IoT on the roofs of municipally governed vehicles for air pollution tracking

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Abstract

One of the biggest challenges for the municipal government is dealing with air pollution. According to data furnished by the World Health Organization 9 out of 10 people worldwide breathe polluted air. Smart city infrastructures provide many opportunities to find solutions to a number of tasks, including the task for collecting information on pollution in different parts of the city. We propose an idea to use municipally governed vehicles, such as police cars, busses, trains, garbage collector machines, etc. as carriers of mobile sensors for collecting data for air pollution. A conceptual model and plans for a series of experiments for the feasibility of this idea are proposed.

Keywords

Smart City, Air Pollution, Data Collection

1. Problem

Air pollution continues to be a major health hazard to the public. The World Health Organisation [1] estimated that ambient air pollution caused 4.2 million deaths per year globally due to stroke, heart disease, lung cancer, acute and chronic respiratory diseases. According to data furnished by the World Health Organization 9 out of 10 people worldwide breathe polluted air. Major sources of air pollution from particulate matter include the inefficient use of energy by households, industry, agriculture, deforestation, waste burning. But also, one of the main pollutants is the transport sector.

By the words of Environmental Protection UK [2] "transport is the biggest source of air and noise pollution in the UK. Surface transport for example is responsible for around a quarter of UK emissions of carbon dioxide (CO2) – a major contributor to climate change, and traffic noise blights many neighbourhoods. Air quality in the UK is slowly improving, but many areas still fail to meet national air quality objectives and European limit values for some pollutants – particularly particles and nitrogen dioxide. In town centres and alongside busy roads, motor vehicles are responsible for most local pollution and most environmental noise."

Sofia, the capital city of Bulgaria – usually it is one very beautiful town. With its rich history, big green parks, mountain surroundings, and mostly nice weather, Sofia is a nice place not only for tourists, but also for living. But sometimes Sofia is in the primary

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places in pollution city ranking, according to IQAir [3]. One of the reasons, especially frequent at the beginning of winter, is that Sofia is located in a valley characterized by temperature inversion. This specific natural phenomenon, in combination with several air pollution sources, like combustion, construction industry and transportation, make Sofia not such a beautiful town in such days.

Fig. 1. Air pollution in Sofia in the period 21.11-20.12.2020 according to IQAir.

Currently, around the end of November and beginning of December 2020 (Fig.1), with the peak of 28th November, the city of Sofia was at the first place in air pollution with fine particles 2.5 microns and smaller (PM2.5) in the World.

For these reasons, one of the biggest challenges for the municipal government is dealing with air pollution, and in particular – to manage city transport in an efficient way. The key moment for assuring adequate reactions is obtaining timely and accurate information about traffic pollution in the city.

2. Current state

In European Union (EU) series of directives and guidelines originating from the Air Quality Framework Directive (1996/62/EC) regulate data gathering and validation regarding air quality. Some of the minimum requirements in the legislation regarding reference and equivalent non reference measurement methods were not entirely feasible for scientific and local government purposes. For example, the EU Air Quality Directive 2008/50/EC requires that as a minimum one rural background station is installed every 100 000 km2 for measuring PM2.5 – this minimum was larger than the total surface area of several Member States. Even though that value was corrected to 25 000 sq.km in 2015 [4] that is still not feasible for practical purposes of the municipal governments. For the sheer purpose of decision making, two types of air quality measurement data are being gathered:

- ambient emissions – data generated by monitoring of the air quality in a particular area, for example – a city plaza or a park, etc.
- on-road drive emissions, which determines the on-road emissions of vehicles – data is generated by sensors in close proximity to the transportation infrastructure.

Along with municipal or state-owned air quality measurement networks, recent developments of sensor technologies and data networking concepts such as the Internet of Things (IoT) provided inexpensive means of building private sensor networks for ambient emissions. One of the pioneering projects – World Air Quality Index project [5] began in 2007 and in 2020 aggregates data from more than 30 000 sensing stations in 200 major cities. The leading North American citizen science weather observation program – Citizen Weather Observer Program [6] provides data for air quality with its 7000 (in 2020) sensing stations. One of the analogous initiatives in European Union – Sensor.Community gathers data from 10 700 locations around the world [7].

The on-road drive emissions measurement networks are generally developed by transport administrations or municipal governments. We have no information on citizen science projects existing in that area. Two key aspects are observed in recent years – the first being emergent term of Real-drive emissions (RDE), especially after the 2015 scandal, which referred to the defeat devices installed on some car manufacturers diesel vehicles that aimed to pass the certification tests in laboratory, but emitted tens of times higher NOx emissions in real-world driving. To study and evaluate that phenomenon several methods aimed towards determination of various classes and even particular vehicles emissions were developed. One of the most recent involved using a mobile measurement platform, focused mostly on chemical pollutants, that was mounted on a vehicle that drove along Los Angeles road network [8]. The second key aspect is integration with the Smart City paradigm – in that case the sensor network provides data to various systems that automate key processes in the city. One such example is the Hong Kong remote sensing network that measures tailpipe emissions, speed, acceleration and the license plate number of a vehicle in half a second when it passes by a measurement site; however, complete automation of the measurement is straitened due to the need of recalibration of the sensors in relatively short time intervals (every two hours) [9].

Another trend that emerged in transportation is the implementation of sensors for in-cabin air quality monitoring. They appeared in heavy-duty industrial vehicles (mining, construction and agricultural industries). In the last decade, however, many car manufacturers started implementing sensors that monitor air in the vehicle and control the ventilation system, and even apply additional filtering accordingly [10]. As a result, in any moment in any city there are a number of private mobile sensing platforms.

3. Intentions and viability

Our general intention is to study the possible application of inexpensive vehicle mounted sensors for the purpose of on-road drive emissions data gathering. The motivation for the research is to develop and propose methods and tools that may both extend citizen science effort or to be implemented by the municipal authorities and all parties that have a sizable enough fleet.

We suggest the following key opportunities:

- Larger area of observation compared to the static sensors;
- Computation of characteristics of the air-quality that may be calculated more easily if we have a moving sensor;
- Inexpensive complement to the static sensor networks.

Two key premises are factors for feasibility, considering application of citizen science. Although some restrictions are innate for the technology of the low-cost sensors designed for hobbyists and education, there is substantial progress towards better quality in the last decade. Several researchers have noted and described the closing gap between the latter and the sensors used in the reference methods, especially in certain weather conditions (air humidity below 65%) [11], [12]; some sensors even reached correlation 0.83-0.91 towards the referent monitor. The other premise is development and wide spreading of access to infrastructure services that made development of Internet of Things (IoT) systems possible with a very tiny budget. In addition to the infrastructure, communication controllers at a price of up to 50 Euro are marketed by various vendors.

A key general constraint of using vehicles as mobile platforms is that they emit their own emissions that would noise the data. We suppose that the noise would greatly vary according to vehicle engine technology – the chemical emissions that may be substantial in internal combustion drives will be far less, or completely missing in electrical or hybrid drive vehicles. The goal of this paper is to present a concept for a series of experiments intended to study that noise.

4. Experimentation

Since data error of the sensors vary according to air humidity [13], we may assume that the noise will also vary and boundary conditions may be found at about 65% relative humidity. To check that assumption, a number of iterations of the experiment have to be conducted with different air humidity conditions.

We propose the following values:

- 1-st iteration at values of 15-20% relative humidity of air;
- 2-nd iteration at 50% relative humidity;
- 3-rd iteration at 60-65% relative humidity.

It is practical to find a day of the year in which all those conditions will be available (in temperate climate in the northern hemisphere there are several such days during the late spring and early summer), so that all the experiments will be conducted during only one day.

We set out several requisites for the site of experimentations:

- 2 km long straight road (track).
- Eight stationary sensor stations, mounted at a height 150 centimetres from the ground, at a distance of 250 meters from each other along the runway. The purpose of those is to measure values that will be used as referent without the noise of the vehicles (static sensor stations). Each will contain a relative humidity sensor, and pollutant sensors.
- Three electric cars, one of which is a platform for a measuring station (mobile sensor platform) containing a relative humidity sensor, and pollutant sensors – same as those in the static sensor stations.
- Three cars with internal combustion engines, one of which is a mobile sensor station.

We have designed the following series of experimentation tasks, each of which will be conducted in every iteration:

- *Task 1: To study the noise of own emissions of the test car.* The test vehicle travels the track straight and back (one lap). The mobile sensor platform measurements are analysed and compared with static sensor stations. That task shall be performed for electrical and internal combustion vehicles.
- *Task 2: To investigate the influence on data of vehicle starting and stopping.* The readings in the first five increments of ten seconds after departure are compared against those by a static car. The readings immediately at braking shall be examined against the readings ten seconds after stopping and against the readings in motion.
- *Task 3: To study the measurements data obtained by a mobile sensor platform in a simulation of road environment with electric vehicles only.* A pack of three electric cars is formed, where the mobile sensor platform is in the middle, making one lap of the track (task one).
- *Task 4: To study the measurements obtained by a mobile sensor platform in a noisy mixed environment – electric cars and cars with internal combustion engines.* A pack of five cars – an electric car and an internal combustion engine car in front of the mobile sensor platform and an electric car and an internal combustion engine car behind the mobile sensor platform, making one lap of the track.

5. Conclusion and discussion

The actual experiments are planned for the next year (2021). We have chosen a 2,5 km long former airstrip, located in an area of low housing and agricultural land, at about 5 km away from a big city boundary. The valley in which the runway is located is oriented east-west, with a strong west wind profile. We have an agreement with a company that offers shared use of electric vehicles to provide us with the needed vehicles for the experiments. The company may eventually join as a carrier of sensors if an operational system is developed.

The set of experiments will give a clearer view of the feasibility of the idea of using low-cost air pollutants sensors deployed on vehicles with electrical drive and internal combustion drive. It will assess the noise influence over data obtained by such sensor platforms.

In case of a feasible idea, potential key users of the data are municipal and state authorities, researchers and developers of data analysis and visualisation tools. A key constraint for usage in EU countries is meeting the guidelines for equivalent measurement methods [14].

For the realization of the idea, the 5 layered IoT architecture will be used, including: *Perception Layer* (where sensors and actuators are used to gather useful information), *Network Layer* (responsible for communication between perception and middleware layer in a secure manner), *Middleware Layer* (responsible for such features like storage, computation, processing, action taking capabilities), *Application Layer* (which manages all application processes based on information obtained from middleware layer), and *Business Layer* (including all tasks, connected with the delivering of obtained results to the consumers in appropriate manner) [15].

The application of citizen science would open opportunities for inclusion of private enterprises such as public transportation companies, short rent-a-car and companies with sizable enough fleets. The network will complement the on-road networks, the same way the ambient air-quality networks complement state or municipality owned.

The idea of using vehicles that are on the rule of the municipal government or are in some relationship with the performance of activities related to the work of the municipality have great advantages because the route of these vehicles covers key road arteries for the city. On the other hand, many large cities currently have a well-developed WiFi network in public transport vehicles, which facilitates IoT implementation. Last but not least, a large part of public transport does not use internal combustion engines – trams and trolleys have been around for century, and currently also electric buses are widely used to serve city lines. One of the reasons for the stations at a height of 150 cm in the experiment is to examine the data collection at a height that is on average between the height of the car ceiling and the ceiling of the vehicles, used for serving municipal tasks [16] – city transport vehicles, garbage machines and so on. In addition, electric car sharing services such as Spark as well as city bicycle rentals would also be of interest as a platform.

Although almost all major cities in Europe have ambient air quality measurement networks, in small cities [16] and in the cities of Eastern Europe such kind of structures are still being developed and this may provide a cheap alternative or complementary option.

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