Noise Pollution Monitoring System

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EE399 - Community-Based Project

Abstract

This project presents the design and implementation of an IoT-based noise monitoring system. The system uses a MAX9814 microphone connected to an ESP32 microcontroller to detect noise levels in real time. The ESP32 calculates the noise level in decibels (dB), displaying the results locally on an OLED screen and transmitting the data points to ThingSpeak, a cloud-based IoT platform for storage.

A publicly accessible website was created using Google Sites, embedding a live chart from ThingSpeak to allows students and staff to monitor the noise levels of Maynooth Library. In addition, a real-time alert system was implemented using a webhook, emailing alerts to relative parties upon exceeding a noise threshold level.

This system contributes to SDG 4: Quality Education by promoting a quiet, distraction-free study environment that supports concentration and academic performance. The system is low-cost, scalable and efficient, offering a solution to improve learning conditions.

Authorship Declaration

We hereby certify that this report and the project it describes is our original work and has not been taken from the work of others and to the extent that such work has been cited and acknowledged in the report.

This project was over seen by Mr. Andrew Meehan and Dr. Majid Sorouri

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1. Introduction

1.1 Background

If silence is golden, why do we allow noise pollution to rob of us of our health and well-being? In today's urban environment, it has become an unavoidable part of daily life, yet effects are often overlooked. Major sources include urban traffic, industrial operations, construction activities, and even everyday household appliances [1]. According to the American Academy of Paediatrics (AAP), noise is defined as an *unwanted or objectionable sound* [2]. Acoustic signals that generate a pleasant sense, such as music, are considered "sound" while signals that cause feelings of discomfort or unpleasantness are "noise" [3]. The World Health Organization (WHO) defines noise pollution as occurring when sound levels exceed 65 decibels (dB), categorizing it as an environmental stressor [4]. The infographic below illustrates common noise sources and their corresponding decibel levels:

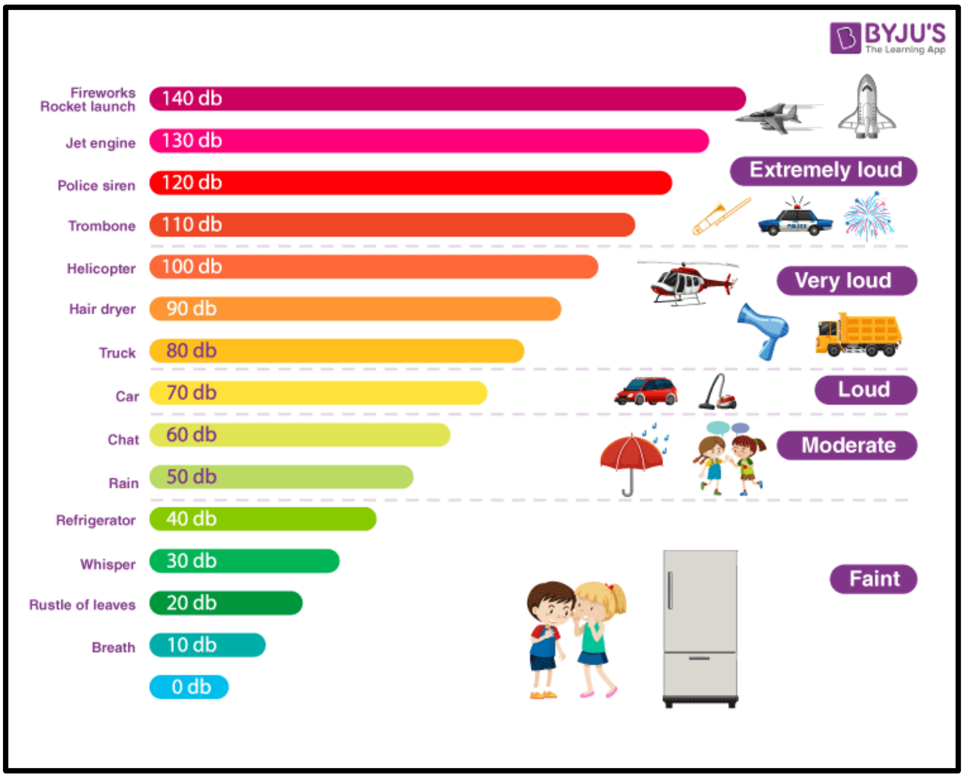

Figure 1: Common Noise Sources and their Decibel Levels, adapted from *[1]*

Noise is an underestimated threat that can cause a number of short and long-term health problems. Common health effects range from sleep disturbances and cardiovascular diseases to hearing impairment and reduced cognitive performance in work & school settings [5]. In the European Union, at least 20% of the urban population are estimated to be affected by harmful levels of road traffic noise. Consequently, long-term transportation noise levels result in at least 18 million people being highly noise annoyed, with a further 5 million suffering from high sleep disturbances [6]. It is important to understand that annoyance and sleep disturbance are proposed as the keys drivers of noise-associated non-communicable disease (NDC) onset and progression [7]. NCDs, also known as chronic diseases, include cardiovascular diseases, such as heart attacks & stroke, cancers and chronic respiratory diseases such as asthma [8]. Below is a figure illustrating the relationship between noise and some of these diseases:

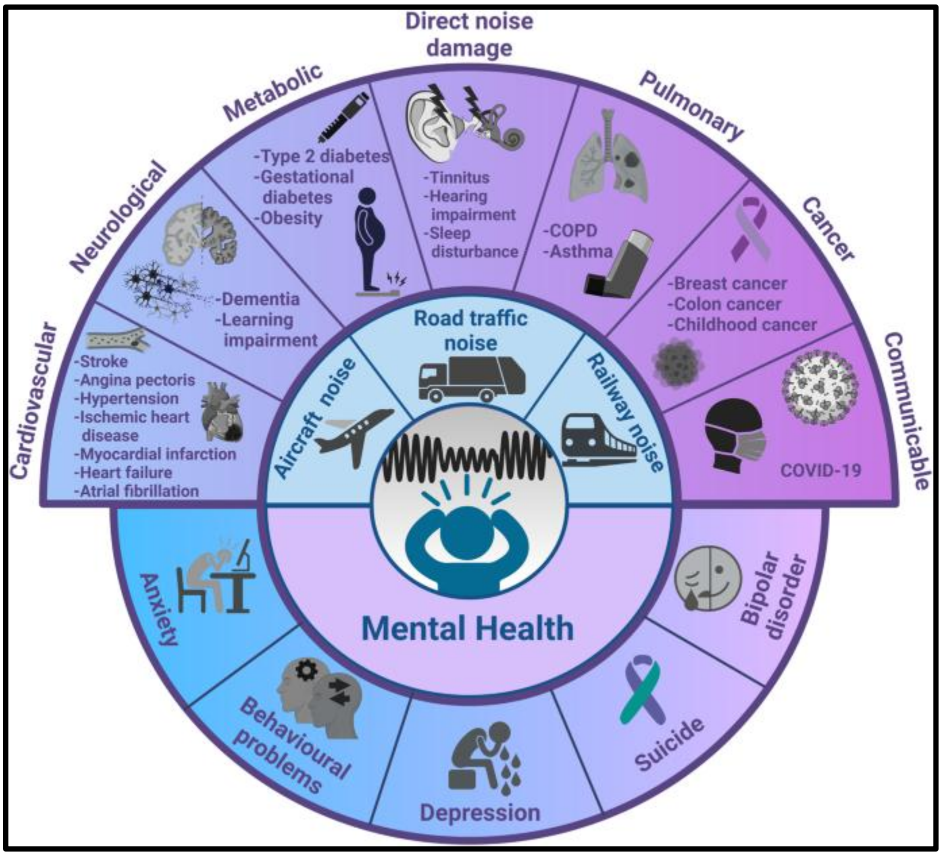

Figure 2: Effect of Noise on Physical and Mental Health, adapted from *[9]*

1.2 Problem Domain

In the context of academic institutions, excessive noise in libraries, lecture halls and student spaces can significantly affect a students' ability to concentrate, study and learn effectively. At Maynooth University, student feedback revealed that noise is a persistent challenge in common areas, even those designated as quiet zones such as the library. Survey data collected as part of this project showed that 66.7% of respondents have experienced noise disturbances in the library, with 42.9% stating that it moderately affects their ability to study (*see Appendix B*). These findings highlight a gap in effective noise management infrastructure on campus and suggest that there's a strong need for a real-time mitigation tool.

This project aims to address that gap by developing by engineering a low-cost, portable, IoT-noise monitoring system. The system continuously measures noise and uploads the data for visualisation & cloud storage, displaying noise levels locally via an OLED screen and alerting library administrators when a predefined threshold has been exceeded at the location of the device.

The system not only empowers students to monitor their environment but also enables staff to make data-driven decisions regarding noise control. This aligns directly with the United Nation's Sustainable Development Goal 4: Quality Education. It promotes a productive and thoughtful learning environment.

2. Literature Review

2.1 Existing Noise Monitoring Solutions

When proposing the chosen idea, it was essential to consider whether similar products already exist to address the same issue.

Traditional noise monitoring methods primarily rely on manual sound level meters and human input surveys, which require labour, usually don't filter out unwanted noise and may be subject to human parallax error. Additionally, many existing systems and products lack a direct communication channel between the customer and the end user. Most current solutions provide noise tracking data visible to customers but do not incorporate features that promote awareness among end users.

This project aims to address these shortcomings through the use of a device that monitors noise levels, improving mindfulness from students, allowing parties to monitor noise levels and alerting administrators when thresholds have been exceeded, ensuring individuals are more aware of noise pollution. By enhancing awareness and providing efficient enforcement mechanisms an improved learning environment can be achieved.

SpotNoise: Noise monitoring solutions that automatically record sound levels exceeding regulatory limits. These systems are designed for residential and industrial applications, providing users with data to address noise nuisances effectively. It differs to the proposed design as it doesn't include our flashing signboard functionality [10].

These systems exemplify current technologies that monitor noise levels and provide immediate alerts, contributing to effective noise management and public awareness.

2.2 Gaps in Current Noise Management Approaches

Noise pollution is a growing concern in urban environments and requires adaptive real-time warning systems to reduce its effects. Traditional noise monitoring solutions often focus on post-analysis, limiting their ability to provide instant feedback. In contrast, modern systems integrate real-time alerts, allowing individuals and communities to react immediately. Additionally, data logging and trend analysis enable long-term noise monitoring, helping policymakers identify patterns and high-risk areas. Many advanced systems incorporate mobile alerts, notifying users when noise levels exceed safe thresholds. Some solutions also employ multiple microphones to determine the direction of noise sources, improving accuracy. However, existing solutions often suffer from high costs and complexity, making them less accessible for widespread adoption.

Additionally, poor community engagement remains a constant challenge, as awareness plays a crucial role in enhancing quality of life and maintaining healthy societies. The device described in this report contains a feature that can encourage public participation in noise reduction efforts.

Another limitation of current systems is their struggle to filter out unwanted noise sources, leading to false warnings. A well-designed monitoring system must integrate intelligent filtering techniques to differentiate between relevant and irrelevant noise. The proposed solution offers real-time feedback at a lower cost (50-60 euros), compared to usual designs ranging from 100 euros and above. This makes it more affordable and accessible than existing high-end noise monitoring systems. By emphasizing public awareness and engagement, this project aims to create a more effective and community-driven approach to noise pollution management.

2.3 User Feedback and Community Engagement

We identified key noise issues on campus based on the survey responses, students at Maynooth University experience significant noise disturbances in various campus areas. The cafeterias and common areas (85.7%) were identified as the noisiest locations, followed by outdoor spaces and student accommodations. While the library is intended to be a quiet zone, some students (9.5%) still report it as a noisy environment, indicating that noise control measures may not be fully effective.

Furthermore, 42.9% of respondents stated that noise moderately affects their ability to study, with 19% reporting that it significantly disrupts concentration. These findings emphasize the need for an effective noise monitoring system to help maintain quiet study spaces.

For noise disturbances in the library and study areas the survey highlights that 66.7% of students have experienced noise disturbances in the library at least sometimes, with 28.6% facing frequent disturbances. The main sources of noise pollution in study areas include:

- Conversations from other students – 76.2%
- External noise from outside the building – 38.1%
- Loud footsteps and chair movement – 23.8%

These results suggest that while external noise plays a role, the majority of noise issues come from within the study spaces themselves, particularly due to student conversations.

Students are also asked about interest in noise monitoring solutions. When asked whether a noise level monitoring system in quiet zones would be useful, 42.9% agreed it would help maintain a quieter environment 33.3% were open to the idea depending on implementation. This indicates that a significant portion of students support the idea of an automated system to monitor and regulate noise levels.

Moreover, 68.7% of respondents have been annoyed by noise but did not leave the study area, while 14.3% have left multiple times due to excessive noise. This reinforces the need for real-time noise awareness and alerts to prevent disruptions before they reach intolerable levels.

Preferred alert system for noise control to ensure that students are aware of excessive noise, the survey asked how they would prefer to receive notifications, and the answers were:

- Visual warning signs (LED indicator) – 42.9%
- Silent notifications via a mobile app – 38.1%
- Automated reminder announcements – 33.3%

3. System Design and Architecture

This section outlines the hardware and software architecture of the noise monitoring system. The system continuously measures the ambient noise levels of a room using a microphone connected to an ESP32 microcontroller. The ESP32 processes and transmit this data via Wi-Fi to an IoT analytics platform service, ThingSpeak, for storage and analysis. When a predefined noise threshold is exceeded, an alert is sent via email. Additionally, a web interface allows any user to monitor noise levels in real time.

3.1 Hardware Design:

Microphone: MAX9814

The microphone captures sound and translates it to a voltage signal. The output of this analogue signal is proportional to the sound intensity which is then processed by the microcontroller. This microphone is ideal as it comes with an automated gain control (ACG) function. ACG enhances accuracy in environments with fluctuating noise levels by automatically adjusting the microphone's sensitivity. This makes the device more reliable for monitoring environments where quiet is expected but occasional sound fluctuations occur – such as a book being dropped in a quiet library.

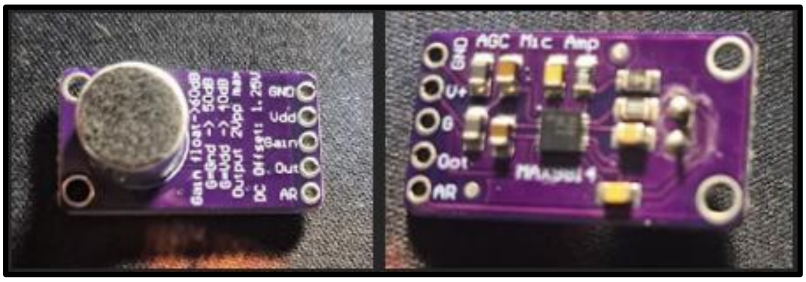

Figure 3: MAX9814 Microphone

Microcontroller: ESP32 Dev WROOM

The purpose of the microcontroller is to receive the analogue input from the microphone and convert it to a digital signal which can then be processed to determine the noise level and transmit the results. The ESP32 is an ideal microcontroller for this system due to its in-built Wi-Fi, support for analogue inputs and compatibility with Arduino IDE, all of which simplified development. Additionally, this board is cost-effective, coming in at under €10, making it a practical choice for student and scalable IoT applications.

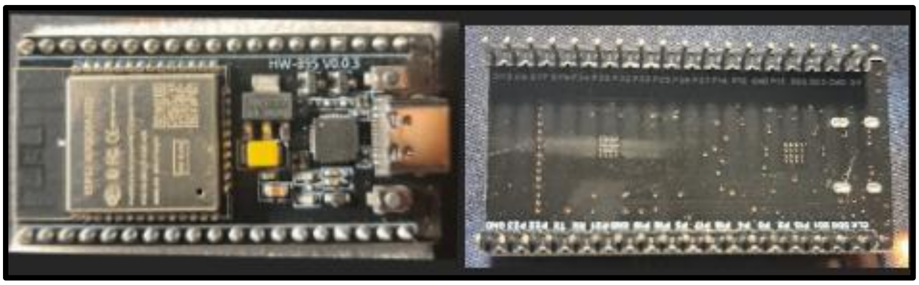

Figure 4: ESP32 Microcontroller

OLED Display:

An organic light emitting diode (OLED) display is used to show real-time noise level readings locally. It provides clear and immediate visual feedback to users, allowing them to monitor the current dB level without accessing the website. The display is easily integrated with the ESP32 via the I^2C protocol. I^2C is a communication protocol that uses only two wires - ideal for a compact embedded system like this. The addition of the OLED is practical, providing instant user-friendly feedback.

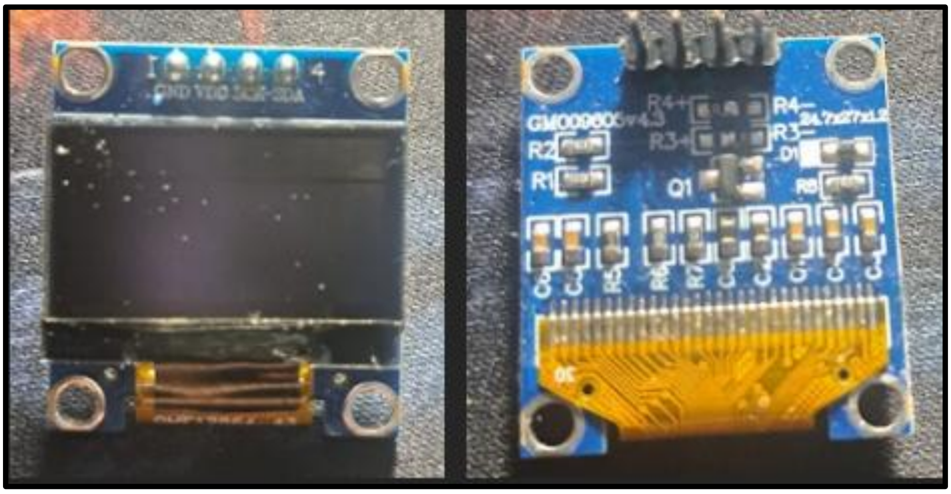

Figure 5: OLED Display

3D Design case

To protect the components and ensure the system is practical for real-world deployment, a custom 3D-printed case was designed using TinkerCad and printed in the library. The case was tailored to securely house the ESP32 board, microphone, OLED display, and led while allowing proper airflow (with holes) and sound input for accurate noise sensing. Openings were carefully placed for microphone exposure, charging access, and clear screen visibility. The case not only protects the electronics from dust and minor impacts but also gives the final product a more professional and portable appearance.

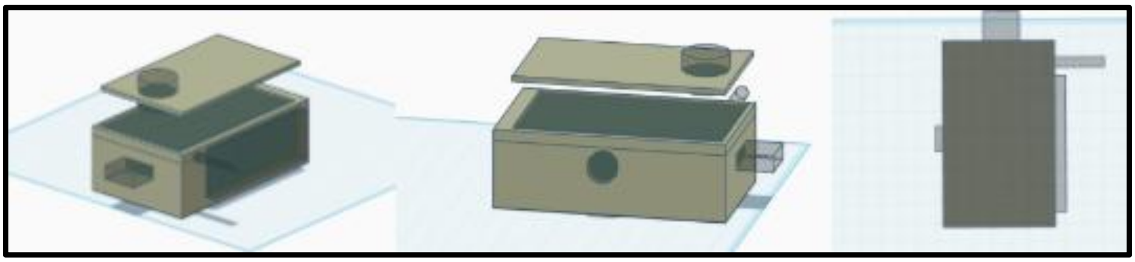

Figure 6: CAD of Case

3.2 Hardware System

The hardware system as shown in Figure 7 is built around the ESP32-WROOM-32 microcontroller, which serves as the central unit responsible for processing data, powering peripherals, and managing communication. The system captures ambient sound using the MAX9814 microphone module. This sound sensor has three main pins used in this project: VCC, GND, and OUT. The VCC pin is connected to the 5V output of the ESP32 to provide sufficient power. The GND pin is linked to the ESP32's ground to ensure a common reference. The analogue output (OUT) from the sensor, which carries the varying voltage corresponding to the noise level, is connected to GPIO 34 an analogue capable input on the ESP32.

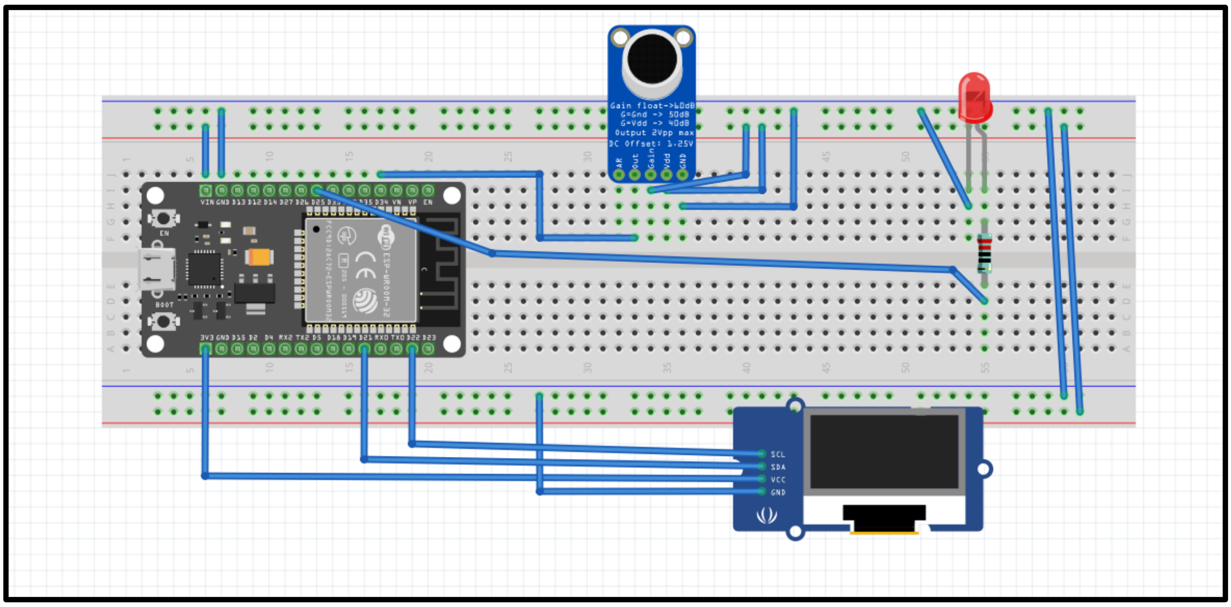

Figure 7: Noise Sensor Hardware System Done with Fritzing

To display the measured noise levels, a 0.96-inch I2C OLED display is used. This display module communicates with the ESP32 over the I2C protocol. The SDA (data line) of the OLED is connected to GPIO 21, and the SCL (clock line) is connected to GPIO 22, which are the default I2C pins on the ESP32. The OLED's power pin (VCC) is connected to the 3.3V output on the ESP32, and its GND pin is connected to the breadboard ground.

In addition to sensing and display, the system includes a basic alert mechanism using a two-pin red LED. This LED acts as a visual warning when noise levels exceed a predefined threshold (70 dB). The anode (longer pin) of the LED is connected to GPIO 25 of the ESP32 through a 220-ohm current-limiting resistor, which prevents excessive current from damaging the LED. The cathode (shorter pin) is connected directly to the ground. When the noise threshold is surpassed, GPIO 25 outputs a HIGH signal, turning on the LED.

All components share a common ground with the ESP32 and they are assembled on a breadboard and inside a custom 3D-printed case for portability. Power for the system is supplied via the ESP32's USB Type-C port, which is sufficient to operate the OLED, microphone, and LED simultaneously. This wiring configuration enables the system to continuously monitor ambient noise, display the readings, and activate alerts when needed.

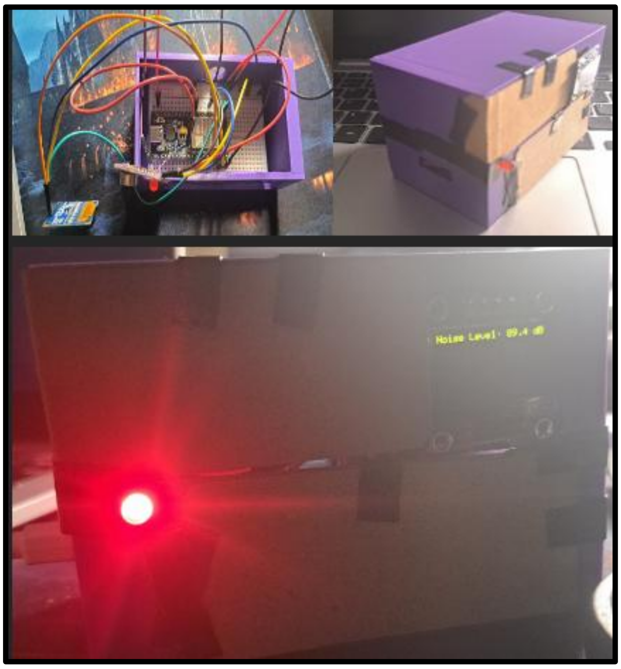

Figure 8: Assembled Device

3.3 Software Design

The Arduino Integrated Development Environment (IDE) was used to develop, compile and upload the firmware for the ESP32 microcontroller. Arduino IDE provided a platform for writing code as well as access and management of vital libraries, such as WiFi.h and HTTPClient.h. The serial monitor was essential for debugging and monitoring outputs. Overall, the Arduino IDE streamlined the development process, enabling rapid prototyping and testing of the system.

3.3.1 Data Acquisition, Processing and Display

The analogue signal from the microphone is read using the ESP32's built-in analogue-to-digital converter (ADC). The signal is sampled repeatedly over 50 milliseconds to determine the maximum and minimum values, calculating the peak-to-peak amplitude. This amplitude is converted into a voltage which is used to calculate the dB value. This formula approximates dB based on voltage amplitude using a logarithmic scale. The result is scaled to range between 30dB and 100dB to better reflect the typical ambient noise conditions.

```
int sample = analogRead(noiseSensorPin);
int peakToPeak = signalMax - signalMin;
float voltage = (peakToPeak * 3.3) / 4095.0;
float dB = 20 * log10(voltage / 0.001);
float c_dB = ((dB - 40.0) * 70.0 / 27.5) + 30.0;
```

Figure 9: Code Summary of ADC Reading and dB Calculation

The dB value is then displayed on the OLED connected via I^2C. A function re-writes the new noise levels read and changes the display accordingly.

```
void updateOLED(float value) {
  display.clearDisplay();
  display.setCursor(0, 0);
  display.setTextSize(1);
  display.setTextColor(SSD1306_WHITE);
  display.print("Noise Level: ");
  display.print(value, 1);
  display.println(" dB");
  display.display();
}
```

Figure 10: OLED Function

3.3.2 Communication with ThingSpeak

Using the ESP32's ability to connect to Wi-Fi, the noise level readings are published to ThingSpeak at regular intervals. ThingSpeak is an IoT analytics platform service that allows the aggregation, visualisation and analysis of live data streams in the cloud. Support for application programming interface (API) calls, integration of MATLAB and data export makes it a versatile and accessible choice for implementing cloud-based IoT solutions. An API is a way for one software or device to send or request data to another system over the internet.

Using the WiFi.h library, prewritten code that provides extra functionality, a Wi-Fi connection is established.

```
// Wi-Fi & ThingSpeak
const char* ssid = "GalaxyA53";
const char* password = "destinynosa";
// Connect to WiFi
  WiFi.begin(ssid, password);
```

Figure 11: Code Describing Wi-Fi Connection to Mobile Hotspot

Data is sent using an HTTP GET request, a type of web request used to send or retrieve data by appending it to a URL. This is formatted with the ThingSpeak API key and fields. The key describes the location the data is getting sent to, the channel, with the field the relating where in the channel the information is going i.e. which graph. The function builds a URL fitted with the data and intended location, via the API key and field, and sends it. This process ensures the noise level data is uploaded and logged for historical tracking and analysis.

```
const char* server = "http://api.thingspeak.com/update";
String apiKey = "T8SPEU5ZT7ILXCJH";

void sendToThingSpeak(float value) {
  if (WiFi.status() == WL_CONNECTED) {
    HTTPClient http;
    String url = String(server) + "?api_key=" + apiKey +
                 "&field1=" + value +
                 "&field2=" + value +
                 "&field3=" + value +
                 "&field4=" + value;

    http.begin(url);
    int httpCode = http.GET();
```

Figure 12: Code Describing Uploading Data via HTTP GET Request

3.3.3 Web Interface

A website hosted on Google Sites fetches the live data using a ThingSpeak API and uses an iframe to embed the channel graph directly. This lets the website display data without storing or calculating anything itself. The site displays a live noise level gauge of Maynooth Library, allowing any user, such as a student, to check the current conditions of the building, improving usability and accessibility (see Appendix X for a screenshot of the website)

Figure 13: *HTML iframe Embed Code used to Display Data Directly from ThingSpeak*

3.3.4 Alerting System

Using a combination of ThingSpeak and IFTTT, a platform that allows for the creation of customized automations, alerts are sent via email to relevant parties. In order to achieve this, a webhook was created using IFTTT. A webhook is a way for one system to automatically notify another. In this context, ThingSpeak triggers the webhook when it detects a reading over the threshold level and instantly alerts IFTTT, sending an email notifying administrators that excessive noise has been detected, enabling a fast and automated response without manual monitoring. Again, the use of a HTTP GET request is employed. Upon exceeding the noise threshold, ThingSpeak sends a GET request to a specific URL, triggering the webhook and sending the email (see Appendix B for a screenshot of the email).

Figure 14: HTTP GET Request Triggering Webhook

3.3.5 Code Structure and Loop Timing

As always, the structure and timing of the code is vital. The main program loop was designed to run every 5 seconds. This allows the ESP32 to perform efficiently: sample noise, process data, update display and upload the result.

```
// Timing
unsigned long lastReading = 0;
const unsigned long readingInterval = 5000; // 5 seconds
if (millis() - lastReading >= readingInterval) {
  lastReading = millis();
```

Figure 15: Code Summary of Loop Timing

3.4 Operation Workflow:

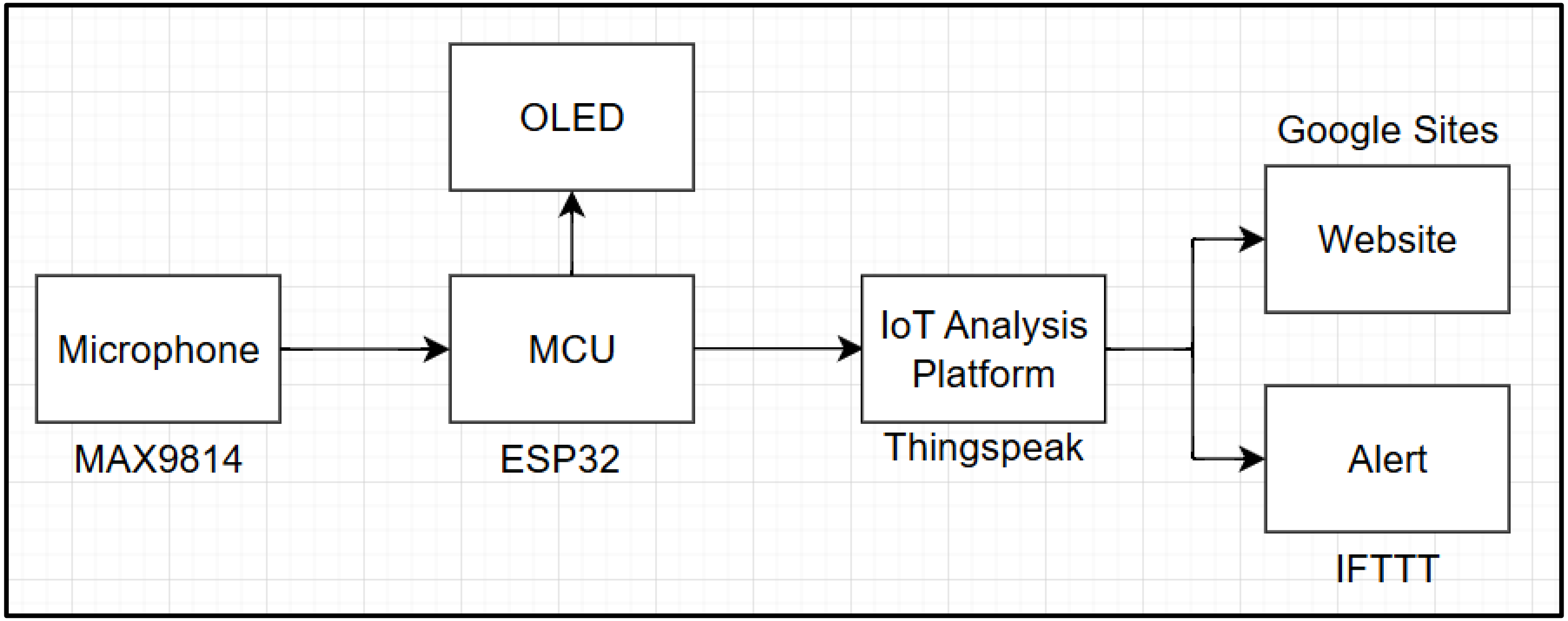

Figure 16: Block Diagram of Operation Workflow

Fig.16 is a block diagram illustrating the flow of data of the system. The analogue signal from the MAX9814 microphone is processed by the ESP32 microcontroller, with live readings displayed on an OLED screen. The controller transmits noise level data to the IoT platform ThingSpeak via Wi-Fi for cloud-based storage. From there, the data can be accessed via a Google Sites webpage and used to trigger real-time alerts via IFTTT when thresholds are exceeded.

4. Implementation:

4.1 Data Collection Planning

For the ground floor of the library, the setup was placed discreetly on a desk near the centre of the room to ensure an unbiased representation of ambient noise and making sure there was not noise coming from the desk. Measurements were taken every 5 seconds throughout the observation period, and each dB value was time-stamped to track changes over time. To complement the quantitative data, manual observational notes were recorded in parallel. These included room occupancy levels, noticeable noise sources (such as chair movement, ventilation, and background conversations), and any visible reactions from library users. This mixed-method approach allowed for a more comprehensive understanding of how environmental noise evolved with occupancy and how it might affect user experience, even if users did not visibly respond to elevated noise levels.

4.2 Hardware Limitations:

The noise monitoring system also presented several hardware limitations that impacted implementation. Most notably, the setup required a continuous connection to a laptop for both power and data logging, which restricted portability and made long-term, unattended deployment impractical. Additionally, the MAX9814 microphone sensor measures overall sound pressure levels in decibels but cannot distinguish between different types of noise (e.g., human conversation, ventilation hum, or chair movement). As a result, the system treats all sounds equally, making it necessary for the user to manually identify and record the noise sources during the observation period.

Environmental factors, such as microphone placement and room acoustics, could also influence the consistency and accuracy of the readings. Although the dB values were not perfectly precise, they were found to be very similar to those measured by a standard smartphone dB meter app (Sound Meter) as shown in Figure 17. This comparison confirmed that the system's readings were sufficiently accurate for general environmental noise monitoring purposes.

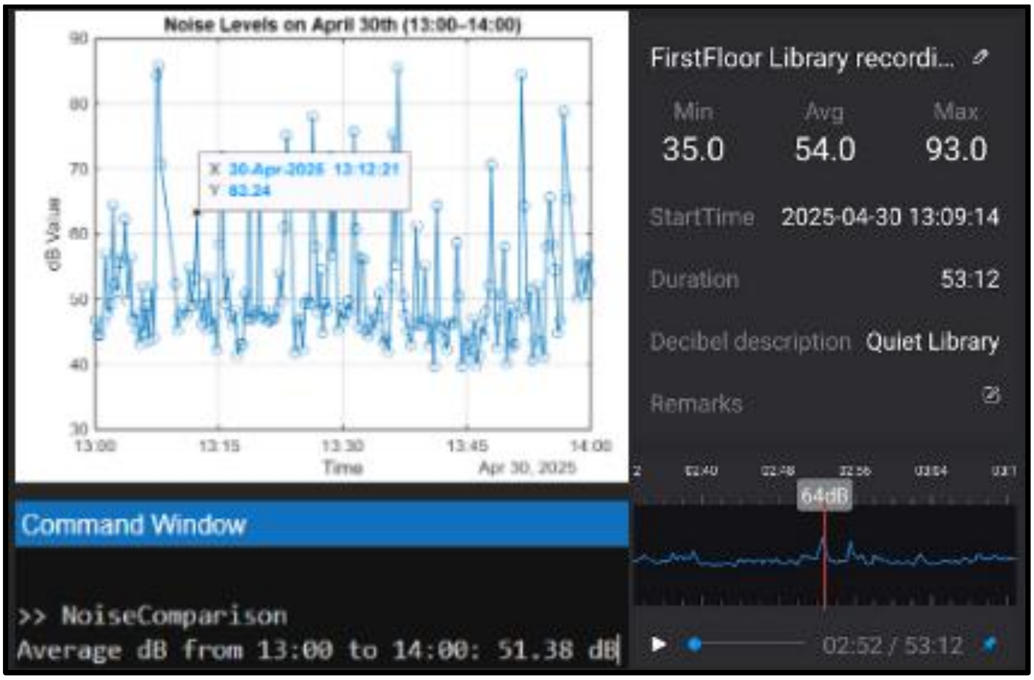

Figure 17: Comparison Between Sensor Readings and Smartphone App: April 30th, 13:00–14:00

5. Testing and Results

To evaluate the effectiveness of the noise monitoring system, a structured testing and analysis process was conducted. The goal was to collect, validate, and interpret environmental noise data from the library's ground and first floors, using real-world conditions and correlating them with occupancy patterns.

5.1 Data Collection in the Library

The system was discreetly placed at central locations on both the ground and first floors of the John Paul II Library; in fig.18 we can see where the noise levels were measure. It remained connected to a laptop via USB, which powered the setup and enabled data logging through the Arduino Serial Monitor.

Figure 18: Ground and First Floor of the Library

During each session, dB readings were recorded every five seconds and sent to ThingSpeak. This high-frequency sampling allowed the capture of subtle noise fluctuations resulting from mechanical systems (such as ventilation), human movement, and conversations. Alongside the quantitative data, observational notes were recorded to track occupancy levels, identify specific noise sources, and document user reactions. These qualitative insights provided valuable context for interpreting noise spikes and patterns.

After each session, the recorded data, consisting of timestamps and dB values was exported into Excel files. To make the dataset more manageable and reveal broader trends, the raw data (sampled every 5 seconds) was grouped into 15 minutes intervals and averaged. This preprocessing smoothed out short-term spikes, such as a book being dropped, and clarified the daily and weekly noise patterns.

5.2 MATLAB Analysis and Visualization

The processed Excel files were imported into MATLAB for analysis. Timestamps were converted into datetime format, and dB values were averaged over each 1-hour block. Graphs (fig.19 and fig.20) were then generated showing noise levels over time, with a horizontal line at 75dB added to highlight moments when the readings exceeded recommended thresholds for quiet environments.

The results showed consistently high noise levels between 12:00 and 18:00 on weekdays, with the ground floor frequently surpassing 75dB and peaking above 85dB. In contrast, weekends had significantly lower noise levels. These findings confirmed that the ground floor regularly exceeds optimal noise conditions for study, while the first floor remains quieter overall.

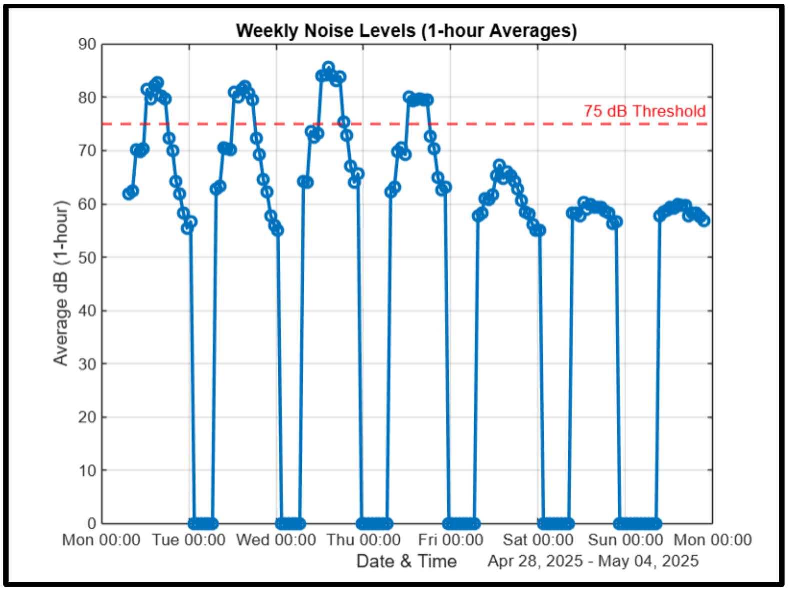

Figure 19: *Weekly Noise Levels (1-Hour Averages) from Ground Floor*

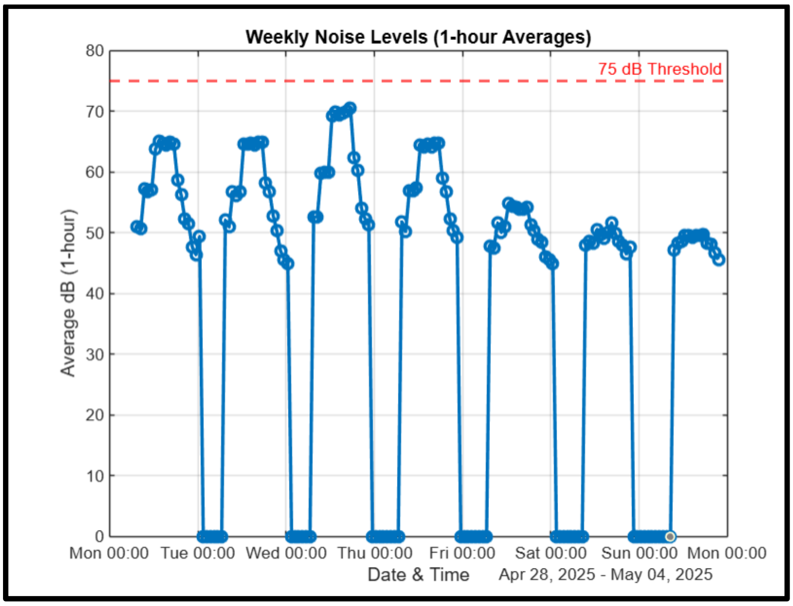

Figure 20: *Weekly noise levels (1-Hour Averages) from First Floor*

5.3 Noise Analysis

5.3.1 First Floor

Noise levels on the first floor were generally lower than on the ground floor, but still fluctuated during peak times. The analysis revealed dB levels ranging between 65–70 dB during busy periods, particularly from Tuesday to Thursday. Background conversations, especially from nearby group seating areas, were a major contributor. Other noticeable sources included keyboard typing, trackpad clicking, and squeaky or dragging chairs.

Brief but sharp spikes in noise were also observed due to incidental disturbances like dropped bottles, coughing, sneezing, and phone vibrations. These momentary spikes, though not sustained, could be distracting in a quiet study setting.

Occupancy levels had a clear impact. Usually throughout the week by 11:30, the floor was nearly full, and noise steadily increased as more people settled in. By around 14:30, the number of users increase slightly, with a corresponding raise in dB levels.

Although the first floor rarely exceeded the 75dB threshold, the frequent presence of high-60s to low-70s dB readings could still disrupt concentration. Avoidable contributors like poorly maintained chairs and sharp tapping from keyboards were identified as key targets for improvement. Addressing these could meaningfully reduce ambient noise and enhance user comfort.

The accompanying forecast charts for the first floor illustrate these trends clearly. Monday to Thursday show gradual noise build-up from morning to early afternoon, with Tuesday and Wednesday exhibiting the highest average dB levels. Weekend charts reveal significantly quieter patterns, with few hours nearing disruptive thresholds. These visual forecasts can be used to advise students seeking quiet study periods or by staff aiming to schedule maintenance during low-traffic hours.

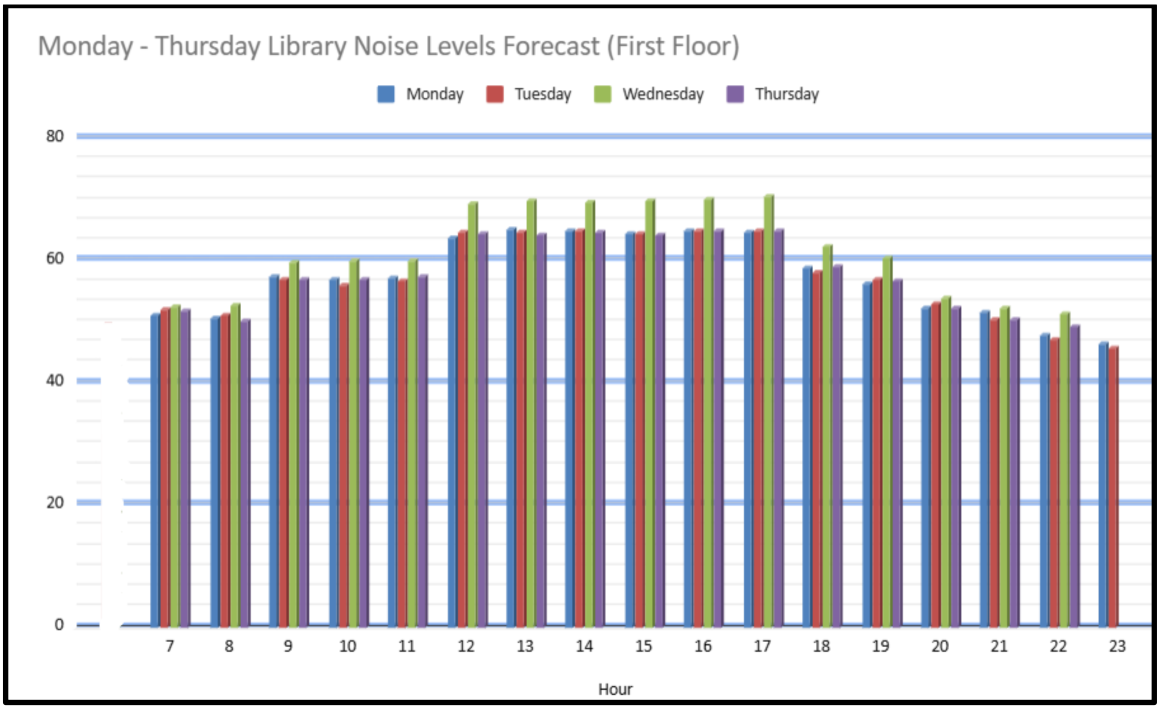

Figure 21: Monday-Thursday Library Noise Levels Forecast (First Floor)

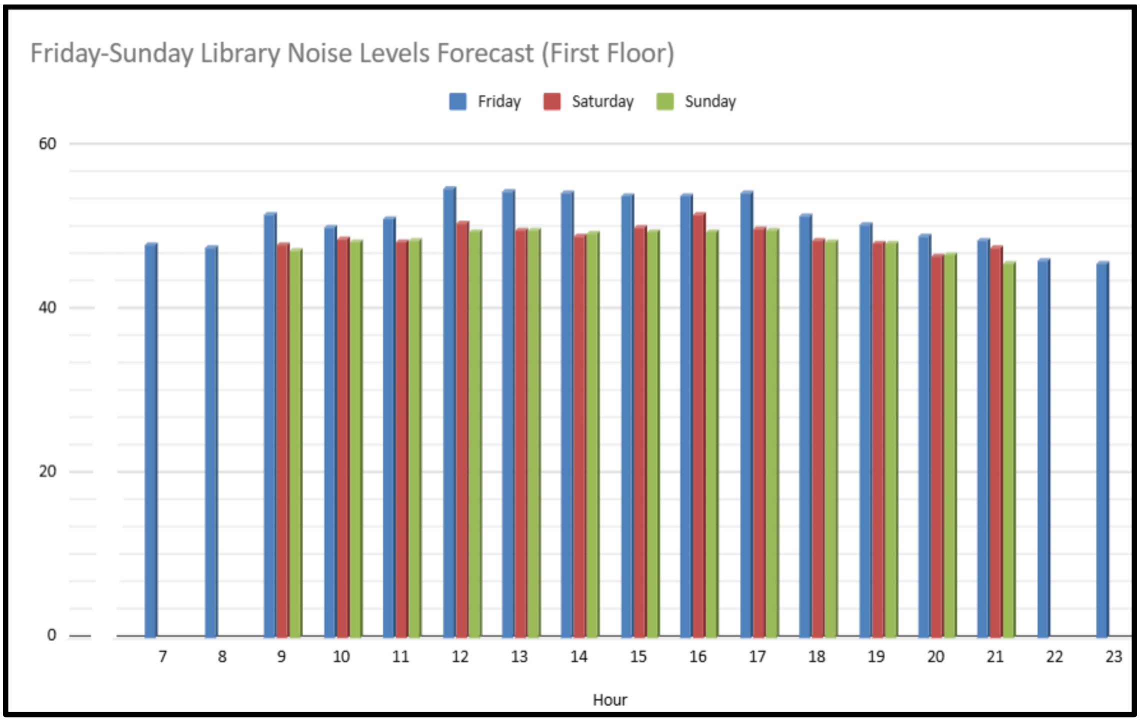

Figure 22: Friday-Sunday Library Noise Levels Forecast (First Floor)

5.3.2 Ground Floor

On the ground floor, three consistent noise sources were identified: the ventilation system, which produced a constant hum; squeaky chair movements due to poor maintenance; and rising levels of background conversation during peak hours.

Even with low occupancy (~10 people), noise levels were elevated as early as 09:20 due to mechanical sources. By 10:25, with the room about half full, noise levels constantly surpassed 75dB. By 11:30, decibel readings often exceeded 80dB, and during peak midday hours, levels reached and sustained values above 82dB during weekdays.

Despite these high readings, no visible signs of discomfort were observed among users. However, research shows that exposure to prolonged noise above 75dB can negatively affect concentration, memory, and learning outcomes, especially in noise-sensitive individuals.

The weekly graph validated these findings, showing consistently high noise between 12:00 and 18:00 from Monday to Friday. Levels fell on weekends, aligning with shorter hours and fewer occupants. The most disruptive conversations occurred in early afternoons, overlapping with the busiest hours. These findings suggest that the ground floor may require acoustic enhancements or behavioural interventions to improve its suitability for study during peak times.

The forecast images for the ground floor provide a visual summary of this issue. They show sharp and sustained dB peaks during weekday afternoons, particularly between 12:00 and 16:00, which are consistently above acceptable quiet-study thresholds. In contrast, the Friday to Sunday charts reflect a significant drop in noise levels, suggesting reduced traffic and activity. These visuals reinforce the recommendation that the ground floor may be unsuitable for silent study during peak times without further improvements.

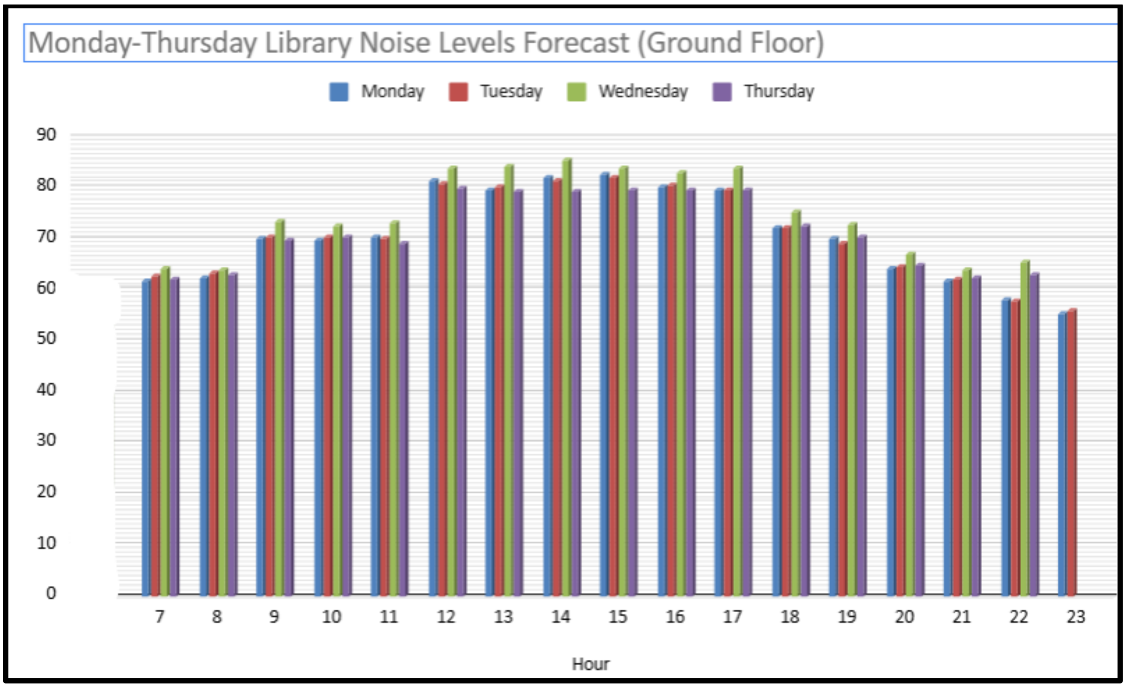

Figure 23: Monday-Thursday Library Noise Levels Forecast (Ground Floor)

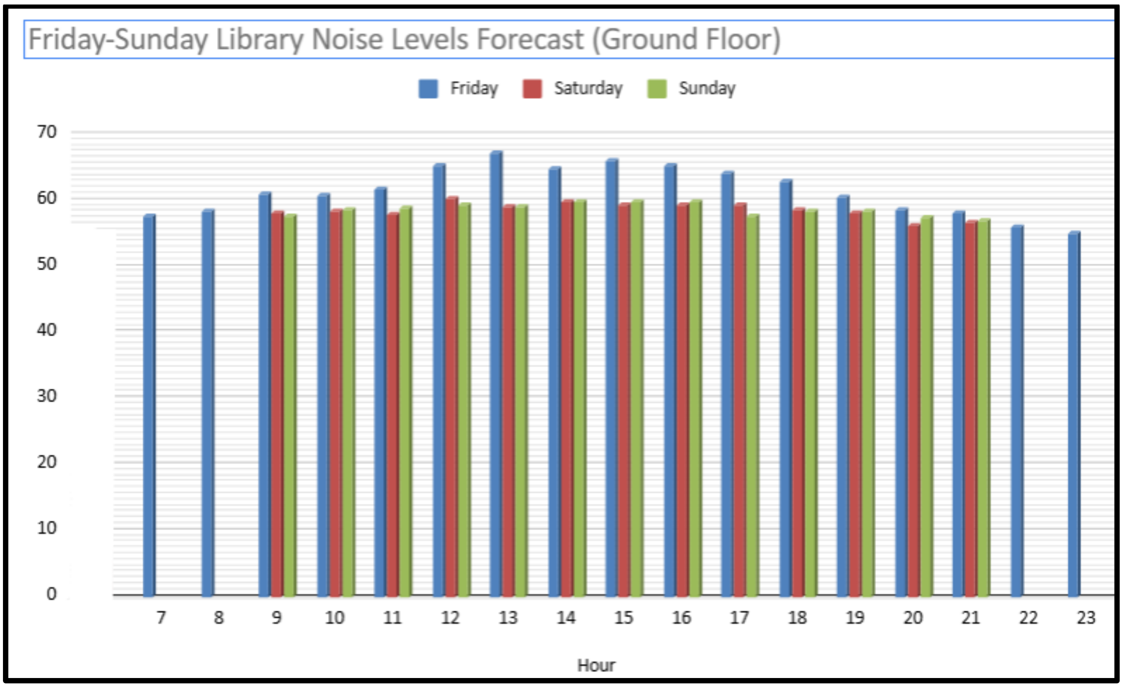

Figure 24: Friday-Sunday Library Noise Levels Forecast (Ground Floor)

5.4 Challenges Encountered During Testing

Several challenges arose during the testing phase, both technical and environmental. One recurring issue involved hardware malfunctions, where the microphone occasionally produced incorrect dB readings. These inconsistencies were sometimes caused by poor connections or momentary glitches and were typically resolved by restarting the ESP32 or re-securing the USB cable. In some cases, readings were skewed by very loud noises occurring close to the sensor. Changing a bit, the location and orientation of the microphone helped minimize the impact of these sudden nearby spikes.

There were also Wi-Fi connectivity issues, particularly in some corners of the library where the signal was weak. When the connection dropped, the ESP32 temporarily stopped transmitting data. However, since the data was averaged over 15-minute blocks, the loss of a few seconds' worth of readings did not significantly affect the results.

A few sessions were affected by the lack of constant supervision such as when the tester needed to take breaks for food or the restroom leaving the device running unattended. In these cases, care was taken to return and check the system promptly, ensuring data integrity.

Another technical obstacle involved prolonged use of the ESP32, which led to the device overheating during long testing sessions. To resolve this, multiple microcontrollers and sensors were prepared and used in rotation, allowing for faster data collection and reducing stress on any single device.

There were also software-related difficulties, such as missing libraries in Arduino IDE. For example, the OLED display could not be used as intended because the appropriate libraries had not been installed in time. Additionally, at one point, the ESP32 board was not recognized by the laptop, which delayed the testing. The issue was resolved by downloading and installing the CP210x USB to UART Bridge VCP driver, which allowed the ESP32's port to appear correctly in the Arduino interface.

Despite these hurdles, the team successfully gathered a substantial amount of high-resolution data, and each issue contributed to a better understanding of how to improve the system for future deployments.

6. Ethical Considerations

6.1 Privacy and Ethical Use

The system is designed to monitor sound levels only and does not record or store audio data, ensuring full compliance with privacy standards and the law, such as the Interception of Postal Packets and Telecommunications (Regulation) Act 1993 and the General Data Protection Regulation (GDPR) [11]. The use of the MAX9814 microphone and ESP32 microcontroller is limited strictly to measuring volume without capturing identifiable speech or conversations. This is critical in a public setting where user privacy must be respected at all times. Clear signage should be used to inform users about the presence and purpose of the noise monitoring system to promote transparency and ethical deployment.

6.2 Environmental Considerations

Encouraging quieter behaviour in shared spaces such as libraries contributes to a more sustainable and productive environment. Reducing noise pollution not only benefits the concentration of users but also lowers indirect energy costs associated with soundproofing study areas. Additionally, the system has been designed using low-power components, minimising energy consumption, especially during continuous operation. Also, the system uses standard, reusable modules (ESP32, sensors) which reduces electronic waste.

6.3 Impact on Students

Our noise monitoring system can significantly improve the acoustic environment of shared study spaces such as the library. Elevated noise levels have been shown to negatively affect cognitive performance, memory retention, and reading comprehension. According to a study by the World Health Organization (WHO), prolonged exposure to noise above 55 dB can impair task performance and increase stress levels in educational settings. [12]

Furthermore, visualizing noise levels fosters a sense of shared responsibility among users and supervisors, promoting quieter, more respectful behaviour or if needed supervision from instructors. Research also suggests that environments with lower ambient noise lead to greater satisfaction, longer stays, and better perceived usefulness of public spaces (Kang & Zhang, 2010) [13].

Additionally, people with sensory sensitivities, such as those with autism spectrum disorder (ASD), ADHD, or anxiety, are more likely to experience stress, distraction, and discomfort in noisy environments. According to Kennealy et al. (2012) [14], individuals with sensory defensiveness showed significantly higher levels of physiological arousal and stress in response to background noise, which can impair concentration and academic performance. [15]

There is also growing concern and evidence that constant digital stimulation (scrolling on social medias, notifications, multi-tasking) is contributing to reduced attention spans, lowered tolerance for distractions and increased baseline stress and sensory overload. A study by Duke University (2016) found that heavy digital media use was associated with increased ADHD-like symptoms in adolescents. [16]
With all these studies mentioned we conclude that minimizing excessive ambient noise is therefore essential to fostering an inclusive and equitable study environment.

6.4 Health and Safety

All electronic components are securely mounted and powered using a low-voltage USB power source, ensuring safety in public areas. Cables are managed to avoid tripping hazards or obstruction. Regular inspection and maintenance procedures must be established to ensure long-term safety and reliability.

7. Impact and Feedback

7.1 Impact

The implementation of the noise monitoring system had a positive impact on our understanding of acoustic conditions in shared learning spaces. One key finding was that many sources of disruptive noise were not conversations, but avoidable mechanical sounds such as squeaky chairs, keyboard typing, and object handling. The collected data also showed that even when the room wasn't crowded, background mechanical noise could still push dB levels to disruptive levels. Additionally, we observed that people do not always perceive or respond to high noise levels, even when readings objectively suggest poor acoustic conditions.

Although most users did not visibly react to high noise levels, the data suggested potential cognitive impacts, especially for those with sensory sensitivities. When compared with readings from a smartphone dB meter, our sensor-based system was validated as accurate enough for environmental monitoring, reinforcing its potential for long-term use.

7.2 Feedback

These questions were used to gather responses from staff:

- **Were you surprised by the noise levels measured? Why or why not?**
- **Do you think this type of system could help improve focus or comfort in study spaces?**
- **Did seeing the live dB values make you more conscious of your own noise?**
- **Should this system be implemented more widely across campus? Why or why not?**
- **What improvements would you suggest for the next version of the system?**

Through the answers to these questions, we got to these conclusions. Peers expressed surprise at how high the dB levels were, particularly during midday study sessions. Many noted that they hadn't realized how much background noise they contributed to until seeing the data. Supervisors found the system practical and suggested its use for monitoring multiple library floors or classrooms in the future. They also appreciated the ethical design, especially the fact that no speech was recorded.

8. Conclusions and Future Work

8.1 Conclusion

This project successfully designed and implemented a low-cost, portable, IoT based noise monitoring system aimed at improving the acoustic environment in shared educational spaces, specifically the Maynooth University Library. The integration of the hardware and software components allowed the system to accurately monitor and log real-time noise levels in decibels (dB) as well as trigger automated alerts (email and LED) when noise thresholds are exceeded. Additionally, the system permits the visualisation of noise trends as well as the ability to raise awareness among staff and students about the impact of noise pollution on study performance. Evidently this project supports the achievement of the chosen Sustainable Development Goal by monitoring and managing noise in shared study spaces. This system helps create 'inclusive, sensory friendly learning environments', especially beneficial for students with ADHD, autism or anxiety. Following this also highlights that this project can be linked to SDG 10. A quiet space enhances focus, cognitive performance and academic success.

8.2 Future Work

While this project successfully demonstrated real-time noise monitoring and pattern analysis in library spaces, there are several key areas where the system could be further improved or expanded. One major enhancement would be the integration of battery power, allowing the system to operate wirelessly. Currently, the device requires a constant USB power connection, limiting its placement flexibility. A portable, battery-powered version would enable long-term, discreet monitoring in a wider range of environments without relying on nearby power sources.

Another promising direction is the implementation of noise source classification. At present, the system only measures the overall dB level, but cannot distinguish between types of sounds such as conversation, footsteps, ventilation noise, or sudden disturbances like dropped objects. Incorporating sound classification would require a more advanced hardware setup (potentially including multiple microphones and onboard processing), as well as machine learning models trained to recognize and label different acoustic patterns.

In addition, the project could benefit greatly from a web or mobile application that allows users to input a date and time and receive a forecast of expected noise levels. This idea was not fully implemented in the current version due to the short data collection period (just over a week), which was insufficient for producing reliable long-term forecasts. However, with more comprehensive historical data, such a tool could provide useful guidance for students seeking quiet study periods or for staff managing space usage.

Expanding the study to include a broader range of locations across the entire campus is another important next step. Due to time constraints, this project focused only on two floors of a single library. Monitoring classrooms, corridors, cafeterias, and other shared spaces would provide a more complete picture of noise dynamics in academic environments and allow for more robust analysis.

Overall, the foundations laid by this project open the door to more scalable and intelligent environmental monitoring systems. Future developments in portability, sound analysis, forecasting, and geographic coverage could significantly increase its usefulness in both academic and professional settings.

9. References

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10. Appendices

Appendix A:

Survey Questions for Noise Pollution Mapping in Maynooth University Campus

1. Which areas on campus do you find to be the noisiest? (Select all that apply)
a) Library
b) Lecture halls/classrooms
c) Cafeterias or common areas
d) Student accommodations
e) Outdoor spaces (walkways, courtyards, etc.)
f) Other (study rooms...)

2. On a scale of 1 to 5, how much does noise affect your ability to study or concentrate?
a) Not at all
b) Slightly
c) Moderately
d) Significantly
e) Extremely

3. Have you experienced noise-related disturbances in the library?
a) Yes, frequently
b) Sometimes
c) Rarely
d) Never

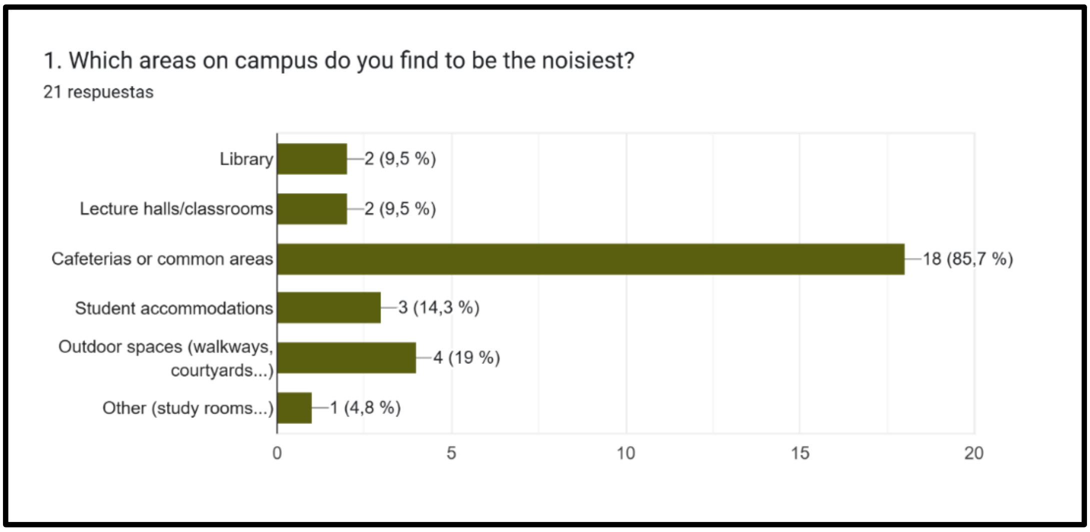
4. What types of noise do you most frequently encounter in the library or study rooms?
a) Conversations from other students
b) Phone notifications/ringtones
c) Loud footsteps/movement of chairs
d) External noise from outside the building
e) Other (please specify)

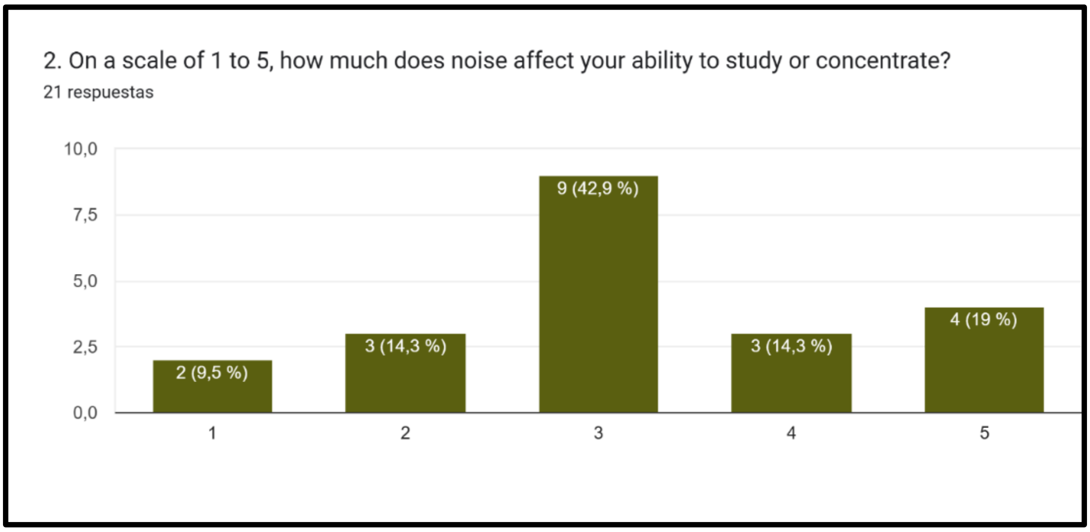
5. Would you find a noise level monitoring system in quiet zones useful?
a) Yes, it would help maintain a quieter environment
b) No, I don't think it's necessary
c) Maybe, depending on how it's implemented

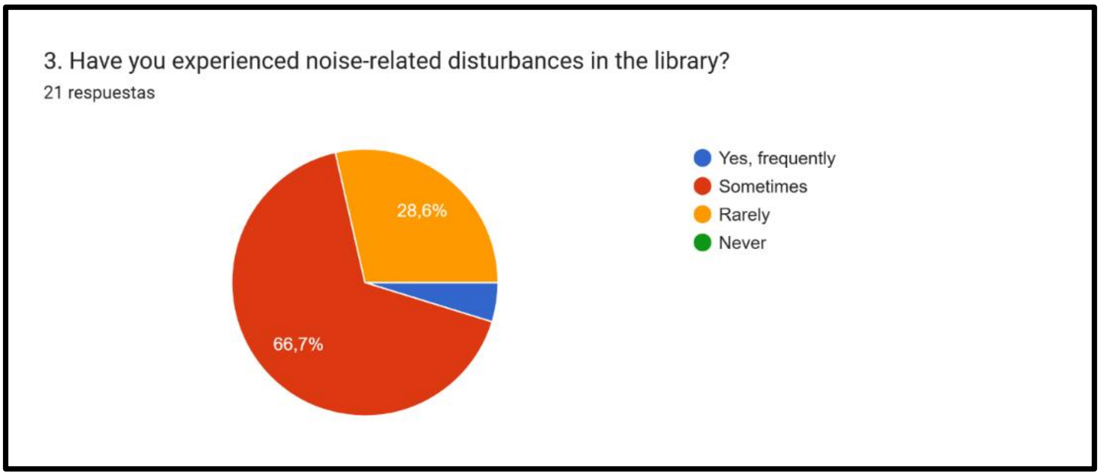
6. How would you prefer to be alerted about excessive noise levels in study areas?
a) Visual warning sign (LED indicator)
b) Silent notification via a mobile app
c) Automated reminder announcement
d) Other (please specify)

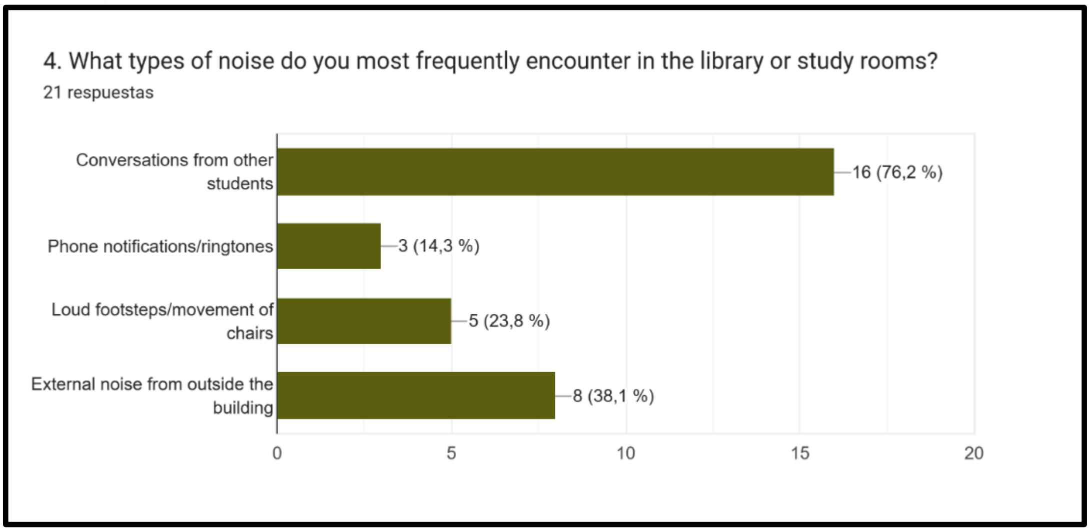
7. Have you ever had to leave a study area due to excessive noise?
a) Yes, multiple times
b) Yes, occasionally
c) No, but I've been annoyed by noise
d) No, noise has never been an issue for me

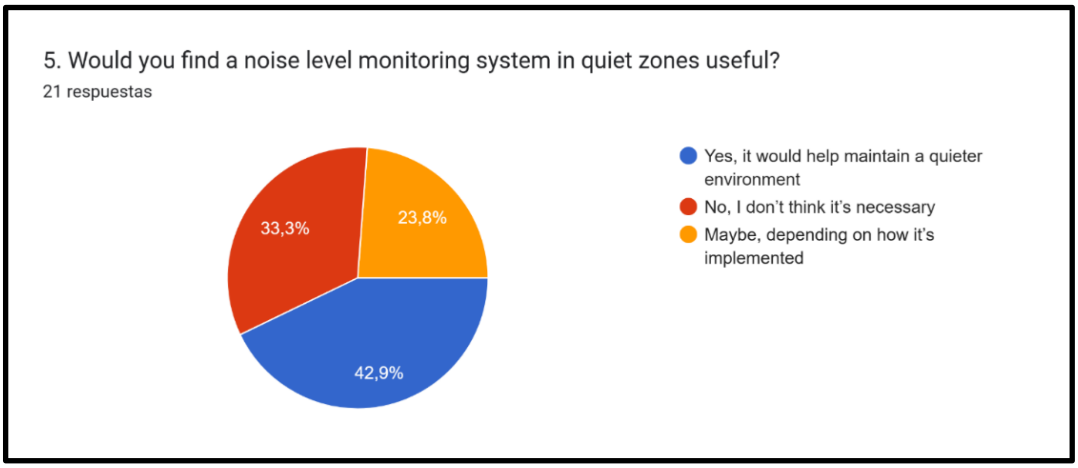
Appendix B: Survey Results

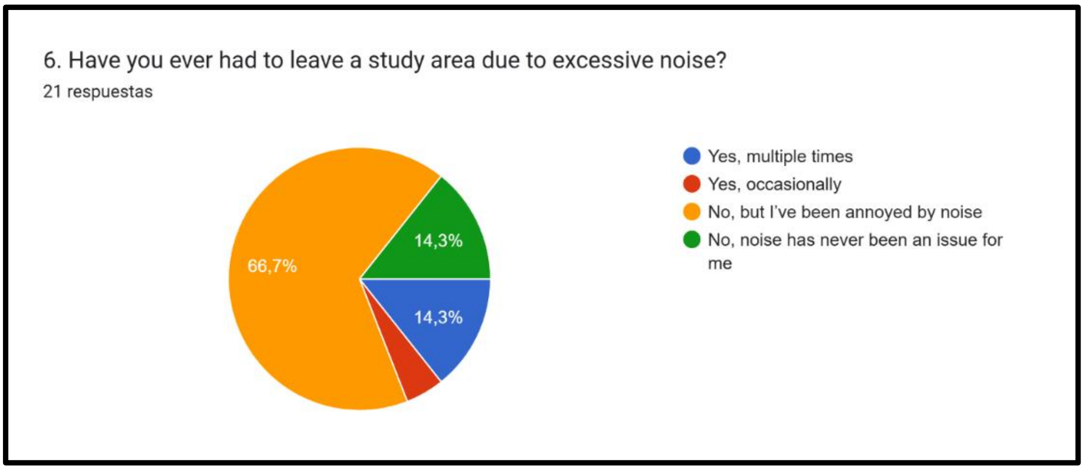







4. What types of noise do you most frequently encounter in the library or study rooms?
21 respuestas
Conversations from other students
Phone notifications/ringtones
Loud footsteps/movement of chairs
External noise from outside the building
16 (76,2 %)
3 (14,3 %)
5 (23,8 %)
8 (38,1 %)
0
5
10
15
20


5. Would you find a noise level monitoring system in quiet zones useful?
21 respuestas
33,3%
23,8%
42,9%
Yes, it would help maintain a quieter environment
No, I don't think it's necessary
Maybe, depending on how it's implemented

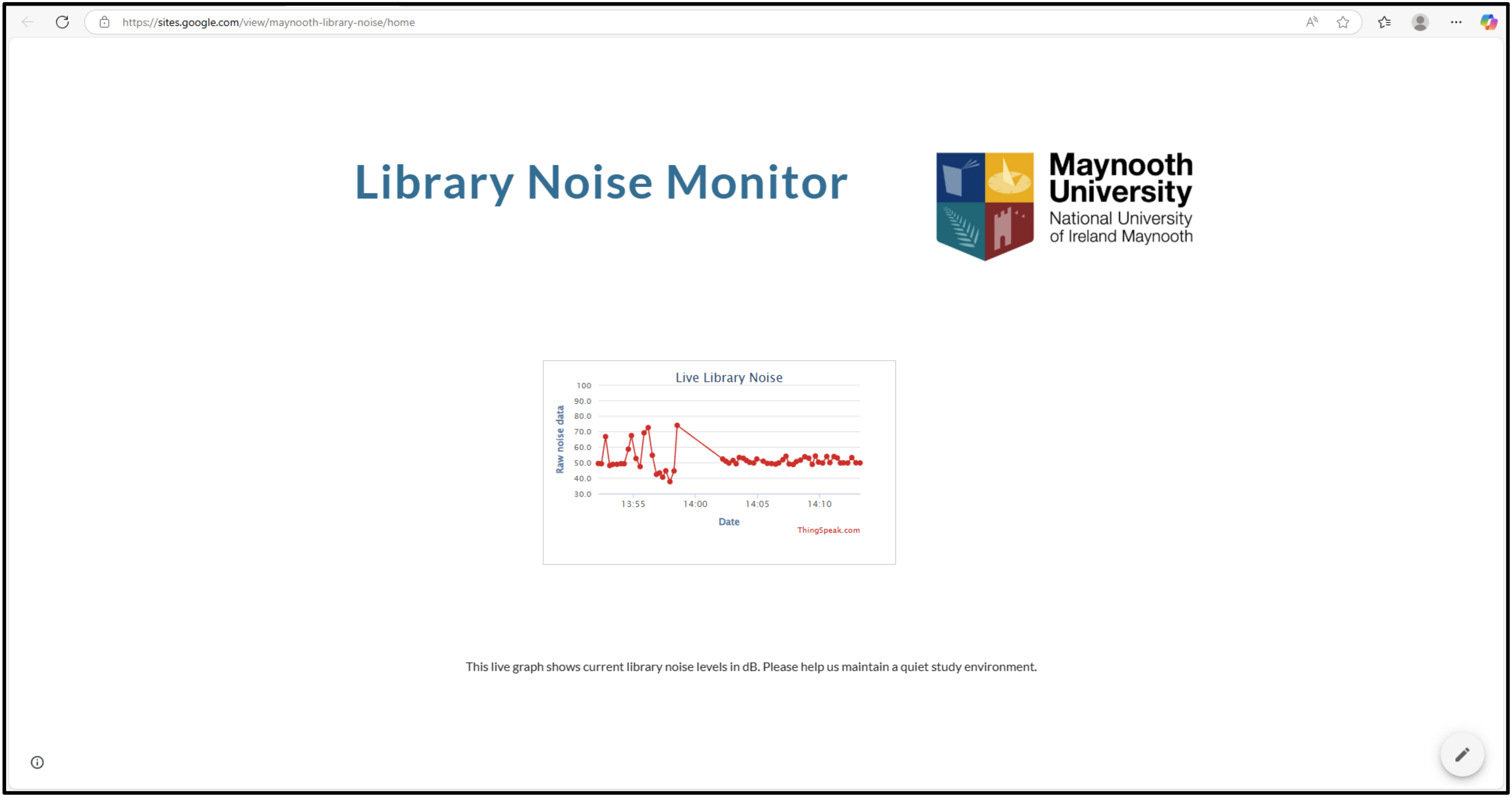

6. Have you ever had to leave a study area due to excessive noise?
21 respuestas
66,7%
14,3%
14,3%
Yes, multiple times
Yes, occasionally
No, but I've been annoyed by noise
No, noise has never been an issue for me

Appendix C: Survey Answers

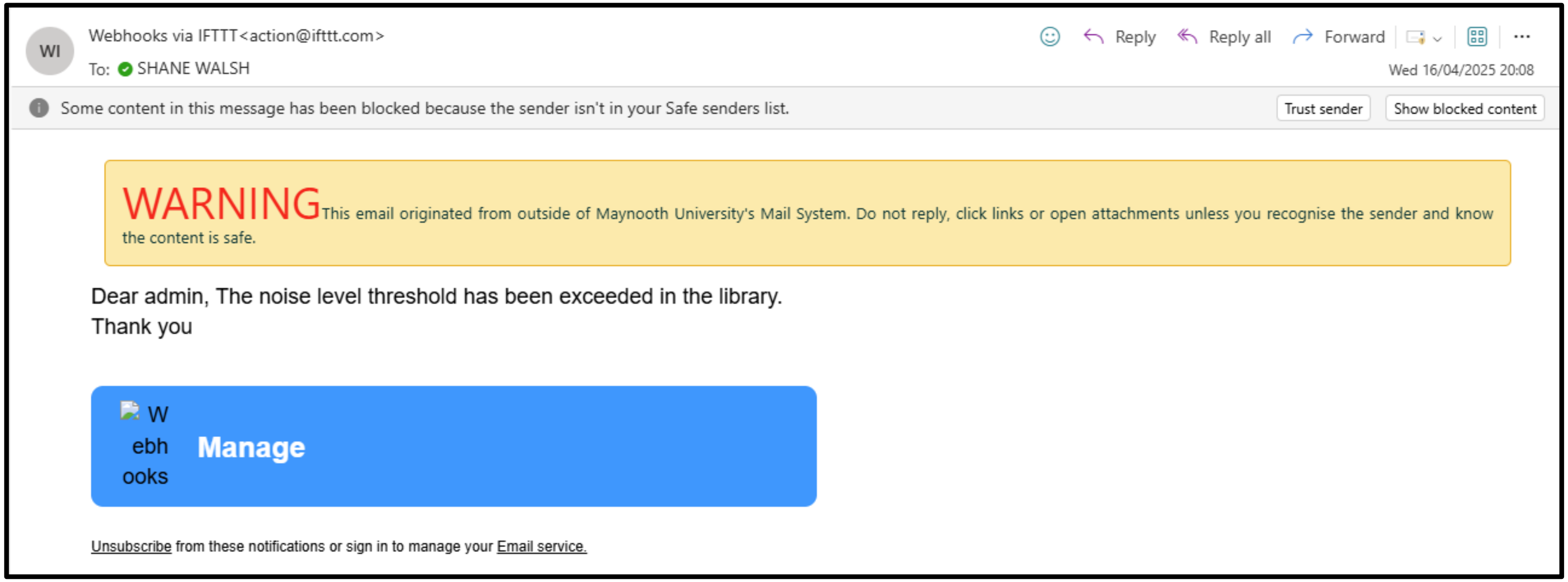
Timestamp	*1. Which areas on campus do you find to be the noisiest?*	*2. On a scale of 1 to 5, how much does noise affect your ability to study or concentrate?*	*3. Have you experienced noise-related disturbances in the library?*	*4. What types of noise do you most frequently encounter in the library or study rooms?*	*5. Would you find a noise level monitoring system in quiet zones useful?*	*6. Have you ever had to leave a study area due to excessive noise?*	*7. How would you prefer to be alerted about excessive noise levels in study areas?*
5/03/2025 14:44:46	Cafeterias or common areas, Outdoor spaces (walkways, courtyards...)	3	Rarely	Loud footsteps/movement of chairs, External noise from outside the building	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Automated reminder announcement
5/03/2025 14:50:30	Cafeterias or common areas, Outdoor spaces (walkways, courtyards...)	3	Sometimes	Conversations from other students, Loud footsteps/movement of chairs	Yes, it would help maintain a quieter environment	Yes, multiple times	Visual warning sign (LED indicator), Silent notification via a mobile app
5/03/2025 15:05:32	Cafeterias or common areas	3	Sometimes	Conversations from other students	No, I don't think it's necessary	No, noise has never been an issue for me	Silent notification via a mobile app
5/03/2025 15:06:35	Library, Cafeterias or common areas, Student accommodations	3	Sometimes	Conversations from other students, External noise from outside the building	Maybe, depending on how it's implemented	No, but I've been annoyed by noise	Automated reminder announcement
5/03/2025 15:09:54	Cafeterias or common areas	5	Sometimes	Conversations from other students	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Visual warning sign (LED indicator)
5/03/2025 15:36:16	Cafeterias or common areas	3	Rarely	Phone notifications/ringtones	No, I don't think it's necessary	Yes, occasionally	Silent notification via a mobile app
5/03/2025 15:45:08	Student accommodations	3	Sometimes	Phone notifications/ringtones	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Silent notification via a mobile app
5/03/2025 16:51:28	Cafeterias or common areas	3	Rarely	Loud footsteps/movement of chairs, External noise from outside the building	Maybe, depending on how it's implemented	No, but I've been annoyed by noise	Visual warning sign (LED indicator)
5/03/2025 17:02:54	Cafeterias or common areas	3	Sometimes	Conversations from other students	No, I don't think it's necessary	No, but I've been annoyed by noise	Automated reminder announcement
5/03/2025 17:13:22	Lecture halls/classrooms, Cafeterias or common areas	4	Sometimes	Conversations from other students, External noise from outside the building	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Automated reminder announcement
5/03/2025 17:18:02	Cafeterias or common areas	3	Rarely	Conversations from other students, External noise from outside the building	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Visual warning sign (LED indicator)
5/03/2025 17:24:10	Library, Cafeterias or common areas	2	Sometimes	Conversations from other students	No, I don't think it's necessary	No, noise has never been an issue for me	Visual warning sign (LED indicator)
5/03/2025 17:24:13	Cafeterias or common areas	2	Sometimes	Conversations from other students, Phone notifications/ringtones	Yes, it would help maintain a quieter environment	Yes, multiple times	Silent notification via a mobile app

5/03/2025 17:28:58	Outdoor spaces (walkways, courtyards...)	4	Sometimes	Conversations from other students	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Automated reminder announcement
5/03/2025 17:41:14	Student accommodations, Other (study rooms...)	5	Yes, frequently	External noise from outside the building	Maybe, depending on how it's implemented	Yes, multiple times	Visual warning sign (LED indicator)
5/03/2025 17:48:00	Cafeterias or common areas, Outdoor spaces (walkways, courtyards...)	5	Rarely	Conversations from other students, Loud footsteps/movement of chairs, External noise from outside the building	Maybe, depending on how it's implemented	No, but I've been annoyed by noise	Automated reminder announcement
5/03/2025 17:48:20	Lecture halls/classrooms, Cafeterias or common areas	1	Rarely	Conversations from other students, Loud footsteps/movement of chairs	No, I don't think it's necessary	No, but I've been annoyed by noise	Silent notification via a mobile app
5/03/2025 18:10:01	Cafeterias or common areas	1	Sometimes	Conversations from other students, External noise from outside the building	No, I don't think it's necessary	No, but I've been annoyed by noise	Visual warning sign (LED indicator)
5/03/2025 19:18:29	Cafeterias or common areas	2	Sometimes	Conversations from other students	No, I don't think it's necessary	No, noise has never been an issue for me	Silent notification via a mobile app
5/03/2025 19:39:50	Cafeterias or common areas	4	Sometimes	Conversations from other students	Maybe, depending on how it's implemented	No, but I've been annoyed by noise	Visual warning sign (LED indicator), Silent notification via a mobile app
5/03/2025 21:52:57	Cafeterias or common areas	5	Sometimes	Conversations from other students	Yes, it would help maintain a quieter environment	No, but I've been annoyed by noise	Visual warning sign (LED indicator), Automated reminder announcement

Appendix D: Website



Appendix E: Alert Email



Webhooks via IFTTT<action@ifttt.com>

To: SHANE WALSH

Reply | Reply all | Forward

Wed 16/04/2025 20:08

Some content in this message has been blocked because the sender isn't in your Safe senders list.

Trust sender | Show blocked content

WARNING This email originated from outside of Maynooth University's Mail System. Do not reply, click links or open attachments unless you recognise the sender and know the content is safe.

Dear admin, The noise level threshold has been exceeded in the library.
Thank you

Webhooks **Manage**

Unsubscribe from these notifications or sign in to manage your Email service.

Appendix F: Source Code

```
#include <WiFi.h>
#include <HTTPClient.h>
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <math.h>

// Wi-Fi & ThingSpeak
const char* ssid = "GalaxyA53";
const char* password = "destinynosa";
const char* server = "http://api.thingspeak.com/update";
String apiKey = "T8SPEU5ZT7ILXCJH";

// Pins
const int noiseSensorPin = 34;  // Analog input from MAX9814
const int ledPin = 25;          // Red alert LED

// OLED Display Settings
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_RESET -1  // Not connected
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);

// Timing
unsigned long lastReading = 0;
const unsigned long readingInterval = 5000; // 5 seconds

void setup() {
  Serial.begin(115200);

  pinMode(ledPin, OUTPUT);
  digitalWrite(ledPin, LOW);

  // Initialize OLED
  if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { // Address 0x3C for most OLEDs
    Serial.println(F("SSD1306 allocation failed"));
    for (;;);
  }

  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(SSD1306_WHITE);
  display.setCursor(0, 0);
  display.println("Connecting WiFi...");
  display.display();
```

```
  // Connect to WiFi
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(250);
    Serial.print(".");
  }

  Serial.println("\nConnected!");
  display.clearDisplay();
  display.setCursor(0, 0);
  display.println("WiFi Connected");
  display.display();
  delay(1500);
  display.clearDisplay();
}

void loop() {
  if (millis() - lastReading >= readingInterval) {
    lastReading = millis();

    int signalMax = 0;
    int signalMin = 4095;
    unsigned long start = millis();

    while (millis() - start < 50) {
      int sample = analogRead(noiseSensorPin);
      if (sample > signalMax) signalMax = sample;
      if (sample < signalMin) signalMin = sample;
    }

    int peakToPeak = signalMax - signalMin;
    float voltage = (peakToPeak * 3.3) / 4095.0;
    if (voltage < 0.001) voltage = 0.001;

    float dB = 20 * log10(voltage / 0.001);
    float c_dB = ((dB - 40.0) * 70.0 / 27.5) + 30.0;

    static float previous_dB = 30.0;
    if (c_dB < previous_dB - 10) {
      c_dB = previous_dB - 5;
    }
    previous_dB = c_dB;

    if (c_dB < 30) c_dB = 30;
    if (c_dB > 100) c_dB = 100;

    Serial.print("dB: ");
    Serial.println(c_dB);
```

```
    // Update OLED Display
    updateOLED(c_dB);

    // LED Alert
    digitalWrite(ledPin, c_dB > 70 ? HIGH : LOW);

    // Send data to ThingSpeak
    sendToThingSpeak(c_dB);
  }
}

void updateOLED(float value) {
  display.clearDisplay();
  display.setCursor(0, 0);
  display.setTextSize(1);
  display.setTextColor(SSD1306_WHITE);
  display.print("Noise Level: ");
  display.print(value, 1);
  display.println(" dB");
  display.display();
}

void sendToThingSpeak(float value) {
  if (WiFi.status() == WL_CONNECTED) {
    HTTPClient http;
    String url = String(server) + "?api_key=" + apiKey +
                 "&field1=" + value +
                 "&field2=" + value +
                 "&field3=" + value +
                 "&field4=" + value;

    http.begin(url);
    int httpCode = http.GET();
    if (httpCode > 0) {
      Serial.println("Data sent to ThingSpeak");
    } else {
      Serial.println("Error sending data");
    }
    http.end();
  } else {
    Serial.println("Wi-Fi not connected");
  }
}
```