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DEVELOPMENT AND IMPLEMENTATION OF AN ARDUINO-BASED SOUND LEVEL MONITORING SYSTEM FOR STEM-ORIENTED PHYSICS EDUCATION

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Abstract

The integration of Science, Technology, Engineering, and Mathematics (STEM) education into modern teaching practices has significantly transformed physics instruction by encouraging hands-on experimentation and problem-solving skills. This study presents the development and implementation of an Arduino-based sound level monitoring system designed for STEM-oriented physics education. The project aimed to create an affordable, portable, and interactive learning tool capable of measuring environmental sound intensity while enhancing students' understanding of wave physics, electronics, and programming concepts. The system was developed using an Arduino Uno microcontroller, a KY-038 sound sensor, an LCD display module, and supporting electronic components.

Experimental activities were conducted with secondary-level physics students to evaluate the effectiveness of the device in classroom applications. The sound monitoring system successfully measured sound intensity levels in different environments with acceptable accuracy compared to commercial sound level meter applications. The experimental results demonstrated that students improved their conceptual understanding of sound waves, decibel measurement, and sensor-based data acquisition. Furthermore, the implementation of the project promoted active learning, creativity, and interdisciplinary problem-solving skills associated with STEM education. The study concludes that Arduino-based educational systems provide cost-effective and efficient solutions for enhancing practical physics learning and increasing student engagement in technology-oriented scientific activities.

Keywords: Arduino Uno, STEM education, sound level monitoring, physics education, sound sensor, microcontroller systems, experimental learning, educational technology

Introduction

The rapid development of educational technologies has encouraged teachers and researchers to integrate innovative teaching approaches into science education. STEM-oriented education has emerged as one of the most influential pedagogical frameworks for improving students' analytical thinking, creativity, and practical problem-solving abilities. In physics education, experimental learning plays a critical role in helping students understand theoretical concepts through direct observation and hands-on activities.

Sound is one of the fundamental topics in physics education. Traditional methods of teaching sound waves and acoustic intensity often rely on theoretical explanations and textbook-based exercises, which may limit students' practical understanding of the subject. Therefore, integrating programmable electronic systems into physics instruction can improve students' engagement and conceptual comprehension.

Arduino-based systems have become popular educational tools because of their affordability, simplicity, and flexibility. Arduino microcontrollers allow students to design and implement real-world scientific applications while simultaneously learning programming and electronics. Sound level monitoring systems based on Arduino platforms can be particularly useful for demonstrating sound intensity measurement, wave behavior, and sensor technology.

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This study focuses on the design and implementation of an Arduino-based sound level monitoring system intended for STEM-oriented physics education. The objectives of the research are:

1. To develop a low-cost sound monitoring device using Arduino technology.
2. To evaluate the accuracy and functionality of the system.
3. To investigate the educational impact of the device on students' understanding of physics concepts.
4. To promote interdisciplinary STEM learning through practical experimentation.

The study contributes to modern educational practices by demonstrating how affordable electronic systems can enhance interactive physics instruction and encourage technological literacy among students.

Literature Review

STEM education emphasizes interdisciplinary learning and practical engagement in scientific and technological activities. According to recent educational research, project-based learning improves students' motivation and academic achievement in science subjects. Physics education, in particular, benefits from experimental approaches because students can directly observe physical phenomena.

Arduino microcontrollers have gained significant attention in educational environments due to their open-source architecture and ease of programming. Researchers have successfully implemented Arduino-based systems in various educational projects, including temperature monitoring, robotics, motion detection, and environmental sensing.

Sound monitoring technologies are commonly used in environmental studies, industrial safety, and urban planning. Commercial sound level meters are often expensive and inaccessible for educational institutions with limited resources. Consequently, low-cost Arduino-based sound monitoring systems have emerged as practical alternatives for educational applications.

Previous studies indicate that Arduino-supported laboratory activities increase students' interest in electronics and programming. Students participating in STEM projects develop better problem-solving skills, collaboration abilities, and scientific reasoning competencies. Furthermore, integrating sensors into physics education supports inquiry-based learning and data analysis skills.

Despite the increasing use of Arduino systems in science education, limited research has focused specifically on sound level monitoring applications for STEM-oriented physics learning. This study addresses this gap by combining physics instruction, sound analysis, and microcontroller programming into a single educational project.

1. Materials and Methods

1.1 System Components

The sound level monitoring system was developed using the following hardware components:

- Arduino Uno microcontroller
- KY-038 sound sensor module
- 16×2 LCD display
- Breadboard
- Jumper wires
- USB connection cable
- Personal computer for programming

The Arduino Uno served as the main processing unit responsible for collecting and analyzing data from the sound sensor. The KY-038 sensor detected sound intensity variations in the environment and transmitted analog signals to the microcontroller.

1.2 Software Development

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The software was programmed using the Arduino Integrated Development Environment (IDE). The program continuously collected analog data from the sound sensor and converted the values into sound intensity indicators displayed on the LCD module.

The basic operational algorithm included the following steps:

1. Initialize the sensor and LCD display.
2. Read analog sound data from the sensor.
3. Process and calibrate the signal values.
4. Display sound intensity levels on the LCD.
5. Continuously repeat the measurement cycle.

The programming language used for the system was C/C++ within the Arduino framework.

1.3 Experimental Procedure

The educational experiment involved 30 secondary school students studying physics. The students were divided into small groups and participated in practical laboratory activities using the Arduino sound monitoring system.

The experiment consisted of three stages:

Stage 1: Introduction to Sound Physics

Students received theoretical explanations regarding:

- Sound waves
- Frequency and amplitude
- Decibel units
- Noise pollution

Stage 2: Device Assembly and Programming

Students assembled the Arduino circuit under teacher supervision. They learned:

- Sensor connections
- Basic Arduino programming
- Data acquisition techniques

Stage 3: Sound Measurement Activities

Students measured sound levels in different environments, including:

- Quiet classroom
- School corridor
- Outdoor playground
- Computer laboratory
- The collected data were analyzed and compared to smartphone-based sound level meter applications.

System Design and Implementation

- The Arduino-based sound monitoring system was designed as a compact and portable educational device. The KY-038 sensor detects sound vibrations through its onboard microphone. These vibrations are converted into electrical signals proportional to sound intensity.
- The Arduino microcontroller receives analog input values ranging from 0 to 1023. The software processes these values and categorizes sound intensity into different levels such as low, moderate, and high noise conditions.
- The LCD module provides real-time visualization of measured sound levels, making the system interactive and user-friendly for students.
- The complete circuit was assembled on a breadboard to simplify modifications and troubleshooting during laboratory activities. Students were encouraged to experiment with sensor sensitivity and observe changes in measured values under different acoustic conditions.
- The implementation process demonstrated the integration of physics principles, electronic engineering, and computer programming within a STEM learning environment.

5. Results and Discussion

5.1 Experimental Results

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The sound monitoring system successfully measured environmental sound intensity in different locations. Table 1 presents the average sensor readings obtained during the experiment.

Table 1. Average Sound Level Measurements

Environment	Arduino Sensor Value	Approximate Noise Level
Quiet Classroom	120	Low
School Corridor	350	Moderate
Computer Laboratory	470	Moderate-High
Outdoor Playground	620	High

The results indicate that the system effectively detected variations in environmental sound intensity. Higher readings were observed in noisy environments, while lower values were recorded in quiet conditions.

The Arduino system demonstrated stable performance throughout the experimental sessions. Although the sensor readings were not equivalent to professional decibel measurements, the values showed strong consistency and practical usefulness for educational purposes.

5.2 Educational Outcomes

Student participation and engagement increased significantly during the practical sessions. Observations and feedback collected from participants revealed several educational benefits:

- Improved understanding of sound wave concepts
- Enhanced interest in electronics and programming
- Better comprehension of sensor technology
- Increased collaboration during group activities

Students particularly appreciated the opportunity to build and test a real electronic system. Many participants reported that the project helped them understand the relationship between theoretical physics concepts and real-world applications.

The STEM-oriented nature of the activity encouraged interdisciplinary thinking. Students simultaneously applied knowledge from physics, mathematics, computer science, and engineering.

Conclusion

This study presented the development and implementation of an Arduino-based sound level monitoring system for STEM-oriented physics education. The system successfully demonstrated the practical application of sound wave concepts, sensor technology, and microcontroller programming within an educational environment.

The experimental results confirmed that the Arduino-based device effectively detected environmental sound intensity variations and provided valuable opportunities for hands-on STEM learning. Students participating in the project showed increased engagement, improved conceptual understanding, and enhanced interest in scientific experimentation. Although the system has certain technical limitations compared to professional sound level meters, its affordability, simplicity, and educational value make it highly suitable for classroom applications.

Future improvements may include:

- Using higher-precision sound sensors
- Implementing wireless data transmission
- Adding graphical data visualization
- Integrating Internet of Things (IoT) capabilities

Overall, Arduino-based educational technologies represent powerful tools for modern physics instruction and STEM education development.

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