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Mid-term and 1st International Networking Workshop of the SmartAQnet Project

December 4th and 5th 2018, Munich

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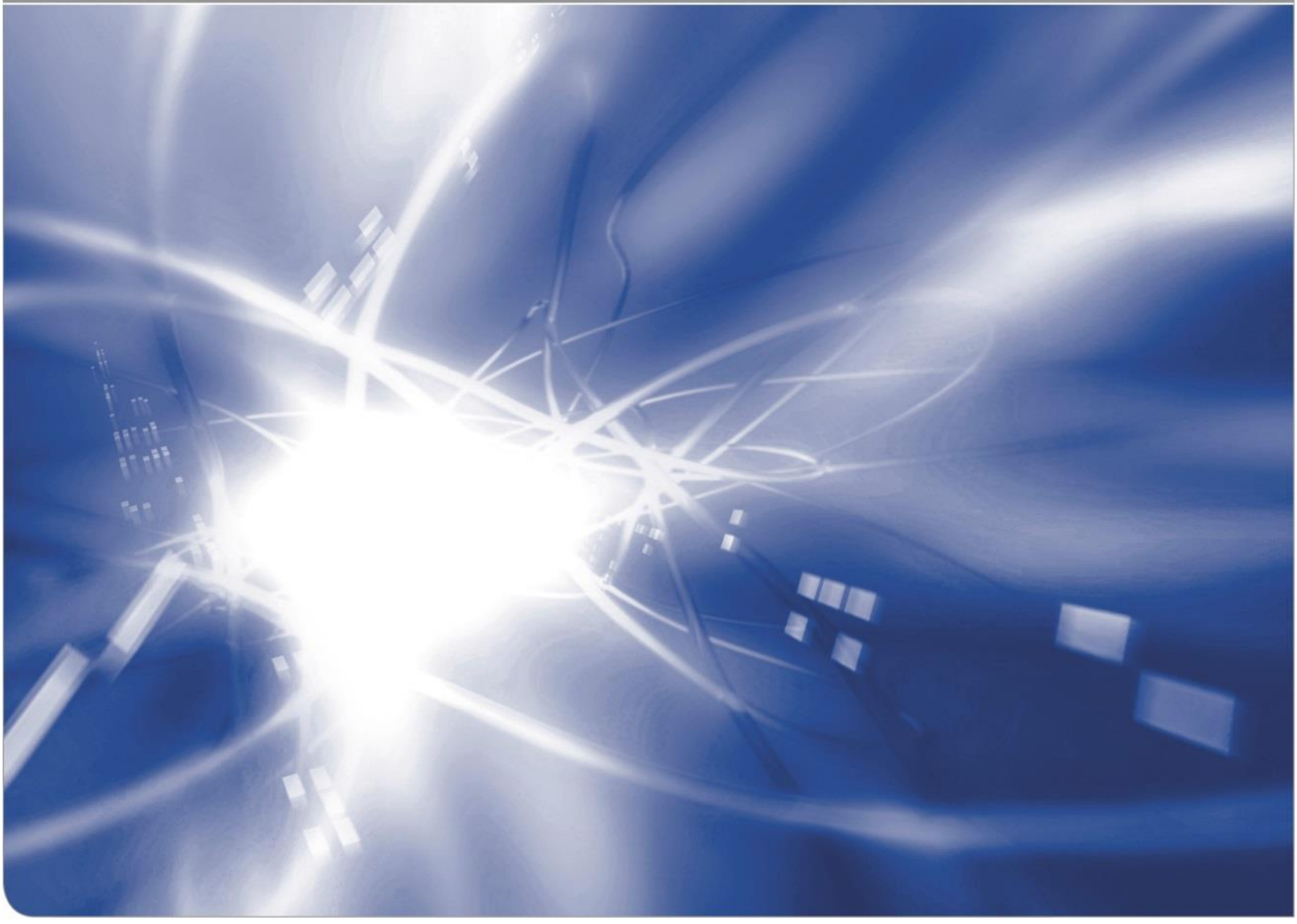

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Preface

This collection holds all abstracts of the oral and poster presentations from the mid-term and international networking workshop of the project Smart Air Quality Network (SmartAQnet)[1], held on December 4th and 5th, 2018 at Helmholtz Zentrum München (HMGU), Munich, Germany.

The goals of the workshop were (1) to present the current project progress to interested external parties and compare it to the initial project plan, (2) to discuss the project in the context of other similar research activities, and (3) to jointly draw conclusions and generate new working ideas that can be addressed collaboratively. As participants, an interdisciplinary audience of researchers and practitioners was invited. Overall, 58 participants attended the workshop, 32 of which presented a talk or poster themselves. Aside from the presentations, the workshop included ample possibilities to engage in both plenary and personal discussions.

A new picture of urban air pollution not only becomes possible, but is also necessary because it can provide information on real hot spots and artifacts. However, the availability of emission data in European countries is very different and often incomplete (e.g. concerning traffic intensity, domestic heating, industry, etc.).

The expert workshop audience is convinced that the increased possibilities to determine air pollution exposure can be best realized by holistic solutions. This may likely include personal low-cost sensors and also means that science will continue to include more community-based efforts, such as grassroots Citizen Science projects. The practical aspects of new sensors and networks are in the focus now because they determine the development of the market. Open data products, which are the goal in SmartAQnet, require adequate descriptions of these data and of the data quality.

Developing countries are very much interested in new sensors for air pollutants because these are cheaper and offer the possibility of emission source determination. U.S. and other national environmental agencies support also the development of new sensors and networks for air quality. These efforts will require the development of test procedures for minimum requirements and certification as well as corresponding test beds.

We as coordinators of the SmartAQnet research initiative draw an overall positive assessment of the workshop and its outcomes and present the most important topics of discussion here.

A second international workshop / symposium in project SmartAQnet is planned at the end of the project runtime (sometime in the first half of 2020). The positive feedback from the external participants and from the consortium underline the importance of the research topic, the relevance of these studies for current smart city developments and the need in epidemiological research.

Dr. Matthias Budde, Dr. Till Riedel, Prof. Dr. Klaus Schäfer

Coordinators of the SmartAQnet project consortium / editors

[1] Project *SmartAQnet* is funded by the German Federal Ministry for Traffic and Digital Infrastructure (BMVI) under grant number 19F2003B.

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SESSION I: Presentation of the Smart Air Quality Network (SmartAQnet) Project

Survey of the Small-scale Variability of Aerosols and Validation of Low-cost Sensors by Mobile Measurements

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According to EEA, more than 400.000 premature deaths in Europe per year are linked to PM2.5 exposure (in Germany around 66.000) while polycyclic aromatic hydrocarbons (PAHs) bonded on these particles are probably most responsible for the cancer development due to polluted air. Nowadays, urban air quality is quite well monitored by stationary measurements, however, the measuring networks are usually not enough dense so we have a lack of information about concentrations within the micro-scale level. The aerosol spatial distribution varies significantly in the small scale depending mainly on sources, geomorphology (closed valleys, street canyons) and meteorology (temperature inversions). The low-cost PM sensors which are under development could increase the density of these networks, however, their precision and reliability are needed to be intensively tested and improved.

Therefore, we developed 3 identical strollers for comprehensive aerosol measurements during walking. Using this equipment, a 11.4 km (3:40 h) long route across the city of Augsburg was repeated several times during the two 28 h long Intensive Observation Campaigns of the SmartAQnet project [1]. For higher temporal variability observation, we conducted overlapping walks starting almost every hour together with 5-10 minutes stops at the LfU LÜB-stations for instrument collocations. PM10, PM2.5, PM1 (using DustTrak DRX, TSI, 1 second time resolution), particle number concentration (PTrak, TSI, 1 sec), aerosol particle size distribution (11E Mini LAS, Grimm, 6 sec / OPS, TSI, 1 sec), black carbon and brown carbon (MA200, AetheLabs, 10 sec) were measured continuously and photos were taken every 5 seconds (Olympus TG-Tracker) for better source identification. GPS and temperature were recorded (Garmin 64s with external temperature sensor, 1 sec). During the walks, the PM2.5 fraction was sampled on a SIOUTAS impactor for later chemical ultra-trace analysis (IDTD-TOF-GC-MS, Orasche et al. 2011 [2]) focused mainly on PAHs and combustion markers.

Air pollution hot spots were identified by plotting the data into maps and by comparison with photos and notes, however, a detailed analysis is still in progress.

Low-cost sensor validations were conducted by placing 3 identical PM10 and PM2.5 sensors (SDS011) and one optical particle counter (OPC-N2, Alphasense) at each stroller for comparisons between each other and with professional instruments during the real urban conditions.

Moreover, all measured data are available for our project partners for their further studies, such as air quality model validation.

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Low-Cost Sensing and Data Management in SmartAQnet

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Continuously integrating data from heterogeneous sensors and other sources in one data management system is an intricate task. Besides appropriate modelling and data storage, solutions for data input and output and data processing are required. In the SmartAQnet project [1], we adopt the OGC SensorThings standard and API [2] for data management. We present the status of our integration efforts and the current input and output interfaces and processing capabilities of our system. This includes different possibilities for data visualization.

As a practical end-to-end example, we present our low-cost sensing activities in the SmartAQnet project. We introduce the employed sensor nodes, smartphone application and sample visualizations from measurements conducted in the recent intensive operation periods (IOPs) of the project. Further results on the topic of low-cost sensing that were achieved in the SmartAQnet project include the characterization of cheap laser-scattering sensors [3] and empirical research concerning the effects of laymen on data quality in measurements with low-cost sensors and mobile sensing technology [4].

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Requirements for a Smart Indicative Ambient Particulate Monitor (SIAPM)

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Limit values for PM10 and PM2.5 given by the world health organisation (WHO) are exceeded worldwide. Effective and efficient clean air strategies hast to be found and to be taken. One of the most important steps for a valuable source apportionment for particles are finding suitable measurement sites for the determination of hot-spots (traffic, industry), urban and regional background concentrations as well as impacts based on long range transports of particles. Another important point is a sufficient measurement quality for particulate matter (PM) to assess the contributions of different sources. In addition, a high time resolution down to minutes and seconds is required to combine particle measurements with meteorological data as well as with gaseous pollutants.

The PM source apportionment during the last decades has mostly been based on measurements carried out by local authorities with approved particle measurement devices. For recent years several small particle sensors has been developed and will be used in addition. Main advantages of these low cost sensors are higher densities of measurement sites as well as big data sets that can be achieved. Disadvantages of particle sensors in comparison to reference PM devices are a lower accuracies and influences on the measurement results due to humidity, changes of temperature and pollution of optics. Other problems that have been observed during our measurements in the frame of the SmartAQnet project [1] are based on unsteady particle properties as changes of refractive index or particle densities. These changes may influence PM measurements with particle sensors dramatically.

The overall strategy of GRIMM in the SmartAQnet project is to start with a scientific scout and to end with a smart indicative ambient air monitor in combination with PM reference technique. First step was using a small optical cell based on the nephelometer principle and improve this cell by using a mini-PC to control an intelligent heating, to run algorithms for PM determination, and handling drifts caused by air temperature changes or pollution of the optics.

In a second step inter-comparisons have been carried out at several locations with hot spot (traffic) or urban background characteristics in Augsburg. A local calibration procedure has been successfully developed by using reference devices of GRIMM, based on aerosol spectrometry. Local calibration means that the scientific scout will be calibrated locally by a PM reference device that is running simultaneously at a different measurement site. By evaluating many data sets it has been find out, that one reference device is capable to calibrate approx. 5 to 10 scientific scouts in parallel. The frequency that is required for local calibration as well as the maximum distance between scientific scout and reference device is depending on the characteristic of the measurement site as well as the pollution level and changes of the aerosol properties. Continuous PM measurements over several months and at different sites with time resolution of 5 minutes have also shown, that scientific scouts at traffic sites has to be calibrated approx. every 3-5 days whereas sites in urban background has to be calibrated only twice per month. New PM algorithms have been developed and successfully tested and allow local calibration for different PM fractions and consider drifts caused by changes of ambient air temperature or pollution of the optics.

Next steps are the improvement of the scientific scout by using a measurement cell with optical particle counting (OPC) and controlling all local calibrations via an intelligent data platform in the SmartAQnet project [1]. This way GRIMM targets to provide scalable smart measurement systems combining indicative and high-quality instrumentation for future networks.

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Mobile Measurements and Applications of Smart Air Quality Networks

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Measurement networks utilizing mobile and stationary low-cost sensors for particulate matter are developing as a trend in the context of citizen science but also developed in atmospheric and environmental science and for administrative interests. However, devices for mobile measurements on aerial and ground-based platforms are still under development and their operational use still quite demanding. However, also the characteristics of the produced datasets concerning the variability of spatial and temporal coverage as well as reliability may be quite challenging for implementation of applications based on those networks. In order to learn more about these difficulties within the SmartAQnet project [1], an experimental statistical forecast model will be developed using reference class forecasts and neuronal networks for several meteorological and urban environment predictors, addressing the temporal variability. Further a spatial traffic routing application will be developed, which allows people to decide preferred routes based on pollution and may help to avoid critical situations at pollution hot spots.

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Temporal and Geographical Contrasts in Pollutant Exposures – Implications for Epidemiological Research

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Epidemiological studies have made important contributions to our understanding of the associations between the air pollution and adverse health effects. While ambient monitoring network data provides highly resolved information on temporal variation in air pollution, it is not able to provide information regarding the spatial variability in concentrations within urban areas. Until recently, studies of long-term exposures have mainly focused on spatial comparisons between cities with different ambient pollutant concentrations. This approach masks any contribution of within-city differences in concentrations. Land use regression (LUR) modeling has been already applied to a number of long-term studies as a method of estimating individual level of exposure (based on residential addresses). Recently exposure assessment approaches for epidemiologic studies of air pollution and adverse health effects have evolved from reliance on available ambient monitoring network data toward approaches to characterize high-resolution temporal-spatial concentration differences. The SmartAQnet project [1] will deliver data for such an approach. Some novel methods to characterize spatial and temporal variation in air pollutants in an urban community will be discussed in the presentation.

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First SmartAQnet Results from Accompanying Air Quality Modelling

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Smart Air Quality Network [1] monitoring activities are accompanied by efforts to provide seamless area-wide and temporally resolved PM by modelling using measurements. The accurate and small-scale spatio-temporal representation of fine dust is a highly challenging task, particularly for fine-dust. Even in alpine valleys and basins, the urban fine-dust is dominated by transport and complex transformation processes outside the urban area of interest [2]. Therefore, multi-scale modelling techniques or precise measurements of the inflow of fine-dust at the model boundaries are necessary to capture one major part of the burden. The other major part is related to strong localized near surface sources such as traffic or residential heating using solid fuels and potentially rapid transformation processes. Moreover, these sources are highly variable in time and space. In order to represent this "localized" part adequately, emphasis is placed on high resolution emission processing, a proper representation of flow and microenvironments such as street canyons, appropriate emission release levels etc. In order to validate emission data, a modelling chain is used and compared with different measurements. First results from the emission procession are shown as well as validation work carried out with the Lagrangian particle model GRAL.

At a later stage, the new PALM4U model will be used to estimate as well rapid transformation processes related to atmospheric chemical processes and aerosol dynamics even at the street canyon scale.

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SESSION II: Concepts of Smart Air Quality Networks

Airbox: A Participatory Ecosystem for PM2.5 Monitoring

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With emerging concerns of air pollution and recent advances in low-cost sensors, air quality monitoring has become one of the most important Internet of Things (IoT) applications in many countries and major cities. One of the most successful systems of this kind is the AirBox project, which is based in Taiwan and operated in a grassroot fashion, and it has deployment more than 4,000 nodes in more than 30 countries till now. The system is also notable for its extremely high deployment density and data frequency, as most of the participating nodes are located in Taiwan and with a high sample rate. In this talk, we present the development of this AirBox project in detail, and we demonstrate several data analysis work that we have carried out for data visualization, anomaly detection, data forecast, and other advanced data services. We also discuss challenges and opportunities for making sense of Internet of Things data based on the lessons learned from the AirBox project.

AirScan: A Distributed, Low-Cost Measurement Network for PM, NO2 and O3 - First Results and Evaluation with Respect to the German 39th BImSchV

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Reliable pollution measurements are time-consuming and expensive. This typically results in either very few measurement points or in lengthy measurement duration (analog measurements such as passive NO2 collectors) resulting in only averages for a larger number of points. There has been a lot of work around low-costs sensor technologies in the last few years, especially for the pollutants particulate matter (PM, sub-divided into the particle sizes <10 µg, <2.5 µg and <0.1 µg) and Nitrogen Dioxide (NO2). Many of the results have been disappointing but there have been some grounds for optimism as well as a clear need to use the sensors in the correct way.

In this work, we present a deployment of 15 measurement "nodes" in Bern, Switzerland with a collection of carefully arranged sensors for PM10, PM2.5, NO2 and O3 measurement. Thanks to a collaboration with local authorities, a calibration procedure could be developed based on local conditions and pollution values to aid measurement around the city. The project will be presented and the results evaluated with respect to the German regulations for indicative/complementary measurements (39th BImSchV).

Estimation of Equivalent Black Carbon Spatial Distribution in WTimpact (Poster)

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Air pollution is in most cases measured by costly, stationary instrumentation at rather few locations. Only few institutes, notably federal and state, are traditionally able to collect high quality pollution data. Once the air quality management problems become more complex, the need for enhanced air quality and exposure monitoring capabilities become more apparent. This is the case with regard to higher spatial resolution and person-based monitoring.

The parameters regulated in the European Union do not include pollutants which are trusted to be associated with adverse health effects: Black Carbon [1], ultrafine particles, and/or specific species. De-centralized measurements using citizens' efforts might therefore fill in some of the gaps in the current air quality observation systems.

The number of community-based air quality observations has been rising over the past years, with several projects being launched on the European scale (e.g., CITI-SENSE, http://www.citi-sense.eu, or CITIZEN SENSE, http://www.citizensense.net). We acknowledge that much focus has been placed on exploring the interaction with citizens (recruitment, awareness campaigns, do it yourself / DIY tool boxes), and the integrated display of many kinds of different atmospheric observations. Nevertheless, we also observe a gap between the (low) quality of community-based observations and the (high) expectations of the scientific community towards related data usability. We are currently not aware of an air quality Citizen Science project that would have pursued a consequent development chain from i) a sensor undergoing a rigid quality assurance based on atmospheric science standards, ii) a seamless and user-friendly data collection framework and display system, iii) an urban-scale real-time air pollution prognosis, iv) a unique visualization, and v) data products that have been designed using the expertise of top scientists.
For the above-mentioned research chain gaps, we propose within the WTimpact project a novel method for using citizen science as a mean for improving the state of the art. WTimpact low cost air quality measurement set will consist of portable micro-aethalometer (AethLabs model MA200, San Francisco, USA), PM sensor (SDS021), and a GPS module (Navilock model NL-8004U, Berlin, Germany). Portable micro-aethalometer will be used to measure equivalent black carbon (eBC) mass concentration with one second time resolution. The GPS device will be used to log the eBC mass concentration and position and the GPS position will be recorded in one second time resolution. A single board computer will be used for data transfer to a Smartphone and data will be send further to a central database in real time. Visualisation tools for verification of spatial data done by the volunteers will be developed. The visualisation will be embedded in interactive browser-based software. The design process of the software will address different levels of products. These are visualisations on smartphones for supporting volunteers while taking data, and to visualise the same data within a larger context, e.g. with forecast data and measured data from other volunteers. Data are delivered continuously to a server embedded in the TROPOS IT-infrastructure. The server software collects and archives incoming data in a database, pre-processes data (e.g. quality assurance), provides graphs and maps for individual sensors and merged data for all sensor units. Visualisation of measurements and prognostic data will be made accessible to the volunteers and the public by internet. Web-based visualisation is instrumental in interacting with the volunteers, allowing timely feedback on technical sensor problems or pollution hot spots. Furthermore, the volunteers will receive a feedback on their personal exposure, an important aspect to motivate them.

Three field-phases will be carried out by TROPOS in 2019 with 90 volunteers in total. In total five sets of low-cost air-quality measurement technology will be used.

WTimpact establishes the basis for future Citizen Science activities on local air pollution observations beyond the project runtime.

It will be the first time that the development, implementation, and proof-of-concept of an infrastructure for personalized measurements, subsequent data processing and visualization will be validated via active participation of Leipzig citizens and TROPOS scientist.

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Combining Satellite and Ground Based Remote Sensing Measurements with In-situ Sensor Network to Derive Spatial Distribution of Pollutants

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Ambient air quality monitoring network often comprises with in-situ monitors. These in-situ monitors are easy to calibrate and provide very accurate data. However, they are only point measurements which are not able to capture the spatial variation of pollutants. On the other hand, satellite based remote sensing measurements provide indispensable spatial information of air pollutants. Spatial distributions of pollutants are derived from the satellite observations of Earth's reflected sun light for the investigation of atmospheric dynamics and emissions from both anthropogenic and natural sources. However, satellite only provide column measurements and the accuracy of satellite observations are highly dependent on the assumption in the retrieval. In addition, the temporal resolution of satellite measurements is often limited to single observation per day. Therefore, it is useful to integrate satellite and ground based remote sensing observations with in-situ sensor network for the investigation of spatial and temporal variation of pollutants. In the presentation, we show the basic principle of satellite and ground based remote sensing measurements and spatial information derived from these measurements. In addition, preliminary surface pollutant concentration maps derived from satellite measurements by using a simple regression technique are also shown.

SESSION III: Measurement Techniques for Smart Air Quality Networks

Field Deployment Experience of Low-Cost Smart City Air Pollution Monitoring Network

Seng-Yong Lau [1], Yu-Ting Chen [1], Chai-Pei Chen [2], Yeuh-Bin Wang [2], Shuenn-Chin Chang [2], Lung-Chi Lin [1], and Chih-Ming Pao [1]

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Increasing, air pollution become an emerging concern and highly public awareness topic. The advance of sensor technology and low power long range communication protocol enabled the development and deployment low cost air pollution monitoring network. Such a network established a higher spatial and temporal density data collection system compare to traditional national air quality monitoring station.

Environmental Protection Administration (EPA), Taiwan, initiated a project of smart city air pollution monitoring network deployment. A total of 10,200 low-cost air quality sensor nodes will be deployed on the street light across the country, covering industrial park, city, small town and countryside. Until Aug 2018, 3200 nodes have been deployed, another 7000 nodes will be installed in 2019. The locations are carefully selected to tackle different application requirements. With 150~300 meters' density in sensitive area, to 1km ~ 1.5km sparse deployment in countryside. Forming a grid network around the area of interest in order to achieve a better understanding of the local air quality condition, propagation of the pollutant, and the source of pollution.

The sensor nodes measure the PM2.5, CO, NO2, O3, related humidity and temperature, and report the reading to a central server every minute. Prior to the deployment, lab evaluation compare the FEM equipment and field evaluation to standard EPA monitoring station was conducted to ensure the quality of the data.

Valuable lessons learned along the course of deployment were documented and several standard operating procedures were standardized. Along with the real field deployment restrictions and problems, negotiation experience with the local authority, as well as the maintenance requirements were also recorded to enable rapid duplicate deployment in different areas.
Traditionally, factory inspections carry out by EPA authority was highly depends on the experience of the inspectors. With the aid of high density spatial-temporal data, and advance machine learning and artificial intelligent analysis, EPA inspectors can effectively pin point the pollution hot zone and emission pattern, tremendously enhance the efficiency of the inspection.

With friendly user interface design and government open data, community citizens can access the air quality information in real time, empower them to limit exposure and reduce pollution through behaviour change, advocacy, and community engagement.

Testing and Inter-comparison of Low-Cost Sensors (SDS 011) and Mid-Cost Sensors (AN2 and AN3) for Particulate Matter

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The low-cost sensor SDS 011 (Nova Fitness Inc.) found meanwhile widespread use within citizen-science projects in Germany for the measurement of PM10 and PM2.5. Therefore, the Duesseldorf University of Applied Sciences (HSD) has built up 50 sensor units for quality assurance tests and for measurements within different student projects.
Moreover, HSD has built up two pairs of sensor units with the AN2 sensor and AN3 sensor, both produced by Alphasense Inc.. The AN2 and AN3 sensors are not as cheap as the SDS011, but show up with real OPC features, as size resolved aerosol measurement and the potential ability to deliver parallel information about PM10, PM2.5, PM1 and PNC.
All Sensors have been field tested by HSD in urban environments under different conditions of temperature and humidity in comparison with a standard reference OPC of the HSD measurement truck. Selected results of these inter-comparisons will be presented within this paper. Moreover, selected applications will be presented for the sensor use.

Differential Column Sensor Network in Munich and Low-Cost NOx Sensor Development

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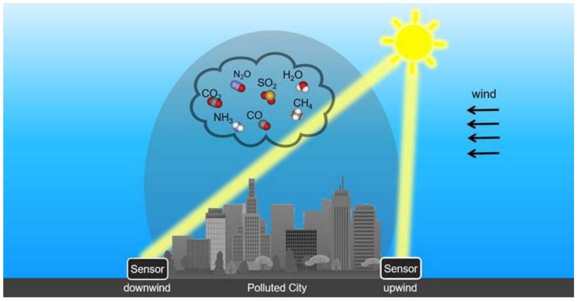
The majority of anthropogenic greenhouse gas (GHG) emissions originate from cities, therefore monitoring emissions in cities is essential to fight climate change. In addition to GHG, nitrogen oxides (NOx) also play an important role in the urban climate. Our current research in the Professorship of Environmental Sensing and Modeling focuses on quantifying greenhouse gas emissions and understanding the metabolism of pollutants in urban environments.

We have established an autonomous urban sensor network based on the method of differential column measurements to quantify emissions of CO2, CH4, and CO [1]–[3]. There we deploy multiple solar-tracking spectrometers (EM27/SUN) measuring column-averaged concentrations upwind and downwind of an emission source or a city (Figure 1). Using these measurements combined with models of atmospheric transport [4], we have demonstrated a new experimental strategy to determine greenhouse gas and pollutant emissions in both local and urban scales.

In addition, we are currently developing low-cost and small-sized NOx sensor based on Cavity Attenuated Phase Shift Spectroscopy and electrochemical cells. These sensors have great potential to further study the emission and distribution of NO2 in the urban areas.



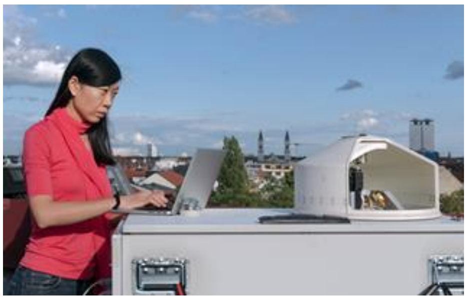


Fig. 1: (left) measurement principle of differential column measurement, (right) automated sensor system performing solar measurements to obtain the column-averaged concentrations of CO2, CH4 and, CO (Photo CC-BY-SA by Andreas Heddergott).

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Investigation of Low-Cost-Dryer Installed on the Low-Cost-Sensors used for Measuring the Particulate Matter in the Ambient Air

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In the field of air pollution control, sensors have been increasingly used for emission measurements for a long time, in addition to the usual emission measuring devices. On the other hand, for ambient air measurements, sensors were not sensitive enough to detect the usually very low concentrations of airborne contaminants in the outside air. Therefore, they were not used for air quality measurements for a long time. In recent years, however, there has been a development in various sensors, which makes them suitable also for ambient air measurements. Currently in many cities, different air quality sensor networks are emerging, some of them with several hundred sensors to determine the air quality, mainly the Particulate Matter (PM) components such as PM10 and PM2.5.

The network operators generally do not put much effort into quality assurance, either because lack of awareness to the need for quality assurance or due to the lack of resources and technology. An important influencing factor on the quality of the results of the PM sensors is humidity. In the presence of high humidity, the particles, due to the hygroscopic effect, grow which in turn lead to false results. Previous studies have shown that the hygroscopic growth is pronounced from around 70% of humidity; this is of big relevance considering that Germany is in a cold region with presence of moisture content in the ambient air most of the year.

The current work focuses on the comparison of PM sensors with a professional aerosol spectrometer and the application of self-made low-cost dryer. The results of comparative measurements of cost-effective sensors from different companies with professional aerosol spectrometers showed that all sensors require a calibration with a reliable standard. After calibration, one type of sensor gave satisfactory results for small particles ranging from 0.3 to 2.5 µm (PM2.5 signal). For coarser particles in the range of 2.5 to 10 µm (PM10-PM2.5 signal), this sensor did not provide satisfactory results. Another sensor type provided satisfactory results for all PM channels, PM10, PM2.5 and PM1. This sensor type also provides reliable results for 16 channels between 0.38 and 17 µm for particle number concentration. The results for the measurements done by using the low-cost dryer show that the dryer works really good and it reduces the effect of humidity.

In summary, the measurement results, obtained from low-cost sensors can be used after the application of quality assurance measures. For QA measures comparison measurements with expensive professional measuring instruments need to be done. Not all sensors deliver the same data quality. Some are even unsuitable for use in the ambient air.
The actual stage of the research with sensors at IFK will be presented.

The Developing of an Economic Laser Particulate Matter Sensor for Outdoor Air Quality Network Application

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Ambient particulate patter (PM) concentrations is a very important factor for air quality monitoring. For the quantifying the spatial and temporal variability of ambient PM concentration, a large quantity and economic PM sensor must be developed. Compared with the Indoor PM sensor which is widely used in air purifier, HVAC etc., the challenges for the outdoor PM sensor are: PM10 testing precision, changeful size distribution and the wide temperature range from -40-70°C etc. this work introduces the recent developed PM4000 laser PM sensor for outdoor air quality network application. In PM4000, a more powerful parallel laser source, a smaller gas flow nozzle and a miniature gas turbo fan had developed, it solves the problem of low particle counting number of PM10 because of the low gas flow, the cross-talking between PM1.0 and PM2.5 to PM10 because of the simple optical design for cost consideration which happened in indoor laser PM sensor. Additionally, different kinds of PM generator such as cigarette smoking, A1, mixing of cigarette smoking and A1 and potassium chloride aerosols (Kcl), with different particle size distribution had used for the calibration of this sensor. An optimal calibration algorithm had developed based on the smart detection of particle types.to decrease the temperature effect, a “matrix calibration” with mass concentration from 0-500ug/m3 and temperature range from -40 to 70°C in a 3m3 calibration room had conducted. The field testing of PM4000 had evaluated compared with the Grimm (optical particle counting) and Metone (US EPA certificated Beta-ray type). The results of this work show the PM4000 can be used for detection pf PM2.5 and PM10 for outdoor air quality network application.

Measurements of Horizontal and Vertical Variability of Atmosphere Pollutants Using a Combination of Small-scale Sensors and Remote Sensing Techniques

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In several German cities the air quality standards for NO2 are exceeded frequently. Therefore, it is important to identify the NO2 sources and to study the human exposure to the highly variable distribution of atmospheric pollutants in different areas. In order to do so, we use a combination of remote sensing techniques and small-scale sensors (Electrochemical Sensors, ECS). The advantage of the ECSs is, that they are low-cost, light weight and portable. In order to ensure measurement data quality frequent calibrations of the sensors are needed. We use a Cavity-Enhanced Differential Optical Absorption Spectroscopy (CE-DOAS) instrument for the calibration before and after each measurement campaign. We performed on road measurements using our measurement bus, as well as a bike trailer, and combined the mobile measurements with simultaneous stationary Long-Path DOAS measurements in order to construct a consistent concentration map of different cities. Furthermore, we used airborne sensors on a UAV, glider planes and a Zeppelin to measure vertical profiles.

SESSION IV: Data Management Systems

Mapping Urban Air Quality Using a Network of Low-Cost Sensors: A Data Assimilation Approach

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Recent advances in sensor technology have enabled the construction of small and low-cost platforms for measuring various parameters related to air quality. These platforms are ideally suited to be used within a crowdsourcing or citizen science framework. Due to their small size and lower cost, such devices can be deployed throughout the urban environment at much higher density than what is feasible with traditional air quality monitoring stations equipped with reference instruments. A large network of such low-cost sensors is thus capable of providing significantly more detail regarding the spatial distribution of air pollutants in the environment. However, despite the increased deployment density, such sensor networks continue to require additional information for producing spatially exhaustive maps of air quality throughout the urban environment.

We present here our recent work on mapping real-time urban air quality by combining crowdsourced observations from the recent generation of low-cost air quality sensors with time-invariant data from local-scale dispersion model. The approach is based on data assimilation, which allows for combining observations with model data in a mathematically objective way and therefore provides a means of adding value to both the observations and the model. The observations are improved by filling spatio-temporal gaps in the data and the model is improved by constraining it with observations. The model further provides detailed spatial patterns in areas where no observations are available.

The results indicate that using a network of low-cost microsensors in conjunction with model information is able to provide realistic high-resolution maps of urban air quality. Such detailed urban air quality maps can then further be used for providing personalized information about air quality to citizens. We present examples of how this kind of real-time data allows end users to find the currently least polluted route through a city or to track their individual personal exposure to air pollutants while moving through the urban environment.

Sensor Data Management based upon the OGC Sensor Things API

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The management of sensor data is one of the base services for all kind of applications related to acquiring, storing, retrieving and analysing data. Because of this broad scope of applications, it is crucial that the service programming interface is easy to use, yet powerful and flexible, technically state of the art and standardized. With the Sensor Things API, the Open Geospatial Consortium (OGC) created such a standard and the rapid acceptance by the sensor community shows that it meets their needs.

OGC, as one of the major international standards developing organization, plays an important role in the description of sensors with spatial reference. The SensorThings API is an OGC standard applying long-term established concepts in sensor data description, while using modern technologies for efficient interfaces. The interface is REST based, the data payload is encoded in JSON and the data access protocol is based on OData.

In the talk I will introduce the SensorThings API standard and demonstrate the FROST-Server, which is a standard compliant implementation and available as open source software. I will also touch on the work in progress on using the SensorThings API as INSPIRE-compatible service.

Computational Intelligence Methods for Low-cost AQ Sensor Performance Improvement

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The computational calibration of low-cost AQ sensors consist of the development of different calibration models for the "correction" of a sensor signal under field conditions. We use low-cost sensor readings (and in some cases additional reference meteorological data) in order to develop Computational Intelligence-oriented models that improve the overall performance. For doing so, we require the side by side operation of a sensor node to reference instruments for a period sufficient to depict seasonal changes. We make use of reference measurements to develop, train and evaluate models that will be applied for improving the performance of low cost AQ sensor nodes under real world operational conditions, by improving the uncertainly of the low-cost sensors. In this way, we can comply with the DQO of the European Air Quality Directive. The approach has already been tested in the frame of the EuNetAir Cost Action with successful results, confirming that the standard in-factory calibration performances can be strongly ameliorated by CI-based algorithms. Improved results can also be obtained for sensor nodes for which no in-factory calibration exists. The use of CI methods allows considering low-cost AQ microsensors as appropriate for the support of official AQ monitoring tasks.

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Distributed Network of Inexpensive Air Quality Sensors for Particulate Matter Monitoring in Poland

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Poland has one of the biggest problems with fine particulate air pollution in Europe. Out of 50 most polluted countries in Europe 33 of them are in Poland. To make it worse, many people are unaware they are breathing polluted air because there are no monitoring stations near their locations. Current number of official monitoring stations is insufficient to measure air pollution with enough resolution and many local governments can't afford them. Airly was created two years ago to fight that problem and increase awareness of people living in polluted areas. We created air pollution monitoring system which consist of inexpensive particulate matter (PM2.5, PM10) sensors which send data every 5 minutes to our Platform. Data are analysed and then presented to the citizens through website, mobile apps and API. We also perform air pollution forecasts based on machine learning models which allow to include human-based patterns. Airly system is a solution for local governments allowing them to monitor air pollution and to increase citizens' awareness. The network has more than 2000 devices installed across Poland and few European countries (Berlin, Budapest). With a density not achievable by official monitoring stations our network is able to detect sources of air pollution such as polluting factories, fires of garbage dumps and other. Data openness allows people to analyse air pollution and to find potential causes. Example of such cases will be presented. Airly website and mobile apps are visited by more than 200 thousand users daily.

SESSION V: Small-scale Numerical Simulations

Air Quality Modelling on Urban Scale over Munich

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Chemical-transport models are a persuasive tool to predict and study air pollution on different temporal and spatial scales. However, due to the complexity of physics and chemistry of air pollutants' interactions and lack of precise input data, these models have uncertainties. In particular, most of the emission data have a too coarse resolution and are not appropriate for application in urban scale air quality modelling. In this study, a downscaling approach is utilized for emission data in order to improve the air pollutants concentration simulation over Munich city using the POLYPHEMUS/DLR chemistry-transport model (CTM). Traffic emission from the Bavarian Emission Kataster (EKATBY) 2004 anthropogenic emissions dataset with 2 km resolution is downscaled to 100 m with regard to the high-resolution OpenStreetMap roads paths and areal emission sources are relocated on the most populated and active sites which have been determined from VIIRS NOAA satellite-derived night light data. In addition, the position and level of emissions from the source points are corrected in anthropogenic emission maps, and the EEA CORINE 2012 land use data is implemented with 100 m grid resolution to improve e.g. the biogenic emissions. The CTM is driven by WRF 3.5 meteorological forecasts. In order to have reliable simulations, the one-way grid nesting method with four domains is employed, where the coarsest domain covers Europe and the finest covers Munich city area.

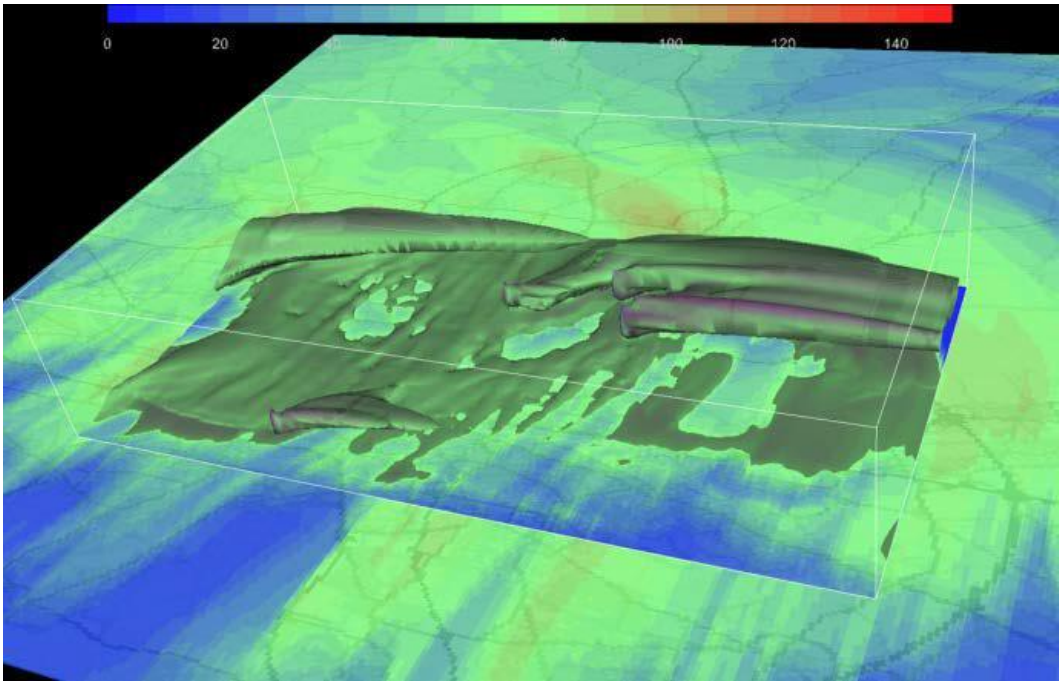

Fig. 1: Simulated NO2 concentration over Munich for the evening second of Feb. 2015

Multiscale Modelling Tools for Flow and Dispersion Calculations in Urban Areas

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2 *Finnish Meteorological Institute, Helsinki, Finland*

Interactions between different spatial and temporal scales play a major role in determining the flow structure and pollutant dispersion in the urban canopy over densely built agglomerations. The intense surface inhomogeneities result in the generation of additional terms in the turbulent transport within the urban atmospheric boundary layer (ABL), which in effect generate equally intense temporal inhomogeneities. Aiming to address the limitations which arise because of these physical differentials between the different scales, schemes for the two-way coupling between mesoscale and the microscale have been applied which utilise collections of multi-dimensional interpolating metamodels. The application of such “proxy” schemes relies on a suitable classification of urban morphologies and land use patterns, including building heights and the orientation of major roads. Application examples include the study of small-sale flows in the cities of Athens and Paris.

In the same context, Large-Eddy Simulation (LES) of the ABL has nowadays become an important research method in accounting for the impact of multiscale interactions in flow and dispersion problems in urban areas mainly because via this method processes across the entire ABL can be resolved. It has recently become possible to include detailed structures, such as buildings in ABL LES, but the modelled areas are still limited in terms of the resolved spatial and time scales. One of the main problems encountered if that the ABL LES domain should cover a large area leading to a need for large computational resources. To account for these problems a two-way nesting was implemented in the parallelized LES model PALM to concentrate resolution to the primary area of interest. In this paper the latest developments in the two-way nesting which are implemented in the parallelized PALM LES model are presented.

High Resolution Urban Air Quality Modelling – Leipzig Case Study

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The objective of this modeling study is to improve our understanding of the budget of short-lived climate forcers and key air pollutants across large urban areas. A special focus is on the influence of cities as local heat source (island effect) and primary emission source of short-lived air pollutants from traffic. The urban impact on airflow and radiation budget will be evaluated for the City of Leipzig using high-resolution atmospheric simulations with grid spacings on the order of 100 m. The simulations will be performed with the COSMO model enhanced by a state-of-the-art building effect parameterization. The dispersion and transformation of air pollutants in the urban environment will then be investigated with the multiscale chemistry-transport model MUSCAT coupled to the urbanized COSMO. Ultimately, this research aims to gain insight into the feedbacks between pollutant emissions, air quality, and climate.

Fine grain air quality and meteorological sensor networks are a promising tool to evaluate and initialize such model simulations. In order to investigate the applicability, a sensor measurement test site will be installed in a city quarter of Leipzig aiming for less than 200m distance between two sensor devices.

SESSION VI: Personal Exposure for Use in Epidemiological Studies

Bioaerosols and Human Health in a Changing World: Need for a Global Electronic Spore and Pollen Information Network (E-SPIN)

Athanasios Damialis [1], Franziska Haering [1], Manuel Glaser [2], Jens O. Brunner [2], Gertrud Hammel [1], Stefanie Gilles [1], and Claudia Traidl-Hoffmann [1,3,4]

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Background: Airborne pollen and fungal spores (bioaerosols) are major causes of respiratory allergy worldwide. Although pollen has been extensively studied, still little is known about fungi. What are the environmental factors affecting bioaerosol abundance? Is there a 'safe' place or time-period that we can 'switch off' bioaerosol exposure and allergies? To answer these, we investigated the spatiotemporal abundance of airborne allergenic pollen and fungal spores in a variety of climatic and pollution regimes, in both field and laboratory conditions and also data-oriented analyses, ultimately attempting to correlate with symptoms of allergic individuals.

Methods: A wide range of pollen and fungal taxa has been examined, locally (Augsburg, Germany), regionally (Bavaria, Germany) and Europe-wide, attempting to detect potential circadian periodicities, seasonality, and long-term trends. Monitoring took place using both conventional volumetric traps (Hirst-type) and novel automatic devices (PoMo, Hund GmbH), on a 2- to 3-hourly basis. Sampling was conducted in a variety of environmental conditions, in terms of vegetation, urbanisation levels, air temperature and pollution levels.

Results: Fungal spores seem to be more abundant when temperature is increased, but with a delay effect, both in field measurements and experimental conditions. Spores showed their peak concentrations mostly in the evening and this pattern was consistent regardless of the bioclimatic zone, air pollution or urbanisation level involved. Regarding pollen, they consistently increased their concentrations with increased temperature and urbanization, locally but also Europe-wide, and seasons became peakier. Specific plant taxa seem to be sensitive indicators of climate change effects, like birch, cypress, plane and plantain. Allergic symptoms of atopic patients are closely related to meteorological factors and abundances of bioaerosols.

Conclusion: Bioaerosol diversity and abundance change over time, in the short- and the long- term. It is expected that this phenomenon will dramatically reflect in the respective allergic symptoms. This poses a potential threat for allergic individuals worldwide and highlights the urgent need for the development of a global bioaerosol information network to warn of high-risk exposure. To achieve this, we need to integrate: novel monitoring techniques like unmanned air vehicles, automatic, real-time bioaerosol monitoring devices, and big data approaches, incorporating bioaerosol distribution data and air quality data.

Using Low-cost Air Quality Sensors for Personal Exposure Assessment

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Quantifying human exposure to air pollutants is a challenging task. In urban areas, air pollution exhibits very high spatial and temporal variability. At the same time, every individual has unique activity-patterns that will result in a different exposure to air pollution. Here we explore how recent developments in sensor and mobile phone technology can enable us to monitor personal exposure to air pollutants while people are performing their daily activities.

We present two methods for assessing personal exposure using low-cost air quality sensors. The first approach involves direct measurement of air pollution using a portable sensor device while a person is moving through the environment. The location information is at the same time provided by the geolocation functionality of the user's mobile phone. The second approach is based on an indirect assessment where only the location information from a mobile phone is required to extract air quality information along a given path from sensor-based up-to-date high-resolution air quality maps. Such maps are typically produced using a static network of low-cost sensors whose observations are combined with information from a high-resolution air quality model.

In both approaches the personal exposure is computed by averaging the air pollutant concentration along a line segment and multiplying it by the time spent on this segment. Moreover, if we measure or otherwise make some reasonable assumptions about the heart rate of the individual it is possible to estimate the inhalation rate (ventilation) and subsequently to assess the inhaled dose over a track. This is important because differences in the ventilation will influence the inhaled doses of air pollution. We demonstrate both approaches with examples from recent projects in both Oslo and other parts of Europe.

Personal Exposure to Ultrafine Particles, Black Carbon and PM 2.5 in Different Microenvironments

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Exposure assessment studies have shown that air pollution measured by fixed monitors at residential locations may not adequately represent individual exposures, especially for times spent away from home. In this study we characterized personal exposures in specific micro-environments to particulate air pollutants from different sources. During three periods, exposure data were collected by a single researcher equipped with personal monitors for continuous measurements of particle number concentration (PNC), black smoke (BS) and PM 2.5 . As pedestrian or passenger in public transportation he was taking the same route including major roads, urban background and industrial areas every day. His position was recorded by a GPS device.

We have shown that personal exposure to PM 2.5 , BC and PNC is always higher than ambient concentration measured at a fixed monitoring station. BC and PNC levels were considerable higher in traffic related scenarios compared to scenarios in residential areas. In contrast, PM 2.5 was found less variable in different scenarios. Moreover, daily averaged personal and ambient concentrations are strongly correlated (PM 2.5 ≈ BC > PNC). This suggests that the day-to-day variation of personal exposure to air pollutants may be sufficiently reflected by a fixed measurement station for use in epidemiological short-term studies. The obtained results provide insight into the potential air pollution levels to which people could be exposed and suggest that personal exposure might be considered in future epidemiological studies in addition to data from the fixed monitoring station in order to get more reliable estimates concerning people’s total exposure to UFP, BS and PM 2.5 , especially when being in traffic or in a near-road environment.

A Novel Tool Supplying Aeroallergen Information and Allowing for Online, Personalized Symptom Monitoring

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Background: Pollen and fungal spores are the most abundant allergen carriers in outdoor air. Pollen allergies affect up to 30% of the German population, causing allergic rhinitis, conjunctivitis and asthma, whereas information about fungal spore allergies in Germany are scarce. Fungal spores have however been associated with the phenomenon of “thunderstorm asthma” in other regions of the globe. It is likely that sensitizations to fungal spores and their clinical relevance are currently underestimated. Smartphone-based “pollen apps” have been available for several years, however, data on the clinical benefit is missing to date. Current “pollen apps”, such as PID´s “Pollen” and “Husteblume”, distributed via the Techniker Krankenkasse, consist of a symptom diary and pollen information based on short-term forecasting models. Throughout the main pollen season, those apps send the users daily reminders to enter their symptoms.

Aim of study and methods: We aim at the development of a novel smartphone-based allergen app that supplies near real-time (3-hourly) pollen and fungal spore information via an automated aeroallergen monitor (“PoMo”; Hund, Wetzlar, Germany). Moreover, the app is supposed to allow patients to enter their symptoms at the very moment they occur, and to supply personalized advice on exposure-relevant behavior and medication to minimize future symptoms. The clinical benefit of receiving aeroallergen information will be evaluated in a randomized controlled trial. In this trial, all patients will be asked to enter their symptoms in the app during their respective allergen season. One group receives near real-time aeroallergen information, a second group receives information based on currently used forecasting models and a third group receives no aeroallergen information at all.

Conclusion: Apart from possible clinical benefit, the app will be a useful tool for exposome research, since it will supply researchers with a high time-resolution of symptom and aeroallergen data.

SESSION VII: Applications of Smart Air Quality Networks

‘Lungs of the City’: A City Center-Scale Intervention Study to Curb Urban Air Pollution

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Environmental innovation company ‘ENS Technology’ is a front runner in the development of innovative solutions to eliminate fine and ultrafine dust from ambient air in new and existing infrastructure (e.g. buildings, public spaces, car parks, tunnels, metro stations).

In the ‘Lungs of the City’ project, we studied the effect of PM emission reduction from car park exhaust by implementation of our proprietary ‘positive ionization’ air purification technology. In close collaboration with Eindhoven University of Technology (TU/e), the effect on ambient air quality was studied using Computational Fluid Dynamics (CFD) simulations, at the scale of a city center (approximately 5 km2; in the city of Eindhoven, the Netherlands). It was shown that the levels of airborne particulate matter (PM) diminished significantly in the direct vicinity of the car parks in which air purification systems were projected. Moreover, this PM-reduction effect extended to a wider area in the surroundings of these car parks. A peer-reviewed manuscript on this study has been published in Journal of Wind Engineering and Industrial Aerodynamics [1].

Recently, we performed an elaborate intervention project to validate this CFD study: In this project, 30 ‘Aufero’ air cleaning systems were deployed to eliminate PM from the total volume of exhaust air of an underground car park in the city center of Eindhoven. Measurements of ambient PM were performed using an extensive network consisting of 14 (Grimm EDM164) environmental monitoring systems, which were placed in a grid surrounding the car park. To our knowledge, this is the first time an ‘in situ’ intervention experiment has been performed on such a large scale. A peer-reviewed scientific publication on this project is anticipated to be published towards the end of 2018.

Further reading:
'Lungs of the City' project website [2], Elsevier Connect [3]

References

[1] Bert Blocken, Rob Vervoort, Twan van Hooff (2016) Reduction of outdoor particulate matter concentrations by local removal in semi-enclosed parking garages: A preliminary case study for Eindhoven city center, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 159, pp 80-98, doi:10.1016/j.jweia.2016.10.008

[2] 'Lungs of the City' project website: http://enstechnology.nl/en/projects/lungs-of-the-city-eindhoven/

[3] Lucy Goodchild van Hilten (2017) How electrifying the air in parking garages could clean our cities. Elsevier Connect, January 25, 2017, https://www.elsevier.com/connect/how-electrifying-the-air-in-parking-garages-could-clean-our-cities

Development of an Air Quality Related Predictive Live Platform Based on Near Real-Time Data (Poster)

Johanna Redelstein [1], Erik Petersen [1], and Andreas Philipp [1]

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Within the context of the SmartAQnet project [1], a forecast model for particulate matter is to be developed. This poster presents the first approaches that make use of the relationship between meteorological variables and particulate matter concentration.
With a cost733class software package developed at the Institute of Geography, a weather classification is to be created, which is specially adapted to particulate matter concentrations in Augsburg. Another method is to train an artificial neural network. For example, GFS forecasts, fine dust measurements of the last hours, vertical profiles of the atmosphere measured with unmanned air vehicles and the time of year are taken as input parameters.

References

[1] Matthias Budde, Till Riedel, Michael Beigl, Klaus Schäfer, Stefan Emeis, Josef Cyrys, Jürgen Schnelle-Kreis, Andreas Philipp, Volker Ziegler, Hans Grimm, Thomas Gratza (2017) SmartAQnet: Remote and In-Situ Sensing of Urban Air Quality, Proc. SPIE 10424, Remote Sensing of Clouds and the Atmosphere XXII, 104240C, doi:10.1117/12.2282698

Applications of Smart Air Quality Networks – a Particle Matter Exposure Driven Traffic Routing (Poster)

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The development of smart air quality networks closes the measurement gap between selective measurements and mesoscalic models or satellite data. This process is driven by the introduction of cost efficient and small air quality measurement units. The thereby achieved knowledge and data can be beneficial for developing applications such as experimental traffic routing driven by particle matter exposure. Such a traffic routing will be developed in the SmartAQnet project [1] using the open source project OSRM.

References

[1] Matthias Budde, Till Riedel, Michael Beigl, Klaus Schäfer, Stefan Emeis, Josef Cyrys, Jürgen Schnelle-Kreis, Andreas Philipp, Volker Ziegler, Hans Grimm, Thomas Gratza (2017) SmartAQnet: Remote and In-Situ Sensing of Urban Air Quality, Proc. SPIE 10424, Remote Sensing of Clouds and the Atmosphere XXII, 104240C, doi:10.1117/12.2282698

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