

DECIGUARD: A Smart Dual-Node IoT System for Real-Time Noise Surveillance

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Abstract

Urban noise pollution has become an important environmental issue that has impacted people and their life health and productivity. The conventional noise reduction tools are based on stagnant monitoring systems or human observations that could not be scaled, provided a spatial resolution or be responsive in real-time. The current paper introduces a smart dual-node Internet of Things (IoT) noise monitoring system that can monitor and detect patterns of environmental sound in both events of static and dynamic conditions [1],[2]. The proposed system will combine the stationary sensing node installed in the noise sensitive indoor settings and a mobile sensing node installed on moving cars to allow the entire spatial temporal noise evaluation. The fixed station constantly monitors the state of ambient sound and sends data to a cloud hosting and undergoes a long-term analysis of the indicators as well as shows them in real time on a screen [3]. The mobile node is an acoustic device that uses geolocation (granting GPS positioning) to map the noise hot spots of areas in cities dynamically. Real-time monitoring and trend analysis are involved with help of cloud-based visualization and data logging. The practical implementation proves the possibility of the system to detect areas with high noise and the time changes. The suggested scalable and modular architecture provides the inexpensive solution to the smart city sound management, planning urban, and environmental awareness programs.

Keywords

IoT, Noise Monitoring, Smart Cities, Environmental Sensing, GPS Mapping, Cloud Analytics

1. Introduction

The effect of fast urbanization and the growth of vehicular density have shown a significant increase in the levels of noise in the environment; thus, noise pollution is a pressing problem in contemporary cities[12],[13]. Excessive exposure to elevated levels of noise has been linked to negative health consequences, such as stress, sleeping problems, and heart problems[15]. Therefore, supervision of noise should be carried out continuously and precisely to ensure proper planning and control of the environment in urban areas.

The traditional noise monitoring systems mainly use fixed monitoring stations or manual regular measurements. Although these methods yield localized data, they have low spatial resolution, high implementation expenses and they are unable to represent dynamic variations of noise. The recent development in the Internet of Things (IoT) technologies, and unified the low-cost and distributed sensing solutions, and yet, several of the currently existing IoT-based noise monitoring systems are only interested in either the data gathering of a location at rest or on the move, hence lacking the comprehensive understanding of the environment [2],[3].

To overcome these restrictions, the study presented in this paper suggests a two-node IoT-based noise monitoring system that combines the two stationary and mobile sensing processes [5]. The proposed system provides better coverage of space and time due to the fusion of real-time indoor noise monitoring with mobile noise mapping based on the GPS signal [8]. Data visualization and storage on clouds also make it possible to analyze the trend and take actionable information.

The primary contributions to this work are the following:

- Design of dual node IoT architecture with stationary noise sensing units and mobile noise sensing units.
- The visualization of space and time patterns of noise in a cloud environment in real time.
- Dynamic noise hotspots that are determined by GPS.
- A cost-efficient scalable framework fitting smart city implementation.

The rest of the paper is structured in the following way: Section 2 will provide a review of related literature in terms of noise monitoring systems based on IoT. Part 3 outlines the system architecture and methodology to be proposed. Results and discussion of the experiments are found in section 4. Section 5 is the concluding part and gives directions of future research.

2.Related Work

The issue of environmental noise monitoring has been given more attention since it has certain effects on the health of the population and sustainability in cities. The conventional noise measurement processes mainly depend on fixed points of monitoring stations which are run by the governing bodies [7],[13]. Though these systems deliver precise measurements, they are costly, densely spaced as well as unable to record finer grains of spatial variations in dynamic cities.

These limitations have been addressed by recent literature on noise monitoring systems based on the Internet of Things. Some of them use low-price sound sensors and microcontrollers and cloud platforms to visualize real-time information [9],[11]. These systems enhance access and lower deployment expenses but most of them cannot monitor a moving object like a traffic or construction site to analyze noise change which limits their capacity to monitor the noise change produced by a moving object. Mobile noise sensing method based on smartphones or car sensor node has been suggested to overcome the space constraints [12].

The benefit of these systems is that they provide dynamic noise mapping using GPS information, but they typically contain a high amount of inconsistent sampling, consume a lot of energy, and cannot be continuously monitored in either indoor or noise-sensitive settings. Also, most of the mobile solutions require the involvement of the user and this causes inconsistent and inaccurate data collection. In few studies hybrid methods with the use of several sensing strategies investigated tend to need complex infrastructure or are expensive to operate. Also, the systems that are currently in place do not often offer real time local responses to occupants within indoor settings, thus minimizing their short-term practical value [4].

Conversely, the work offered proposes the dual-node model of IoT that will merge stationary and mobile units of noise sensors into one system. The proposed system can help to fill the gaps existing in the current ones through the implementation of a hybrid approach that comprises continuous indoor monitoring with GPS-based noise mapping at the mobile scale and cloud-based analytics to improve both spatial and temporal coverage at minimal cost and scalability [3],[14].

3. Proposed System Architecture and Methodology

3.1 System Overview

The proposed system will take a dual-node architecture of internet of things as a stationary noise monitoring node and a mobile noise monitoring node, both of which will be linked to a cloud service that will store and visualize their data centrally. The hybrid design also allows focusing noise analysis to both fixed indoor sites and dynamic outdoor sites.

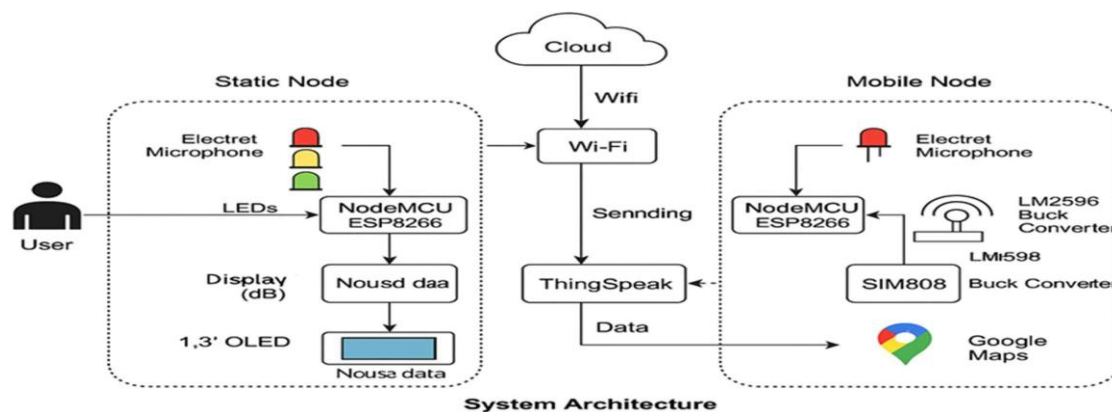


Figure 1. Overall architecture of the proposed dual-node IoT-based noise monitoring system.

3.2 Stationary Noise Monitoring Node

The stationary node has been made to be used in an indoor environment where noise is sensitive, therefore it can be deployed to classrooms, libraries, and offices. It constantly records

the ambient sound levels with the help of acoustic sensor connected to a microcontroller. The perceived information is computed locally to come up with the level intensity of noise. To give real time notification, the node is fitted with visual positioners like LEDs and display module that displays the noise conditions in real time.

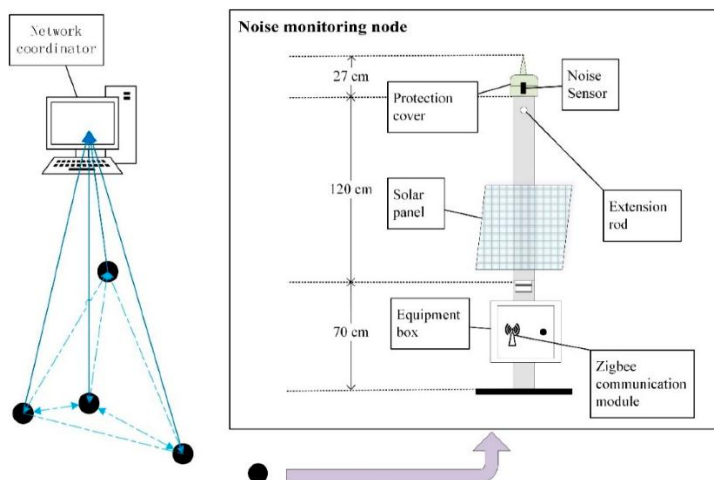


Figure 2. Deployment and operational flow of the stationary noise monitoring node.

At the same time, the processed noise data is wirelessly sent to a cloud platform where it is recorded to be analyzed over the long term and their trends are monitored.

3.3 Mobile Noise Monitoring Node

The mobile node is placed on mobile structures like vehicles to record dynamic interactions of noise in the outdoors. Besides, the acoustic sensing, this node has a GPS component that will match each noise signal to accurate geographical locations [6]. The data related to noise and location is uploaded to a cloud-connected spreadsheet or database periodically to be visualized by demonstrating the level of noise in various areas of the city. This technique enables these noise hotspots to be determined and provides the opportunity of analyzing spatial noise without depending on local infrastructure.

3.4 Cloud Integration and Data Visualization

The two nodes are connected to a cloud platform which is a centralized data storage.

The cloud system supports:

- Real-time data monitoring
- Historical data storage
- Patterns Noise graphical representation of noise patterns.
- Location noise mapping.

The cloud version can be expanded and the noisy data would be amplified and transmitted to the end users remotely to analyze it and make a choice.

The general research approach entails:

1. Noise measurement of the immobile and mobile nodes continuously.
2. local data analysis and threshold analysis.
3. Data is relayed to cloud by use of wireless.
4. Storage, visualization of spatial-temporal analysis.

This workflow is modular such that it provides an efficient acquisition of data that in turn has less power besides scales the system.

4. Experimental Setup and Implementation

To test the efficiency of the offered dual-node noise monitoring framework based on IoT a prototype system was worked out and tested both in interior and exterior conditions. In the installation of the stationary noise monitoring node, we placed it in one of the sound sensitive areas of the house, where there was constant monitoring of the ambient sound levels whereas on the installation of the mobile noise monitoring node we mounted it on an on the move vehicle to have the dynamic patterns of noise in the outdoors environment.

The acoustic sensors were adjusted to reflect the level of sound intensity in the range of noise in the normal environment of the urban setting. Data was being collected at regular time scales and threshold-based processing to classify the noise levels was also carried out. Wireless communication modules supported real-time data transmission on the two nodes and the cloud platform. The fixed node offered direct visual feed-back in the form of LED and display interface, which gave information about the allowable and over-tolerable conditions, of noise. At the same time, the data about noise were still sent to the cloud to be stored and visualized long term.

The mobile node took the noise measurements with the GPS coordinates and sent the data to a spreadsheet, which was linked to the cloud, and allowed geo-referenced noise mapping. To ensure that the level of noise recorded during various times of the day, data were collected through various sessions in various times of the day. With this type of experiment, the dynamics of noise in space and in time could be fully tested.

5. Results and Discussion

The experimental results demonstrate that the proposed system effectively captures and visualizes environmental noise variations across both static and mobile contexts.

5.1 Stationary Noise Analysis

Measurements made there at the stationary node showed that there are significant changes in the books' levels that are associated with the various activity levels. The peak occupancy times were recorded to have high noise levels whereas the weak ones were recorded in quiet times. The

visual feedback mechanism in real-time was useful in creating awareness of the excessive noise state in real time that enhanced effective control of noise in an indoors setting. Visualization of cloud technology also facilitated continuous monitoring and trend analysis, which would be able to observe the behavior pattern of noise over a long period of time. These findings affirm that the system is ideal in the indoor noise sensitive applications.

5.2 Mobile Noise Mapping

The node on the move was able to record noise readings and the GPS positions of the noise on outdoor places effectively. The data gathered supported the identification of areas where noise is rampant and especially in places where there is a lot of traffic of road vehicles. Dynamic noise mapping provided a depiction of spatial change in noise distribution, which is hard to realize with traditional systems that do not move because of non-spatial fixed monitoring. The geolocation information was integrated into the system substantially improving the spatial resolution and making available pragmatic outcomes in the detection of urban noise hotspots.

5.3 System Performance and Discussion

The dual-node hybrid architecture enhanced the level of temporal and spatial coverage as opposed to traditional methods of noise monitoring. Low-cost IoT devices were used to guarantee low cost of deployment whereas the cloud integration technique allowed scalability and easy accessibility. The proposed framework is a balanced and holistic approach to noise assessment in cities compared to the current systems that have developed basing on all the available options exclusively on either the static or mobile sensing.

The findings justify the feasibility in implementing the system to smart city use and urban planning, environmental monitoring. Both the hardware design was assembled by using modular hardware components which were connected using a bread board and PCB connected to a permanent node and a mobile node, respectively. The microcontroller used was the Node MCU ESP8266 which controlled all the inputs and outputs. The microphone to record sound levels was the MAX9814 electret microphone which was connected to the analog input pin (A0). To describe the visual feedback three LEDs (red, yellow, green) were connected to digital GPIO pins (e.g. D5, D6, D7) with resistors 220 ohms of each, to restrain current and avoid damaging them.

Table 1 : Pin connection between Mic & Esp8266

MAX9814 Pin	Description	Connected to (ESP8266)
OUT	Analog audio output	A0
VCC	Power supply (2.7–5V)	3.3V or 5V (Vin)
GND	Ground	GND
AR	Auto gain control ref	Not connected (optional)
Gain	Gain setting	Set via on-board jumper

Table 2: LED to Esp8266 connection

LED	Function	Connected GPIO Pin	Resistor Used
Green	Safe sound level	D5 (GPIO14)	220Ω
Yellow	Moderate level	D6 (GPIO12)	220Ω
Red	High noise alert	D7 (GPIO13)	220Ω
GND	Ground	CommonGND	

Table 3:OLED to Esp8266

OLED Pin	Description	Connected to (ESP8266)
VCC	Power supply	3.3V or 5V (NodeMCU Vin)
GND	Ground	GND
SDA	I ² C Data	D2 (GPIO4)
SCL	I ² C Clock	D1 (GPIO5)

Table 4: Buck pin wiring

Buck Pin	Description	Connected to
IN+	Input from battery	12V DC Source (Battery)
IN-	Ground	Battery Ground
OUT+	Regulated 5V Output	NodeMCU VIN, SIM808 VCC
OUT-	Ground	NodeMCU GND, SIM808 GND

6. Conclusion and Future Work

The paper has described a dual-node IoT noise monitoring framework, which is aimed at examining the sound patterns in the environmental setting both in the room (static) and in the field (dynamic). The proposed system will become comprehensive spatial-temporal noise assessment through the combination of mobile monitoring via GPS and cloud-based visualization with the stationary noise sensory measurement. Experimental assessment proved that the system can detect the noise variation, determine high-noise areas, and provide the real-time observation with a minimum infrastructure. The design is scalable and modular (the framework) adopts the smart city noise control and environmental awareness programs. The next generation of work will aim at incorporating machine learning methods that will be used to classify noise automatically, provide predictive analytics to forecast noise trends, and implement edge computing to ensure even lower latency and energy use. Also, mass deployment and interconnection with municipal surveillance can be considered to facilitate the strategies of noise control in urban areas.

6.1 CODE IMPLEMENTATION

Embedded programming based on the Arduino IDE gets the functionality of both the static and mobile nodes. The code is coded in C/C++ and it combines sensor input, conditioning logic as well as communication. The static system has the Node MCU receiving the value of the MAX9814 microphone through analog, as the determiner of the level of noise, LEDs, output on the OLED display and transmits the output to the ThingSpeak system via Wi-Fi. The SIM808 module is also controlled by the code and used to transmit GPS position and GPRS data to update a Google Spreadsheet in the mobile node. Again modularity and connection to the network are available using the standard libraries like ESP8266WiFi.h, ThingSpeak.h, SoftwareSerial.h and U8g2lib.h. The layer of code is the basis of the real time sensing and remote data logging features of the system.

6.2 VISUAL NOISE FEEDBACK USING LEDs

The system has used three LED indicators as colors to illustrate the ambient sound levels, i.e. red, yellow and green, to give an immediate intuitive representation of the ambient sound levels. These LEDs are also directly driven under the value of decibel calculated directly as an output of the analog of the MAX9814 microphone with the NodeMCU ESP8266. Once sound signals are received, the microcontroller works with the input and identifies the noise as a safe one, a moderate one, or a harmful noise.

A green LED is lit up indicating safe environments (usually below the level of 30 dB), yellow LED is on indicating moderate noise (around 30 - 60 dB) and red LED is indicating above the harmful sound level (above 60 dB). This easy-to-understand color coded feedback enables users to gauge the amount of noise of a digital device in real time without necessarily displaying some numbers on a device. The LEDs are mounted on the board through individual digital output pins of the ESP8266 and controlled by conditional statements within the code.

This is a light feed-back mechanism that can improve the system when it is in use especially in places such as the classroom or even the libraries where users can be reminded by physical visual signs to ensure the right level of noise.

6.3 DATA COLLECTION & CLOUD INTEGRATION

The information provided by the system to detect the noise in the environment is with the assistance of the MAX9814 electret microphone that provides an analog voltage that is proportional to the ambient sound aids. The signal is read by the analogue pin in the NodeMCU ESP8266 and an approximate of the noise level in decibels (dB) is converted. When it has been determined then it is implemented into the local feedback and remote monitoring. The processed data posted on ThingSpeak platform is displayed upon the OLED screen and the LED indicators

at the same time when it is positioned on the ThingSpeak cloud platform by using the Wi-Fi connection.

The information will be sent in the form of the sequence of HTTP POST messages with the format of API key and special channel field. ThingSpeak stores the data and gives graphical dashboards that could be accessed in observing the information live and in the past thus making it very simple to trace the trends. Noise information that is received on the mobile node is compared to actual time GPS co-ordinates, which is rendered by SIM808 module.

The NodeMCU interprets the data of the place and time and receives the interaction with the module through a serial interface. Such aggregated information is encoded in a URL string, and delivered over GPRS to a Google Spreadsheet through a Google Apps Script Webhook. Considering this integration then real time logging can be experienced in the cloud without necessarily having to tailor the server infrastructure.

6.4 CLOUD BASED VISUALIZATION

The data obtained by the system is also represented in the cloud platforms, to enable long term monitoring and real time tracking. There are packages of both the static and mobile nodes where data on the level of environmental noise are viewed location and time wise.

6.4.1 THINGSPEAK VISUALIZATION (Static Node)

In the static node, ThingSpeak will be deployed to provide real-time decibel levels due to the graph of automatically updating lines. APIs keys are used to push the data onto fields in a special channel in ThingSpeak. The platform has ordered readings by time and include trend, and threshold alert tools.

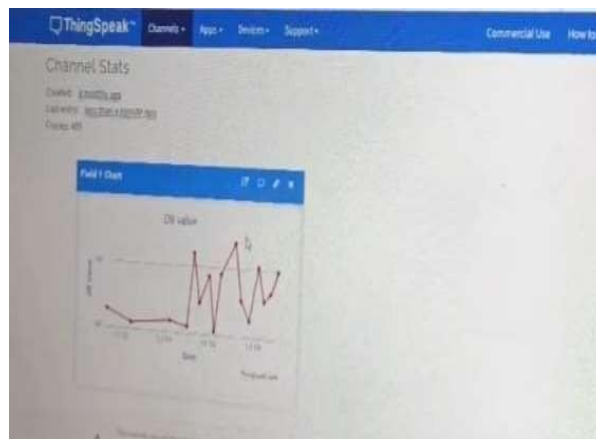
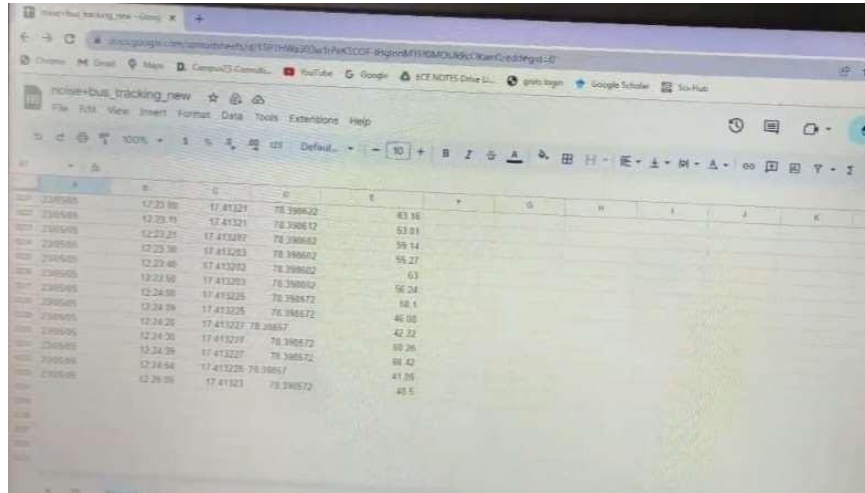


Fig 6.1. ThingSpeak Channel Graph displaying real-time sound level data

6.4.2 SPREADSHEET VISUALIZATION (Mobile Node)

In the case of the mobile node, GPS coordinates, time and the value of the decibel is recorded in a Google Spreadsheet using a Google Apps Script Webhook. Its spreadsheet serves as a database, as well as record keeping platform. It enables one to filter, sort and export the data to be analyzed further.



	A	B	C	D	E	F	G	H	I	J	K
23/05/2022	12:25:06	17.41321	78.39852								
23/05/2022	12:25:11	17.41321	78.39852								
23/05/2022	12:25:21	17.41322	78.39852								
23/05/2022	12:25:38	17.41323	78.39852								
23/05/2022	12:25:48	17.41323	78.39852								
23/05/2022	12:25:50	17.41323	78.39852								
23/05/2022	12:26:00	17.41325	78.39852								
23/05/2022	12:26:09	17.41325	78.39852								
23/05/2022	12:26:28	17.41327	78.39857								
23/05/2022	12:26:30	17.41327	78.39857								
23/05/2022	12:26:39	17.41327	78.39857								
23/05/2022	12:26:44	17.41326	78.39857								
23/05/2022	12:26:55	17.41323	78.39852								

Fig6.2. Google Spreadsheet showing time stamped sound data with location.

6.4.3 GOOGLE MAPS VISUALIZATION (Mobile Node)

The GPS data of the spreadsheet is logged in the Google Maps service in My Maps or GIS-based applications. Colored markers are used to illustrate the severity of noise each data point with red colored marks representing high noise and green colored marks representing low noise, etc. With the help of this type of geospatial visualization, it becomes possible to identify the noise hotspots and evaluate patterns in various regions.

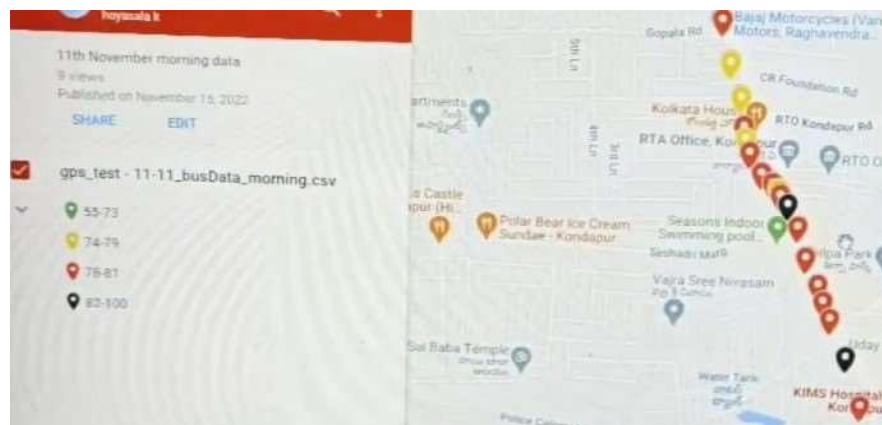


Fig 6.3. Google Maps highlighting noise levels by location using color-coded legends.

7. CONCLUSION

The full operation of both the static and the mobile node managed to achieve the successful process of monitoring, analyzing, and visualizing the environmental levels of noise in real-time. The fixed indoor version worked well in a consistent fashion and was useful in capturing different levels of sound upon which LED indicators showed the sound levels, which could be displayed using OLED display and on a graph on a cloud system using Thing Speak. Wi-Fi integration to the cloud platform has offered the system to be integrable with ease to record and visualize consistent data by adding the capabilities of GPS based tracking and GPRS based data transmission.

Through the SIM808 module, the system could record noise data accurately on the location and remotely update a Google Spreadsheet. The additional access to Google Maps also made the data even more useful as it was now possible to know where noise pollution was hotspotted during a movement with the help of the system that was durable, mobile, and responsive. Components worked successfully and the output of the data was reliable and readable. The development of the prototypical system and its practical application demonstrated that the system can be a useful instrument in terms of a smart sound monitoring of the environment in stationary as well as mobile settings.

8. FUTURE ENHANCEMENT

The system has a solid base in future improvement in technical as well as application-oriented aspect.

The possible improvements are:

- **Machine Learning Implementation:**
The use of predictive models in detecting noise trends, anomalies or breakthrough prediction of noise pollution.
- **Battery-Powered Wireless Nodes:**
Switching to a rechargeable battery power with mode of sleep to maximize operation in distant locations.
- **Mobile Interface:**
The creation of an app to serve as a companion mobile application to receive real-time alerts, view dashboard application, and track location.
- **Multi-Sensor Integration:**
This can be completed with sensors of temperature, humidity or air quality to make it a complete environmental monitoring solution.
- **Data Analytics and Reporting:**

Significantly, the modern analytics or dashboards involve a greater understanding and auto-generation of reports.

The proposed smart monitoring system, which follows the growth of urban settings, can become a significant factor in the population health awareness system, compliance system on regulations, and environmental planning one. The latter would make user interaction, and accessibility better, and more battery-powered types of both nodes with low-power options can be introduced to enable it to run more without the necessity to use fixed power sources, especially by the implementation of remote or outdoor use.

It could be enhanced with the help of incorporating machine learning algorithms that will analyze the tendencies of long-term data and enhance the system of classifying the types of sounds (e.g., traffic, human voices, machinery). It would not only identify the degree of noise but also inform us about noise pollutants sources which would in turn allow the local officials or the environmental bodies to take certain action. One can also add to it other sensors of the environment such as the quality of the air, the temperature or humidity and it will be an entire multi-parameter intelligent system of monitoring which is ideal within the context of the smart city. Moreover, creating an automatic reporting option, it could have been possible to schedule the reports or report in case such thresholds are reached with notifications or mail.

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