A LOW-COST AIR-POLLUTION MONITOR AND ITS APPLICATION FOR MEASURING VEHICULAR EMISSIONS

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ABSTRACT

A low-cost monitor capable of measuring the quality of ambient air is presented in this study. The monitor utilizes a number of metal dioxide electrochemical sensors to measure the concentration of the most important gaseous air pollutants (i.e., NO, NO_2, SO_2, CO_2 and O_3). A small data acquisition board converts the electric signals from the sensors to concentrations and stores the data on a removable Secure Digital (SD) card for later processing. All the components of the monitor are enclosed in a small durable and watertight yet ultra lightweight and compact casing, making the monitor suitable for unattended field measurements. The whole system costs less than 1,000 EUR, making it a highly attractive solution for distributed online monitoring at the urban environment.

To demonstrate the capabilities of the monitor, we deployed it to determine the emission footprint of the vehicles passing through a small residential road in the city of Mytilene, Greece. In order to probe the air close to the tailpipe of each passing-by vehicle we used an air sampling line running to the middle of the traffic lane. The measurements took place over a period of 24 hours, during which more than 1200 vehicles passed from the sampling point. All sensors showed a good response to the air pollutants emitted from the passing vehicles. Preliminary analysis of the recorded data showed that only a small fraction of the vehicles (ca. 4%) could be classified as high-polluters, while the majority of the fleet (ca. 79%) as moderate polluters. The rest of the fleet was indentified either as non-polluters (bicycles, electric vehicles, etc) or as non-interpretable.

Keywords: Air pollution monitor, on-road measurements, electrochemical gas sensors, vehicular emissions.

1. Introduction

Gaseous and particulate emissions from road vehicles are major sources of air pollution that can cause adverse effects upon human health. It is not a surprise, therefore, that recent studies place vehicular emissions among the top ten risks faced by humans (Krewski, 2009). To mitigate these effects, technological improvements in internal combustion engines such as Gasoline Direct Injection (GDI) and Exhaust Gas Recirculation (EGR) have been implemented during the last decade to reduce gas emissions. These improvements, however, were overwhelmed by the rapid increase in vehicle population worldwide (according to the World bank statistics, the global vehicle registrations surpassed one-billion in 2010). As a result, global CO_2 emissions increased by 9% during the last decade, resulting in the exceedance of 400 ppm in 2015 (Solomon *et al.,* 2011).

Studies carried out in the USA and Europe have shown that a small percentage of the car fleet (ca. 5%) can account for the 40 - 50% of the total air pollution in urban centres (Zhang *et al.*, 1995; Kurniawan and Schmidt-Ott, 2006). These observations drive governments and local authorities in many countries to constantly monitor vehicular fleet and establish regulations for reducing the number of high-emitting vehicles on the streets. However, monitoring the car fleet in large cities systematically can easily become complicated and expensive. Bourgeois *et al.*, (2003) and later Chiesa *et al.*, (2012) proposed networks or arrays of cost-effective fixed monitoring stations to create real-time, high-resolution air pollutant concentration maps.

Here we have built and tested a low-cost monitor for measuring the gaseous emissions of passing vehicles at a stationary point at the side of the road. The monitor uses commercially available solid-state gas sensors manufactured by Alphasense that are compact in size and inexpensive to manufacture and can be produced in arrays to allow sensing of multiple gaseous species simultaneously. The air pollution monitor was used together with a piezoelectric traffic density sensor that recorded each vehicle that passed from the sampling point. We performed 24-hour measurements with the scope to identify the super-polluting passing-by vehicles.

2. Methodology

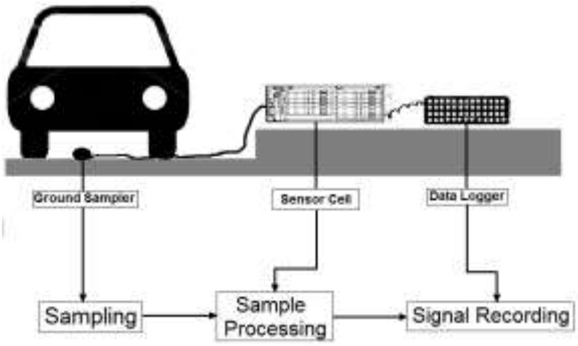

Figure1: Schematic diagram of the measuring system.

The gases emitted from the passing vehicle are sucked by a ground sampler mounted on the road in such a way that it intersects with the vehicle's path. A miniature vacuum pump (Thomas 6/02-4) connected at the end of the sampling line drives the air sample inside the sensing cell at a flow rate of 2.6 lpm. The air sample is delivered to the gas sensor array which includes a nitric dioxide (NO_2) (Alphasense NO2-B4), an ozone (O_3) (Alphasense O3-B4), a nitric oxide (NO) (Alphasense NO-B4), a carbon monoxide (CO) (Alphasense CO-B4) and a sulphur dioxide (SO2) (Alphasense SO2-B4) sensor. The temperature of the monitor is continuously measured by a Platinum Resistance Temperature Detector (RTD) and used to correct the reported concentration measurements. All sensors are connected to an Analogue Front End (AFE) circuit board that performs a first processing of the signals. Figure 1 shows the schematic diagram of the measurement system.

The voltage signals from the AFE are transmitted to a data acquisition board (Arduino Mega) which uses a specially developed algorithm to transform voltage signals to gas concentration readings for each sensor used in this measurement system. Although technological advancements (such as wireless technology) can enable remote storage of the measurements (Hanrahan *et al.*, 2004), for reasons of simplicity we have used a system for storing the measurements locally, in a micro-SD card that provides sufficiently large storage space. A piezoelectric traffic sensor was also deployed to monitor the traffic density at the measuring site in order to link each passing vehicle to changes in gas concentrations (i.e. the emissions signature). The whole system is powered by three 7.4V, 4000mah Lithium Polymer (LiPo) rechargeable batteries – one for the vacuum pump, one for the air quality monitor and one for the traffic sensor.

The measurements took place in the city of Mytilene, Greece. The equipment was deployed in a residential, one-way, single-lane street that was slightly sloped to ensure that the passing vehicles would operate under engine power. A number of high buildings are located at both sides of the street, acting as barriers against the wind, to form a street canyon effect.

3. Results and discussion

During the 24-hour sampling, 1288 vehicles passed from the sampling point. From those, 554 (43%) were passenger cars, 453 (35%) were motorcycles and 281 (22%) were heavy vehicles.

Figure 2 shows time series of the traffic density together with the concentrations of vehicular gaseous emissions from 08:00 to 17:00 during the sampling day. The concentrations of all pollutants follow the traffic density variability quite well. For example, CO concentration increases sharply when the early-morning rush hour peak is observed between 08:30 and 09:00. Interestingly, similarly high concentrations are observed later during the day when the traffic density is low. This can be explained either by the possibility that the vehicles passing by are higher polluters, or by micro-meteorological conditions (mainly the wind direction) that can affect the dilution of the sampled air.

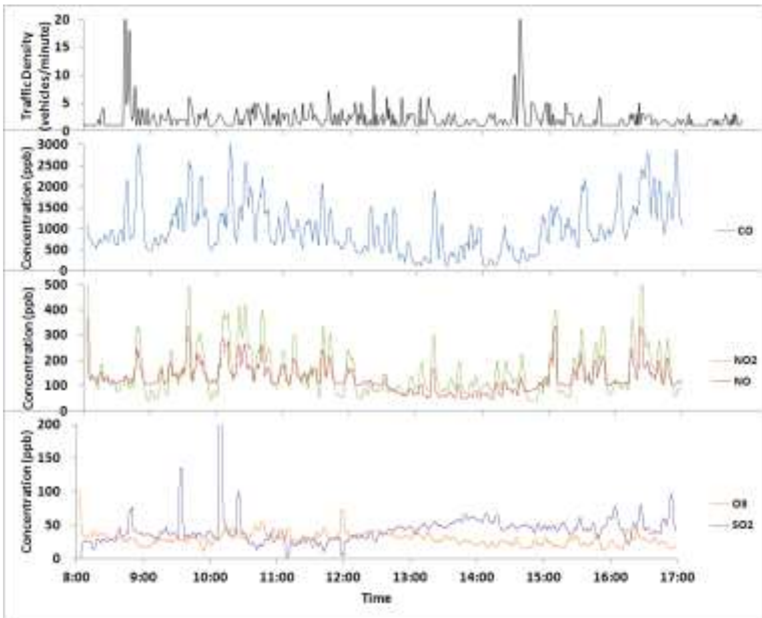

Figure2: Time series of the traffic density (top) and gaseous pollutant concentration during a period of 9 hours.

Figure 3 shows concentration measurements during a 7-minute period when 4 vehicles passed from the sampling point. Vehicle 1 caused a significant increase in CO and NO_x concentrations, while vehicles 2 and 3 that passed only a few seconds apart each other caused a small increase. Although a moderate increase in concentration was observed, because the two vehicles passed by immediately the one after the other we could not easily distinguish what is the contribution of each one to the resulting peak of the concentrations. Finally, vehicle 4 was a motorcycle which caused a negligible increase in the concentration of the measured pollutants.

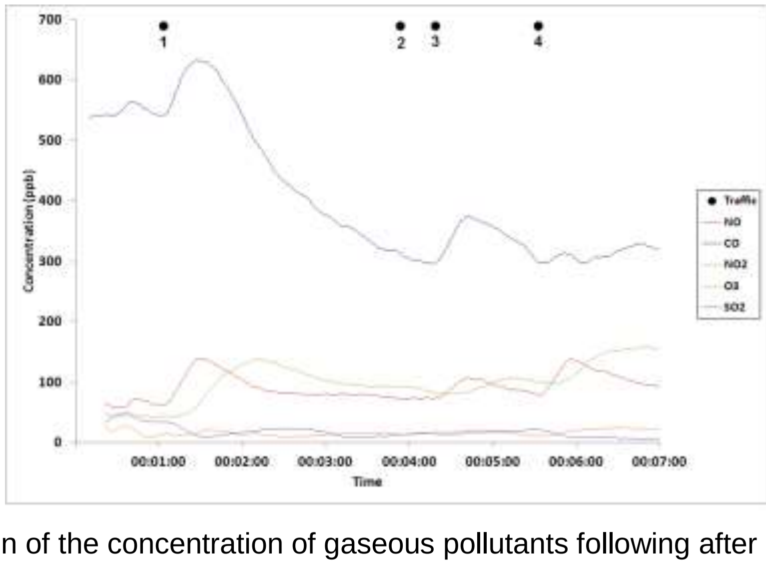

Figure3: Evolution of the concentration of gaseous pollutants following after individual vehicles of different categories passed by.

The vehicles that caused sharp increases in the concentration diagrams, similarly to vehicle 1 discussed above, were categorized as high-polluters, whereas those that had similar behaviour with vehicle 2, 3 and 4 discussed above as moderate polluters. Using this parameterisation we concluded that 57 vehicles (4.4% of the sampled fleet) were high-polluters. The majority of the fleet (1013 vehicles or 78.7% of the sampled fleet) showed a moderate emission profile, similarly to that of vehicles 2, 3 and 4 discussed above. It should be noted here that the emission signature of 218 vehicles (16.9%) was marginal (in many cases below the noise level of the sensors) and therefore could not be classified in any of the categories. These could be erroneous traffic sensor readings (i.e. pedestrians walking on the road due to lack of pavements) and/or non-polluting vehicles such as bicycles or electric powered vehicles.

4. Conclusions

We have built a compact and cost-effective air quality monitor to classify passing vehicles according to their emission signature. The monitor consists of a set of solid-state sensors and a piezoelectric traffic sensor to measure the traffic density. The correlation between traffic density and measured air pollutant concentrations was high, which builds confidence for the application of these monitors for systematic monitoring. The emission footprint of every individual passing vehicle was recorded and analyzed in order to classify them according to their emissions. Although a first classification can be made in this way, other factors (most importantly meteorology that can affect dilution of the sampled gas) need to be taken into account in order to establish guidelines based on which passing vehicles are classified with higher accuracy. Given the facts that there is no real-world vehicular emission pattern available yet, our system can provide a tool for estimating the contribution of passing-by vehicles to atmospheric pollution.

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