Multiple Gas Sensors System for Environmental and Air Quality Assessments
A Way to Perform Environmental Monitoring in Smart Cities

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Abstract: In recent years, people are getting more and more concerned with air quality and other environmental nuisance. Whether it's indoors or outdoors, humans are getting more sensitive to the issue. Implementing a more accessible commercial low cost environmental surveillance systems have proven to be a rapidly growing solution. Therefore, we are specially focused on environmental quality measurements, integrating environmental and gas sensors in wireless communicating systems in order to provide a wide-range monitoring solutions suitable for several environmental case study. We have also created different indicators which convey the wellbeing state in encountered situations where user can rely on these indicators to assess their environment quality. In this work we present a framework for monitoring real time particulate matter evolution in a construction site and the implementation of different acoustic noise measurement systems for mapping the noise evolution in a chosen city. Achieved results show the effectiveness of such systems in nuisance detection and qualifying living environments.

1 INTRODUCTION

Today's cities are facing two major evolutions. Firstly, people are slowly increasing their awareness of environmental issues, global warming, the decreasing quality of air and water, the increasing amount of waste, and other current environment degradations (Hadfield, 1999). Secondly, the data tsunami, initiated by the internet and amplified by excessive smartphone use, implies that citizens are becoming dependent on a direct and real time access to any information at any given time.

These deep changes in the way people interact and take into account their environment are directing cities to a new concept: the smart city concept (Paskaleva, 2009). Tomorrow's cities have to deploy large and dense sensors networks to furnish local, accurate, comprehensible and relevant information to its citizens. This is the major challenge that faces all sensors networks stakeholders.

This work illustrates a way to surpass this challenge for the precise case of environmental urban monitoring. We present our developments work on a wireless and solar powered multiple sensors systems that monitor noise, weather and air quality. After presenting the generic platform, we focus on enlightening the difficulty to match sensor's accuracy and cost issues that are needed for a large and dense sensors network that delivers high quality data. Finally, we focus on the must be performed data processing to transform sensors raw data signals into relevant and easily understandable information by citizens.

2 GENERIC PLATFORM

The GreenBee is a multiple sensors system developed to achieve the monitoring of a large range of parameters in the environmental field. It includes the acquisition of noise, temperature, relative humidity, wind (speed and direction), solar radiation, ozone concentration and 1 µm particulates concentration. All these measurements are performed by a wireless system autonomous in both energy and communication. Data are sent to our server by several kinds of wireless networks solutions. Eventually, the whole system is powered by a solar cell.

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Figure 1: A GreenBee with weather sensors. Ozone, particulates and noise sensors are behind the solar panel.

2.1 Multiple Sensors

Multi-sensors systems in environmental monitoring have to be able to target different kind of environmental parameters whom mostly are incompatible like wind speed and acoustic noise. Each of these parameters is of different nature hence the need of different type of sensors. Therefore developing a system capable of harmoniously control and integrate different sensors from different types and technologies could become a major obstacle that could not be easily overcome. To resolve this problem, an electronic controller had been standardized and utilized for all GreenBee® systems. This controller is compatible with different sensors technologies by having analog and digital programmable inputs and outputs that can be used by different sensors. Onboard processors can be used to communicate with these sensors by insuring an adapted signal when needed.

2.2 Multiple Network Protocols

This same electronic controller can be used to send collected environmental data to our servers. Data can be sent on a daily, hourly, real time or custom basis. The communications protocol can be chosen between, GPRS, Zigbee, Home-Rider, CORONIS … protocols. Whenever communications are down, and to insure an uninterrupted data collection, unsent data can be stocked for a very long time before communications could be restored.

3 AIR QUALITY SENSORS

The need for an air quality monitoring system is growing largely. This is mainly caused by communities' sensitivity toward the proven correlation between bad air quality and poor citizen's health (Peden, 1996). Mainly, we focus on two air quality aspects: oxidizing gases like O_3 and NO_2, and the suspended particles (P.M.).

3.1 Photo Oxidizing Sensor

O_3 and NO_2 gases are generated by different sources. These sources can be anthropogenic, like gas emissions from combustion engine and fuel based energy production as seen for NO_2. Or biogenic, like the rise of temperature and direct contact of air pollutant with a high sunlight flux, as seen for O_3. The presence of these gases can be noticed, with increasing concentration through the last decades, in every city and urban area around the world. Their oxidizing effect can be linked to the rise of asthma and other respiratory health issues (Scoggins, 2004). Different types of technology already exist to sense their presence. These technologies can be divided into two groups: Photoemission, where gas molecules are stimulated by a photon, and electrochemical sensing by focalizing on the oxidant nature to create an electric signal. Sensors using these technologies defer in resolution, precision and price. Although photoemission based sensors show higher performances than electrochemical sensors, they are hard to miniaturize, are more expensive to produce, and have higher energy consumption. Hence their use is in a disadvantage in low cost multi-sensors units. For these main reasons GreenBee systems use electrochemical gas sensors.

The following figure shows GreenBee's performance in oxide gas detection using an electrochemical gas sensor in comparison with an air quality control station operated by the French air quality surveillance network in the Rhone-Alps region (Air Rhone-Alps) in the city of Chambery,

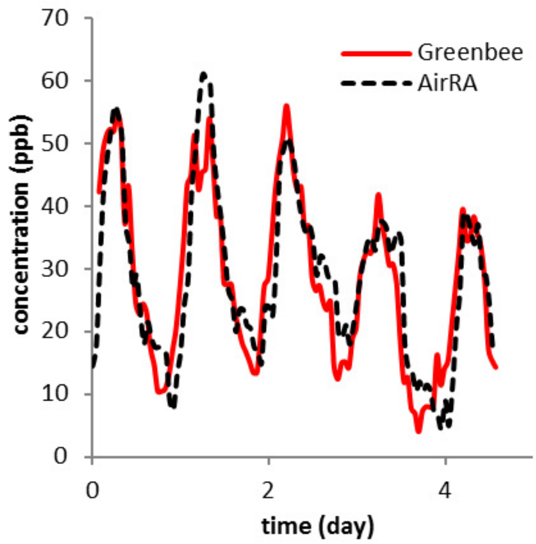

Figure 2: Comparison of a GreenBee's measured O_3/NO_2 concentrations with measured concentrations from an air quality surveillance system station.

south-eastern of France. This solution offers an acceptable precision with a relative error lower than 15%. Such an average precision can be compensated by a low price and a low electrical consumption, therefore making these sensors a very propitious choice to make.

3.2 Particulate Matters Sensor

The term Particulate Matters (PM) signifies a mixture of solid and or liquid particles suspended in the air along with surrounding gases. A PM is characterized by various parameters: chemical, number concentration, mass concentration, particle size, granulometric repartition ... Most of the time, these particles are not homogenous, that is to say it contains particles of several sizes ranging from a few nanometers to several tens of microns. By definition, PM are very heterogeneous in their chemical composition and are subjected to equilibrium between gas and particulate phases.

All through the literature we can find different groups of PM like PM_{10}, PM_5 … The small number in the description signify that these particles have an aerodynamic diameter equals or inferior to the given number in µm. Hence PM_{10} are a group of particle with a diameter equal or inferior to 10 µm. The lower the diameter is, the deeper these particles can penetrate through the human body, and hence the more dangerous they are (Polichetti,2009)

The Primequal (French Interagency Research Program to Improve Air quality at the Local level) report (2005) points out that the large particles (d> 5 µm) stop in the nasopharyngeal region, particles of 1 to 5 µm in the tracheobronchial region, while fine particles less than 1 µm, can reach the bronchiolar and alveolar regions and be persistent. These particles are the most hazardous for humans; therefore their monitoring is very interesting for a life quality point of view.

There are several optical techniques which provide access to a measure of the amount of PM in the air. The simplest is the optical absorption with a visible or infrared light. It is mainly used in the case of very high concentrations because of its low sensitivity to low pollution levels. The other main technique uses scattered lights by PM, it is nephelometry. The intensity of scattered lights, by particles of diameter close to the wavelength of the incident radiation, varies with the number of particles in the illuminated volume. This technique has several advantages. It is much more sensitive than the absorption method and much simpler and cheaper than the standardized measures. Moreover, the measurement can be made continuously, a quality that is sought in the context of such monitoring. Sadly such systems are cumbersome and are not miniaturized. Therefore we use this technology as a calibration and comparison reference for other type of low cost sensors.

In an objective of measuring health hazardous particles, we took into ourselves to measure the number of present particles with a diameter equal or less than 1µm, hence measuring PM_1. Usually, PM monitoring is made by measuring the mass of these particles. But in our case we chose to work with particulates count number in order to obtain information on the hazardous exposure to these particles.

A low cost optical sensor has been chosen. Tests were conducted by burning incense and introducing different PM emission sources. Sensor's measurements were compared with a *TSI aerotrak 9306* nephelometry based instrument. The latter instrument is capable of measuring different size of particulate matters. Measurements are shown in figure 3. A high correlation can be noticed between the prototype sensor particulates count and the TSI instrument particulates' count for particles with a diameter of 1µm and less. Hence the chosen sensor has shown its potentials for PM_1 particle sensing.

This prototype sensor had been integrated in a GreenBee system and put in a construction site where we were intending to monitor dust and aerosol emissions. Figure 4 shows the measured particulates count during 4 days of testing. The first two days being weekend days, where construction works were on hold, measured particulates count was stagnant and therefore we could consider it

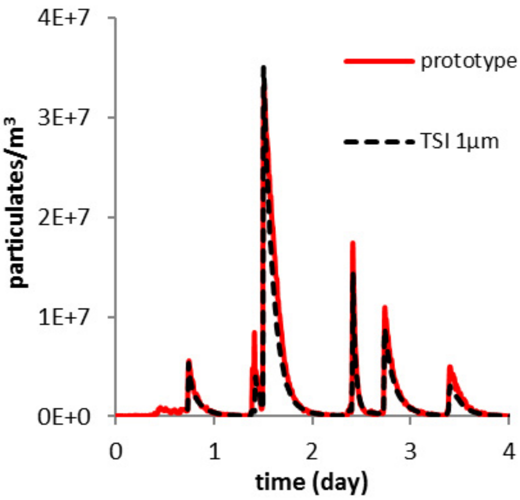

Figure 3: Particles count comparison between a TSI and sensors prototype.

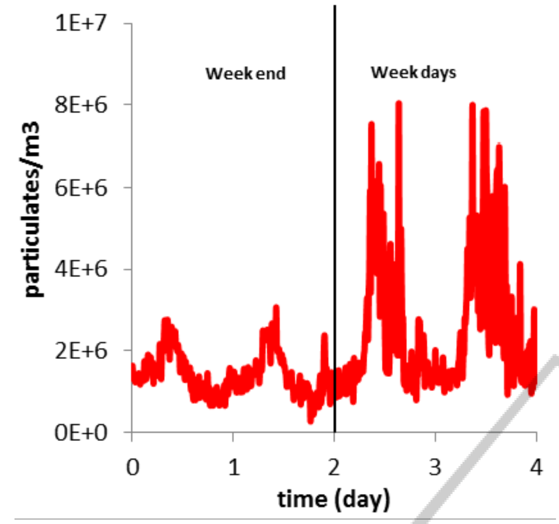

Figure 4: PM_1 evolution in a construction site as measured by the prototype sensor.

equal to the background emissions. On the other hand, the following two days witnessed dynamic measurements where particulates count where increasing and decreasing along with construction works.

The prototype sensor response shows a dynamic sensitivity towards particulate matters emitted by a construction site. The chosen sensor targets particulates with a diameter range close to 1µm. Hence this sensor is suitable for our desired application on hazardous PM_1 monitoring.

4 DATA PROCESSING

Low cost multi sensors systems are well in the reach of common people. Therefore data should be processed in order to be rapidly understood by users despite their educational background. Hence a road map should be drawn in order to define data utilization, diffusion, and targeted users (pro/public). Therefore data processing should be rigorous and unified. Indicators could be used to convey different information about the severity of a variable. Also Colors and letters could be used as an easy display of these indicators in order to obtain an easy recognition. Incorporating these indicators in a map could allow for nuisance mapping to pinpoint the source of certain events. These indicators are calculated based on time exposition or concentration exposition when dealing with hazardous gases. The interval period for this calculation could be a real time basis or a specified time period (hour, day, week …).

For example, several GreenBee units were placed in a city in southern of France. Figure 5 shows an example of 2 units placed on a map, where each unit is represented in a color and an alphabetical index describing the severity of the nuisance surrounding it. In this example, monitored nuisance is the acoustic noise pollution, and shown indicators are calculated on a monthly basis. Hence, using these indicators, users could easily distinguish a noisy part form a calm part of the city.

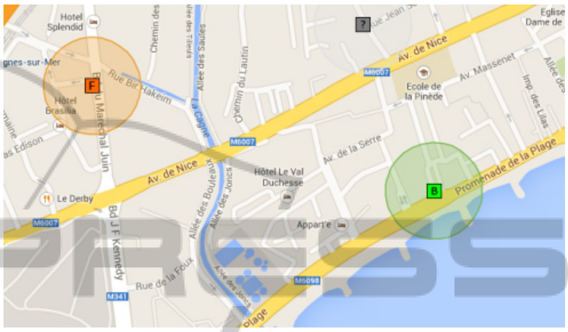

Figure 5: Acoustic noise mapping in a city, example using 2 units with color and alphabetical indicators.

Different indicators could be obtained from a GreenBee unit depending on the number of monitored parameters. Therefore, we could aggregate some of these indicators in order to construct a more general indicator, for example: a wellbeing indicator.

5 CONCLUSIONS

Advancements in sensors technology like miniaturization and industrial production are pushing the development of relatively low-cost multi-sensors systems to a new limit. These systems have begun changing the way we live and communicate with our surrounding environment. Using these advancements, we have developed a continuously evolving multi-sensors system for environmental monitoring. These systems are autonomous with the help of a solar panel. They are small in dimension and can communicate in any communication protocol. They could be used anywhere to monitor environmental nuisance, even the hazardous ones. The relative low cost of these systems could lead to a more realistic pollution or nuisance mapping in a city or a given urban location. Such mapping could lead to a better localization and understanding of pollution and nuisance dynamics in these locations which hopefully could lead in itself to a better life quality.

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