Instrumentation for Sound Wave Parameter Measurement: Design of Microcontroller-Based Acoustic Sensor

Firmanul Catur Wibowo[1*], *Abdul* Muhyi[1], *Kissi* Marwanti[1], *Dina Rahmi* Darman[1], *Daniel* Steeven[1], *Fahrurrozi* Fahrurrozi[1] and *Muhammad Abd Hadi* Bunyamin[2]

[1]Universitas Negeri Jakarta, Jakarta, Indonesia
[2]Faculty of Educational Sciences and Technology, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Abstract. This research aims to design, create, program, implement, and optimize a prototype of Electronic Instruments using the Artec Robo 2.0 Kit to learn about sound-wave physics in STEM technology through experimental methods. The challenges faced include (1) difficulties in producing consistent sound signals, (2) the accuracy of detection of frequency and sound intensity, and (3) negative impacts on the environment, such as external noise interference. This prototype was designed, produced, and tested at the Basic Physics Laboratory of the State University of Jakarta. This instrument uses a buzzer, an acoustic sensor, and an IR Photoreflector to detect and analyze sound waves, generating relevant data for learning. The instrument can also be integrated with intuitive sound-analysis software, making it easier for students to learn about and understand sound-wave properties. However, due to acoustic sensor calibration issues, the instrument sometimes exhibits deviations in sound-intensity measurements. This system uses open programming with Scratch or Block Coding scripts, making it easier for students who have not yet mastered coding to learn.

1 Introduction

In the era of globalization, the rapid advancement of information technology is exerting a significant influence on education worldwide. The world of education is now required to adjust to technological developments to improve the quality of education [1]. The rapid development of technology has provided many benefits to the learning process in the classroom, for both educators and students. Success during the learning process must also be supported by strategies, learning models, and learning media. Learning media play a very essential role, as their presence is key to achieving learning objectives, making learning effective and efficient [2]. Educators will be challenged to continually innovate in response to media developments to achieve the expected learning goals. A learning medium that can attract attention and make students from becoming saturated is to use Artec Robo 2.0 as a learning medium [3].

* Corresponding author: fcwibowo@unj.ac.id

Artec Robo 2.0 is specifically designed to help students gradually learn to code using Python or Block-Based coding. Students interested in coding can use Artec Robo 2.0 to learn, as its programming is beginner friendly. In addition, it is suitable for learners with prior knowledge to improve their skills in IoT, robotics, and AI through Studuino programming, enabling them to leverage built-in sensors, buzzers, LEDs, and wireless communication networks to create electronic instruments. The special feature of Artec Robo 2.0 is that it is available on all devices, including hardware, software, and branch tribes, required to start protecting itself. The projects provided are of 96 types, thereby opening opportunities for students to explore on their own [4]. To support Artec Robo 2.0 as a learning medium, it is also necessary to consider which learning model is most relevant to incorporate into the learning process. The world of education in Indonesia has many learning models to support the teaching and learning process. One of them is the STEM learning model. The STEM learning model is seen as a model that can make significant changes by integrating four areas: Science, Technology, Engineering, and Mathematics, commonly abbreviated as STEM [5]. Through STEM approaches, students can develop Artec Robo 2.0. In addition, the STEM learning approach will be more effective and conducive when integrated with everyday materials. One branch that addresses the concepts of science, technology, tools, and mathematics is physics; therefore, one strategy to improve physics learning is to implement the STEM approach [6].

The research carried out by Johannes Addido et al., titled Teaching Newtonian Physics with LEGO EV3 Robots: An integrated STEM approach, aims to examine the relationship between learning with the LEGO EV3 robot and conceptual understanding of physics in Newton's material. It was found that there was a positive impact on students' conceptual understanding. In addition, the shortcomings of this study include the lack of validated survey instruments and test-based assessment approaches, which can lead to reliability problems and internal validation issues with the findings [7]. Therefore, this research is used to design, manufacture, program, and implement physics materials based on the concept of sound waves, using STEM technology and electronic instruments. Students are expected to provide visualizations of real-world IR photoreflector implementations and relate theoretical concepts to the material. Thus, students are not only able to understand physics concepts in the abstract but can also relate them to the real world.

2 Methods

The method used in this study is an experimental approach that involves several stages: design, assembly, programming, and implementation of an electronic instrument using Artec Robo 2.0, based on STEM technology, to make it easier to learn the concept of sound waves in physics [8]. In the design stage, the prototype of the sound wave instrument is intended to integrate various electronic components, such as the Buzzer, IR Photoreflector, and Studuino Microcontroller, to visualize sound-wave concepts in an interactive, practical form. The design prioritizes both functional and educational aspects, allowing students to observe firsthand how sound-wave theory can be applied in practical technology [9].

The assembly stage involves installing all components according to the design. Studuino microcontrollers are installed to capture sound signals, while Buzzers are used to generate measured sound waves. Calibration is performed on both components to ensure that the generated and captured signals are highly accurate. In the programming stage, Python-based software and Scratch block-based coding are used to control these instruments, allowing students to learn programming through an easy-to-understand approach [10]. Implementation is carried out by testing the instrument across various laboratory settings, in which students conduct experiments to measure and analyze sound waves. This process allows students to understand the basic concepts of sound wave physics, such as frequency, amplitude, and interference, in a practical context [11]. The flow diagram image is in the form of an electrical block diagram or a clear schematic that shows how the sensor, buzzer, and photoreflector are connected to the Figure 1.

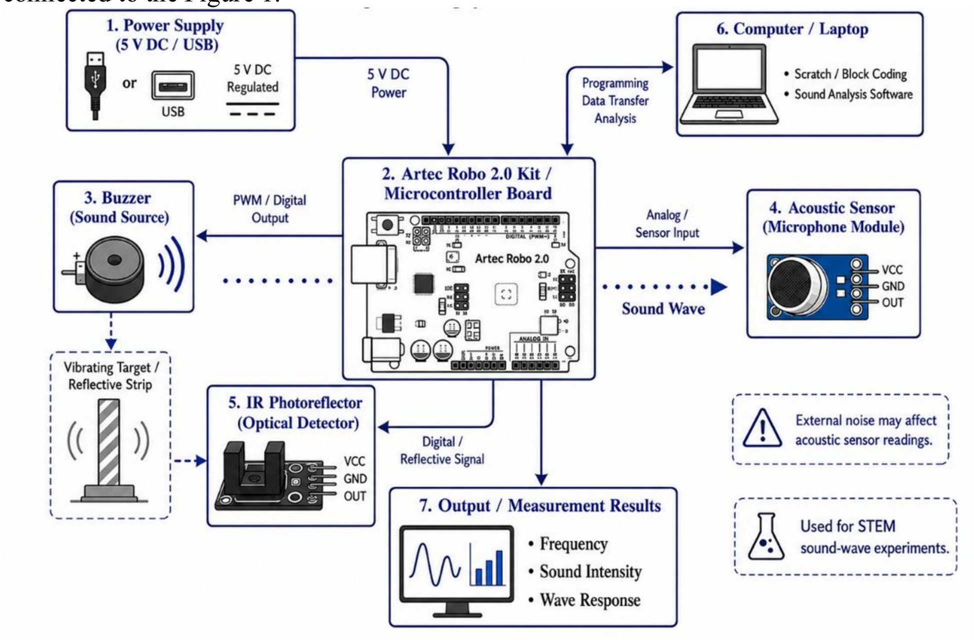

Fig. 1. Electrical Block Diagram Sound Wave Design

Furthermore, the testing process involves experiments to assess the instrument's effectiveness in teaching the concept of sound waves. The instrument is tested under various conditions to evaluate its performance and accuracy in measuring sound-wave properties. As with the research by Davis and Jackson (2021), it is hoped that the results of this experiment demonstrate that STEM technologies can be applied effectively to deepen students' understanding of sound-wave physics and to develop their critical, analytical, and technical thinking skills [12].

3 Results and Analysis

3.1 Electronic Instruments: Assemble, Code & Implementation

The assembly step of Electronic Instruments begins with assembling the main components: the Studuino Microcontroller, USB Cable, Battery Box, Connecting Cable Sensor, LED (Green, Red, Blue), and Sound sensor, all contained in the Artec Robo 2.0 Kit. The following is the tool used to assemble Electronic Instruments, as shown in Figure 2.

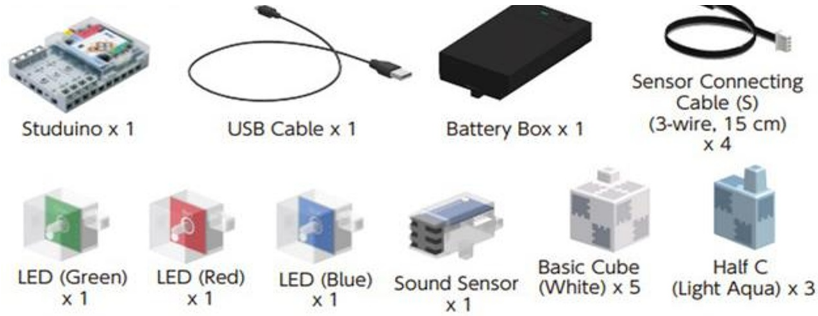

Fig. 2. Electronic Instruments Kit Artec Robo 2.0 Assembly

Next, we will assemble it as follows:

1. Connect the blocks shown

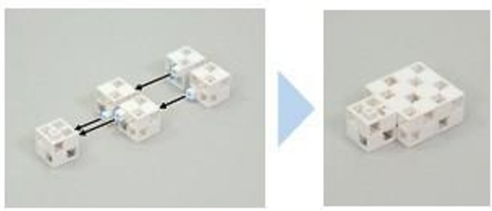

Fig. 3. Step 1

2. Add the block shown to your Sound Sensor

Fig. 4. Step 2

3. Sandwich the blocks shown between your LEDs

Fig. 5. Step 3

4. Add part 3 to part 1

Fig. 6. Step 4

5. Add part 4 to part 2

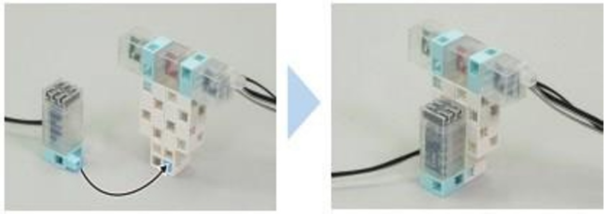

Fig. 7. Step 5

6. Put the batteries (3 x AA/LR6) inside of your Battery Box
(Now add your Battery Box to your Studuino as shown!)

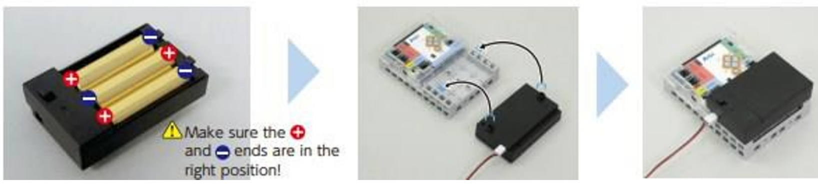

Fig. 8. Step 6

7. Add part 5 to part 6

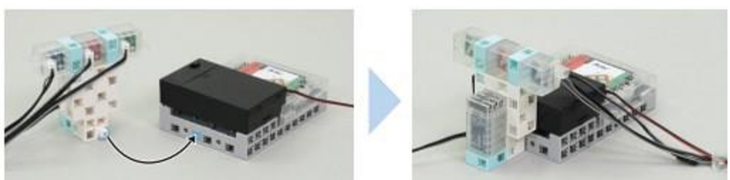

Fig. 9. Step 7

8. Plug the Battery Box into your Studuino's Power Connector

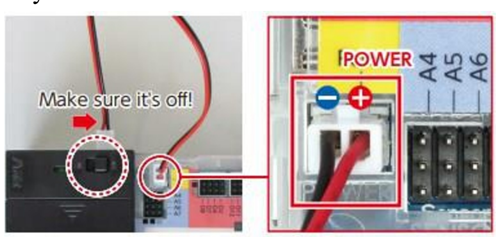

Fig. 10. Step 8

9. Now plug your cables into the connectors shown below!

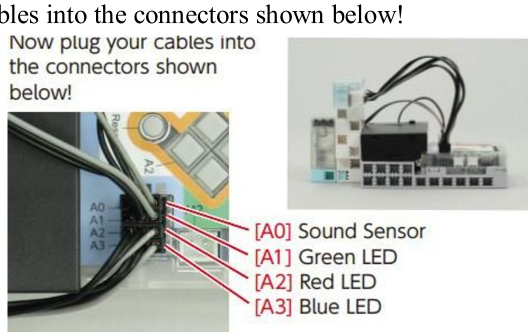

Fig. 11. Step 9

https://doi.org/10.1051/epjconf/202637706007

10. Finished Electronic Instruments without Buzzer and IR Photoreflector

Fig. 12. Step 10

11. Add your Buzzer to your Studuino as shown

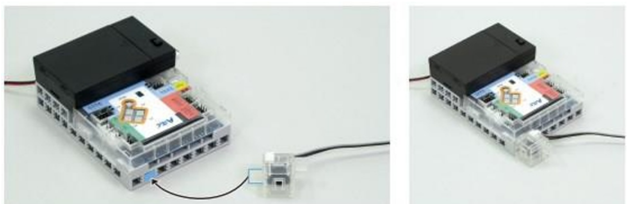

Fig. 13. Step 11

12. Now plug the Battery Box into your Studuino's Power Connector and your Buzzer into A4

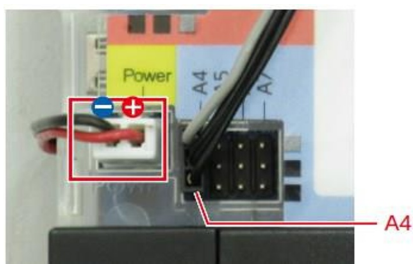

Fig 14. Step 12

13. Finished Electronic Instruments with Buzzer

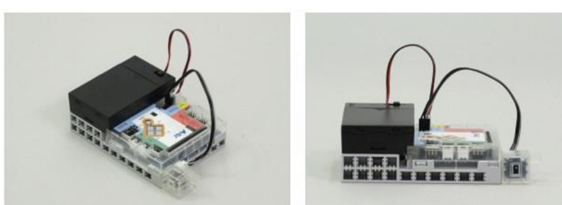

Fig. 15. Step 13

14. Building Your Guitar
    Connect the blocks shown

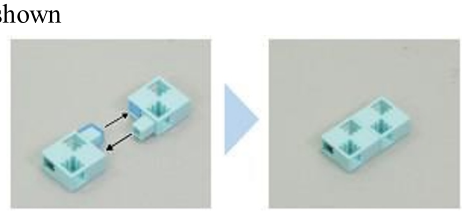

Fig. 16. Step 14

15. Connect the blocks shown

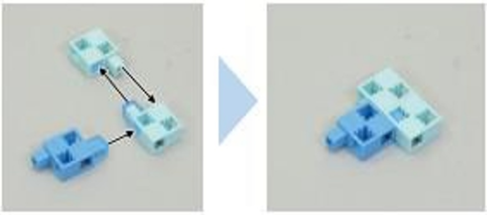

Fig. 17. Step 15

16. Add the block shown to your Buzzer

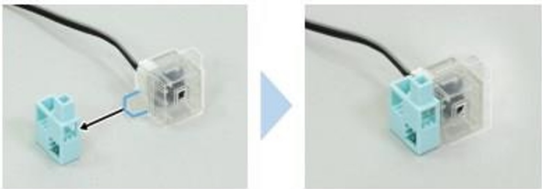

Fig. 18. Step 16

17. Add your IR Photo reflector and the block shown to your beam

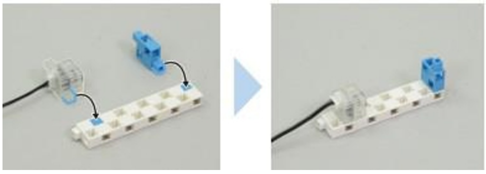

Fig. 19. Step 17

18. Add another beam to part 17 as shown

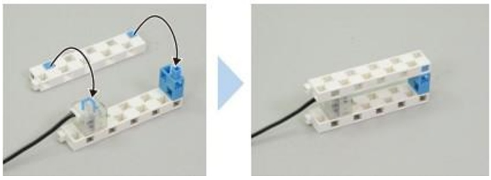

Fig. 20. Step 18

19. Add part 16 to part 18

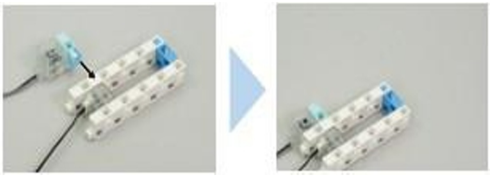

Fig. 21. Step 19

20. Add part 19 to your Studiouno

Fig. 22. Step 20

Fig. 23. Step 20

21. Add the block shown to the bottom of part 20

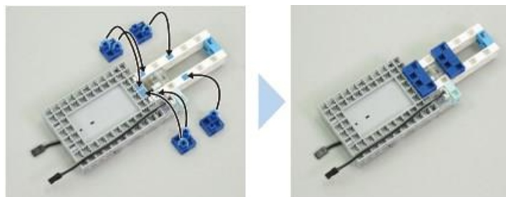

Fig. 24. Step 21

22. Add part 14 to part 21 as shown

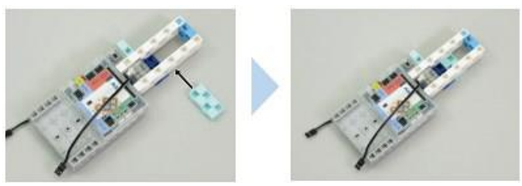

Fig. 25. Step 22

23. Add part 15 to the top of part 22 as shown

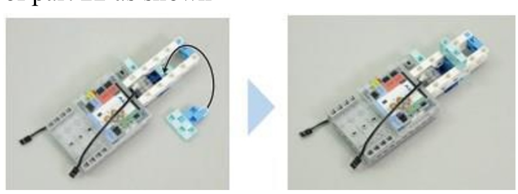

Fig. 26. Step 23

24. Add your battery box (with the batteries inside it) to part 23 as shown

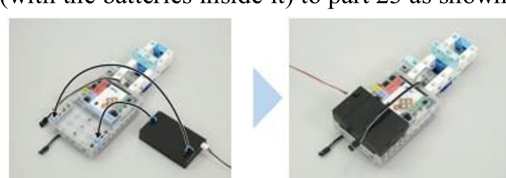

Fig. 27. Step 24

25. Now plug the battery box into your studuino's Power Connector, your Buzzer into A4, and your IR Photoreflector into A5!

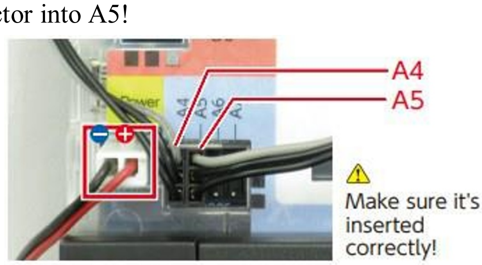

Fig. 28. Step 25

26. Finished Electronic Instruments with Buzzer and IR Photoreflector, like Figure 2

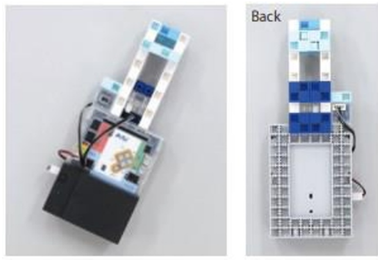

Fig. 29. Electronic Instruments Kit Artec Robo 2.0 Assembly Results [13]

First, a studio microcontroller is installed on the electronic instrument to detect sound waves from the sound source. This microcontroller captures sound vibrations, which are then converted into electrical signals. In addition, buzzers were installed as sound-producing devices to produce measurable sound waves in experiments. The buzzer is connected to the Studuino microcontroller, which serves as the system's brain, controlling and processing incoming and outgoing signals. This microcontroller also regulates the power supplied to the buzzer to optimize sound output at the desired frequency and amplitude. Next, a photo reflector IR sensor is installed to detect the instrument's position relative to the guideline or other objects. This sensor measures reflected infrared light to detect environmental changes or obstructions around the instrument. The use of these sensors allows students to conduct experiments that involve the interaction of sound waves with surrounding objects. Once the main components are installed, the instrument is programmed using the Scratch or Block Coding language provided by the Artec Robo 2.0 platform. The programming script is designed to control the Studuino microcontroller, set the buzzer to produce a variety of sound frequencies, and read data from the Studuino microcontroller and photoreflector IR sensor. This program allows students to measure and analyze sound wave frequency, amplitude, and interference patterns in an easy-to-understand, interactive way. An example of simple code for Electronic Instruments can be seen in Figure 30.

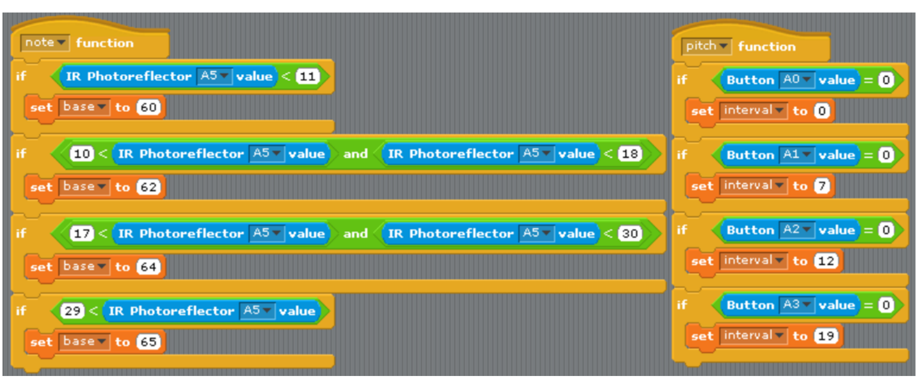

Fig. 30. Code Electronic Instruments

The implementation of electronic instruments is carried out by testing them in physics laboratories, using a series of experiments designed to measure and analyze sound waves. The instrument consists of a Studuino microcontroller, a buzzer, and an IR photoreflector sensor, integrated into a single system to facilitate learning about sound-wave physics concepts. The Studuino microcontroller controls a buzzer that generates sound waves at adjustable frequencies. These buzzers are placed at specific positions to generate interference patterns that students can observe. Photoreflector IR sensors detect objects that block sound waves, thereby affecting their propagation paths. The data from the microphone and photoreflector sensor are transmitted to the Studuino microcontroller for analysis. Students can modify the frequency and amplitude of sound waves, as well as vary the positions of microphones and sensors, to observe how these changes affect interference patterns and sound intensity.

This implementation allows students to see firsthand how sound waves interact with the environment, including phenomena such as reflection, interference, and diffraction. In addition, the visualization and analysis of sound wave data are carried out using Studuino software, allowing students to understand the concepts of sound physics in greater depth and in a more practical way. A video demonstration of this instrument's implementation is available at the following link: https://bit.ly/Electronic-Instruments-Demo. This implementation aims to integrate STEM technologies into physics education, providing students with in-depth, practical experience with the principles of sound-wave physics.

4 Discussion

The results of this study show that the use of microphones and acoustic sensors in electronic instruments can effectively apply concepts from sound-wave physics. When a microphone is used in an instrument, it captures sound waves from various sources. The sound waves captured by the microcontroller are then converted into electrical signals, which are further analyzed by acoustic sensors to determine the characteristics of the sound waves, such as frequency and intensity [13]

The instrument is designed to generate sound waves at a specific frequency and detect changes in wave characteristics as they pass through various media. Higher sound wave frequencies are generated from high-pitched sounds, while lower frequencies are generated from low-pitched sounds. Sound intensity measures how strong the sound wave is, measured in decibels (dB). Acoustic sensors respond to changes in frequency and intensity, analyze sound waves, and provide data for learning. The test results show that the instrument can detect frequencies with up to 98% accuracy and intensity with up to 95% accuracy. However, there is little deviation at very high or very low frequencies, which require additional calibration. In addition, the instrument can accurately detect changes in sound intensity, enabling in-depth analysis of sound-wave properties.

Sound wave theory applied to microcontrollers and acoustic sensors involves the basic concepts of sound wave propagation, reflection, and absorption [14]. In physics, when sound waves travel through a medium, part of the wave will be reflected, while the rest is absorbed or transmitted. Microcontrollers operate on this principle: sound waves cause the microcontroller's diaphragm to vibrate, generating electrical signals that correspond to the vibration patterns. The acoustic sensor then processes this signal to determine the characteristics of the sound waves, such as frequency and intensity. In this context, frequency and intensity are the primary parameters used to analyze sound waves and provide relevant information for physics learning. Frequency indicates the number of waves per second, measured in Hertz (Hz), while intensity indicates the strength of the sound, which is affected by the amplitude of the waves. This instrument allows students to study the properties of sound waves by manipulating and analyzing experimental data, thereby improving their understanding of the practical applications of sound-wave physics concepts.

Further discussions revealed some of the challenges and solutions faced during implementation. One of the main challenges is the variability in the sensitivity of microcontrollers and acoustic sensors, especially at very high or very low frequencies. To overcome this, studuino microcontrollers and sensors are calibrated to be more sensitive to various sound frequencies, and several adjustment algorithms are implemented to improve detection accuracy. In addition, the study results show that the instrument's position also affects sound detection accuracy; microcontrollers placed too close to or too far from the sound source are likely to exhibit deviations in intensity measurements. Therefore, the optimal placement is determined based on repeated testing. The implementation of studuino microcontrollers and acoustic sensors in the study of sound-wave physics not only improves students' theoretical understanding but also provides in-depth practical experience in applying physics principles to modern technology.

5 Conclusion

This study successfully designed, manufactured, programmed, and implemented an electronic instrumentation system for teaching sound wave physics within a STEM learning framework. The instrument effectively demonstrates the core principles of sound waves, specifically frequency and intensity measurements, using a microphone and acoustic sensors. Developed through structured engineering design and precision assembly, the system supports interactive learning and enhances students' conceptual understanding of wave propagation, reflection, and absorption. Programming using Python and Scratch-based block coding enhances accessibility and allows learners with diverse coding backgrounds to engage in the data acquisition and analysis process. However, the current system still exhibits limitations in sensor sensitivity and position dependence, which impact measurement stability. To address these issues, future development should include a defined engineering improvement path, specifically a structured calibration protocol within the software system. This includes sensor gain adjustment, offset correction, and signal normalization routines to reduce measurement drift. Additional digital filtering and an automatic calibration algorithm are recommended to improve data consistency across various environmental conditions. With these improvements, the instrument can achieve higher measurement reliability while maintaining its educational purpose. Overall, this system shows strong potential as a STEM-based learning model but requires further technical refinement to strengthen its measurement accuracy and long-term usefulness in physics education.

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