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Opportunistic mobile air pollution monitoring: A case study with city wardens in Antwerp

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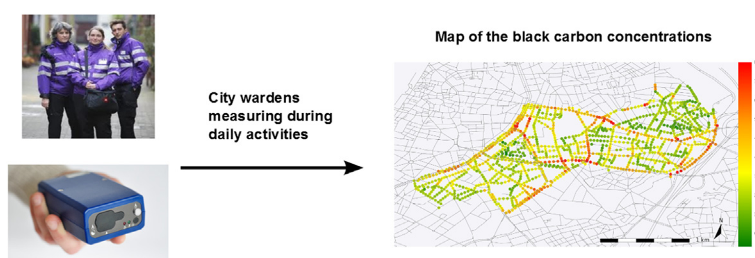
HIGHLIGHTS

- An opportunistic mobile monitoring campaign is conducted with the collaboration of city employees.
- The opportunistic approach can identify broad spatial trends of the urban air quality.
- It is a challenge to collect sufficient data to cover both spatial and temporal variability.
- The evaluation of this set-up is relevant for participatory and crowdsourcing campaigns.

GRAPHICAL ABSTRACT



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ABSTRACT

The goal of this paper is to explore the potential of opportunistic mobile monitoring to map the exposure to air pollution in the urban environment at a high spatial resolution. Opportunistic mobile monitoring makes use of existing mobile infrastructure or people's common daily routines to move measurement devices around. Opportunistic mobile monitoring can also play a crucial role in participatory monitoring campaigns as a typical way to gather data.

A case study to measure black carbon was set up in Antwerp, Belgium, with the collaboration of city employees (city wardens). The Antwerp city wardens are outdoors for a large part of the day on surveillance tours by bicycle or on foot, and gathered a total of 393 h of measurements. The data collection is unstructured both in space and time, leading to sampling bias. A temporal adjustment can only partly counteract this bias. Although a high spatial coverage was obtained, there is still a rather large uncertainty on the average concentration levels at a spatial resolution of 50 m due to a limited number of measurements and sampling bias. Despite of this uncertainty, large spatial patterns within the city are clearly captured.

This study illustrates the potential of campaigns with unstructured opportunistic mobile monitoring, including participatory monitoring campaigns. The results demonstrate that such an approach can indeed be used to identify broad spatial trends over a wider area, enabling applications including hotspot

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identification, personal exposure studies, regression mapping, etc. But, they also emphasize the need for repeated measurements and careful processing and interpretation of the data.

1. Introduction

Air quality is of increasing concern, given its impact on human health (Pope et al., 2009; Lim et al., 2012). In the urban environment, the exposure to air pollution is largely influenced by the activity patterns of the population and the high spatial and temporal variability in pollutant concentrations (Setton et al., 2011; Dons et al., 2012). Especially traffic-related pollutants such as NOx, ultrafine particles (UFP) and black carbon (BC) show large differences in concentration levels in space and time on a small scale (Vardoulakis et al., 2011; Peters et al., 2014). It is important to take this within-city variability into account for accurate exposure estimation (Fruin et al., 2014). Traditional central monitoring stations may not always accurately characterize the spatial variability in the surrounding area and may thus not be representative for the whole city (Wilson et al., 2005). In contrast, mobile platforms are able to acquire air quality data at a high spatial resolution. As such, mobile data are increasingly used to assess the variability within the urban environment and to map the concentration levels people are effectively exposed to (Peters et al., 2014). Given the high temporal variability of urban air quality, a limited number of mobile measurements may only represent a snapshot and may thus not be representative. To map the urban air quality in a reproducible way and at a high spatial resolution, a sufficient number of repeated measurements is required (Van den Bossche et al., 2015). However, this is generally much more labour intensive compared to stationary measurements. One way to collect the large amounts of data that are needed, is to take advantage of existing mobile infrastructure or people's common daily routines to move measurement devices around through the city, without specifically designing the travelled route of the mobile carrier for the measurement campaign. We will further call this *opportunistic mobile monitoring*. Different forms of opportunistic data collection can be distinguished, and they will be described in more detail in the next section. Opportunistic mobile monitoring can also play a crucial role in participatory monitoring campaigns as a typical way to gather data.

In this paper, we describe a case study using such an opportunistic data collection scheme, consisting of mobile measurements of black carbon (BC) and carried out with the collaboration of city wardens of the city of Antwerp. As a consequence of their working routines, there is no control over the followed route and the campaign has an unstructured set-up. The data collection is unevenly spread in space and time, leading to sampling bias as different locations will possibly be measured at different days and/or hours of the day and complicating the data interpretation. This is a major problem which has to be addressed to be able to compare the results between these locations and to use the results for air quality mapping. The issues discussed in Van den Bossche et al. (2015) concerning the representativeness of mobile measurements, the sensitivity to peaks and varying background concentrations, will now be even more important, and will have to be reevaluated.

The goal of this paper is to explore the potential of an opportunistic mobile monitoring approach with an unstructured set-up, as could for instance be the case in an unstructured participatory monitoring campaign, to obtain a reliable, high-resolution map of the urban air quality (not a city-wide map but restricted to the measured locations). It will be evaluated whether or not the recommendations for mapping the urban air quality with a structured mobile monitoring campaign as outlined in Van den Bossche et al. (2015) can be applied here. The focus of this paper is on the characterization of the sampling bias, its impact on the result and ways to counteract the sampling bias through the application of temporal adjustment. The resulting air pollution concentrations will be compared to concentrations from a targeted campaign.

2. Opportunistic mobile monitoring

We define *opportunistic mobile monitoring* as data collection making use of existing carriers to move measurement devices around. The movement of the carriers (the travelled route) is uncontrollable from the point of view of the researcher, as it is not designed and performed with the data collection in mind as primary goal. The data collection takes advantage of existing mobile infrastructure or people's common daily routines. This contrasts with *targeted mobile monitoring*, which is a coordinated, goal-driven approach in which the mobile measurements are deliberately planned and carried out with a specific purpose in mind (see e.g. case studies described in Peters et al. (2013, 2014) and Van den Bossche et al. (2015)). Opportunistic mobile monitoring is a promising approach to collect large data sets that give useful additional information at a reasonable cost compared to classical data collection methods. But, depending on the set-up of the data collection, such new data can lead to new challenges in data processing and interpretation.

This is closely related to opportunistic people-centric sensing as presented by Campbell et al. (2008). They describe a new sensing paradigm leveraging humans as part of the sensing infrastructure. By using small computational devices carried by individuals in their daily activities, information related to human activity and to the environment around them can be sensed opportunistically (Campbell et al., 2008; Kapadia et al., 2009; Kumar et al., 2015). As the data originates from sensors carried by people, new challenges for information security and privacy have to be addressed (Kapadia et al., 2009). However, in this paper, we do not restrict it to people and focus more on the uncontrolled aspect of the data collection and its implications for the processing and interpretation of the results.

Opportunistic data collection can take different forms. We can consider two axes along which opportunistic data collection campaigns can vary. Firstly, they can vary according to the degree of human interaction they need. Possible human interactions are related to carrying the measurement system, the operation and maintenance of the measurement system and to the data collection and handling. Examples of campaigns that can run independently for long periods without human interaction after initial set-up are those based on sensors mounted on vehicles such as cars, buses or trams. The more human interaction the data collection needs, the more the user-friendliness of the instrument and the motivation of the people involved become important issues. Secondly, the data collection can follow a repeated structure along the same routes and/or within the same time frame or can be rather unstructured.

The studies of Hasenfratz et al. (2015) and Hagemann et al.