

Multi-sensor Systems for Safety-related Monitoring

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Abstract:

The benefits of combining different types of sensors to multi-sensor systems should be demonstrated by means of three different examples of actual developments carried out by BAM Federal Institute for Materials Research and Testing: a micro-drone for gas measurement in hazardous scenarios, sensor enabled RFID tags for safeguard of dangerous goods, and a multifunctional sensor for spatially resolved under-surface monitoring of gas storage areas. Objective of the presented projects is to increase the personal and technical safety in hazardous scenarios. These examples should emphasize the potential of multi-sensor systems and point to application specific challenges for the applied components and infrastructure.

Key words: multi-sensor system, condition monitoring, safety management, hazardous scenarios, data-fusion

Introduction

The handling of dangerous substances (toxic, explosive, harmful for human and/or the environment) often requires the usage of sensor systems, e.g. to measure the status of a process, to enable early warning in case of an accident, or to evaluate the situation after an accident happened. In many cases not only one measuring variable is sufficient for a comprehensive evaluation of such scenarios, demanding for technical solutions with integration of multiple types of sensors. Technical enhancements like miniaturization, data processing, and wireless communication are the basis for application specific multi-sensor solutions. Data-fusion offers sophisticated possibilities to analyze and clarify the hazard potential of relevant situations – in many cases quasi in real-time.

The following examples present multi-sensor concepts applied in different scenarios of condition monitoring and safety management.

Micro-drone for Gas Measurement in Hazardous Scenarios

A research project was carried out at BAM with the objective to develop a flying remote-controlled measuring system. The system is capable of operating in a variety of scenarios of gas emission, e.g. exhaust gas from a chimney, flue gas in case of a fire, gas emission in case of an accident of chemical or hazardous goods [1]. Another addressed field of application is spatially resolved emission control of geody-

namic active regions, waste disposals, stockpiles, landfills, CO₂ storage areas (CCS), industrial sites and pollution critical areas. Due to its mobility the system can measure the gas concentration in the immediate vicinity of the object which causes the emission. A further stage of extension is the enhancement of the system for identification of gas source locations, and gas distribution modeling/mapping (GDM). The latter applications are implemented based on the combined analysis of position dependent gas concentrations and wind vector data.



Fig. 1. Micro-drone equipped with gas-sensitive payload in flight.

Gas concentration measurement from an airborne platform (AR 100-B, AirRobot, Germany, Fig. 1) is demanding in terms of weight, dimensions, energy consumption, influence of the rotors, and speed of the sensing device. A gas-sensing payload was developed on basis of a commercially available gas detector (X-am

5600, Draeger, Germany), which was originally designed as personal safety equipment. The device features low weight and compact design. The modular concept allows the ad hoc exchange of four sensors in the gas detector, which enables users to customize it for their specific application.

Due to the weight restrictions imposed by the platform (max. payload 200 g), the micro-drone does not carry any wind sensing modalities. Instead, wind measurements are estimated by fusing the different on-board sensors of its inertial measurement unit to compute the parameters of the wind triangle [2]. The wind triangle is commonly used in navigation and describes the relationships between the flight vector, the ground vector, and the wind vector. The micro-drone can be operated manually or in GPS mode, e.g., by autonomous waypoint following.

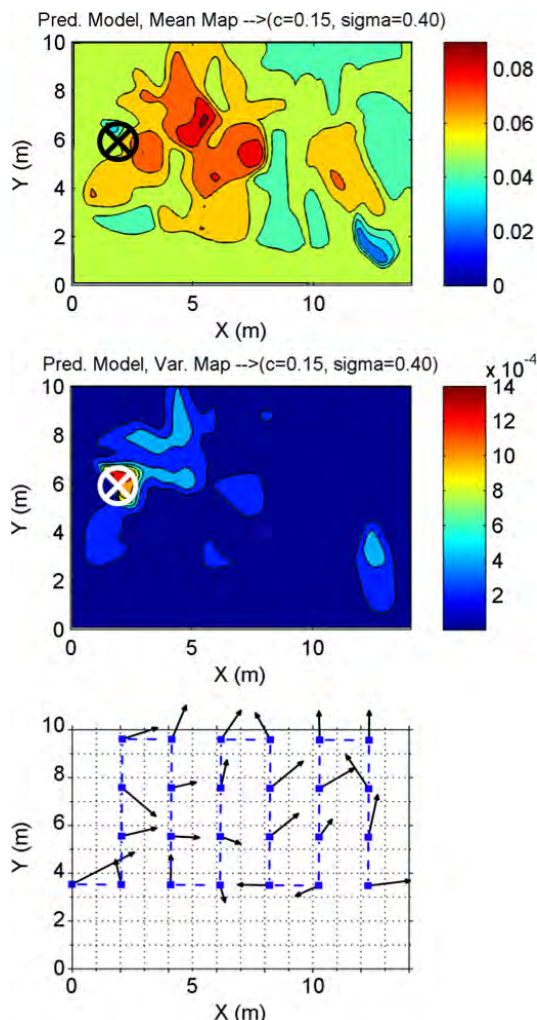


Fig. 2. GDM Experiment: Predictive mean (top) and variance map (middle) of the gas distribution and the corresponding mean airflow map (bottom) and the path of the micro-drone created using Kernel DM+V/W. The gas source was located approx. at position (2, 6) m and is denoted by the cross. The concentration value of CO_2 is given in % by volume.

Both, gas distribution modeling and plume-tracking were enabled using data-fusion algorithms. For plume tracking three promising algorithms were implemented and adapted accordingly to meet the system characteristics of the micro-drone: the surge-cast algorithm (a variant of the silkworm moth algorithm), the zig-zag/dung beetle algorithm, and a newly developed algorithm called “pseudo gradient-based algorithm”. First successful tests were performed in real-world experiments [3].

To build a predictive gas distribution model, the Kernel DM+V/W algorithm introduced by Regente and Lilienthal [4] was used. The input to this algorithm is a set $D = \{(x_i, r_i, v_i)\}_{1 \leq i \leq n}$ of gas sensor measurements r_i and wind measurements v_i collected at locations x_i . The output is a grid model that computes a confidence estimate, as well as the distribution mean and variance for each cell k of the gridmap (Fig. 2).

Additional instrumentation for temperature and humidity is implemented but so far not taken into account. It is conceivable to use these data for sensor compensation algorithms or to correlate the environmental conditions, e.g. in the case of fire. Integration of optical or IR data is another viable aspect.

Sensor Enabled RFID tags for Safeguard of Dangerous Goods

The project SIGRID investigates and assesses possibilities to improve safety and security of dangerous goods transports through the use of the latest RFID technology [5]. This technology can be used to greatly enhance the transparency of the supply chain and aid logistics companies in complying with regulations. In the context of SIGRID custom RFID sensor tags (Fig. 3) were developed to monitor dangerous goods during transport and help to prevent hazards by allowing timely countermeasures. This requires the combination of communication technology and sensor functionality with low power consumption and small design.

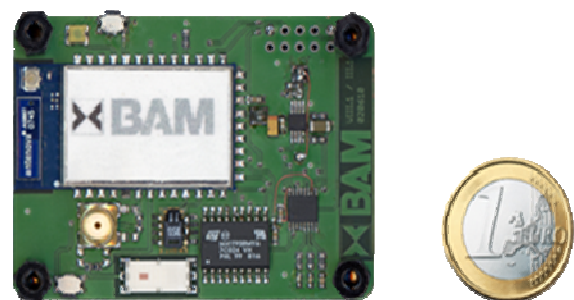


Fig. 3. Prototype of the sensor enabled RFID tag

To achieve long battery-life, the use of very energy efficient sensors is mandatory. Other

Glass fiber optical sensors use the effects of stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS) for spatially resolved measuring of temperature and strain. Distributed strain measurements can also be performed with polymer optical fibers using optical time-domain reflectometry (OTDR). BAM develops, validates and uses such sensor systems in different areas of application, such as geotechnics, structural engineering, and physical protection.

Combining these two sensor types (membrane sensor and fiber sensor) to a multifunctional sensor offers an innovative and promising approach for spatially resolved monitoring of large-scale areas. Both technologies offer advantageous specifications, which support and encourage their combination:

- Distributed, area-wide applicable measuring system with spatially resolution of all variables
- Scalable and adaptable form of application, depending on monitoring object and problem
- Non-invasive system (no influence on the monitoring object, due to permanent presence of the sensor in the ground)
- No sensitivity against electro-magnetic fields (e.g., lightning and high-voltage lines)
- Applicable in explosive surroundings (no electrical components at the measuring locations)
- High thermal and chemical robustness
- Comparatively reasonable components

The structural combination is accomplished by linkage of the sensitive elements membrane sensor and optical fiber. For this purpose, geogrid materials (Fig. 6) act as a carrier material.



Fig. 6. Geogrid with integrated fiber optical sensors.

Combined data analysis should be investigated and further developed to attain synergy effects, increase the sensitivity and informational value, and address new fields of application. Using sensor data fusion allows in-depth analysis of

soil processes and early detection of relevant changes. For instance, the combined analysis of gas concentration, temperature, and strain can enable an indication of very small crack formation and gas emission, with significant higher reliability compared to sole gas measurements.

Two immediate fields of application are addressed: Landfills produce greenhouse gas and warmth. The combination of both measurement methods should allow a potent landfill monitoring by containment of chemical active areas and leakages. Underground storage of CO₂ as part of CCS as well as extraction and production of gases from geological areas can lead to mechanical changes of the deck rock (lowering / elevation) with which a regional tension field is build up. Thus gas-leading gaps can be induced which cause local ground structure changes. The simultaneous measurement of spatially resolved gas concentrations and strain allows the development of an efficient early warning system.

The validation, optimization, and practical demonstration of the overall system are carried out on the BAM Test Site Technical Safety (BAM TTS) [9]. For this purpose, a test field in application relevant scale of 20 x 20 m² is under construction.

Conclusion

Safety related monitoring often is necessary in complex scenarios. It requires distinct information to evaluate the situation and to determine the further operation. The combination of several measurands can improve the informative value of a monitoring system in terms of measuring diversity and accuracy.

To display the great potential of such systems, three examples for monitoring in safety relevant scenarios are presented in this paper, which combine multiple application specific sensor techniques. Using data-fusion offers broad possibilities to further enhance the performance of multi-sensor systems.

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