The Aeroflex: a bike for mobile air quality measurements

Bart Elen [1,*], Martine Van Poppel [1], Nico Bleux [1], Jan Theunis [1], Matteo Reggente [1,2], Jan Peters [1], Arnout Standaert [1]

[1] VITO, Boeretang 200, 2400 Mol, Belgium; E-Mails: <firstname>.<lastname>@vito.be
[2] Ghent University, Department of Information Technology (INTEC), Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium

***** Author to whom correspondence should be addressed; E-Mail: bart.elen@vito.be;

Abstract: In this publication we present the Aeroflex, a bike for mobile air quality measurements. The Aeroflex is able to measure a wide variety of air quality and other components. It has been designed with both adaptability, reliability and user friendliness in mind. Furthermore, the Aeroflex is equipped with automatic data transmission, automated data pre-processing and data visualization. It is the product of continued development. The Aeroflex has already been successfully used in numerous projects of VITO, its partners and its customers.

Keywords: Air quality mapping; Mobile measurements; Measurement bike; Automated data infrastructure

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1. Introduction

Air pollution is considered a major environmental risk to health by the World Health Organization [1]. Urban outdoor air pollution is estimated to cause 1.3 million deaths worldwide per year. Diseases caused by air pollution include respiratory infections, heart diseases, and lung cancer. Fixed measurement stations are unfitted to map air pollution levels present in streets of urban environments. A mobile measurement solution is required. We developed an air quality measurement bike called Aeroflex, which has been used in research projects (such as [2] and [3]) and is made commercially available. In the next section, we present the Aeroflex and its measurement devices. Also, we explain both the need for and the realization of its abilities for automated data synchronization, adaptability and dealing with failures. In section 3 we discuss the Aeroflex data infrastructure: its data transmission, data storage, automated data pre-processing and automated data visualization functions. We end in section 4 with some conclusions and future plans for the Aeroflex.

2. The Aeroflex measurement bike

2.1. The Aeroflex and its measurement devices

The Aeroflex has been realized as a measurement bike and not as a measurement car or van such as in [4], [5] and [6]. The reason for this is that a bike can come on most locations were pedestrians and bikers can come without emitting air pollutants which could disturb the measurements. The advantages compared to the usage of a measurement back-pack, such as in [7], is that longer distances can be covered by bike then on food, and a higher weight of measurement equipment is possible.

In Figure 1 the Aeroflex and its measurement devices are depicted. The Aeroflex is able to measure a number of air quality parameters: Ultra Fine Particle (UFP) concentrations with a TSI P-Trak, Particle Matter PM_1, $PM_{2,5}$, and PM_{10} concentrations with the Grimm 1.108, Black Carbon (BC) concentrations with the Magee Scientific microAeth model AE51, and low cost CO measurements with an Alphasense CO-BF electrochemical cell. Care has been taken to protect the sensitive optical measurement devices from exposure to shocks during the measurement drives. Furthermore the Aeroflex is equipped with a number of additional measurement devices: a GlobalSet BU-353 GPS, a Center 322 sound level meter, a Microsoft LifeCam Cinema 720p HD camera, a Tinytag Plus high sensitivity vertical acceleration sensor, a temperature and a relative humidity sensor. Also a netbook with additional display on the steering wheel is used in combination with a USB data network. Both will be discussed in the next section. Due to the rather larger amount of electronic devices used, we choose for the usage of 2 powerful rechargeable Lithium-Polymer batteries as a central power supply to power them all. The Aeroflex has a guaranteed battery autonomy of 1 working/measurement day of 8 hours.

Figure 1. The Aeroflex and its measurement devices

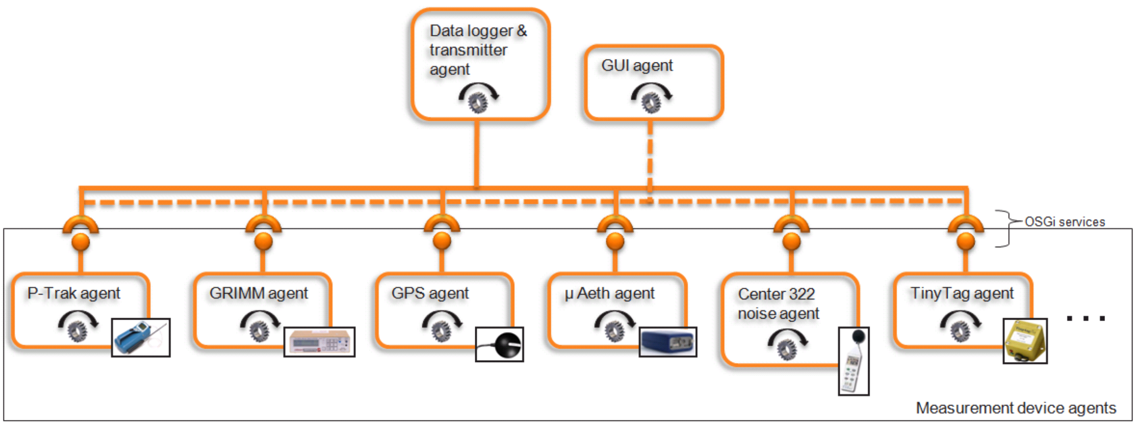
2.2. The need for data synchronization

Fixed measurement stations often offer hour, half our or even minute measurements. For mobile measurements we require a higher temporal resolution of 1 second. Due to this requirement, we want to be sure all measurements are synchronized on the second. In the past we realized this by manually checking the clocks of all used measurement devices before each measurement drive. This approach turned out to be too cumbersome and very error prone, causing the measurements of a lot of measurement drives to be unfit for further usage. Today, the Aeroflex is able to automatically synchronize all measurement data from all used measurement devices by using a single netbook computer as central data logger. Every second, it reads out all measurement devices. A USB data network is used, allowing up to 127 measurement devices to be read out simultaneously.

2.3. The need for adaptability

Due to constant evolution of new measurement devices coming on the market and the specific requirements of each measurement project, it is crucial for us to be able to easy add, remove and replace measurement devices on the Aeroflex. In hardware this was realized by the “plug-and-play” functionality of the used USB data network. From the software side the Aeroflex software platform had to be able to support an ‘ever changing’ set of measurement devices whose presence needs to be detected automatically. We were able to meet those requirements by implementing an autonomous ‘Measurement device agent’ for each measurement device which is responsible for all device specific task including detecting the port(s) on which the measurement device is present, reading out the measurements, and if available the error codes of the measurement device. Each agent is implement as a separate OSGi bundle which can been added and removed when needed. The ‘Data logger and transmitter agent’ brings every second the measurements from the ‘Measurement device agents’ together, logs them to a data file and/or transmits them over the Internet to the Aeroflex data back-end (see section 3.1). The GUI agent is responsible for drawing and updating the graphical user interface. All agents operate completely autonomous and are only loosely coupled to each other through OSGi services. An overview of the software platform on the Aeroflex is shown in Figure 2.

Figure 2. Aeroflex adaptable software architecture with autonomic operating software agents



2.4. Dealing with failures

In contrast to consumer electronics, air quality measurement devices and their software are often not designed to be very easy to use. This is typically not a big problem since the professionals conducting the measurements can spend some time to get to know the measurement devices. For the Aeroflex, being easy to use is a key requirement. Everybody who ‘can ride a bike’ should be able to conduct air quality measurements with the Aeroflex. We had to learn the hard way that incorrectly started measurement devices, badly connected cables and devices failures during the measurement device do occur more frequent then we emancipated on. Too often measurement drives needed to be redone due to lacking data. We successfully overcame this issue with our 'Traffic light' user interface, depicted in Figure 3. The display on the steering wheel colors green when all measurement devices are operating correctly. It colors orange when warnings are present such as 'no GPS lock' or minor warnings from measurement devices. And, it colors red when measurements should be halted immediately due to a failing measurement device or loose data cable. The concept of a traffic light is quite naturally understood by our users and turned out to be easier to observe while biking compared to showing a text message or playing a sound signal. Also a few key sensor values are depicted on the Traffic light GUI to give the driver an impression of the current measurement values.

Figure 3. 'Traffic light' user interface on small display

3. The Aeroflex data infrastructure

3.1. Data transmission and storage

The Aeroflex is able to transmit it's measurements in real time to the data back-end. This looked interesting since it allows to follow up the progress of the measurement drives remotely and to advise for more measurements when needed. In practice, we encountered plenty of connectivity problems with the used GPRS connection which seem to be caused by bad coverage of the GPRS network and the mobility of the measurement platform. The connectivity problems made us decide to move from real-time data transmission to near real-time data transmission at the end of the measurement drive.

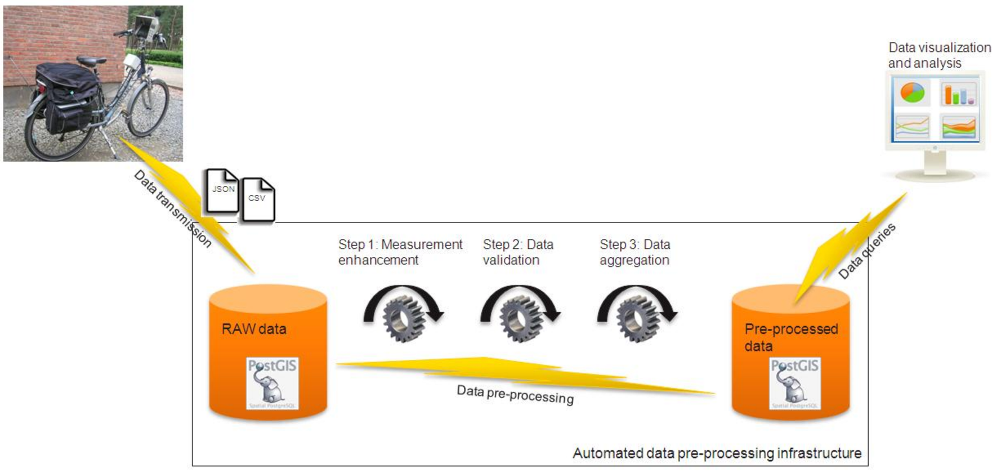
We were surprised to note the chosen JSON data format, which is very handy for our automated data back-end, was considered as 'not enough' by our users. They are used to autonomous measurement devices which generate easy to use data files that can be used immediately. The Aeroflex also needed to be able to be used autonomously. Additional to the JSON files all measurements are now also logged on the Aeroflex in CSV files.

3.2. Data pre-processing

Before the measurement data is ready for visualization and analysis, a number of automated data pre-processing steps need to be executed. At the moment, we are working on an automated data pre-processing infrastructure as depicted in Figure 4. In the first step the measurements are enhanced where possible. Examples of this are interpolation of lacking GPS locations and enhancement of the

Micro Aethalometer black carbon measurements, which often contain too high peeks and negative BC concentrations. In the second step the data is validated by filtering out incorrect measurements. During the third data pre-processing step the measurements are aggregated for each road segment.

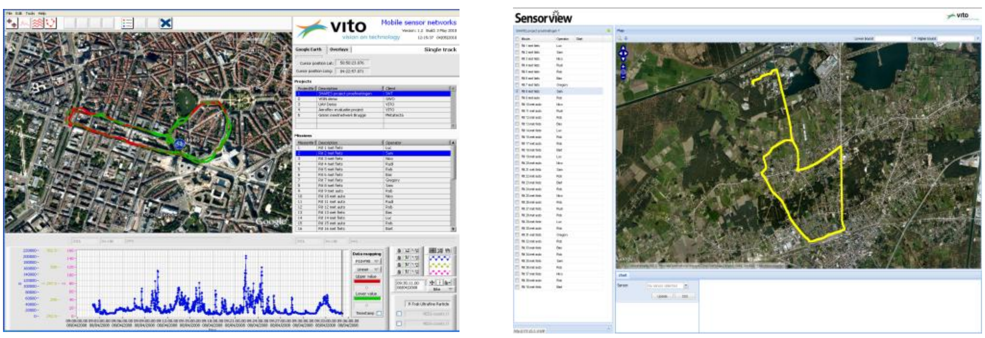
Figure 4. Automated data pre-processing infrastructure



3.3. Data visualization

The measurements from the Aeroflex are automatically visualized on maps and graphs by a LabView based desktop application shown in the left part of Figure 5. In the future, the Aeroflex measurements will also be visualized on the SensorView web application which is currently under development (see right part of Figure 5). Those automated visualizations allow to get a quick impression of the conducted measurements and make the measurements accessible to a broader audience. The applications make use of respectively the OGC Web Feature Service (WFS) and the OGC Web Mapping Service (WMS) to display the measurements. Both web services are offered by a GeoServer. For a thorough analysis of the measurement data both GIS (ArcGIS, Quantum GIS, …) and statistical software (Matlab, R, …) are used.

Figure 5. (**Left**) Desktop applications for automated visualization of Aeroflex measurements. (**Right**) Web application (under construction) for automated visualization of Aeroflex drives



4. Conclusions and Outlook

The Aeroflex has successfully been used for mobile measurements in Antwerp, Gent, Brussels and other cities in Belgium. It contains a number of strong features such as it's automated data synchronization, it's ability to check for measurement device failures, its strong adaptability and its quite elaborated automated data back-end. The most important lessons learned during the development traject of the Aeroflex were that both usability, robustness and being able to deal with failures are crucial to obtain good mobile measurements. Although already a lot of progress has been made, we plan to keep these as important points of attention for the future. Furthermore, we see a lot of potential for new application specific extensions to the Aeroflex data pre-processing infrastructure.

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