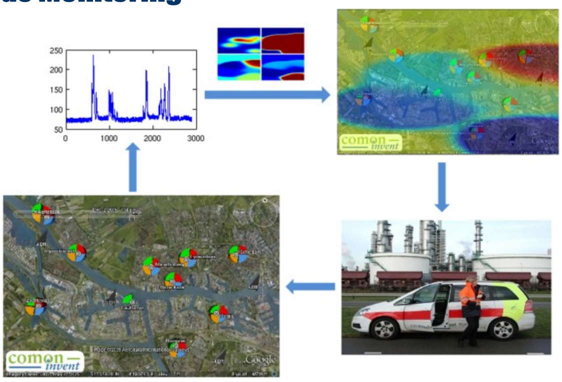
Gas Monitoring

The gas monitoring component handles two tasks: Gas Distribution Modeling (GDM) and Sensor Planning.

The main objective of the Advanced Gas Distribution Models module is to provide data-driven approaches to model gas distribution in a real-world environment. Data-driven gas distribution models reside at the very base of the Diadem system providing domain-specific expertise to the other Diadem components.

The main objective of the Sensor Planning module is to determine the direction of attention for acquiring gas sensor data based on the developed statistical, data-driven gas distribution models. The sensor planning algorithms make suggestions to support control room people in their decision where to send field operators to collect further measurements. They are a central element in Diadem, residing at the end of a decision support chain.

Gas Monitoring



In the scenario addressed by Diadem, data are continuously collected by a network of gas sensors and need to be interpreted on-line to aid the overall assessment of the situation and to point out locations for additional measurements (sensor planning). The gas monitoring component is integrated into the DIADEM system via the Dynamic Process Integration Framework (DPIF) wrapper agents.

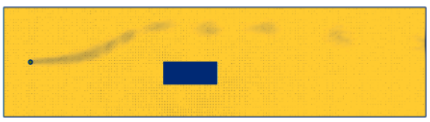
Evaluation

The developed algorithms were evaluated using simulated data and real sensor data from small-scale experiments before they have been applied to large-scale data acquired in Diadem.

Simulated Data

Concentration data can be simulated for situations in which boundary conditions are known. Simulated data are noise-free, directly represent actual concentrations and come with full ground truth.

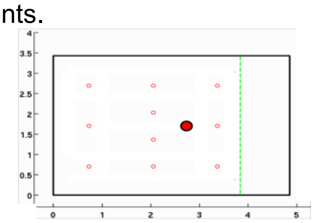
The gas dispersal simulation package developed for Diadem integrates an OpenFOAM fluid flow simulation and a filament-based gas propagation model.



Snapshot of simulated concentration data for a simple situation with a single obstacle. The gas source is located on the left (indicated by a circle).

Small Scale Sensor Data

Using small scale data allows to test the GDM and Sensor Planning approaches in partially controlled experiments with a sufficient number of sensor measurements.



Small scale experiment in a controlled indoor room with size of 3.4x4.4 m^2 and 10 stationary sensors.

Diadem Large Scale Sensor Data

The developed algorithms are used to interpret large-scale data collected with gas sensors by Danish Emergency Management Agency (DEMA) and DCMR Environmental Protection Agency in the port of Rotterdam.

Diadem sensor network in the area of 6000x7000 m^2 with 30 stationary sensors.

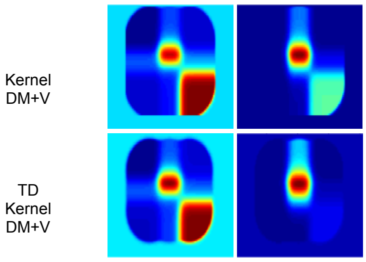
Advanced Gas Distribution Models

Time Dependent Gas Distribution Modelling

While a time-independent random process can capture certain fluctuations in the gas distribution, more accurate models can be obtained by modelling changes in the random process over time. Time-dependent gas distribution modelling introduces a time-scale parameter in a recency function, which relates the age of a measurement to its importance for building the gas distribution model. The time-scale can be learned from the data. It represents a compromise between two conflicting requirements for obtaining accurate gas distribution models: using as many measurements as possible and using only very recent measurements. Time-dependent gas distribution model (TD Kernel DM+V) has been compared with Time-independent gas distribution model (basic Kernel DM+V) on real-world data sets.

Comparison of TD Kernel DM+V and Kernel DM+V

Time-dependent and time-independent models were compared in terms of how likely new measurements are compared to the prediction of the respective model. This is measured with the Negative Log Predictive Density (NLPD). In the comparison, TD Kernel DM+V showed a better performance than Kernel DM+V.



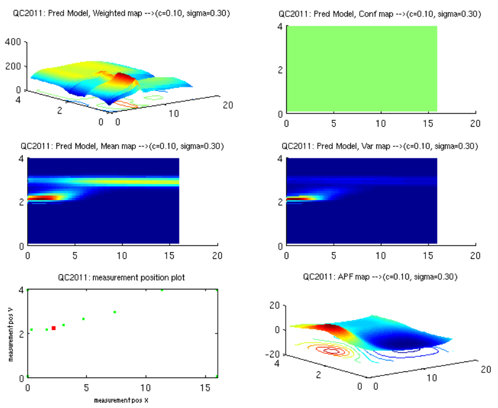
Created maps of predictive mean (left) and variance (right) using Kernel DM+V (top) and TD Kernel DM+V bottom for a small scale experiment.

Data	NLPD (Kernel DM+V)	NLPD (TD Kernel DM+V)	Kernel size(m)	cell size(m)
Small scale experiment	-1.778	**-2.180**	0.420	0.100

Comparison of the NLPD of the time-independent model (Kernel DM+V) and the time-dependent model (TD Kernel DM+V). A lower NLPD is better since it corresponds to a higher likelihood of the predicted measurements. The meta-parameters of the algorithm were learned from the data.

Sensor Planning

To perform sensor planning, an artificial potential field (APF) based approach is used. This approach allows including a number of objectives in the sensor planning, such as even exploration, a tendency to investigate areas of increased gas accumulation and also areas of large model uncertainty. Areas of increased gas accumulation and large model uncertainty are inferred from the gas distribution model. Additional priorities can be smoothly added by operators.

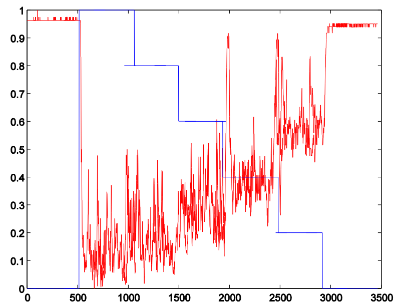


Top: (Left) the integrated weight map and (Right) the confidence map created by the Kernel DM+V algorithm on simulated data. Middle: (Left) the predictive mean map and (Right) the predictive variance map. Bottom: (Left) area with the suggested next measurement points (green dots) and (Right) the calculated APF map.

Using the history of suggested sampling locations and a scoring function allows computing sequences of measurement locations that avoid jumps in the sensor trajectory and are thus suitable for mobile sensors.

Change Point Detection

The main purpose of the Gas Monitoring component is to provide domain-specific information for decision makers. Apart from creating full gas distribution maps by combining sensor measurements obtained at different locations, the Gas Monitoring component also analyzes the sequence of local measurements in order to identify important changes in the sensor response. Due to the response characteristic of the MOX gas sensors used in Diadem, a change is not straightforwardly reflected in an immediate rise or decay of the sensor response. Change points rather have to be detected and discriminated from noise using multivariate time series analysis applied to the set of gas sensors installed at the particular location. The detected changes are then communicated as possibly important events to the decision makers.



Blue line shows the normalized concentration value of ethanol at the source location. The red line in the diagram represents the corresponding normalized sensor response of a Figaro 2611gas sensor.

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Project

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