NEMO: Internet of Things based Real-time **N**oise and **E**missions **MO**nitoring System for Smart Cities

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***Abstract*—With the advent of ubiquitous sensors and Internet of Things (IoT) applications, research and development initiatives on smart cities are ramping up worldwide. It enables remote monitoring, management, and control of devices and the generation of fresh and actionable insight from huge quantities of real-time data. Real-time noise and emissions monitoring of vehicles remain indispensable in a smart city context. Effective management and control of noise and emissions of vehicles on the road are necessary and possible through analyzing lots of sensor data in real-time to take an actionable insight. To contribute to this, as part of an ongoing effort of the European Union project called "NEMO: Noise and Emissions Monitoring and Radical Mitigation", in this paper, we present the design and development of an IoT-based real-time noise and emissions monitoring system for vehicles in a smart city context. Real-world sensor data of the vehicles in some European cities are collected during the pilot tests. We have developed a complete application for infrastructure managers and analysts to monitor the sensor data related to noise and emissions of vehicles in real-time. The data of the individual road vehicles and trains in selected EU cities and from trains on a track in the Netherlands are collected in the cloud and analyzed with artificial intelligence (AI) algorithms for classification such as high emitter, medium emitter, and normal emitters. We present the development of a complete software solution that can be integrated with existing intelligent transportation systems in smart cities. Finally, we report the initial vehicle classification results from the Rotterdam (Netherlands) pilot test as a representative example for the NEMO monitoring system.**

***Index Terms*—Artificial Intelligence, Internet of Things, Sensors, Smart cities, Noise, Emission, Monitoring system, Real-time.**

I. Introduction

The rapid advancement in sensor technologies has made it possible to sense different events in the environment for varieties of Internet of Things (IoT) applications [1]–[4]. The development of new IoT applications is enabling Smart City initiatives worldwide to seamlessly allow remote monitoring, management, and control of devices, as well as the generation of fresh and actionable insight from huge quantities of real-time data [5]. Vehicle noise and emissions monitoring in real-time is essential in a smart city environment. According to World Health Organization (WHO), noise emissions from road traffic is one of the biggest environmental problems affecting health after air pollution [6]. Noise and emissions from vehicles are regarded as two of the most serious risks to quality of life and health. Indeed, due to population growth, urbanization, and growth linked with automobile use, noise pollution will continue to grow in scale and intensity. Therefore, effective management and control of noise and emissions of vehicles on the road are necessary, which is possible through analyzing lots of sensors data in real-time to take an actionable insight.

There have been several pieces of research in the past to monitor vehicle noise [7]–[14]. Most of these works are confined to either general measurements of road traffic noise in a single city or pass-by noise measurements from a single-vehicle. Some related works such as [8] [10] have successfully studied the vehicle noise emission modelling. However, there is clearly a lack of availability of the data of the real-time measurements of different types of vehicle noise and emission. Due to this, effective modelling and estimation of different types of vehicles' noise and emission are irrecoverable. To contribute to this, as an ongoing effort of the European Union project called "NEMO: Noise and Emissions Monitoring and Radical Mitigation[1]", in this paper, we present the design and development of an IoT based real-time noise and emissions monitoring system for vehicles in a smart city context. Real-world sensor data of different types of vehicles in multiple European countries such as the Netherlands, Austria, Italy, and Spain are being planned for collection during the pilot tests. We have developed a complete application that allows an infrastructure manager and analyst to monitor sensors data relating to vehicle noise and emissions in a real-time. Data from individual road vehicles and trains are collected in the cloud and evaluated using artificial intelligence (AI) algorithms to classify them as high emitters, medium emitters, and normal emitters. We demonstrate the creation of a comprehensive software solution that can be integrated with existing intelligent transportation systems in smart cities.

The rest of this paper is organized as follows. Section II describes the NEMO system model and its data flow. NEMO analytics components are presented in Section III. This section also presents the initial pilot test results from the Rotterdam (Netherlands) site. Finally, the conclusions and future directions are given in Section IV.

II. NEMO:Noise and Emissions Monitoring and Radical Mitigation System Model

The NEMO system model is shown in Fig. 1. Similarly, the flow of the sensors and related data in the NEMO system is shown in Fig. 2. As mentioned earlier, NEMO is an EU-funded project that is creating and testing a completely new remote

[1] https://nemo-cities.eu/

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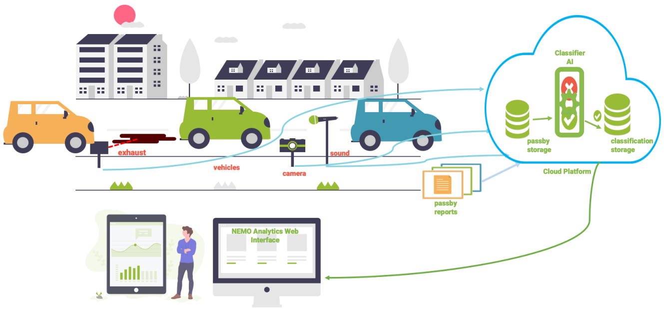


Fig. 1: NEMO Monitoring System Model

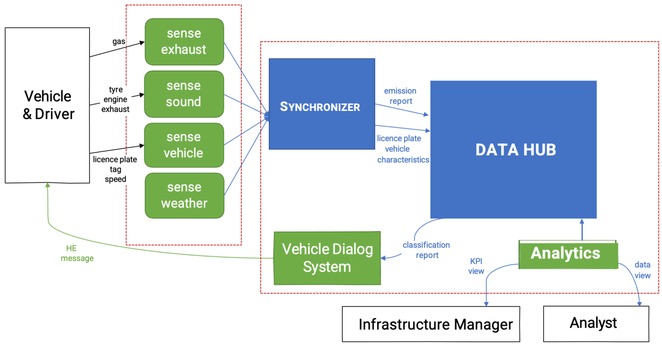


Fig. 2: NEMO Components Dataflow Diagram

sensing technology that can measure noise and emissions from individual road vehicles and trains in real-time, along with the multispectral camera technology to measure emissions from cruise ships. The system aims to limit access or implement a charging system based on the actual environmental impacts of a vehicle. Fig. 1 is self-explanatory. Therefore, we will focus on explaining the data flow model for the NEMO monitoring system model as in Fig. 2.

As shown in Fig. 2, the software infrastructure that integrates remote sensing and data processing to obtain a categorization of a vehicle's noise and emissions has four major components: the Synchronizer, the Data Hub, the Vehicle Dialog System, and the Analytics. The remote sensing technology for noise and exhaust emissions is installed at various locations, such as a tolling station on the roadside or along a railway line. The raw measurement data collected by the numerous sensors is synchronized at each site to obtain accurate information of the vehicle's emission. After synchronizing the raw data, the Synchronizer then consults a vehicle registry database to gather vehicle characteristics related to the classification process, such as fuel type, noise emission type-approval limit, and so on. This information, along with sensor data, is subsequently sent to a centralized cloud platform from the sensing site. The data is sent through a method known as a Pass-by Report. Pass-by Reports are stored in a document database, which is implemented as a PostgreSQL database in our NEMO system. The database has a JSON support. This means that all the Pass-by Reports can be queried based on all the individual attributes in the reports. The Data Hub in the cloud records the Pass-by Report information, resulting in the creation of a complete registration for each vehicle that goes by. The noise and gaseous emissions are classified based on the vehicle features and measurement data. The emissions are then compared to the emissions of similar vehicles, to particular type-approval limitations, or to high-emitting limits (based on type-approval or general emission limits by vehicle type). It then flags the high emitters based on a customizable categorization logic tailored to the location, the road authority, and/or the territory's regulations. The classifications made are also saved in the Data Hub in the cloud. Following classification, the Data Hub notifies the Classification Dialog System, which transmits the classification result back to the remote sensing site and reports the classification result to the vehicle driver or owner. Analytics acts as a data analysis platform for the infrastructure manager and NEMO analyst internal usage to investigate noise and emissions in-depth, enriching the reasoning used to create restrictions for high emitters.

The Data Hub in the cloud provides supports the following sub-processes:

1) Receive incoming Pass-by Reports
2) Store the Pass-by Reports
3) Classify the emission of the individual vehicle pass-by
4) Store the Classification Reports
5) Notify the Classification Dialog System of a new Classification Report
6) Provide a Query Interface for Analytics to access pass-by and classification data

The privacy-related information of the vehicles is removed by pseudonymizing the vehicle registration data.

The classification of vehicles is performed in the Data Hub, and the Classification Report is communicated either to the vehicle/vehicle owner or driver or to the infrastructure manager. The time needed to measure pass-by levels, classify noise levels, and read the license plate to achieve vehicle info is currently estimated to be about 10 seconds. This puts some constraints on the location of a NEMO system if the classification results are needed for immediate action, like defining a tolling fee or access to an environmentally protected zone.

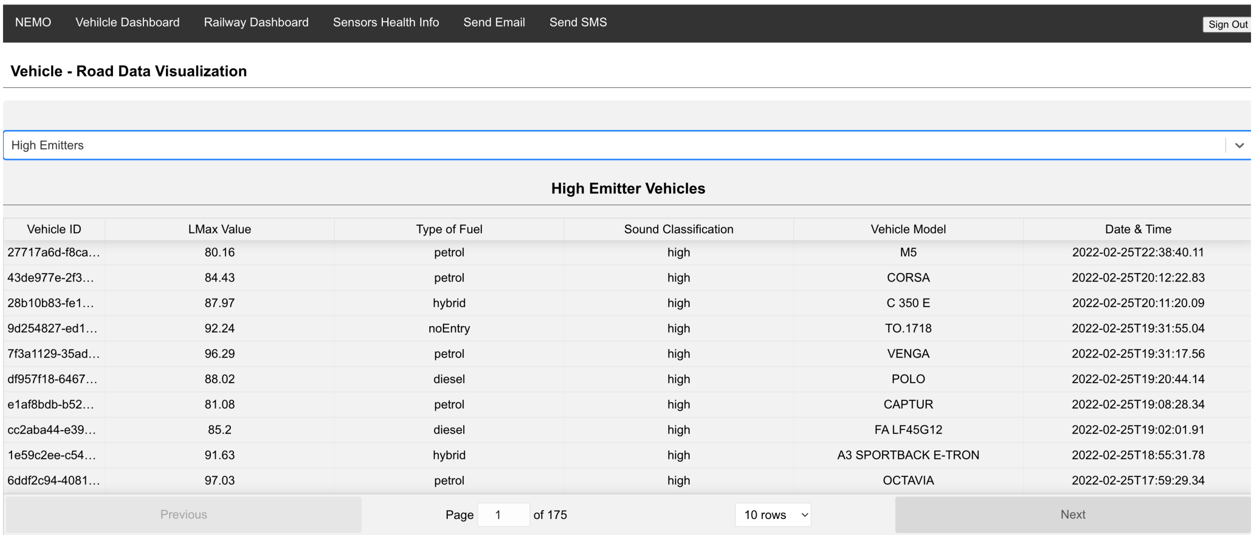
Based on the Classification Dialog System, the different options of a feedback have been laid out:

1) Feedback to the vehicle's on-board unit (OBU)
2) Feedback to the vehicle owner through SMS/Mobile app
3) Feedback to a variable message sign

III. NEMO Graphical User Interface (GUI) - Analytics Component

The results stored in the Data Hub cloud can be queried via the Query Interface module and are made available to the GUI for further analytics. The Query Interface is a Hasura GraphQL[2] interface that provides the specific credentials to be

[2]https://hasura.io/



Vehicle ID	LMax Value	Type of Fuel	Sound Classification	Vehicle Model	Date & Time
27717a6d-f8ca…	80.16	petrol	high	M5	2022-02-25T22:38:40.11
43de977e-2f3…	84.43	petrol	high	CORSA	2022-02-25T20:12:22.83
28b10b83-fe1…	87.97	hybrid	high	C 350 E	2022-02-25T20:11:20.09
9d254827-ed1…	92.24	noEntry	high	TO.1718	2022-02-25T19:31:55.04
7f3a1129-35ad…	96.29	petrol	high	VENGA	2022-02-25T19:31:17.56
df957f18-6467…	88.02	diesel	high	POLO	2022-02-25T19:20:44.14
e1af8bdb-b52…	81.08	petrol	high	CAPTUR	2022-02-25T19:08:28.34
cc2aba44-e39…	85.2	diesel	high	FA LF45G12	2022-02-25T19:02:01.91
1e59c2ee-c54…	91.63	hybrid	high	A3 SPORTBACK E-TRON	2022-02-25T18:55:31.78
6ddf2c94-4081…	97.03	petrol	high	OCTAVIA	2022-02-25T17:59:29.34

Fig. 3: NEMO High Emitter Vehicles Classification Information on Dashboard

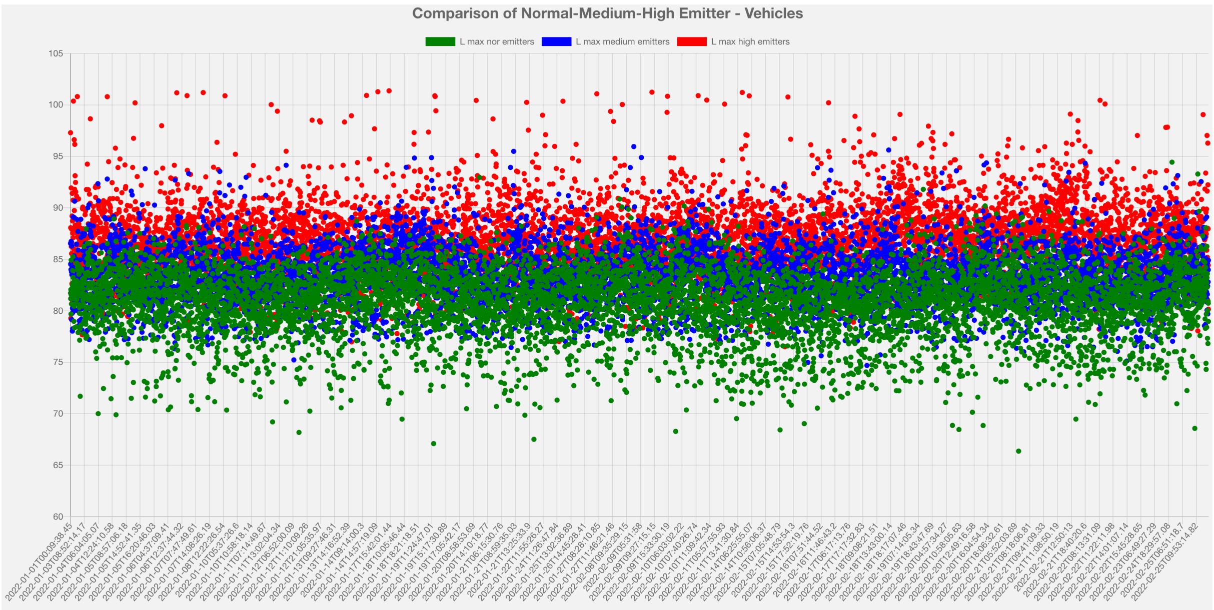


Fig. 4: Comparison of Normal, Medium and High Emitter Vehicles

verified for the analytics module to query and retrieve the pass-by and vehicle's classification data successfully. Therefore, a GUI for displaying the data of the road vehicles from the Data Hub is presented here in this section. The Data Hub uses OAuth.2.0[3] authorization with bearer tokens. The machine-to-machine authentication from Analytics to the query interface is done automatically. We have created and implemented the NEMO analytics dashboard using ReactJS[4]. ReactJs is a popular JavaScript library for building user interfaces. We have created a dashboard with a login page and implemented the protected route to check whether the user is logged in successfully and gained access to the dashboard page. Users are expert and basic NEMO users. The users are created with predefined credentials such as username and password that are validated by the GUI when the user tries to access the dashboard. The expert user is the one who has access to all components of the dashboard with different options for selecting and querying the interface. While the basic user has only access to limited components that have been set up only for displaying the data on the dashboard. The login page checks for the user and password match. The user will be automatically transferred to the dashboard page in case of a match. Further, If the user tries to access the dashboard page without going through the login process, then the user will be redirected to the login page automatically. After successful lo-

[3]https://oauth.net/2/
[4]https://reactjs.org/

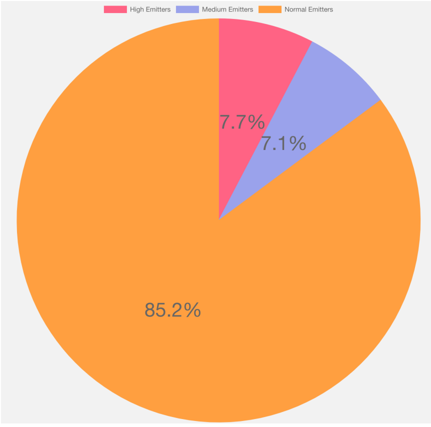


Fig. 5: Vehicles Classification - High, Medium & Low Emitters

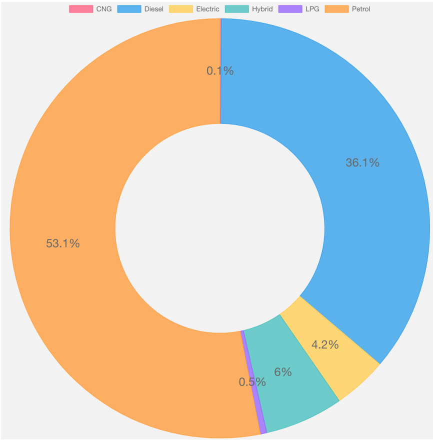


Fig. 6: High Emitter Vehicles Based on Fuel Type

gin, the user can click on Vehicle Dashboard to see the results related to vehicles data. Similarly, the user can also click on Railway Dashboard to see the results related to Train/Railway data. The Expert user can query the Querying Interface with specific parameters of the vehicles to gain knowledge about the High/Medium/Low emitters vehicle classification. The result of the query is returned from the Data Hub, and it is displayed in the form of tables and charts. The GUI also has options for displaying the health of different sensors installed on site, sending emails and SMS to high emitters.

Since NEMO is still an ongoing EU project, at the time of writing this paper, the sensing system for the pilot test has only been set up in Rotterdam (Netherlands), and the corresponding vehicles data are captured in the Data Hub.

In Fig. 3, the high noise emitter vehicles classification results for 25th February 2022 are shown. The NEMO infrastructure manager can sort the data based on ascending or descending order by clicking on the particular column in the table. Similarly, in Fig. 4, we report the comparison of maximum noise level (Lmax) values [15] of the vehicles for high, medium, and normal emitters over the period of 1st January 2022 to 25th February 2022. This information on the dashboard gives an idea regarding the traffic density and Lmax values of the high, medium, and normal emitters over time.

Similarly, in the NEMO analytics dashboard, the infrastructure manager has the option to visualize the information in the form of different charts and graphs. In Fig. 5, the same information from Fig. 4 is displayed in the form of a pie chart. It can be seen that 85.2% of the vehicles were classified as normal emitters, 7.1% were medium emitters, while 7.7% of the vehicles were classified as high emitter vehicles.

In Fig. 6, high emitters vehicle classification based on different fuel types is presented in the doughnut chart for 25th February 2022. It can be seen that 53.1% of high emitter vehicles were of petrol type, 36.1% were of diesel type, 4.2% were electric vehicles and so on. All of this information gives a comprehensive overview of the classification results on the NEMO GUI dashboard. Note that these data are based on a preliminary classification model for noise only and not exhaust emissions. These are not representative of the final classification model in the Data Hub.

IV. Conclusions and Future Works

Vehicle noise and emissions monitoring in real-time is essential in a smart city environment. According to WHO, noise and emissions from vehicles are regarded as one of the most serious risks to quality of life and health in urban areas. In this paper, we present the design and development of an IoT-based real-time noise and emissions monitoring system for vehicles that is being carried out under the European Union project called “NEMO: Noise and Emissions Monitoring and Radical Mitigation.” We presented the developed NEMO system model and its data flow components in detail. We also reported the results of the initial pilot test in Rotterdam that can be viewed from the NEMO GUI dashboard. We presented the development of a complete software solution that has the potential to be integrated with existing intelligent transportation systems in smart cities.

Since this is an ongoing work, the results of the trains still need to be integrated into the dashboard. Tests are being planned in the future, and the data related to trains will be collected in the Data Hub. Also, a pilot test is being scheduled in Teesdorf (Austria), where the communication from the Vehicle Dialog System will be tested with the vehicle’s onboard unit and drivers in real-time. Detailed results of different pilot tests are expected to be presented in future works.

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