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Arduino-Based Vibration System with Phyphox for Physics Education

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Abstract
The study aims to develop an Arduino-based vibration system integrated with the Phypox application as an inexpensive and portable physics learning tool. This system is designed to generate controlled mechanical vibrations and record real-time oscillation data using a smartphone accelerometer. The experimental results show that the system produces a very stable vibration frequency of approximately 49.74 Hz, supported by a very small standard deviation (SD = 0.00203 Hz). Linear regression analysis between the vibration duration and the number of oscillations resulted in R^2 = 0.9999997, indicating an almost perfect linear relationship. These findings are in line with previous studies that demonstrate the effectiveness of smartphone sensors for harmonic motion analysis and digital-based practical activities. The integration of Arduino and Phyphox also supports discovery-based learning, as emphasized in the *Kurikulum Merdeka*, by providing easily accessible experimental tools to enhance scientific skills. This research offers a practical solution for schools with limited laboratory facilities and highlights the potential for further development in the study of resonance, forced vibration, and digital signal analysis.

INTRODUCTION

Physics is a branch of natural science that explains various natural phenomena through a scientific and systematic approach. Understanding the concepts of vibration and waves is very important because they form the basis for various technological applications, from sensors and communications to modern instrumentation (Iman, 2022). Recent studies confirm that mastery of wave concepts provides an important foundation for understanding signal-based technologies and oscillation systems that are widely used in modern life (Boimau & Laos, 2024; Evains et al., 2024). Furthermore, understanding the principles of oscillation and wave propagation opens up opportunities for integrating physics concepts into engineering, health, and digital systems (Pirinen et al., 2024).

However, physics education in schools still faces challenges, especially with abstract material such as vibrations, which require visual representation and direct laboratory experience. Limited laboratory facilities, such as the unavailability of oscilloscopes or vibration generators, often pose a major obstacle to the learning process. This situation results in low student engagement and difficulty in understanding phenomenon-based concepts (Julianto et al., 2024; Nabil et al., 2023; Raharja et al., 2025; Yasaroh et al., 2021).

The implementation of the *Kurikulum Merdeka* emphasizes discovery-based learning, hands-on experiments, and the use of digital technology to improve students' science literacy. An academic study of the *Kurikulum Merdeka* (Kemendikbudristek, 2024) emphasizes the importance of investigative activities, data analysis, and the use of sensor-based instruments as part of strengthening scientific reasoning. This policy direction is in line with international frameworks such as the Next Generation Science Standards (NGSS), which place investigation design and the use of digital measuring instruments as key competencies for the 21st century.

Recent studies show that the use of smartphone sensors in physics education can improve the quality of scientific investigation because these devices enable portable, real-time experiments that are easy for students to operate. Imtinan & Kuswanto (2023) emphasize that Phyphox provides direct access to a variety of built-in smartphone sensors and supports accurate and relevant quantitative experiments for 21st century learning. Similarly, Sari & Wahyuni (2025) found that the use of Phyphox-based practical e-modules can increase student engagement and understanding through independent, flexible, and digitally-based experimental activities.

In this context, the need for inexpensive, portable, and accurate experimental devices is becoming increasingly important, especially for schools with limited laboratory facilities. Research over the past 5 years shows that simple digital devices, including smartphone sensors, can improve science process skills and the quality of inquiry-based physics learning. Therefore, the development of an Arduino-based vibration system integrated with a smartphone accelerometer sensor is a relevant solution to support modern laboratory practices and aligns with the demands of the *Kurikulum Merdeka.*

Advances in digital technology in the Industry 4.0 era have also led to the emergence of innovative learning tools, one of which is the Phyphox (Physical Phone Experiments) application, which utilizes smartphone sensors to measure physical quantities in real time. Recent research shows that Phyphox improves students' access to independent experiments, especially in inquiry-based learning and distance learning (Sayyadi et al., 2024). However, this application cannot generate physical vibration without external devices.

Recent studies show various efforts to develop smartphone-based experiment support devices. For example, Yasaroh et al. (2021) developed sensor-based experiments to determine moment of inertia, while Raharja et al. (2025) developed smartphone-based mechanics modules. However, devices capable of generating controlled vibrations while analyzing the signals in a single integrated system are still limited. This creates a need for inexpensive, portable, and easy-to-operate practical tools for students.

Therefore, the development of an Arduino-based vibration motor system integrated with Phyphox is an important innovation in modern physics education. This system allows students to generate vibrations with controlled frequencies while recording data in real time via a smartphone. Its probability and efficiency make this tool relevant for schools with limited facilities and for independent learning. This study aims to test the frequency stability and the system's ability to record vibrations so that it can become a low-cost digital practical solution.

METHOD

This study applies an experimental design to develop and evaluate the performance of an Arduino-based vibration motor system integrated with the Phypox application. The research procedure follows five main components: system design, frequency control programming, data acquisition, calibration validation, and data analysis (see Figure 1.).

1. System Design and Hardware Configuration: The vibration system was assembled using Arduino Uno, a Linear Resonant Actuator (LRA) type DC motor, a transistor as a current amplifier and controller, a 10 kΩ resistor as a current limiter, and a reverse current protection diode. The circuit diagram is shown in Figure 2, which confirms the voltage distribution flow and the role of each component in maintaining motor stability. The Arduino Uno was chosen based on empirical findings that this microcontroller platform is effective for constructing low-cost, portable laboratory instrument precision

(Rainhate & Koto, 2023). The microcontroller is programmed through the Arduino IDE to operate the motor at five different time intervals, namely 5, 10, 15, 20, and 25 seconds.
2. Reasons for Selecting a Vibration Frequency of Around 50 Hz: The frequency range of around 50 Hz was selected based on pedagogical and technical considerations. From a pedagogical perspective, low frequencies are easier to observe, analyze, and interpret in the context of physics education. Technically, LRA motors tend to produce stable vibrations in this range. Recent findings from Caminos et al. (2024) show that accelerometers in various smartphone models have optimal accuracy at low frequencies, with some devices only capable of recording accurate signals up to around 50 Hz. The selection of low frequencies also reduces the potential for aliasing and simple rate instability, thereby increasing data reliability.
3. Data Collection Using Phyphox: Measurements of frequency, period, and acceleration of vibration were performed using the Phyphox application, which accesses the smartphone's internal accelerometer. During operation, the motor was placed on the surface of the smartphone screen, which served as a platform for recording real-time oscillations using a high sampling rate. The effectiveness of using smartphones as experimental instruments has been proven through several studies. Rohman & Nurhayati (2020) reported that the use of smartphone sensors increases measurement accuracy while strengthening science process skills. Abdullah et al. (2021) emphasized that digital devices can support inquiry-based learning by providing real-time data that can be processed directly by students. Furthermore, Mehamud et al. (2023) showed that modern digital sensors have high sensitivity in recording mechanical vibrations, thereby strengthening the validity of this approach
4. Calibration and Validation Procedures: Accuracy validation is performed by comparing the Phypox measurement result with the frequency reference generated by a function generator and digital oscilloscope. The smartphone is placed on a calibrated vibration platform and vibrated at several standard frequencies. The measurement deviation obtained is within a small range, so the system is declared valid as an economical and accurate alternative laboratory instrument.
5. Research Variables and Data Analysis Techniques: The independent variable is the duration of motor operation (5-25 seconds). the dependent variables include vibration frequency, period, and number of oscillations measured by Phyphox. Data analysis was performed descriptively and quantitatively to assess frequency stability and the linear relationship between motor activation duration and the number of oscillations produced.

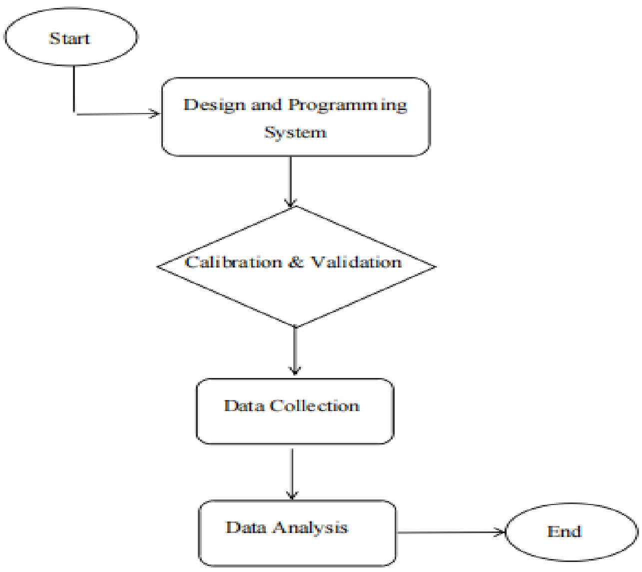

Figure 1. Research Flowchart

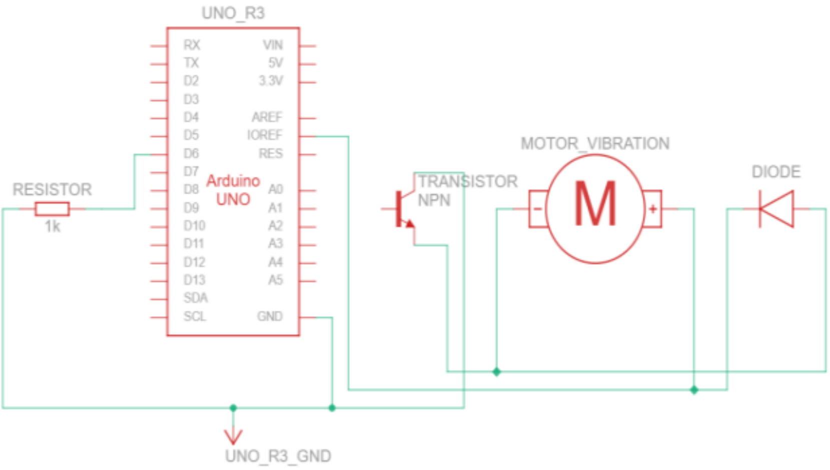

Figure 2. System Circuits

RESULT AND DISCUSSION

The frequency data obtained through the Phyphox application shows a very high level of stability across all measurement intervals. The average frequency recorded was 49.7387 Hz with a standard deviation of SD = 0.00203 Hz, which illustrates very small fluctuations in the motor vibration output. The standard deviation value was calculated based on the standard deviation equation:

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}}$$

where x_i is the individual frequency, $\bar{x}$ is the average frequency, and N is the amount of data. This stability shows that the Arduino-controlled LRA motor is capable of maintaining a consistent rotation speed, making it ideal for vibration-based physics experiments.

To further assess the consistency of the system, a linear regression analysis was performed between the motor activation duration and the number of vibrations recorded by Phyphox. The analysis results produced a coefficient and an almost perfect linear relationship. The R^2 value was calculated using the equation:

$$R^2 = \left(\frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}\right)^2$$

where x_i is the motor activation time, y_i is the number of vibrations, $\bar{x}$ and $\bar{y}$ are the average values of both variables. This value, which is very close to 1, confirms that the increase in the number of vibrations is directly proportional to the motor activation time, while also reflecting excellent frequency stability (see Figure 3.).

This finding is consistent with previous research by Harjono (2021), which showed that accelerometers on smartphones, when operated using applications such as Phyphox, are capable of detecting oscillatory motion with high precision comparable to laboratory sensors. Furthermore, this strong linearity is also in line with Pirinen et al. (2024), who proved the accuracy of smartphone-based spectral analysis in frequency measurement. In this context, *n* represents the number of vibrations, *f* is the frequency (Hz), and *t* is the duration of time (seconds).

The data in Table 1. shows a consistent increase in vibration as the motor activation duration increases, reinforcing the conclusion that the system can accurately record vibration data. Phyphox also facilitates real-time measurement and efficient data export, supporting further analysis.

In terms of implementation, this system offers several advantages, namely high portability, ease of use, and much lower costs compared to conventional laboratory instruments such as oscilloscopes. These advantages make the Arduino Phyphox system a relevant alternative for schools or institutions with limited laboratory facilities.

However, there are several limitations that need to be considered. The frequency range that can be generated is highly dependent on the specifications of the LRA motor, and the use of smartphones as the main measuring devices causes variations in performance between devices. These limitations can be an obstacle in learning environments that do not have uniform digital devices.

Overall, the results of this study indicate that the Arduino Phyphox system is effective as an inexpensive, accurate, and suitable mechanical vibration laboratory tool for physics education. Further development is recommended, such as the implementation of multilevel frequency control and expansion of the frequency range produced, so that this tool can be used in more types of experiments and meet the needs of more complex physics education.

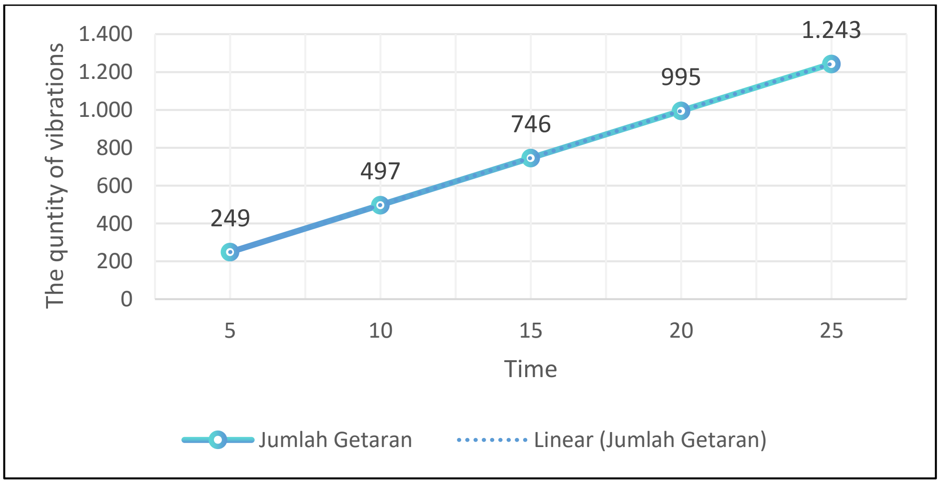

Figure 3.Effect of time on the quantity of vibrations

Table 1.Experimental Data

No	Time (s)	Frequency (Hz)	Period (s)	The quantity of vibrations
1.	5	49.73993454	0.020104570085347	248.6996727
2.	10	49.73519107	0.0201064875490786	497.3519107
3.	15	49.73982916	0.0201046126793733	746.0974374
4.	20	49.73674958	0.0201058575086724	994.7349916
5.	25	49.73995356	0.020104562397585	1,243.498839

CONCLUSION

The Arduino Phyphox vibration system developed in this study proves that low-cost, portable, and easy-to-assemble digital instruments can produce highly stable and accurate frequency measurements for physics education purposes. Statistical analysis shows a very small frequency standard deviation (SD= 0.00203 Hz) and an almost perfect linear relationship between motor activation duration and number of vibrations (R^2 = 0.9999997). These findings confirm that the Arduino Phyphox system can serve as an effective alternative to some conventional laboratory equipment, especially in schools or institutions with limited facilities. In addition, the characteristics of this digital technology-based system are in line with the *Kurikulum Merdeka* and Next Generation Science Standards (NGSS), which emphasize investigation-based learning, experimentation, and real-time data analysis.

This system also has broad potential for further development. Its ability to generate and record vibrations with adjustable parameters allows for application, including resonance, simple harmonic motion, damped and forced vibrations, and spectrum analysis using Fast Fourier Transform (FFT) with simple modifications, such as adding additional sensors or re-configuring the load mass and motor control, this system can be expanded for studies related to waves, superposition, and modal characteristics. Its high portability and compatibility with various types of smartphones make this system ideal for classroom demonstrations, student independent projects, as well as distance learning and virtual laboratories.

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