A Mobile Small Sized Device for Air Pollutants Monitoring Connected to the Smart Road: Preliminary Results

Stefano Chiesa[1], Maurizio Pollino[2,3], and Sergio Taraglio[1(✉)]

[1] Robotics Laboratory, ENEA, Rome, Italy
{stefano.chiesa,sergio.taraglio}@enea.it
[2] Analysis and Protection of Critical Infrastructures Laboratory, ENEA, Rome, Italy
maurizio.pollino@enea.it
[3] EISAC.it, Italian Node of the European Infrastructure Simulation and Analysis Centre, Rome, Italy

Abstract. The work in progress on a small sized air pollution monitoring system mountable on board urban vehicles is described. The system exchanges data exploiting a "Smart Road" infrastructure with a central computing facility, the Smart City Platform, a GIS-based Decision Support System designed to perform real time monitoring and interpolation of data with the aim of possibly issuing alarms with respect to different town areas. Early experimental data gathering in the Rome urban area and subsequent spline interpolation processing are presented. Thus, air pollutants distribution maps have been produced. Finally, protocols for data exchange have been designed. Work is in progress on algorithms for data fusion among different monitoring systems and interpolation of data for a geographically denser map.

Keywords: Air pollution · Smart Road · Monitoring · Mapping

1 Introduction

Human health is adversely affected by the exposure to air pollutants with chronic and long-term ailments ranging from upper respiratory irritation to deadly morbidity such as lung cancer or heart diseases [1]. The underlining cause is represented by the ever increasing energy consumption: most of it is still in the form of fossil fuels burning. This produces huge amounts of carbon dioxide (CO_2) contributing to the global warming of our planet, but, at the same time, it outputs a series of air pollutants of direct and harmful influence on human health: carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matters of several sizes (PM_1, $PM_{2.5}$ and PM_{10}). In addition, long term exposure has been linked to premature mortality [2].

This problem has been tackled at a legislative level with the installation of monitoring systems in urban areas. Current systems are usually sparsely distributed in the urban area with a very low spatial resolution: in the area of Rome there are 13 monitoring stations,

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managed by ARPA Lazio environmental agency [3], of which 10 are inside the GRA ("Grande Raccordo Anulare", the beltway around the town). If an average radius of 9 km is considered for the GRA, it means that each station covers a surface of 25 km^2, if evenly distributed. If the whole surface of the municipality is considered (1,285 km^2), and all the available systems, this figure rises to 99 km^2. The situation is similar in most large towns around the world, e.g. in Beijing there are 22 stations each covering 113 km^2, in London 14 stations each covering 112 km^2 [4].

The sparseness of the data has had as a consequence the need for estimates of the pollutants in unmeasured areas using a variety of methods, e.g. spatial averaging, nearest neighbour, Inverse Distance Weighting (IDW), Spline interpolation, Kriging, Land-Use Regression (LUR) modelling, dispersion modelling, neural networks, etc. [4].

In recent years the availability of smaller pollution sensing devices and of the Global Navigation Satellite System (GNSS) has opened the way for small size mobile systems for the monitoring of air pollutants [5]. This increases the density of measurements, yet it does not solve the sparseness problem, since the mobile measurements are usually performed along the streets or in specific areas. In order to have a larger view, the same methods previously developed for interpolation of data of monitoring stations have been applied also in the case of mobile air pollution data [4].

The aim of this paper is to briefly describe the work in progress on an air pollutant monitoring system based on a mobile small sized device which can be carried by vehicles in the urban area: private cars, mass transport buses, service vehicles. The system is directly interfaced with an intelligent infrastructure, namely a "Smart Road", which relays the data to a central computing facility which can perform a real time monitoring and interpolation of data, possibly issuing alarms with respect to different areas of the town.

In Sect. 2 it is described the Smart Road infrastructure and its features and capabilities together with its use in the present scenario. In Sect. 3 the monitoring unit is described. In Sect. 4 some examples of data collection/exchange and interpolation processing are given together with a comparison with the actual data from the available fixed monitoring systems. In the last section the conclusions and comments are given with the direction towards which further work is foreseen.

2 The Smart Road

The Smart Road is a rather *fuzzy* concept which has gained the limelight in recent years together with its companions: Smart City, Smart District, Smart Building, Smart Home. They all describe the concept of pervasive computing: all the parts of the nowadays life can be made *smart* with the help of some processing power, communication and, above all, data. The trigger (and effect) of this smart wave is the so-called Internet of Things (IoT), i.e. the possibility to equip nearly every electronic device with communication and elaborative powers, together with an ever decreasing cost of computing power and storage memory. The Smart Road concept has been instantiated and implemented in different ways in different places, but it is intimately linked to the Intelligent Transportation System (ITS) framework [6]. The idea is that transport and mobility must be reconsidered as an integrated and above all dynamic system where control, information and management operate synergistically and synchronously [7].

For example, in Sweden the Smart Road is considered as an infrastructure able to recharge electric vehicles while they are moving in it [8, 9]. In Italy the main road administrator, ANAS (https://www.stradeanas.it/en), is currently making smart some sections of the Italian road network with an approach centred on the safety of the journey. They are equipping road-side street lights with sensors and with a wireless network to communicate with cars and passengers for traffic related warnings and to monitor road status [10].

ENEA is currently involved in a project to set up an experimental Smart Road in order to study applications and solutions for a better quality of life and energy saving. The basic architecture is shown in Fig. 1. Through the communication network of the roadside lamps, the electric/autonomous vehicle is able to dialog with the Smart City computing centre. In one direction the vehicle furnishes data gained with proprioceptive sensors (e.g. position, speed, battery charge, etc.) or exteroceptive ones (e.g. air temperature, pollution, road surface conditions, etc.) acting as a sort of mobile sensor device. In the other direction the vehicle may receive from the computing centre relevant information which it cannot directly and locally access: e.g. an alarm condition on the future path to be followed or a meteorological alert of any kind. In addition, the vehicle can receive instructions concerning its recharging, e.g. where and when, compatible with the overall status of the electrical grid and the wishes of the vehicle itself, such as being near to the trip destination.

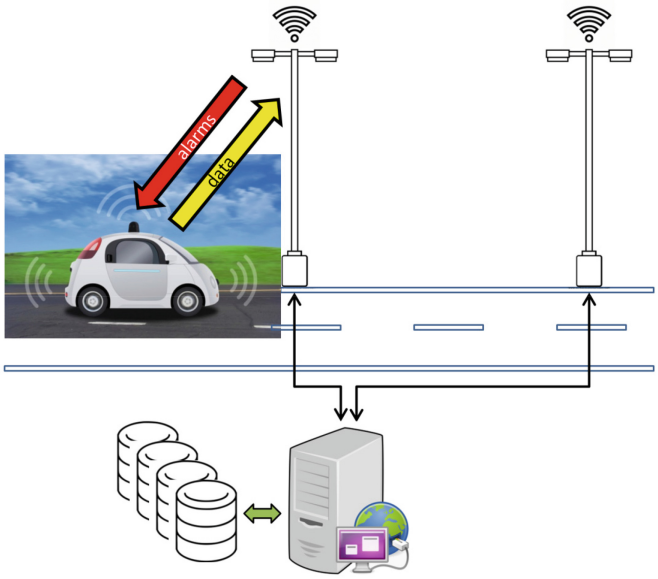

Fig. 1. The Smart Road architecture

The Smart Road aspect of interest in this work is that of air pollutants monitoring. The idea is that some vehicles in the town are equipped with a mobile air pollutant monitoring system. This system checks some chemicals with a given frequency and then transmits

back the data to the central facility. The prototype system envisaged is small and light and can be conceivably mounted on almost any vehicle, however it may be mounted chiefly on mass transit buses or other service vehicles of the municipality. The central computing facility gathers data from the different mobile systems and interpolates data both spatially and temporally, greatly increasing the real time awareness of the pollution situation in the town.

3 The Monitoring System

The monitoring system is shown in Fig. 2. It is capable of detecting SO_2, CO, NO, NO_2, volatile organic compounds (VOC), O_3 and particulates in the three values of PM_1, $PM_{2.5}$ and PM_{10} and some atmospheric physical parameters such as temperature, humidity and pressure. At the same time, it is equipped with a GPS sensor, thus yielding georeferenced values. Table 1 lists the sensors on board the device.

In Fig. 2 it is possible to see the sensors sensitive to the individual chemical species (the cylinders in the centre of the image), the particulate sensor (the black box on the left) and above the chemical sensors the control and management electronic card based on the single-board computer Raspberry-Pi.

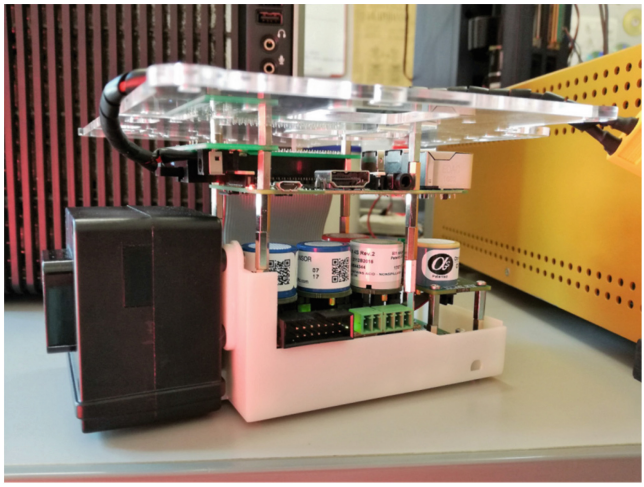

Fig. 2. Air monitoring payload: the cylinders in the centre are the chemical sensors, the black box on the left the particulate sensor and on top the single board computer

The Raspberry-Pi takes care of the management and interrogation of the sensors and provides the data to the Smart Road system via a WiFi internet connection, implementing a web service, which can be remotely accessed. The size of the device is about 10 × 17 × 9 cm, with a weight of around 500 g, it needs a power source in the range 7–36 V and a power of about 3 W.

The unit, mounted on the vehicle, will provide the intelligent infrastructure with georeferenced chemical and atmospheric concentration data with a given frequency,

Table 1. Air pollution sensors

Chemical	Model	Technology	Range
CO	DDScientific - GS+4CO	Electrochemical	0–2000 ppm
SO_2	SO2 4S CiTiceL	Electrochemical	0–20 ppm
VOC	Figaro TGS8100	Semiconductor	1–30 ppm (H2)
O_3	Alphasense OX-A431	Electrochemical	0–20 ppm
NO	DDScientific - GS+4NO	Electrochemical	0–250 ppm
NO_2	DDScientific - GS+4NO2	Electrochemical	0–30 ppm
Particulate	Alphasense OPC-N2	Optical	0.38÷17 μm

presently estimated in the order of once every few seconds in order not to saturate the available bandwidth.

4 Early Experimental Data Processing

4.1 Data Collection

Some experimental data collection has been performed mounting the system on the roof of a vehicle and driving it in the town of Rome. Two different modes of operation have been tested. In the first one (February 19, 2020, 11:00 AM) it has been followed a path in the neighbourhood of one of the fixed air pollution analyzers placed by the ARPA Lazio [11]. In the second (February 19, 2020, 11:25 AM) the route of a mass transport bus has been followed.

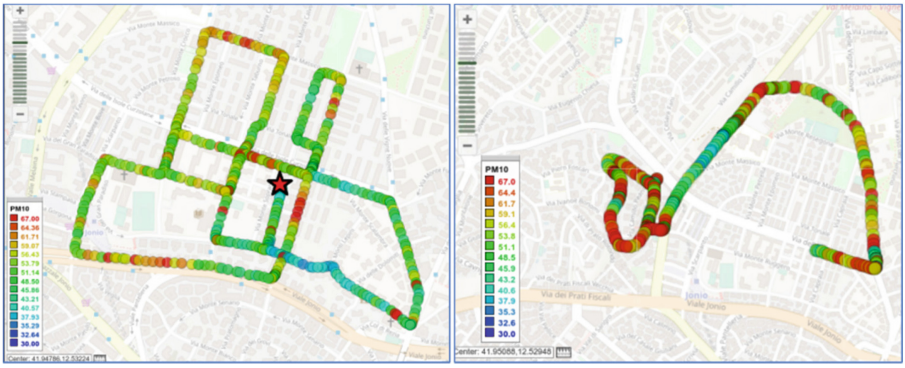

Fig. 3. Left: the collection of PM_{10} data in the neighbourhood of one of the fixed municipal monitoring systems (red star); right: the collection of PM_{10} following the route of bus n. 349

In the first mode the system has monitored a relatively small area with a relatively large number of samples. The idea was to simulate the contribution of many different air

monitors installed on board several different cars. In addition, the location has been chosen such that there is a ground truth for the chemicals provided by the above-mentioned monitoring station ("Bufalotta" [11]). The second mode is intended to simulate the case in which the system equips a mass transit bus. In order to have a simulation very comparable to a real recording, the vehicle has followed a bus along its route, stopping behind it at every bus stop.

In Fig. 3 are shown the two examples of experimental data recording: on the left the collection of experimental data in the neighbourhood of the fixed municipal monitoring system, on the right a part of the route of a mass transit bus in the same neighbourhood. Both the displayed graphs are relative to the PM_{10} measurement in a northern semi peripheral part of Rome, as an example. The same type of graph can be provided for any of the on-board sensors.

4.2 Data Processing and Integration

The Smart Road conceived in the present work will allow the dialogue between a Smart City Platform (SCP, i.e. a suitable application to manage urban data, provide services and support local authorities) and the vehicles circulating in it. To this end, the system has been designed to send, in one direction, data collected from the vehicle to the SCP and, in the other, to provide alert messages or other information services. All these data can be managed in the SCP by means of a GIS-based Spatial Decision Support System (SDSS) [12]. Thus, the values recorded during the experimental activity have been processed in GIS environment with the aim of mapping the spatial distribution of air pollutants within the area of interest and sharing this information by means of the SCP.

All the data acquired by the vehicles are sent to the SDSS to be ingested and interpolated. Given the heterogeneity of the data, an exchange format based on JSON (JavaScript Object Notation) has been adopted.

Several techniques of spatial interpolation (IDW, spline, Kriging, etc.) can be used within a GIS environment for air pollution distribution mapping [13]. In particular, the spline interpolation method estimates values by means of a mathematical function minimizing the overall surface curvature and resulting in a smooth surface that passes exactly through the input points [14]. This method is more suitable in interpolation processes for generating gently varying surfaces such as pollution concentrations [15].

For the aims of the present work, the regularized spline technique has been used for data processing of the air pollutants collected (listed in Table 1), in order to produce the interpolated maps. As an example, in Fig. 4 is depicted the PM_{10} distribution map produced on the basis of the sample points acquired on February 19, 2020. In order to remove some outliers in the measured data a threshold have been placed at 80 $\mu g/m^3$ and a centred moving average, of sample window 5, has been used to reduce noise. The value measured, at the same time, by the PM_{10} sensor installed in the "Bufalotta" fixed station was 37 $\mu g/m^3$ (legal limit according to the Italian legislation: 40 $\mu g/m^3$). The official PM_{10} data from the fixed stations is posted just once a day as a daily average, thus the comparison is only indicative. According to the recent historical data [3], during the first six months of 2020 the PM_{10} exceeded 22 times the legal limit [16], notwithstanding the lockdown due to the Covid-19 emergency. For this reason, it is opportune to monitor it and analyse the relative trends and behaviour.

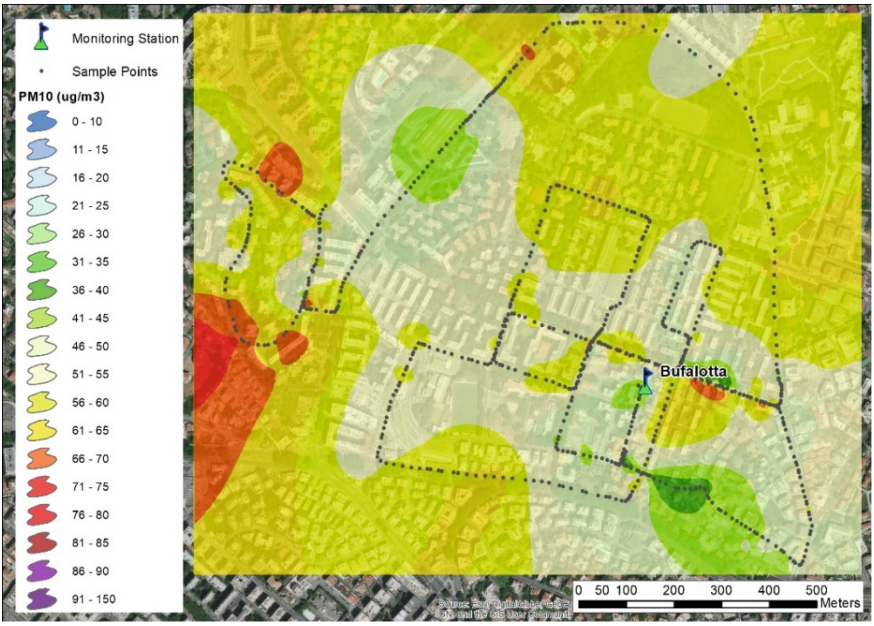

Fig. 4. PM_{10} distribution map: interpolation from data acquired (February 19, 2020) in the neighbourhood of a monitoring station ("Bufalotta") and following the route of bus n. 349

Finally, all the interpolated maps produced for the various pollutant values collected by the vehicles (in different times) can be integrated within the SDSS: here it is also possible to perform additional spatial analysis, by overlapping the pollutant distribution maps with other information layers about the urban area considered (e.g. meteo-climatic data, traffic conditions, etc.)

5 Discussion, Conclusions and Future Work

The central idea presented in this work concerns the availability of a much larger dataset than what presently available and in near real time, gathered with lightweight and small mobile monitoring systems. In many fields of application, the availability of a large quantity of data, even if of a lower quality, yields a non trivial contribution to the description of a state. The concept of data fusion in many different fields of application is an example of this approach: to estimate a measurement several different sensors of different characteristics and precisions can be exploited, all contributing in different degree to the final value [17].

Here a large number of experimental points sampled by several vehicles is a wealth not to be disregarded, even if the quality of the data is far from being optimal. The here employed low cost chemical sensors are usually affected by diverse sources of error [18]. Basically, they should be periodically calibrated. In the operative conditions envisaged, the monitoring system is placed on a bus or on a private car. Possibly, in the first case, a scheduled maintenance by the mass transit operator may be set up, but, in the second

one, the calibration would be entrusted to the single citizen with a probably much worse result. A further problem is that of the measure itself on a vehicle, the reference data from static monitoring systems is not affected by any air flow, the data on a vehicle is clearly variable with the air flow due to the vehicle speed. This should be at least coarsely modelled in order to have better measurements.

Further work should be directed towards the integration and interpolation algorithms. On one side, a strategy to estimate the reliability of the data coming from the various mobile monitoring system should be set up on the basis of the characteristics of the single measuring system (e.g. time from last calibration, use, location, etc.). On the other, algorithms for data fusion are to be studied to fuse together data coming from different monitoring systems, static and mobile, and performing geographical interpolation, algorithm possibly based on Kalman filtering or neural networks, see e.g. [19, 20].

In this work the general setup of an air pollution monitoring system has been presented. The system is based on the use of light and small mobile monitoring devices able to yield in real time georeferenced pollution data through an intelligent infrastructure, the Smart Road. Some experimental tests to collect data in the town of Rome and some first experiments on data interpolation and exchange have been performed. Further work is in progress on the side of strategies and algorithms for the fusion of data coming from different monitoring systems and interpolation of data for a geographically denser map to be shared by means of the SDSS application.

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