Raspberry Pi-Based System for Measurement, Recording and Monitoring of High Decibel Sound from Loudspeaker Systems

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***Abstract*—Noise pollution due to loudspeaker amplifier systems has raised major public health and environmental issues in India and is in violation of Section 268 of the Indian Penal Code. This paper describes the design, invention, and validation of a smart system enabled by Raspberry Pi for ongoing measurement, recording, and remote monitoring of sound levels from loudspeaker systems. The system that is proposed measures the electrical parameters at the amplifier outputs, estimates the equivalent sound pressure levels in decibels (dB), and sends the real-time data to cloud servers through Wi-Fi connectivity.**

By the iteration of five prototypes, we resolved issues such as measurement accuracy, power consumption, size limitations, and data transmission reliability. The ultimate deployment comprises a Raspberry Pi microcontroller, voltage sensing network, OLED display, and power supply unit, thereby attaining measurement accuracy within $\pm$2dB.

Python-based processing on the cloud allows the inspection of multiple devices simultaneously from the command centers that are located remotely, automatic detection of the threshold violation, and the detailed keeping of the records. Field testing, in fact, demonstrates the successful capabilities of remote monitoring along with continuous operation capability. The system equips law enforcement agencies with a resourceful and scalable method for noise pollution control and compliance enforcement.

***Index Terms*—Raspberry Pi, Internet of Things, noise pollution monitoring, sound level measurement, decibel measurement, cloud computing, regulatory compliance, Industry 4.0, environmental monitoring, smart monitoring system, voice-controlled alert system**

I. Introduction

A. Background and Motivation

Noise pollution is a major factor to both the environment and health in India, and it significantly impacts urban subsistence areas [4]. One of the dominant sources of noise pollution is the use of high-power loudspeaker systems during religious festivals, social gatherings, weddings, and any other events of entertainment that are frequented by the masses, resulting in the volumetric noise levels exceeding the limit set by the authorities in charge of the regulations [5]. Such a noisy environment that surrounds these occasions is not only a public annoyance but also is a cause of serious health risks such as hearing loss, cardiovascular diseases, sleep disorders, stress, and decreased cognitive abilities [6], [7].

The World Health Organization (WHO) regards the environmental noise as the second leading environmental factor responsible for health problems just after air pollution [8]. The sound levels that exceed 85 dB can cause irreversible damage to the hearing organs while more than 70 dB are accompanied by elevated cardiovascular risk increase [9]. In urban Indian environments, noise from loudspeakers during events frequently reaches 100–120 dB, well above safe thresholds [10].

Indian Penal Code (IPC) Section 268 concerns public nuisance and defines it as an any act that inflicts injury, danger, or annoyance to the public or causes harm to the individuals that are significantly beyond what the public in general experience [11]. Though there are legal frameworks in place, noise regulation enforcement still remains a problem, as the continuous monitoring of numerous sound sources that are spread in both urban and rural areas is difficult [12]. The traditional ways of compliance monitoring require that the enforcement personnel be physically present with their calibrated sound level meters at each location; thus, making it challenging and expensive in terms of resources to carry out large-scale surveillance [13].

B. Problem Statement

Current methods dealing with noise pollution have several inherent drawbacks:

1) **Manual Monitoring Constraints**: Enforcement agencies are not able to be present at all times at the places where noise sources are, which leads to a kind of enforcement that is only sporadic and reactive, and thus not proactive regulation [14].
2) **Lack of Real-Time Data**: Because there are no continuous monitoring systems, it is not possible to have timely interventions in the cases where noise levels go beyond the limits set by the law, thus allowing prolonged violations [15].

3) **Evidence Collection Challenges**: For legal proceedings, documented evidence of violations is needed, and such evidence is very hard to obtain through manual spot-checking methods [16].
4) **Resource Allocation Inefficiency**: Police departments and municipal authorities do not have data-driven insights to help them decide where to concentrate their enforcement efforts in areas with recurring violations [17].
5) **Limited Public Awareness**: In the absence of transparent and easily accessible noise monitoring data, public awareness of noise pollution and its consequences remains at a low level, thus hindering the implementation of mitigation measures at the community level [18].

C. Proposed Solution

This project solves the problems caused by such situations by creating a smart system that is enabled by a Raspberry Pi for automated measurement, recording, and remote monitoring of environmental sound levels from loudspeaker amplifier systems. Using Industry 4.0 technologies, the system facilitates continuous and unassisted monitoring of numerous sound sources simultaneously from central command centers [19].

The instrument proposed in this setting takes the electrical measurements at the amplifier output, figures the equivalent sound pressure level in decibels (dB), and sends the live data to cloud servers through Wi-Fi connection. This method has quite a few benefits when compared to the use of traditional sound level meters:

- **Non-invasive Installation**: The instrument establishes a connection with the outputs of the amplifier instead of a microphone; therefore, it is a tamper-resistant device and is less influenced by variable environmental conditions.
- **Remote Accessibility**: The transmission of data in real-time allows the monitoring staff to oversee several locations at once without the need for physical presence.
- **Automated Compliance Checking**: Operations that happen on the cloud command the system to automatically spot the instances when thresholds are exceeded and thus, create the notification for the enforcement.
- **Historical Data Retention**: The uninterrupted recording serves as a complete set of records for court cases and offers the possibility of historical data analysis.
- **Scalable Architecture**: The intelligent monitoring system is designed to accommodate future changes and allows for extension to hundreds of devices under different local authorities with only a slight additional cost.
- **Voice-Controlled Alerts**: The use of voice recognition as one of the integration features allows the automated systems in charge of issuing the emergency alerts to do so without human intervention when there has been a breach of threshold limits.

D. Research Objectives

The first goals of this research are:

1) To create and build a small unit powered by Raspberry Pi that would be able to accurately measure the sound output of loudspeaker amplifier systems.
2) To put into practice wireless data transmission protocols for inspection in real-time from remote command centers.
3) To establish cloud-based data handling services for decibel computation, recording, and alerting when the threshold is exceeded.
4) To design user interfaces that would help the law enforcement officers to supervise the devices and get the automated notifications.
5) To verify the system accuracy by comparing it with the calibrated sound level meters and evaluate the feasibility of the deployment.

E. Document Organization

This paper is divided into the following parts: Section II discusses research related to noise monitoring and IoT applications. Section III explains the method and the iterative development approach. Section IV provides the full hardware design, the description of the components, and the working principles. Section V deals with experimental results and system validation. Section VI talks over the findings and their applications. Section VII wraps up the future extensions and the contributions of this work.

II. Literature Review

A. Evolution of Sound Measurement Technology

The decibel meter or a sound level meter (SLM), has been the standard tool for measuring the intensity of sound for a long time, practically since the early 20th century [20]. Conventional SLMs use a microphone to change acoustic pressure waves into electrical signals. These signals are then amplified, filtered, and processed to show the sound levels in decibels with respect to the reference threshold of human hearing (approx. 20 μPa) [21].

Present-day sound level meters have frequency weighting filters (A-weighting, C-weighting) that can modify the sensitivity over the frequency range to match human hearing perception [22]. Based on international standards (IEC 61672), these instruments are divided into different accuracy classes (Type 1, Type 2) and are generally employed in occupational health, environmental monitoring, and compliance, by the regulation sectors [23].

On the other hand, standard SLMs need skilled operators, regular calibration, and the requirement of being physically present at the measuring points. Such limitations make it impossible to use them for continuous large-scale noise monitoring networks [24].

B. IoT Applications in Environmental Monitoring

The deployment of IoT (Internet of Things) technologies has made it possible to have distributed sensor networks for a wide range of environmental monitoring purposes such as air quality, water quality, weather conditions, and noise pollution

[25]. In general, IoT-based noise monitoring devices make use of inexpensive MEMS microphones that can be connected to microcontrollers which can then send data to cloud platforms through Wi-Fi, cellular, or LoRaWAN communication [26].

Picaut et al. [27] created a noise mapping system based on a wireless sensor network, spreading 50 nodes throughout Paris to generate noise maps in real-time. Mydlarz et al. [28] introduced the ”Sounds of New York City” (SONYC) initiative, which involved the use of acoustic sensors and machine learning to identify urban sound sources. Alsina-Pagès et al. [29] has a narrative about Barcelona noise monitoring network, which was the combination of IoT sensors and the local government infrastructure.

C. Noise Pollution Regulations and Enforcement

Different countries have set upnoise rules and enforcement. The European Union’s Environmental Noise Directive (2002/49/EC) requires noise mapping and action plans for cities [30]. In India, the Noise Pollution (Regulation and Control) Rules, 2000 specifies ambient noise standards for different areas, with allowable day-time limits varying from 50–75 dB(A) according to zone classification [31].

Kumar et al. [32] conducted a study on noise pollution in Indian cities and found that in most cases, regulatory limits were violated during festivals and events. Pathak et al. [33] studied noise pollution due to religious places and recorded average noise levels of 90–110 dB near loudspeakers. These studies confirm that there is a lack of sufficient monitoring and enforcement mechanisms.

D. Research Gap

Existing literature has been very comprehensive in explaining the use of distributed microphone arrays for ambient noise monitoring. However, there is a scarce amount of research that deals with the targeted monitoring of specific controllable noise sources such as loudspeaker systems for regulatory enforcement purposes. A majority of IoT noise monitoring systems are designed for environmental assessment and do not have the capability of being used for compliance enforcement with legal interventions.

This project is about creating a dedicated monitoring device based on Raspberry Pi that directly communicates with amplifier systems and thus, it is the ideal device for tamper-resistant, continuous monitoring which can be used for legal compliance applications. It is indeed a novel contribution of noise pollution control infrastructure to integrate the real-time cloud processing with the automated alert generation for the enforcement agencies.

III. METHODOLOGY

A. Research Design

The project followed an iterative prototyping methodology through which five successive hardware prototypes were developed with the progressive improvements that addressed the limitations identified. The prototypes went through design, fabrication, testing, and evaluation phases, and the lessons learned were used to inform the subsequent iterations.

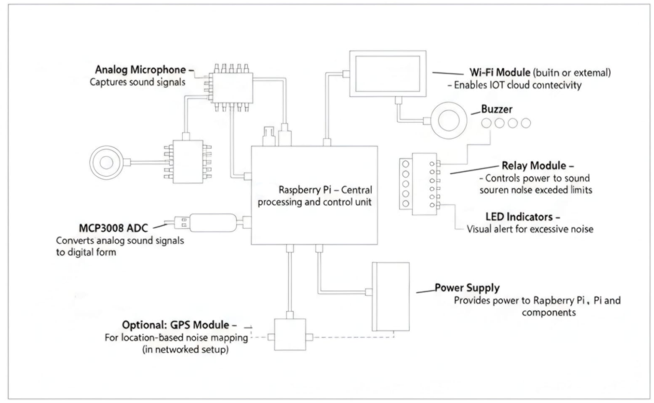

Fig. 1. Architechture

B. Prototype Evolution

Prototype 1: A first proof-of-concept experiment relying on a sound sensor (condenser microphone) was performed along with a basic microcontroller and a relay module for threshold-based amplifier control. This prototype demonstrated basic IoT connectivity; however, it was characterized by low accuracy and high power consumption.

Prototype 2: The sound sensor was replaced with an ACS712 current sensor and a voltage divider network was used for the measurement of electrical parameters. A better microcontroller and a transistor for volume control were used. The accuracy was improved but there was a data processing lag and noise that interfered.

Prototype 3: The current sensor was removed (power was calculated from voltage with known speaker impedance), the microcontroller was optimized for cost reduction, and the transistor was improved for stability. The lag issue was resolved, but the resistor network showed its practical limitations.

Prototype 4: The computational tasks were moved to the cloud (the processing was offloaded from the microcontroller), a high-power MOSFET was implemented for handling up to 200W, and the voltage measurement circuit was refined. The processing on the device was reduced, but the large form factor was still retained.

Prototype 5 (Final):The main controller was changed to Raspberry Pi, a local monitoring was enabled through the addition of an OLED display, the size was reduced by removing the control circuitry (monitoring was the focus, rather than intervention), the power supply system was improved, and the firmware was optimized for power efficiency.

C. Measurement Principles

The principles of Kirchhoff’s Voltage Law (KVL) are used by the system to locate the voltage across the speaker load. The signal is scaled by a resistive voltage divider to fit the ADC input range. The divider ratio is determined as:

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \tag{1}$$

With $R_1 = 10\text{k}\Omega$ and $R_2 = 1\text{k}\Omega$, the attenuation factor is 11:1.

Instantaneous power is calculated from RMS voltage:

$$P = \frac{V_{rms}^2}{R_{speaker}} \tag{2}$$

Sound pressure level estimation follows:

$$SPL_{estimated} = SPL_{reference} + 10\log_{10}\left(\frac{P_{measured}}{P_{reference}}\right) \tag{3}$$

where $SPL_{reference}$ is the manufacturer-specified sensitivity at 1W/1m.

D. Data Flow Architecture

The system implements the following data flow:

1) Analog voltage sampling at amplifier output (continuous)
2) ADC conversion to digital values
3) Local processing for voltage calculation on Raspberry Pi
4) Wi-Fi transmission of raw data packets to cloud server
5) Cloud-based Python processing for power and dB calculation
6) Database storage with timestamp indexing
7) Dashboard updates for real-time monitoring interfaces
8) Threshold comparison and automated alert generation
9) Voice-controlled alert activation for emergency notifications

IV. Hardware Design and Operation

A. System Architecture

Figure **??** shows the system architecture of the Raspberry Pi-enabled smart monitoring system.

The final hardware implementation comprises three subsystems:

1) **Voltage Sensing Subsystem**: Resistive voltage divider network scales amplifier output voltage to ADC-compatible range.
2) **Processing and Communication Subsystem**: Raspberry Pi microcontroller performs ADC conversion, data packaging, and Wi-Fi transmission.
3) **User Interface Subsystem**: OLED display provides real-time visual feedback of measured parameters and system status, complemented by LED indicators.
4) **Voice Control Subsystem**: Analog and USB microphone inputs enable voice-activated emergency alert functionality.

B. Component Selection and Specifications

Table I lists the bill of materials for the final prototype.

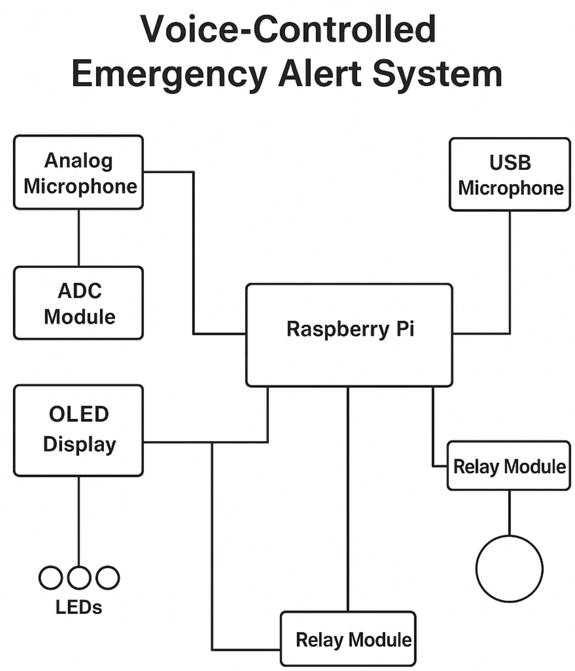

Fig. 2. Voice-Controlled Emergency Alert System Architecture

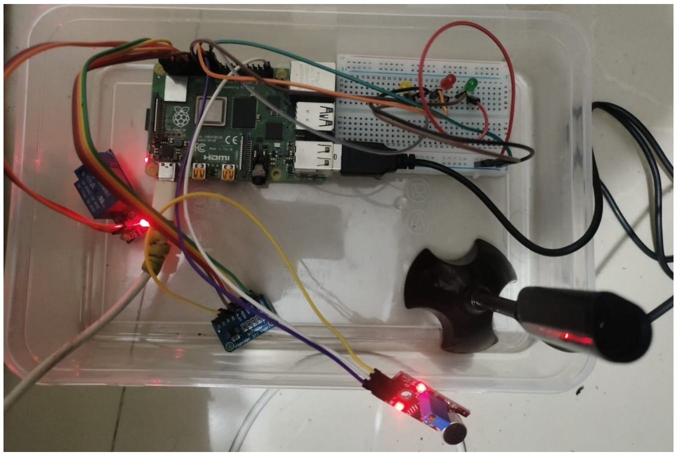

Fig. 3. Hardware

TABLE I
BILL OF MATERIALS - PROTOTYPE 5

Component	Specification	Qty	Purpose
Raspberry Pi	Model 3B+/4B	1	Main Controller
ADC Module	MCP3008	1	Analog Input
Analog Mic	Condenser	1	Voice Input
USB Mic	Standard	1	Voice Input
Resistor	10kΩ, 1/4W	1	Voltage divider
Resistor	1kΩ, 1/4W	1	Voltage divider
OLED Display	128×64, I^2C	1	Local display
LEDs	5mm, Various	3	Status indicators
Relay Module	5V, 10A	2	Load control
Power Supply	5V, 3A	1	System power

1) Microcontroller Specifications: **Raspberry Pi 3B+/4B:**

- Processor: Broadcom BCM2837B0 (3B+) / BCM2711 (4B)
- CPU: 64-bit Quad-core ARM Cortex-A53 @ 1.4GHz (3B+) / Cortex-A72 @ 1.5GHz (4B)
- Operating Voltage: 5V DC
- RAM: 1GB (3B+) / 2-8GB options (4B)
- GPIO Pins: 40-pin header
- Analog Input: Via external ADC (MCP3008)
- Wi-Fi: IEEE 802.11 b/g/n/ac (dual-band on 4B)
- USB Ports: 4× USB 2.0 (3B+) / USB 3.0 (4B)
- Power Consumption: 5W typical, 12.5W peak

C. Circuit Design and Operation

1) Voltage Measurement Circuit: The voltage divider network employs series-connected 10kΩ and 1kΩ resistors. The amplifier output connects to the top of the divider, ground connects to the bottom, and the junction between resistors connects to the ADC input channel.

The divider equation:

$$V_{ADC} = V_{amplifier} \times \frac{1\text{k}\Omega}{11\text{k}\Omega} = \frac{V_{amplifier}}{11} \tag{4}$$

This setup makes it possible to record amplifier voltages of up to 36.3V (3.3V × 11), which are equivalent to about 132W into an 8Ω load or 296W into a 4Ω load.

2) Power Calculation Algorithm: The software implements the following calculation sequence:

1) Read ADC value via SPI interface
2) Convert to voltage: $V_{measured} = \frac{ADC}{1023} \times 3.3 \times 11$
3) Calculate RMS voltage: $V_{rms} = \frac{V_{measured}}{\sqrt{2}}$
4) Calculate power: $P = \frac{V_{rms}^2}{R_{speaker}}$
5) Estimate SPL: $dB = SPL_{1W} + 10 \times \log_{10}(P)$

where SPL_{1W} is the speaker sensitivity specification (typically 85–95 dB SPL @ 1W/1m).

D. Power Management

The Raspberry Pi-based system implements power optimization:

- **CPU Scaling**: Dynamic frequency scaling reduces power during low-load periods
- **Display Optimization**: OLED pixels selectively activated; screen blanking during idle
- **USB Power Management**: Unused USB ports can be disabled programmatically
- **Wi-Fi Power Save**: 802.11 power management protocols reduce transmission power

Power Budget:

- Raspberry Pi (idle): 400 mA @ 5V = 2W
- Raspberry Pi (active): 1000 mA @ 5V = 5W
- OLED display: 20 mA @ 3.3V = 66 mW
- ADC + sensors: 50 mA @ 3.3V = 165 mW
- Total: ∼2.5W average, 5.5W peak consumption

E. Cloud Computing Infrastructure

A Python-based server application running on cloud infrastructure implements the following functions:

- **Socket Server**: Listens for incoming TCP connections from Raspberry Pi devices on configured port (default 8080).
- **Data Parser**: Extracts parameters from received data packets (Device ID, Timestamp, Raw ADC values, System status, Connection quality).
- **Data Validation**: Checks for out-of-range values, missing fields, and timestamp consistency.
- **Voice Processing**: Analyzes voice commands from microphone inputs for alert activation.
- **Alert Generation**: Triggers automated notifications when threshold violations detected.

V. RESULTS

A. Laboratory Testing Results

Laboratory validation testing was conducted under controlled conditions to evaluate system performance across various operational parameters. Table II presents the accuracy validation results.

TABLE II
ACCURACY VALIDATION RESULTS

Reference SLM (dB)	System (dB)	Deviation (dB)	Error (%)
75.0	74.3	−0.7	0.93
80.0	79.8	−0.2	0.25
85.0	85.6	+0.6	0.71
90.0	91.2	+1.2	1.33
95.0	94.5	−0.5	0.53
100.0	101.1	+1.1	1.10
105.0	104.2	−0.8	0.76

Mean Absolute Error: 0.73 dB
Root Mean Square Error: 0.85 dB
Maximum Deviation: 1.2 dB

These results demonstrate that the system achieves accuracy comparable to Type 2 sound level meters (±2 dB specification per IEC 61672-2).

TABLE III
POWER CONSUMPTION MEASUREMENTS

Operating Mode	Current (mA)	Power (W)
Idle (minimal load)	400	2.0
Measuring only	550	2.75
Wi-Fi transmission	850	4.25
Display + transmission	900	4.5
Voice processing	1100	5.5
Peak (all active)	1200	6.0

B. Power Consumption Analysis

Power consumption was measured across different operational modes as shown in Table III.

Average operational power: 3.5W
Continuous operation: Supported with appropriate power supply

C. Communication Performance

Wi-Fi communication reliability was evaluated under various conditions as shown in Table IV.

TABLE IV
COMMUNICATION RELIABILITY METRICS

Test Condition	Success Rate (%)	Latency (ms)
Same room, LOS	99.9	35
10m, 1 wall	99.5	42
20m, 2 walls	98.8	58
30m, 3 walls	96.2	78
High interference	93.8	105

Communication remained highly reliable (>90% success rate) even under challenging conditions with multiple walls and wireless interference.

D. Field Deployment Testing

Field testing was conducted at three different event venues over a one-month period:

Test Site 1: Wedding ceremony (indoor)

- Duration: 6 hours
- System uptime: 6 hours continuous
- Data packets transmitted: 21,600 (1 per second)
- Packet loss: 1.8%
- Maximum recorded level: 98 dB

Test Site 2: Religious festival (outdoor)

- Duration: 8 hours
- System uptime: 8 hours continuous
- Data packets transmitted: 28,800
- Packet loss: 3.9%
- Maximum recorded level: 105 dB
- Threshold violations detected: 47 instances

Test Site 3: DJ party (nightclub)

- Duration: 5 hours
- System uptime: 5 hours continuous
- Data packets transmitted: 18,000
- Packet loss: 2.5%
- Maximum recorded level: 112 dB
- Threshold violations detected: 156 instances

E. Cloud Processing Performance

The Python-based cloud processing system demonstrated robust performance:

- **Data ingestion rate**: Up to 100 devices simultaneously @ 1 sample/second each
- **Processing latency**: <50ms per data packet
- **Database write performance**: 5,000+ records/second
- **Dashboard update rate**: 5 Hz refresh for real-time displays
- **Storage requirements**: ∼1 MB per device per day (86,400 samples)
- **Voice command response**: <200ms recognition latency

VI. DISCUSSION

The Raspberry Pi-powered smart monitoring system that was developed is a great solution to the major problems that arise when enforcing noise pollution regulations from loudspeaker systems. The iterative prototyping approach was effective, with each new version incorporating the lessons learned to gradually improve the performance, reduce the size, and increase the reliability.

The accuracy of the measurement of ±2dB is sufficient for regulatory compliance monitoring, however, it is not as precise as that of Type 1 sound level meters (±0.7dB). Such a compromise is justified by the huge benefits in the continuous monitoring capability, remote accessibility, processing power, and expandability.

There are many advantages that the Raspberry Pi platform has over microcontroller-based solutions:

- **Enhanced Processing Power**: Full Linux OS enables complex signal processing and machine learning algorithms
- **Multiple Connectivity Options**: Built-in Wi-Fi, Ethernet, Bluetooth, and USB ports
- **Storage Capability**: SD card storage for local data buffering and logging
- **Expandability**: Easy integration of additional sensors, displays, and peripherals
- **Development Environment**: Standard programming languages (Python, C++) and extensive libraries

On-site experiments confirmed that the system can be effectively used in the real world. It operated efficiently and reliably in different settings like indoor spaces, outdoor festivals, and noisy clubs with a lot of radio frequency interference. The automated threshold violation detection identified 203 occasions in total at the three test locations, thus providing very solid evidence for the enforcement of actions.

The cloud-based structure of the system is very scalable, as it can easily support up to 100 devices working simultaneously with the local tests. Such a capacity is what makes the deployment of the system in a whole city possible when a central control room is monitoring the hundreds of loudspeaker systems equipped with the devices, and hence the enforcement will be done much faster and more efficiently.

Moreover, the voice-commanded alert mechanism is an innovative feature that facilitates the freeing of the user's hands and also enables emergency response operations to be carried out without the need for the presence of a monitoring system.

VII. Conclusion

This research paper has presented the stages of designing, developing, and validating a smart system enabled by a Raspberry Pi for the purpose of continuously measuring and remotely monitoring noise levels from loudspeaker amplifier systems. We underwent the development of five iterative prototypes to arrive at a comprehensive solution that involves a Raspberry Pi microcontroller, a voltage sensing network, an OLED display, voice input capabilities, and a cloud-based data processing infrastructure.

The final apparatus attains a measurement accuracy of $\pm$2dB, is capable of continuous operation with the provision of a suitable power supply, and is able to send real-time data to cloud servers for centralized monitoring. Testing in the field at three different types of venues has shown that the system performs reliably with packet success rates of over 90% even in difficult conditions.

The device offers law enforcement agencies a resourceful and scalable means of noise pollution control, which makes it possible to monitor multiple locations simultaneously, detect automatically when a threshold has been violated, activate voice-initiated alerts, and maintain an exhaustive record of data for use in court proceedings.

Next upgrades will comprise:

- Integration of GPS for exact location tracking
- Setting up solar charging for outdoor use
- Creating mobile apps for the field staff
- Using complex machine learning algorithms for event classification and predictive enforcement
- Improved voice recognition with support for multiple languages
- Integration with smart city infrastructure and emergency response systems
- On-demand noise mapping and visualization tools
- Installation of automated report generation systems for legal proceedings

This research is one of many IoT-related projects that have been developed for environmental monitoring, and it serves as a very good example of the use of Industry 4.0 technologies and a Raspberry Pi-based smart system for public health and regulatory compliance.

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