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Machine Learning-Enhanced Odor Detection System as Next-Generation Forensic Technology

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Summary:
In this work, we present an innovative scent-based detection system able to rapidly detect and correctly classify unique odor signatures released by biological materials from deceased humans as a revolutionizing form of forensic evidence. Our device, equipped with 32 metal oxide semiconductor (MOS) chemiresistive sensor elements and integrated with machine learning algorithms, was applied to different scenarios, demonstrating the potential of its application in forensic investigations.

Keywords: novel forensic technology, electronic nose, machine learning, volatile organic compounds, MOS sensors

Background, Motivation and Objective

Understanding the volatile organic compound (VOC) profile released during the early post-mortem period (0-72 h interval) is essential for applications in search and rescue operations to rapidly locate victims and survivors [1]. Gas chromatography-mass spectrometry (GC-MS), commonly used to analyze odor profiles in the laboratory, requires multiple data processing steps and is not suitable for *in situ* use and rapid response [1,2]. Specially trained dogs, so called cadaver detection dogs (CDDs), have been successfully used in forensic investigations since 1888 [3] to locate missing people, identify human remains or even detect traces of human decomposition odors. However, although CDDs are considered the most rapid and efficient tool for the search and detection of human remains, from a juridical perspective, their results cannot be used as physical evidence in court.

Here, we demonstrate that our proposed machine learning (ML)-enhanced gas sensor technology is a promising solution that can help investigators overcome current limitations in the use of CDDs, thus advancing forensic practices and outcomes [4-6].

Description of the New Method or System

Blood, putrefaction fluids, and muscle tissue samples were collected from the National Board of Forensic Medicine, Department of Forensic Medicine in Gothenburg, Sweden, during forensic autopsies of four individuals of different age and gender. The samples were stored in aliquots of 1 mL or approximately 1.5 g at -20°C ±1°C and defrosted immediately before VOC measurements. All ethical aspects of handling biological materials from deceased humans were carefully considered and appropriate Ethical Committee approval was obtained from the Swedish Ethical Review Authority in accordance with ethical review legislation, Act (SFS 2003:460), Reg. No. 2023-05783-01. Measurements were carried out using an electronic nose (e-nose) prototype consisting of 32 commercially available metal oxide semiconductor (MOS) gas sensors from the Figaro TGS2X product line [7]. Each measurement lasted 10 min including exposure to the target sample (5 min) and recovery to the baseline (5 min). The measurement sampling rate was set to 0.1 s, meaning that, for each individual measurement, we obtained 32 voltage-time signals, resulting in a dataset with dimensions of 32 × 6000. The obtained sensor signals were smoothed using a Savitzky-Golay filter and then normalized. Before developing the ML models, standard PCA was performed to investigate the primary sources of variance in the data and to identify any underlying patterns or clusters that may distinguish between classes. We then extracted 85 features from each signal to ensure a detailed representation of the signals across both time and frequency domains, and developed a sensor utility evaluation algorithm based on Pearsson correlation coefficients for binary classification tasks.

We studied the e-nose response to VOCs in three different forensic scenarios. In the first case (see Fig. 1), we analyzed samples from deceased and living individuals to demonstrate the ability of our model to distinguish between *post-mortem* and *ante-mortem* samples as a critical factor in determining the time and circumstances of death. In the second case, we compared animal and human tissue samples as a key discriminant in complex forensic scenarios, particularly in the detection and identification of human remains. In the third case, we studied the aging process of pig meat to understand the dynamics of organic tissue decomposition over time.

Results

The Optimizable Ensemble was found to be the most effective model for all classification tasks. The obtained results showed that our model was able to distinguish between *post-mortem* and *ante-mortem* human biosamples with highest accuracy of 98.1%, sensitivity of 98.4 %, and specificity of 97.9%. A majority-voting mechanism was implemented to finalize classifier decisions on the status of samples. Furthermore, our model, based on a smartly designed feature matrix, was capable of accurately classifying animal and human samples, achieving 97.2% accuracy. Finally, using pig meat samples as a model, we demonstrated the capacity for precise post-mortem interval estimation down to a single day in the early stages of decomposition (1, 2, 3 days).

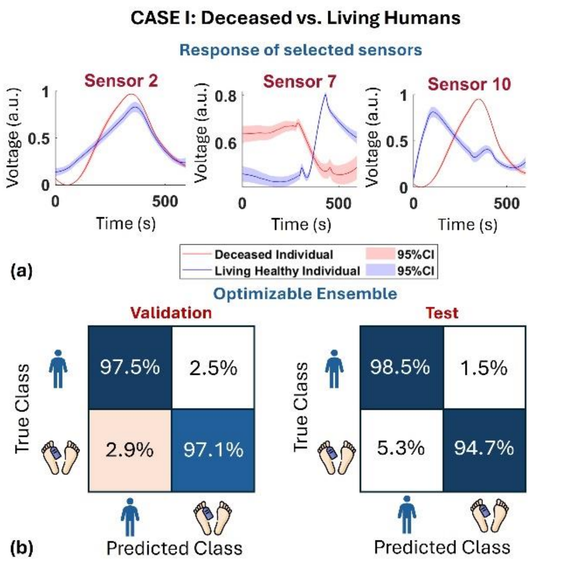

Fig. 1. Performance of the e-nose in one of the three forensic scenarios studied. CASE I: Discrimination between post-mortem and ante-mortem samples. (a) Averaged signals with confidence intervals from selected sensors for deceased and living humans. (b) Validation and test confusion matrix showing classification performance.

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