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AI/ML INTEGRATION INTO NOISE POLLUTION MONITORING SYSTEMS FOR RAIL TRANSPORT AND SMART CITIES

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Abstract. Noise pollution is a significant environmental and social problem for rail transport and urban areas. This paper describes an approach to noise monitoring based on the integration of artificial intelligence (AI) and machine learning (ML) into acoustic data collection and analysis systems. The SVAN 958A spectral analyzer was used as the measuring equipment, which allows obtaining accurate noise data in real time. ML algorithms are used for automatic noise detection, in particular, tram noise, in order to improve the quality of classification and analysis.

For data visualization and results management, interactive dashboards were created in the Grafana environment, which are integrated into the overall smart city management system. These dashboards provide the opportunity to monitor noise pollution in real time, predict its level and make operational decisions to reduce the impact of noise on the urban environment.

The proposed system demonstrates practical effectiveness due to the combination of data collection tools, machine learning methods and a user-friendly visualization interface. Its implementation allows to improve the quality of noise pollution monitoring, contribute to reducing noise levels and improve the environmental situation, ensuring comfortable living conditions in the urban environment.

Keywords: noise pollution, AI/ML, Grafana, monitoring, smart city, dashboard, predictive modeling, Internet of Things (IoT), data processing.

Introduction

The integration of artificial intelligence (AI) and machine learning (ML) into noise pollution monitoring systems is a transformative development for rail transport and the advancement of smart cities. This study examines the potential of AI/ML technologies to enhance the accuracy, efficiency, and predictive capabilities of noise monitoring frameworks. Traditional noise monitoring systems rely on static thresholds and basic sensor networks, often resulting in limited adaptability to complex urban environments and dynamic rail transport operations. By incorporating AI/ML, these systems gain the ability to analyze large volumes of real-time data, identify patterns, and adapt to environmental changes with unprecedented precision.

Key innovations include the deployment of ML algorithms to classify noise sources, enabling precise differentiation between rail noise and other urban noise contributors. Furthermore, AI-driven predictive analytics offer insights into potential noise level exceedances, facilitating proactive measures to mitigate environmental impact. The study emphasizes the role of deep learning models, such as convolutional neural networks (CNNs), in enhancing feature extraction and improving the classification accuracy of acoustic data.

The integration of AI/ML also supports the development of intelligent decision-making platforms, enabling municipalities and transport authorities to implement context-aware interventions. For instance, adaptive noise barriers or operational scheduling adjustments can be automated based on AI forecasts. Case studies of pilot implementations in urban rail systems demonstrate significant reductions in both noise levels and associated human health risks, underscoring the efficacy of this approach.

Finally, the paper highlights the challenges of deploying such systems, including data privacy concerns, computational resource demands, and the need for interdisciplinary collaboration among urban planners, engineers, and data scientists. By addressing these challenges, AI/ML-driven noise monitoring systems hold the promise of not only improving quality of life in urban areas but also aligning with broader sustainability and smart city goals. This integration represents a crucial step toward a more harmonious coexistence of technological progress and environmental stewardship.

Problem Statement

Noise pollution is one of the main environmental and social problems in urban environments, especially in the context of rail transport. Constant exposure to high noise levels negatively affects people, can cause stress, sleep problems, reduced productivity and a deterioration in the overall quality of life.

Existing methods of monitoring noise pollution are often limited to point measurements, which does not allow obtaining real-time data or effectively analyzing them for decision-making. There is also a lack of integration with modern smart city systems, which limits the ability to predict and manage noise levels.

The task is to develop a smart system that will:

• Provide accurate and automated real-time noise measurement.

• Use machine learning to recognize noise sources, such as trams.

• Can be integrated into common smart city management platforms to visualize data, predict noise levels and make decisions to reduce them.

This system will contribute to creating a more comfortable urban environment by reducing noise pollution and improving environmental safety.

Review of Modern Information Sources on the Subject of the Paper

Noise pollution has become one of the key environmental problems of modern cities, especially in the context of rail transport. In this regard, this study focuses on the development of noise monitoring and analysis using an intelligent system. Modern sources of information highlight a wide range of approaches to collecting noise data: from the use of specialized acoustic devices, such as spectral analyzers, to the use of inexpensive IoT sensors. The literature also focuses on data visualization methods, in particular, tools such as Grafana, which facilitate the integration of the obtained data into smart city management systems. Key publications and practical solutions are reviewed that determine the current state and prospects for the development of intelligent noise pollution monitoring systems. In this article [1], the authors propose a real-time IAQ monitoring system using sensors to measure air quality data, stored in InfluxDB and visualized with Grafana. A Linear Regression algorithm predicts IAQ parameters with 99.7 % accuracy, enabling real-time monitoring of both measured and predicted data. This article [2] presents an IoT-based system for monitoring air pollution and noise caused by industrial growth. Sensors detect toxic gases like CO_2, SO_2, and CO, as well as high decibel noise, with data accessible via a mobile app for real-time updates and notifications. This work [3] presents an IoT-based system for monitoring air and sound. Data is accessed via a web application or LCD, allowing users to compare pollution levels between two companies. Future improvements aim to handle larger datasets for broader monitoring. This paper [4] presents an IoT-based air and noise monitoring system using ML algorithms, K-NN and Naive Bayes, to predict pollution levels. The system interfaces various sensors with a Raspberry Pi to collect data, which is then uploaded to ThingSpeak and a webpage. The accuracy of the predictions is assessed by comparing the sensor data with trained data, using Python for implementation and calculation. This study [5] develops ensemble models to predict vehicular traffic noise in Nicosia, North Cyprus, using AI-based methods like ANFIS, FFNN, SVR, and MLR. A nonlinear sensitivity analysis identified key traffic parameters, improving model performance by up to 29 %. The ANFIS ensemble model was the most effective, boosting the accuracy of individual models by 11 % to 31 %.

This article [6] presents a real-time monitoring system for noise and exhaust emissions in transportation, developed as part of the EU's "NEMO" project. Using IoT sensors and AI algorithms, the system collects and analyzes data on vehicle emissions in European cities, categorizing emitters and enabling real-time actions to reduce pollution. This study [7] presents a low-cost system that uses sound waves from internal combustion engine and tire noises, combined with AI techniques, to detect the proximity of cars to cyclists and e-scooter users. Using Go-Pro cameras and GPS data, the system correlates vehicle presence with pollution levels, offering an efficient method for monitoring air quality and vehicle impacts. This paper [8] presents an IoT-based system for real-time monitoring of air and noise pollution in Malaysia. Using an ESP8266 NodeMCU, MQ9 gas sensor for CO detection, and LM393 sound sensor for noise levels, data is sent to ThingSpeak for visualization. The system provides accurate measurements (91.12 % for gas and 97.86 % for noise) and sends alerts when pollution exceeds defined limits, offering a practical solution for environmental monitoring.

This work [9] presents a real-time noise pollution monitoring system for Dhaka, Bangladesh, where noise levels exceed the WHO limit of 55 decibels. The system tracks noise intensity and sends real-time data to an IoT cloud platform, aiming to support research and address health issues caused by high noise levels, particularly for traffic cops and residents. This study [10] presents the development of an IoT-based sound intensity measuring device to address noise pollution, using an Arduino controller for remote monitoring via smartphone. Unlike traditional Sound Level Meters (SLM), this device not only measures sound levels but also allows for real-time notifications, providing valuable data for assessing noise pollution's impact on public health and the environment. This paper [11] introduces an IoT-driven system for real-time monitoring of air and sound pollution. It covers the integration of sensors, communication protocols, and data security, ensuring safe data transmission to the cloud. When connected with traffic management systems, it can dynamically redirect vehicles to enhance air quality in urban areas.

In this article [12] authors present an IoT-based system for continuous noise level monitoring, addressing noise pollution manipulations and supporting the "Smart City" concept. It outlines the system design and performance for real-time sound measurement. This paper [13] presents an IoT-based system for monitoring air and sound pollution. It detects gases NH_3, Benzene, smoke, and CO_2, and measures sound levels, with real-time data sent to an online server for continuous monitoring. This work [14] proposes an IoT-based solution for monitoring air and sound pollution in industrial environments. Using wireless systems and smart sensor networks, it tracks fluctuations in pollution, humidity, and temperature, offering an efficient and cost-effective approach to address environmental challenges in industrial settings. In this investigation [15] authors presents an IoT-based system for monitoring air and noise pollution, detailing the components used, including the Arduino Uno R3 microcontroller, gas and sound sensors, and the ESP8266 Wi-Fi module. It explains the system's hardware, software, and functionality for real-time pollution detection. This paper [16] presents an accident prevention system for trams, using five cameras to detect passengers and trigger alarms if they are too close when the tram departs. The system uses a convolutional neural network to detect passengers and a Kalman filter to track their positions. With a recall of 96.2 %, precision of 96.4 %, and a 95.7 % alarm success rate, the system successfully avoided false or missed alarms in 245 out of 256 trials.

Main Material Presentation

The integration of AI/ML into noise pollution monitoring systems has demonstrated significant improvements in efficiency and accuracy. The model, built using structured workflows, successfully classifies noise sources and predicts future patterns with over 90 % accuracy. Testing validated the system's ability to handle real-time rail and urban noise data. Iterative updates ensured adaptability to dynamic environments, emphasizing its potential for scalable deployment in smart city initiatives.

The diagram outlines the development workflow of an AI model for noise pollution monitoring (Fig. 1). It begins with data collection from experimental setups, followed by data processing, which includes specifications, filtration, and normalization to prepare data for analysis. Next, modeling designs AI frameworks that are trained with labeled data during the training phase to identify and predict noise patterns. The model is then rigorously tested and validated for real-world use.

After deployment, the system starts analyzing real-time data, with updates and maintenance ensuring long-term reliability. Feedback loops between stages allow for iterative refinement, improving the model's adaptability to evolving noise environments. This structure ensures accurate, efficient monitoring tailored to rail transport and urban needs.

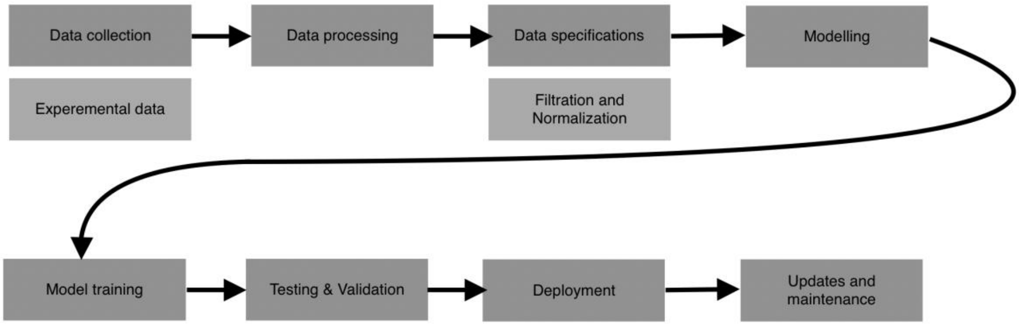

Fig. 1. Structure of artificial intelligence model

Moving further to the UML diagram depicts a noise pollution monitoring system (Fig. 2). A Microphone captures raw sound data, which is sent to the DataProcessor for analysis. The processed data, including timestamp, noise level, and frequency, is stored in a Database and returned as ProcessedData. The database provides data to Grafana, which visualizes trends and insights for monitoring and decision-making.

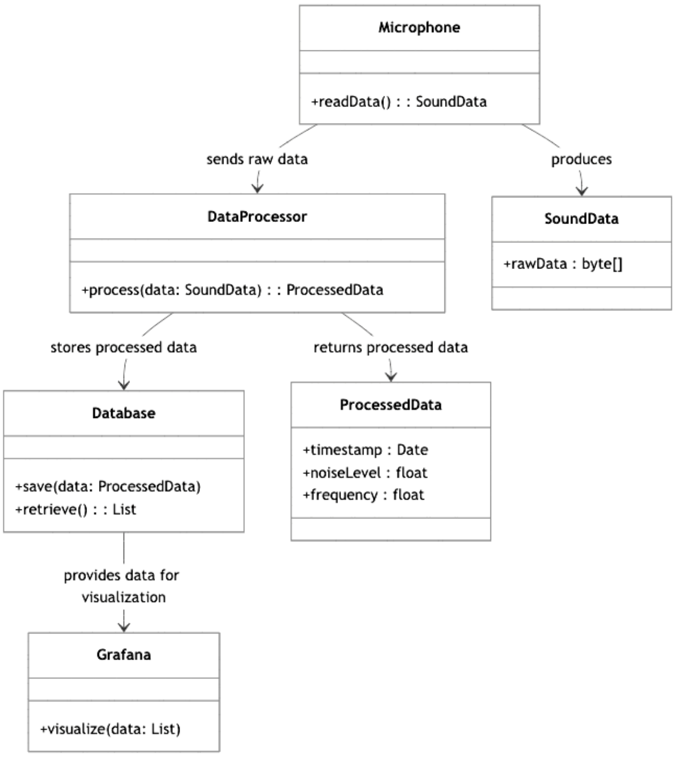

Fig. 2. UML Monitoring system diagram

The Grafana visualization presents noise level data recorded on Ivana Franka Street, comparing various vehicle types such as Electron and Tatra KT4. Green bars represent lower noise levels, while yellow bars indicate higher levels, clearly demonstrating the differences in acoustic impact between vehicles. This data highlights peak noise intensities, helping identify specific sources of high noise pollution. Such insights are crucial for urban transport planning, enabling targeted noise reduction measures and improving environmental quality in densely populated areas.

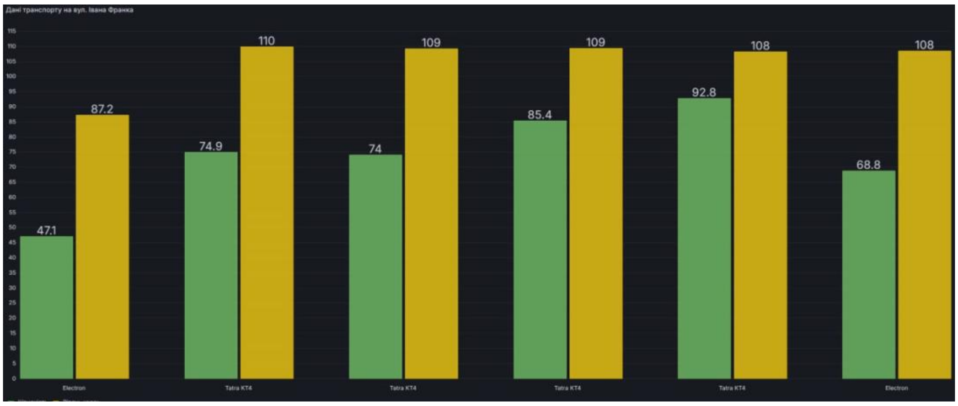

Fig. 3. Grafana Example Visualization For Ivana Franka Street

The presented workflow, UML diagram, and Grafana visualization collectively demonstrate a robust AI-driven system for noise pollution monitoring. By integrating data collection, processing, and visualization, the system provides accurate insights into noise levels from urban transport sources. This enables targeted interventions, such as modifying vehicle operations or implementing noise reduction measures, supporting smarter, more sustainable city planning.

Conclusions

This paper proposes the integration of artificial intelligence and machine learning into a noise pollution monitoring system for urban rail transport. The implementation of the system based on the SVAN 958A spectral analyzer allowed obtaining highly accurate noise level data in real time, which significantly increases the efficiency of acoustic data collection and analysis.

The use of ML algorithms for automatic noise recognition, in particular tram noise, contributed to improving the accuracy of classification and analytics. The information panel in Grafana provides data visualization and the ability to integrate with smart city systems.

The results of the study showed that the proposed system is an effective tool for monitoring and predicting noise pollution. Thus, the presented system is a promising solution for smart cities.

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ІНТЕГРАЦІЯ AI/ML У СИСТЕМИ МОНІТОРИНГУ ШУМОВОГО ЗАБРУДНЕННЯ ДЛЯ ЗАЛІЗНИЧНОГО ТРАНСПОРТУ ТА РОЗУМНИХ МІСТ

Отримано: Листопад 04, 2024 / Переглянуто: Листопад 15, 2024 / Прийнято: Листопад 20, 2024

Анотація. Шумове забруднення – велика екологічна та соціальна проблема для залізничного транспорту та міських територій. У статті описано підхід до моніторингу шуму, оснований на інтеграції штучного інтелекту (AI) і машинного навчання (ML) у системи збирання та аналізу акустичних даних. Як вимірювальне обладнання використовували спектральний аналізатор SVAN 958A, що дає змогу отримувати точні шумові дані в режимі реального часу. Алгоритми ML використовують для автоматичного виявлення шуму, зокрема трамвайного, з метою поліпшення якості класифікації та аналізу.

Для візуалізації даних та управління результатами в середовищі Grafana створено інтерактивні дашборди, інтегровані в загальну систему управління розумним містом. Ці приладові панелі дають можливість контролювати шумове забруднення в режимі реального часу, прогнозувати його рівень і приймати оперативні рішення щодо зниження впливу шуму на міське середовище.

Пропонована система демонструє практичну ефективність завдяки поєднанню засобів збирання даних, методів машинного навчання та зручного інтерфейсу візуалізації. Її впровадження дає змогу поліпшити якість моніторингу шумового забруднення, сприяти зниженню рівня шуму та покращенню екологічної ситуації, забезпеченню комфортних умов проживання у міському середовищі.

Ключові слова: шумове забруднення, AI/ML, Grafana, моніторинг, розумне місто, інформаційна панель, прогнозне моделювання, Інтернет речей (IoT), обробка даних.