A Crowdsensing-Based Framework for Sound and Vibration Data Analysis in Smart Urban Environments

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Abstract
In this paper, we introduce a framework tailored to the precise analysis of sound and vibration data in the dynamic context of smart cities. By harnessing the power of crowdsensing data, our system offers a robust and highly adaptable solution for the real-time monitoring and comprehensive assessment of acoustic and vibrational parameters within urban environments. The rise of smart cities, fueled by sensor tech and data analysis, demands advanced tools to tackle urban environmental issues and improve residents' quality of life. Our framework empowers city stakeholders, offering insights for informed decisions in urban planning, transportation, infrastructure maintenance, and public health. Key features of our system include data acquisition through mobile crowdsensing application, advanced signal processing algorithms for noise and vibration identification, and the integration of geospatial information to provide location-specific context. Furthermore, our framework supports scalable and adaptable data analytics, ensuring the efficient utilization of resources and the effective management of urban environments. The presented framework addresses the challenges of noise pollution, structural health monitoring, transportation optimization, and public safety in smart cities. By exploiting crowdsourced data, it promotes a collaborative approach to data collection, analysis, and decision-making, fostering an environment where cities can continuously evolve and adapt to the evolving needs of their residents. This paper offers a detailed exploration of the system's architecture, and showcases its practical implementation, affirming its potential as a powerful starting point for advancing the science of smart cities.

Keywords: sound and vibration in traffic, data analysis, urban planning, noise pollution, crowdsensing.

1. Introduction
A smart city is one that operates sustainably and intelligently, integrating its infrastructures and services for cohesive functioning through the use of intelligent devices for monitoring and control [1].

Smart cities contribute to sustainability and enhance residents' quality of life, a vital aspect in environmental management and sustainable development. Notably, the concept of smart cities extends beyond technology to encompass elements closely connected to people and community [2].

While recent years have seen an increased focus on the computational aspect of the sound environment [3], its importance in the human experience within urban settings is often overlooked. The auditory experience is directly linked to human health and well-being, underscoring the need for attention to this aspect.

Another neglected concern is the impact of traffic vibrations on human health and the environment. Daily commutes via buses, trams, or trains can affect both mental and physical health, with potential damage to nearby buildings due to vibrations. Recognizing that the human body is not naturally equipped to handle vibrations emphasizes the necessity of understanding their impact on human health [4].

Information about the traffic environment is gathered through sensors, essential for any smart infrastructure's ability to monitor and act intelligently. By deploying sensors on public infrastructures such as bridges, roads, and buildings, valuable data is collected for more efficient resource utilization. Real-time monitoring eliminates the need for scheduled inspections, reducing costs. Additionally, road sensors collect essential data for implementing Intelligent Transportation Systems (ITS) [5].

Mobile crowdsensing, an emerging paradigm based on sensors and crowdsourcing, plays a pivotal role in this context. Utilizing sensors in mobile devices enables the acquisition of local geospatial information and the provision of valuable data. Knowledge sharing among users and the broader community forms the basis for mobile crowdsensing [6]. This research paper specifically concentrates on data collected through mobile crowdsensing technology, aiming to establish a model that effectively utilizes vibration and sound data obtained from the environment.

2. Literature review

Numerous scholarly works concentrate on investigating the association between noise exposure and risk factors for disease or mortality. This emphasis is particularly pronounced in the domain of traffic noise, given that vehicular traffic serves as a substantial source of both noise and vibrations. In [7], the researchers are focused on the relationship between long-term exposure to traffic noise and mortality. They are doing a systematic review and meta-analysis of epidemiological evidence for a period between 2000 and 2020. In [8], the researchers focused on road traffic noise and cardiovascular disease risk factors in UK Biobank (a company in the UK). They have proven that exposure to road traffic noise >65 dBA, independent of nitrogen dioxide, was associated with small but adverse changes in blood pressure and cardiovascular biochemistry. In [9], researchers are focusing on finding a connection between accelerated aging and age-related diseases (CVD and Neurological) due to air pollution and traffic noise exposure. They were able to recognize the role of environmental factors (such as air pollution and noise exposure) as crucial determinants of the aging process.

In the study presented in [10], scholars are engaged in the formulation of dynamic traffic noise maps through the integration of noise monitoring data and traffic speed information. The devised approach entails two primary components:

- A model, delineating the interplay between noise levels and traffic speed, is introduced to dynamically update the noise source intensity across the entire road network in response to real-time noise monitoring data.

- Precomputed acoustic attenuation terms are then amalgamated with the updated noise source intensity to generate updated noise maps for the specified regions.

Within the context of [11], the investigators are leveraging traffic sounds, specifically honking events, to enhance the predictive accuracy of traffic noise emanating from vehicles. The road traffic parameters under scrutiny encompass traffic volume, the proportion of heavy vehicles, instances of honking, and the equivalent continuous sound pressure level. The outcomes derived from their analyses are evaluated through metrics such as mean square error, correlation coefficient, coefficient of determination, and accuracy. Notably, the findings reveal that honking stands out as a significant parameter, playing a noteworthy role in the overall composition of traffic noise, particularly in congested traffic conditions prevalent in Indian road networks.

3. A Crowdsensing-Based Framework for Sound and Vibration Data Analysis in Smart Urban Environments

Urban environments are characterized by a complex interplay of sound and vibration, both of which significantly impact the quality of life for inhabitants. To address the challenges associated with urban acoustics and vibrations, we propose a novel framework grounded in crowdsensing technique.

By capitalizing on the ubiquity of mobile devices, our framework integrates seamlessly into the fabric of smart cities, offering a dynamic and real-time approach to data collection and analysis.

3.1. Framework Architecture

The proposed framework comprises four essential components.

3.1.1. Data Acquisition Module

Leveraging the sensors embedded in mobile devices, the framework facilitates the collection of sound and vibration data from diverse urban locations. Users become active participants in the data generation process, contributing valuable insights into the environmental acoustics and vibrations they experience.

3.1.2. Analytical Engine

The collected data undergoes a rigorous analytical process within the framework. Machine learning algorithms and statistical models are employed to decipher patterns, trends, and anomalies in the sound and vibration datasets. This analytical engine serves as the backbone for deriving meaningful conclusions and informing decision-making processes related to urban planning and management.

3.1.3. Visual Mapping Module

This component focuses on translating the analyzed data into visual representations. Through advanced mapping techniques, it provides visual insights into the distribution of sound and vibration levels across different urban zones. Visual mapping enhances the interpretability of data, aiding urban planners and policymakers in identifying specific areas of concern and priority.

3.1.4. Regulatory Compliance Module

This component ensures alignment with existing noise and vibration regulations and standards. It assesses the framework's outputs against established guidelines, providing a regulatory compliance score. This information is valuable for urban planners and policymakers in ensuring that the city's sound and vibration levels adhere to established standards for environmental quality and public health.

3.2. Key Functionalities

Key functionalities of the proposed frameworks are explained below.

3.2.1. Real-Time Monitoring

The framework enables continuous, real-time monitoring of sound and vibration levels in urban environments. This capability allows for immediate responsiveness to emerging trends or unusual events, facilitating proactive interventions in urban management.

3.2.2. Environmental Impact Assessment

By harnessing crowdsensed data, the framework supports comprehensive assessments of the environmental impact of sound and vibration in different urban zones. This functionality aids in identifying potential stressors and formulating targeted strategies for mitigation.

3.2.3. Community Engagement

Incorporating a participatory approach, the framework fosters community engagement by empowering residents to contribute to the collective understanding of urban acoustics and vibrations. This inclusivity enhances the accuracy and depth of the dataset.

3.2.4. Health and Well-being Monitoring

The framework incorporates health-oriented metrics, utilizing sound and vibration data to assess potential impacts on residents' physical and mental well-being. By correlating data with health indicators, it provides valuable insights for public health interventions and policy-making.

3.2.5. Anomaly Detection and Early Warning

Leveraging advanced analytical algorithms, the framework excels in anomaly detection. It can identify unusual patterns or sudden spikes in sound and vibration levels, triggering early warning systems for potential safety or environmental hazards.

3.2.6. Transportation System Optimization

The framework aids in optimizing transportation systems by analyzing the impact of traffic noise and vibrations. Insights derived from the data can inform traffic management strategies, contributing to the development of intelligent transportation systems that minimize noise and enhance overall urban mobility.

3.3. Context and Architecture diagrams

The framework is further explained using the context diagram on the figure below.

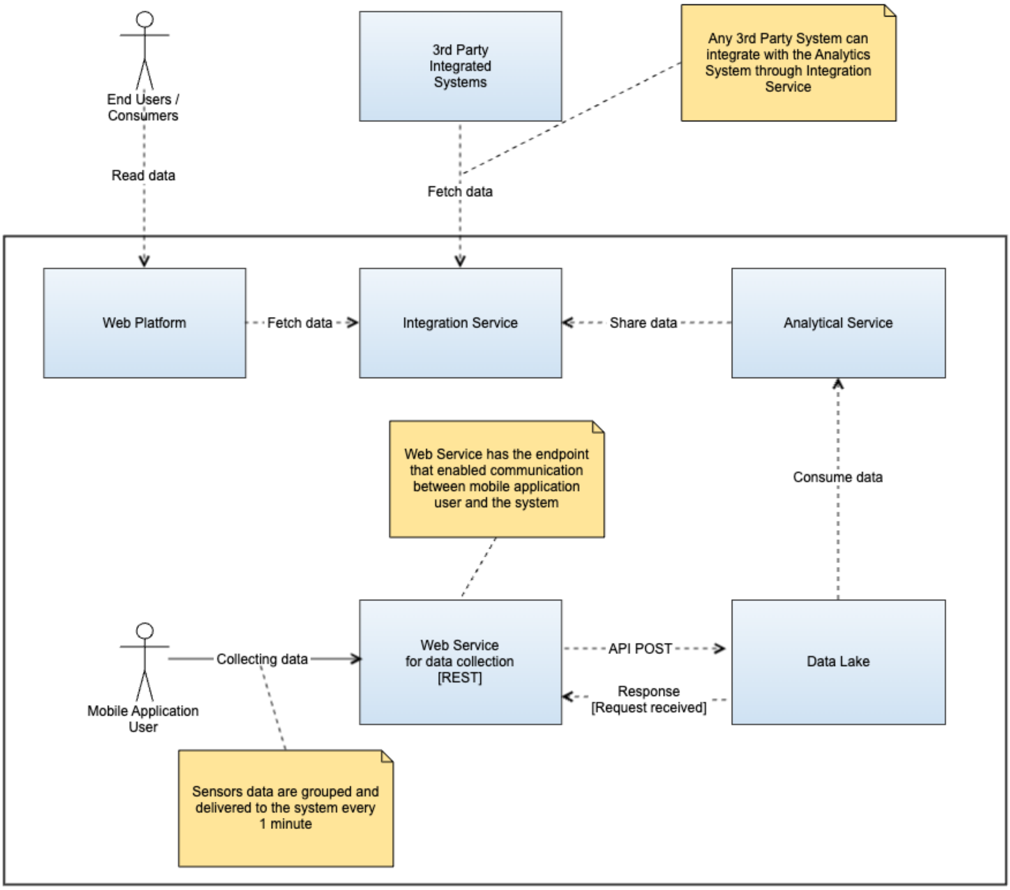

Fig. 1. Context diagram of the proposed framework

On the context diagram, the general idea behind the framework is explained. Mobile users are using they mobile phone sensors to measure noise and vibration levels in the traffic. The data collected with mobile phone sensors are grouped on the mobile device and delivered to the web service for data collection every minute. The data is after that sent to the data lake using POST HTTP method. Analytical service consumes the data from the data lake and process it. It does perform analytical operations on the data from the data lake, like data cleaning, data validation, data processing and data engineering. Data is then stored in a form of raw or conformed/enriched data, which can later be consumed by Integration Service. Integration Service is a layer between Analytical Service and end consumers (Web Platform and Third Party Services). Web Platform is used by end users / consumers to get information about the current state of the noise / vibration levels in the city. Third Party Services can also integrate to this platform and use that data to enrich their services.

The framework components are further explained using the architecture diagram on the figure below.

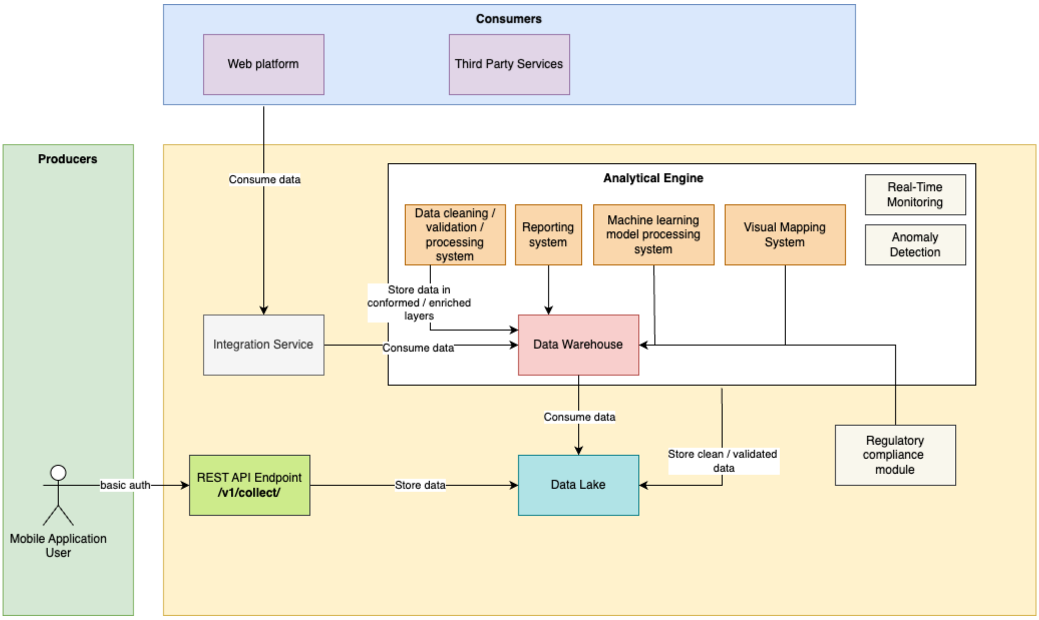

Fig. 2. Architecture diagram of the proposed framework

4. Discussion

In the realm of smart city research, investigations into the analysis of sounds and vibrations have garnered considerable attention. These studies predominantly center on discerning the medical implications of excessive sound and vibration pollution on human health. It is imperative to underscore that beyond the medical dimension, the deleterious effects of surplus sound and vibration extend to environmental harm. Despite a growing awareness of environmental pollution stemming from traffic, current solutions exhibit ample room for enhancement. As clarified in [12], the impact of noise pollution on health within urban landscapes has been a focal point. The researchers propose an application capable of generating noise maps, offering a cost-effective means to manage potential noise pollution. The conventional approach necessitates the installation of reliable noise measuring devices at various locations over an extended period for data collection. Conversely, their application facilitates the creation of noise maps in targeted regions at a significantly reduced cost, alerting users to potential increases in the sound pressure level within urban areas.

In [13], the authors concentrate on employing a crowdsensing-based platform for the monitoring and management of transportation infrastructure in smart cities. Termed an emergent framework, this platform harbors the potential to evolve into an advanced monitoring tool, facilitating the management of infrastructure systems with heightened efficiency and diminished costs in future smart cities. Through this framework, existing infrastructure systems can be broadly assessed to identify key elements exhibiting abnormal behavior, thus obviating the need for detailed on-site monitoring or individual infrastructure inspections. Envisaging a future trajectory, the authors anticipate the platform's transition to an open-source model, accommodating diverse algorithms and data formats.

The envisioned framework posited herein primarily seeks to render information on traffic-related sound and vibration more perceptible and comprehensible to a general audience. This endeavor serves as the foundation for mitigating sound and vibration pollution in smart cities, thereby enhancing the overall comfort of urban living. It is pertinent to acknowledge certain limitations inherent in the proposed model. Foremost among these limitations is the model's exclusive reliance on sound and vibration data, neglecting other potential sources of pollution within the traffic milieu of smart cities.

5. Conclusion

In conclusion, the articulated framework represents a comprehensive and adaptable solution for the nuanced analysis of sound and vibration data within the complex fabric of smart urban environments. By seamlessly integrating diverse components, this framework transcends traditional approaches, offering a holistic approach to data acquisition, analysis, and subsequent decision-making in urban planning and management.

The Data Acquisition Module stands as a testament to the framework's commitment to inclusivity, leveraging mobile devices to transform users into active contributors. This participatory element not only enriches the dataset but fosters a sense of community engagement, aligning with the evolving dynamics of modern urban living.

At the heart of the framework, the Analytical Engine employs cutting-edge machine learning algorithms and statistical models to uncover intricate patterns and trends within the sound and vibration datasets. Beyond providing descriptive insights, the Analytical Engine serves as a proactive tool for decision-makers, offering the capability to identify anomalies and predict future trends.

The Visual Mapping Module introduces a visual dimension to the framework, translating analytical outcomes into spatial representations. This feature aids urban planners in pinpointing specific areas requiring attention and resources, facilitating strategic interventions for sound and vibration management.

Ensuring adherence to established standards, the Regulatory Compliance Module adds a layer of accountability, aiding policymakers in aligning urban soundscapes with existing environmental quality regulations. This not only promotes public health and well-being but also establishes a framework that aligns with broader regulatory frameworks.
The inclusion of a Reporting system serves as a conduit for effective communication, allowing stakeholders to access key findings in real-time. This feature not only streamlines decision-making processes but also enhances the transparency and accessibility of crucial information for various stakeholders.

Beyond being a standalone solution, this framework is designed with interoperability in mind. Its modular structure allows for seamless integration with other services and platforms, fostering a broader ecosystem of smart city applications. As urban environments evolve, this framework offers an adaptable and scalable foundation for easy data acquisition and integration into diverse urban services, contributing to the realization of more intelligent, sustainable, and livable cities.

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