/RevMexFisE.21.010207.
[21] R. Repnik, D. Robič, and I. Pesek, "Physics Learning in Primary and Secondary Schools with Computer Games—An Example — Angry Birds," in *E-Learning - Instructional Design, Organizational Strategy and Management*, InTech, 2015, pp. 203–226. doi: 10.5772/60604
[22] A. Asrizal, Y. Yohandri, and Z. Kamus, "Studi Hasil Pelatihan Analisis Video dan Tool Pemodelan Tracker pada Guru MGMP Fisika Kabupaten Agam," *J. Eksakta Pendidik.*, vol. 2, no. 1, pp. 41–48, May 2018, doi: 10.24036/jep/vol2-iss1/84.
[23] A. Anissofira, F. D. E. Latief, L. Kholida, and P. Sinaga, "Newton's Cradle Experiment Using Video Tracking Analysis with Multiple Representation Approach," *J. Phys. Conf. Ser.*, vol. 895, p. 012107, Sep. 2017, doi: 10.1088/1742-6596/895/1/012107.
[24] X. Ai *et al.*, "A Common Tracking Software Project," *Comput. Softw. Big Sci.*, vol. 6, no. 1, p. 8, Dec. 2022, doi: 10.1007/s41781-021-00078-8.

## Declarations

**Author contribution** : Ananda Aprilia was responsible for the data collection and data analysis of the research project. She also led the writing of the manuscript and the collaboration with the second author. Wipsar Sunu Brams Dwandaru participated in the initial idea of the research project and supervising the project. He also wrote and revised the manuscript. Both authors approved the final manuscript.

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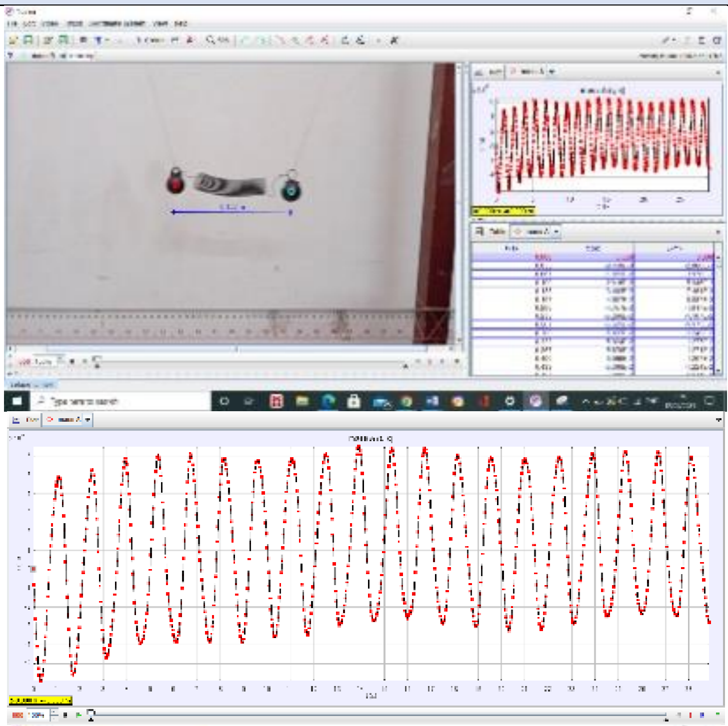
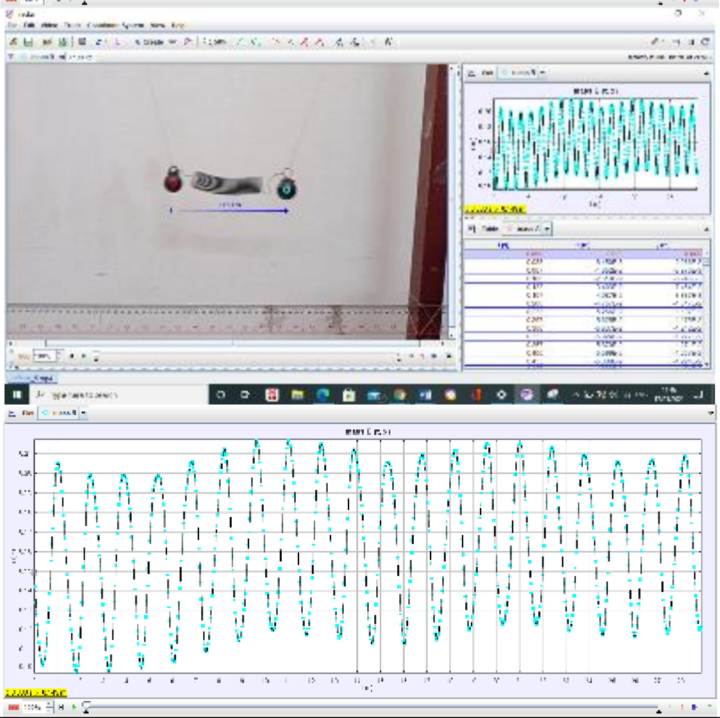
**Conflict of interest** : Both authors declare that they have no competing interests.

**Additional information** : No additional information is available for this paper.

**Appendix A**: Observation results.

**Table 3.** Observation results using the Tracker.

| No. | Oscillatory Motion | Results Tracker and Graphs |
|---|---|---|
| 1. | In-phase (Pendulum A) |  |
| | In-phase (Pendulum B) |  |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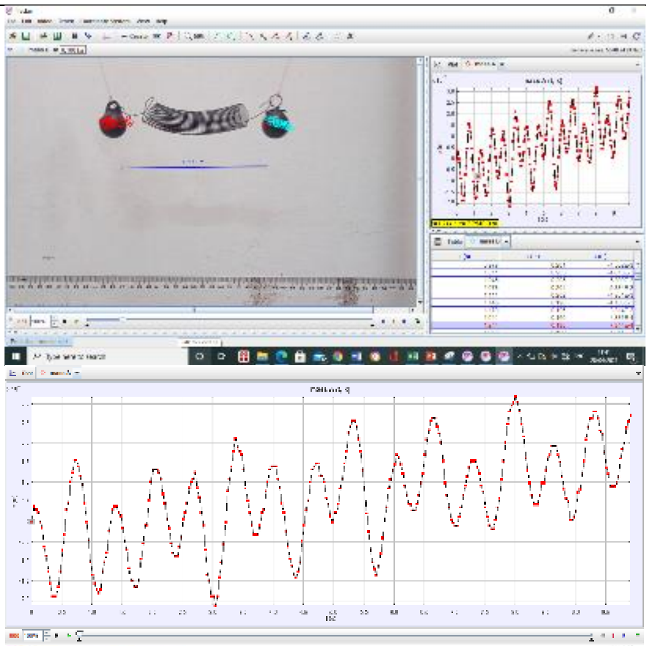
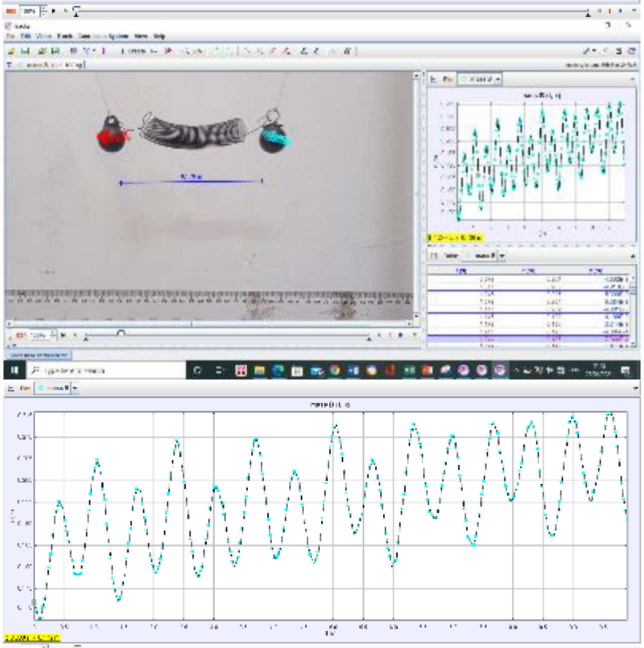
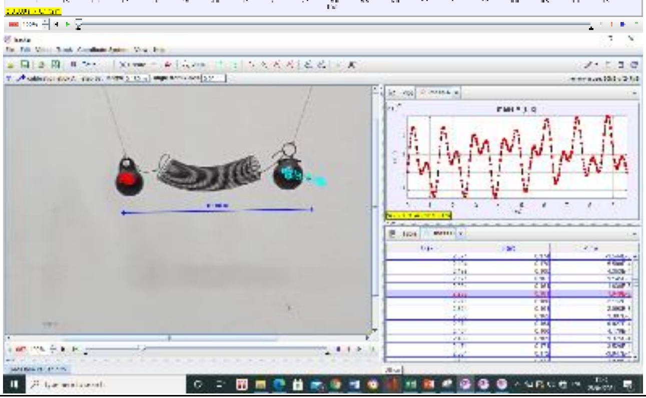
| | | |
|---|---|---|
| 2 | Inward out-of-phase (Pendulum A) |  |
| | Inward out-of-phase (Pendulum B) |  |
| 3 | Outward out-of-phase (Pendulum A) |  |



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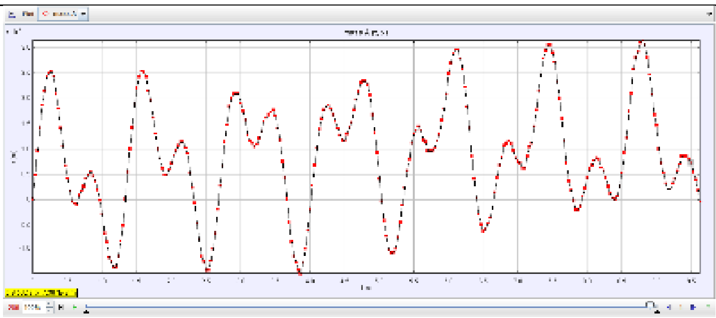
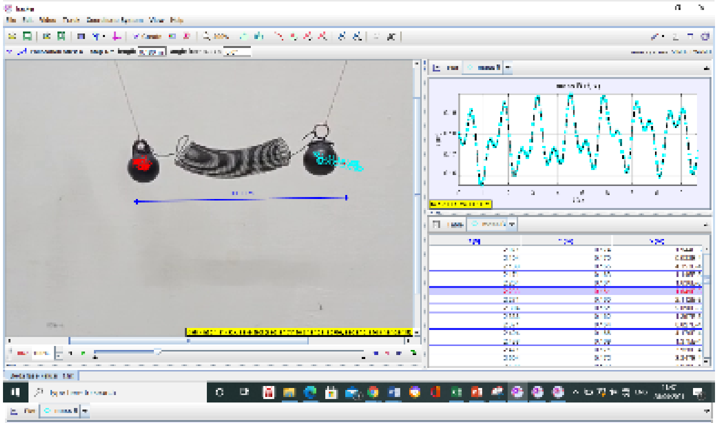
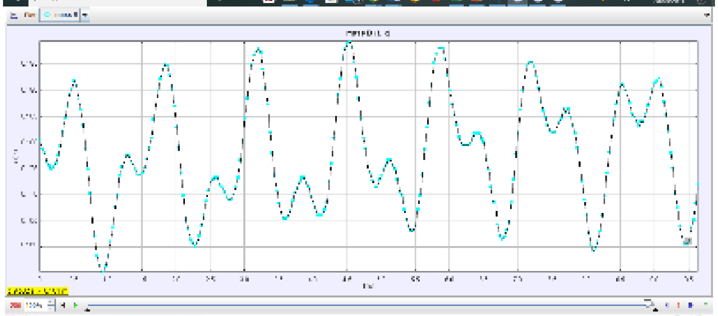
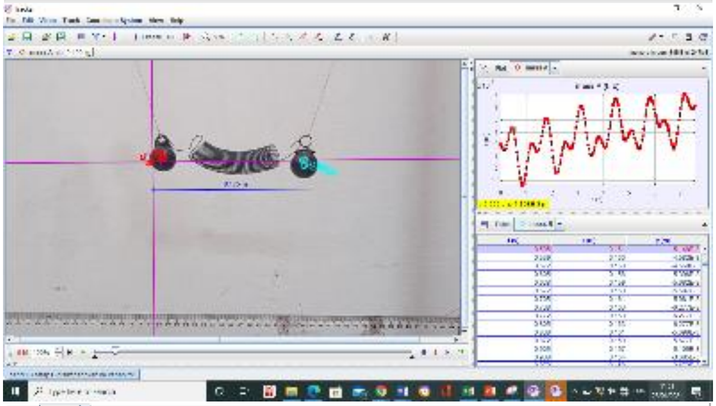
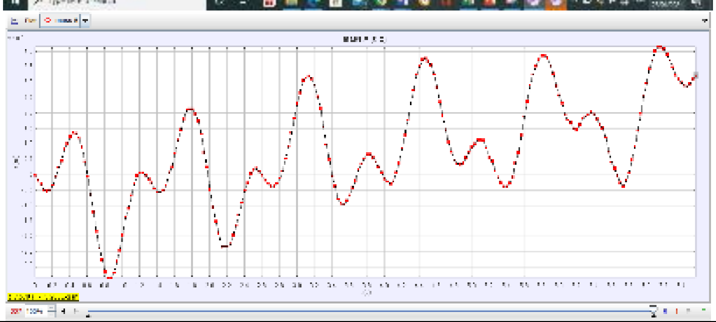
| | | |
|---|---|---|
| | |  |
| | Outward out-of-phase (Pendulum B) |   |
| 4 | Out-of-phase of Pendulum A Fixed and Pendulum B Displaced (Pendulum A) |   |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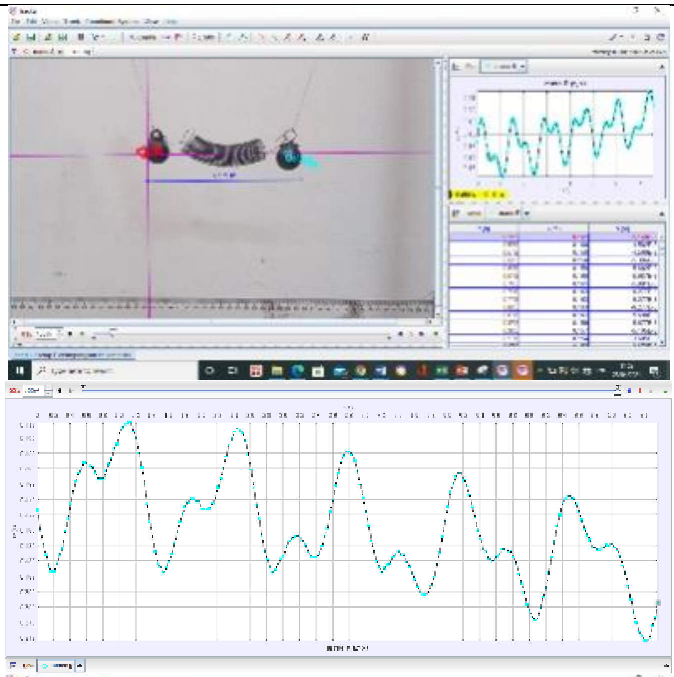
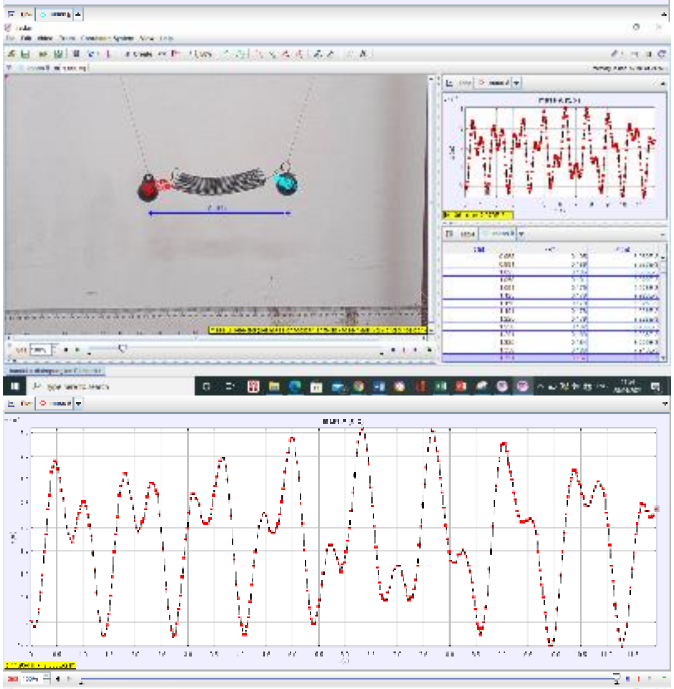
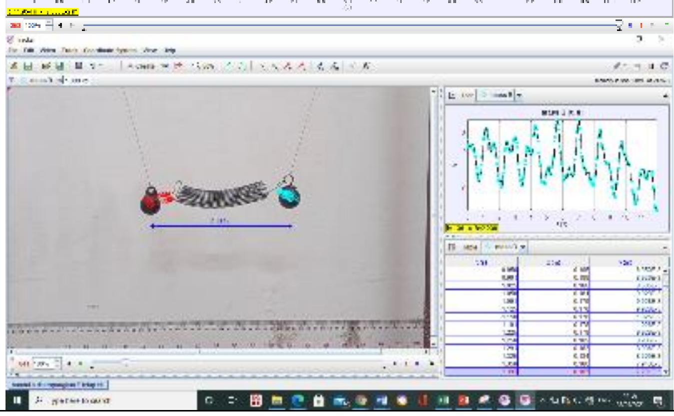
| | | |
|---|---|---|
| | Out-of-phase of Pendulum A Fixed and Pendulum B Displaced (Pendulum B) |  |
| 5 | Out-of-phase of Pendulum A Displaced and Pendulum B Fixed (Pendulum A) |  |
| | Out-of-phase of Pendulum A Displaced and Pendulum B Fixed (Pendulum B) |  |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