PREFACE

The rapid advancements in artificial intelligence (AI) and its application in various domains have transformed society and industry, making them smarter and more sustainable. However, this progress has come at a cost, as our air ambience is increasingly being polluted with hazardous gases and odors. The real-time detection and estimation of these harmful substances have become crucial for ensuring a safe and healthy environment.

This thesis focuses on the accurate detection and estimation of gas/odor using gas sensor arrays. Traditionally, highly selective gas sensors have been required for precise detection, but recent studies have shown that cross-selective gas sensors can achieve high-performance classification of gases/odors leveraging AI algorithms. This has led to the development of electronic noses (e-Noses), which utilize arrays of broadly selective gas sensor elements. By exploring innovative techniques for enhancing the performance of gas sensor arrays and by leveraging the physical sensor responses into additional virtual sensor responses, we present a novel approach based on CNNs for real-time detection and estimation of hazardous gases. The findings and methodologies discussed herein contribute to the advancement of gas sensing systems and offer valuable insights for creating safer and healthier environments.

In this research work, we propose a novel technique called the three-input and three-output (TITO) technique for deriving efficient virtual sensor responses (VSRs) from the physical gas sensor array (GSA) responses, in real-time. We demonstrate the effectiveness of our technique using a GSA consisting of four elements. Our results show that the proposed technique significantly augments the VSRs by four times compared to its peer technique, thereby enhancing the performance of e-Noses.

To evaluate the efficacy of our proposed technique, we employ nine fundamental classifiers, including linear support vector machine, decision tree, multi-layer perceptron neural network, K-nearest neighbor, logistic regression, Gaussian process with radial basis function, linear discriminant analysis, random forest, and AdaBoost. Ten-fold cross-validation is employed to minimize biasing impact, considering intra- and inter-class variance. Remarkably, four classifiers achieve an accuracy of 100 percent, thereby validating the efficiency of our proposed technique.

Furthermore, we address the pressing need for real-time detection and estimation of hazardous gases in the air ambience. To achieve higher accuracy in this context, we present a novel approach based on the analysis of multi-element gas sensor arrays using convolutional neural networks (CNNs). The raw sensor responses are spatially upscaled and processed on the edge using lightweight CNNs. We verify our hypothesis using a four-element metal-oxide semiconductor (MOS)-based thick-film gas sensor array, fabricated by our research group. The target hazardous gases considered in this study are acetone, carbon-tetrachloride, ethyl-methyl-ketone, and xylene.

Our experimental results demonstrate that the proposed CNN-based approach accurately detects and estimates the target hazardous gases. The Mean Squared Error (MSEs) of detection is found to be 1.42×10^{-14}, while the estimation accuracy is 2.43×10^{-3} for the considered gases. The success of our designed system highlights its generic nature and potential for extension to other gases and odors of interest.

Further, during disasters, the release of hazardous gases and VOCs poses significant risks to human life and the environment. Therefore, the timely and accurate detection of these substances becomes crucial for effective disaster response and mitigation. Our proposed intelligent gas sensor systems can be deployed on UAV platforms, enabling real-time monitoring of hazardous gases and VOCs in disaster-stricken areas. The UAVs equipped with gas sensors can swiftly navigate through the affected regions, collecting and transmitting data about the concentration and distribution of hazardous substances. This information can then be processed using advanced algorithms and data fusion techniques to generate comprehensive situational maps and aid in decision-making for SAR operations. By integrating intelligent gas sensor systems with UAV-assisted SAR missions, it becomes possible to enhance the situational awareness and response capabilities of SAR teams.

Accordingly, in this thesis we have also addresses the critical component of search and rescue (SAR) operations in disaster situations, where public communication infrastructure is often damaged, impeding timely exchange of emergency data. The utilization of unmanned aerial vehicles (UAVs) emerges as a key solution to mitigate the challenges faced during disasters. UAVs offer an adaptable and reliable emergency communication backbone, facilitating swift construction of communication networks and enhancing search and rescue efforts.

Therefore, this thesis also evaluates the network performance of UAV-assisted intelligent edge computing, which demonstrates significant improvements in delay, throughput, traffic sent and received, and path loss. The proposed parameter optimization enhances network performance, thereby leading to more efficient search and rescue missions in disasters and harsh environments.

This doctoral thesis encapsulates an interdisciplinary and cutting-edge research work that contributes to the fields of gas/odor detection, environmental monitoring, and disaster management. The presented methodologies, techniques, and findings serve as valuable assets to researchers, practitioners, and policymakers alike, enabling them to develop more accurate gas sensors, enhance real-time detection capabilities, and expedite search and rescue operations in critical situations.

This thesis work has been presented in the following six chapters:

Chapter 1: presents the introduction and literature survey, starting from the very primitive historical context.

Chapter 2: presents details about MOX gas sensors and their response modalities, including the background of ANN and CNN for gas/odor classification.

Chapter 3: presents a novel data-driven technique to produce multi-sensor virtual responses for gas sensor array-based electronic noses.

Chapter 4: presents a novel spatial upscaling-based algorithm for detection and estimation of hazardous gases.

Chapter 5: presents a UAV computing-assisted search and rescue mission framework for disaster and harsh environment mitigation.

Chapter 6: concludes the thesis with the highlights of presented works and future scopes.