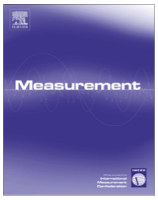
ARTICLE IN PRESS

Measurement xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement



Emerging miniaturized technologies for airborne particulate matter pervasive monitoring

Marco Carminati *, Giorgio Ferrari, Marco Sampietro

Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, 20133 Milano, Italy

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Air quality
Dust
Participatory sensing
High-resolution capacitance detection

ABSTRACT

In order to address the increasing demand for real-time and pervasive monitoring of air quality and, in particular, of particulate matter, novel solid-state sensor technologies and compact instrumentation for dust detection have been recently proposed. Within the context of distributed dust monitoring in urban areas, we briefly review the most recent advances in miniaturized optical, mass-sensitive and capacitive approaches based on solid-state technologies for the detection of micrometric and nanometric airborne particles. Different application scenarios (spanning from dense wireless networks in smart-cities, composed of several fixed or mobile nodes, to pocket-sized personal dosimeters) are also discussed. New participatory and ubiquitous monitoring and mapping strategies are presented, being enabled by the embedment of these ultra-miniaturized sensors in handheld mobile devices, such as smartphones, already integrating several MEMS sensors.

1. Introduction

Nowadays, in both developed and developing countries, the concern for the risks for health related to continuous exposure of citizens to particulate matter (PM) is rapidly growing [1]. At the same time, and at the same pace, the awareness of the inadequacy of current air quality monitoring approaches is also growing. Severe limitations in terms of spatio-temporal resolution affect the consolidated approaches [2], often lacking the measurement of the granulometric spectrum of PM (i.e. the size distribution of the particles, extremely relevant from the toxicological point of view, since the penetration in organism depends on the particle equivalent aerodynamic diameter). Laser scattering offers the capability to estimate the diameter of single particles on a wide size range (from 0.3 to 30 μm), the lower limit being dictated by the laser wavelength. However, being based on sophisticated optical components, these instruments are bulky and expensive and, thus, not suitable for mass deployment. Representing the state-of-the-art for granulometry, they are competing with the gravimetric gold standard to become a reference also for the legislation [2].

Consequently, as illustrated in Fig. 1a, traditional PM monitoring approaches are based on a very limited number (<10) of monitoring stations, either fixed or mobile. Fixed stations are usually installed in specific plants (1), such as waste incinerators, whose emissions must be continuously monitored by law or in a few cabins or shelters (2) used to monitor air quality. Mobile laboratories (3) are also employed by local environment protection agencies to perform periodical measurement campaigns along reconfigurable spatial patterns or in specific "hot-spots", for instance during emergency events. The main limitation of this architecture is the poor spatial resolution (only a few sampling points across the city, definitely insufficient to capture the dynamics of street canyons [3]). Also, for some technologies, the temporal resolution can be too poor to

---

* Corresponding author at: Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, P.za Leonardo da Vinci, 32, 20133 Milano, Italy. Tel.: +39 02 2399 6102.

E-mail address: marco1.carminati@polimi.it (M. Carminati).

http://dx.doi.org/10.1016/j.measurement.2015.12.028
0263-2241/© 2015 Elsevier Ltd. All rights reserved.

Please cite this article in press as: M. Carminati et al., Emerging miniaturized technologies for airborne particulate matter pervasive monitoring, Measurement (2015), http://dx.doi.org/10.1016/j.measurement.2015.12.028

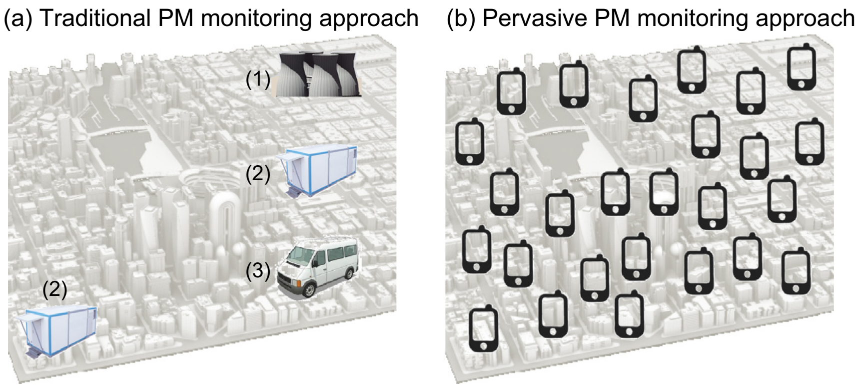


Fig. 1. Envisioned evolution from currently sparse (a) to future ubiquitous and very dense networks (b) of PM monitoring nodes based on the combination of microfabricated sensors, high-sensitivity integrated detection electronics, WSNs and smartphones.

provide real-time information, suitable for modeling and prediction purposes [2,3].

A new monitoring paradigm based on dense networks (Fig. 2b) is emerging, in particular within the context of "smart cities" [4]. The feasibility of this alternative approach is supported by the fast development and convergence of smartphone-based and geo-localized services with wireless sensors networks (WSN) and with the Internet-of-the-Things (IoT). These dynamic infrastructures are constituted by thousands of wireless interconnected nodes, often endowed with low-cost and compact sensors measuring physical quantities of direct interest to the population. Thus, it can be envisioned that, due to its relevance for air quality assessment, PM sensors can be embedded inside such sensing nodes, along with other sensors (such as, for instance, gas sensors [5,6] and microphones for noise pollution [7]).

Of course, the full potential of these highly dense sensors networks is achieved when they are combined with Cloud-based, very powerful and efficient "big data" collection and analysis algorithms. An example is the Green Horizon project, a recently started 10-year joint initiative between IBM and the Chinese government, committed to improve air quality, in particular starting from the most critical situations such as in Beijing municipal area.

In this paper we briefly review the most significant advances in miniaturized technologies, oriented to portable and, thus, personal and pervasive PM monitoring. Section 2 reports an introductory analysis on the possible deployment and integration scenarios enabled by these technologies. In Section 3 the most recent solutions targeting micron-sized particles are presented, while Section 4 focuses on the detection of nanoparticles. Finally, a critical comparison and some concluding considerations are discussed in Section 5.

2. Networking scenarios

The best deployment strategy and the specific type of WSN in which such PM sensors can be inserted depend on their degree of integrability, i.e. mainly on their size, cost and power consumption [8]. As pictured in Fig. 2, the sensor bulkiness determines the network type (fixed vs. dynamic, proprietary vs. participatory). Three possible scenarios can be envisioned. In the first case, when the size, cost, volume and power consumption of the detector do not allow personal transportation - but still hundreds of units can be installed in fixed positions in the city - a dense network operated by municipal agencies can be installed. Such nodes can be powered, for instance, by means of photovoltaic panels (Fig. 2a) and wirelessly interconnected by means of dedicated radio networks. A preliminary example of such an approach has been tested for dense monitoring of ground-level PM in the area of the London Heathrow airport (within the SNAQ project [9]) by means of up to 50

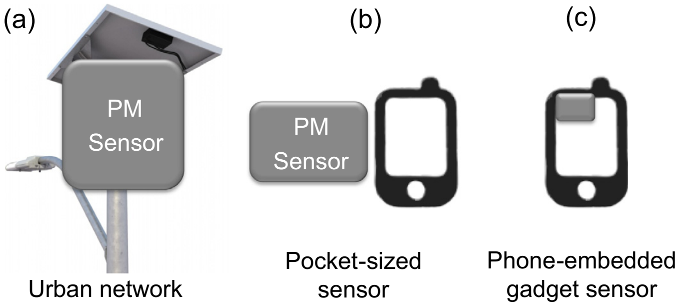


Fig. 2. Possible future network integration scenarios depending on the PM detector size and power consumption: (a) fixed nodes, (b) portable nodes and (c) miniaturized sensors integrated inside handheld consumer devices.

Please cite this article in press as: M. Carminati et al., Emerging miniaturized technologies for airborne particulate matter pervasive monitoring, Measurement (2015), http://dx.doi.org/10.1016/j.measurement.2015.12.028