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Extended Abstract

Simulating Defects in Environmental Sensor Networks Using Stochastic Sensor Models†

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Abstract: Chemiresistive gas sensors are an important tool for monitoring air quality in cities and large areas due to their low cost, low power and, hence, the ability to densely distribute them. Unfortunately, such sensor systems are prone to defects and faults over time such as sensitivity loss of the sensing material, less effective heating of the surface due to battery loss, or random output errors in the sensor electronics, which can lead to signal jumps or sensor stopping. Although these defects usually can be compensated, either algorithmically or physically, this requires an accurate screening of the entire sensor system for such defects. In order to properly develop, test, and benchmark corresponding screening algorithms, however, methods for simulating gas sensor networks and their defects are essential. In this work, we propose such a simulation method based on a stochastic sensor model for chemiresistive sensor systems. The proposed method rests on the idea of simulating the defect-causing processes directly on the sensor surface as a stochastic process and is capable of simulating various defects which can occur in low-cost sensor technologies. The work aims to show the scope and principles of the proposed simulator as well as to demonstrate its applicability using exemplary use cases.

Keywords: environmental sensors; sensor networks; fault detection

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1. Introduction

Networks of chemiresistive gas sensors can be used to continuously monitor the different gases in areas of interest with a considerably high spatial density [1]. One major drawback of using this technology can be their stability over long time scales. As different faults can occur over time, the measurement accuracy can degrade consecutively. Such defects can be caused by different processes on the sensor, which can affect the signal output in different ways. Examples would be a loss of sensitivity, sensor stopping, signal jumps and battery loss as they are shown in Figure 1.

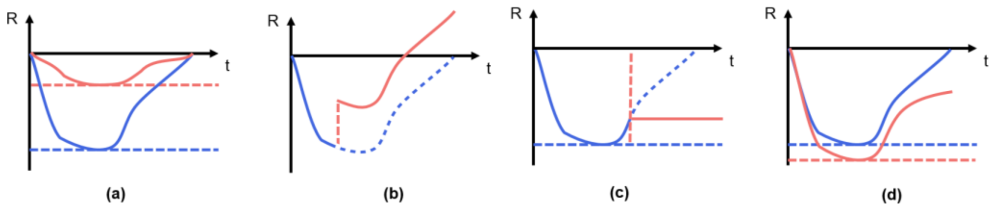


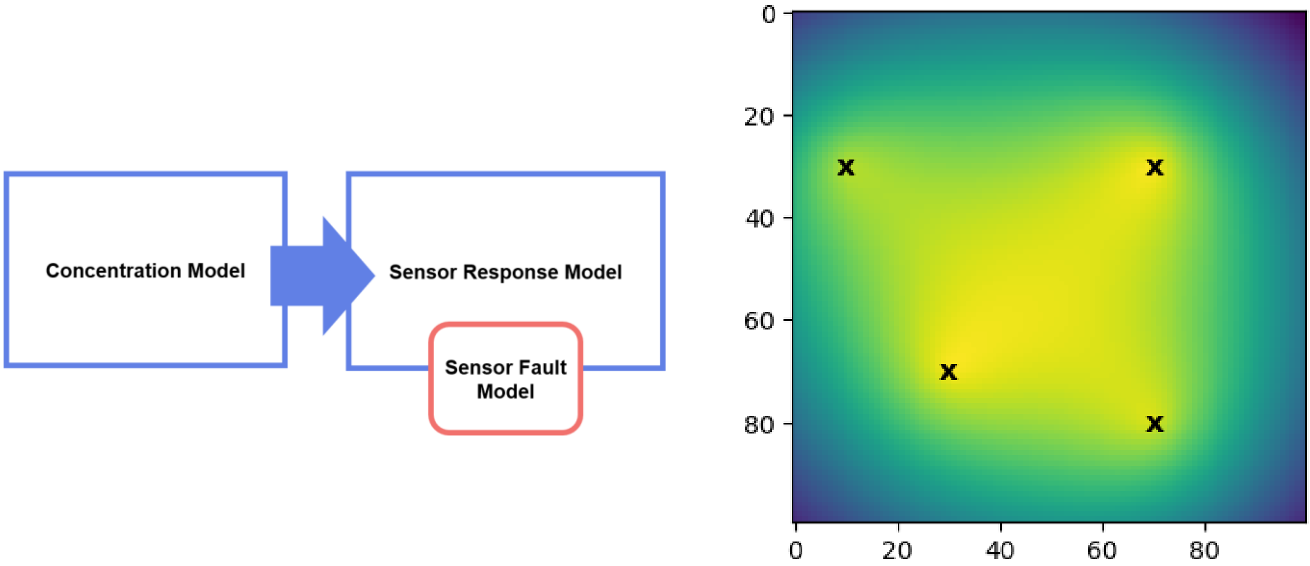
Figure 1. Different examples of defects (original signal in blue, defect in red). (a) Sensitivity Loss leading to a lower resistance response to a gas concentration. (b) Signal Jump causing an abrupt additive change in the signal. (c) Sensor Stopping leading to constant sensor outputs and (d) Battery Loss causing a lower heating temperature, which leads to a slower sensor recovery process.

In order to repair or replace individual faulty sensors inside the network, it is necessary to have screening algorithms which continuously evaluate the current state of the sensor network in terms of possible defects. Hence, for general wireless sensor networks, such algorithms have been already investigated [2]. In order to generate and assess such algorithmic approaches for chemiresistive gas sensors, however, simulation data exploring different sensor network scenarios is necessary. For the specific case of sensor drift, such frameworks have already been investigated to evaluate calibration algorithms, e.g. in [3]. Therefore, in order to study other fault types, we want to present a framework based upon a stochastic sensor simulator [4], which can provide sensor network simulations specifically feasible for a number of different sensor defects.

2. Methods

Our sensor network simulation framework consists of three different parts, which are depicted in Figure 2 (a). In the **Concentration Model**, an array of different gas sources is simulated in order to calculate the spread of the emitted gases across the simulation area and thus simulate their local distributions. The output of this model is the time-dependent concentration series which would be measured at each of the sensor locations. These concentration time series are then the input of the **Sensor Response Model**. An illustration of the concentration distribution calculated by the Concentration Model is shown in Figure 2 (b).

The Sensor Response Model then translates the input concentrations at each sensor location to the expected sensor signal measurements. This is done by using a stochastic sensor model which has been developed in previous research [4].



(**a**) (**b**)

Figure 2. (a) shows the setup for the simulation framework. (b) shows an exemplary gas distribution created by four gas sources which are marked inside of the image.

In particular, the Sensor Response Model simulates the processes which are directly occurring on the sensor surface by modeling its adsorption and desorption processes on a microscopic level. Finally, the **Sensor Fault Model** generates faults in the synthetic signals. Due to the flexibility of the sensor model, two different approaches can be followed here, as shown in Figure 3.

On the one hand, the faults can be generated after the signal simulation by manipulating the output signal (**post-simulation faults**). On the other hand, the faults can be generated intrinsically in the sensor simulation as well (**intrinsic faults**). Here, sensitivity loss can be modeled by switching off sensor sites in the sensor surface simulation, whereas battery loss can be generated by changing the heating properties in the model parameters. Both these methods have advantages and disadvantages. Post-simulation faults tend to be rather efficient, since they can be generated spontaneously from a normal signal with respect to the needed sensor fault. However, since a formula is applied here after the simulation, these defects seem to be less accurate. This is the main advantage of the intrinsic approach, since the defect is simulated on the sensor surface, leading to a higher accuracy. This approach is less efficient, however, since every case has to be simulated beforehand.

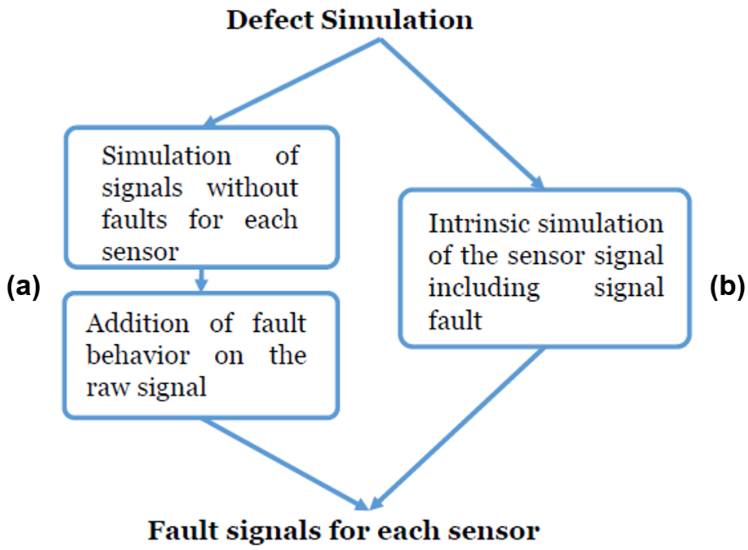


Figure 3. Different Approaches for the Sensor Fault Model. (a) shows a post-simulation approach, where the faults are added after the sensor signal was simulated by the Sensor Response Model. (b) shows the intrinsic simulation approach, where the fault behavior is integrated in the Sensor Response Model.

3. Results and Discussion

The different defect types have been implemented intrinsically in the stochastic sensor model by adjusting the heating parameters for battery loss fault simulation and changing the amount of responsive binding sites on the simulation grid for sensitivity loss simulation. Signal Jumps and Sensor Stopping have been implemented as post-simulation faults. In order to test the model, a set of four concentration pulses followed by clean air have been simulated to show the impact of the different faults on the signal. These can be seen in Figure 4.

It can be seen that the sensitivity loss leads to a lower response to the concentration pulses, which is in-line with the physical expectations. Also for the battery loss, which should lead to lower heating capabilities, a signal change can be seen. Here, the recovery process for the sensor signal is not as efficient as for the original signal, which leads to an additive drift caused by slow recovery. Also the processing defects such as Sensor Stopping and Signal Jumps are represented well in the simulation experiment.

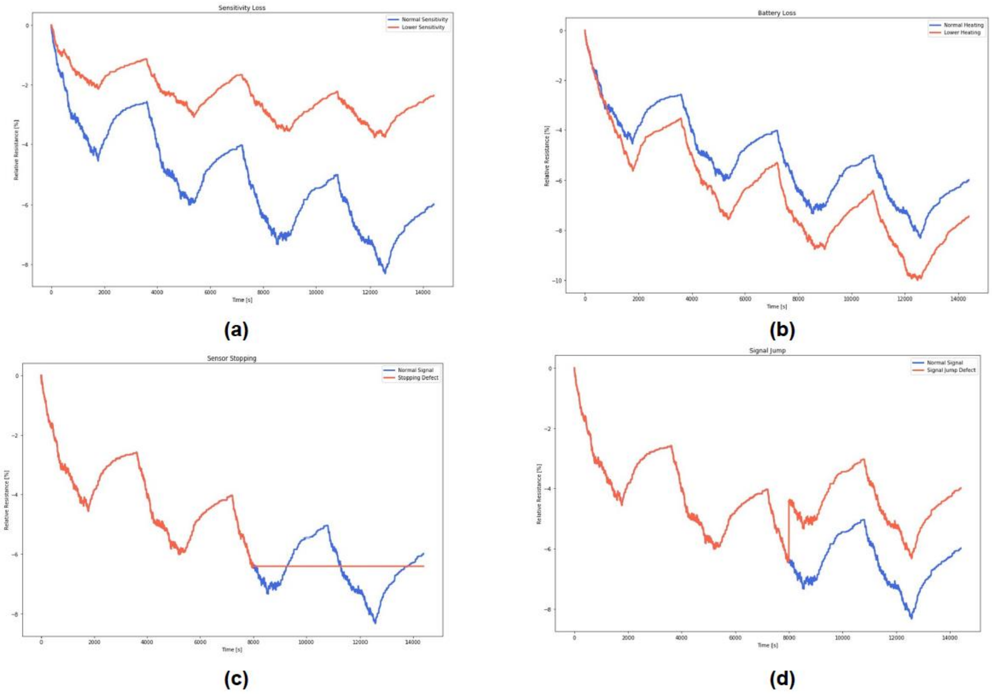


Figure 4. Different Signal Outputs for the different sensor fault types implemented in the stochastic model. (a) Sensitivity Loss (b) Battery Loss (c) Sensor Stopping (d) Signal Jumps.

4. Conclusion and Outlook

It can be noticed, that our simulation framework is suited for simulating various defect effects which can be used for algorithm development for fault detection. There are different design choices to be made which are influenced by computational efficiency and fault accuracy. Therefore, additional research has to be done in this area as well.

In future research, also other faults might be considered for simulation. For example, interfering gases might be an effect which should be studied in more detail for this kind of sensor.

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