DIGITAL APPLICATIONS USING REAL-TIME VEHICLE EXHAUST INFORMATION

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ABSTRACT

Vehicle emission is a major source of air pollution that causes a significant number of deaths globally. It has a profound impact on energy and the environment as well. The existing vehicle emission monitoring system is unable to help mitigating the pollution properly and therefore, requires precise real-time pollution measurement. The purpose of this paper is to discuss novel applications using the real-time measurement of pollutants from a vehicle tailpipe where exhaust gases enter the environment. Today, it is possible to measure such emission due to the emergence of affordable digital technologies such as the Internet of Things (IoT), wireless connectivity, cloud platform, and artificial intelligence.

This paper discusses how digital technologies can be used for real-time monitoring of NOx gas as a measure of vehicle emission and predictive analytics applications. A description of data collection and pre-processing methodologies, actual collected data, and an approach to identify patterns between inputs such as vehicle speed and altitude and output such as NOx emission are included. Applying a simple neural network has produced promising results and is a first step towards developing predictive applications.

Key words: Digital, Vehicle Exhaust, IoT, AI, Predictive Analytics

INTRODUCTION

Air pollution is a health hazard. Its impact on health is beyond imagination. The different organ of the human body is directly affected by air pollution (Kampa and Castanas, 2008). Mobile sources, such as vehicle exhaust, are the significant sources of nitrogen oxides, carbon monoxide, and sulfur dioxide and also one of the significant causes for particulate matter and volatile organic carbon (US EPA Air Emissions Inventories, 2014). As vehicle emission is one of the major sources of air pollution, it is necessary to monitor the concentration of exhaust gases so that it cannot exceed a threshold value.

In recent years, many publications related to real-time vehicle exhaust monitoring using Digital platforms have been reported. Real-time air quality monitoring by mobile sensing (Devarakonda and Sevusu, 2013), real-time traffic emission monitoring (Chi-man Vong, 2013), low-cost environmental monitoring system using Raspberry Pi and Arduino (Deshmukh and Shinde, 2016), IoT model for traffic pollution and noise monitoring (Patil, 2017) are some of the recent publications on IoT based vehicle emission control. But above-mentioned researches were primarily done for ambient air quality. In order to understand the real impact of vehicle exhaust on the surrounding environment, the emission

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measured at the point of the exhaust is needed to correlate the vehicle emission data with ambient air quality correctly. In this paper, the real-time monitoring of NOx and On-board diagnostics (OBD-II) data collection with IoT technology are discussed. One of the primary focus of this paper is to discuss high-value conceptual novel applications that can be implemented by using a digital platform in monitoring real-time vehicle exhaust emission. The paper is organized as follows: an introduction to the digital platform, a description of novel applications data collection, predictive analytics, and conclusion with the recommendation.

DIGITAL PLATFORM

Digitalization or “Digital” means creating new value using data. The use of data requires a few basic components: data generation in a cyber-physical system is primarily provided by IoT platform that converges sensing, processing, and connectivity functionalities; data connectivity that is provided by wireless technology such as 5G; and extraction of intelligence from data that is provided by Artificial Intelligence (AI) technology. The intelligence extraction can happen on a cloud platform with Big Data or within the IoT platform itself. The digital platform has penetrated all spheres of life because of its affordability, technology advancement, and ability to generate exceptional value. Similarly, it is expected that innovative digital applications of vehicle exhaust monitoring can generate significant value.

DESCRIPTION OF APPLICATIONS

1. Next Generation Tollways:

Applications: Real-time vehicle emission monitoring, variable toll, better assessment of environmental impact, feedback to motorists on vehicle emission, the penalty for repeat offenders, etc.

Benefits:

- Better environment
- Improved vehicles fuel efficiency
- Eliminate periodical testing needs

Market channels:

- Toll authorities, Global market

2. Drive-Thru Application:

Applications: Mobile phone message, display to turn-off engine, control intake air, improve drive-thru environment, etc.

Benefits:

- Improve customer experience
- Better environment

3. Air Pollution Alert:

Applications: Real-time vehicle emission monitoring, better assessment of environmental impact, cloud-to-mobile alert applications, Integrated with face mask offerings.

Benefits:

- Companies touting health /environmental products can bundle with alert apps
- Service from municipalities
- Better face masks

4. Connected Automobiles

Applications: Automobiles are fitted with both tail-pipe and air-intake sensors, activate filters of following cars, adjacent cars are communicating exhaust and intake air quality information to each other.

Benefits:

- Intelligent mobility improving environment

5. Traffic Control

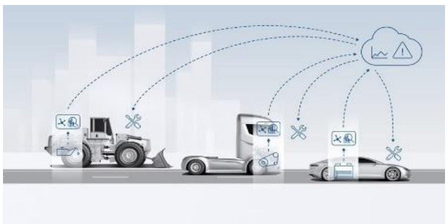
Applications: Emission Monitoring, feed to the traffic control system, vary the flow of traffic to reduce air pollution, etc.

Benefits:

- On-demand traffic control trigger by real-time air pollution
- Saves energy
- Improves overall driving experience. Healthy.
- Reduces time on-road. Improves Productivity.

6. Predictive Maintenance

Applications: Maintenance at fleet and parcel companies, determining a threshold NOx value that indicates that fuel efficiency is decreasing, capturing a pattern between NOx and all inputs using a simple Machine Learning, etc.



Benefits:

- Predicts when maintenance is actually needed
- Keeps vehicle efficiency at a high level which lowers fuel consumption
- impact on the environment and economic benefit

7. Autonomous Vehicle

Applications: Driving vehicles efficiently given traffic conditions, big data applications, inverse reinforcement learning, etc.

Benefits:

- Fuel efficiency
- Environment protection

DATA COLLECTION

Two types of data are collected. NOx emission data measured at the tailpipe of the car. Wi-NOx™ by SensorComm Technologies, Inc.[1] is used for this purpose. An IoT platform is also developed using commercially available off-the-shelf (COTS) components to measure NOx emission. Another is OBD-II[2] data like vehicle speed, throttle position, etc. are measured from OBD-II port via data logger[3,4].

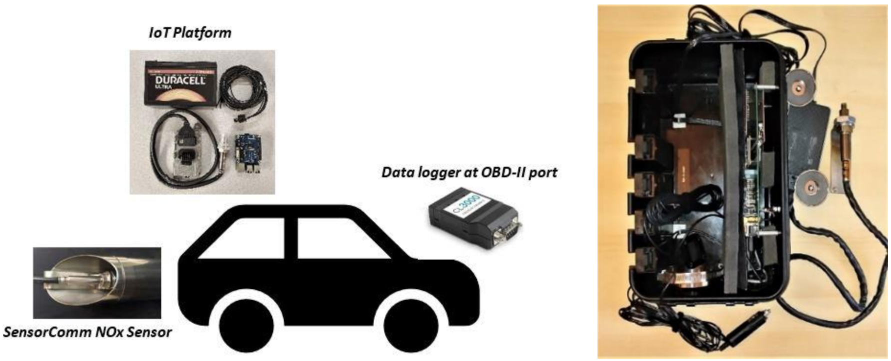


Figure 1: Data Collection Instruments and Wi-NOx™

SensorComm Technology

A real-time IoT based NO_x emissions monitoring system developed by Sensorcomm, known as Wi-NOx™, is installed in the tailpipe of the vehicles and data is stored in the Raspberry Pi as well as in a cloud platform.

Description of the Technology

The main objective of using Wi-NOx™ is to measure NOx concentration. Wi-NOx™ uses the OEM NOx[5] sensor. The NOx sensor is mounted in the tailpipe, where the actual pollution comes in contact with the environment. The NOx produced by the car is measured as a voltage output and connected to a motherboard.

Figure 2: Wi-NOx Sensor Mounted on Tailpipe

The motherboard consists of two parts. One is the Redboard along with the CAN-BUS shield, and the other one is the Raspberry Pi board. Wi-NOx™ has a GPS module that measures location and elevation data. Data is recorded per second frequency. The power cord is connected with the 12V power source of the car. The NOx sensor and the motherboard got power as soon as the car starts. The data is stored as a CSV file in the memory card of Raspberry Pi.

OBD-II Data (CAN-bus logger)

For collecting the OBD-II (On-board diagnostics) data, CAN bus logger was used. The CAN bus logger has built-in Wi-Fi connectivity to transmit the data wirelessly to a PC or mobile phone. It is a plug-n-play logger, which records the data into a 16 GB SD card with real-time clock timestamps. The data can be transferred to a cloud server through Wi-Fi.

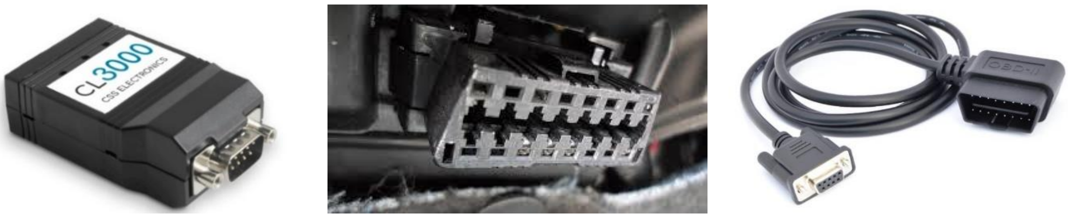


Figure 3: CAN-BUS Logger (CL3000), OBD-II Port and DB9 Adapter Cable

OBD-II Data Collection Process

OBD data consists of vehicle speed, throttle position, mass air flow rate, engine rpm, engine load, etc. can be captured by OBD logger. OBD data is needed for calculating the correlation with the NOx emission in the VEMA project. OBD logger can capture the data from CAN bus through OBD-II port normally found below the steering wheel.

CAN-bus logger software allows us to select the parameter one wants to measure. Before connecting the logger to the car, first, it needs to be connected with the computer, and the configuration file needs to be fixed. Users can select vehicle speed, throttle position, etc. from a list of OBD-II parameters and save the configuration file so that in future when the CAN logger is plugged in the car, it can measure the selected OBD-II parameters.

IoT Platform with COTS

In addition to SensorComm Prototype, an alternate IoT solution is also developed.

Figure 4: IoT Platform

[i] See Endnote in References

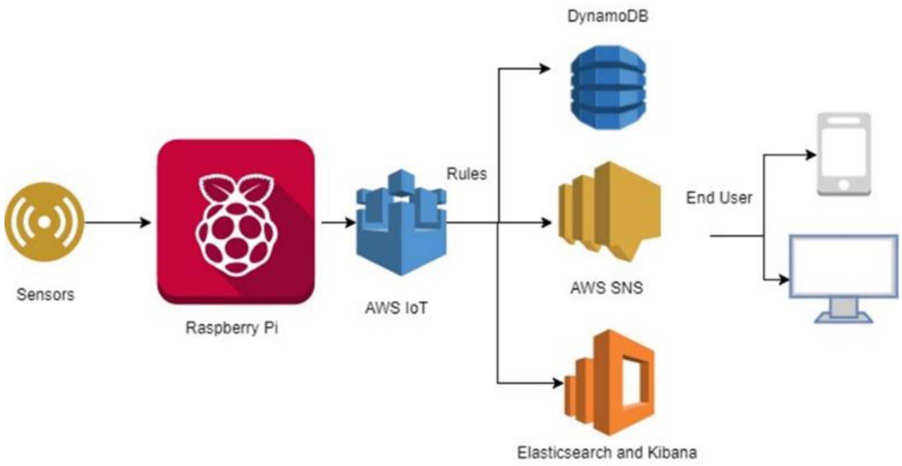


Figure 5: IoT Platform Schematics

Figure 5 shows the overall IoT schematics of the platform with COTS. The sensor will send the data to Raspberry Pi that will go to the cloud e.g. AWS[6] IoT. From AWS IoT, different rules according to the application can set and raw data can be stored in the database like DynamoDB, a notification can be pushed to the mobile user via AWS SNS and analytics and visualization can be done on application software, Elasticsearch, and Kibana. Amazon web service (AWS) were tested with some other sensors.

DATA ANALYSIS AND RESULTS

As part of the research, actual NOx emission data from tailpipe and OBD-II data from CAN-bus of the vehicle were collected that would be necessary to develop predictive applications as described later. The below table shows the type of data that was collected at various locations within the State of Washington, USA.

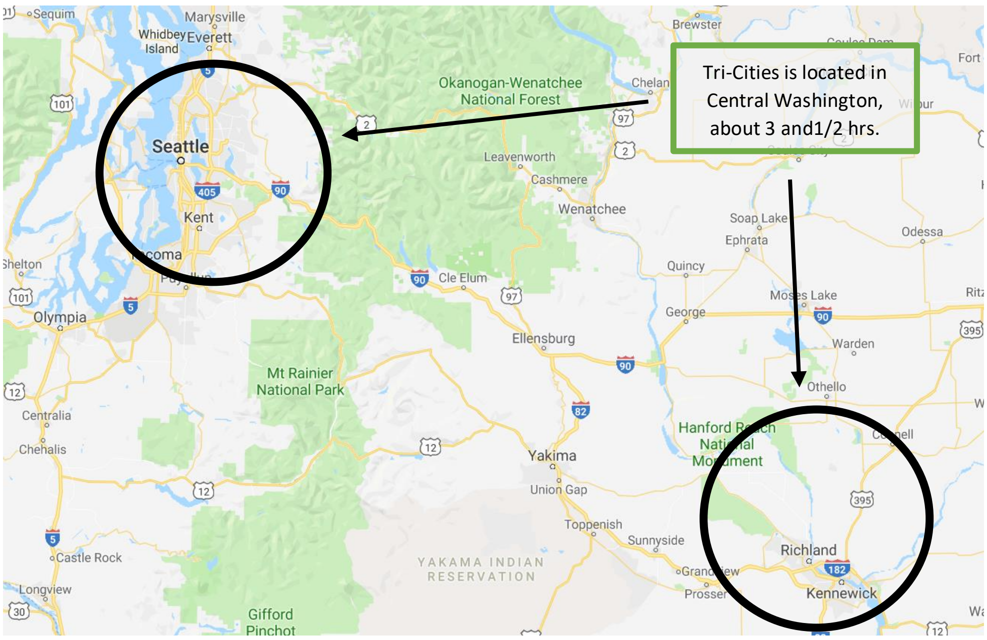


Figure 6: Map Showing Data Collection Areas

Table 1: Data collected in the State of Washington

	Start Point	***End Point***	***Duration (Min)***	***Elevation (feet)***	***Speed (mph)***	***Car Model***
1	Richland	White Pass	120	384 - 4500	35-55 (City) 60 -70 (Highway)	Nissan Sentra 2019
2	White Pass	Mt. Rainier	120	4500 - 5400		
3	Mt. Rainier	Kent	135	5400 - 426		
4	Kent	Burlington	135	426 - 60		
5	Orcas	Moran State Park	40	200 - 2400		
6	Anacortes	North Bend	120	23 - 440		
7	North Bend	Richland	180	440 - 384		

PREDICTIVE APPLICATIONS

Besides novel applications discussed in section Digital Applications, the research focused on predictive applications and how the collected data can be used in developing such applications. Below is a brief introduction of two such predictive applications.

Predictive Maintenance

The general idea of predictive analytics encompasses the implementation of a variety of statistical techniques from data mining, predictive modeling, and machine learning. In predictive analytics, past or present data can be used for future events.

Fleet and transportation companies do the regular maintenance of their vehicles. However, if the maintenance requirement can be predicted accurately, then that may help a fleet company in 2 ways. First, it can pinpoint the time when a vehicle needs maintenance and, thereby, eliminates the need for maintenance when it is not required. On the other hand, by maintaining the vehicle properly means the vehicle continuously perform with high efficiency. Both approaches will lower operating costs, reduce environmental air pollution, and increase a vehicle's life expectancy. All these benefits will contribute to the bottom line of fleet companies considering they own and operate tens of thousands of vehicles. Vehicle emission in terms of NOx is one of the vital indicators of how the car engine is working. NOx emission is closely related to the engine's performance (Naimoli and Schultz, 2017). As nitrogen and oxygen are present in ambient air, they will be found in the air-fuel mixture in the process of combustion in gasoline and diesel engines. NOx is formed during combustion, and it is impossible to make an internal combustion engine without producing NOx (Naimoli and Schultz, 2017).

Therefore, real-time NOx emission monitoring can be helpful for predictive maintenance. The data model that will be helpful for prediction of maintenance requirement will consist of NOx emission as an output, whereas vehicle speed, altitude, as throttle position can serve as input parameters. Other types of data that can be captured as well and may be used in the data model shall include outdoor temperature, vehicle weight, and even tire pressure.

From data analytics, the relation between different input and output data can be established through the Machine learning model like a neural network. From the model, a threshold value of NOx can be determined. This threshold value is selected according to the different car models and environmental conventions. Now, if the NOx emission is crossing the threshold value for a consistent period of time, the vehicle's maintenance needs can be predicted. The maintenance is dependent on real-time pollution and the machine learning model. So, it can be replicated for different cars and situations like weather, road conditions, etc.

In the case of using a neural network, the first step is to capture the pattern between various inputs and NOx emission as an output. In order to obtain such a pattern, input and output data are used in order to train a neural network. A simple approach of training is to predict NOx emission and compare the predicted emission with real values. The error between the actual values and predicted values are fed back through the neural network and adjust the network parameters such as weighting coefficients of connections between neurons within a network. This approach is commonly known as backpropagation. After training the neural network, it is also tested in order to ensure that the input-output model is robust. The testing is done by using a new set of input data and comparing predicted NOx emission with real data.

In this way, Real-time NOx emission monitoring can mitigate environmental pollution, and a considerable amount of money can be saved too.

Autonomous Vehicle Learning as How to Drive Fuel Efficiently

In the case of the Autonomous Vehicle (AV), the idea is very simple. The data collected, as described above with predictive maintenance, can be reused here as well. However, in this case, once the input-output pattern is established, that pattern is inversed to teach the AV as to how to drive efficiently. So, for example, once the initial model or pattern is inversed, then AV can determine what should be the throttle position in order to minimize the NOx emission given the road condition, altitude, outdoor temperature, etc.

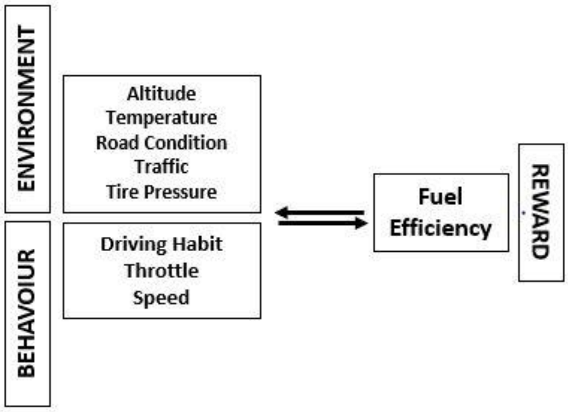


Figure 7: Inverse Reinforcement Learning

In this context, an Inverse reinforcement learning (IRL) can be utilized in improving fuel efficiency based on numerous input conditions. Inverse reinforcement learning (IRL) is a recent development of a machine learning framework (Gonfalonieri, 2018). It can be used to solve the problem of reinforcement learning.

Inverse reinforcement learning can be used to create an inverse relationship, and for specific fuel efficiency and environmental condition, what should be the throttle position can be obtained.

Artificial Neural Network Model Implementation

The key goal in predictive applications is to correlate NOx with other vehicle parameters such as speed and altitude. If such a correlation is established then a tool can compare actual NOx with a threshold value and trigger a service request when such threshold value is exceeded. In the case of autonomous vehicle case, a tool can adjust the speed of the vehicle in order to achieve the desired fuel efficiency as indicated by NOx emission value. This research studies such correlation development using Artificial Neural Network but narrowly and using limited data.

For artificial neural network implementation, python machine learning libraries were used. Spyder was used as an integrated development environment (IDE) with Anaconda distribution. *Keras*, an open-source neural-network library written in Python is used data training and prediction. It is capable of running on top of TensorFlow. A simple schematic of the supervisory ANN is shown in Figure 8.

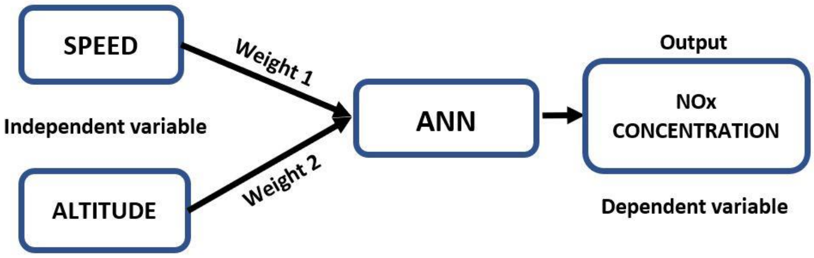


Figure 8: Simple ANN Network

Correlating NOx Concentration with Speed and Elevation

The speed was segmented with an increment of five. The average NOx emission was calculated for every speed segment and plotted. There is a total of seven divisions. The elevation is also segmented, and the corresponding mean NOx concentration is calculated. The graphs are plotted according to the segments. In all seven segments, the mean NOx concentration increased with the increase of altitude.

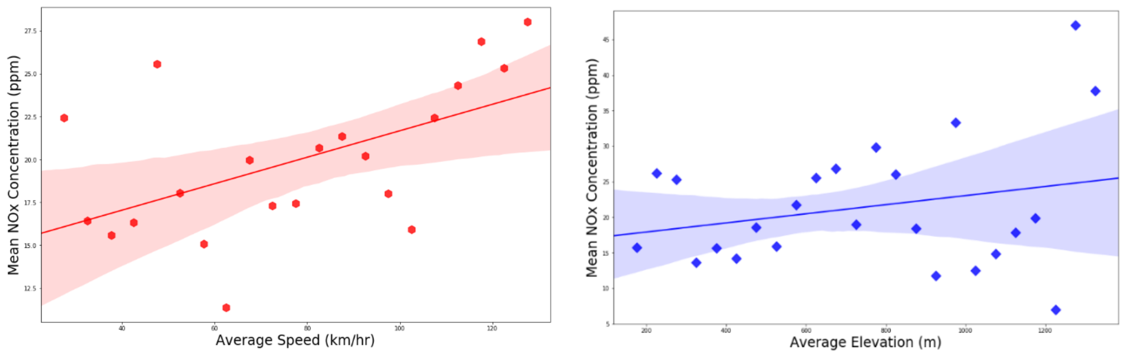


Figure 9: NOx Emission vs. Average Speed/Average Elevation (Richland to White Pass)

CONCLUSION AND RECOMMENDATION

A low-cost method of real-time vehicle emission monitoring has been developed using off-the-shelf products. Vehicle emission data have been collected at various locations within the State of Washington, USA. The use of real-time vehicle emission data can be utilized in a variety of novel applications that can improve the environment and offer economic benefits.

A method of using a simple neural network is presented that can be utilized for predictive applications such as vehicle maintenance while reinforcement learning may be appropriate for teaching an autonomous vehicle as to how to drive fuel efficiently. More data is required along with further research for the development of predictive applications.

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