chemistry proceedings

Proceedings

Characterization of Unpleasant Odors in Poultry Houses Using Metal Oxide Semiconductor-Based Gas Sensor Arrays and Pattern Recognition Methods †

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† Presented at the 1st International Electronic Conference on Chemical Sensors and Analytical Chemistry, 01—15 July 2021; Available online: https://csac2021.sciforum.net/.

Abstract: In this study, the ability of an electronic nose developed to analyze and monitor odour emissions from three poultry farms located in Meknes (Morocco) and Berlin (Germany) was evaluated. Indeed, the potentiality of the electronic nose (e-nose) to differentiate the volume fractions of hydrogen sulphide, ammonia and ethanol is investigated. Furthermore, impact change of relative humidity values (from 15% to 67%) on the response of gas sensors has been reported and reveals that the effect remains less than 0.6%. Furthermore, the relevant results, confirmed that the developed e-nose system was perfectly classify and monitor the odorous air of poultry farms.

Keywords: Poultry odorous air monitoring; electronic nose; gas sensors; pattern recognition methods

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Chem. Proc.* **2021**, 3, x. https://doi.org/10.3390/xxxxx

Published: 01 July 2021

1. Introduction

Unpleasant odors are an integral part of poultry production. They come from wastes and emissions of animals. In addition, poultry farms in close proximity to the population generate volatile organic compounds (VOCs) in the air, resulting in a foul odor similar to that of rotten eggs and waste [1]. Moreover, odor nuisance from poultry farms has raised serious concerns about the quality of human life worldwide. Unpleasant smelling air affects the mental and physical health of the population and causes anger [2]. Similarly, the health of hens and farm workers can be threatened by malodorous chemical compounds (such as hydrogen sulfide and ammonia) emanating from poultry farms [3]. Therefore, appropriate methods and techniques are needed to characterize and monitor odorous air samples and to help determine the effects of malodorous air on chickens, humans and the agricultural environment.

Although olfactometric techniques are the most widely used to analyze odorous air based on the perception of a group of human sniffers. These techniques are very expensive and do not provide information on chemical composition [4]. Elsewhere, analytical methods are widely used for quantitative analysis of odorous air samples to identify unknown organic compounds and their concentration [5]. However, they provide little information on the observed effect of odors on receptors, and are expensive, time-consuming and non-portable. The problems associated with the use of conventional odor air analysis methods could be replaced by the application of faster and cheaper e-nose technology. Electronic noses are devices equipped with a set of gas sensors combined with pattern recognition methods that provide a specific signature of the analyte [6,7]. The last few decades have seen a significant increase in interest in chemical sensors, which is reflected in the growing number of papers and conferences on this topic. For this purpose, these instruments are used in various applications for routine, rapid and inexpensive assessment related to the environmental sector [8,9]. Similarly, in recent years, odor emissions from livestock farms have received increased attention due to their large number resulting in the production of high concentrations of hydrogen sulfide and ammonia [10,11]. Electronic noses are also applied in other fields, including biomedical, pharmaceutical, food, security, and so on [12–15].

In this work, the ability of an electronic nose to discriminate malodorous VOC from three poultry farm sites was investigated. In parallel, the monitoring of malodorous air emissions from a poultry farm as a function of the time and date of collection was carried out. In addition, the effect of relative humidity on the response of the gas sensors was checked. The sensitivity to hydrogen sulfide, ammonia and ethanol was tested. Pattern recognition methods such as Principal Components Analysis (PCA), Discriminant Function Analysis (DFA) and Support Vector Machines (SVMs) were used for processing the data from gas sensors responses.

2. Materials and Methods

2.1. Odorous Air Samples Collection

Odorous air samples were collected using 2L-Tedlar bags from two poultry farms located in Meknes (Morocco), and Berlin (Germany). In parallel, to verify the ability of e-nose to monitor odorous air samples from a poultry farm, odorous air samples were collected in the poultry farm of Meknes neighbor at different times and in three different days, with an interval of two days of one week. In total, 126 odorous air samples were collected (14 samples by each time collection performed at 09:00 a.m., 12:00 p.m. and 18:00 p.m.).

2.2. Gas Sensors System

The developed electronic nose system consists of six MQ-type chemical sensors (MQ-3, MQ-4, MQ-5, MQ-8, MQ-9 and MQ-135) from Winsen Electronics Technology Co, Ltd, Zhengzhou, China. The sensor chamber contains also a relative humidity sensor (HIH 4000) and a temperature sensor (LM35) to monitor the environmental conditions during measurements. All the sensors were installed in a Teflon chamber with a volume of 270 cm^3. The collected odorous air samples were transferred to the sensor chamber using a Tedlar bag and a micro air pump. The sensor responses were acquired by NI-USB 6212 data acquisition from National Instruments (Texas, USA). It allows signal conversion and preparation for further analysis by changing the analog signal produced by the sensors into its discrete digital representation.

2.3. Sensing Measurements

During analysis, the samples were pumped during 5 minutes into the sensor chamber at a flow rate of 250 mL/ min. The data were acquired every second. After each measurement, synthetic air was injected during 5 min into the sensor chamber to clean the surface of the sensors to return to their baselines.

The volume fractions of Hydrogen sulfide (6 ppm), Ammonia (7 ppm), and Ethanol (3 ppm) were adjusted with the Gas Mixing System (GMS) of BAM, Berlin.

2.4. Data analysis

2.4.1. Features Extraction

In this study, three features were extracted from the response of each gas sensor:

- $\Delta G = (G_S - G_0)$: the difference in conductance with G_S and G_0 are the average value of the conductance in the 60 last and first seconds, respectively.
- A: area under curve of the sensor conductance between the 1st and the last minute of sample measurement. This area was calculated using trapeze method.
- dG/dt: the slope of the sensor response, determined dynamically in a range of 60 to 540 seconds.

Eighteen variables defined the developed system (6 sensors x 3 extracted features).

2.4.2. Pattern Recognition Methods

The extracted features were arranged in a confusion matrix and will be treated by using pattern recognition methods (PCA, DFA and SVMs) to estimate the performance of the e-nose in order to classify and monitor odorous air samples from poultry farm. The main objective of PCA is to reduce the dimension of the original data by placing the relevant information on axes called principal components. The aim of DFA is to maximize the distance between groups and minimize the distance within groups. The purpose of using SVMs method is to define a space in which the different classes are separable to the maximum. In this method, the second polynomial kernel function is used to project the training data into a space that maximizes the margin hyperplane. In addition, the one-vs.-one approach and leave-one-out cross-validation methods were used.

3. Results and Discussion

3.1. Sensors Calibration through Relative Humidity Variation

To clearly observe the effect of relative humidity on the response of gas sensors, we represent in Figure 1 the normalized conductance of the sensor arrays at three different relative humidity values. We can see from this figure that when the relative humidity values increase from 15% to 67%, the variation of the conductance doesn't exceed 0.6% for all the sensors. In conclusion, it can be noticed that the calibration of the gas sensors at the considered relative humidity values led to a slight difference in the responses of gas sensor arrays.

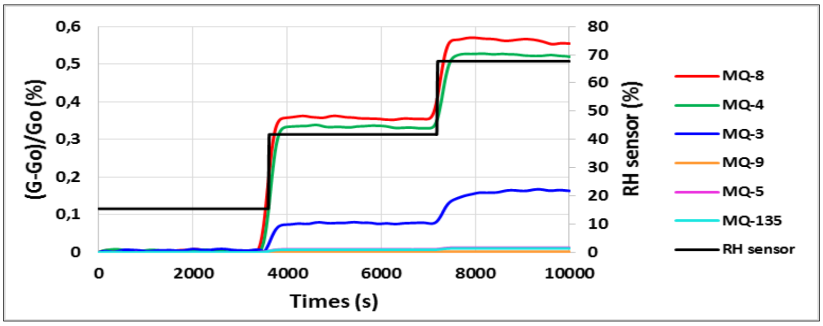

Figure 1. Conductance changes of sensor arrays and relative humidity in function of measurement time by adjusting RH values from 15% to 67%.

3.2. Sensing Behavior of Gas Sensor Arrays to Hydrogen Sulfide, Ammonia and Ethanol at Room Temperature

Ammonia and hydrogen sulfide are harmful gases generated during the bacterial decomposition of livestock manure [16]. Therefore, it is necessary to test the sensitivity of gas sensors using ammonia and hydrogen sulfide gases. Figure 2 shows a plot of the time dependence of the difference in conductance ($G-G_0$) when the sensors are exposed to: hydrogen sulfide Figure 2a, ammonia Figure 2b, and ethanol Figure 2c at a fixed volume fraction of 6, 7, and 3 ppm, respectively. It can be seen from this figure that all gas sensors are sensitive to the three tested synthetic gases, except of MQ-8 sensor. Furthermore, each gas sensor has a different response for the three gases studied, which means that the electronic nose is able to differentiate between these gases.

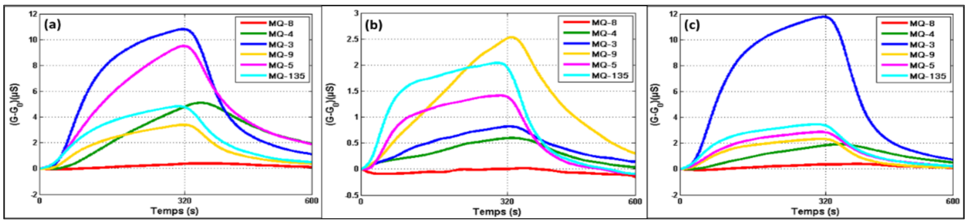

Figure 2. Conductance changes of gas sensor arrays in presence of: (a) hydrogen sulfide, (b) ammonia, and (c) ethanol with volume fractions of 6, 7, and 3 ppm, respectively.

3.3. Classification Results of the Odorous Air Samples Collected from Poultry Shed and Clean Air

3.3.1. Radar Plots

The sensory pattern results for six sensors to four odorous air samples are depicted in Figure 3. As shown in this figure, the sensory patterns (fingerprints) of the odorous air emitted from poultry sources are clearly different.

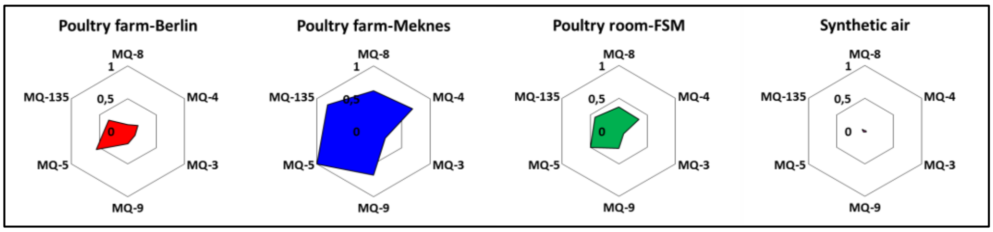

Figure 3. Radar plots of poultry odorous air samples and synthetic air (control) expressed as the difference in conductance ($\Delta G = (G-G_0)$) extracted from gas sensors responses.

3.3.2. PCA Classification

PCA analysis was applied to the database gathered from the gas sensors responses to verify the ability of e-nose to discriminate odorous air samples collected from poultry shed and clean air. Figure 4 represents the projections of the experimental results on a two-dimensional plot (2D). The first two principal components represent 94% of the data variance in the database. In the PCA plot, we can see that the clusters corresponding to the different odorous air samples were clearly separated.

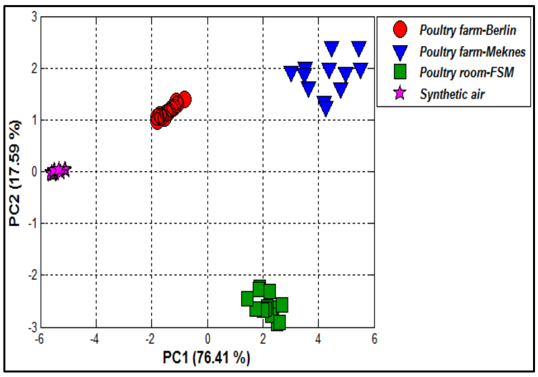

Figure 4. PCA plot performed on poultry odorous air samples and synthetic air by using the features (ΔG, area, and slope) extracted from gas sensors responses.

3.4. Classification Results Depending on the Time and Date of Samples Collection

3.4.1. DFA Classification

DFA was applied to the database gathered from sensors responses to verify the ability of the developed e-nose to monitor odorous air samples collected at different dates and times in a poultry farm from Meknes. Figure 5 shows the DFA plot with 89% of data variance explained by the first two Discriminant Functions (DFs). It can be seen from this figure that all clusters are separated from each other. The DFA results prove that the e-nose system was capable to clearly discriminating odorous air samples from poultry farm according to the date and time of collection.

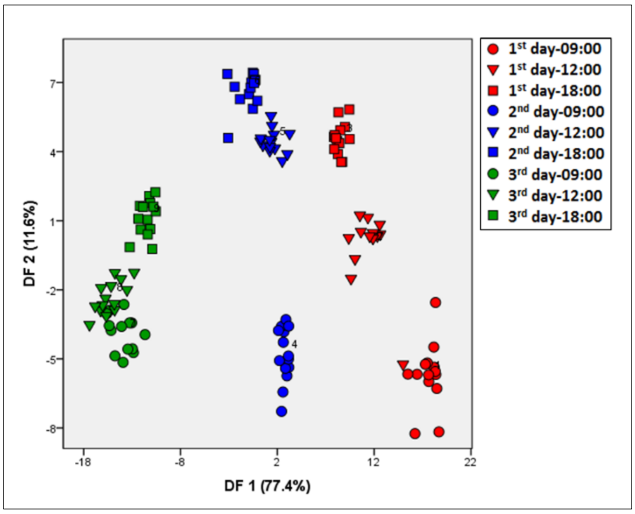

Figure 5. DFA plot performed on odorous air samples collected at different times and dates on a poultry farm (Meknes) using the features (ΔG, area and slope) extracted from gas sensor arrays response.

3.4.2. SVMs Classification

SVMs is a supervised learning method. It was applied to the same dataset like DFA to verify the monitoring capability of the developed e-nose to monitor the odorous air samples in a poultry farm. Table 1 shows the SVMs confusion matrix for odorous air samples recognition. In this study, only two misclassified samples were observed in the datamatrix. Therefore, 98.41% accuracy in the recognition of the odorous air samples was achieved. This outcome was in good agreement with the obtained DFA results. This founding confirms that e-nose system was able to monitor odorous air samples from poultry farm.

Table 1. SVMs classification results of odorous air samples collected at different times and dates on a poultry farm from Meknes using the features (ΔG, area and slope) extracted from gas sensors responses (Total score: 98.41%).

1st day-09:00	13	1							
1st day-12:00	1	13							
1st day-18:00			14						
2nd day-09:00				14					
2nd day-12:00					14				
2nd day-18:00						14			
3rd day-09:00							14		
3rd day-12:00								14	
3rd day-18:00									14

4. Conclusion

The present study demonstrated that cheaper, portable and easy to use e-nose system was able to discriminate odorous air samples from three sites of chicken livestock. The effect of relative humidity on gas sensor responses was also studied. Similarly, the sensitivity of the sensor array to hydrogen sulfide, ammonia and ethanol was checked. The radar plots showed a significant change in the odorous air samples patterns according to the sampling sites. PCA shows that the e-nose system was able to clearly discriminate odorous air samples from three sites of chicken livestock and unpolluted air samples (synthetic air). In order to monitor odorous air samples depending on their time and date of collection, database was also treated by DFA, SVMs and showed clear discrimination among samples. We can conclude that the developed e-nose system can be effectively used as rapid easy to use and inexpensive tool for poultry farm odorous air samples analysis and monitoring.

Acknowledgments: We would like to thank Moulay Ismaïl University of Meknes for financial support of the project “Research support”. This work is funded by the federal Ministry of Education and Research (Germany) and Ministry of Higher Education, Scientific Research and Executives training (Morocco) under the Framework program of Moroccan-German scientific research cooperation, project under grant agreement n° PMARS N°2015-87. Additionally, we have to thank Mr. Jihed Ben Majed of BAM, Berlin, Germany for his help and advice.

Conflicts of Interest: “The authors declare no conflict of interest.”

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