Indoor Air Quality Monitoring in Mobility Situations by car around Paris using low-cost technologies : methodology and evaluation of performances compared to standard methods

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1 Introduction

In many industrialized countries, people spend more than one hour a day in their vehicles where particulate matter (PM) could reach high concentrations. The lack of concentration data highlights the need to monitor and control the pollution in such atmospheres. In order to tackle this challenge, attention has been redirected towards low-cost sensing units due to their interesting features such portability, high-frequency operation, fast-deployment and cost. However, while the technical developments of the last few decades have fostered the development of new paradigms, the performance of these emerging and innovative products calls for caution and a better understanding of the metrological limits intrinsic to their technology through field studies. Contrary to fixed-point monitoring situations are emerging (LCSQA 2018), there are currently no studies in the car interior and in real driving conditions where the microsensors performances are considered. The project QABINE 2 (Air Quality in Moving Airs 2) provided the opportunity to compare measurements from low-cost sensors and optical indicators with reference ones in identical environments. Thus, low-cost microsensors' performances evaluation is performed through two in-field campaigns, almost forty different tests.

2 Materials/Methods

Two sampling in-field campaigns were undertaken with a car moving in the Paris area, mainly motorways. The monitoring of $PM_{2.5}$ particulate concentrations was carried out using two measurement techniques: gravimetry as reference method and optical techniques. $PM_{2.5}$ was chosen because this range is covered by most sensors available on the market. Regarding the standard method, $PM_{2.5}$ were collected during nearly forty tests by the cascade impactor PM10 Impactor Dekati® equipped with Quartz Filters (Pall®, 25 mm and Whatman®, 47 mm) at a flow rate of 30 L/min for at minima 3 hours. The weighing values were obtained according to the recommendations of NF ISO 15767 and EN 12341. Then the average particulate mass concentrations and the associated uncertainties for each test performed were evaluated. In parallel, optical indicators (DUST-TRAK, TSI® and Dust Monitor 1.108, Grimm Aerosol Technik®) and three low-cost sensor units were used. In addition to $PM_{2.5}$ measurement information, the sensors also provide minute-by-minute monitoring of temperature, relative humidity and position via GPS.

The two measurement campaigns were carried out in a family crossover-type vehicle during urban journeys in and around Paris. The locations of the indoor air sampling and measurement points were selected to allow the evaluation of an exposure measurement and are based on the experience gained during a previous study (INERIS 2017).

3 Results and Discussion

During the first measurement campaign, 19 $PM_{2.5}$ samples were taken in car interiors and in urban mobility situations over an average period of 3.02(±0.15) hours. Following the recommendations of the NF ISO 15767 standard, nine gravimetric tests are compliant with the quantification limit experimentally determined at 23.9µg. The subsequent average gravimetric concentrations are confronted to those provided by the optical methods. While the results show significant differences in the mean values, the values of Student's set of statistics seem to validate the hypotheses of linearity between the variables ($p < 0.05$) as illustrated in Figure 1.

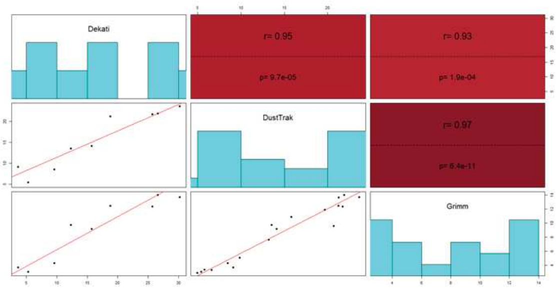

Figure 1: Correlation matrix for the comparison of values obtained by gravimetry (Dekati) with values obtained by optical methods (DustTrak and Grimm).

The high values for the correlation coefficients ($r > 0.93$) then lead to believe that the biases observed between the reference values and those from the optical meters are indeed due to the calculation assumptions, particularly on density, taken by default. Thus, the optical indicators can be used to have a better representation of the temporal variability of $PM_{2.5}$ in the interior of the car.

For the second campaign, the average sampling time has been extended to 5.75(± 0.13) hours. Eight tests were carried out with the gravimetric sampler, the optical indicators and the low-cost sensing units. Once again, optical methods strongly underestimate the $PM_{2.5}$ values. For optical meters, the DustTrak again shows a mean value (11.25 ± 3.83 µg/m^3) closer to the reference value (20.57 ± 5.83 µg/m^3) than the Grimm (5.13 ± 1.89 µg/m^3). The sensor values are close to each other (1.88 ± 0.59 µg/m^3; 2.33 ± 0.84 µg/m^3; 2.33 ± 0.44 µg/m^3) but completely wrong with respect to the reference value (20.57 ± 5.83 µg/m^3).

In a similar way to Campaign 1, a correlation matrix was produced from the average values obtained by each piece of equipment and for each of the trials of the second campaign. The reading of this matrix led to the rejection of Sensor #3 due to a too low statistical significance during the confrontation. For the other equipment combinations, the linearity hypotheses are statistically significant. The comparison with the gravimetric values leads for Sensor #1 and Sensor #2 to identical correlation coefficients ($r = 0.74$) and slightly higher for the DustTrak and the Grimm.

4 Conclusion

The protocol used is the first to propose to compare data from gravimetric measurements, low-cost micro-sensors and optical indicators in a car cabin and in a mobile situation. The comparison of the results shows a linear relationship between the different methods. Although micro-sensors may subsequently be relevant to track the motorists' exposure dynamics if calibration specific to the conditions of deployment is provided for, their use to quantify the exposure levels of motorists is currently impossible.

The consistency of the data provided by micro-sensors and optical indicators shows that the latter can help to understand and improve the performances of low-cost devices, notably on issues of long-term drifts or biases due to temperature or humidity.

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