Development of an Environmental Information System for Odour using Citizen and Technology Innovative Sensors and Advanced Modelling

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Keywords: e-nose; odour monitoring; odour modelling system; information system.

1 Introduction and Motivation

Odours from industry or livestock breeding are a great deal of air quality annoyance for neighbours in rural and urban locations and they are listed as the second source of complaints by ADEME in France and the Environmental Policy in Wallonia (Belgium). Odour cannot be monitored or regulated like a pollutant: its perception is linked to a human sense and it must be evaluated in terms of potential annoyance on people (see 1). The level of the annoyance depends in a complex way on the release and strength of odour emissions, their dispersion under ambient conditions and finally on the exposure and perception of citizens.

OMNISCIENTIS brings together the state of the art technologies and open communication capabilities to mitigate odour annoyance. In order to support this novel approach, a comprehensive solution is worked out, using recent technological developments in information and communication technologies, atmospheric modelling, sensors and measurements to build a generic Odour Environmental Information System (OEIS), see **Fig. 1**. The latter is a service oriented platform, which also allows inhabitants to act as human sensors with sociological behaviour, i.e. indicating odour perception, discomfort and nuisance using geo-mobile applications.

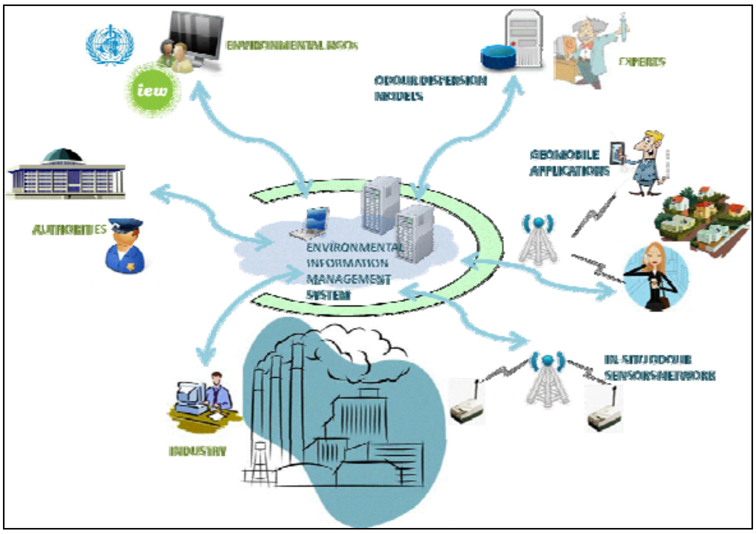

Fig. 1. Architecture of the OEIS.

In the OMNISCIENTIS solution, the neighbours (citizens) can use a mobile device (Smartphone, Tablet) to provide information and get direct feedback. Furthermore, due to the subjective nature of odour perception, new monitoring (sensors) and fast modelling techniques have to be used to assist and adjust the information given by citizens. In order to describe the fade of odour from emission to perception, the flow and dispersion characteristics must be known. Flow and dispersion modelling allows interrelating the release by the sources (e.g. industry) with spatial odour exposure levels. The odour experts will use information from the mobile devices to help in calibrating the measuring equipment and in developing and testing the new odour dispersion model. The major goal of OMNISCIENTIS is to develop a new completely integrated environmental information system for an innovative environmental management, involving all possible stakeholders, i.e. industry, citizens and authorities.

The system performances will be verified and validated on the field, using two distinct pilot cases: a pig fattening farm in Austria and a major industrial site in Belgium.

2 Odour Dispersion Modelling within OMNISCIENTIS

Particular care has to be devoted to one peculiar characteristic of odour human perception: few minutes above the perception threshold are enough to give the impression of odour annoyance. Such a phenomenon, which was demonstrated by several studies and researches, cannot be neglected for a proper modelling of odour impact. The point is that, in general, dispersion models use hourly or half hourly meteorological data and if available simple temporal cycles (e.g. diurnal cycles based on hourly values) to describe the temporal emission behaviour. Consequently, they provide hourly or maybe half hourly mean concentrations and are not able to capture odour fluctuations due to turbulent perturbations of the flow motion (see **Fig. 2**).

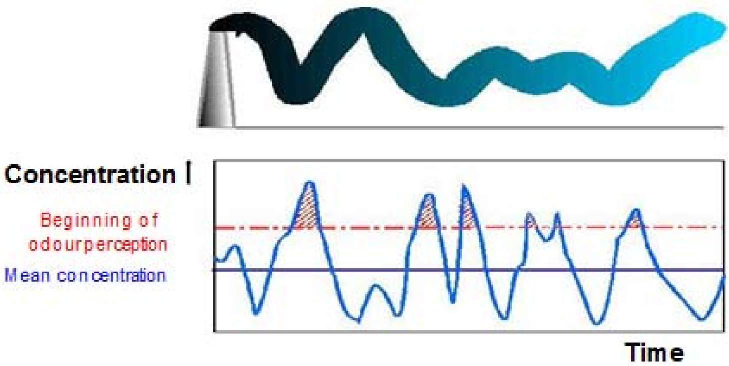

Fig. 2. Peaks above the perception threshold cause annoyance even if the mean concentration is below the same threshold.

Within OMNISCIENTIS, a new improved odour modelling system is developed, considering the following aspects:

- Existing flow and dispersion models must be able to use information about wind and atmospheric turbulence on time scales order of minutes.
- Emissions also have to be measured by electronic noses on time scales order of minutes and passed to the dispersion model as an input.
- Simulations have to be run in transient mode.
- Due to the smaller time resolution and to provide citizens and other stakeholder's immediate feedback, the model system used must be extremely fast.

At this aim, the pollutant dispersion model "GRAL-System" of the Graz University of Technology (TUG) (see 2, 3, 5) is employed and modified to be applied for odour simulations. Therefore the main parts of the GRAL-System are transferred so that they can run on GPUs (Graphical Processing Units) instead of CPUs.

The model is presently under development to be used with odours within OMNISCIENTIS. A transient and optimized version of GRAL-System has already been issued, which is considered as the basis for the on-going code acceleration on GPUs. First test simulations for winter time PM10 using emission inventories established during the EU project PMinter (www.pminter.eu) from the European scale (MACC emissions) down to the local scale (own processing of traffic and domestic heating emissions) indicate promising results of the new model under development (see **Fig. 3** and **Fig. 4**). Here, a combined modelling approach using WRF/chem (see 7) to simulate secondary formed aerosols and the impact of regional scale transport together with GRAL to simulate the impact of locally emitted primary PM10 mainly originating from domestic heating and traffic were utilized. In **Fig. 3** comparisons between PM10 concentration measurements (see 8) and simulations results at a receptor point in Leibnitz (Austria) are shown, while in **Fig. 4** the area contour map of the simulated January PM10 mean concentration is presented.

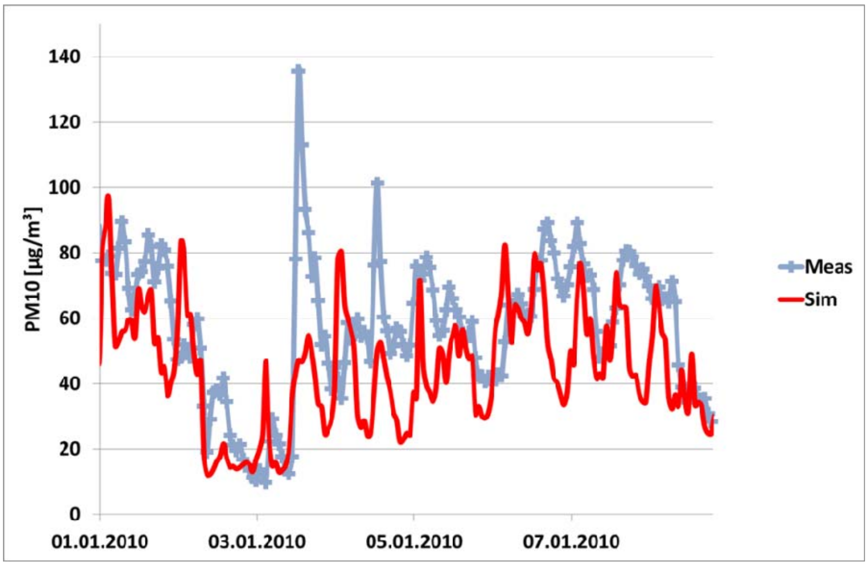

Fig. 3. Comparisons between measurements and simulation results obtained with the new GRAL-System and WRF/chem for Leibnitz, Austria.

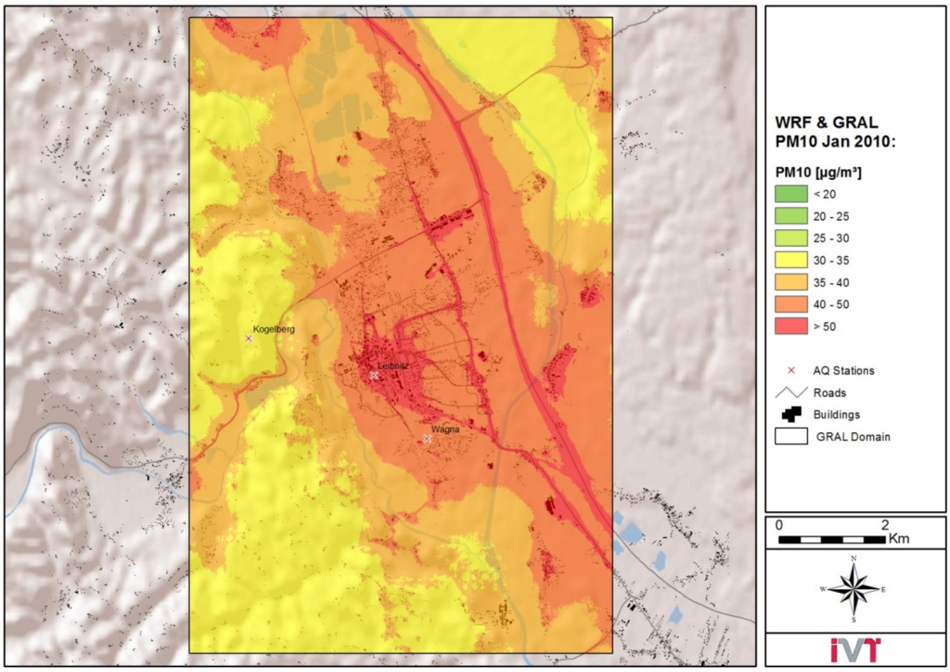

Fig. 4. Simulated January Mean 2010 PM10 concentration map obtained with a combined approach using GRAL and WRF/chem for Leibnitz, Austria.

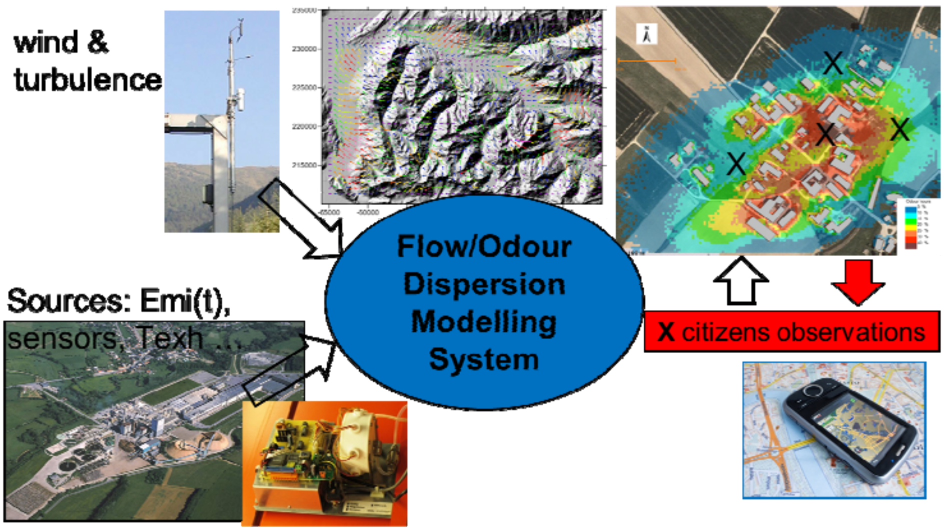

Fig. 5. Architecture of the flow/odour dispersion modelling system.

Fig. 5 shows the architecture of the modelling system and its interfaces with measurements and citizens observations. On one side, input data in terms of meteorological conditions and sources emissions are provided to the model through OMNISCIENTIS system, which collects the output of the different on-site sensors and conveys them to the model; on the other side, the simulation output is given back to the system in the form of odour concentration maps, which can be compared and cross-checked with citizens' observations. Particular care must be devoted to the interfaces coding, in order to properly handle the input/output data exchange.

Actually, the model itself can be considered as constituted mainly by two different tools: a flow model and a dispersion model. The former calculates the flow field, on the basis of the measured meteorological conditions (wind and turbulence characteristics) and on the basis of the computational domain topography (terrain elevation, use of the soil and size and location of buildings). The latter computes the dispersion of the odour emitted by the different sources, by tracking odour particles trajectories as driven by the simulated velocity field. The final result takes the form of expected odour concentration values within the computational domain.

As shown in **Fig. 5**, these data are then transferred back to OMNISCIENTIS system and compared with citizens´ observations in an interactive way, thanks to the mobile devices tool. In fact, the smartphone application not only allows collecting "watchmen" evaluations of odour perception, but can be also used to request their feedback at particular spatial locations, in order to benchmark model performances or to monitor places of interest. Furthermore, model output data can be post-processed to produce long-term statistics, like annual mean values or percentiles.

The final goal of such an approach is to create a powerful odour dispersion simulation tool, in the framework of a completely integrated environmental information system for an innovative environmental management involving all possible stakeholders.

3 Pilots Implementations

As first applications of the developed system, two different pilot cases have been chosen, which are complementary to each other as shown in **Table 1**. **Fig. 6** and **Fig. 7** provide an impression bout the different pilot sites.

Table 1. Main characteristics of the two OMNISCIENTIS pilots.

	Pig Farm (Austria)	**BURGO Paper Mill (Belgium)**
Population	Rural sparsely populated region	Populated pilot region
Surroundings	Flat terrain	Hilly terrain
Sources	• Well defined (stacks, forced ventilation) • One small diffusive source • Farm management known	• Complex (3 main stack sources identified, time fluctuations) • One main diffusive sources
Aim	Dispersion model testing	Involved citizens, living lab testing

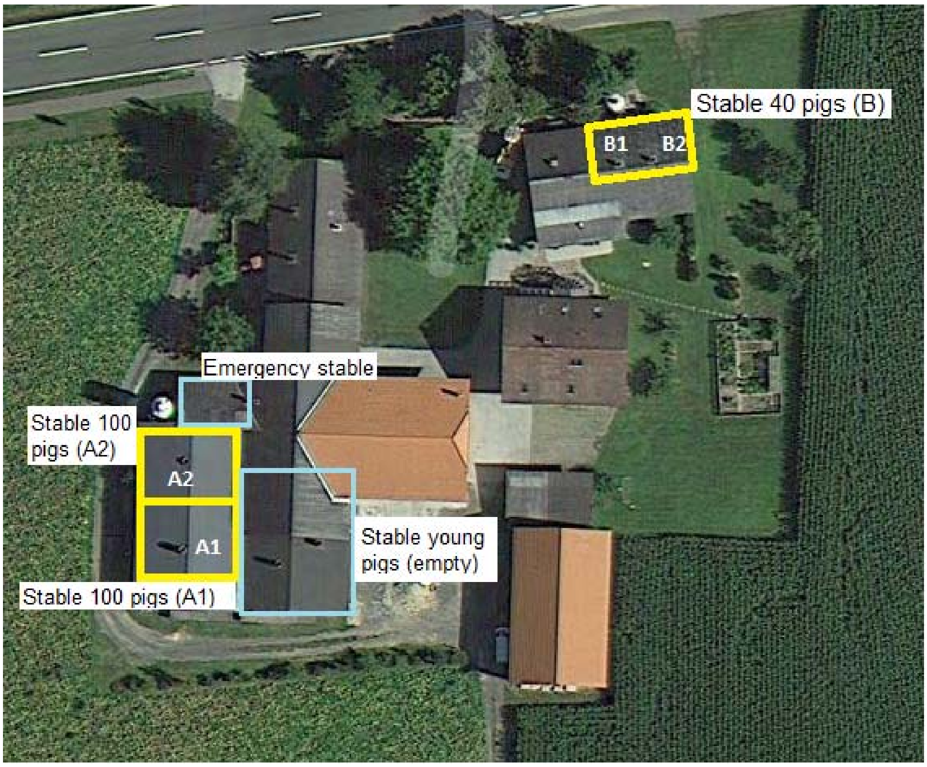

Fig. 6. Pig farm and surrounding area.

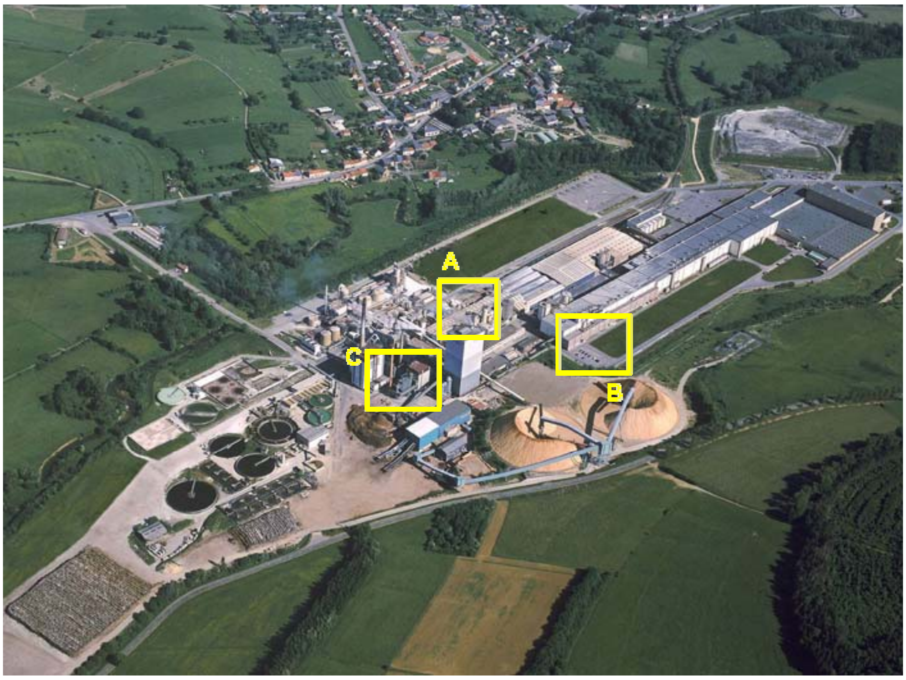

Fig. 7. BURGO plant overview with main sources.

While model development is on-going, a preliminary odour measurement campaign was performed in the pig farm, in Gosdorf (Austria), on the 27th and 28th of March 2013, a period that corresponds to the end of the first fattening period. The pig farm includes two stables (A and B): at the time, stable A contained 100 pigs of 90 kg, while stable B contained 40 pigs of 100 kg. Sensors were placed in the two different fattening pig units.

An initial test was performed with a tailor-made electronic nose. The instrument was developed at the University of Liege and consisted in a six-sensor metal-oxide sensor array (FigaroTM) arranged in a PTFE 200 ml-chamber (see 9). For the following stages of the project, the idea is to install some e-noses in the farm, in order to be able to monitor continuously the odour emission.

The first results for the first pig farm campaign (see **Table 2**) show, rather obviously, that the odour variables are linked to the number of pigs.

Table 2. Odour results in the pig farm.

	A (100 pigs. 90kg)	B (40 pigs, 100 kg)
Odour concentration average (Ou/m^3)	6917 (in the stack)	3252
NH_3 concentration (ppmv)	30	10
H_2S Concentration (ppmv)	0.5	0.6
Flow rate (m/s)	1.2	Ventilation off
Temperature (°c)	20.4	17.3

Several measurements have already been performed for the second pilot location, i.e. the industrial site in Belgium, see **Table 3**. This site presents a much more complex structure in terms of sources locations and characteristics. Further analysis and surveys will be carried out to properly identify and quantify emissions, with the aim of providing appropriate input data for the model.

Table 3. Odour data set measured in the Belgian industrial site.

Source	Time	Odour concentration (uo$_E$/m³)	Odour rate (uo/s)	Process variables				
				O2 (%)	NOx (mg/Nm³)	SO_2 (mg/Nm³)	TRS (mg/Nm³)	Temp (°C)
Stack 1	6/3/2013 13h35	2373	198204	4	200.2	0.7	0.3	160
	14/3/2013 11h30	14201	1221121	2.5	165.9	0.6	0.3	162.6
Stack 2	6/3/2013 11h	4029	65873	8.8	83	53.5	36.9	194.9
	16/04/2013 11h20	3612	39028	/	/	/	/	/
wastewater treatment	14/3/2013 10h20	409961	676151					
	16/04/2013 10h10	63100	1032458					

4 Conclusions

The paper presents an innovative Odour Environmental Information System (OEIS), based on the most recent technological developments in information and communication technologies, atmospheric modelling, sensors and measurements.

Within the complete system, the flow and dispersion model provides the link between the sources and the citizen's perception, describing the spatial and temporal evolution of odour dispersion. Based on the fast model results, an immediate feedback can be given to all stakeholders and additional targeted citizen's observations may be also requested.

The OEIS combines the active participation of all stakeholders (with a specific focus on the neighbours, representing a "citizens-based observatory"). Thanks to that, authorities and industries can analyse the information collected through the service platform (OEIS) in order to better understand odour nuisance and to improve their decision-making capacity. Furthermore validated data are made available, which can be used to improve the national and European legislative framework.

Some results are shown, which represent the initial step to describe the nuisance generating processes. In particular, first test runs with the new model system are presented, which reveal promising results for complicated air pollution simulations during winter time for PM10. Furthermore, data obtained during some preliminary odour measurement carried out at the two pilot sites are given.

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