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(Research Article)

Smart noise pollution monitoring system

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Abstract

Increasing pollution poses serious health risks, necessitating urgent control measures for a healthier future for all. Among various pollution types, sound pollution significantly impacts quality of life and well-being, especially in densely populated urban areas. This proposal describes the creation and deployment of an Internet of Things (IoT)-based noise pollution monitoring system intended to track sound levels in certain regions in real time. The core of this system comprises advanced sensors strategically placed to measure sound intensity accurately.

These sensors can detect even minor variations in noise levels, providing precise and reliable data. After being gathered, the data is sent to a microcontroller, which effectively processes it. This microcontroller ensures the data is accurately captured and sent over the internet to an online server. Once the data reaches the online server, it becomes accessible for analysis and monitoring by authorities. The system's real-time data capability is crucial for timely intervention. Authorities can continuously monitor noise levels and identify trends or spikes in sound pollution, allowing them to address issues promptly.

This feature is particularly beneficial for sensitive areas such as schools, hospitals, and residential zones, areas with heavy traffic, library, Where excessive noise can have severe health effects, including stress, sleep disturbances, and hearing loss. The system includes an alert mechanism that notifies relevant authorities when noise levels exceed predefined thresholds. These alerts enable quick responses to mitigate noise pollution. For instance, in a school, reducing noise levels can enhance the learning atmosphere and improve students' concentration.

In hospitals, maintaining a quiet environment is crucial for patient recovery. The integration of IoT technology in this noise pollution monitoring system not only enhances efficiency but also provides a scalable solution adaptable to various urban and rural settings. This scalability ensures the system can be expanded to cover larger areas or multiple locations as needed.

Keywords*:* IoT; Microcontroller; Noise Pollution; ESP32; Sound Sensor

1. Introduction

The rising concerns over air and noise pollution demand immediate action. A project proposes an IoT-based solution to monitor Air Quality Index (AQI) and Noise Intensity with four key modules: AQI Monitoring, Sound Intensity Detection, Cloud-based Monitoring, and Anomaly Notification. Initially, AQI is assessed based on five key pollutants, while dedicated sensors measure sound levels concurrently. Data aggregation occurs via a Wi-Fi-enabled Raspberry Pi, enabling periodic analysis through the Cloud-based Monitoring Module. The Anomaly Notification Module promptly alerts stakeholders to any irregularities, aiming to provide timely insights for effective pollution control measures[1].This chapter introduces smart cities, emphasizing sound as vital urban data. It explores computational analysis applications in urban sound, focusing on audio surveillance and noise pollution monitoring via dense sensor

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networks and machine listening. It compares mobile and static sensing strategies, proposing a cost-effective acoustic sensing solution for distributed machine listening. Addressing challenges in sound event detection and classification, it covers feature design, learning methods, and advancements such as convolution networks and data augmentation. The chapter concludes with insights on mobile sensing potential, current research data limitations, and future research directions [2].

For citizens of the United States, urban noise pollution poses a serious threat to health, causing problems such as heart disease, hypertension, sleep disorders, and hearing loss. In response, New York City has been using 55 sensor nodes for more than two years, collecting data on sound pressure levels for more than 75 years as well as audio recordings for more than 35 years. In order to evaluate the health of the sensors, these sensors also track telemetry data. A model developed over an 18-month period using 31 sensors is 69.1% accurate in identifying pre-failure situations. Better urban noise management and enhanced quality of life are promised by the infrastructure, which outlines sensor operations and data production while showcasing a created defect detection mechanism ready for future system integration.[3].A quarter of the air compounds and more than half of the nitrogen oxide and carbon monoxide emissions were caused by transportation. Throughout their lives, cars and trucks emit pollutants, and pollution is also released during vehicle operation, refuelling, production, and disposal. Cities are becoming noisier by the day because of increased traffic and powerful motors. These issues are resolved by our suggested approach, which makes use of the internet of things. The traffic department and national environment agencies will be notified if a vehicle exceeds the threshold value set by our system, which monitors the amount of pollution and noise produced by vehicles. [4].

Noise pollution has become a significant global issue, affecting hearing, behaviour, sleep, and speech intelligibility. In educational settings, high noise levels can disrupt learning and teaching processes. IoT technology offers a solution for monitoring environmental noise to ensure human safety. This paper presents the development of an IoT-based noise monitoring system using a sound sensor, NodeMCU, LCD, and LEDs. The system provides real-time alerts if noise exceeds the threshold set by health standards. Data from the sensor is sent to a cloud server and displayed on an Android app for remote monitoring. A case study at University Technology Malaysia (UTM) measured noise levels on weekends and weekdays. According to the Charted Institution of Building Service Engineers (CIBSE), 60dBA is the permissible ambient level for speech intelligibility. The study found that weekends are suitable for studying all day, while weekdays are best for studying during midnight based on noise level readings[5].Due to the high decibel levels and harmful chemicals in the air that directly affect human health, air and noise pollution are becoming major problems in metropolitan areas and require special care. This study offers a conceptual design for an adaptable, flexible, and economical air and sound quality monitoring system for a specific location. We suggest an IOT-based air quality and sound pollution monitoring system that enables real-time monitoring and assessment of both factors in a given area [6].

This article proposes and analyzes an IoT-based system for monitoring air and sound pollution, which is highly desirable for pollution control. The system detects pollution levels over time. The article details the hardware and software components used, including the IoT framework, the Arduino Uno R3 microcontroller and its architecture, the gas sensor and its features, the sound sensor and its specifications, and the ESP8266 Wi-Fi module[7].All devices in the system inclusive of ESP8266, Xmega 2560, sound sensor as well as WiFi are connected via Internet of Things (IoT). ThingSpeak environment is used for recording the collected sound and air quality information. Alert is sent to the authorities whenever the pollution exceeds a certain set limit[8].

Vehicular noise pollution is alarmingly increasing, particularly from lorries, vans, cars, and buses, posing significant health risks in smart cities. Key areas like hospitals, educational institutes, and organizations are heavily affected, leading to neurocognitive issues. Controlling vehicular noise is crucial for mitigating these health problems. However, there is limited research on using IoT technology to monitor vehicular noise in smart cities. This paper proposes an intelligent IoT-enabled system for real-time monitoring of vehicular noise using sensors, 360° cameras, 360° LIDAR, and GPS. The system aims to notify stakeholders (vehicle owners, city authorities) and store data in the cloud, enhancing noise control and raising public awareness[9]. Monitoring is necessary because noise pollution poses serious risks to the environment and public health. Using a Node MCU with an ESP8266 WLAN adapter, a DHT11 sensor, a MQ9 gas sensor, an LM393 sound sensor, and other sensors, this project constructs an Internet of Things-based sensor network to monitor environmental noise and air quality. Pollution levels are predicted by neural network methods such as CNN, SVM, and ELM, with the latter demonstrating the greatest performance in terms of RMSE, MSE, and MAE metrics. This concept works well in places with a lot of pollution and noise. [10].

2. Literature review

The human ear perceives sound as a change in pressure wave migrating through the air. However, noise may be quite unpleasant. The distinction between loudness and sound is identified by the receiver and the situation.

Fatema, Tashfat*et al.,* [11] Noise pollution critically affects health and quality of life. The WHO highlights its impact on well-being, such as hearing loss in pregnant women and illnesses in children. An IoT-based monitoring system using Arduino IoT Cloud collects real-time noise data, enabling effective management through web and mobile applications. This portable solution aims to transform cities like Dhaka by efficiently capturing and analyzing noise data to improve urban living.

Gunatilaka, Dolvara*et al.,* [12] Noise pollution adversely affects urban health. Traditional noise monitoring methods are costly and time-consuming. IoT technology offers an efficient alternative, automating the process and expanding coverage. This paper presents an IoT-enabled acoustic sensing platform with an affordable NB-IoT device for continuous sound measurement and event recording, supported by a back-end system for data collection and device management. The low-cost microphones are calibrated for accuracy. The system's reliability, latency, and energy consumption are evaluated.

Anachkova, Maja*et al.,* [13]As opposed to the conventional noise mapping procedures that involve costly and time-consuming measurement process with a traditional high-priced noise level meter, the low-cost wireless sensor networks provide a method for achieving data collection and analysis with a higher level of granularity. This paper presents a wireless noise sensor unit design for continuous environmental noise level monitoring as a framework for the realization of the Internet of Things (IoT) and „Smart city" concept. The concept involves the complete noise data information system, from sensor structure to data visualization and data analysis.

Aarthi.*et al.,* [14]Sound pollution is a serious issue, leading to various diseases. The Sound Pollution Monitoring device, accessible via a mobile app, allows users to check pollution levels and can detect fires, notifying authorities for prompt action. Utilizing IoT, this system combines electronics and computer science to access and store data remotely, eliminating the need for physical presence in the monitored area.

Salazar .*et al.,* [15] Noise pollution is a significant environmental issue, with government agencies seeking control solutions. Traditional methods use expensive devices for real-time monitoring. Recently, IoT offers low-cost sensors for real-time data capture and better decision-making. This summary reviews 17 high-impact articles on IoT-based noise solutions, addressing layers for noise control, technological elements, and current limitations. A four-layer IoT system for monitoring and analyzing noise levels was defined through identifying critical terms, locating and evaluating literature, and summarizing findings.

Dobrilović.*et al.*, [16] Traffic noise on city roads has been identified as one of the major problems in urban settlements. Fortunately, it can be monitored and controlled in a way that can reduce its level and negative effects. One of the most effective and cheapest ways to monitor and control traffic noise is to use wireless sensor networks, IoT technology, and cloud-based architectures.

Patila, Ashwini S.,*et al.,*[17] Every form of pollution is primarily caused by rapid industrialization. The following are the main causes of environmental deterioration: vehicle emissions, industrial emissions, burning of fossil fuels and fires, agricultural operations, population growth, etc. The ecology is deteriorating due to industrial noise, waste water outflow, and toxic gas emissions. This study has Identified and reported the sources of emissions in the industry. This study presents the usage of IoT method to reduce industrial area noise pollution. The noise level in that region is ascertained by using the noise sensors, which then process the signal and provide it to the microcontroller. The WiFi module is utilized to communicate the noise level to the server and is also shared with that authority.

Kazmi, Aqeel, *et al.,* [18] A major contribution in noise pollution comes from road traffic. The research presented here offers a novel Internet of Things-based method for tracking and controlling road traffic noise in smart cities. Our method gathers and integrates data streams from various sensing devices using an IoT platform. Following data analysis, traffic noise events are identified; if a given road's noise level surpasses a predetermined threshold, specific actions are taken to regulate traffic flow. We also talk about a prototype system installation and research approach.

Vanitha, *et al.,* [19] This system presents a low cost flexible and reliable automation system with personal alert messages using Arduino along with internet connectivity and remote control over devices by using a smart phone application. The suggested system detects human speech in a closed space using an Internet of Things [IoT] paradigm. Using a smartphone, the user can also receive the alert messages. The automation of a noise detection system using an Arduino Nano, a battery, an LCD panel, and buttons is presented in this research project. This application has been programmed in the C programming language. PROTEUS and Pick2kit are two tools that can be used to construct this application. The suggested noise detector system can be utilized in workplace, school, and library settings to identify noisy individuals and take appropriate action against them.

Srikanth, G*, et al.,*[20] Global concerns over noise pollution have led to detrimental effects like hearing impairment, social behavior issues, and sleep disturbances. In educational settings, high noise levels disrupt learning and teaching. Leveraging IoT technology, a system can monitor environmental noise to ensure safety. This system is practical in labs, libraries, and classrooms, identifying instances where noise exceeds predefined thresholds and generating alerts. It uses microphones for precise noise measurement in three directions and an ATMega controller for development. Users set maximum allowable noise levels via the device's display and buttons. The system remains green when noise is below the threshold; if noise exceeds the limit, a buzzer alerts users to reduce it. If noise persists, repeated alerts and a high noise message are displayed until the noise is reduced. This system acts as an intelligent, automatic noise pollution controller.

3. System model and methods

3.1. Hardware components used in proposed model

We utilize one micro-controller, one bread board, one noise detecting sensor for environmental noise detection, and a WiFi networking to monitor the noise strength. We also used a Web site to provide updates to the user. The Table 1 shows a brief functionality of all the hardware component used in our project. It described the breadboard, LM393, ESP32, module.

Table 1 The Inventory of Hardware Parts for Our Designed System

Hardware component	Functionality
Breadboard	The board will link all of the hardware parts that are required to create a complete working prototype of our suggested system.
Microphone sound detection sensor module LM393	It will evaluate the surrounding noise level. After that, the sensor output will be converted to dB.
Esp32 NodeMCU	It will function as the main microcontroller component. We transmit sensor data to the cloud using this MCU so that noise intensity forecasts can be made.
Jumper Wires	Remote electric circuits used for printed circuit boards are connected using it.

3.2. Explaining hardware in details

3.2.1. Microphone sound detection sensor module

It has an amazing dynamic microphone that records the sound level directly from the source. The sound sensor, as seen in Figure 1, is a small circuit board that has a microphone (50Hz–10kHz) and circuit connections that translate sound waves into electrical pulses. This electrical pulse is received by the LM393, a comparator IC, which digitises the signal and is coupled to the OUT pin. The noise sensor has three pins: OUT, VCC, and GND.

3.2.2. ESP32module

The ESP-32 module, that includes the ESP32 chip and a microcontroller, is included with the ESP32 that was seen in Figure 2. This CPU operates at a frequency of 80MHz to 160MHz and supports RTOS. For storing data and programs, the NodeMCU features 4 MB of Flash memory and 128 KB of RAM. It's perfect for Internet of Things projects due to its powerful processing capacity and integrated Wi-Fi or Bluetooth. The key part of this system is the NodeMCU ESP32, which connects all of these parts' pins together and keeps the system's operation fluid and manageable while employing frontend display for Vue.js to maintain the Sensor Module LM393. The figure 2 ESP32 is an amazing component that makes it possible to maintain everything on a single breadboard. It is logically connected to the appropriate pins by wired connections.

Figure 1 Sensor Module LM393

Figure 2 ESP32

4. Implementation of the system

The ESP32 and the LM393 sound sensor module were used in the construction of our system. The GND of the Sensor Module is connected to the GND of the ESP32 to complete the connection. Furthermore, the ESP32's 3V3 and A0 pins are linked to the sensor module's VCC and OUT pins, respectively. Figure 3 displays the block diagram. The pin connections between the three hardware components, ESP32 , microphone sound detection sensor module LM393 display accordingly are depicted in Table 2 as follows.

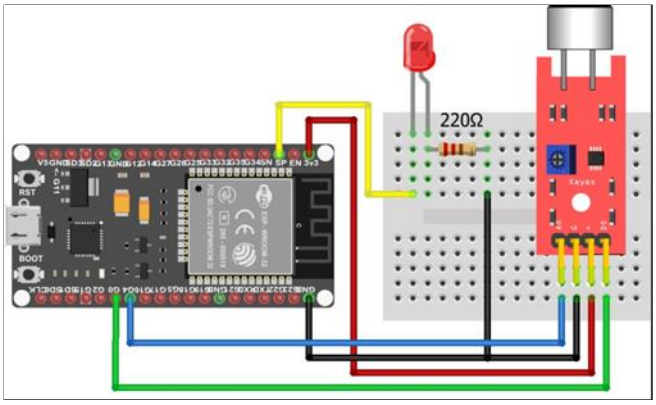

Figure 3 Connecting Components

Table 2 ESP32 and LM393 pin configuration

ESP32 – (Microprocessor ship) Pin	Microphone sound detection sensor module LM939 Pin
GND	GND
G4	A0
G0	D0
3V3	+

To connect the Arduino IDE software to the IoT cloud, we need to follow some setup steps according to our system's needs. After logging in, we'll set variables like the decibel level and connect the WiFi to the cloud. Next, we'll set up the board by configuring the ESP-32 microprocessor and adjusting the port settings. Before connecting the hardware, we'll also need to start the Arduino agent on our PC.

We'll develop and upload our code to the board and software once these procedures are finished. Upon successful uploading, the system will begin collecting ambient real-time data. Following login, the program ought to establish an automated connection with the server. The technology gathers environmental data when a user checks in and displays the noise level on the user's dashboard. With Figure 4 presenting the architecture .

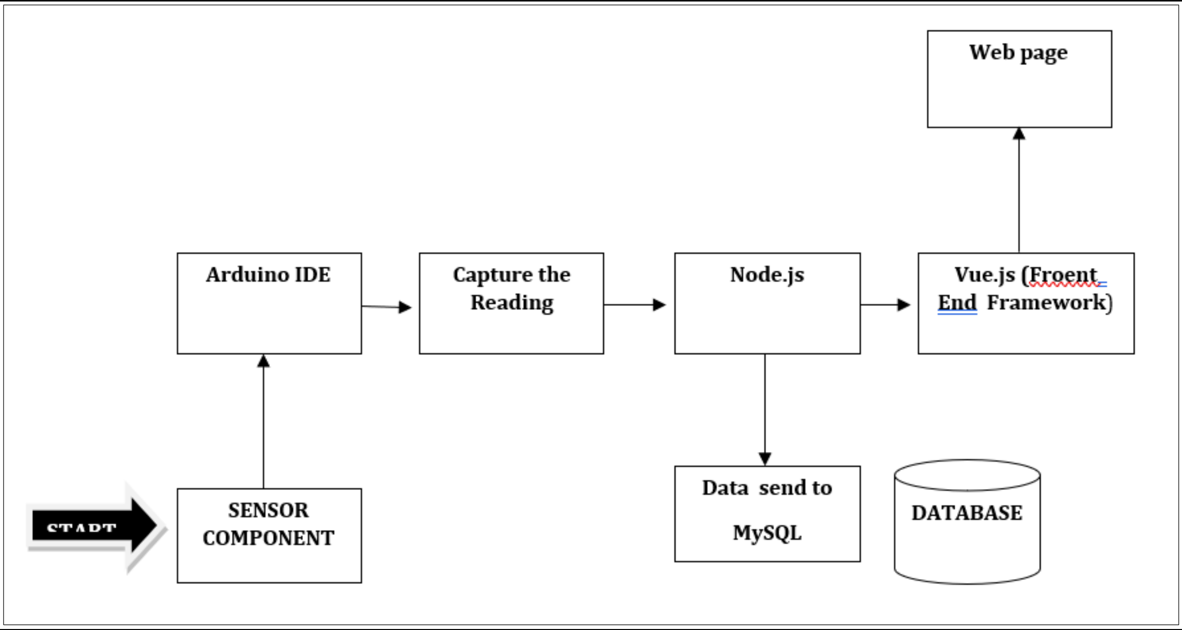

Figure 4 The architectural diagram and system setup for the suggested system.

Initially, we utilize code to construct every variable required for the application. To get the single at the right place, we set the signal maximum value to 0 and the signal minimum value to 1024. In order to receive the data, this will be reversed. Then, the while loop was used to evaluate the state of the real signal. The analog reading is set to zero by default. The first if condition checks to see if the sample in our input signal is smaller than 1024; if it is, the loop continues and the second condition, which compares the sample value to the maximum value, is checked. If it is, the value is saved in the signal maximum variable; if not, it Once that is done, check the other condition and put the value in the signal minimum variable. Once all requirements have been confirmed, we will calculate the difference between the largest and lowest signal. Next, use calibration to convert the result to the real variable, db, which has a decibel value.

5. Results and analysis

In the results and analysis section, we focused on ensuring the system operated as smoothly and effectively as possible, aiming for the highest level of success in our project. We conducted various tests to validate the system's performance. For example, we tested the system's response to loud noises to confirm it was functioning correctly, and it consistently delivered accurate results. We also reduced noise intensity in specific areas to check if the system could detect the difference, and it successfully displayed the expected outcomes at the base station.

The sensor readings are displayed on both the Website and the IoT Cloud dashboard, as shown in Figure 5. To improve accuracy and visualization, we used a MySQL database to track noise levels in specific areas and categorize the noise mode. For instance, Figure 6 shows an image of an Vue.js (Frame work) display indicating the noise level in decibels and the corresponding sound level classification, such as "QUIET" for that location. We presented the results on the dashboard using a graph chart that plots data against time, following the initial display on a gauge meter. This chart primarily shows noise intensity levels across different environments.

Additionally, we used a gauge meter labeled with the variable "decibel" in Figure 6, ensuring that the decibel output matches the displayed noise intensity. Figure 7 demonstrates how the Database also displays noise intensity levels, with the dashboard featuring both a gauge meter and a graph for easy understanding. In today's technology-driven world, a cloud-based application that provides real-time information about noise levels in specific areas could be highly beneficial to the general public, as most people have access to Website.

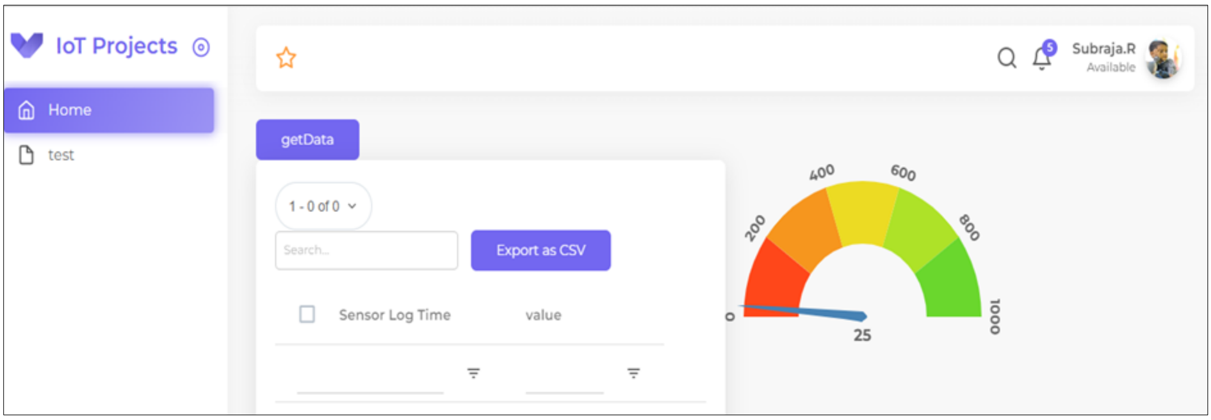

Figure 5 Display indicating the noise level

In the results and analysis section, we emphasized the critical importance of ensuring the system's flawless functionality, with the ultimate objective of attaining optimal performance throughout the entire span of the project. We embarked on an extensive series of evaluations meticulously designed to scrutinize the system's overall performance and operational capabilities under diverse conditions. A particularly noteworthy evaluation involved analyzing the system's response to loud auditory disturbances. This was essential for validating the system's ability to process extreme acoustic stimuli while maintaining precision and reliability. In each case, the system consistently exhibited its capacity to function effectively, delivering accurate and dependable results even when subjected to elevated noise levels.

Furthermore, beyond evaluating its response to loud noises, we conducted an additional experiment aimed at examining the system's sensitivity to more subtle environmental fluctuations. Specifically, we attenuated the noise intensity in targeted areas to assess whether the system could detect and respond to more minute variations. This experiment enabled us to evaluate the system's ability to discern different noise levels, demonstrating its flexibility in adapting to changing conditions. Impressively, the system accurately recognized these more refined variations and relayed the anticipated outcomes to the base station, further reinforcing its efficacy in practical applications where the detection of subtle changes is crucial. Collectively, these evaluations affirmed the system's robustness, precision, and reliability across a broad spectrum of scenarios, underscoring its potential for integration into dynamic environments.

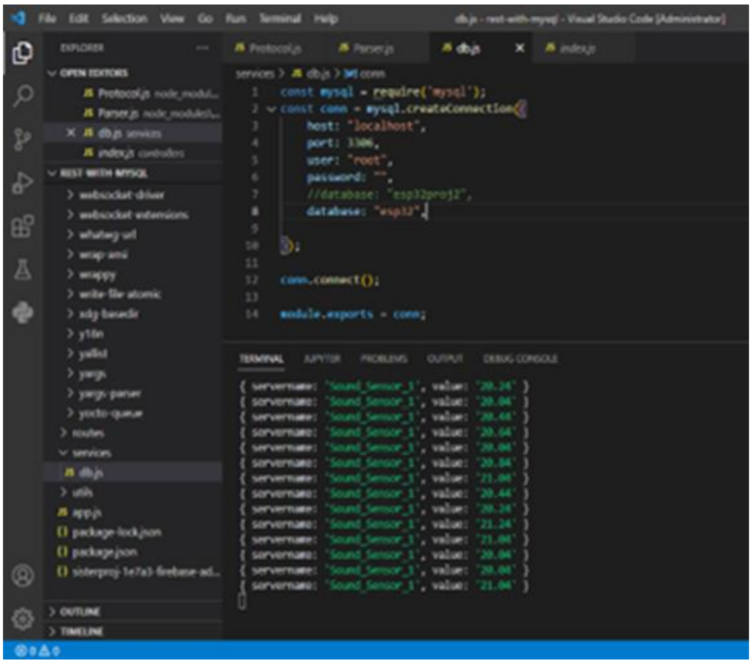

Figure 6 Displayed noise intensity

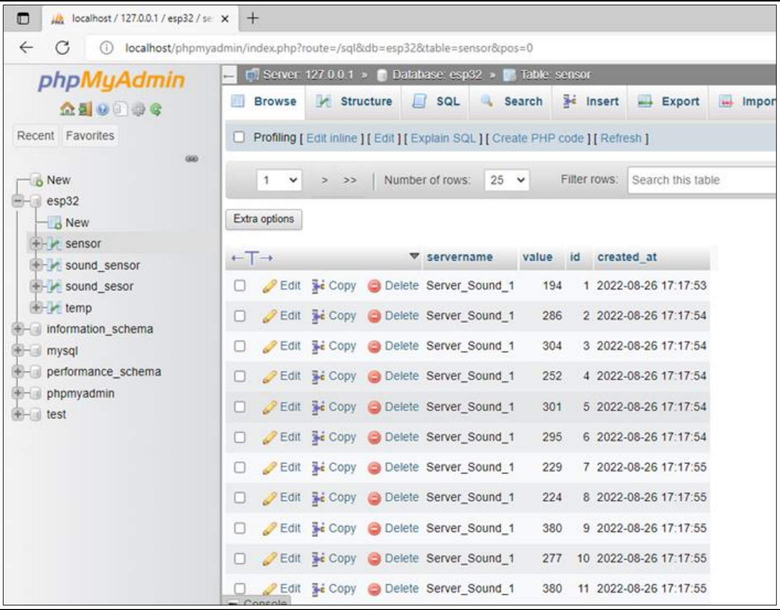

Figure 7 Store the data to MySQL Database Server.

6. User satisfaction level

After we finished our system, we asked several people to try it out and share their thoughts on how satisfied they were, as well as any suggestions or feedback for improvement. Table 4 shows the users' satisfaction ratings and their recommendations. The feedback was very positive, showing that the system works well. The suggestions provided will help us improve the system's features and make it easier to maintain by fixing any issues that were pointed out.

Table 3 User satisfaction and suggestion

Features	Satisfied %	Suggestion
ESP32	80%	It functions fine, however adding the WiFi module would improve it much further.
Microphone sound detection sensor module LM393	70%	It works pretty well.
IoT Cloud dashboard	99%	Seeing something different was interesting.
Data access (web and mobile)	99%	could really obtain information.

7. Conclusion

Our system is designed to measure noise levels in different environments and categorize them with specific labels, such as quiet, moderate, or high, based on the noise level in that area. This helps raise awareness about the potential health risks associated with noisy environments. The primary goal of our system is to collect field data to support further research aimed at reducing noise pollution and educating people about these risks.

We used the Arduino IoT cloud to gather data in real-time, allowing users to monitor noise levels live through the Arduino IoT cloud's mobile application. Our system is user-friendly and portable, making it easy to carry and use in various settings. The real-time data collection and storage capability of our system make it valuable for future machine learning research. Its compact design allows users to effortlessly gather noise intensity data in their daily lives. Additionally, since the system is web-based and mobile-friendly, users can easily monitor noise levels in different environments.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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