

Development of an IoT-Based Noise Hazard Monitoring and Alert System in a Sugar Factory

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Abstract

This study aims to develop a real-time hazardous noise monitoring and alert system using Internet of Things (IoT) technology, provide safety notifications via the LINE application when noise levels exceed 85 A-weighted decibels (dB(A)), and compare the continuous monitoring coverage of the proposed IoT system with traditional spot-measurement methods. The methodology involved the installation of an ESP8266 microcontroller integrated with an industrial-grade RS485 noise sensor (SN-3002-ZS) in the vicinity of a grinding machine within a sugar factory. A linear transformation compensation algorithm was applied to correct calibration offsets, ensuring measurement integrity. Data samples were continuously collected at 10-second intervals over a 20-day period during the sugarcane milling season, incorporating distance variation tests ranging from 10 to 100 meters. All acquired data were transmitted via a Pocket Wi-Fi network to a cloud-based platform (Google Sheets) for storage and data processing. The results indicated that the system successfully recorded a total of 99,974 data sets. The maximum noise level detected was 91.54 dB(A), with an overall average L_{eq} of 74.51 dB(A). Ultimately, the developed IoT system effectively addresses the limitations of traditional, discontinuous measurement methods by enabling 24-hour continuous monitoring, thereby providing a practical and robust tool for safety officers to efficiently manage hazardous zones.

Keywords

Internet of Things (IoT), Noise Monitoring System, Sugar Factory, RS485 Sensor, Real-time Alert.

1. Introduction

The sugarcane and sugar industry is a primary sector driving Thailand's economy. During the milling season, factories operate large machinery at full capacity 24 hours a day to process agricultural products. Within this complex manufacturing environment, heavy equipment—particularly grinding machines—inevitably generates high-intensity noise pollution. According to occupational health and safety standards, the permissible noise exposure limit for workers over an 8-hour workday is 85 dB(A) (Department of Labor Protection and Welfare, 2018). To proactively prevent auditory damage before reaching this cumulative threshold, immediate interventions are required. Prolonged exposure to noise levels exceeding this limit directly impacts the auditory system, leading to permanent Noise-Induced Hearing Loss.

Currently, conventional industrial noise management predominantly relies on periodic spot-checking by safety personnel. However, previous studies highlight the necessity of continuous monitoring, as conventional area sampling often fails to accurately capture individual noise exposure (Bunyamalik, 2023; Wundersitz et al., 2015). To address these vulnerabilities, Internet of Things (IoT) technology provides a network of physical objects embedded with sensors to exchange data seamlessly (Ashton, 2009), effectively bridging the physical and digital worlds (De, 2011). Recent advancements have proven IoT's effectiveness in continuous environmental monitoring (Somsuphaprunyos et al., 2024) and hazard alerts using microcontrollers like the ESP8266 (Tangkawanich, 2024). While some systems employ complex architectures such as Raspberry Pi with camera integration for silent zones (Sanadi, 2023), there is a critical need for a ruggedized, cost-effective solution tailored for high-interference industrial environments.

Therefore, this study aims to develop a real-time IoT-based noise monitoring system. A microcontroller unit was integrated with an industrial-grade noise sensor to automatically collect sound intensity data near grinding machines and wirelessly transmit the datasets to a cloud-based system. By establishing an immediate warning trigger at the 85 dB(A) limit, the system dispatches instant messages via the LINE Messaging API to safety officers, ensuring prompt Personal Protective Equipment (PPE) enforcement. Furthermore, this study will compare the continuous monitoring coverage of the proposed IoT system with traditional measurement methods to validate its efficiency in a real-world sugar factory setting. This automated monitoring framework allows safety officers to promptly implement corrective measures or issue verbal warnings, ensuring a compliant and secure working environment.

1.1 Objectives

The primary objectives of this research are:

- 1.1.1 To develop a real-time hazardous noise monitoring and alert system using Internet of Things (IoT) technology.
- 1.1.2 To provide instant safety notifications via the LINE application to safety officers when the noise level exceeds the safety threshold of 85 dB(A).
- 1.1.3 To evaluate and compare the continuous monitoring efficiency of the proposed IoT system against traditional manual spot-checking methods.

2. Literature Review

Traditionally, industrial noise assessment relies heavily on Area Sampling methods utilizing handheld Sound Level Meters. While these standardized devices offer high measurement precision, they are inherently limited to periodic spot-checking. This manual approach fails to capture the cumulative and dynamic noise exposure of workers continuously. Wundersitz et al. (2015) emphasized that relying solely on periodic checks often underestimates true workplace hazards, advocating for the necessity of continuous monitoring to ensure comprehensive occupational safety.

To address these gaps, recent advancements have increasingly integrated Internet of Things (IoT) technologies into environmental and safety management. Ashton (2009) and De (2011) described IoT as a seamless integration of physical devices with digital networks, enabling real-time data exchange. In practical applications, Waisayadamrong and Kraipanyapong (2018) successfully applied IoT systems for environmental monitoring, demonstrating the reliability of automated data logging. Similarly, Somsuphaprunyos et al. (2024) highlighted the efficiency of real-time sensor data collection centers, proving that continuous wireless monitoring can operate effectively over extended periods without human intervention.

In the specific domain of hazard alerts and security, microcontrollers such as the ESP8266 have become highly preferred due to their cost-effectiveness and built-in wireless capabilities. Settha (2024) demonstrated the successful application of microcontrollers for industrial safety alerts, emphasizing their rapid response times. Furthermore, the integration of these microcontrollers with mobile communication platforms—such as the LINE application—has proven highly effective for instant notification systems. Studies by Tangkawanich (2024) on security alarms and Phiphatkamtorn et al. (2023) on smart notification systems both validated that pushing alerts directly to users' smartphones significantly reduces response latency during critical events.

Despite these technological advancements, literature addressing continuous IoT noise monitoring specifically tailored to the harsh conditions of heavy manufacturing remains limited. For instance, Sanadi (2023) developed an IoT-enabled noise monitoring device for silent zones using complex architectures like Raspberry Pi integrated with cameras.

However, these approaches present challenges such as high power consumption, elevated implementation costs, privacy concerns regarding continuous image capture, and a lack of ruggedness against electromagnetic interference (EMI).

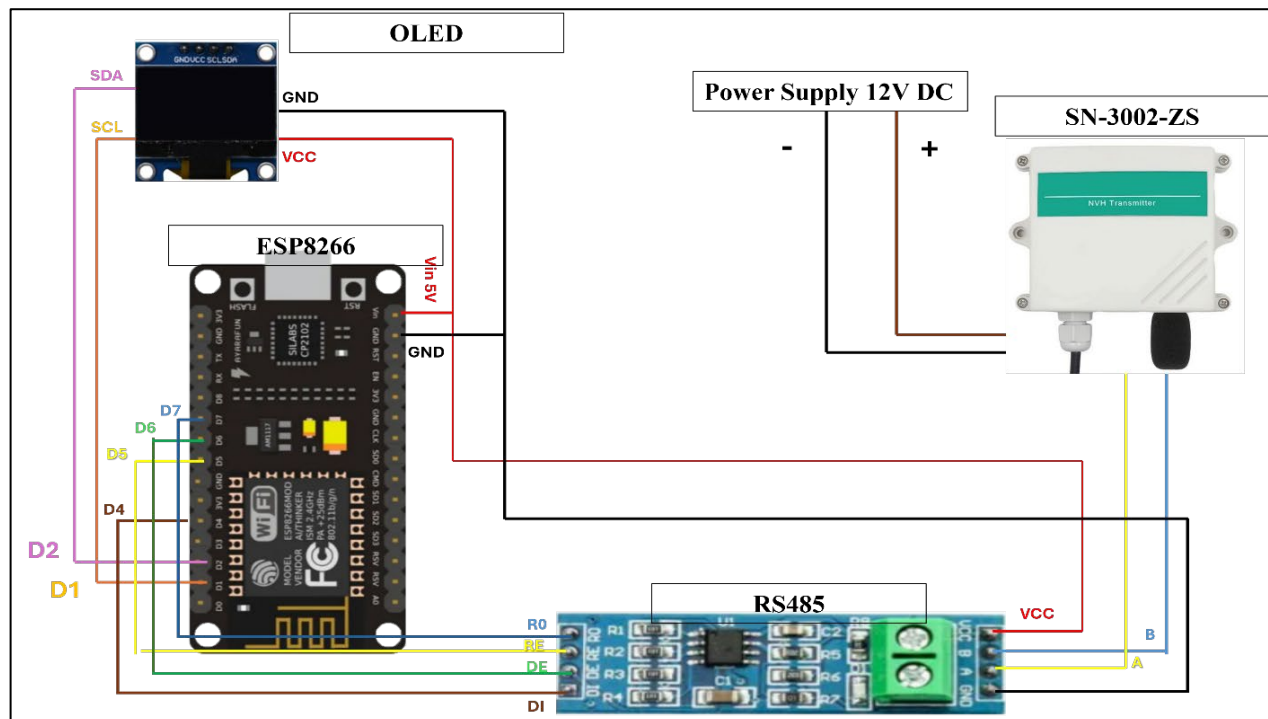
To overcome these limitations, recent international studies heavily emphasize the integration of advanced technologies for continuous monitoring. For instance, Madahana et al. (2024) developed an artificial intelligence-based early warning system for occupational noise using smart wearables and hearing muffs equipped with sound sensors. Their system applies machine learning algorithms, such as Random Forest and Decision Tree, to classify noise priority levels in real-time. Similarly, Dhirani et al. (2021) highlighted the necessity of bridging Information Technology (IT) and Operational Technology (OT) security gaps to safeguard Machine-to-Machine (M2M) communications in Industrial IoT (IIoT) environments. Furthermore, Farooq et al. (2023) presented a comprehensive four-layer IIoT architecture—comprising perception, network, processing, and application layers—which utilizes protocols like MQTT and ZigBee to enhance smart manufacturing operations seamlessly.

3. Methodology

The proposed system architecture is designed to address the challenges of large-scale industrial monitoring. For the hardware configuration, a microcontroller is utilized as the central processing unit due to its high efficiency in handling sensor inputs and executing rapid data transmission over wireless networks (Settha, 2024; Hadkhuntod and Sangkudluo, 2024). This wireless approach effectively overcomes the traditional limitations of wiring distance and high installation costs in expansive factory areas (Waisayadamrong and Kraipanyapong, 2018). Furthermore, to ensure real-time responsiveness, the software system integrates an automated alerting mechanism via a chat application API. Delivering instant notifications directly to a designated chat group has proven to be a highly effective method for rapid incident management and continuous safety monitoring (Phiphatkamtorn et al., 2023).

3.1 System Architecture and Hardware Design

The core processing unit of the proposed system is the NodeMCU ESP8266 microcontroller, selected for its cost-effectiveness and built-in Wi-Fi capabilities (Espressif Systems, 2019). To ensure industrial-grade accuracy and durability against electromagnetic interference (EMI) from heavy machinery, an SN-3002-ZS noise sensor utilizing the RS485 communication protocol was implemented (Measurement Sensor Data, 2022). The sensor continuously measures noise levels ranging from 30 to 130 dB(A). A local OLED display (128x64) was installed for real-time on-site visualization. The entire system was powered by a 12V 5A adapter and connected to the cloud via a standalone Pocket Wi-Fi router to ensure uninterrupted data transmission (Figure 1).



3.2 Sensor Pre-Deployment Validation and Software Compensation

Additionally, a linear transformation compensation algorithm ($y = 1.1173x - 18.288$) derived from two standard reference points (94 dB and 114 dB) was integrated directly into the ESP8266 microcontroller's code. The relatively large offset (-18.288) was implemented to account for the baseline hardware shift between the sensor's factory default calibration and the Type 1 acoustic calibrator standard, thereby ensuring dynamic measurement integrity across varying sound intensities.

3.3 Software Implementation and Cloud Integration

If the measured noise intensity exceeds the 85 dB(A) safety threshold, the system autonomously pushes an alert notification using the LINE Messaging API to designated safety officers(Figure 2).

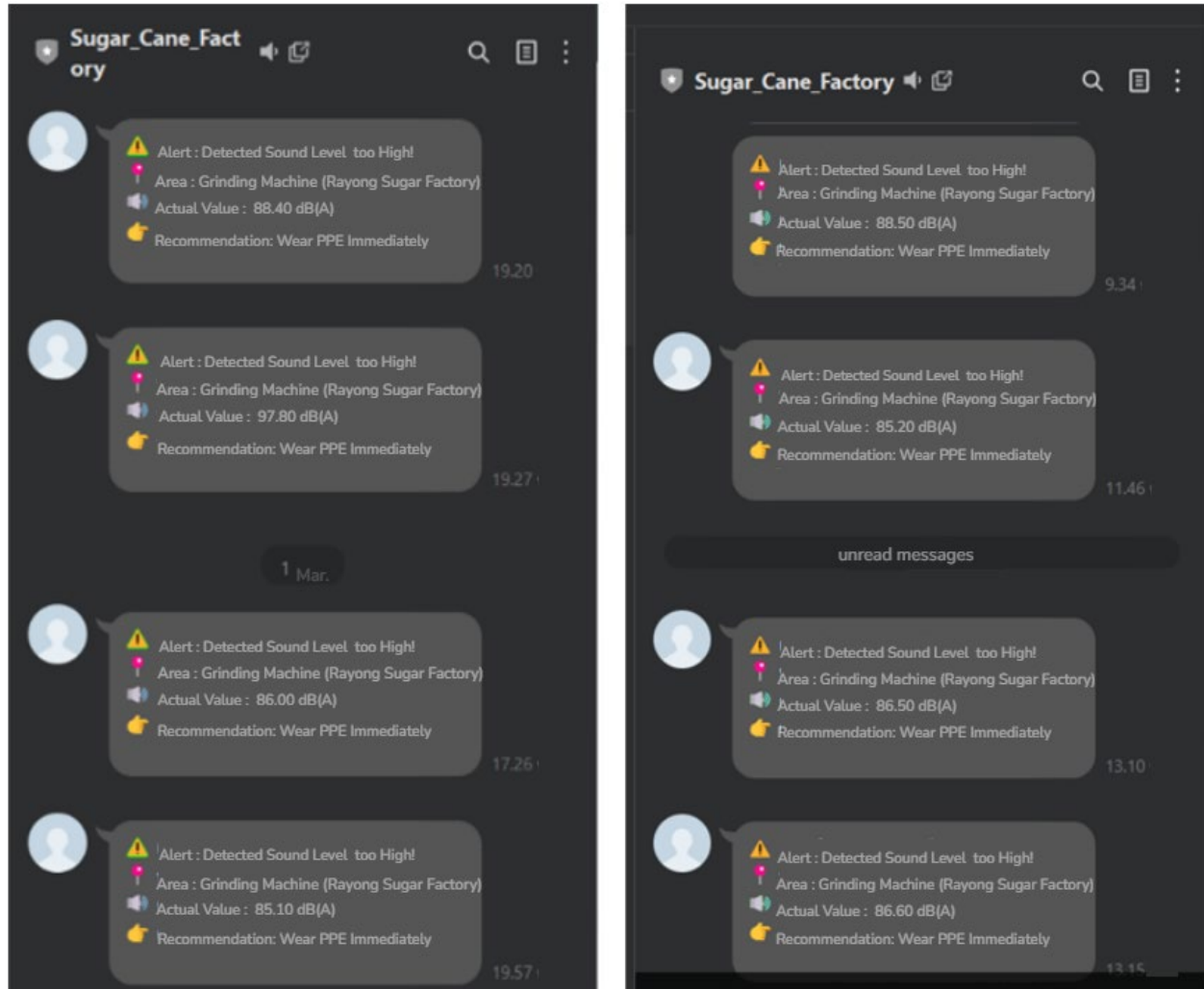


Figure 2. Real-time alert notification via the LINE application when noise exceeds 85 dB(A).

3.4 Data Processing and Visualization

Since noise levels are measured in decibels (dB), which operate on a logarithmic scale, calculating the standard arithmetic mean is mathematically invalid. Therefore, the Equivalent Continuous Sound Level (L_{eq}) equation was integrated into the Looker Studio dashboard to accurately determine the Time-Weighted Average (TWA). The logarithmic formula used for data processing is as follows:

$$L_{eq} = 10 \log_{10} \left(\frac{1}{N} \sum_{i=1}^N 10^{\frac{L_i}{10}} \right)$$

where L_{eq} is the equivalent continuous sound level in dB(A), N is the total number of recorded data points during the specific period, and L_i is the individual noise level measurement acquired by the IoT module. This ensures the visualized dashboards strictly align with occupational safety calculation standards.

4. Data Collection

The operational testing and field data collection were conducted at the Rayong Sugar Factory in Chaiyaphum Province, Thailand. The monitoring module was specifically installed within the grinding machine zone during the peak sugarcane milling season. The data collection process spanned 20 consecutive days. To comprehensively analyze the spatial attenuation of the noise, the monitoring module was initially placed 10 meters from the noise source. Subsequently, it was incrementally moved outward by 10 meters every two days, up to a maximum distance of 100 meters (Figure 3).



Figure 3. Field deployment of the IoT noise monitoring module within the grinding machine

5. Results and Discussion

The implementation results demonstrate the reliability and efficiency of the proposed IoT-based noise monitoring system. The system provides extensive continuous data tracking, offering significantly broader temporal coverage compared to traditional manual spot-measurement methods. The automated logging removes human error and allows for a more comprehensive analysis of noise patterns.

5.1 Comparative Analysis of Monitoring Efficiency

The analysis revealed a maximum recorded noise level of 91.54 dB(A) and an overall average L_{eq} of 74.51 dB(A). While this spatial average represents the overall factory environment, the critical exposure risk was heavily localized at the operator's station within 10–20 meters (Table 1).

Table 1. Performance comparison between the traditional spot-checking method and the proposed IoT monitoring system over a 20-day period.

Evaluation Metrics	Traditional Method (Spot-Checking)	Proposed IoT System
Data Acquisition Frequency	Discontinuous (2 times / shift)	Continuous (Every 10 seconds)
Total Data Points Collected	120 data points (Estimated)	99,974 data points
Real-time Hazard Alert	None (Delayed reporting)	Instantaneous (via LINE Messaging API)
Man-hour Requirement	High (Requires active patrol)	Low (Automated data logging)
Hazard Zone Detection	Theoretical estimation	Empirical data-driven (Distance vs. Noise)

The empirical data in Table 1 clearly illustrates the limitations of the traditional method, which generated an estimated 120 data points over 20 days, capturing only snapshots of the acoustic environment. In stark contrast, the IoT system autonomously logged 99,974 data points, providing a high-resolution, 24-hour continuous dataset. This comprehensive data capture allowed the IoT system to identify 2,620 instances where the noise intensity exceeded the 85 dB(A) threshold—critical hazard events that periodic manual spot-checks would likely miss. Furthermore, the IoT system completely eliminated the latency in hazard reporting by providing immediate LINE notifications, significantly reducing the man-hours required for manual surveillance while enhancing the precision of occupational health interventions.

5.2 Overall Noise Monitoring Data

Throughout the monitoring period, the noise intensity exceeded the 85 dB(A) permissible limit 2,620 times, accounting for 2.62% of the total monitored duration. It is important to note that the regulatory 85 dB(A) threshold is defined as an 8-hour Time-Weighted Average (TWA) exposure according to industrial standards. The 2,620 exceedances detected by this IoT system represent instantaneous peak levels rather than cumulative TWA exposures. Therefore, these automated alerts function as a proactive, early-warning mechanism to prevent prolonged exposure, rather than a standalone legal compliance measurement. This empirical evidence underscores the necessity for targeted occupational health interventions and adequate hearing protection within the grinding machine area.

5.3 Distance vs. Noise Attenuation Analysis

Generally, the data exhibited a logarithmic attenuation trend. Under a free-field approximation, sound pressure level is expected to decrease logarithmically with distance according to the inverse-square law. However, beyond a distance of 50 meters, the noise attenuation ceases and plateaus at approximately 68–70 dB(A) out to 100 meters. This plateau indicates that the extreme 85 dB(A) hazard zone is confined strictly to the immediate vicinity of the source, and readings at further distances are primarily dominated by the general ambient noise floor of the factory rather than the grinding machine itself (Figure 4).

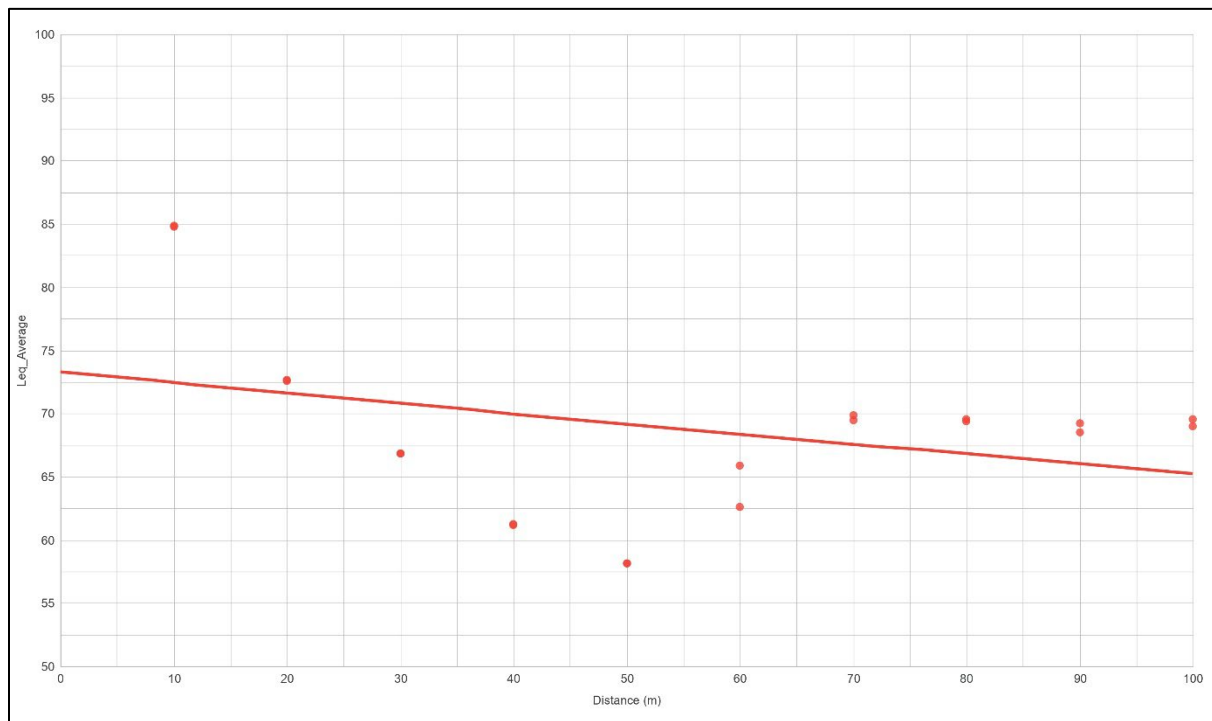


Figure 4. Scatter chart showing the logarithmic relationship between noise intensity and distance
(After Software Compensation)

5.4 System and Implementation Limitations

This legal framework currently hinders the full, autonomous deployment of IoT monitoring technology as a standalone regulatory enforcement tool in factories, necessitating a hybrid approach of IoT monitoring and human verification. Furthermore, regarding the spatial analysis, the sensor module was relocated outward every two days. Consequently, the distance variable is confounded with day-to-day variations in machine load and adjacent factory activities, which represents a limitation of this single-pass spatial sweep methodology.

6. Conclusion

The generated extensive dataset provides safety officers with an actionable, data-driven framework to demarcate precise Hazard Zones and enforce strict PPE compliance, ultimately safeguarding workers against Noise-Induced Hearing Loss.

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