

Real-World Chemical Plant Monitoring and Event Classification by Multi-Modal Low-Cost Sensor Network

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Summary:

The project MIMOSE-A combines industry and academic efforts to improve monitoring of chemical industry parks. The goal is to detect and locate unwanted events such as gas leaks and fires using low-cost wireless sensor networks. Field tests at a chemical plant site deploy multi-modal sensor nodes equipped with metal oxide (MOX) volatile organic compound (VOC) sensors, and particulate matter (PM) sensors. A fire event near the plant site served as first real-world validation case. A preliminary statistical analysis of PM and VOC sensor responses demonstrates the ability to classify events and in combination with a wind analysis provides initial indicators for possible emission sources.

Keywords: sensor network, leakage detection, gas sensors, fire detection

Background, Motivation and Objective

Unintended gas leaks and fire events at industrial plants pose significant challenges for safety, operational efficiency, and regulatory compliance. Current plant monitoring relies on dedicated sensor systems designed for special applications, e.g. environmental compliance, usually associated with high costs. Trained human operators supplement these systems by detecting unusual or hazardous conditions through olfaction and visual inspection. A low-cost, sensor network could improve spatial coverage and enable continuous automated monitoring. In the project MIMOSE-A, a multi-modal wireless sensor network was proposed and deployed at two chemical facilities in Germany [1]. This paper aims to evaluate the feasibility of the multi-modal sensor network for event detection, classification, and source attribution by a statistical analysis.

Approach

This study presents a first analysis of real-world field test data from the chemical park ISH at Höchst. The sensor nodes, as described in [1], were installed at the plant site, covering an area of 4.6 km². Each node comprises sensors for environmental parameters such as temperature, humidity, gas and VOC (Sciosense ENS160), and PM (Sciosense APC1). The nodes were mounted on poles at heights of 2.0–2.5 m above ground. Meteorological data, including wind direction and wind speed, was obtained from the ISH environmental monitoring stations and

integrated with the sensor data for joint analysis. A root cause analysis requires a documented reference event with known location and time to validate sensor responses against. A fire at the Woolworth store in proximity to the ISH site on 18.02.2025 [2], serves as validation case. The sensor and event locations are depicted in Fig. 1. The fire emits PM and VOC, providing a signature detectable by the sensor [3]. The correlation between VOC and PM sensor responses is analyzed for event classification, and wind data is studied for source attribution.

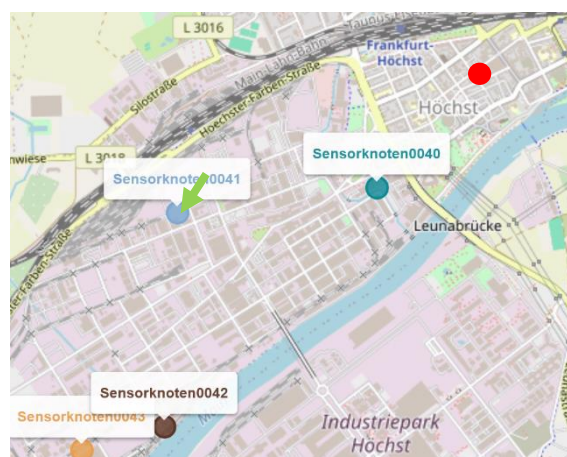


Fig. 1 Positions of the sensor nodes, wind sensor (green arrow in mean wind direction) and fire event (red dot).

Results

The fire event was first reported at 17:30, a strong PM increase was recorded at a public environmental measurement station at Höchst main station at 19:00 [2]. At 20:00 the fire was reported to be under control [2]. Therefore, the period from 18:00 to 22:00, was considered in this study for all evaluations.

During this period, the ISH meteorological station recorded a prevailing wind direction of NNE (32.9° , $\sigma = 10.1^\circ$) with speed 3.0 m/s ($\sigma = 0.4$ m/s), transporting the fire plume towards the sensor nodes, see Fig. 1.

The VOC responses recorded by the sensor nodes in Fig. 2 lack distinctive features attributable to specific sources. The observed PM magnitudes (Fig. 2) significantly exceed background levels from traffic or construction activity, indicating a large-scale combustion event. Clear PM peaks are visible in the time from 19:30 to 21:00, see Fig. 2. Node 40, closest (≈ 1.0 km downwind) to the fire, recorded the largest increase among all nodes. Smaller peaks are visible even ≈ 2.5 km downwind at nodes 42 and 43. Node 41 is located crosswind and shows the least significant response.

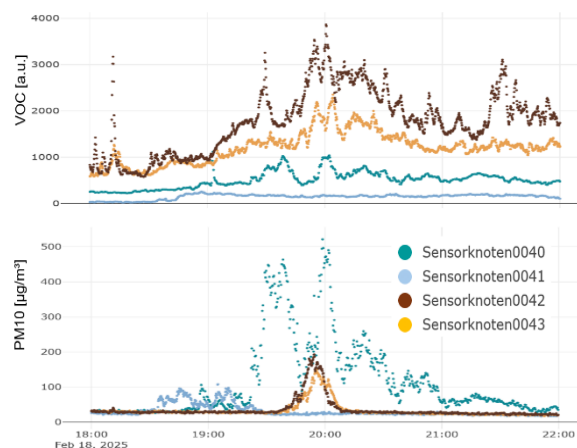


Fig. 2 VOC and PM10 sensor response in the period of the fire event. PM shows clear peaks. VOC responses show ambiguous features.

Fig. 3 depicts the Pearson correlation between VOC and PM responses during the period considered. Node 40, closest to the fire, shows a PM-VOC correlation of ≈ 0.81 , consistent with co-located PM and VOC from a single source. At nodes 42 and 43 (≈ 2.5 km downwind), the local PM-VOC correlation drops to ≈ 0.40 , indicating that VOC signals at this distance may reflect additional local emission sources rather than the fire plume. A cross-node correlation of ≈ 0.90 between VOC-VOC as well as PM-PM at node 42 and 43 supports this interpretation, as both nodes share a common industrial environment with possibly independent emitters.

SK ₄₀	PM	1.000	0.807	-0.219	0.324	0.440	0.599	0.506	0.628
	VOC	0.807	1.000	-0.246	0.667	0.190	0.759	0.244	0.793
SK ₄₁	PM	-0.219	-0.246	1.000	0.171	-0.097	-0.308	-0.075	-0.243
	VOC	0.324	0.667	0.171	1.000	0.032	0.578	0.003	0.623
SK ₄₂	PM	0.440	0.190	-0.097	0.032	1.000	0.390	0.902	0.361
	VOC	0.599	0.759	-0.308	0.578	0.390	1.000	0.388	0.907
SK ₄₃	PM	0.506	0.244	-0.075	0.003	0.902	0.388	1.000	0.409
	VOC	0.628	0.793	-0.243	0.623	0.361	0.907	0.409	1.000
		PM	VOC	PM	VOC	PM	VOC	PM	VOC
		SK ₄₀		SK ₄₁		SK ₄₂		SK ₄₃	

Fig. 3 Pearson correlation matrix of VOC and PM10 for individual nodes (SK) based on 1400 datapoints.

In conclusion, the significant increase in PM magnitudes - far exceeding background levels - indicates a large-scale combustion event as the primary source. A gas leakage, by contrast, produces a predominantly VOC response with negligible PM increase. The combined evaluation of both sensor modalities therefore enables classification of fire versus leakage events.

Summary and outlook

This study validates a low-cost multi-modal sensor network for event detection and classification at an industrial chemical park. PM sensors detect the fire plume up to 2.5 km downwind, while the combined PM-VOC correlation enables discrimination between combustion events and gas leakages. The sensor network thus provides a scalable complement to conventional plant monitoring at low cost.

Further work includes evaluation of temperature modulated MOX sensor signals, assessment of machine learning methods for the detection of unwanted events and methods for gas source localization.

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