

Low cost air pollution sensors: New perspectives for the measurement of individual exposure?

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1. Introduction

Air pollution is a major environmental issue in urban areas. Chronic and high concentration exposure presents a health risk with cardiovascular and respiratory problems and longer term nervous, carcinogenic and endocrine problems (Kampa et Castanas, 2008). Air quality is a major source of concern for European citizens (European Commission, 2010), who feel strongly exposed to the outside and to a lesser extent in environments interiors (Grange *et al.*, 2010 and 2012).

Exposure to air pollution is estimated on daily basis and broadcasted by state and local air quality agencies. These estimates are based on simulations of both background and regional pollution and of the pollution induced by the traffic. Models use point data of outdoor hourly pollutant concentrations from fixed stations of air quality monitoring networks (Chow *et al.*, 2002; Jeannée *et al.*, 2006). However this estimated air pollution data reflects the exposure of a regional population, and not the exposure of each individual, that depends on their activities and environments at much finer spatial and time scales (Ambroise *et al.*, 2005). Nor does it reflect the high variability of pollution at these fine scales, according to the proximity of emission sources and the urban morphology outside (Duché, 2013).

To approach this pollution by individuals, two approaches are generally adopted in the literature:

- The first approach focusses on the exposure of a particular group of individuals, such as children or cyclists (Ashmore and Dimitroulopoulou, 2009; Boogaard *et al.*, 2009; Edwards *et al.*, 2001; Jarjour *et al.*, 2013). The method consists in having the concerned public wear sensors during one of their activities or during their day. These measurement campaigns spread from a few days to a few weeks and use passive sensors (omitting the time dimension) or active sensors (until recently too large and / or expensive to be able to carry out regular measurements on a long time);
- The second approach targets the micro-environments or areas frequented at a local scale (workplace, schools, different modes of transport) (Almeida *et al.*, 2011; Kaur and Nieuwenhuijsen, 2009; Goodman *et al.*, 2007; Briggs *et al.*, 2009). In that case, the method used to estimate the pollution is indirect and consists in monitoring the levels of pollutants in the environments frequented by a group of individuals. The pollution experienced by the individuals can then be estimated by crossing these measurements with information regarding their mobility and activities in each frequented areas (Steinle *et al.*, 2013).

The emergence of citizen science and the progress of miniaturized electronics, low-cost and accessible to (almost) everyone, offers new opportunities for the monitoring of air pollution, particularly within a participatory framework. In this communication, we will focus on the relevance and usefulness of such sensors from a scientific point of view. In other words, can they allow us to gain a more detailed knowledge of individual exposure and spatial variability in particle concentrations?

2. Participatory projects of citizen sensors for the monitoring of air pollution

In this section, we briefly review some recent projects involving low cost, miniaturized and portable sensors, combining smartphones and GPS. Tables 1 and 2 list several of such projects.

Two major large-scale participatory projects began in 2011 (Table 1). They bring together enthusiasts, engineers and researchers with the common objective of assessing individual exposure to pollution by using low cost sensors. In particular, the goal is to make these individual measurements of concentrations of pollutants available to a large community through a large database of open and global data. The *AirCasting project*, initiated in New York, focuses on the measurement of outdoor pollution during transportation. For this, two sensors were created: *Aircasting* in 2013, measuring nitrogen dioxide and carbon monoxide, and *AirBEAM* in 2014, measuring fine particles. The *AirQualityEgg project*, gathering hobbyists from New York and the Netherlands, aims at measuring indoor air pollution, such as nitrogen and carbon monoxide. Other projects have emerged, such as the '*Citoyens Capteurs*' project in France or *SafeCast* in Japan. All these projects rely on the philosophy of open access to information. The mounting instructions, codes to query the sensors and the measured data are therefore easily accessible.

The scientific interest for these participatory projects is mainly based on the new opportunities they bring to improve the knowledge of the variability of pollutants on a fine spatial and temporal resolution (one meter and one minute) and to get large databases from citizen volunteers. Several research projects (Table 2) are pointing

in this direction: *MESSAGE* between 2006 and 2009 in UK, *CommonSense* between 2008 and 2010 in California (Willet *et al.*, 2010), *CitiSense* since 2010 in California (Bales *et al.*, 2014), *Citi-Sense-MOB* since 2013, a Norwegian project in collaboration with *CITI-SENSE*, a project funded by the European Union (Castell *et al.*, 2015), *GasMobile*, a Swiss project (Hasenfratz *et al.*, 2012). All these research works currently use gaseous pollutant sensors because they are smaller, more documented and accessible than particle sensors. In the *AirProbe International Challenge project* (APIC), European researchers have simultaneously launched a competition in Antwerp (Belgium), in Kassel (Germany), in London (UK) and Torino (Italy) in which participants are asked to work either on the sensor or on data visualization. They are studying the measurements and perceptions of participants (Sirbu *et al.*, 2015).

	Countries	Years	Pollutants and meteorological sensors	References
AirCasting	USA (NYC)	2011- ...	Nitrogen dioxide Carbon monoxide Particles Humidity and temperature	aircasting.org Blog : www.takingspace.org
AirQualityEgg	USA Netherlands	2012- ...	Nitrogen dioxide Carbon monoxide Humidity and temperature	airqualityegg.com Wiki : airqualityegg.wikispaces.com
Citoyens Capteurs / Citizen Air	France (Paris)	2012- 2014	Nitrogen dioxide Carbon monoxide	www.citoyenscapteurs.net hackens.org/projets/citizenair

Tab. 1 Some participatory project on air quality.

	Countries	Years	Pollutants and meteorological sensors	References
Citi-Sense-Mob (in collaboration with CITISENSE, a project funded by the European Union)	Norway	2013- ...	Gaseous pollutants : nitrogen dioxide, nitrogen monoxide, carbon monoxide, ozone, sulphur dioxide	Castell <i>et al.</i> , 2015
CitiSense	USA (San Diego)	2010- ...	Nitrogen monoxide, carbon monoxide	Bales <i>et al.</i> , 2014
CommonSense	USA (Californie)	2008- 2010	Nitrogen monoxide, carbon monoxide	Willet <i>et al.</i> , 2010
MESSAGE	UK	2006- 2009	Nitrogen monoxide, carbon monoxide	bioinf.ncl.ac.uk/message/
AirProbe International Challenge	Belgium (Antwerp), Germany (Kassel), UK (London) et Italy (Torino)	2013- ...	Black carbon	cs.everyaware.eu/event/airprobe Sirbu <i>et al.</i> , 2015

Tab. 2 Some research projects using low cost air quality sensors.

3. Test of particle sensors: the Shinyei PPD42NS and the Sharp GP2Y10

After a review of the available low-cost sensors (<http://www.howmuchsnow.com/arduino/airquality/grovedust/>, <http://www.takingspace.org/>, Budde *et al.*, 2014), we chose to test two sensors: the Shinyei PPD42NS and the Sharp GP2Y10. They measure fine particles of an aerodynamic size of between 1 micron to 2.5 microns, cost about 10 € and have a small size (Fig. 1).

The detection of the particles suspended in air is done optically by monitoring the light of an infrared LED scattered towards a photodetector. The pulsed signal is reflected by an occupancy time at low voltage (Pulse Occupancy time - LPO), corresponding to the concentration of particles per volume unit (Fig. 2).

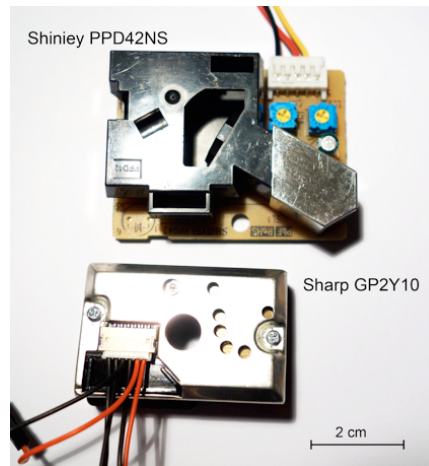


Fig. 1 Photography of the Sharp GP2Y10 and the Shinyei PPD42NS particle sensors.

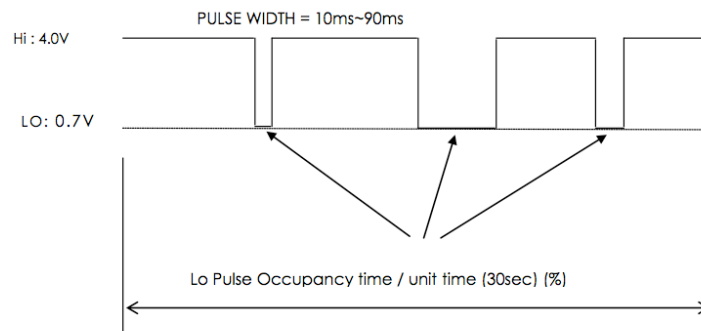


Fig. 2 Schematic of the low voltage occupation time principle (LPO), source: documentation Shinyei PPD42NS.

We tested the two sensors on the inside with a temperature around 19°C and relative humidity (48%) stable over the measurement time. Taking into account the work by Holstius *et al.* (2014), we placed the Shinyei PPD42NS sensor in position upright and away from a light source by putting it in a box. We put our sensors under the same conditions. In order to calibrate the levels of particles from low cost sensors, signal levels were compared to the portable analyzer Dustmate from Turkey Instruments, using another measurement method, the laser nephelometer, and to measure individual exposure (Soubise *et al.*, 2008). The data were plotted on the same graph, and the minimum and maximum scales are adjusted to 0.1 * minimum concentration and 0.1 * maximum concentration to allow for a better comparison (see i.e. Fig. 3). In the results presented here, we forced particulate emissions by burning a piece of paper, in order to test the responsiveness of the sensors.

4. Results

Figure 3 shows the evolution of particulate levels measured simultaneously by the Shinyei and by Dustmate with a time interval of one minute in calm conditions (up to measurement 87) then in a forced situation. Both curves have the same allure. The observed peak, due to a significant release of particles is shifted by 2 minutes for the Shinyei sensor compared to the Dustmate (reference). During the calm period of time, particle levels measured by the Dustmate are between 8 $\mu\text{g}/\text{m}^3$ and 27 $\mu\text{g}/\text{m}^3$ with two plateaus: the first one characterized by relatively low levels, far from any air movements and the second with larger levels with air movement forcing particles into suspension (Fig. 4). The levels measured by the Shinyei follow this trend, but they are much more variable.

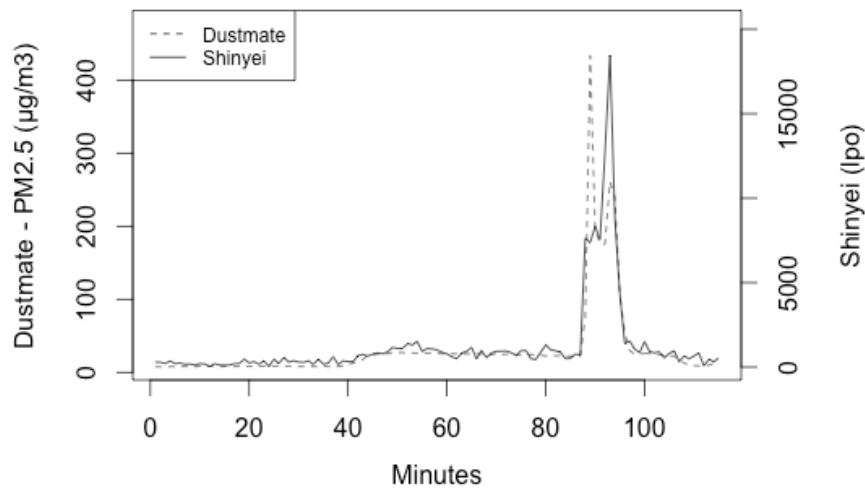


Fig. 3 Comparison between the Shinyei PPD42NS sensor and the certified Dustmate sensor under calm and forced conditions.

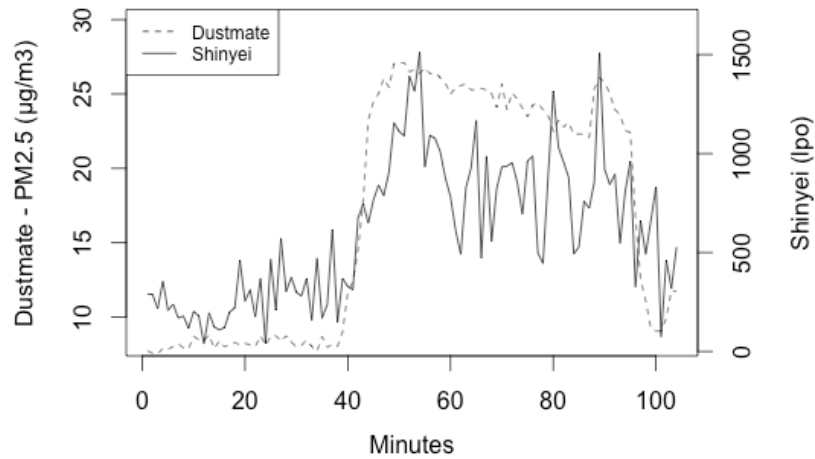


Fig. 4 Comparison between the Shinyei PPD42NS sensor and certified sensor under calm conditions.

Figure 5 shows the levels of particles measured simultaneously by the Sharp and the Dustmate sensors with a time interval of one minute in calm conditions and in forced conditions. The peak of particles between the 180th and 200th measurement is similar for both sensors. Under cam conditions, both curves decrease both from the 1st to the 160th minutes, which is explained by a lack of air movement (no presence in the room during these minutes). The levels measured by the Sharp display a lot of noise compared to the Dustmate.

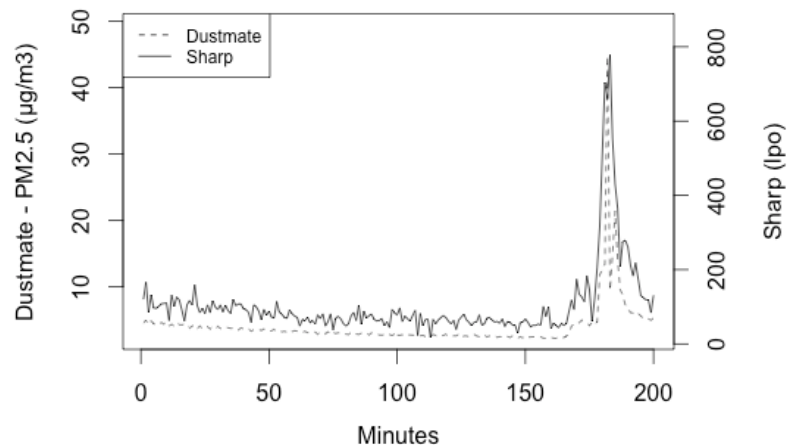


Fig. 5 Comparison between the Sharp GP2Y10 sensor and the certified Dustmate sensor under calm and forced conditions.

The results are thus quite conclusive for both low cost sensors, with an evolution similar to that measured by the Dustmate sensor. The correlation of the measurements with the certified sensor is higher for the Shinyei ($r = 0.83$) than for the Sharp ($r = 0.74$). In general, the results are encouraging and we are currently testing a larger number of sensors (a dozen) in order to evaluate their reliability. Preliminary tests outdoor have been performed in Paris and Grenoble and show promising results (Figure 6) with a larger concentration of particles in the main roads with a lot of traffic.

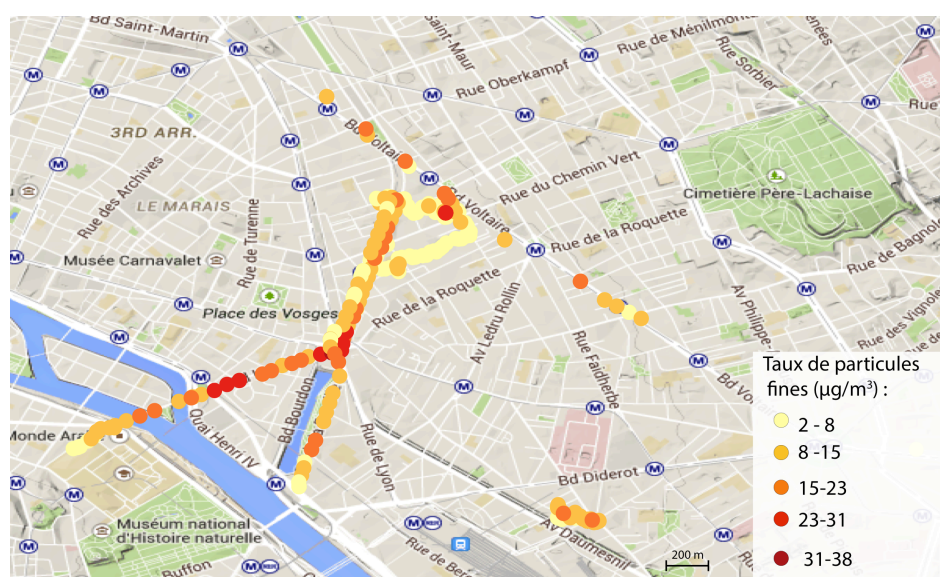


Fig. 6 Fine particle measurements recorded during a bicycle trip on the 22nd and 23rd of March 2013 in Paris.

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