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Advancing Urban Noise Monitoring: Bridging Cost and Class 1 Accuracy Performance in Smart City Applications

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ABSTRACT

This paper extends the "Development Of Low-Cost Noise Monitoring Terminals (NMT) Based On MEMS Microphones" from Internoise 2022, introducing a cost-effective solution for urban noise monitoring in smart cities, the Svantek model SV 303. Compliant with Class 1 standards (IEC 61672-1:2013 and IEC 61260-1:2014), this terminal offers a 30 dBA to 130 dB RMS operating range, ideal for urban environments, and ensures Class 1 accuracy.

A significant focus of this development is on achieving excellent directional characteristics, crucial for effective "urban noise" measurements. The terminal also boasts the best environmental performance among our NMTs, operating reliably from -20 °C to 50 °C in diverse urban settings.

Equipped with USB 2.0 and UART interfaces, it integrates seamlessly into existing urban monitoring systems, accommodating a wide range of devices. This adaptability is essential for smart city applications.

The paper explores the design, operational parameters, and integration potential of the terminal. By merging high-performance noise monitoring with cost efficiency, the terminal emerges as a key advancement in smart city noise monitoring, offering a practical solution for accurate, large-scale urban noise evaluation.

1. INTRODUCTION

The primary goal of smart cities is to improve the quality of life for their residents. Reliable noise level data are essential for creating environments that enhance well-being, minimize stress, and make urban spaces more enjoyable. Such data enable the development of strategies that effectively reduce noise pollution, contributing to the overall health and happiness of the community.

The trust of the public in city policies significantly depends on the reliability of the data these policies are based on. Decisions grounded in data from dependable instruments boost the credibility of efforts to tackle issues like noise pollution, thus encouraging public support and cooperation. Consequently, accurate and trustworthy data are crucial for adhering to both national and international environmental noise regulations. This compliance helps cities avoid legal issues and fines, ensuring that urban areas maintain noise levels that are safe and acceptable for everyone.

2. SPECIFICATIONS REQUIREMENTS FOR THE DEVELOPMENT OF LOW-COST NOISE MONITORING TERMINALS FOR SMART CITY APPLICATIONS

The term "Noise Monitoring Terminal" (NMT) refers to instrumentation used for automated continuous noise monitoring which monitors the A-weighted sound pressure levels, their spectra, and

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all relevant meteorological quantities such as wind speed, wind direction, rain, humidity, atmospheric stability (ref. ISO 1996-2:2017).
Developing low-cost Noise Monitoring Terminals (NMTs) for smart cities aims to balance the need for high-quality performance with affordability. In urban noise monitoring, challenges such as ensuring wide operating ranges, accurate frequency measurements, durability in various weather conditions, and deploying enough points to accurately assess noise levels are critical. These technical requirements highlight the need for effective, reliable noise monitoring solutions that can adapt to the complexities of urban environments.
The need for extensive coverage through numerous monitoring points in smart cities makes cost-effectiveness a critical factor for noise monitoring systems. The challenge is twofold: meeting the technical specifications required for effective noise monitoring and ensuring these solutions are affordable. This drives the innovation of Noise Monitoring Terminals (NMTs) designed to deliver both high performance for urban noise pollution management and affordability for broad implementation. Achieving this balance is key to integrating noise monitoring technologies into smart city infrastructures effectively, to improve urban living conditions in a financially sustainable manner.

2.1.1. Operating Ranges and Frequency Accuracy

In the context of integrating cost-effective Noise Monitoring Terminals (NMTs) into smart city infrastructures, specifying technical requirements is crucial for ensuring the accuracy and reliability of noise data. These specifications are vital for effective noise monitoring and management:

- **Compliance with IEC 61672-1**: NMTs must conform to recognized standards, such as IEC 61672-1, to provide the level of accuracy needed for effective noise analysis and decision-making. This standard outlines the requirements for sound level meters, including frequency response and directional response.
- **Operating Range**: NMTs should be capable of measuring a wide range of sound levels to reflect the diverse acoustic environments of urban areas. The operating range should span from quiet night-time ambiance **at LAeq 30 dB to the peak noise levels of daytime traffic at 125 dBA**. This range ensures the capture of the full spectrum of urban sounds, facilitating accurate noise mapping and analysis.
- **Dynamic Range**: **A dynamic range of 100 dB is necessary**, defined as the difference between the A-weighted noise floor and the maximum sound pressure level (SPL) within tolerance. This specification allows NMTs to accurately measure both low and high noise levels, crucial for assessing exposure and implementing mitigation strategies.
- **Frequency Accuracy**: Accurate frequency response is essential for NMTs to correctly identify, and measure sounds across a broad spectrum. This accuracy enables the system to distinguish between different types of noise sources, from low-frequency hums to high-frequency sirens, ensuring effective noise analysis. For class 1 sound level meters, the frequency of the sound signal is specified **up to 16 kHz, and for class 2 sound level meters, up to 8 kHz.**
- **Directional Response**: NMTs should offer an equal response to sounds from all directions of sound incidence, with acceptance limits for deviations as provided by IEC 61672-1. This ensures that NMTs can accurately capture noise data from various directions, which is essential for detailed noise mapping and source identification.

By adhering to these specifications, NMTs for smart cities can provide the detailed and accurate data necessary for assessing urban noise pollution, developing effective mitigation strategies, and enhancing the quality of life for city residents.

2.1.2. Weather Conditions

For outdoor noise monitoring systems, particularly those integrated into smart city applications, the capability to function effectively across a variety of weather conditions is crucial. These systems must be resilient to rain, wind, extreme temperatures, and humidity to ensure that performance is not compromised. Such durability is essential for the continuous collection of data and the maintenance of the integrity of long-term noise studies, which are foundational for the formulation and implementation of noise mitigation policies.

The IEC 61672-1 standard, which specifies requirements for sound level meters, including those used in outdoor noise monitoring, categorizes equipment into two classes based on their tolerance levels to environmental conditions:

- Class 1 Tolerance Levels: These are suitable for precision ambient noise measurements, with a defined temperature range of -10°C to +50°C. This range is critical for ensuring accurate data collection in environments subject to significant temperature variations.
- Class 2 Tolerance Levels: Aimed at general environmental noise monitoring, with a temperature range of 0°C to +40°C, suitable for less extreme conditions.

However, given the reality of outdoor measurements and the potential for wide temperature fluctuations, it is recommended that **Noise Monitoring Terminals (NMTs) designed for smart cities should ideally operate within an expanded temperature range of -10°C to +50°C**. This broader range ensures that NMTs can reliably capture noise data under nearly all weather conditions encountered in urban settings, thereby supporting comprehensive noise analysis and effective mitigation strategy development.

2.1.3. Number of Monitoring Points

The intricate nature of urban soundscapes requires a comprehensive network of monitoring points to accurately map spatial variations in noise levels. This dense network is essential for understanding the full scope of noise pollution within a city, allowing for targeted noise reduction strategies and improved urban planning. However, the challenge lies in the deployment of a sufficient number of high-quality, accurate sensors. The costs associated with purchasing, installing, maintaining, and managing the data from these sensors can quickly become a significant barrier, particularly for extensive urban areas where the need for coverage is greatest. Balancing the demand for detailed noise mapping with the financial realities of implementing such a system is a key consideration in the development of smart city infrastructures.

2.1.4. High Performance vs. Low Cost

Achieving a balance between high performance and low cost in noise monitoring systems, particularly those based on Micro-Electro-Mechanical Systems (MEMS) technology, presents a significant challenge. MEMS microphones, with their advantages of compactness, affordability, and durability in harsh environmental conditions, have emerged as a promising option for smart city applications. However, a notable drawback is that many MEMS-based systems fail to meet the rigorous accuracy requirements mandated by standards such as IEC 61672-1. Adherence to these standards is essential to ensure the reliability of noise measurements, which are foundational for effective noise management and informed policy-making. The quest to develop MEMS-based noise monitoring systems that combine both cost-effectiveness and compliance with high accuracy standards is crucial for their successful integration into smart city infrastructures.

2.1.5. MEMS Microphones and IEC 61672-1 Compliance

The exploration of MEMS (Micro-Electro-Mechanical Systems) microphones within the context of noise monitoring projects underscores the industry's pursuit of solutions that strike a balance between accuracy, affordability, and standard compliance. Despite the potential of MEMS microphones to revolutionize environmental noise monitoring with their cost-effectiveness and robustness, the challenge lies in selecting models that meet the stringent performance criteria necessary for this application. This effort is reflective of a wider industry effort to identify sensors that not only are economically viable but also meet the accuracy and reliability standards mandated by regulations such as IEC 61672-1. Compliance with such standards is paramount to ensure the integrity of noise data, a critical factor in the successful deployment and effectiveness of new noise monitoring systems.

MEMS (Micro Electrical Mechanical System) microphones consist of three main parts: SENSOR (microphone), ASIC, and package. The SENSOR and the ASIC are packaged together in a cavity that is surrounded by a substrate and a lid.

A sound inlet (acoustic port) is present either in the substrate or in the lid, and, most of the time, positioned directly in the MEMS cavity.

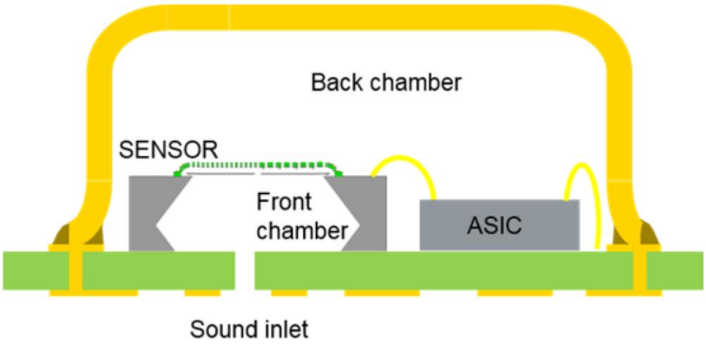


Figure 1. Example of MEMS microphone construction.

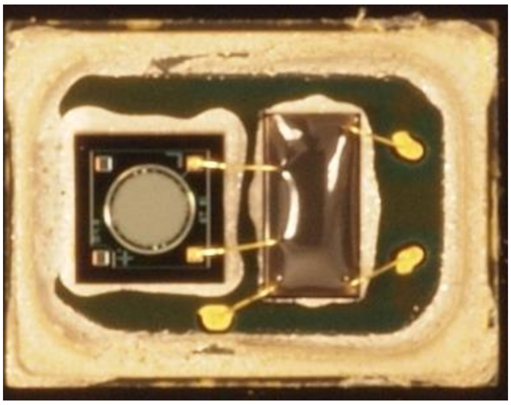


Figure 2. Transducer and ASIC of an Analog MEMS Microphone

The SENSOR shown in Figure 1 is a **miniaturized polarized condenser microphone** with a typical polarity of 50V. One surface, called the backplate, is fixed and covered by an electrode. The other surface, being the diaphragm, is movable and has many holes, that is, acoustic holes.
A sound wave passing through the acoustic holes of the backplate will set the diaphragm in motion, creating a change of capacitance between the two corresponding surfaces. This is converted into an electrical signal by the Application-Specific Integrated Circuit (ASIC).

There are two types of MEMS microphones: analog and digital. In the analog type, an ASIC contains an impedance converter (preamplifier) and a charge pump for generating a polarization voltage. The digital microphone's ASIC additionally includes a sigma-delta A/D converter with PDM output. The PDM format is a standard input for most Codecs available on the market (a pulse density modulated PDM format is an a1-bit high sample rate data stream).

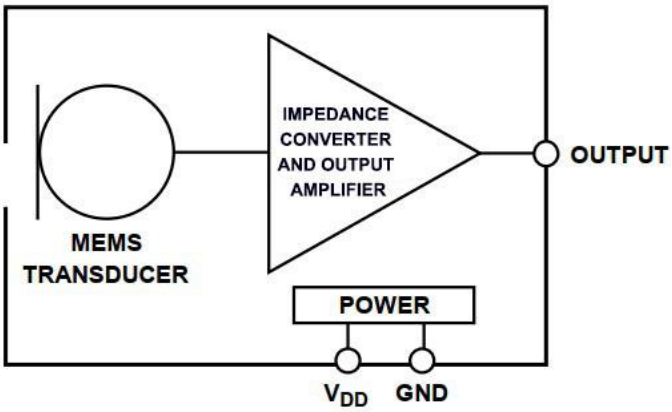


Figure 3. Typical analog MEMS microphone block diagram

2.1.6. Electrical testing of NMT with MEMS according to IEC 61672-1.

The IEC 61672-1 requires providing **an electrical equivalent of the microphone** for electrical testing. In the case of MEMS microphones, it is a challenging, but possible task.

3. STUDY: VALIDATION OF KEY SPECIFICATIONS THE MEMS-BASED NMT

3.1.Measurement instrumentation.

In this section, we validate the features of a MEMS-based NTM for conformance with IEC 61672-1 in 2022. The performance of Svantek SV 303 based on ST 30B MEMS microphone (½" housing) with a nominal sensitivity of 36 mV/Pa.

Figure 4. Svantek SV 303

3.2.Linear operating range following IEC 61672-1

The typical outdoor noise measurement is conducted within the range between 30 dBA and 125 dBA, which requires a dynamic range of 100 dB (defined here as the difference between the A-weighted noise floor and the maximum SPL within tolerance). On any level range and at the stated frequency, the deviations of sound levels measured by an NMT need to be within the acceptance of IEC 61672-

The validation shows that the linear operating range of NMT SV303 is 30 dB ÷130 dB LAeq.

The specifications for environmental noise measurements are met in both cases by the linear operating range.

3.3.Frequency response following IEC 61672-1

Noise Monitoring Terminals conforming to IEC 61672-1 should have a specified frequency response for the sound incident on the microphone from one principal direction in an acoustic-free field or random directions.
The validation shows that SV303 comply with the frequency response criteria thanks to compensation filters, which improve frequency characteristics and meet IEC 61672-1 standard, as shown by the below figures.

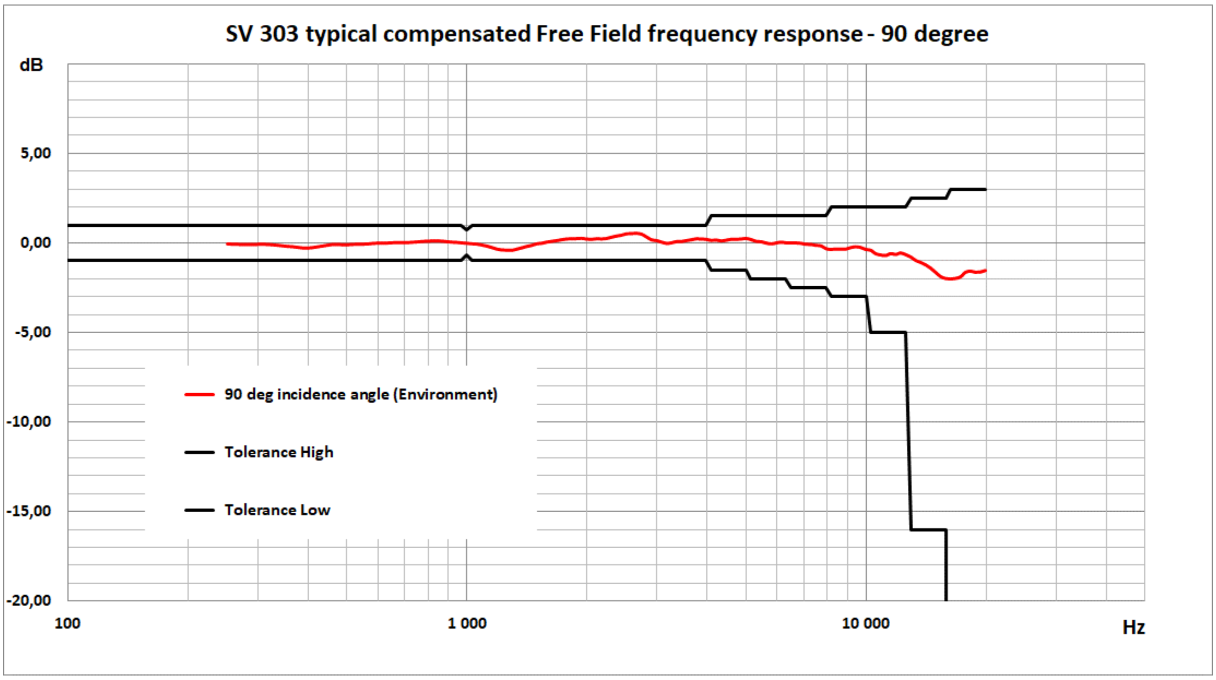
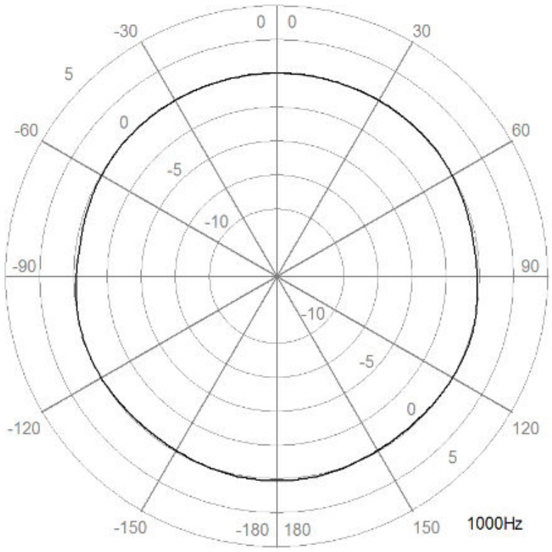


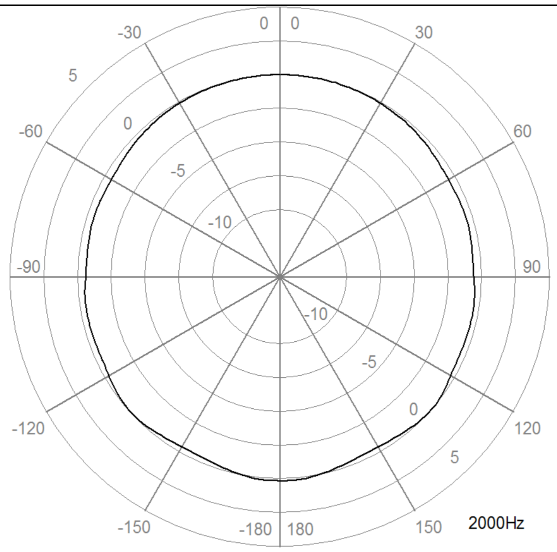
Figure 5. Frequency response of SV 303 NMT with MEMS microphone.

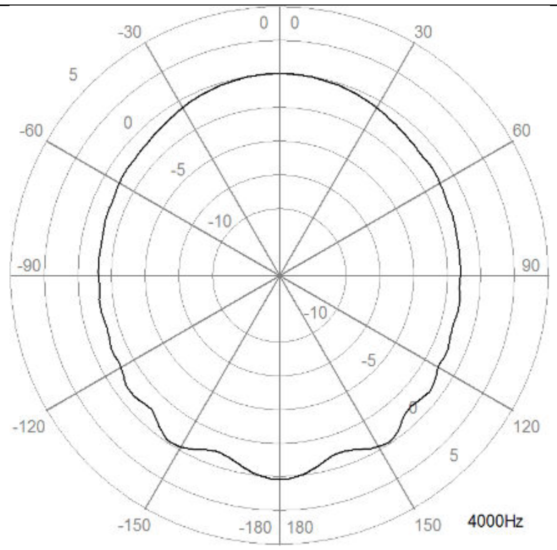
3.4.Directional Response following IEC 61672-1

For any frequency in the range of NMT, the directional-response design goal is an equal response to sounds from all directions of sound incidence. The IEC 61672-1 provides acceptance limits for deviations from the design goals. For class 1 sound level meters, the frequency of the sound signal is specified as up to 12.5 kHz and for class 2 sound level meters up to 8 kHz. The figures below compare the directional response of NMT with a condenser microphone and MEMS microphone, both meeting the IEC 61672-1 specification.

SV 303 with MEMS







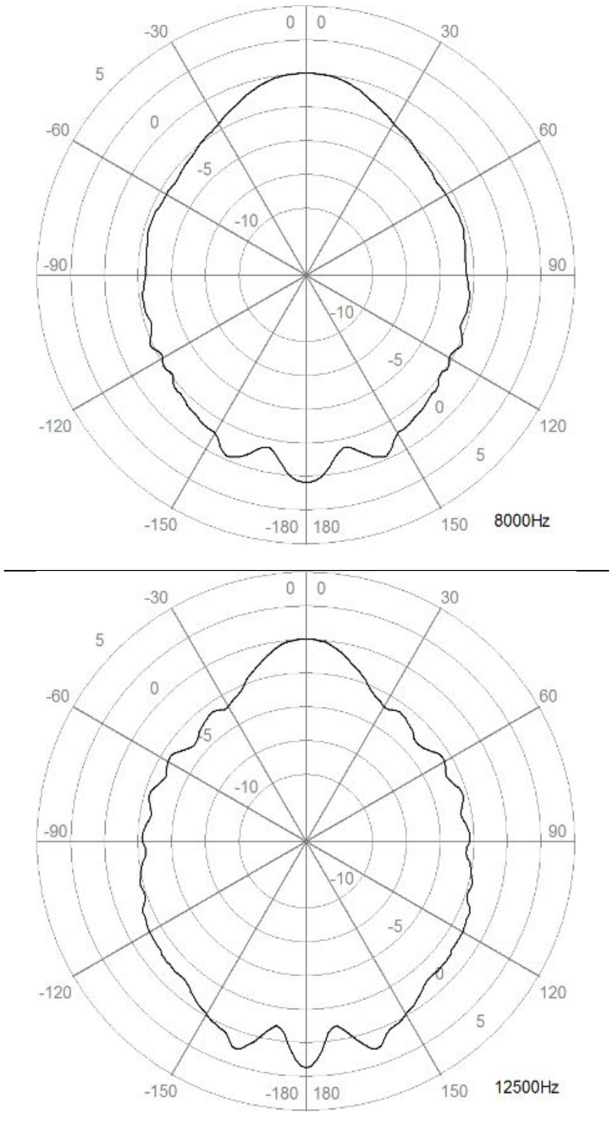


Figure 6. Directional response of SV 303

3.5.Temperature operating range

IEC 61672-1 defines two tolerance levels for outdoor noise: Class 1 and Class 2. These ranges govern the temperature range of -10°C to +50°C, as well as 0°C to +40°C. They are significant factors when it comes to ambient noise measurements and environmental noise monitoring, respectively.
In real measurements, at least the temperature range for NMT should be no less than (-10°C) to +50°C which is due to the wide fluctuations in temperatures when measuring outside.

The validation shows that the temperature operating range of SV 303-based MEMS operating range is specified from (−20 °C) to +50 °C

3.6. Long-term stability

Long-term stability is a crucial consideration when considering NMT since noise monitoring is an unattended type of measurement. In the case of long-term noise monitoring, the ISO 1996-2 standard refers to the ISO 20906/Amd1:2013 acoustic check for NMT sensitivity verification. The ISO requires the installation of an automated system check that will notify whether the system is functioning properly or is potentially faulty.

Systems based on condenser microphones use a classic system check based on an electrostatic actuator. However, the use of an electrostatic actuator in outdoor measurements is troublesome and costly, mainly due to the required high voltage and environmental conditions.

MEMS microphones cannot be tested with electrostatic actuators because of housing, but the small size makes it feasible to design a multi-microphone array inside of an ½" microphone housing. Using such an array one can make a dynamic system check continuously based on real acoustic signal measured. The concept of the dynamic system check uses a continuous comparison of microphone sensitivity.

3.7.Powering.

When it comes to noise monitoring, one of the most important factors is power and communication. The data must be transmitted to remote servers in the unattended type of measurement. In such a situation, there is the possibility of no electricity during the day hours. As a result, NMT should have at least 24 hours of battery life. With the use of MEMS that have extremely low power consumption, it is easier and cheaper to fulfill such requirements.

3.8.Shock resistance.

The damage to classic condenser microphones due to mechanical shock is one of the highest cost sources in noise measurements. Because of their construction, MEMS microphones are extremely robust and can withstand shocks up to 10000 g (100 000 m/s2).

3.9.Integrating noise monitoring capabilities into existing urban data collection points

Incorporating noise monitoring functions into the existing urban sensor networks offers a strategic and cost-efficient method to augment smart city frameworks. This integration capitalizes on the pre-existing sensor and data collection infrastructure, thereby reducing the necessity to install new devices throughout the city. The use of UART (Universal Asynchronous Receiver-Transmitter) emerges as a practical choice for this purpose, attributed to its straightforwardness, ubiquity, and broad compatibility with various devices and systems.

The advantages of employing UART for integrating noise monitoring include its simplicity and low cost, requiring minimal hardware and software resources, thus presenting an economical solution for enhancing current systems. Its wide compatibility ensures that noise sensors can be easily added to urban data collection systems like traffic lights, air quality monitors, and weather stations, which often already support UART communication. The capability of UART to facilitate real-time data transmission is vital for dynamic noise management, allowing for the immediate processing and analysis of noise data. Moreover, UART's adaptability makes it suitable for a range of noise sensors, including those necessitating high sampling rates for precise noise measurement, offering cities the flexibility to select optimal sensors for their specific needs without compromising the integrity of their existing data collection network.

However, several implementation considerations must be addressed, including the power supply requirements of noise sensors and ensuring data integrity during transmission in the electrically dense urban environment. Additionally, the integration of new data types demands meticulous planning around data storage, management, and analysis to ensure the urban systems' capacity to manage increased data volumes and analyze noise data effectively. Compliance with relevant standards, such as IEC 61672-1, is essential to guarantee the accuracy and reliability of noise measurements, which are critical for informed decision-making in noise management and policy formulation.

4. AI NOISE SOURCE RECOGNITION AND UNATTENDED NOISE MONITORING IN SMART CITIES

The appearance of new AI solutions has significantly enhanced the capability for automatic noise source identification, marking a pivotal advancement in urban noise monitoring. When combined with a network of numerous monitoring points, these AI technologies enable the possibility of comprehensive, unattended noise monitoring within smart cities. This development aligns closely with the initial goal of improving urban living conditions by accurately identifying, analyzing, and managing noise pollution sources without the need for constant human oversight.

This approach not only streamlines the process of noise data collection and analysis but also enriches the quality of the data obtained, offering detailed insights into the specific sources of noise pollution. By leveraging AI to automatically recognize and categorize noise sources, cities can implement more targeted noise mitigation strategies, directly addressing the root causes of noise pollution. This capability is crucial for the proactive management of urban noise, ensuring that interventions are both effective and efficient, thereby contributing to the overarching aim of enhancing the quality of life for city residents.

5. CONCLUSIONS

As demonstrated in the article, the use of MEMS microphones in NMT ensures that parameters such as linear operating range, frequency response, directional response, and temperature operating range conform to IEC 61672-1. Other factors, environmental robustness, power consumption, and data exchange may be considered while drafting Noise Monitoring Terminal requirements.

Because of the design low cost and very good performance NMT systems based on MEMS microphones are the **right choice for multipoint noise monitoring in Smart Cities**.

6. REFERENCES

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