Pacific Northwest
NATIONAL LABORATORY

PNNL-29189

Vehicle Exhaust Monitoring Applications using IoT platform

September 2019

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

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Final Report

September 23, 2019
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Final Report

Vehicle Exhaust Monitoring Applications using IoT platform
A LDRD project that has been completed
In collaboration with WSU- Tri-Cities.

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PNNL Scientist/Engineer: Richard A. Buractaon/ Md Jan E Alam
WSUTC: Academic Advisor: Prof. Akram Hossain
WSUTC Master's student: Mohammad Fahad Bin Alam

Summary of Project Goals

The primary goals of this project can be stated as follows:

1. Study the importance of Vehicle Emission on Energy and Environment.
2. Develop novel applications based on real-time vehicle emission monitoring.
3. Study, procure, and develop IoT (Internet of Things) platforms for vehicle emission monitoring.
4. Study, develop an approach on how data can be analyzed and selected applications can be implemented.

This 2-year project was launched in collaboration with WSUTC and project scope was included within a Master's thesis at WSUTC.

Major Deliverables at the end of 1st year (FY 2018):

1. A detailed literature study that shows Vehicle emission is a major source of air pollution. A significant number of deaths is associated with air pollution. The existing vehicle emission monitoring system is unable to mitigate the pollution properly. Real-time pollution measurement is necessary to address the problem more precisely.
2. Acquired an off-the-shelf exhaust gas monitoring prototype from a start-up company.

3. The acquired prototype was used to collect some preliminary data in and Richland, WA to understand how this can be used for more data collection in order to studying and developing selected applications.
4. In addition, a low-cost IoT (Internet of Things) platform has been developed that can be used to take samples of various types of pollutants that are present in the exhaust gas. The platform demonstrates that a flexible plug-and-play system is possible to create with readily available commercially-off-the-shelf components (COTS) for monitoring a variety of exhaust gases. The platform can transmit the sensor data using multiple wireless modes such as wi-fi, Bluetooth, or network service.
5. We also have studied a variety of applications that can benefit from real-time monitored vehicle exhaust emission data as part of our goal of creating a roadmap of developing new applications. Below is a list of such applications:

Application 1: Next generation Tollways

- Real time Vehicle Emission Monitoring
- Variable toll.
- Better assessment of environmental impact
- Feedback to motorists on vehicle emission
- Penalty for repeat offenders

Value Proposition:

- Better environment
- Better Vehicles engine efficiency means reducing energy consumptions
- Reduce testing needs
- Market channels: Toll authorities. Global market

Application 2: Real Time Air Pollution Alert

- Real time Vehicle Emission Monitoring
- Better assessment of environmental impact
- Cloud-to-mobile alert applications
- Integrated with face mask offerings

Value Proposition:

- Market channels: Toll authorities. Global market companies touting health /environmental products can bundle with alert apps
- Service from city authorities, department of transportation and municipalities
- Face mask companies

Application 3: Connected automobiles

- Automobiles are fitted with both tail-pipe and air-intake sensors
- Activate filter of following cars
- Cars are communicating exhaust and intake air quality

Value Proposition:

- Connected vehicles autonomously activates appropriate filters thereby improving passengers health.
- Alerting vehicles on emission problems- opportunity to improve engine efficiency, environment, and reducing energy consumptions
- Connected vehicles providing Big Data on the cloud for machine learning and improving overall transportation systems and vehicle design for energy and environment impact.

Application 4: Traffic Alert

- Real Time Vehicle Emission Monitoring
- Feed to live traffic control system
- Vary flow of traffic to reduce air pollution, smog

Value Proposition:

- Transportation department control traffic
- Saves energy, lives
- Improves overall driving experience. Healthy.
- Reduce time on-road. Improves Productivity.

Application 5: Drive-Thru Applications

- Mobile phone message
- Display to turn-off engine
- Control intake air
- Install air-purifying stations surrounding the drive-thrus.

Value Proposition:

- Better customer experience, better environment, energy reduction
- Healthy environment.
- Better assessment of environmental impact
- Feedback to motorists on vehicle emission
- Penalty for repeat offenders

Application 6: Measure vehicle emission in national and state parks

- Install a simple senor when vehicles enters parks
- Pay a fees based on measuring total emission during stay

Value Proposition:

- Healthy environment. Saves parks and wilderness.
- Promotes motorists to use high-efficiency vehicles or EVs
- Data can shed light on potential impact of emission on environment and ecology

At the end of the FY 2018, it was decided to focus on predictive applications using real-time vehicle exhaust gas monitoring. They are listed as below:

Application 7: Predictive analytics for fleet companies or large enterprises

- NOx emission is a measure of fuel efficiency
- Measure NOx along with other vehicle data such as number of miles traveled, profile of vehicle speed, outdoor temperature, types of roads traveled, even tire pressure.
- Capture a pattern between NOx and all inputs using a simple Machine Learning (ML) method.
- Also, determine a threshold NOx value that indicates that fuel efficiency is decreasing.
- Monitor real-time NOx and compare the trend with predicted profile from ML.
- If actual value decreases as compared to predicted vale, then it is about time for maintenance

Value Proposition:

- Predicts when maintenance is actually needed. Therefore, keeps vehicle efficiency at high level which lowers fuel consumption and also helps environment.
- On the other hand, accurate prediction means avoiding unnecessary early maintenance using regular schedule
- The potential impact on environment and economic benefit can be significant since fleet and enterprises own and operate large number of vehicles. Just imagine, if US govt. adapts a policy to use predictive analytics for determining time for maintenance.

Application 8: Predictive analytics for Autonomous Vehicles

- AV needs to be taught as how to drive vehicles efficiently given traffic condition, weather condition, vehicle speed, vehicle types, altitude, number of passengers- given a variety of conditions.
- This is truly a Big Data applications in which a large number of AV or normal cars are driven and all input data are recorded along with NOx emission.
- A ML captures a pattern between NOx and a principal input variable such as vehicle speed given all other boundary conditions.
- The ML is then inversed and the inverse model will predict vehicle speed or throttle position for a desired fuel efficiency or NOx emission value.

Value Proposition:

- Truly a game- changing application that can save money be consuming less fuel and save environment.

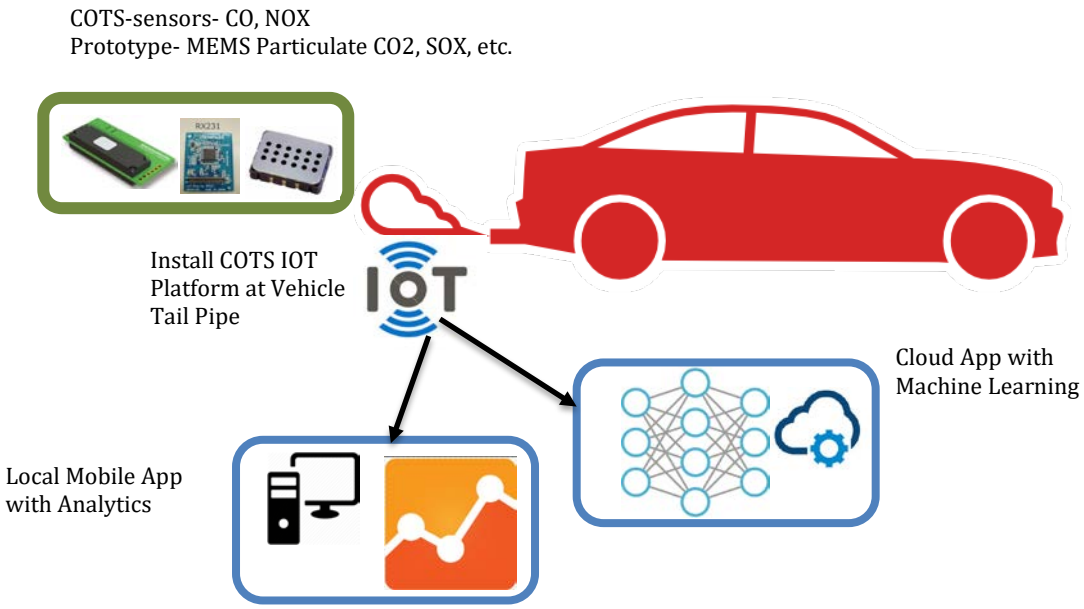
Major Deliverables at the end of 2nd year (FY 2019):

1. A complete methodology was developed as how to collect data using NOx monitoring prototype, engine OBD (On-board Diagnostics Tool), and mobile phone.
2. A total of close to 20 hours of data was collected by driving vehicles between Richland and Pullman and then Richland to Seattle via Mt. Rainier and then continuing to Mt. Constitution in Orcas Island. From there, we returned back to Richland but via Seattle
3. We have developed a simple process of data curation by statistical methods. By such process, raw data is filtered and clustered data is used for final analysis.
4. We have found positive correlation of NOx emission with increase in altitude. That is to say that generally NOx increases or fuel efficiency decreases with increase in altitude while the reverse trend is observed when altitude decreases.

5. A simple supervisory neural network with back-propagation method for training has been used in capturing pattern between NOx emission and average speed.
6. The IoT platform that was developed in the first year was further integrated with a new NOx sensor and tested in order to verify that all components for NOx monitoring can be procured as COTS products and can be assembled easily and affordably.

Additional reports:

1. Annual reports, both for FY 2018 and FY 2019, have been received from WSUTC and uploaded at the LDRD site.



Schematic of VEMA Implementation

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