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Development of a Simple Harmonic Motion Data Acquisition System Based on Arduino and LabVIEW for Basic Physics Practicum

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Abstract

This study aims to develop a data acquisition system for measuring Simple Harmonic Motion (SHM) using an Arduino Mega, a VL53L0X distance sensor, and LabVIEW for Basic Physics laboratory activities. The research employed a Research and Development (R&D) approach consisting of needs analysis, hardware and software design, prototype assembly, system testing, and expert and user validation. The developed system is capable of acquiring displacement data continuously and determining the spring constant using both the extension and oscillation methods. Experimental results showed that the extension method produced a stable spring constant of 9.8 N/m, while the oscillation method yielded an average value of 8.69 N/m with a relative error of 11.29%. The relative error decreased as the number of oscillations increased, indicating improved measurement stability for longer-duration observations. Expert validation classified the system as highly feasible, while student responses indicated a very high practicality level of 96.57%. Several previous studies have primarily focused on technical data acquisition systems without emphasizing interactive laboratory implementation. Therefore, this study integrates LabVIEW-based interactive visualization with SHM laboratory activities to support more engaging and technology-enhanced physics practicum learning. Overall, the developed system demonstrates adequate performance and practicality for Basic Physics laboratory learning.

Keywords: *Arduino, Simple Harmonic Motion, LabVIEW, Learning, Spring.*

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1. INTRODUCTION

Physics learning plays an important role in helping students understand various natural phenomena and technological applications through experimental and analytical activities. A solid understanding of physics concepts is essential in various fields, including engineering, materials science, and applied sciences. One of the fundamental concepts in physics is Simple Harmonic Motion (SHM), which is widely applied in various mechanical and electronic systems (Serway & Jewett, 2018).

In physics education, laboratory activities play a vital role in enhancing students' understanding of theoretical concepts. However, laboratory implementation often encounters challenges, particularly in obtaining accurate and continuous data acquisition. One potential solution to this issue is the development of a technology-based data acquisition system that facilitates students in directly observing and analyzing physical phenomena (Halliday et al., 2013; Hidayat & Sari, 2021).

Arduino is a widely used microcontroller platform in physics experiments due to its flexibility, ease of programming, and affordability. By utilizing Arduino, measurement data of simple harmonic motion in a spring–mass system can be acquired with adequate precision and transmitted to a computer for further processing (Banzi & Shiloh, 2014). One of the software platforms that can be employed for data analysis and visualization is LabVIEW. LabVIEW provides an intuitive interface and is capable of displaying data graphically, thereby assisting students in understanding the characteristics of simple harmonic motion more effectively (Travis & Kring, 2006; Bagenda & Rudati, 2020).

Several previous studies have reported the use of Arduino-based systems and LabVIEW interfaces for physics experiments and data acquisition (Taneo et al., 2021; Bulaka et al., 2025). However, most of these studies primarily focused on technical measurement and monitoring aspects without emphasizing interactive visualization and implementation in Basic Physics laboratory learning. In addition, studies specifically integrating the VL53L0X distance sensor, oscillation analysis, and educational practicality evaluation within a Simple Harmonic Motion (SHM) laboratory system are still limited (Wulandari & Sari, 2023). Therefore, there is a need for a more integrated and user-friendly SHM data acquisition system that not only performs continuous measurement and visualization but also supports interactive laboratory activities and technology-enhanced physics practicum learning.

This study aims to design and implement a data acquisition system for measuring simple harmonic motion in a spring–mass system based on Arduino and LabVIEW as a medium for basic physics laboratory activities (Bulaka et al., 2025). Through this system, students are expected to conduct experiments more efficiently, obtain more stable measurement data, and perform oscillation analysis more interactively.

Unlike previous studies that mainly emphasized data acquisition performance, this study integrates Arduino Mega, VL53L0X sensor-based oscillation detection, and LabVIEW interactive visualization into a single laboratory learning system specifically designed for SHM experiments in Basic Physics courses. Furthermore, the developed system combines technical performance testing with expert validation and student practicality evaluation to support more effective and modern laboratory implementation.

Based on the background described above, the research problems are formulated as follows: (1) How can a data acquisition system for measuring simple harmonic motion in a spring–mass system based on Arduino and LabVIEW be designed? (2) How accurate is the developed system in measuring SHM parameters, particularly in determining the spring constant (k) based on spring oscillations? and (3) How practical and feasible is the implementation of this system as a Basic Physics laboratory medium based on expert validation and student responses?

2. METHODS

The study employed a Research and Development (R&D) method adapted from the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Sugiyono, 2019; Waruwu, 2024). In this study, the stages included: (1) needs analysis, (2) hardware and software design, (3) prototype assembly and development, (4) preliminary testing and calibration, and (5) evaluation and refinement. The ADDIE-based approach was selected because it provides systematic procedures for developing and evaluating educational technology products.

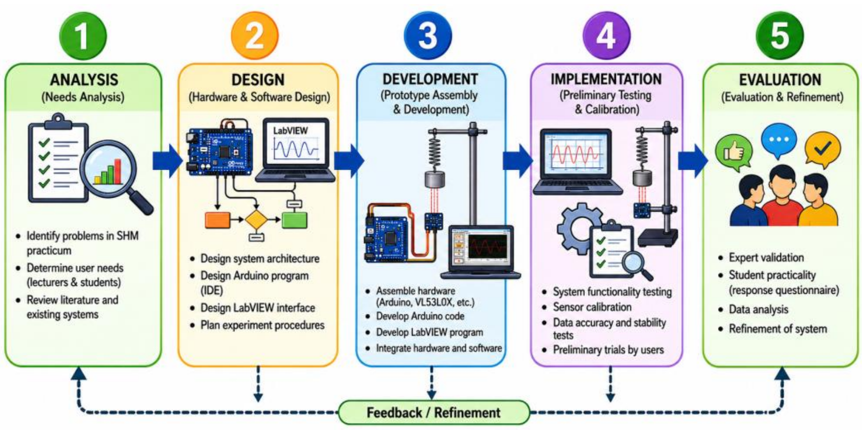


Figure 1. Research Design (ADDIE-based R&D Approach)

The research was conducted from June to December 2025 in the Physics Laboratory and in Basic Physics classes at Universitas Sembilanbelas November Kolaka. The research subject was the developed data acquisition system. The initial validation involved media experts, subject-matter experts, and students participating in the Basic Physics laboratory course.

The VL53L0X distance sensor was used to detect the displacement of the oscillating spring mass continuously through serial communication between Arduino Mega and LabVIEW. Prior to data collection, the sensor was calibrated by comparing the sensor readings with manual distance measurements using a ruler at several reference positions. This calibration procedure was conducted to minimize measurement deviation and improve reading consistency during oscillation experiments.

The procedures in this study consisted of: (1) literature review and problem identification; (2) development of the hardware and software components of the system as a laboratory learning medium; (3) accuracy testing of the developed system; (4) validation testing of the developed system; and (5) implementation in Basic Physics laboratory classes.

The research instruments used in this study consisted of: (1) validation sheets for subject-matter and media experts, (2) student response questionnaires, and (3) LabVIEW output data sheets containing displacement, oscillation period, and spring constant measurement results. Meanwhile, the Arduino Mega-based SHM data acquisition system, the VL53L0X sensor, and the LabVIEW interface functioned as the developed research product rather than as research instruments.

The validation instruments were reviewed by subject-matter and media experts to ensure content validity and suitability for laboratory implementation. The student response questionnaire employed a four-point Likert scale to evaluate practicality aspects, including ease of use, interface clarity, usefulness, and operational effectiveness of the developed system.

The data analysis techniques in this study were designed to address three main research focuses: (1) the accuracy of the system in measuring simple harmonic motion (SHM) parameters; (2) the feasibility of the prototype as a laboratory learning medium as evaluated by experts; and (3) the practicality of the system based on students' responses. The analysis was conducted according to the type of data obtained from each research instrument, including both numerical data generated from sensor-based acquisition and qualitative data derived from observations and questionnaires. In addition to descriptive analysis, the measurement results were interpreted by observing data consistency, relative error trends, and variations among repeated measurements (Nduru et al., 2025).

a) Analysis of LabVIEW Output Data (Spring Constant Calculation)

The numerical data consisted of displacement (y), average period (T), spring extension (Δy), and the calculated value of the spring constant (k). The value of k was analyzed using two different calculation methods. The first method was based on spring extension (Δy), in which the spring constant was calculated using Hooke's Law equation:

$$k = \frac{m \cdot g}{\Delta y} \quad (1)$$

where k is the spring constant (N/m), m is the mass of the load (kg), g is the gravitational acceleration (9.8 m/s^2), and $\Delta y = y_2 - y_1$ represents the extension of the spring (m) (Taneo et al., 2021).

The data were interpreted by analyzing the stability of the k values obtained from three repeated trials. Since this method does not utilize a sensor, it was used as a reference value for comparison in evaluating the accuracy of the oscillation-based method.

For the second method, namely the spring oscillation method (period T), the spring constant was calculated based on the oscillation time using the following equation:

$$k = \frac{4\pi^2 m}{T^2} \quad (2)$$

Where T represents the average period (s), determined from the number of oscillations detected by the VL53L0X sensor, and m denotes the load mass (kg).

In the second method, the analysis focused on several factors, including the influence of the number of oscillations (n) on period stability, variations in the calculated spring constant (k) for n = 10, 20, and 30, and the decreasing error trend with increasing n, which reflects enhanced accuracy for long-duration measurements.

Furthermore, a relative error analysis was performed to compare the two methods and to assess the accuracy of the oscillation method relative to the extension method. The relative error was calculated using the following equation:

$$Relative\ Error = \left|\frac{k_{\Delta y} - k_T}{k_{\Delta y}}\right| \times 100\% \quad (3)$$

Where $k_{\Delta y}$ refers to the reference spring constant obtained from the extension method, while k_T represents the spring constant derived from the oscillation method (Bagenda & Rudati, 2020). The relative error analysis was conducted to assess the precision of the VL53L0X sensor and to determine contributing error factors, including sensor noise, initial amplitude variations, oscillation damping effects, and human interaction factors.

b) Expert Validation Analysis (Media and Subject-Matter Experts)

Likert-scale data were analyzed using the following equation:

$$Feasibility\ Percentage = \frac{Obtained\ Score}{Maximum\ Score} \times 100\% \quad (4)$$

The feasibility classification was determined according to the percentage-scale interpretation criteria established by (Lestari & Widodo, 2019). This analysis was conducted to assess the conceptual accuracy of the physics content, the precision of the data generated by the instrument, the quality of the user interface, and the overall suitability of the device for laboratory use.

c) Analysis of Student Response Questionnaire

The questionnaire comprised 15 items covering five aspects. The collected data were analyzed using the following equation:

$$Practicality\ Percentage = \frac{Total\ Score}{Maximum\ Score} \times 100\% \quad (5)$$

The practicality percentage obtained from student evaluations was used to determine the extent to which the simple harmonic motion data acquisition system is suitable for laboratory implementation (Hidayat & Sari, 2021). If the practicality percentage is ≥ 80%, the device is categorized as "Highly Practical," indicating that it is easy to operate, understandable, and aligned with students' learning needs. A percentage range of 60% - 79% is classified as "Practical," meaning that the device is sufficiently effective but still requires minor improvements. If the percentage is below 60%, the device is categorized as "Less Practical," indicating the need for significant revisions before laboratory implementation. Therefore, a higher practicality percentage reflects greater student acceptance of the device and demonstrates that it effectively and efficiently supports the learning process.

3. RESULTS AND DISCUSSION

System Design and Assembly

The development of the Arduino Mega-based Simple Harmonic Motion (SHM) data acquisition system began with the design of a schematic system layout. The proposed system architecture consists of three primary modules: (1) Input Module, where the spring oscillatory motion is detected by the VL53L0X time-of-flight distance sensor; (2) Processing Module, in which the Arduino Mega performs signal acquisition, filtering, and data processing before transmitting the processed data via serial communication protocol; and (3) Output and Visualization Module, where a laptop running LabVIEW receives the transmitted data and performs displacement-time graphical visualization and data monitoring. The integration of these modules enables continuous displacement measurement and synchronized visualization. The overall system architecture developed in this study is illustrated in Figure 2.

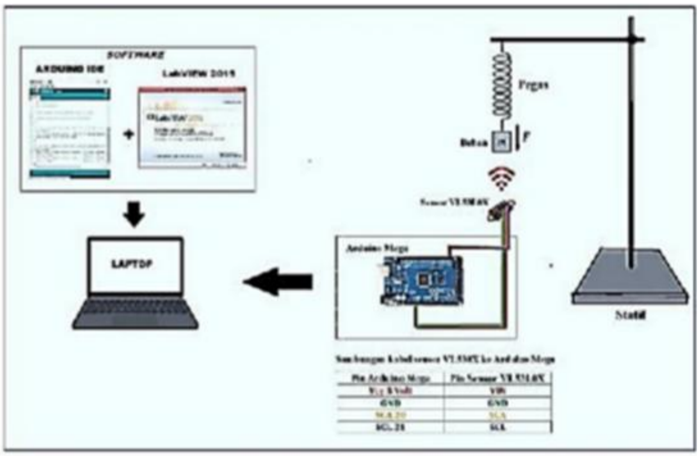


Figure 2. System architecture of the Arduino Mega and LabVIEW-based spring SHM apparatus

After completing the system layout, the hardware assembly was performed. The input module consists of a spring–mass system mounted on a retort stand. The processing module includes a VL53L0X distance sensor and an Arduino Mega board housed in an enclosure. The sensor measures the displacement of the oscillating mass, while the Arduino processes and transmits the data.

The output module is a laptop running Arduino IDE and LabVIEW, connected to the Arduino Mega via USB for displacement–time visualization. The assembled prototype is shown in Figure 3.

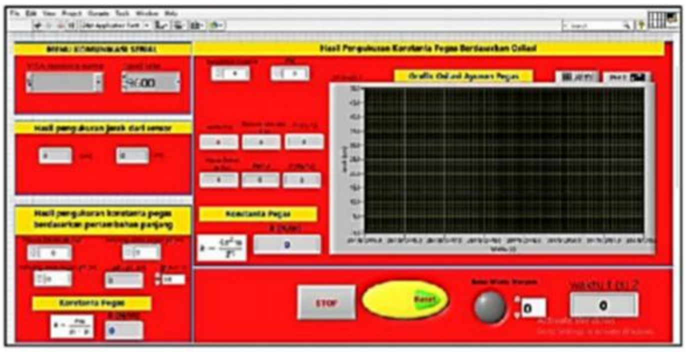
Figure 3. Hardware assembly of the proposed system

Software Development Using Arduino IDE and LabVIEW

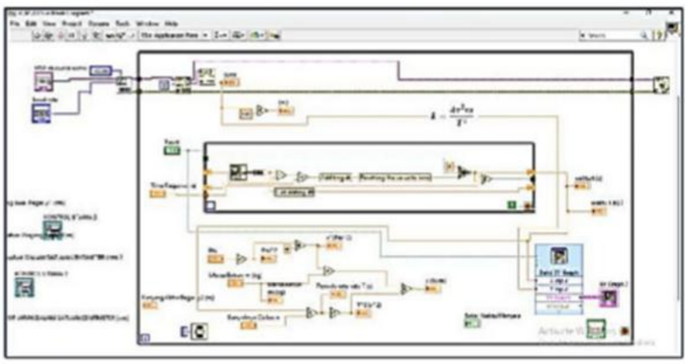
After the hardware assembly was completed, the software design stage was carried out, including the development of algorithms in Arduino IDE and LabVIEW. The process began with designing the Arduino algorithm, which was then uploaded to the Arduino Mega board. This programming process embeds instructions into the microcontroller to initialize the VL53L0X sensor, acquire and process signals, and transmit data in a format compatible with the serial communication protocol used by LabVIEW (Bagenda & Rudati, 2020). In this way, the Arduino IDE generates firmware that enables bidirectional data communication between Arduino and LabVIEW. The developed Arduino IDE algorithm is shown in Figure 4.

Figure 4. Arduino IDE Algorithm Design

After uploading the firmware to the Arduino Mega, the program was developed in LabVIEW 2015. LabVIEW is a graphical programming environment that functions as a platform for data acquisition, processing, and visualization. Real-time monitoring is performed using the VISA-based serial communication block without modifying the hardware configuration. The LabVIEW program operates and communicates with the VL53L0X sensor and the Arduino Mega board. The LabVIEW program design is shown in Figure 5.



(a)



(b)

Figure 5. LabVIEW program for spring SHM data acquisition: (a) Front Panel, (b) Block Diagram

System Testing (LabVIEW Output Data)

The system testing was conducted to evaluate the performance of the Arduino–LabVIEW-based data acquisition system in measuring the spring constant using two methods: (1) the spring extension method (Δx) and (2) the oscillation method. The evaluation focused on sensor reading stability, data consistency, and the accuracy of the spring constant displayed on the LabVIEW front panel.

In the extension method, the initial spring length (y_1) and final length (y_2) were measured using a Hooke's law apparatus. The mass (m) and gravitational acceleration (g) were manually entered into the LabVIEW front panel. When the LabVIEW program was executed, the spring extension (Δy) was automatically calculated and displayed.

Based on three experimental trials, the spring constant consistently yielded a value of 9.8 N/m. This consistency occurred because the length measurements were performed manually and remained unchanged across trials. Moreover, the VL53L0X distance sensor was not used in this method, eliminating digital reading fluctuations.

In the second method, the spring constant was determined from the oscillation time of the spring, which was processed numerically within the LabVIEW block diagram. The computed spring constant was then displayed on the LabVIEW front panel as the final output value. In this approach, the VL53L0X distance sensor was utilized to detect the spring's oscillatory motion in real-time. LabVIEW calculated the average period (T) based on a predetermined number of oscillations (n) prior to each experiment. This approach allows the period calculation to be based on multiple oscillation cycles, thereby improving measurement stability.

Three experimental trials were conducted with variations in the number of oscillations (n). The results obtained from these trials are presented in Table 1.

Table 1. Determination of the Spring Constant (k) Based on the Oscillation Method

n	T (s)	k (N/m)	Relative Error (%)
10	0.611	8.44	13.88
20	0.599	8.78	10.41
30	0.590	8.86	9.59
Average	-	8.69	11.29

Based on the results presented in Table 1, the calculated spring constant increases as the number of oscillations (n) increases. This occurs because measuring a larger number of cycles reduces the average timing error in the period measurement obtained from the sensor. The period (T) becomes more stable at higher oscillation counts, as indicated by the decreasing variation in measured period values across trials. Furthermore, the average spring constant obtained using the oscillation method is lower than the value obtained from the extension method (9.8 N/m). A comparison of the results from the two spring constant measurement methods is presented in Table 2.

Table 2. Comparison of Spring Constant Values and Relative Error Between the Extension and Oscillation Methods

Method	Sensor Dependency	Average k (N/M)	Average Relative Error (%)
Extension Method (Δy)	Not using a sensor	9.8	0 (reference value)
Oscillation Method	Using VL53L0X sensor	8.69	11.29

Based on Table 2, the relative error analysis shows that the oscillation method exhibits an error range of 9.59% - 13.88% with respect to the extension method (Δy), with an average value of 11.29%. The magnitude of this relative error is primarily influenced by several factors. First, the sensitivity of the VL53L0X sensor to small positional changes of the spring may introduce noise, particularly at the initial stage of oscillation, thereby affecting the period measurement. Second, slight variations in the oscillation period due to damping effects, although relatively small, still influence the estimation of the average period (T), especially in short-duration measurements.

Nevertheless, the decreasing trend in relative error from 13.88% (n = 10) to 9.59% (n = 30) indicates that a greater number of oscillations produces a spring constant value closer to the reference value. Thus, the oscillation method implemented in this system performs adequately; however, it requires a longer oscillation duration to achieve optimal measurement accuracy.

The decrease in relative error as the number of oscillations increased indicates that longer observation durations improve the stability of period measurements obtained by the VL53L0X sensor. This phenomenon occurs because averaging measurements over a larger number of oscillation cycles reduces the influence of timing fluctuations and initial transient errors during oscillation detection. In addition, damping effects and small positional variations of the spring become less significant when the oscillation period is calculated over multiple cycles. Therefore, increasing the number of oscillations contributes to producing a spring constant value that approaches the reference value obtained from the extension method.

Although the average relative error of 11.29% is still relatively higher than ideal precision laboratory instruments, this error range remains acceptable for educational laboratory applications, particularly for introductory Basic Physics practicum activities. Several factors may contribute to this error, including sensor sensitivity limitations, slight oscillation damping, environmental disturbances, and serial communication delay between Arduino and LabVIEW. Similar studies involving Arduino-based physics instrumentation also reported measurement deviations caused by sensor noise and oscillation instability during dynamic measurements (Taneo et al., 2021; Bagenda & Rudati, 2020).

The experimental results also demonstrate relatively consistent trends among repeated measurements, indicating that the developed system provides stable data acquisition performance for SHM experiments. The decreasing variation in period values with increasing oscillation cycles further suggests improved measurement consistency during longer-duration observations.

Expert Validation

Expert validation was conducted to evaluate the feasibility of the Simple Harmonic Motion (SHM) data acquisition system prototype as a Basic Physics laboratory medium. Two validators were involved: a subject-matter expert and a media expert.

The subject-matter expert assigned a score of 36 out of a maximum score of 40, corresponding to a feasibility percentage of 90%. This percentage indicates a very high level of feasibility, and the system was therefore categorized as "*Highly Feasible*". The results demonstrate that the device is consistent with the physics concepts of Simple Harmonic Motion and learning competencies, capable of presenting representative oscillation data and graphical visualization, and supported by a sufficiently clear practicum module to facilitate experimental activities. The subject-matter expert provided minor recommendations, including improving the clarity and systematic structure of the practicum module and enhancing sensor data accuracy through calibration.

The media expert assigned a score of 36 out of 40, corresponding to a feasibility percentage of 87.5%, which categorizes the system as "*Highly Feasible*" as a laboratory learning medium. This percentage indicates that nearly all evaluated aspects including interface design, clarity of information, sensor reading stability, Arduino reliability, as well as the neatness and safety of the hardware construction meet a very high-quality standard.

The result also reflects that the system effectively performs its primary function of displaying oscillation data and is easy for students to operate, with only minor shortcomings. Therefore, the 87.5% score confirms that the device is highly ready for implementation in Basic Physics laboratory activities.

However, the validator recommended further development, including the addition of a relative error indicator panel on the LabVIEW front panel to display the relative error between the spring constant obtained from the extension method (as the reference) and that obtained from the oscillation method, enabling clearer comparison between the two measurement approaches. In addition, simplification of the operating procedure was suggested to make the system more accessible for beginner students.

Based on the validation results from both the subject-matter expert and the media expert, it can be concluded that the developed Simple Harmonic Motion (SHM) data acquisition system prototype meets a very high feasibility standard as a Basic Physics laboratory medium. Both experts assigned high ratings, categorizing the system as "*Highly Feasible*".

These results indicate that the device is consistent with fundamental physics concepts, capable of presenting oscillation data accurately and representatively, and equipped with an interface design and hardware construction that support its implementation in educational laboratory settings.

Student Response Analysis

The results of the questionnaire completed by all respondents including the total score, mean score, percentage of the maximum score, and the evaluation category for each student are presented in Table 3.

Table 3. Student Questionnaire Responses to the Developed System

No	Respondent	Total Score	Maximum Score	Mean	Percentage (%)	Category
1	R1	59	60	3.93	98.33	Highly Practical
2	R2	60	60	4.00	100.00	Highly Practical
3	R3	59	60	3.93	98.33	Highly Practical
4	R4	57	60	3.80	95.00	Highly Practical
5	R5	60	60	4.00	100.00	Highly Practical
6	R6	60	60	4.00	100.00	Highly Practical
7	R7	60	60	4.00	100.00	Highly Practical
8	R8	59	60	3.93	98.33	Highly Practical
9	R9	54	60	3.60	90.00	Highly Practical
10	R10	57	60	3.80	95.00	Highly Practical
11	R11	59	60	3.93	98.33	Highly Practical
12	R12	60	60	4.00	100.00	Highly Practical
13	R13	57	60	3.80	95.00	Highly Practical
14	R14	46	60	3.07	76.67	Practical
15	R15	58	60	3.87	96.67	Highly Practical
16	R16	60	60	4.00	100.00	Highly Practical
17	R17	60	60	4.00	100.00	Highly Practical
	Total	**985**	**1020**	**65.67**	**1641.67**	
	Average	**57.94**	**60**	**3.86**	**96.57**	**Highly Practical**

Based on the data presented in Table 3, the total score obtained was 985 out of a maximum of 1020, with an average score of 57.94 out of 60 per student. When converted to the average score per item, the result was 3.86 out of 4, indicating a very high evaluation across all assessed aspects. The overall average practicality percentage was 96.57%, which, according to the interpretation criteria, falls into the "Highly Practical" category.

These results indicate that students expressed very positive perceptions of the developed data acquisition system prototype. The consistently high ratings from nearly all respondents suggest that the system is easy to operate, features a clear and user-friendly interface, and presents oscillation data in an informative manner. Furthermore, the system was perceived to improve laboratory efficiency and to assist students in observing and analyzing Simple Harmonic Motion phenomena more interactively through graphical data visualization.

Overall, the high average score and the consistency of responses among participants indicate that the Arduino and LabVIEW-based Simple Harmonic Motion data acquisition system is highly practical for use in Basic Physics laboratory activities and effective in supporting student learning.

However, one respondent (R14) provided a lower practicality score compared to the other participants. This response may indicate that some students still experienced initial difficulties in operating the system or interpreting the LabVIEW interface during laboratory activities. Differences in students' familiarity with digital laboratory technology and data acquisition systems may also influence individual perceptions of practicality. Nevertheless, since the overall average practicality percentage remained within the "*Highly Practical*" category, the system can still be considered effective and acceptable for laboratory implementation.

4. CONCLUSION

Based on the results of this study, the development of the Arduino Mega- and LabVIEW-based Simple Harmonic Motion (SHM) data acquisition system successfully produced a feasible and practical laboratory prototype for Basic Physics learning. The developed system was capable of performing displacement measurement and oscillation analysis continuously through the integration of the VL53L0X sensor, Arduino Mega, and LabVIEW visualization interface.

The experimental results demonstrated that the oscillation-based measurement method produced relatively stable spring constant values, with measurement accuracy improving as the number of oscillation cycles increased. Although the oscillation method still exhibited measurement deviations compared to the extension method, the obtained error range remains acceptable for introductory educational laboratory applications. In addition, expert validation and student responses indicated that the developed system is highly feasible and practical for implementation in Basic Physics practicum activities.

This study contributes to the development of technology-enhanced physics laboratory learning by integrating sensor-based measurement, interactive visualization, and laboratory practicality evaluation into a single instructional system. The developed prototype has the potential to support more interactive and modern laboratory activities, particularly in introductory physics experiments involving oscillatory motion analysis.

Future research may focus on improving sensor precision, reducing measurement noise, and implementing automated data analysis features to further enhance system accuracy and laboratory usability.

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