

Human Activity Recognition Using Distributed Colorimetric Chemical Sensors Based on CO₂ and Formaldehyde Inks and Interpretable Machine Learning

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Summary:

This work presents a novel approach for human activity recognition based on distributed colorimetric chemical sensors using inks selective to carbon dioxide and formaldehyde. Sensor nodes were deployed in a pilot residential environment to capture spatial and temporal variations in indoor air composition during daily activities. Experiments followed a structured protocol and involved up to sixteen participants. Distinct activity dependent chemical signatures were observed. An interpretable machine learning model was used to classify activities from sensor data. Results demonstrate robust and privacy preserving activity recognition based on environmental chemistry.

Keywords: Colorimetric chemical sensors, Human activity recognition, Indoor air quality sensing, Distributed sensor Systems, Interpretable machine learning

Background, Motivation and Objective

Human activity recognition (HAR) is typically addressed using vision or motion-based systems, which may raise privacy concerns and require complex infrastructure. Chemical sensing provides an alternative by capturing indirect signatures of human activities through changes in indoor air composition. In this work, we explore HAR using distributed colorimetric sensors based on chemically selective inks for carbon dioxide (CO₂) and formaldehyde (CH₂O), combined with interpretable machine learning.

Description of the New Method or System

The sensing platform integrates two previously developed colorimetric inks: (i) a water-based ink for CO₂ detection based on reversible amine–CO₂ interactions and [1] (ii) a primary amine/pH-indicator ink for ppb-level formaldehyde detection based on imine formation reactions [2]. These inks were printed and embedded into multiple identical sensing nodes measuring CO₂, CH₂O, relative humidity, and temperature.

The sensing nodes were deployed at different locations within a pilot residential environment. A structured experimental protocol was designed to ensure reproducible activity patterns, including cooking, eating, dish cleaning, and hygiene-related tasks, each performed following predefined sequences and durations. Experiments

were conducted under semi-controlled conditions involving up to 16 participants performing these activities across different locations within the dwelling.

The sensing system was implemented using a compact IoT platform integrating colorimetric sensors, environmental sensors, and a low-power microcontroller.

Results

Time-resolved measurements from the distributed sensing nodes reveal clear activity-dependent chemical signatures across different locations within the dwelling (Fig. 1). Cooking activities are characterized by strong temperature-driven responses and moderate CO₂ variations, while cleaning-related activities, particularly dish cleaning, produce pronounced humidity increases and correlated CO₂ responses, especially in sensors located near the kitchen sink. Formaldehyde signals exhibit lower amplitude but provide complementary information associated with specific indoor emission sources.

These results demonstrate that each activity generates a distinct temporal and spatial chemical fingerprint, enabling differentiation based on environmental sensing alone.

To further analyze the contribution of each sensing variable, a feature relevance analysis was

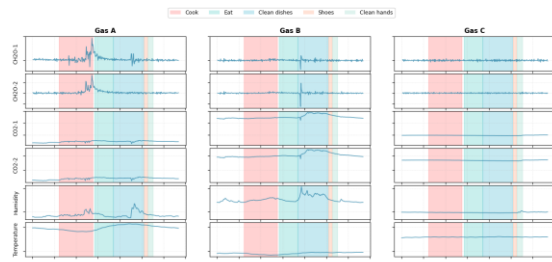


Fig. 1. Time-resolved signals from distributed colorimetric sensors based on CO₂ and formaldehyde inks during controlled household activities. Distinct activity-dependent chemical signatures are observed across different sensing nodes, highlighting spatial and temporal variability in indoor air composition.

performed (Fig. 2). The results show that activity discrimination relies on localized sensor responses rather than global trends. Cooking activities are mainly associated with temperature and CO₂ signals, particularly in specific sensing nodes, whereas cleaning activities are strongly correlated with humidity-driven response and CO₂ variations in other locations. This spatial differentiation highlights the importance of distributed sensing.

A lightweight and interpretable machine learning model was trained to classify activities from the sensor data. The results demonstrate robust discrimination between activities and improved generalization when combining multiple sensing locations. Feature importance analysis confirms that the model leverages physically meaningful variables, directly linked to the underlying

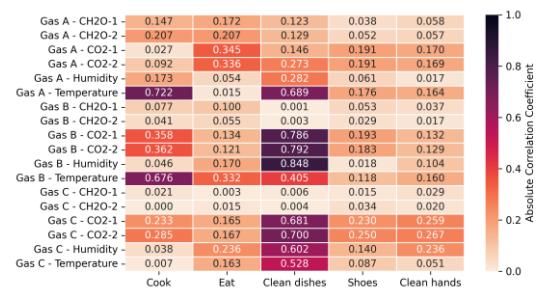


Fig. 2. Feature relevance analysis showing the contribution of each sensor signal to activity discrimination. Cooking activities are mainly associated with temperature and CO₂-related responses, while cleaning activities are strongly correlated with humidity-driven signals, particularly in specific spatial locations.

sensing mechanisms of the inks. To better understand the contribution of each sensing variable, a feature relevance analysis was performed (Fig. 2).

Conclusions

This work demonstrates that combining chemically selective colorimetric inks with distributed sensing and interpretable machine learning enables reliable human activity recognition based solely on indoor air composition. The proposed approach provides a low-cost and privacy-preserving alternative to conventional HAR systems and highlights the potential of artificial olfaction for smart environment applications.