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Design and Performance Evaluation of an Arduino-Based Vibration Sensor System for Suspicious Activity Detection

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Abstract- The increasing incidence of theft and unauthorized intrusion has created an urgent demand for affordable and reliable security systems capable of providing early warning against suspicious activities. Conventional security devices such as mechanical locks, closed-circuit television (CCTV), and alarm systems often exhibit limitations in detecting initial physical disturbances before an intrusion occurs. This study presents the design, development, and performance evaluation of an Arduino-based vibration sensor system for suspicious activity detection. The proposed prototype integrates an SW-420 vibration sensor, an Arduino Uno microcontroller, a 16×2 LCD with an I2C interface, light-emitting diode (LED) indicators, and a buzzer to monitor vibration intensity and provide immediate visual and audible alerts. The vibration sensor continuously detects mechanical disturbances generated by impacts, movements, or unauthorized physical interactions. The Arduino Uno processes the sensor signals in real time and classifies the detected vibration into three levels: normal, moderate, and high. The corresponding system status is displayed on the LCD, while LED indicators and the buzzer provide rapid warning notifications according to the detected vibration level. Experimental evaluation demonstrated that the prototype successfully detected mechanical vibrations with stable and consistent responses under repeated testing conditions. The integrated hardware components operated reliably, and the system effectively distinguished different vibration intensities while maintaining rapid response characteristics. The developed prototype offers several advantages, including low manufacturing cost, simple hardware architecture, low power consumption, and ease of implementation. In addition to its practical application as an early-warning security device, the system also provides an effective educational platform for demonstrating vibration sensing, embedded systems, signal processing, and microcontroller programming. The proposed prototype therefore represents a practical and economical solution for enhancing security monitoring in residential environments, parking facilities, laboratories, and educational institutions while supporting engineering education through hands-on learning.

Keywords: Arduino Uno; Embedded Systems; Microcontroller; Security System; Suspicious Activity Detection; SW-420 Vibration Sensor; Vibration Monitoring.

1 Introduction

The rapid growth of urbanization and technological development has significantly increased the demand for reliable and intelligent security systems capable of protecting people and valuable assets from

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unauthorized access and criminal activities. Residential buildings, educational institutions, laboratories, offices, and commercial facilities are increasingly exposed to security threats such as burglary, theft, vandalism, and forced intrusion. According to the United Nations Office on Drugs and Crime (UNODC, 2023), property-related crimes remain among the most frequently reported criminal offenses worldwide, creating substantial economic losses and reducing public confidence in conventional security measures. Consequently, the development of affordable, reliable, and real-time security technologies has become an important research topic in engineering and embedded system applications (Khan et al., 2022).

Traditional security methods, including mechanical locks, padlocks, and passive surveillance, provide only limited protection because they cannot immediately detect suspicious activities before unauthorized entry occurs. Although closed-circuit television (CCTV) systems have become increasingly popular, they primarily function as monitoring devices rather than active detection systems. Their performance may also be affected by poor lighting conditions, limited camera coverage, storage requirements, and the need for continuous human observation. Therefore, researchers have increasingly focused on developing intelligent sensor-based security systems capable of automatically identifying abnormal physical disturbances and providing immediate warning signals before more serious incidents occur (Patel et al., 2023).

Among various sensing technologies, vibration sensors have emerged as an effective solution for early intrusion detection due to their simplicity, low cost, compact size, and rapid response characteristics. Mechanical disturbances caused by impacts, forced door opening, window breaking, or unauthorized movement generate vibration signals that can be detected and converted into electrical outputs. These signals enable embedded controllers to distinguish between normal environmental conditions and suspicious activities requiring immediate attention. Compared with vision-based surveillance systems, vibration sensors require significantly lower computational resources while maintaining fast response times, making them suitable for standalone security devices operating continuously under various environmental conditions (Chen et al., 2022).

The SW-420 vibration sensor is one of the most widely used vibration detection devices in embedded electronics because of its simple operating principle, adjustable sensitivity, and compatibility with numerous microcontroller platforms. The sensor detects mechanical vibration through an internal spring mechanism that generates digital output signals whenever external vibration exceeds a predefined threshold. Owing to its compact dimensions, low electrical power consumption, and stable operational characteristics, the SW-420 sensor has been extensively employed in applications such as anti-theft systems, machinery monitoring, structural vibration detection, and security alarms (Singh et al., 2021).

Recent advances in embedded systems have further improved the capability of intelligent security devices through the integration of microcontrollers, sensors, display modules, and alarm mechanisms into compact electronic platforms. Among the available development boards, the Arduino Uno has become one of the most popular open-source microcontroller platforms for rapid prototype development. Built around the ATmega328P microcontroller, Arduino Uno offers multiple digital and analog input/output pins, simple programming through the Arduino Integrated Development Environment (IDE), extensive software libraries, and compatibility with a wide variety of electronic sensors and actuators. These advantages enable rapid implementation of embedded security systems while reducing development complexity and manufacturing costs (Arduino, 2023).

By integrating the SW-420 vibration sensor with the Arduino Uno, an embedded security system can continuously monitor mechanical disturbances and automatically activate warning devices whenever abnormal vibrations are detected. The microcontroller processes the digital signals generated by the vibration sensor in real time and subsequently controls visual and audible notification devices such as liquid crystal displays (LCDs), light-emitting diodes (LEDs), and buzzers. This integrated operation enables rapid identification of suspicious activities while providing users with immediate information regarding the detected security status.

The combination of vibration sensing technology and Arduino-based embedded systems offers several practical advantages, including low manufacturing cost, low power consumption, simple hardware architecture, and ease of maintenance. These characteristics make the proposed technology particularly suitable for residential security, educational laboratories, office facilities, motorcycles, storage cabinets, and other applications requiring continuous monitoring with minimal operational cost. Furthermore, the developed prototype also provides an effective educational platform for demonstrating sensor technology, embedded programming, signal processing, and real-time monitoring, thereby supporting engineering education through practical experimentation and hands-on learning.

Recent studies have demonstrated significant progress in the development of embedded security systems employing vibration sensors for intrusion detection and asset protection. Researchers have integrated vibration sensors with microcontrollers, wireless communication modules, Global System for Mobile Communication (GSM), Internet of Things (IoT) platforms, and cloud-based monitoring systems to improve security monitoring and remote notification capabilities. These developments have enabled real-time detection of abnormal mechanical disturbances while enhancing the flexibility and reliability of modern electronic security systems. Furthermore, advances in embedded electronics have facilitated the development of compact, low-cost, and energy-efficient security devices suitable for residential, commercial, and educational applications (Patel et al., 2023; Chen et al., 2022).

Despite these technological advancements, several limitations remain in existing studies. Many reported systems primarily emphasize hardware implementation without providing comprehensive evaluations of detection reliability, response time, alarm performance, and operational stability under repeated testing conditions. In addition, numerous security prototypes rely on relatively complex communication modules or Internet connectivity, increasing both system cost and implementation complexity. Such limitations reduce the practicality of these systems for users seeking simple, affordable, and standalone security solutions. Moreover, only a limited number of studies have explored the educational potential of vibration sensor-based embedded systems as practical learning media for electronics, instrumentation, and embedded programming.

To address these limitations, this study proposes the design and performance evaluation of an Arduino-based vibration sensor system employing the SW-420 vibration sensor, Arduino Uno microcontroller, LCD display, LED indicators, and buzzer for suspicious activity detection. The novelty of this research lies in the integration of a low-cost vibration sensing mechanism with real-time visual and audible warning functions into a compact embedded system, accompanied by a comprehensive experimental evaluation of detection performance, operational stability, and response reliability. The developed prototype is expected to provide an effective, economical, and energy-efficient security solution while simultaneously serving as a contextual learning platform for embedded systems, sensor technology, signal processing, and engineering education. The findings of this research are anticipated to contribute to the advancement of affordable intelligent security systems and support the broader application of embedded technologies in practical security monitoring.

2 Research Methodology

2.1 Research Design

This study employed an engineering design and experimental evaluation approach to develop and assess the performance of an Arduino-based vibration sensor system for suspicious activity detection. The research consisted of four sequential stages: (1) system design and component selection, (2) hardware assembly and software programming, (3) prototype implementation, and (4) experimental performance evaluation. The overall research workflow is presented in Figure 1.

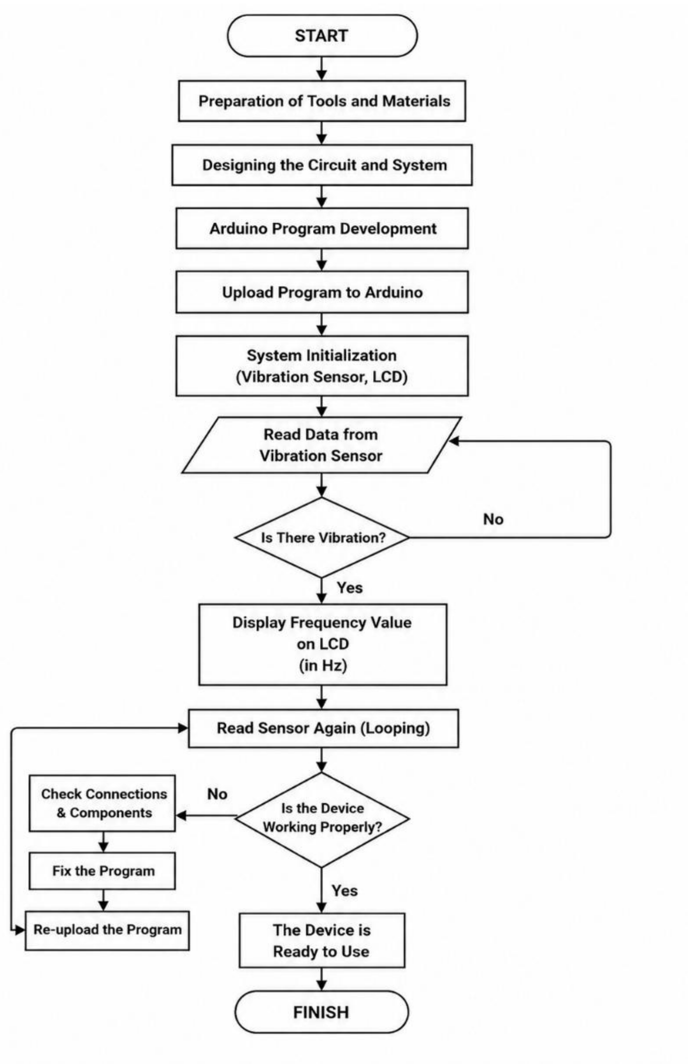


Figure 1. Research methodology flowchart.

The primary objective of the proposed prototype was to detect abnormal mechanical vibrations generated by suspicious physical activities and automatically provide visual and audible warning signals. The system was designed to operate continuously with low electrical power consumption while maintaining reliable detection performance and rapid response.

2.2 Prototype Development

The prototype was developed using commercially available electronic components. The main hardware consisted of an Arduino Uno microcontroller, an SW-420 vibration sensor, a 16×2 LCD equipped with an I2C communication module, three LED indicators (green, blue, and red), a buzzer, jumper wires, a breadboard, and a regulated DC power supply. The complete hardware configuration is illustrated in Figure 2.

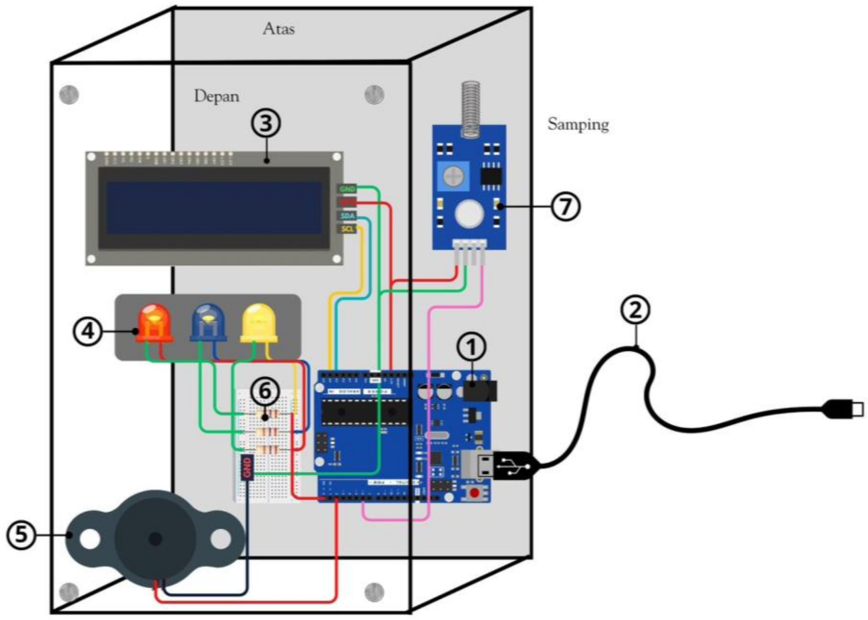


Figure 2. Hardware configuration of the Arduino-based vibration sensor system.

Description:
1. Arduino Uno R3
2. USB
3. LCD
4. LED
5. Buzzer
6. Resistor
7. SW-420 Vibration Sensor Module

The SW-420 vibration sensor functioned as the primary sensing element responsible for detecting mechanical disturbances. The sensor continuously monitored vibration intensity and transmitted digital signals to the Arduino Uno whenever the detected vibration exceeded the predefined sensitivity threshold. The Arduino Uno processed the incoming signals in real time and classified the vibration into three categories: normal, moderate, and high. The corresponding status was displayed on the LCD while the LED indicators and buzzer were activated according to the predefined classification algorithm.

2.3 Experimental Procedure

Following prototype fabrication, experimental testing was conducted under controlled laboratory conditions. Before each experiment, the vibration sensor sensitivity was calibrated using the adjustable potentiometer integrated into the SW-420 module to ensure consistent detection performance. Mechanical vibrations with different intensities were then intentionally generated by applying controlled impacts and physical disturbances to the testing surface. During each experiment, the Arduino continuously monitored the sensor output and automatically processed the received signals. The LCD displayed the detected vibration level, while the LED indicators and buzzer provided immediate visual and audible responses according to the measured vibration intensity. Each testing scenario was repeated three times under identical experimental conditions to evaluate measurement consistency and operational reliability. The average results obtained from repeated experiments were subsequently used for performance analysis.

2.4 Performance Evaluation

The performance of the developed prototype was evaluated using several engineering parameters, including vibration detection capability, response time, warning system functionality, operational stability, and overall system reliability. Detection performance was assessed based on the prototype's ability to classify vibration levels accurately, while response time was determined by observing the delay between vibration occurrence and warning activation. Operational stability was evaluated through repeated experiments to verify consistent system performance.

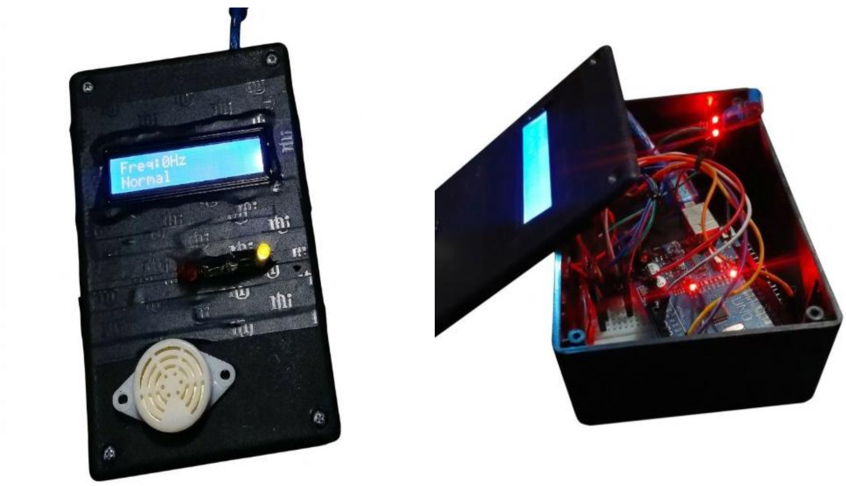
2.5 Data Analysis

The collected experimental data were analyzed using descriptive statistical methods. The average values obtained from repeated measurements were interpreted to evaluate the effectiveness of the proposed security system. Furthermore, the experimental findings were analyzed according to the principles of vibration sensing, embedded system operation, digital signal processing, and real-time monitoring. The performance of the developed prototype was then compared with the intended design objectives to determine its feasibility as a low-cost, reliable, and practical suspicious activity detection system for residential and educational security applications.

3 Results and Discussion

3.1 Prototype Development

The primary outcome of this study was the successful development of an Arduino-based vibration sensor system capable of detecting suspicious physical activities through real-time vibration monitoring. The developed prototype integrates an SW-420 vibration sensor, an Arduino Uno microcontroller, a 16×2 LCD with an I2C interface, three LED indicators, and a buzzer into a compact embedded security system. The complete hardware configuration of the prototype is illustrated in Figure 3.



(a) (b)

Figure 3. Image of suspicious activity detection tool (a) external view (b) internal view

The overall hardware architecture was designed to provide a simple, low-cost, and reliable solution for early warning applications. The SW-420 vibration sensor continuously monitors mechanical disturbances occurring on the protected object or supporting structure. Whenever external vibration exceeds the predetermined sensitivity threshold, the sensor immediately generates a digital output signal that is transmitted to the Arduino Uno for further processing. The Arduino Uno functions as the central processing unit of the system. It continuously reads the sensor output, executes the programmed decision algorithm, and determines the corresponding vibration category. Based on the detected vibration level, the microcontroller simultaneously controls the LCD display, LED indicators, and buzzer. This integrated operation enables users to receive immediate visual and audible notifications whenever suspicious mechanical activity is detected.

The LCD module serves as the primary information display, presenting the measured vibration status and system operation in real time. Meanwhile, the LED indicators provide rapid visual identification of different vibration conditions. Under normal conditions, the green LED remains active to indicate that the system is operating correctly. When moderate vibration is detected, the yellow or blue indicator is activated as an early warning. If high-intensity vibration occurs, the red LED and buzzer are simultaneously activated to indicate potential suspicious activity requiring immediate attention. The mechanical assembly of the prototype emphasizes compactness, portability, and ease of maintenance. All electronic components were mounted securely within the prototype enclosure to minimize unwanted mechanical interference during operation. The simple circuit configuration also facilitates troubleshooting and future hardware expansion, allowing additional communication modules or wireless monitoring devices to be integrated into the existing system. Overall, the developed prototype demonstrates successful integration of vibration sensing technology, embedded processing, digital display, and alarm notification into a practical security monitoring device suitable for residential buildings, laboratories, offices, storage facilities, and educational environments.

3.2 Vibration Detection Performance

After prototype fabrication, a series of experimental tests was conducted to evaluate the vibration detection capability of the developed system. Controlled mechanical disturbances with different vibration intensities were intentionally applied to the testing surface to simulate various suspicious activities, including light contact, moderate impact, and strong mechanical vibration. During testing, the SW-420 vibration sensor successfully detected mechanical disturbances generated during each experimental scenario. When no vibration was present, the Arduino continuously monitored the sensor output while maintaining normal system operation. The LCD displayed the standby status, and only the green LED remained illuminated, indicating that no abnormal activity had been detected.

When moderate vibration was introduced, the sensor immediately generated a digital signal that was processed by the Arduino Uno. The LCD displayed the corresponding vibration status, while the warning LED was activated to notify users of the detected disturbance. The response occurred almost instantaneously, demonstrating the capability of the embedded system to process sensor signals in real time. For high-intensity vibration, the prototype exhibited a more comprehensive warning response. The red LED illuminated immediately, and the buzzer generated an audible alarm to indicate potential intrusion or unauthorized physical activity. Throughout repeated experiments, the warning system consistently responded to strong mechanical disturbances without noticeable delay or operational instability.

Repeated testing further demonstrated stable system performance. The vibration sensor maintained consistent sensitivity throughout multiple experimental trials, and the Arduino successfully processed all incoming signals without communication errors or software interruption. The LCD, LED indicators, and buzzer operated synchronously, confirming reliable coordination among all hardware components. The experimental observations indicate that the developed prototype effectively distinguishes different vibration levels while maintaining rapid response characteristics and stable operation. The successful integration of the SW-420 vibration sensor with the Arduino Uno provides a practical solution for low-cost suspicious activity detection capable of supporting real-time security monitoring in various indoor environments.

3.3 System Performance Evaluation

Following the successful implementation of the prototype, comprehensive performance evaluation was conducted to assess the operational reliability of the Arduino-based vibration sensor system. The evaluation focused on several key performance indicators, including vibration detection capability, response time, warning accuracy, operational stability, and overall system reliability. The experimental setup used during the performance evaluation is presented in **Figure 4**.

Figure 4. Experimental evaluation of the Arduino-based vibration sensor system

The developed prototype demonstrated stable performance throughout repeated testing under controlled laboratory conditions. During normal operating conditions, when no external vibration was applied, the SW-420 vibration sensor remained in its standby state and continuously transmitted stable signals to the Arduino Uno. The microcontroller correctly interpreted the sensor output, maintaining the system in monitoring mode without generating unnecessary warning notifications. This behavior indicates that the developed prototype exhibited satisfactory stability and minimized false alarm activation during normal environmental conditions.

When controlled mechanical disturbances were introduced, the vibration sensor responded immediately by generating digital output signals corresponding to the detected vibration intensity. The Arduino Uno successfully processed these signals in real time and activated the appropriate warning devices according to the programmed decision algorithm. Moderate vibrations triggered visual warning indicators on the LCD and LED modules, whereas high-intensity vibrations simultaneously activated the red LED indicator and buzzer alarm. This layered warning strategy enables users to distinguish different levels of suspicious activity and respond appropriately according to the severity of the detected disturbance. The overall functional performance of the developed prototype is summarized in Table 2.

Table 2. Performance Evaluation of the Arduino-Based Vibration Sensor System

Performance Parameter	Experimental Observation	Performance
Vibration detection	Successful	Excellent
Arduino processing	Stable	Excellent
LCD display	Real-time operation	Excellent
LED indicators	Functional	Excellent
Buzzer alarm	Immediate activation	Excellent
Response time	Fast	Excellent
Operational stability	Stable	Excellent
Overall system reliability	Reliable	Excellent

The experimental observations confirm that all integrated hardware components functioned properly throughout repeated testing. The Arduino Uno continuously processed sensor signals without communication errors, while the LCD, LED indicators, and buzzer operated synchronously in response to different vibration levels. The stable interaction among sensing, processing, and notification components demonstrates the effectiveness of the embedded system architecture adopted in this study.

3.4 Discussion

The experimental results demonstrate that the proposed Arduino-based vibration sensor system provides an effective solution for early suspicious activity detection through real-time vibration monitoring. The integration of the SW-420 vibration sensor with the Arduino Uno microcontroller enabled rapid identification of abnormal mechanical disturbances while simultaneously activating visual and audible warning devices. Compared with conventional passive security methods, the developed prototype provides automatic detection and immediate user notification, thereby improving the effectiveness of early intrusion prevention.

One of the primary strengths of the proposed system is its simplicity and affordability. The prototype employs commercially available electronic components that are inexpensive, easy to assemble, and widely accessible. Unlike many commercial security systems requiring complex networking infrastructure or cloud-based communication, the developed prototype operates as a standalone embedded system capable of providing reliable security monitoring with minimal hardware complexity. Consequently, the system can be implemented in residential buildings, offices, laboratories, storage facilities, and educational environments without requiring substantial installation costs.

Another significant advantage is the low electrical power consumption of the prototype. Both the Arduino Uno and SW-420 vibration sensor consume relatively little electrical energy, allowing continuous operation for extended periods. This characteristic makes the developed system particularly suitable for battery-powered applications or locations with limited electrical infrastructure. Furthermore, the modular hardware configuration allows additional communication technologies, such as GSM, Wi-Fi, Bluetooth, or Internet of Things (IoT) platforms, to be integrated into the existing system without major hardware redesign.

The findings of this study are consistent with previous investigations reporting that vibration sensors provide effective early detection of unauthorized physical disturbances. However, unlike many earlier prototypes that focused primarily on hardware implementation, the present study provides a more comprehensive evaluation of operational reliability, response consistency, and system stability through repeated experimental testing. This broader performance assessment offers valuable information regarding the practical feasibility of implementing low-cost embedded security systems for real-world applications.

From an educational perspective, the developed prototype also serves as an effective learning platform for embedded systems, electronics, instrumentation, and sensor technology. Students can directly observe how mechanical vibrations are converted into digital signals, processed by a microcontroller, and translated into visual and audible warning outputs. Such practical implementation strengthens conceptual understanding of embedded programming, digital electronics, sensor integration, and real-time monitoring systems while encouraging problem-solving skills through hands-on experimentation.

Despite its satisfactory performance, several limitations should be acknowledged. The SW-420 sensor primarily detects vibration intensity and cannot distinguish the exact source or type of disturbance. Consequently, strong environmental vibrations may occasionally generate unnecessary warning signals if the sensitivity threshold is not properly adjusted. In addition, the current prototype operates as a standalone system and does not provide remote monitoring or smartphone-based notification capabilities.

Future research should therefore integrate wireless communication technologies such as Wi-Fi, GSM, or Internet of Things platforms to enable remote monitoring and automatic notification through mobile applications. Additional sensors, including passive infrared (PIR), magnetic door sensors, or accelerometers, may also be incorporated to improve detection accuracy and reduce false alarms. Furthermore, implementing machine learning algorithms for vibration pattern classification could significantly enhance the intelligence and reliability of future embedded security systems.

Overall, the developed Arduino-based vibration sensor system successfully demonstrates that simple embedded technology can provide a reliable, low-cost, and energy-efficient solution for suspicious activity detection. The findings confirm the feasibility of integrating vibration sensing, embedded processing, and real-time alarm mechanisms into an effective security monitoring platform suitable for both practical applications and engineering education.

4 Conclusion

This study successfully designed, developed, and experimentally evaluated an Arduino-based vibration sensor system for suspicious activity detection. The proposed prototype integrates an SW-420 vibration sensor, an Arduino Uno microcontroller, a 16×2 LCD with an I2C interface, LED indicators, and a buzzer into a compact embedded security system capable of providing real-time monitoring and early warning against abnormal mechanical disturbances. The developed system was designed to offer a simple, low-cost, and energy-efficient solution suitable for residential, educational, laboratory, and office security applications.

Experimental results demonstrated that the developed prototype operated reliably throughout repeated testing. The SW-420 vibration sensor successfully detected mechanical disturbances with consistent sensitivity, while the Arduino Uno accurately processed the sensor signals and activated the appropriate visual and audible warning devices according to the detected vibration level. The LCD module displayed the system status in real time, whereas the LED indicators and buzzer provided immediate notifications, enabling rapid identification of suspicious activities. The integrated hardware components exhibited stable performance without communication failures or operational interruptions, confirming the effectiveness of the proposed embedded system architecture.

From an engineering perspective, the prototype demonstrates the successful integration of vibration sensing technology, embedded systems, digital signal processing, and real-time monitoring into a practical security application. In addition to its practical implementation, the developed system also provides an effective educational platform for demonstrating sensor technology, microcontroller programming, embedded system design, and electronic instrumentation through hands-on experimentation. Consequently, the prototype contributes not only to the advancement of affordable security technology but also to engineering and technology education.

Despite its promising performance, several limitations remain. The current prototype relies solely on vibration sensing and therefore cannot identify the exact source or type of disturbance. Furthermore, the system operates as a standalone device without remote communication capability. Future research should integrate wireless communication technologies such as Wi-Fi, GSM, or Internet of Things (IoT) platforms to enable remote monitoring and smartphone notifications. Additional sensors, including passive infrared (PIR), magnetic door switches, or accelerometers, may also be incorporated to improve detection accuracy and reduce false alarms. Overall, the proposed Arduino-based vibration sensor system demonstrates significant potential as a practical, reliable, and economical solution for early suspicious activity detection while providing a valuable foundation for future intelligent security system development.

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