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Abstract

Smart Odour Sensing for Automated Monitoring of Bread Products †

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Abstract: This work proposes an electronic nose (e-nose) system based on resistive gas sensors to predict the cooking evolution of different types of bread. The e-nose includes six metal-oxide semiconductor (MOS) gas sensors, a low-noise electronic system for signal conditioning and data acquisition, and a classification algorithm for real-time detection of the cooking stage. Baking tests with five different recipes were carried out, and the system performances were evaluated by a panel of tasters, obtaining a -88% accuracy for the automatic detection of cooking time.

Keywords: electronic nose; gas sensors; process control; industry 4.0; real-time classification

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1. Introduction

E-nose application in the food industry represents a low-cost solution for quality assessment, process monitoring, and optimization of energy resources [1]. During bread baking, different groups of volatile organic compounds (VOCs) are released in each stage of the fermentation and cooking process, but few studies in the literature have shown that e-noses can be used to monitor this process [2]. For example, Gancarz et al. and Ponzoni et al. [3,4] demonstrate the applicability of e-noses for the detection of key aromas of different bread cooking stages, but do not show the real-time operation of the system in the harsh environment of in-oven operation. In this context, this work presents a new e-nose system for the real-time detection of the cooking stages of bread, applied to a set of five different recipes.

2. Materials and Methods

The experimental setup included a commercial oven, where six gas sensors of different types (Figaro TGS26-00/10/20) were installed, along with temperature and relative humidity sensors. A low-noise electronic system was used for modulated signal conditioning and acquisition to track the sensor resistance and the environmental sensor signals. A data acquisition board logged the data on a computer where a classification algorithm implemented in Matlab was used to predict the bread cooking status. The bare captured resistance traces were affected by the (i) electronic noise of the system, dominated by 1/f contributions from thin-film resistors (Figure 1a) and amplifiers [5] and (ii) huge oscillations due to the humidity changes inside the oven, where a heating element was periodically activated. The acquired signals were thus filtered to remove the oscillations, while 1-kHz signal modulation mitigated 1/f noise. Five bread recipes, with different ingredients and baking procedures, were considered: bread roll (BR), semola (SE), ciabatta (CB), multigrain

(MG), and Val Venosta (VV). To account for the different lengths of different bread analyses, an algorithm based on principal component analysis (PCA) was used to select the best down-sampling frequency to apply to the acquired data. After this frequency was selected, a set of two features was extracted from the down-sampled version of the analysis and used as input for the Support Vector Machine (SVM) classifier, which had been trained considering 84 analyses, whose features (area under the curve and resistance ratio) were extracted at 3 different times, representative of the "Medium", "Cooked", and "Burnt" stages.

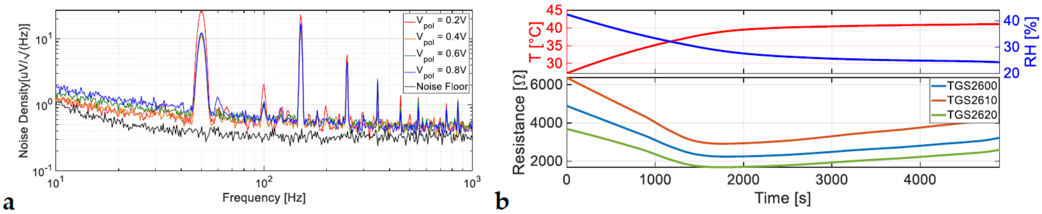

Figure 1. (**a**) Measured noise density of a TGS2620. (**b**) Temperature, humidity and resistance values of three of the gas sensors during the bread baking process.

3. Discussion

The real-time operation of the system was then tested. The classification algorithm uses the features extracted from the real-time acquired signals (Figure 1b) to predict the cooking stage (Figure 2a). After the fifth "Cooked" prediction, the oven was stopped, and the bread was evaluated by a panel of tasters on a scale from 1 to 5. The correct cooking stage of 3–4 was obtained for ~88% of the analyses (Figure 2b). These performances will be further improved by expanding the training dataset, leading to a reliable e-nose system for smart ovens.

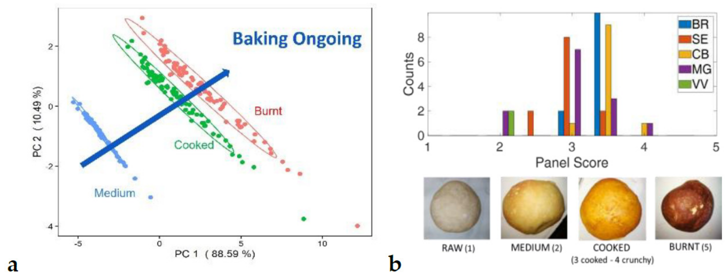

Figure 2. (**a**) PCA score plot of the dataset. (**b**) Sensorial evaluation of bread samples.

Author Contributions: C.B.: project management, e-nose training; B.d.D.: software; A.T.: noise measurements; N.D. and F.C.: project management; G.L.: supervision; L.C.: project coordination, supervision. All authors have read and agreed to the published version of the manuscript.

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