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Gas sensor array for reliable fire detection

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Abstract

In fires, release of volatiles usually happens before generation of smoke/airborne particles. Therefore, fire detection systems based on chemical gas sensors may respond faster than systems based on smoke detectors, which currently cope the market. However, fire detectors based exclusively on gas sensors are prone to false alarms. A key element in those systems is the associated signal and data processing since the detector should discriminate fires form other volatile sources (nuisances). Here, we present a gas sensor array composed of different gas sensing technologies for early and robust fire detection. The gas sensor array was placed in a measurement chamber along with commercially available smoke-based detectors. To test the prototype different types of fire and nuisances were performed in the chamber. Results confirmed the benefits of the gas sensing approach since nuisances were rejected and, for some types of fire, the system based on gas sensors triggered the fire alarm faster than the smoke-based detectors.

Keywords: Fire detector; Sensor fusion; Fire alarm; Gas sensor array; Machine Olfaction; Multisensor system

1. Introduction

Nowadays, widespread fire alarm systems are based on the detection of smoke. Basically, two sensing techniques for smoke detection emerge for commercially available fire alarm systems: photoelectric detectors (light scattering) and ionization detectors. The main hypothesis underlying the development of fire detectors based on gas sensors is

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that gases and volatiles appear, in many fire types, before smoke is released. The early emission of gas opens the possibility to build fire alarm systems with shorter response times than smoke-based detectors.

First steps in fire detection with chemical sensors began with sensitivity studies of different sensing technologies to relevant combustion products, mainly CO and CO_2. Although sensor sensitivity to volatiles released in fires confirmed the feasibility of chemical sensing for fire detection, gas sensors also show significant cross-sensitivity to water vapor and to wide range of volatiles that are released during many common daily activities [1–3]. As a result, chemical based fire detectors are prone to false alarms. Therefore, sensor developments for reliable fire detectors need to go beyond the mere study of sensor sensitivity to combustion products, and the investigation of cross-sensitivity to interfering volatiles/scenarios is necessary as well.

In order to suppress the mentioned cross-sensitivities of chemical sensors and provide reliable fire detection systems, sensor fusion algorithms have been explored in the literature. The challenge of the algorithms is the detection of fires while rejecting nuisances. Different algorithmic solutions have been explored, such as logic rules [4], neural network [5], probabilistic neural network [6], hierarchical Linear Discriminant Analysis [7] or k-nearest neighbors [8]. However, still further work is necessary to improve detection time and nuisance rejection of fire alarms based on chemical sensing.

2. Methodology

2.1. Experimental Setup

A prototype based on off-the-shelf gas sensors was integrated in a 272-liter measurement chamber in which different fire types and nuisance scenarios were performed. More specifically, the customized sensor platform was composed of an 8-MOX gas sensor array (two units of AS-MLK, AS-MLC, AS-MLX, AS-MLN; provided by AMS, working at two different temperatures each sensor type), a PID sensor (PID-A1; Alphasense), a NDIR CO_2 sensor (IRC-AT; Alphasense), a CO electrochemical sensor (CO-BF; Alphasense), and a temperature and humidity sensor (SHT75; Sensirion). The prototype integrated signal conditioning electronics and communication protocol for data acquisition.

For further reference, additional commercially available gas sensors and fire alarms systems (smoke detectors) were also integrated in the measurement chamber. Such systems enabled the benchmark of different sensing technologies and the comparison of response time of chemical sensing fire alarms with respect to smoke detector alarms. Multisensor x7000 (Dräger), PID sensor ppbRAE 3000 (RAE Systems) and NDIR CO2 GasCheck (Edinburg Sensors) were continuously sampling the air next to the developed prototype. Moreover, two smoke detectors were also placed in the measurement chamber: photoelectric smoke detector SLR-24H (Hochiki) and ionization smoke detector S250 (NOVA-500). Figure 1 shows the developed prototype and the reference smoke detectors that were placed at the top of the measurement chamber.

2.2. Experimental Protocol

Fire carried out in the measurement chamber were designed to resemble fire standards (EN-54) as much as possible. To do so, burning materials were carefully selected and their quantities were adjusted to the dimension of the chamber. Additionally electrical fire (cable) was included in the set of conditions. Also, different nuisance scenarios were performed in the measuring chamber. In particular, we employed distilled boiling water, air freshener, ethanol (96% purity), and two commercial cleaning products (vinegar and floor cleaner). Table 1 details all fires and nuisances that were performed in the chamber in four days.

2.3. Sensor Fusion algorithms

Classifiers to discriminate fire from non-fire scenarios were built using Partial Least Squares Discriminant Analysis (PLS-DA). After sensor selection, PLS-DA classifiers were trained using the MOX 8-sensor array, NDIR and electrochemical sensors from Alphasense, electrochemical sensor for H_2 included in the Dräger system, and humidity sensor from Sensirion. The measurements performed in 3 days were selected to train the model (2 or 3 replicates of each scenario). The measurements from the remaining day were used to validate the model. This methodology was repeated 4 times, until each replicate was used for model validation.

Fig. 1. The developed multi-sensor platform was placed on 272-liter measurement chamber in which different type of fires and nuisances were performed. Two commercially available fire alarms based on smoke detection were also integrated in the measurement chamber.

Table 1. Repetitions of fire and nuisances performed in the chamber. SF (smoldering fire); N (nuisance).

Scenario	Type	Number of Repetitions
TF2 (pine wood)	SF	3
TF2bis (beech wood)	SF	4
TF3 (braided cotton wick)	SF	3
Electrical fire (flat cable)	SF	4
Ethanol	N	4
Boiling water	N	4
Cleaning product	N	3
Air freshener	N	4
Vinegar for cleaning	N	3
Temperature increase	N	3

3. Results

Sensor signals captured during a TF3 fire and during a cleaning product exposition are shown in Figure 2. It confirms the challenge of fire detection using chemical sensors: gas sensors respond to combustion products, but they also respond to the presented nuisance (cleaning). Nevertheless, presented measurements provide an example of the ability of the calibration model to discriminate fire from non-fire as the system triggers the alarm for TF3 but the alarm is not set when cleaning products are introduced in the chamber. Moreover, the chemical-based fire detector triggered the alarm before smoke-based systems (in this particular example only ionization detector set the fire alarm). Detector sensitivity increased for larger time windows used for the prediction model. However, larger time windows resulted in larger system response times.

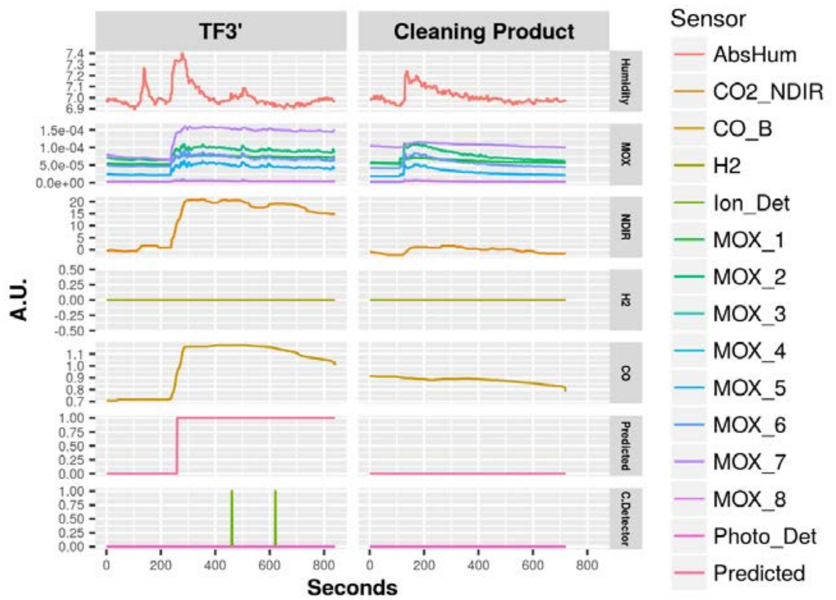

Fig. 2. Sensor signals when they are exposed to fire (left) and nuisance (right). Smoke-based fire alarms (bottom panel) trigger alarm after chemical-sensing system (second bottom panel). In this example, photoelectric detector does not trigger alarm for TF3.

4. Conclusions

A multi-sensor system based on chemical sensing was integrated in a measurement chamber in which different fire types and nuisances were performed. A model based on PLS-DA was trained to build a classifier to discriminate fire from non-fire situations. Results indicated that the system is able to discriminate fire from non-fire scenarios, and, for certain fire types, trigger the alarm faster than traditional fire detectors based on smoke detection. Nevertheless, further work is still required to shorten response time and improve the reliability of fire detection systems based on chemical sensing.

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References

[1] D. Gutmacher, U. Hoefer, J. Wöllenstein, Gas sensor technologies for fire detection, Sensors Actuators, B Chem. 175 (2012) 40–45.
[2] G. Pfister, Detection of smoke gases by solid state sensors - A focus on research activities, Fire Saf. J. 6 (1983) 165–174.
[3] J. Knoblauch, N. Illyaskutty, H. Kohler, Early detection of fires in electrical installations by thermally modulated SnO2/additive-multi sensor arrays, Sensors Actuators B Chem. 217 (2015) 36–40.
[4] T. Oyabu, An algorithm for evaluating disasters by fuzzy reasoning, Sensors Actuators B. Chem. 10 (1993) 143–148.
[5] D. Kohl, J. Kelleter, H. Petig, Detection of Fires by Gas Sensors, Sensors Updat. 9 (2001) 161–223.
[6] S.L. Rose-Pehrsson, R.E. Shaffer, S.J. Hart, F.W. Williams, D.T. Gottuk, B.D. Strehlen, S.A. Hill, Multi-criteria fire detection systems using a probabilistic neural network, Sensors Actuators, B Chem. 69 (2000) 325–335.
[7] T. Conrad, P. Reimann, A. Schütze, A hierarchical strategy for under-ground early fire detection based on a T-cycled semiconductor gas sensor, Proc. IEEE Sensors. (2007) 1221–1224.
[8] M. Ni, J.R. Stetter, W.J. Buttner, Orthogonal gas sensor arrays with intelligent algorithms for early warning of electrical fires, Sensors Actuators, B Chem. 130 (2008) 889–899.