Real-time measurement of inhabitants exposure to noise and air pollutants with a network of sensors

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Abstract.

Recent EU legislation has placed a focus on the assessment of environmental pollutants and informing the public of their own exposure levels. This paper investigates the possibility of using a network of sensors to monitor pollutants using Dublin city as a test case. Air and noise pollution are modelled and the distribution of network nodes is determined from prediction results with a focus on hot spots. Results are then augmented by mobile nodes resulting in a dynamic grid. The paper concludes with the unveiling of a novel interactive dissemination technique.

Keywords: air quality modelling, environmental noise, network of sensors, pervasive sensing, dissemination of results.

1 Introduction

Living or attending school near major roadways has been associated with numerous health outcomes in recent years, including asthma (Matthew J, 2004), other respiratory illnesses (Dockery and Pope, 1994) and increased risk of mortality from cardiopulmonary (Pope et al., 2002) and cardiovascular diseases (Pope et al., 2004). While the potential for a large public health impact has been established and well documented, it remains current practice to derive inhabitants' exposure from the measurements of very sparse fixed monitoring stations even for large size cities. This approach does not fully capture spatiotemporal patterns of air pollutants, and atmospheric dispersion models often lack adequate emissions inputs and spatiotemporal precision.

One of the topics in which the European Commission (2008/50/EC) has shown a greater concern is the necessity of developing actions that allow increasing the knowledge on transport dynamics and related atmospheric pollution to assure the accomplishment of legislation and to inform the population about their levels. It is indeed very important to increase the general public awareness about air pollution: high levels of air pollutants are "invisible killers", they can't be seen and therefore,

the unaware inhabitants of polluted cities may underestimate them with detrimental effects to their health.

The aim of the research presented in this paper is based on the necessity to understand the dynamics of air pollution with the aim of obtaining a spatiotemporally precise estimation of the air quality and the cities inhabitants' exposure through high-resolution modelling and a network of environmental sensors. Dublin is used as a "living lab" for assessing the performances of this conceptual framework, which will be then possible to extend it to other cities.

To date, the modelling process has been utilised to have an accurate and reliable estimate of the pollution within the city, which leaded to the identification of noise and air pollution hot spots. The layout of the network of sensors and its grid mesh according to the results from the modelling procedure is under study at the moment: the resolution of the grid is higher around hot-spots and lower in areas of low pollution, such as parks and low-traffic roads. Ad-hoc strategies for optimizing the layout, configuration, functionality and performance of such system are studied and tested.

Alternative dissemination solutions aimed at increasing the general public awareness about air pollution are proposed, such as the use of augmented reality in smartphones applications and cars satellite navigation systems.

This paper gives a broad description of the overall project, from the identification of pollution hotspots through modeling to the dissemination of real-time measurements of noise and air pollution levels.

2 Modelling

Artificial neural networks and air quality models are used to have an insight into the complex non-linear relations between traffic, weather, city geometry and concentration of air pollutants at street level for Dublin (Figure 1).
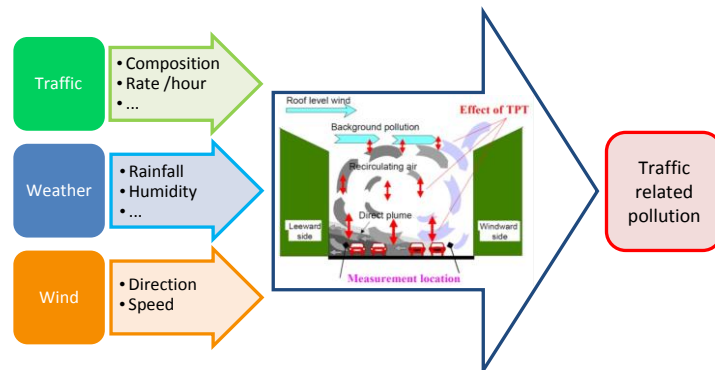

Figure 1: Air quality model flowchart (Berkowicz et al., 1997)

Once the different air pollutants concentration levels are calculated, they are imported in ArcGIS and dedicated layers are created along with thematic layers for traffic and population density. The capabilities of this software, such as for example the

possibility of selecting only some data features and combining different thematic layers, are very important for unveiling patterns of air pollution and possible connection with particular activities or succession of events (Figure 2).
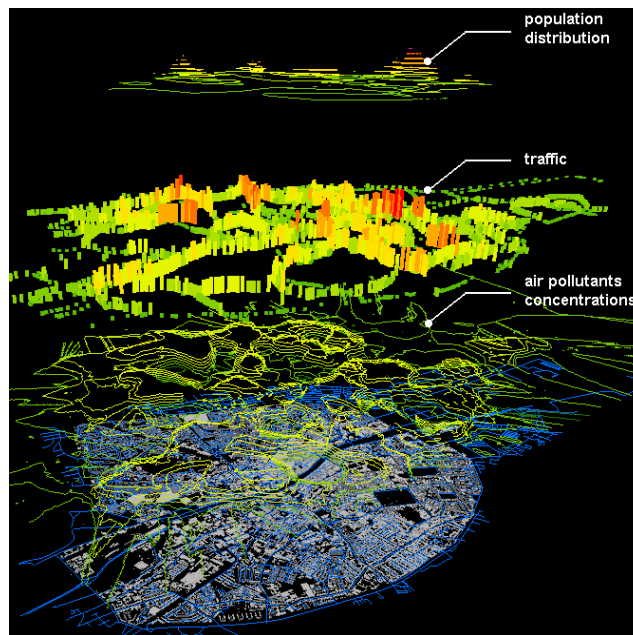

Figure 2: Visualisation in ArcGIS of the different layers

The three layers are combined in ArcGIS and an estimate of the population exposure varying with time and location is calculated.

3 The hybrid network of sensors

High exposure to air pollutants hot spots will be identified within the area of Dublin by following the procedure described in the previous session and the layout of the grid of sensors will be designed accordingly. The nodes of the grid will be fixed or mobile to respond at best to the spatiotemporal variation of locations of the hot-spots. A hybrid network of mobile/fixed sensors is believed to have the capability to provide a higher resolution description of the distribution of air pollutants in cities and also a more direct approach for quantifying the inhabitants' exposure. The exploration of the potential of this approach is being carried out in collaboration with the SENSEable City Laboratory, M.I.T., USA.

Mobile monitoring protocols can successfully characterise concentration patterns with adequate spatiotemporal resolution (Resch B. et al., 2009), but to date they have been generally focused on small geographic areas for short periods of time, given budgetary and personnel constraints tied to the available monitoring and data synthesis technologies. As such, no study has demonstrated the ability to characterise small-

scale spatiotemporal patterns of traffic-related pollutants across an entire city, a crucial step in reducing exposure misclassification and developing enhanced understanding of the health effects of air pollutants. Additionally, pervasive environmental sensing is a reality and will become more so as sensor size, power needs, and costs rapidly decrease while sensor resolution and stability increase and wireless data collection and synthesis abilities expand. The use of such technologies will become available to the public and may lead to a significant change in the relationship of the public and their environment.

A first trial of this concept was carried out in Copenhagen (Resch B. et al., 2011) as part of the "Copenhagen wheel" project[1]. During this small scale test, ten bicycles were instrumented with Ecosenspod sensors from Sensaris[2], connected to mobile phones via Bluetooth (Figure 3). Measurements for position, temperature, humidity, noise, CO, NO_2 were recorded by the Ecosenspod and then transmitted in real-time to a dedicated server in MIT. The outcomes of this trial were very exciting: the bicycles covered a vast area of the city (Figure 4) and it was also possible to cross-plot the measurements and find particular correlation between the variables.

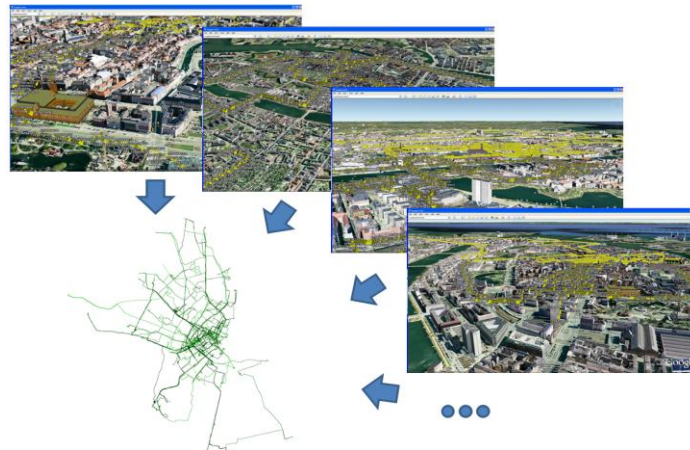Figure 3: Ecosenspod (left) connected via Bluetooth to an android phone (right)

Figure 4: Traces of all the bycicles overlaid on the map of Copenhagen

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[1] http://senseable.mit.edu/copenhagenwheel/
[2] http://www.sensaris.com

In the near future a larger number of sensors will be deployed in Singapore where small-scale spatiotemporal patterns of traffic-related pollutants across an entire city will be studied as part of the "LIVE Singapore!" project[3](Foth et al., 2011).

The experience gained during the collaboration with the SENSEable City Laboratory and the lessons learnt from the trials described above will be applied to the design of the hybrid network of mobile/fixed sensors for the city of Dublin. As part of this large scale trial, a data collection and synthesis system that can remotely combine real-time air pollution and GPS data from multiple sensors into a high-quality and analysis-ready data set will be developed. Multiple monitoring protocols using different forms of mobile monitoring (using vehicles, bicycles, and pedestrians) will be implemented as well as fixed monitoring stations (Resch B. et al., 2011). The benefits from this framework will be a real-time dynamic measurement of the air quality of Dublin and also a high definition description of the personal exposure to air pollutants of its inhabitants, focused in particular on pollution hot spots and on location of interests, such as schools and hospitals. As such, traffic and mobility strategies can be enacted to decrease the pollution in target areas and the outcomes quantified with the sensors measurements.

4 Dissemination

As mentioned above, one of the topics in which the European Commission has shown a greater concern is the necessity of informing the population (2003/4/EC) about the air pollutants levels and also educating them towards a more environmentally friend interaction with the surrounding environment. A possible solution is to avail of augmented reality applications (apps) for tablets, smartphones and car navigation systems. At the time of writing, this solution is been studied.

The measurements from the grid of sensors will be transmitted in real time to a central server and air pollution levels will be calculated for the whole city by interpolating the values between the nodes and correcting them according to real-time traffic data when necessary. This information will be made freely available to users of the app. The air pollutants will be made visible through the tablets and smartphones with augmented reality and users will thus be able to relate such abstract phenomena to the surrounding environment. Thus air pollution will no longer be an "invisible killer". The authors believe that if the general public has a better understanding of air pollution, then they will be in position to make more educated choices about, for example, where to spend their time and send children to school.

Most smartphones and tablets are equipped with GPS with information about orientation and direction. As such, when the user will look through the device's screen to the street he's walking towards, the augmented reality app will display the levels of pollutants in that street (Figure 5).

The same augmented reality app could be installed on next generation navigation systems using transparent displays/touch screens with air pollution information. This

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[3] http://senseable.mit.edu/livesingapore/

navigation system could be also equipped with an algorithm to calculate the personal exposure of the people within the car according to the "outdoor" pollution levels received by the server and car parameters recorded by on-board sensors, such as windows open/closed, ventilation flux, etc. The navigation system could then suggest alternative solutions aimed to minimise the exposure to air pollution of the passengers, such as closing the windows, reducing the air intake from outside, a possible less polluted route, etc.

Figure 5: Application with augmented reality on smartphone

5 Further Applications

While the primary focus for the development of this network of sensors would be for the monitoring of air pollution, its flexibility would enable the monitoring of another invisible harmful pollutant, environmental noise. According to the World Health Organization, the growth in urban environmental noise pollution is unsustainable, because it involves both the direct and cumulative adverse effects on health and also adversely affects future generations by degrading residential, social and learning environments. The WHO recently estimated that at least 1 million healthy life years are lost every year from traffic-related noise in the western European countries, including the EU Member States (WHO, 2011). Furthermore the social costs of environmental noise across the EU was recently estimated at around €40 billion a year at which 90% is related to road traffic noise (EU, 2011).

King et al. (King et al., 2009) reported that a combined approach to monitoring and assessing air and noise pollution would be of significant benefit to the decision making of urban planners and policy makers in a variety of urban contexts. For this purpose they developed an air–noise pollution reduction index (ANP$_r$) which could be developed further in the context of the proposed Framework. Thus, rather than viewing noise and air pollution impacts separately for planning and environmental sustainability considerations, a combined approach could be adopted. This would be of sig-

nificant importance in the context of EU Directive 2002/49/EC, which calls for the development of strategic noise maps and action plans for all European agglomerations of over 100,000 inhabitants. Most noise maps to date have been developed through predictive means but a network of sensors with the capability of monitoring noise would be an invaluable tool for validating noise maps and assisting in the development of noise action plans.

While Resch at al. (Resch B. et al., 2009) demonstrated the potential for a fixed network of environmental sensors, Bennett et al. (Bennett et al., 2010) demonstrated that it may be possible to acquire noise measurements in transit. Tests conducted in Dublin city center indicated that measurements taken by a pedestrian with a microphone mounted on his person yielded similar results to the standard fixed measurement methodology. Other transport modes including bicycles and cars were also investigated (Figure 6).
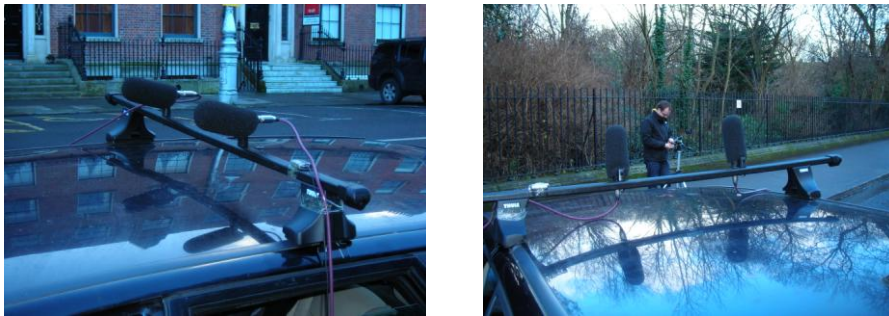

Figure 6: Microphones mounted to a car roof compared with fixed position.

The Copenhagen Wheel trial (Resch B. et al., 2011) also demonstrated the advantages in terms of covered area that a mobile network of environmental sensors would have if compared to a similar deployment of stationary sensors.

Finally the Environmental Noise Directive (2002/49/EC) places a strong focus on public engagement so the dissemination techniques described above would be of great value. It has been noted that the dissemination of information related to environmental noise is a particular area in need of research and has received little attention to date.

6 Conclusions

The benefits from this framework will be a real-time dynamic measurement of the air quality of Dublin and also a high definition description of the personal exposure to air pollutants of its inhabitants, focused in particular on pollution hot spots and on location of interests, such as schools and hospitals. As such, traffic and mobility strategies can be enacted to decrease the pollution in target areas and the outcomes quantified with the sensors measurements, which will lead to short and long-term improvements in air quality and associated health benefits.

The traffic and mobility strategies can be distinguished in two general actions:

- Traffic management: the traffic is directed on alternative routes. Generally it can be shown that there is great benefit in spreading any pollutant over a larger area, it brings the concentrations below critical levels.
- Mobility management: the public transport on particular routes is increased and promoted and the public is made aware of this action. This should result in a decrease of the number of vehicles on a commuting corridor and therefore in a reduction of the emissions.

The framework will also provide a powerful public engagement tool, allowing the general public access to a wealth of information about the environment in a novel interactive format. For the proposed work Dublin will be a "living lab" which will be an archetype to be applied to other cities.

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