Developing a novel network of CBRNe sensors in response to existing capability gaps in current technologies

Szklarski, Łukasz, Maik, Patryk, Walczyk, Weronika

Łukasz Szklarski, Patryk Maik, Weronika Walczyk, "Developing a novel network of CBRNe sensors in response to existing capability gaps in current technologies," Proc. SPIE 11416, Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XXI, 114160Y (24 April 2020); doi: 10.1117/12.2558044

SPIE.

Event: SPIE Defense + Commercial Sensing, 2020, Online Only

Developing a novel network of CBRNe sensors in response to existing capability gaps in current technologies

Łukasz Szklarski, Phd[a], Patryk Maik[a], Weronika Walczyk[a]
[a]ITTI Sp. z. o.o., Rubież 46, 80-180 Poznań, Poland

ABSTRACT

State-of-the-art CBRNe detection systems are predominantly available as standalone detectors, rarely offering the potential of networking and data fusion. This paper presents a novel CBRNe detection and identification system based on the network of heterogeneous sensor nodes. The system uses a novel data fusion algorithm combining data from the sensors, advanced machine-learning and modelling algorithms to significantly reduce false alarm rates. The situational awareness tools and training compounds supplement the system to provide innovative real capabilities for CBRNe practitioners.

Keywords: CBRNe, detector, sensor network, situational awareness, heterogeneous sensor nodes.

1. Introduction

Recent years have shown without doubt that the threat of chemical weapon use against civilians will not cease without action. Both military and civil defence require fast and reliable methods for detecting agents at or below levels that pose a health risk for accurate assessment of severity and extent of a hazard and efficient use of countermeasures.

Following the progress reports under the EU CBRNe Action Plan and under the Action Plan on Enhancing the Security of Explosives in 2012, a new CBRNe Agenda was set out to focus on key priorities to be addressed at EU level.[1] The new CBRNe Agenda states that the following issues must be addressed in any effective mitigation strategy to improve the detection of risks and promote awareness-raising, training sessions, and exercises amongst others:

- The effectiveness and performance of existing equipment and processes;
- New threat substances;
- New modus operandi for attacks;
- New concealment methods to attempt to by-pass security controls;
- New attack targets (soft targets, critical infrastructures, public areas, non-aviation areas).

Better detection is especially highlighted in the new CBRNe Agenda because fast detection of an incident is paramount to safeguard the life and health of the population. The ability to rapidly detect CBRNe incidents equates to faster response times, reduced hazard exposure, and more efficient use of limited resources. This requires building robust situational awareness for first responders and the crisis management in (near) real-time.

The EU-SENSE consortium has been collaborating with the ENCIRCLE – a European project that aims to strengthen the CBRNe efforts in Europe by consolidating communities of suppliers and practitioners. One of ENCIRCLE's activities includes cataloguing gaps in CBRNe technology, allowing to set the direction of projects based on the crucial needs of the present CBRNe detection. EU-SENSE consortium comprising SMEs, research institutes and academic entities took on designing and developing novel tools corresponding with the identified needs.

Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XXI,
edited by Jason A. Guicheteau, Chris R. Howle, Proc. of SPIE Vol. 11416, 114160Y

The EU-SENSE targets the following gaps:

- Detection system capable of detecting a large spectrum of agents;
- Systems integrating technological tools with security management organizational frameworks;
- Advanced noise-filtering algorithms based on machine learning;
- Databases of environmental noise (clutter) from various environments based on raw sensor data;
- Scalable systems for monitoring large areas and environments;
- Improved real-time dispersion modelling;
- Systems available for an untrained person;

The targeted gaps are compliant with studies conducted by the International Forum to Advance First Responder Innovation.

This paper proposes another step in chemical detection, by developing a novel network of sensors for CBRNe applications through the exploitation of chemical detection technologies, advanced machine learning, and modelling algorithms.

The EU-SENSE consortium took on developing a system network of stationary and person-worn sensors, capable to detect a large-spectrum of chemical agents through the implementation of heterogeneous sensor nodes – nodes that incorporate different types of sensors. EU-SENSE created a unified data model to guarantee the interoperability of the network components working with heterogeneous data. The novel data fusion algorithms allow for correlation and combination of data from sensors, machine learning of the environment and contamination modelling to significantly reduce false alarm rates. To support smooth implementation of the system within end-user institutions, better decision-making, and preparation of emergency scenarios, the EU-SENSE includes a training mode of the sensor system for effective familiarization with the equipment, practise and emergency planning.

The work on the discussed CBRNe system is conducted in the European consortium working on the EU-SENSE project funded by the European Commission under grant agreement no. 787031.

2. EU-SENSE system architecture

The defined EU-SENSE system architecture is divided into three layers, namely the Situational Awareness layer composed of the Situational Awareness Tool and the training module, the Computational layer composed of four data processing tools: Data Fusion, Source Location Estimation Tool, Hazard Prediction Tool, and Environmental Noise Learning Tool, and the Network of Sensors layer composed of network of a sensor controller and multipurpose chemical sensor nodes, both stationary and mobile (Figure 1).

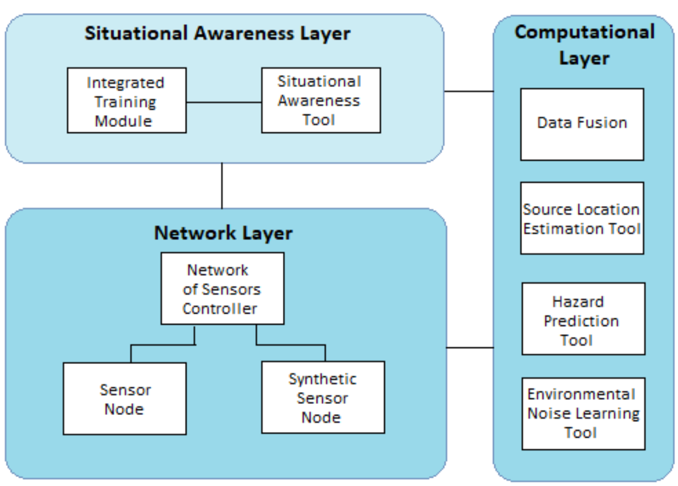

Figure 1: EU-SENSE system high-level view (Source: own material)

In order to ensure that the system is extendable and scalable the concepts of component-based and modular architectures are being used in compliance with the system-of-systems approach to define and specify the EU-SENSE system architecture. Moreover, a unified data model and interfaces were defined as a part of the work on the architecture. The EU-SENSE platform works as a distributed system, which can be easily extended by implementing additional components and functionalities such as additional sensor nodes (of various types) and computational tools (e.g. additional data fusion tools).

International standard ISO/IEC/IEEE 21839 (ISO, 2009) provides a following definition of System of Systems:

System of Systems (SoS) — *Set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on its own,*

while Maier (1998) suggests a set of characteristics of a SoS: 1. Operational independence of component systems; 2. Managerial independence of component systems; 3. Geographical distribution; 4. Emergent behaviour; 5. Evolutionary development processes.[2]

There are four categories used in literature to describe SoS, based on the communication within the SoS (Figure 2)[3]:

- Virtual SoS: The SoS does not have a central management authority or a centrally decided common purpose.
- Collaborative SoS: The individual constituent systems work together to fulfil a shared central purpose. However, there is no central authority to manage the SoS-related activities of the constituent systems.
- Acknowledged SoS: The SoS has a designated central management nod and recognized objectives on the SoS level.
- Directed SoS: The central management unit responds to the elements of the system.

For the EU-SENSE system, the SoS approach is mainly realized as a Directed System of Systems through the use of independent tools. These tools are:

- Situational Awareness Tool (SA Tool) – A software component providing an access point to the EU-SENSE system and to the Graphical User Interface (GUI). The SA Tool renders visualization and network of sensor control functionalities including sensors location, readouts, and status.
- Hazard Prediction Tool – This tool will run FOI Dispersion Engine to perform air dispersion calculations to predict concentration levels following a chemical release described either directly by the SA tool or as calculated by the Source Estimation tool.
- Source Location Estimation Tool - This tool will run an inverse version of the FOI Dispersion Engine together with an optimization algorithm to calculate the source's strength and position.
- Environmental Noise Learning Tool - The component will be deployed on a standalone system and mainly implements algorithms for processing of continuously incoming raw sensor data in order to detect anomalies (in the preparedness phase) and verify whether the situation has normalized through normality detection (in response phase).

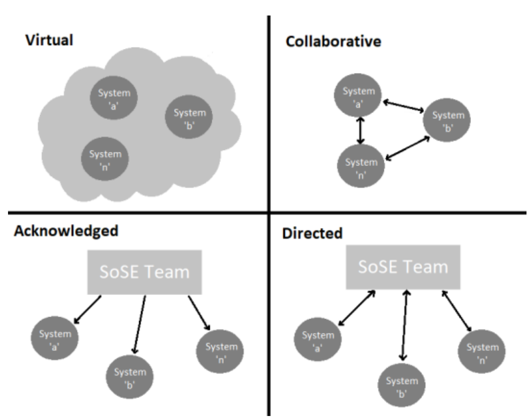

Figure 2: Types of Systems of Systems (adapted from Lane, 2013)[3]

The development of complex sensor networks and application of the system-of-system approach is often burdened with interoperability issues which, in the case of the discussed system, stem from the differences in data schemas, formats, and models in particular components. This is especially evident in the discrepancies in third party devices including Proengin FPD detector and TNO MO detector. In the case of these sensors, the data format cannot be modified.

The proposed network system puts a high priority on ensuring the sensor node interoperability, understood as the capability to connect a node with any of the supported sensors and adaptability with different sensor sets. The desired interoperability is achieved by a unified data model based on two elements. The first is a network configuration standard, which is implemented as a set of XML files meant to be shared among the system components. This ensures that every EU-SENSE component "knows", which sensor is connected to the network and what kind of data is available. The standard is based on a hierarchical structure, which reduces the information redundancy. The XML files are divided based on the abstraction level of the description - including inter alia, network, node, and sensor levels. The second element of the EU-SENSE data model is a set of files describing communication between the system components. These include mainly protobuf messages description files. Some of the messages, especially those describing sensor data frames, are based on the XML configuration files and can be generated automatically, enabling developers easy adaptation of the system to the potential new sensors.

This paper focuses on the network of sensors solutions and the situational awareness tool - as well as the added value of heterogeneous sensor nodes.

3. Network of sensors

3.1 Network of Sensors Controller

The central point of the network of sensors layer of the system is the Network of Sensors Controller, connected wirelessly to the Sensor Nodes. The controller is responsible for the communication and direct management of the sensor nodes, as well as reconfiguration of the network, thanks to the standardised configuration schemas. The component is capable of receiving and merging data, forwarding it to the local database and subscribers in real-time. The controller provides an interface to the system allowing a user to configure it and register to the list of subscribers.

Main functions and capabilities of the controller include:

- Collecting and decoding raw streams of measurements from connected Sensor Nodes.
- Transmitting sensor measurement data collected from the Sensor Nodes into the local database.
- Configuring and reconfiguring Sensor Nodes.
- Checking the status of the network components.

The system provides near-real-time (data refreshed per 1 second) localisation information of each sensor node.

From the development view, The Network of Sensors Controller's main functionality is to provide a standardized and unified communication with sensor nodes. The implementation of this component enables the separation of the data collection layer from other subsystems. Moreover, it facilitates the network of sensors management process. A Network of Sensors Controller diagram is presented in Figure 3.

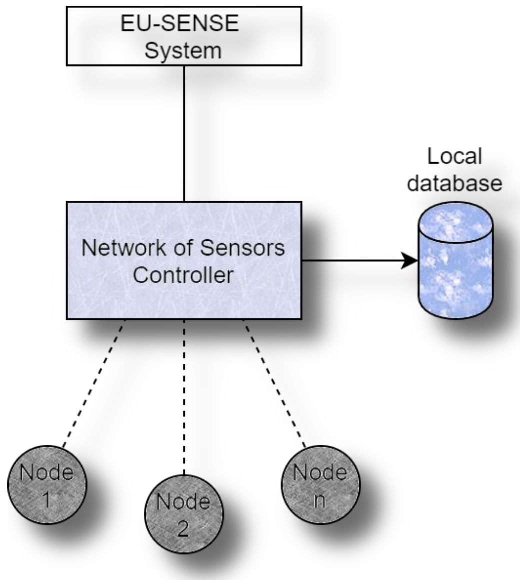

Figure 3: Network of Sensors Controller (Source: own material)

The Network of Sensors Controller includes three components: process control, runtime configuration and local database for sensor data storage. The first one manages sending and receiving of messages, both external and internal, while the second one stores and manages current configuration. The database is responsible for storing historical measurements and environmental data. The controller can check the status of a sensor on request and periodically.

There are four major functionalities of the Network Controller. The first is a configuration, which covers the initialization and remote calibration of nodes. XML configuration schemas are sent to the network of sensors controller, which verifies if all required sensors are available and is responsible for nodes configuration. The second functionality is to subscribe and unsubscribe requests. Other components can send a subscription request to the network of sensors controller. The controller sends all received sensor data to the active subscribers.

The main activity of the network of sensors controller is dedicated to the acquisition, storage, and transmission of sensors data. The data are broadcasted from sensor nodes to the controller. When the data are received, they are sent simultaneously to active subscribers and local database storage. Apart from the subscription-based access to data, the network controller also provides an interface for historical data acquisition.

3.2 Heterogeneous sensor nodes

Figure 4: Sensor Node Prototype (Source: own material)

The network of sensors layer is composed of heterogeneous chemical sensor nodes (Figure 4). Heterogeneity in the context of the project means, that several chemical detectors based on different technologies are being applied within a single node. The heterogeneous sensor nodes providing a large variety of data, together with data fusion algorithms allow for the detection of a large spectrum of chemical agents and reduction of false alarms.

Since EU-SENSE aims at creating an adaptable and multipurpose detection system, the network is based on both stationary and mobile sensors, which allow for adapting the network to different conditions and various mission types including mass events or industrial incidents.

The sensor node unit comprises sensors for chemical detection, a node controller based on STM32F4 microcontroller, pre-processing algorithms and configuration components. The applied sensors provide interfaces to the node controller while the node configuration component stores the list of sensors, description of data format, and interfaces specification. Such design allows for quick reconfiguration of the node and simple adaptation of various sensor types. The node controller is the core processing point of the node, which is responsible for receiving/sending messages to external components and acquiring data from the sensors. The pre-processing algorithms are a conceptual component that ensures algorithmic functionalities.

The sensor node integrates the following 4 specific detectors (Figure 5): Airsense IMS detector with ammonia chemistry with integrated Photon Ionisation Detector (PID), Airsense IMS detector with water chemistry with integrated Electrochemical Cell (EC), TNO SRD MetalOxide detector, and Proengin AP4C flame photometric detector (FPD)

As for the technologies used, the detectors based on Ion Mobility Spectroscopy (IMS) draw air into the reaction region where its content is ionized. Subsequent reactions of charged molecules create a pattern registered by a detector plate. A plot of ion current generated over time indicates the agent's concentration. Flame Photometry detectors burn an air sample, emitting light of specific wavelengths, extracted by an optical filter. Most elements produce a wavelength characteristic enough to be differentiated this way.[4] Metal Oxide sensors detect the concentration of substances by measuring the resistance change of the metal oxide due to the adsorption of gases. Oxygen at the surface of the metal oxides is reduced by the target gases, allowing more electrons in the conduction band of the material, which is recorded as a sensor signal correlating to the concentration of the target gas.[5]

These sensor units are connected to the sensor node, which communicates via dedicated interfaces, i.e. Bluetooth, RS232, and USB. Based on STM32F4 microcontroller, the sensor node integrates the data from all connected detection devices. The device provides a microSD memory card slot. Furthermore, the microcontroller has been equipped with a GPS module, which serves a dual purpose. The primary purpose of this module is to attribute a timestamp to each generated data frame by the node. Each data frame consists of data from readouts from all connected sensors. One data frame is generated per second. The secondary use of GPS is the positioning of the node, which is essential to establish its localisation in the SA tool. The integrated output of the sensor node is transferred by the network of sensors controller for post-processing by the data fusion component.

As a rule, the lower the frequency, the higher the transmission range may be achieved at the expense of bandwidth. For this reason, network devices use the 2.4 GHz frequency for communication. The communication is established with the use of modules based on ESP8266 chips. The modules are supplied with 3.3V voltage, which when powered by a battery will keep the device portable. These modules are controlled via the UART interface with a built-in command interpreter for easier functionality.

Figure 5: Detectors (Source: own material)

3.3 Network communication

Internal communication between the Network of Sensors Controller and Sensor Nodes uses WiFi devices and their protocols (Figure 6). Sensors are divided into smaller networks with Sensor Nodes serving as Central Units of these networks. Each of those smaller networks is connected to the Network of Sensors Controller to form a larger, long-distance network. This type of network can be classified as a Tree Topology Network.

- Sensors transmit data over much shorter distance, allowing the use of low-power transmitters or direct cable connection.
- Splitting the network into subnetworks makes it easier to manage.
- Does not require a line of sight between the Network Controller and individual sensors.
- A line of sight between the Network of Sensors Controller and Sensor Nodes might be required to achieve a better signal range.

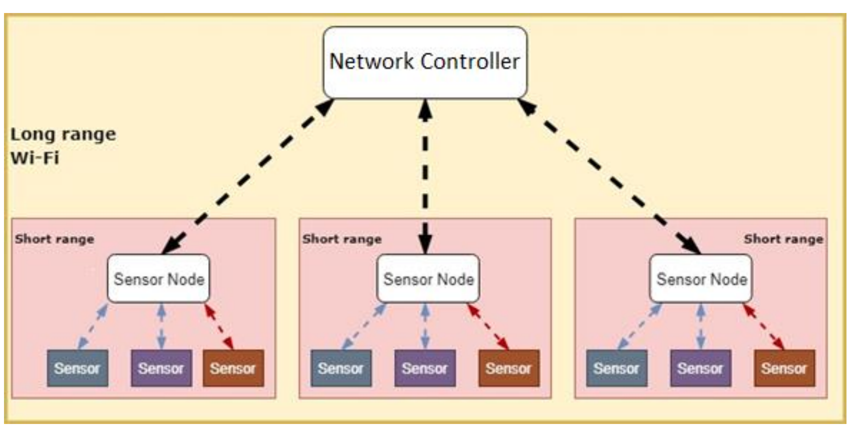

Figure 6: Internal communication schema (Source: own material)

The Wi-Fi module is responsible for creating a TCP server for the network controller to connect. A remote user can control and supervise the system during the data collection. The necessary node configuration e.g. information about the connected sensors, addresses of Bluetooth devices, node identification parameters are stored locally on the SD card.

4. Situational awareness tool

One of the salient purposes of the project is the improvement of the situational awareness of CBRNe practitioners. Therefore the highest layer of the EU-SENSE system is the Situational Awareness layer, which integrates the results coming from the network of sensors and data fusion output, display the data to CBRNe practitioners and aid the decision making process. The Situational Awareness Tool is an access point to the system from the end user's perspective.

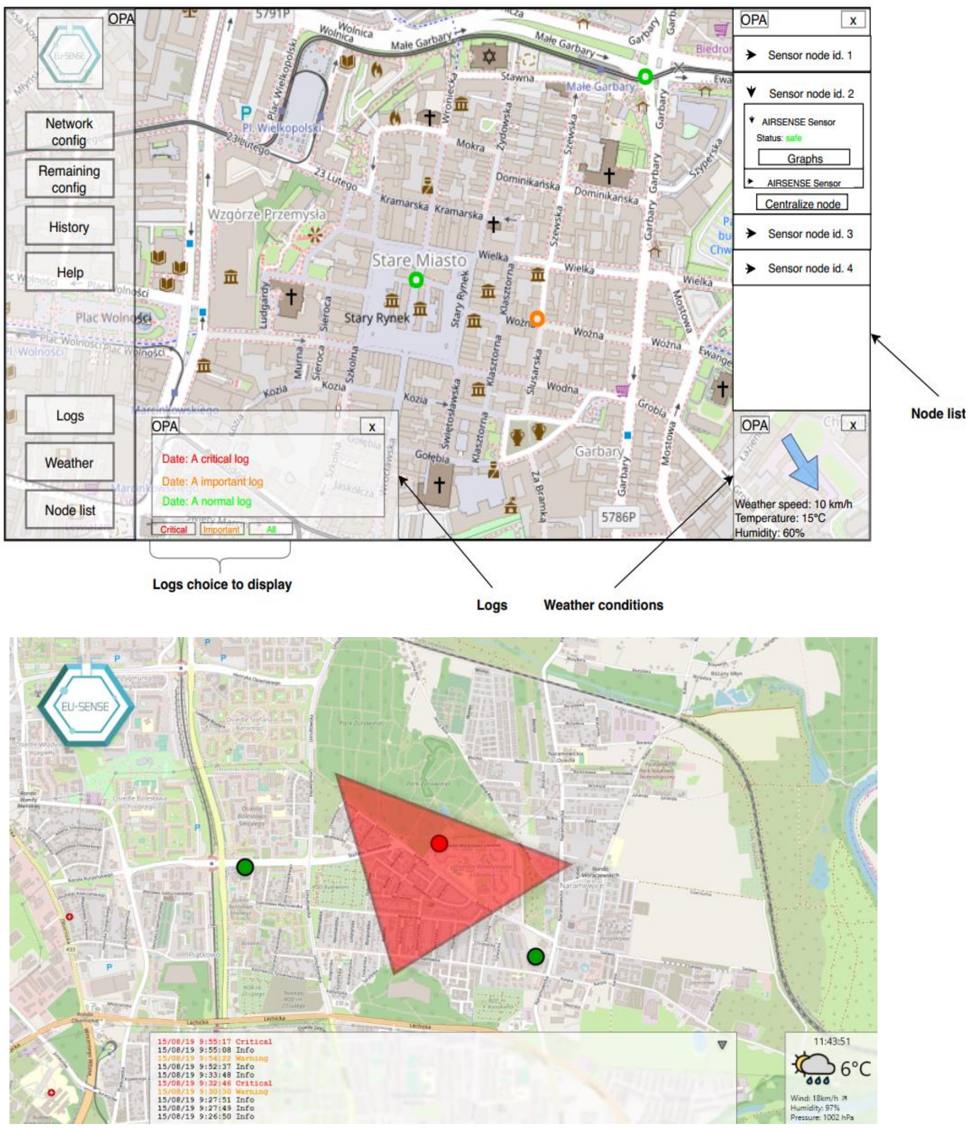

Figure 7: Prototype of the situational awareness tool graphical user interface (Source: own material)

Situational Awareness Tool outputs visualization of sensors location, readouts, and status, as well as the network of sensors control functionalities. All of the computational Tools of the EU-SESNE system can be accessed through the SA Tool.

The tool is responsible for managing the computations (especially in case of Hazard Predication and Source Location Estimation tools) by preparation of the necessary input data. The implemented graphical user interface (GUI) (Figure 7) allows for processing pipeline configuration as well as for selection of the active components. Manual control, such as triggering hazard prediction with a pre-defined source location, raising and cancelling the alarm is also being enabled. A user of the system can select system operation mode in GUI between the following available options: Training, Preparedness, and Response. Furthermore, this layer covers training functionality, implemented as an integrated module in the Situational Awareness Tool.

5. Conclusions

The ambition of the EU-SENSE project is to provide real capabilities for European CBRNe practitioners in order to improve three salient aspects including threat detection, situational awareness, as well as training and simulation.

The proposed system incorporates a modern and highly effective network of sensors, novel computation tools and algorithms, an intuitional user interface and a training mode allowing to introduce all these components to the end-user effectively. The heterogeneous sensor nodes in conjunction with the novel data fusion algorithm create the next step in the detection of a wide range of substances while reducing false alarm rates. The developed situation awareness tool makes access to the system for untrained users easier than ever before.

The value coming from the EU-SENSE is its open architecture design. It allows scalability and further extendibility of the system with additional hardware and software items of external companies. Therefore, is believed that the EU-SENSE system will give impetus to the development of novel hardware and software solutions which provide innovative real capabilities of CBRNe practitioners.

References

[1] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a new EU approach to the detection and mitigation of CBRN-E risks. May, 2014.

[2] Maier, M.W., "Architecting Principles for Systems-of-Systems." Systems Engineering, 1998.

[3] Lane, J.A., What is a system of systems and why should I care? [online] USC Center for Systems and Software Engineering, 2013.

[4] Institute of Medicine (US) Committee on R&D Needs for Improving Civilian Medical Response to Chemical and Biological Terrorism Incidents; Washington (DC): National Academies Press (US), 1999.

[5] N. Barsan, U. Weimar, Fundamentals of Metal Oxide Gas Sensors, Institute of Physical and Theoretical Chemistry, University of Tuebingen, , Germany, 2012.