Received: 29 September 2022 | Revised: 10 February 2023 | Accepted: 27 February 2023 | Published online: 27 February 2023

Artificial Intelligence and Applications
2023, Vol. 1(2) 70–81
DOI: 10.47852/bonviewAIA3202434

REVIEW

Review on Discrimination of Hazardous Gases by Smart Sensing Technology

Gangadhar W. Bandewad[1,*], Kunal P. Datta[1], Bharti W. Gawali[2] and Sunil N. Pawar[3]

[1]Deen Dayal Upadhyay KAUSHAL Kendra, Dr. Babasaheb Ambedkar Marathwada University, India

[2]Department of Computer Science and IT, Dr. Babasaheb Ambedkar Marathwada University, India

[3]Department of Electronics and Communication Engineering, Jawaharlal Nehru Engineering College MGM University, India

Abstract: Real-time detection of hazardous gases in the ambient and indoors has become the prime motive for curbing the problem of air pollution. Keeping the concentration of hazardous gases in control is the main task before human society so as to keep environmental balance. Researchers are concentrating on smart sensors because they can detect and forecast the presence of gas in real-time, provide correct information about gas concentration, and detect a target gas from a mixture of gases. This smart gas sensor system can have applications in the field of military, space, underwater, indoor, outdoors, factories, vehicles, and wearable smart devices. This study reviews recent advances in smart sensor technology with respect to the material structure, sensing technique, and discrimination algorithm. Focus is given on reducing the power consumption and area of a sensor circuitry with the help of different techniques.

Keywords: smart gas sensor, algorithm, hazardous gases

Smart gas sensors are the need of the era. In each and every sector, gas sensors are required. They can have applications in Medical, Industries, and households and for monitoring the environment by discriminating the concentration of the mixture of gases and predicting the concentration. Therefore, the study of Smart sensing technology is very much important.

1. Introduction

The World is currently going through a transition phase due to digitization. Industries, Hospitals, Malls, Schools, and all are adopting Internet of Things(IOT)-based technologies for self-working and smart infrastructure (Kumar et al., 2019; Mutunhu et al., 2022; Madaan et al., 2022). The heart of IoT is the sensors interconnected with various devices which are used for sensing the data. To fulfill the increasing demand for power sources, there is an increase in the use of fossil fuels and the cutting down of forests. Hazardous gases emitted affect the environment and health of human beings causing various respiratory diseases, chronic disorders, and eye-related disorders (Jorquera & Villalobos, 2023). There is a requirement for highly sensitive, low-powered, multiple gas sensing detection technique that could detect the presence of gas concentration in air and transmit data in real time for further action. Although there are many sensors in the market, there are certain limitations to them. Gas sensing is different as compared to another parameter sensing, for example, level sensing, temperature sensing, etc, and in gas sensing, there is a mixture of gases in the air, and from that mixture, we have to sense or detect a particular gas. Gas sensors are used for detecting air pollution, food testing, fuel gas pipeline leakage, and the detection of diseases based on which gas is exhaled from a person (Nikolic et al., 2020).

Gas sensors are said to be good if it satisfies the following criteria: high selectivity, high sensitivity, low consumption power, fast response time, fast recovery time, reliability, and low cost (Nikolic et al., 2020). The challenge is to design a technology or sensing material to sense the gas in real time at room temperature at a low cost. Depending on the sensing mechanism, gas sensors are classified into various categories. Recent research is focused on sensing gas from a mixture of gases in real time and discriminating the concentrations of each gas. The basic concept of this smart sensing technology is to design a sensor material that can respond to the mixture of gas and discriminate the gas, processing and transmission mechanism of the signal, drift compensation, and algorithms for discrimination of gas. The requirement of smart gas sensor technology can be related to (1) low cost, (2) reliability, (3) low power consumption, (4) wireless transmission of signals, and (5) algorithm for discrimination. The smart gas sensor technology has to be of low power consumption as it has a direct relation with air pollution; if this technology has to apply in vast levels, then it has to be low cost, be reliable, be able to transmit the signal over wirelessly and with low power consumption, and discrimination method or algorithm.

*Corresponding author: Gangadhar W. Bandewad, Deen Dayal Upadhyay KAUSHAL Kendra, Dr. Babasaheb Ambedkar Marathwada University, India. Email: gbandewad@gmail.com

In the following parts, in Section 1 an overview of air pollution and its sources is presented; in Section 2, gas sensor and sensing is discussed; in Section 3, algorithms for discrimination and power consumption are explained; in Section 4, challenges and solution are discussed pertaining to smart gas sensing technology; in Section 5, conclusions are discussed.

2. Air Pollution and Its Sources

Due to COVID-19 crisis, almost transportation and production in industries were shut down; as a result of it, air pollution decreased. Post-COVID-19 crisis, the condition of air pollution is getting worsened as levels before COVID-19 pandemic (Dutheil et al., 2021). The level of air pollution in India is rising over last few decades resulting in adverse health impacts of living beings (Gautam, 2020; Kaur & Pandey, 2021). Air pollution is the most dangerous form of pollution. The causes of air pollution are natural and manmade. Some of the natural causes enlisted are storms, volcano eruptions, forest fires, decomposition of animals and trees, flora, and fauna. In case of manmade causes, cutting down of forests, increased urbanization, population rise, vehicle rise, excessive use of fossil fuels, burning of woods in villages and cities, increased use of pesticides and fertilizers in farms, indoor use of paints and volatile organic compounds (VOCs)-related materials and increased industries. Post lockdown, the world has now picked up the pace of development (Chen et al., 2007; Mannan & Al-Ghamdi, 2021; Shehzad et al., 2021; Shupler et al., 2020). In this development process, industrial sectors, transportation, and coal-powered plants have raised their working capabilities, due to which there is growing pollution of air, water, and soil (Tyagi et al., 2021). Hazardous contaminants such as various chemicals and gases are directly released into the environment. Hazardous gases such as NO, NO2, CO, CO2, SO2, and many more are causing adverse effects on the environment as well as the health of living beings (Marlier et al., 2016). Many harmful and life-taking diseases have raised like cardiovascular, lung diseases, cancer, and depression (Balakrishnan et al., 2019; Kampa& Castanas, 2008; Pandey et al., 2021). According to World Health Organization, around 7 million deaths and respiratory disorders were caused globally due to air pollution. Lower resource countries are exposed more to ambient and household air pollution than developed countries (World Health Organization, Ambient (Outdoor) Air Pollution, 2021). Figure 1 shows the deaths and disability-adjusted life-years due to air pollution.

Pollution is the mixing of unwanted particles into pure things. Air pollution is the mixing of fine particles of a variety of sizes and shapes in the air. Fine particles can be of different shapes, sizes, gas molecules, and dust particles. The sources of these fine particles are outdoor and indoor. These fine particles are termed particulate matter or PM. Fine particles, or particulate matter 2.5 (PM2.5), refer to small particles or droplets in the air that are two- and one-half microns or less in width. Fine PM2.5 is an air pollutant that is a concern for people's health when levels in the air are high. Figure 2 shows the effect of PM2.5 on the mortality rate in India. The sources of PM2.5 are from vehicles like cars, trucks, buses, and off-road vehicles (e.g., construction equipment, snowmobile, locomotive) exhaust, and other operations that involve the burning of fuels such as wood, natural resources like coal, and petrochemicals. Fine particles also form from the reaction of gases or droplets in the atmosphere from sources such as power plants. These chemical reactions can occur miles from the source of the emissions. Because fine particles can be carried long distances from their source, events such as wildfires or volcanic eruptions can raise fine particle concentrations hundreds of miles from the event. PM2.5 is also produced by common indoor activities. Some indoor sources of fine particles are tobacco smoke, cooking (e.g., frying, sautéing, and broiling), burning candles or oil lamps, and operating fireplaces and fuel-burning space heaters (e.g., kerosene heaters) [Report from New York State Department of Health, Fine Particles (PM 2.5) Questions and Answers].

Particles in PM2.5 can enter the human body and affect various systems of the body like the respiratory system; also, it can affect the eyes and skin and cause breathlessness. Exposure to these particles in the long term can cause severe diseases such as interstitial lung diseases, chronic bronchitis, and depression. Elderly

Figure 1
Causes of DALYs (A) and deaths (B) attributable to air pollution in India, 2019 (Ravishankara et al., 2020; Pandey et al., 2021)
Individual causes are shown as a percentage of total DALYs or deaths. DALYs = disability-adjusted life-years.

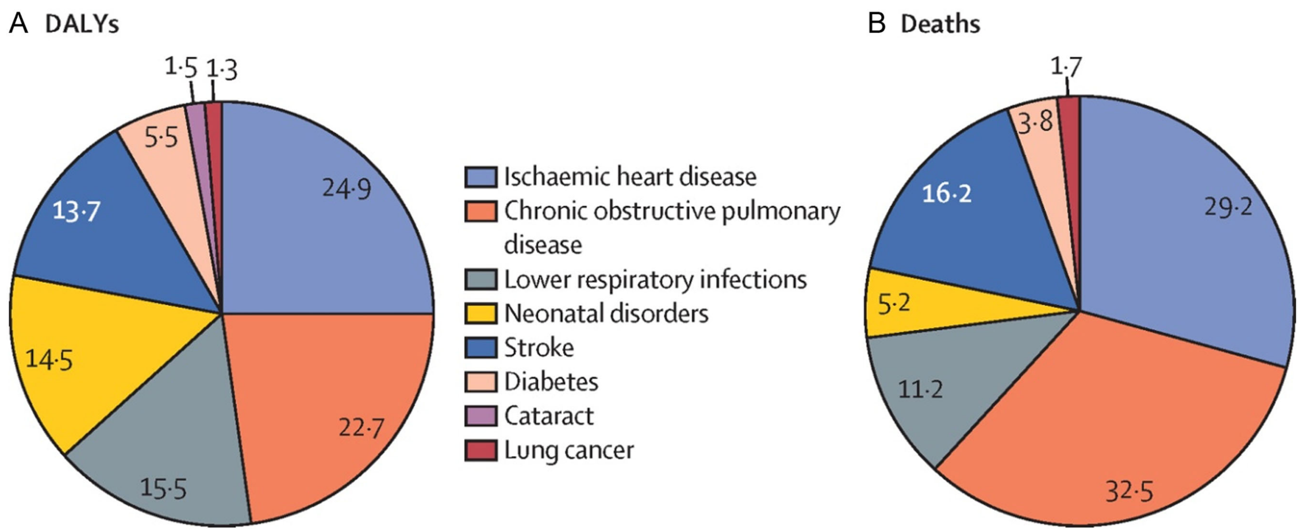
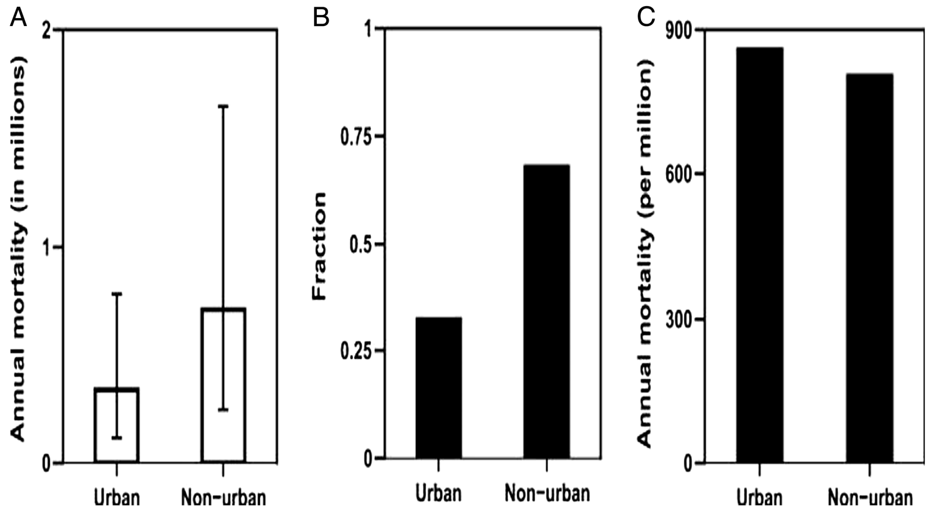


Figure 2
(A) Total annual premature deaths attributed to PM2.5 over urban and nonurban regions in India. The lower and upper limits of the error bars correspond to the 5th and 95th percentile; a fraction of mortality attributed to urban and nonurban regions in India (B); and total annual premature deaths attributed to PM2.5 per million people over the urban and nonurban regions in India (C) (Ravishankara et al., 2020)



persons, pregnant women, and children when exposed for a long period may cause breathing and heart problems. According to a WHO report, in the year 2019, the concentration of fine PM2.5 was 34.7 μg/m^3 which is several times higher than the annual mean WHO air quality safety standard of 10 μg/m^3. For India, the age-standardized mortality rate attributed to household and ambient air pollution (per 100,000 population) was recorded as 184 (World Health Organization, Ambient (Outdoor) Air Pollution, 2021). The other main sources of air pollution are hazardous gases like VOCs, Ozone, CO2, NH3, CO, NOx, and many more as listed in Table 1.

Exposure to hazardous gases to humans causes several adverse effects on human health, and long exposure causes death also. Some of the adverse effects arose due to the gases are listed in Table 2.

For curbing this problem, there is a need for a very highly sensitive, selective, robust, and smart sensing technique for the detection of hazardous gases. This smart sensing technique is a combination of interdisciplinary studies (Feng et al., 2019). Some sensors in the market can identify the targeted gas and its concentration but there is a requirement for a smart gas sensing technique that can give smarter results such as deciding which gas is present, gas concentration, proper signal transmission, and action after sensing the gas. In this review, we will study a smart sensing technique which is shown in Figure 3 and will focus on how to cope with various issues like power consumption, size, and discrimination of gas from a mixture of gases.

3. Gas Sensors and Sensing

Gas sensors are devices that measure the gas concentrations in the surrounding environment. Gas sensors are the basic part of a complex integrated smart sensing system that is used in various domains like medical (Staerz et al., 2016), indoor (Ortiz Perez et al., 2018), industries (Jain & Kushwaha, 2012), military (Li et al., 2020), space (Hunter et al., 2007), security, and environmental monitoring (Suriano, 2021). Gas sensors have a

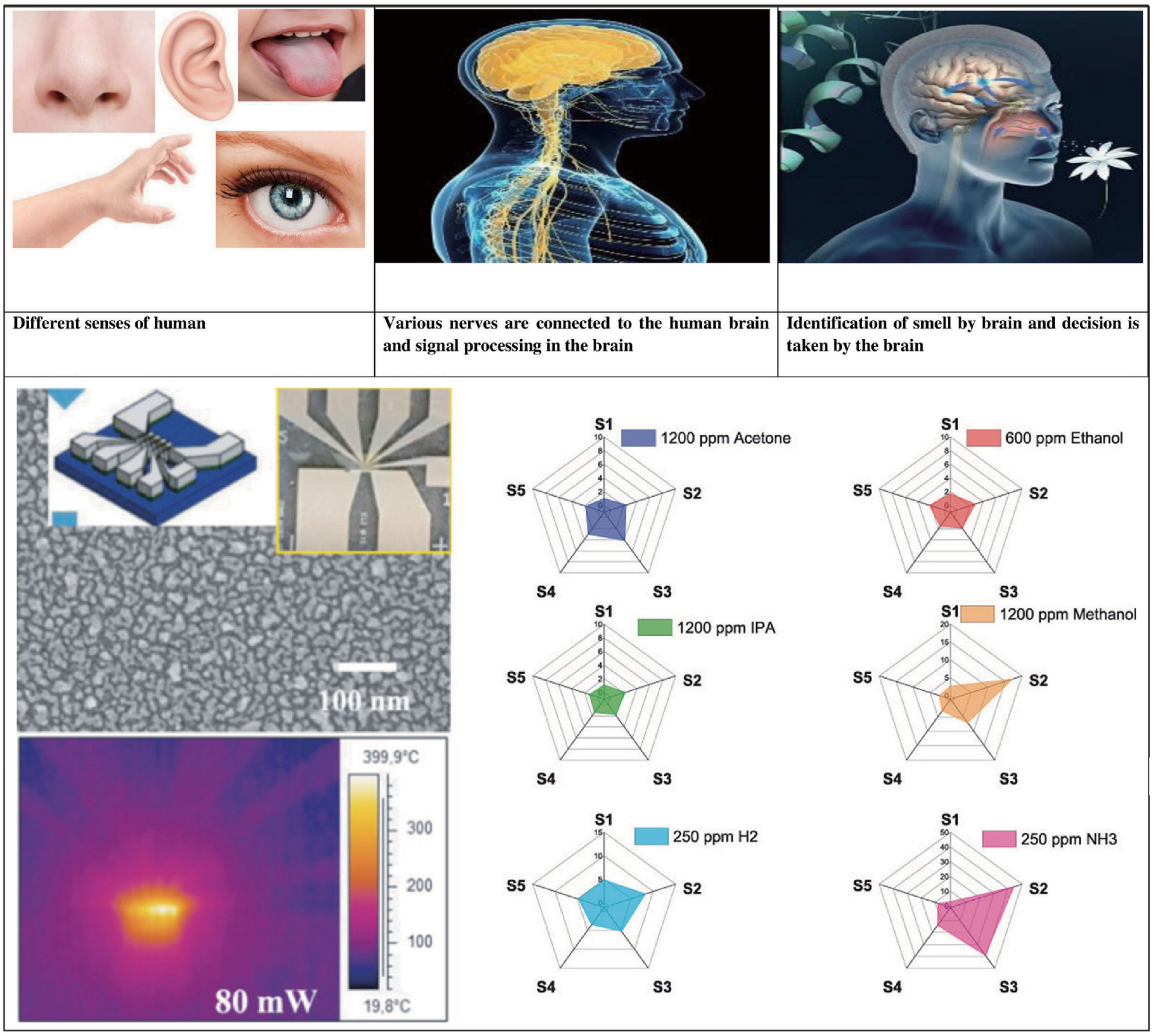
Table 1
Sources of pollution

Air pollution source	Pollutant gas	References
Building materials	VOCs, Plasticizers, formaldehyde, benzene	Mannan & Al-Ghamdi (2021), Hasager et al. (2021), Hasager et al. (2019), Salthammer & Bahadir (2009)
Carpets, Perfumes, furniture	VOCs	Hasager et al. (2021), Hasager et al. (2019)
Computers, printers, electronics	Ozone	Hasager et al. (2021), Hasager et al. (2019), Destaillats et al. (2008)
Paints	VOCs	Hasager et al. (2021), Hasager et al. (2019)
Peoples	CO2, NH3, H2O	Hasager et al. (2021), Hasager et al. (2019), Salthammer & Bahadir (2009)
Combustion	CO, CO2, PM	Hasager et al. (2021), Hasager et al. (2019), Satish et al. (2012)
Asparagus fern	Benzene, Toluene, Trichloroethylene, Octane	Hasager et al. (2021), Hasager et al. (2019), Yang et al. (2009)
Industries	CO, CO2, SO2, NH3, NO2, SOx, NOx,	Hasager et al. (2021), Hasager et al. (2019), Marlier et al. (2016), Guttikunda et al. (2014)
Farming	CO, CO2, NOx,	Hasager et al. (2021), Hasager et al. (2019), Chakraborty & Basu (2021)

Table 2
Hazardous gases and its adverse effects

Pollutant	Effect on human beings	References
Carbon monoxide (CO)	Mixes with hemoglobin in the blood and causes headaches, nausea, dizziness, breathlessness, fatigue, and excessive exposure can lead to coma and death	Balakrishnan et al. (2019), Pandey et al. (2021), Shupler et al. (2020), Hasager et al. (2021), Hasager et al. (2019), Satish et al. (2012)
Nitrogen dioxide (NO2)	Respiratory problems	
Benzene (C6H6)	Cancer, drowsiness, dizziness, changed and irregular heartbeat, headaches, and unconsciousness	
Particulate matter (PM)	Stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma, reduced lung function, and mortality	
Ozone (O3)	Respiratory effects, chest tightness, cough, wheezing, and lung function decrement. cute respiratory problems in asthmatics	
Formaldehyde (CH2O)	Cancer, sensory irritation, irritation of the eyes and upper airways	

Figure 3
Comparison of working of brain and smart gas sensor (Van Duy et al., 2022)



On a single Chip there is Gas Sensors, Transferring of sensed signal and there is interpretation of gas (Van Duy et al., 2022) transducer and sensing layer; this combination converts the gas signal into desired measurable signal like frequency, voltage, resistance, and current. Whether a sensor is good or not can be decided by various parameters like shape and size, cost, power consumption, selectivity, resolution, accuracy, response time, recovery time, device sensitivity, precision, the limit of detection, and reversibility (Nazemi et al., 2019). Gas sensors use a variety of materials of gas sensing like metal oxides (Cao et al., 2022), conducting polymers (Zhu et al., 2022), carbon nanotubes (Lim et al., 2022), graphene (Rattan et al., 2022), piezoelectric, and others (Pasupuleti et al., 2022). For good selectivity and sensitivity, all sensing materials are going to nano-level. At the nano-level, the surface area of the sensing layer gets increased and power consumption gets decreased (Saleem et al., 2022). Merely using a single gas sensor for sensing is insufficient since it may display the incorrect gas concentration value due to environmental influences such as changes in temperature, humidity, or pressure. Also, the selection of various gases by a single sensor is not possible. For this purpose, there is a requirement for a gas sensor array. Gas sensor arrays can detect individual gas from the mixture of gases (Chu et al., 2021); this is the major benefit of the gas sensor arrays.

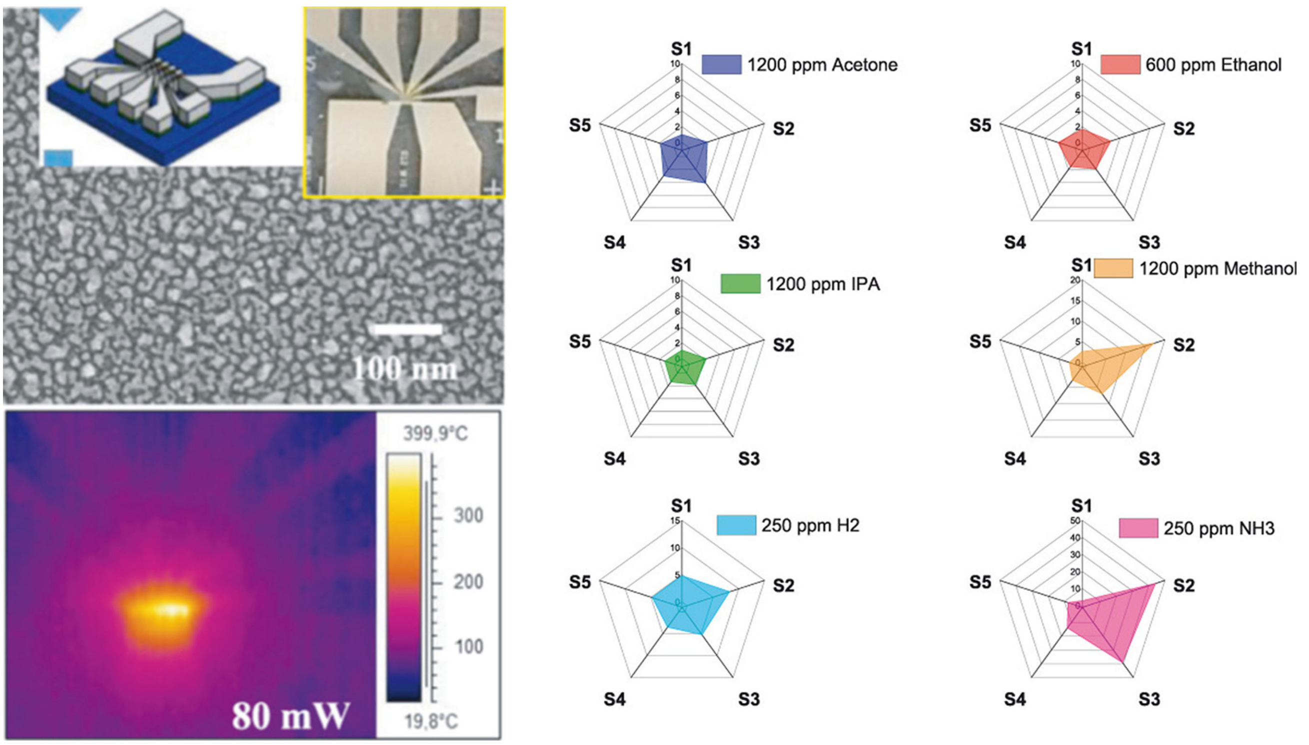
3.1. Gas sensor array

There are many sensors available in the market for the detection of hazardous gases. If we take any single gas sensor, then it is prone to show an error. If we consider an array of sensors, then the possibility of error in the sensed signal will be reduced. Also, the external effects will be reduced by using a sensor array. Fabrication of gas sensor array can be made using metal oxides, conducting polymers, carbon nanotubes, graphene, and other materials (Cao et al., 2022; Chu et al., 2021; Lim et al., 2022; Nazemi et al., 2019; Rattan et al., 2022; Zhu et al., 2022). For the making of these sensor arrays, mostly metal oxides are used. Metal oxides are well known for their selectivity of specifically targeted gases as shown in Figure 4 below (Van Duy et al., 2022). These metal oxides are well suited for making the sensor arrays but there is one problem using these metal oxides that they require an elevated temperature for sensing the gas. Research is going on to reduce the elevated temperature operability and make them used at room temperature. For increasing selectivity and sensitivity of the sensors, a combination of various materials is being done, and heterostructures are prepared for gas sensing. For increasing sensitivity and selectivity of the gas, the sensors are using sensing layer nanoparticles vanas and they increase the surface area of the sensing layer.

4. Algorithms for Discrimination

A sensor is a device that gives a response to any stimuli. The sensor array consists of several individual sensors connected, and these individual sensors give an independent response to the gases. This array consists of its processing unit, pattern

Figure 4
Fabricated array of 5 sensors for detection of ethanol, methanol, isopropanol, acetone, ammonia, and hydrogen (Van Duy et al., 2022)



recognition software, and valid reference data for gases. This array of sensors generates the data from all individual sensors, and these data generated are processed further to create a pattern. This pattern generated is in response to the individual gas sensor (Gardner, 1991; Li & Wang, 2006). In this way, the database is created from the sensor array. Unique patterns are generated for each sensed gas. The study of these patterns can be done, and a perfect database can be created by a lot of repetitions; then, these databases can be called later as reference databases, and finally, we get the artificial intelligence in these sensor arrays (Chiu & Tang, 2013; Feng et al., 2019; Gardner, 1991; Hallil & Heidari, 2020; Li & Wang, 2006). Following is the discussion of these sensor arrays and pattern recognition made for various gases.

MOSFET array was created consisting of six individual sensors for the discrimination of hydrogen gas from the mixture, and the discrimination model used was linear and nonlinear partial least square (PLS) models (Sundgren et al., 1990). The sensor array of thin-film semiconductor sensing material was fabricated of 1 wt% Pd-doped SnO2, 6 wt% Al2O3-doped ZnO, WO3, and ZnO for identification of CH3SH, (CH3)3H, C2H5OH, and CO gases in the concentration range of 0.1 to 100 ppm by using neural network pattern recognition, and this technique was useful to discriminate gases with a probability of 100% (Hong et al., 1996). The doping of TiO2 nanoparticles increases the conductivity of the GeSe monolayer and makes it selective for SF6 detection purposes (Sun et al., 2022). Functionalized semiconducting CNT arrays can be used for the detection and discrimination of hazardous explosive gases (Doshi & Fahrenthold, 2022). A gas sensor array of five sensors of bilayer SnO2/Pt film was fabricated for the improved sensor array response, and they used an effective microheater design (Van Duy et al., 2022). This designed sensor array could sense different gases such as ethanol, methanol, isopropanol, acetone, ammonia, and hydrogen. An upgraded convolutional neural network (CNN) was used to provide a new technique for gas identification with drift counteraction for electronic noses (Feng et al., 2022).

A smart gas sensor needs to sense the gas and transfer the data with proper routing technique to the monitoring system or in the network. When there is a requirement to monitor the leakage of gas in undersea or in the industry where the supply of dangerous gases is present inside water, monitoring the leakage of gas becomes challenging. While considering underwater routing protocol, we must use a different technique since there are many problems such as high noise and interference, cost, high energy consumption, path loss, Doppler effect, propagation delay, data compression, and many more. Ismail et al. (2022) proposed most appropriately the underwater wireless sensor network (UWSN) for various applications such as underwater pipeline monitoring and environmental monitoring. UWSN uses acoustic signal for communication since Radio Frequency (RF) are heavily attenuated in water. According to Ismail et al. (2022), information can be better transferred using H2-DAB as it provides a greater packet delivery ratio. Also, AHH-VBF provides a lower end-to-end latency and lower energy usage compared to the other protocols for both end-to-end and energy consumption.

A gas sensor array was fabricated consisting of eight sensors for VOC detection from cucumber which is grown by using the different quantities of fertilizers. metal oxide semiconductor (MOS) e-nose sensor array was used for sensing and detection of VOC differences in small print signatures associated with different urea application rates. The signals received from the sensor array were subjected to four different statistical models linear and quadratic discriminant analysis Linear Discriminant Analysis and Quadratic Discriminant Analysis (LDA-QDA), support vector machines (SVM), and artificial neural networks (Tatli et al., 2021). A comparison of gas sensor and their sensing technique is shown in Table 3. A gas sensor was fabricated for detection and discrimination of chloroform, methane, and ethanol by using an array of 4 sensors by using a sensing layer as pTh. The response of sensing layers films to various gases was subjected to differentiation by using a pattern recognition algorithm (Sakurai et al., 2002). In the reduced graphene oxide (RGO)-based chemiresistor sensor, a sensor array was created to distinguish dimethyl methylphosphonate (DMMP) vapor from other vapors that could interfere with DMMP vapor. The referenced sensor array was built employing a variety of RGOs created by combining several reducing agents during RGO synthesis. The reduction of graphene oxide, which is made by chemical oxidation of graphite, was done with three different reducing agents: hydrazine hydrate, ascorbic acid, and sodium borohydride (Alizadeh & Soltani, 2016).

Van Duy et al. (2022) designed and fabricated and effective sensor that could detect multiple gases at a time. The multiple gas detection requires elevation of the temperature for proper detection; for this purpose, microheaters were used. If we need to sense different gases by using separate sensors, then that circuitry will consume more power and area. In this case, on only one sensor, the five different types of gas sensing are done. Also, the Radar plots and PCA were used for discrimination and classification of the gases. IOT-based technologies are required for this kind of smart sensing, which employs a discrimination technique and a multi-gas sensor array.

Partial least square modeling with latent variables was used for the prediction of hydrogen gas only; other gases like ethanol, ammonia and ethylene were not able to predict using this PLS method (Sundgren et al., 1990). PCA and neural network pattern recognition analysis techniques were useful to discriminate gases, and the probability was 100% (Hong et al., 1996). PCA is used for increasing the selectivity of gas sensors, and LDA is used to derive exact features from available data. SVM is useful in improving the accuracy of the sensor by slightly removing sensor drift (Alizadeh & Soltani, 2016; He et al., 2017; Lu et al., 2006; Ma et al., 2022; Mitzner et al., 2003; Shao et al., 2022; Sinju et al., 2022; Star et al., 2006; Wang et al., 2022). Sensor drift can be removed by an augmented convolutional neural network (ACNN), and accuracy can be increased (Feng et al., 2022). ACNN is a continuously updated framework, and it automatically counteracts sensor array drift. In all other methods like SVM, backpropagation neural network, ensemble classifiers, and ensemble classifiers with uniform weights as well as the normal CNN model, the drift remains, and hence, we get the error. So ACNN is giving the best results as compared to others for discrimination of gas and drift removal.

If we consider any sensor, power consumption plays a very important role in the life of a sensor. If a sensor needs to be connected to many devices, the power consumption calculation and the circuitry need to be designed in such a way that it will consume less amount of power. In case of a smart sensor, there is an array of sensors. These array of sensor consumes a large amount of power. Chaudhri et al. (2022) developed a novel algorithm approach by using zero-padded virtual sensors and spatial augmentation, and CNN algorithm reduced the power consumption of a sensor array by 50%. The sensor array was consuming 10 Watts of power when unoptimized, and after optimization, it consumed 5 Watts of power. The advantage of

Table 3
Comparison of gas sensor and sensing technique

Gas Sensor	Discrimination Technique	References
e-Noses with the gas sensor array	Augmented convolutional neural network (ACNN), a continuously updated framework that automatically counteracts the e-nose drift and increases accuracy by 30%	Feng et al. (2022)
Electronic nose having an array of gas sensors for discrimination of 12 kinds of VOCs	Multitask deep learning, accuracy is about 95%	Wang et al. (2022)
Electronic nose with an array of gas sensors, six indoor air contaminants, and their binary gas mixtures can be identified with high classification accuracy.	Hierarchical classifier (HC) and partial least squares regression (PLSR); concentration estimation is obtained accurately	Ma et al. (2022)
e-Nose using ZnO nanowires-based multiple sensors surface of nanowires was modified with a thin layer of different sensitizers namely Au, Cu, Ni, and MgO	PCA study implies that the developed e-nose can detect toxic gases both qualitatively as well as quantitatively.	Sinju et al. (2022)
Covalent organic frameworks (COFs) selective sensing performance toward triethylamine (TEA)	Machine learning methods, including principal component analysis (PCA) and support vector machine (SVM)	Shao et al. (2022)
Reduced graphene oxide-based gas sensor array for DMMP vapor discrimination from VOCs by the RGO-based gas sensor array.	PCA method was used for the classification of the vapors	Alizadeh & Soltani (2016)
Electronic sensor array based on single-walled carbon nanotubes (SWNTs) for detection of, CH4, CO, H2, and H2S gases	Principal component analysis (PCA) and multivariate partial least squares regression (PLS Regression)	Star et al. (2006)
Carbon nanotube sensor array with 32msensing elements NO2, HCN, HCl, Cl2, acetone, and benzene	Principal component analysis	Lu et al. (2006)
Electronic nose with five metal oxide semiconductor gas sensors for carbon monoxide, methane, hydrogen, benzene, formaldehyde, ethylene, propane, and ethanol gas detections	Dictionary learning method (DL) method reduces computation time in the training and testing phases but also obtains very competitive accuracy in identification tasks	He et al. (2017)

this approach is that the redundant sensors used in the gas sensor array were removed without hampering the actual functioning of the gas sensor array. In this approach, four hazardous gases were discriminated. In this approach, CNN is used with zero-padded virtual sensors and spatial augmentation as shown in Figure 5. From the array of four sensors, two physical sensors are replaced by a zero padding virtual dataset of those replaced sensors, and spatially augmented data vectors were used for testing and training purposes. They found the best results for SnO_2, ZnO-based sensors array. By using the approach of Chaudhri et al. (2022), there can be a reduction in cost, hardware, and power consumption for the smart sensors.

For a sensor to be smart, there must be a mechanism of powering the overall system wirelessly. This mechanism can be called as wireless rechargeable sensor network (WRSN). For powering the system various charging schemes can be seen in Figure 6. Qureshi et al. (2022) discussed various optimization techniques in WRSN and discussed the pros and cons for each technique as shown in Table 4. Almagrabi et al. (2020) proposed a novel Fair Energy Division Scheme that optimizes the energy division at the start of every cycle then starts the perpetual network operation.

5. Challenges and Solutions

1) Sensor which is present in the sensor array should detect the target gas even at low concentrations. Most of the sensors are of metal oxides, and metal oxides require an elevated temperature for proper working. This problem can be solved by raising the temperature of the gas sensor by increasing the heating capacity of the micro/nano heater of the sensor. For heating purposes, metals which are having good heating properties can be considered like platinum. Nanosensors need to be used as they consume less amount of power, and they are able to detect the smallest changes. After sensing material, the focus should be on the interconnection of the circuitry, and the routing of internal and external circuit is very much important based on this only the power consumption is dependent.
2) WRSN technique is discussed for wireless charging. By using approach of Van Duy et al. (2022), multiple gas sensing is possible on a single sensor with reduced power consumption.
3) Sensor array data generated should be applied with a proper algorithm for the discrimination of target gases from the gas mixture. The main problem of detecting the gas from a mixture of gases can be well recognized by using the ACNN method of pattern recognition. ACNN algorithm can give better results compared to the other algorithms for the discrimination and selectivity of the target gas. By using the approach proposed by Chaudhri et al. (2022) in multiple gas sensor array, the gas sensor elements can be reduced by using the technique of zero padding and spatial augmentation and CNN. As discussed by Chaudhri et al. (2022), the circuitry of a gas sensor can be reduced, and we can save almost 40-50% of power consumption. By using these novel techniques, a smart gas sensor can be developed.
4) For proper networking, wireless communication should be adopted so that it will be possible to get data in the cloud and controlling/action taking could be very much easier, and real-time sensing could be achieved. When the sensor's area and interfacing increases, power consumption rises. So by using Multiphysics

Figure 5
(a) Block diagram of sensor array using traditional ANN approach; b) Block diagram using 2D-CNN approach, zero padding and spatial augmentation (Chaudhri et al., 2022)

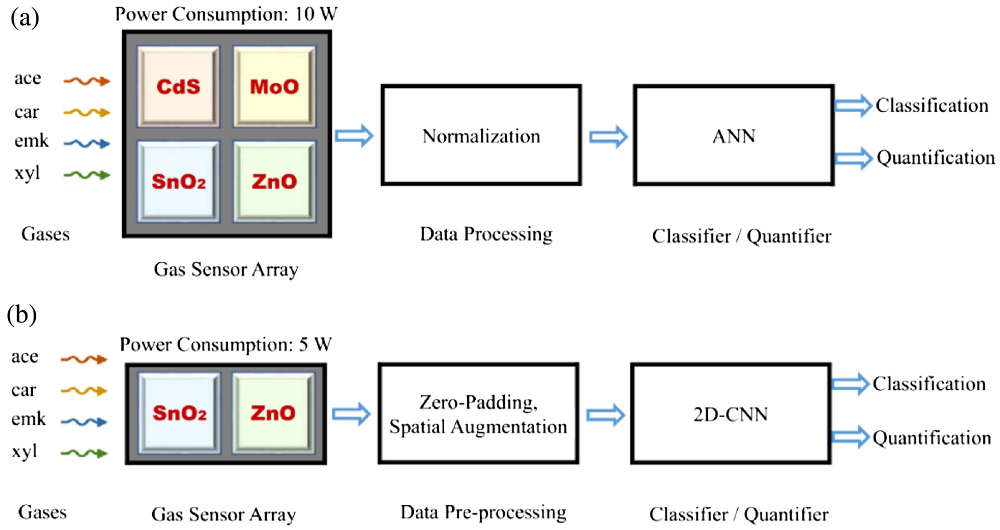


Figure 6
Schematic representation of currently employed charging schemes (Qureshi et al., 2022)

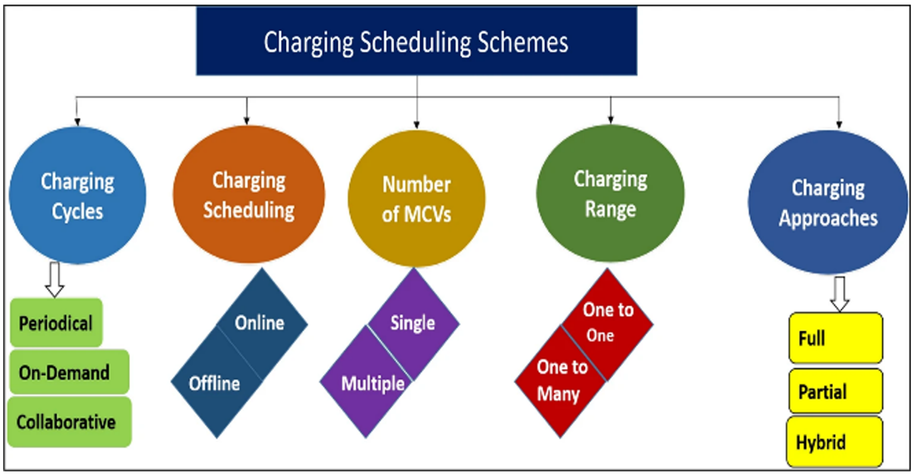


Table 4
WRSN techniques

2017	Clustering and designed energy-efficient traveling path with multiple WCV with multi-node charging	Tomar & Jana (2017), Qureshi et al. (2022)
2018	Clustering, improved charging efficiency, reduce charging latency	Han et al. (2018), Qureshi et al. (2022)
2019	Energy-balanced joint routing and charging (EbJRC) framework	Liu et al. (2019), Qureshi et al. (2022)
2020	Charging scheme based on actor-critic reinforcement learning (ACRL) algorithm	Yang et al. (2020), Qureshi et al. (2022)
2020	Fair energy division scheme	Almagrabi et al. (2020), Qureshi et al. (2022)

software, the power consumption should be calculated first and the sensor arrays should be fabricated. By using the approach of Qureshi et al. (2022), the charging of sensor circuitry can be done properly. If it is followed, then the power consumption will also get reduced, and the life of the sensor circuit can be increased.

6. Conclusions

It is precarious and contradictory that climate change, by far the most serious issue confronting human society, is widely neglected. The smart gas sensing technique requires a combination of multiple disciplines. It involves material science, electronics engineering, computer science, and mechanical engineering. The review here outlines the sensing of target gas in real time using an interdisciplinary approach which includes a physical device, sensing material, electronic circuit, networking, statistics, and machine learning method. A sensor can be fabricated using a sensing material which has affinity to sense the targeted pollutant. Gas sensor arrays can be fabricated using that selected sensor. Metal oxide-based sensors are promising and tend to give better results in terms of sensitivity, selectivity, and reproducibility. The only problem for MOS-based sensor is the requirement of elevated operating temperature which can be solved by designing a heater using Multiphysics software so that the whole device consumes less power and achieves desired heating temperature. To reduce the area, the power dissipation of the sensor array, Multiphysics software should be adopted and values of the same to be computed to get better results. The drift in the sensor which comes in due course of time can be removed by the PCA algorithm, and the ACNN algorithm of pattern recognition will be adopted for selective discrimination of gas from a mixture of gases. The smart gas sensor requirement is based on three main factors: the sensing element, the sensing circuit, and power consumption. These three aspects can be taken care of if we adopt the approach of Qureshi et al. (2022), Chaudhri et al. (2022) and Almagrabi et al. (2020). From these approaches, the power consumption and the area of a sensor circuitry can be reduced making it portable and fixable in IOT-based devices. If the device is bulkier, then it will consume large amount of power. The discrimination algorithm technique also makes the circuitry smaller as if we consider the zero padding technique can replace the sensors by using its data.

The need of the future is an autonomous smart device that can sense the hazardous gases in the ambient and indoor environment and warn about their concentrations of it. This smart device should provide the recorded data in real time and to a large distance with minimum power consumption and with the highest selectivity to target gases from a mixture of gases using a brain like decisions.

Recommendations

The findings reveal that the complex mechanism of the hazardous gas sensor for discrimination of different gases can be simplified by using the CNN algorithm. The size of a sensor circuit can be reduced by using the zero padding technique in which the actual sensors are replaced by virtual sensors. Therefore, the use of algorithms for discrimination of hazardous gases is recommended for reduction in area and cost of the circuitry. Since the gas sensors which detect poisonous gases are a very critical thing, any fault in the system may lead to severe casualties. So, for making devices smart the use of algorithms is recommended.

Acknowledgement

This work is done post-hands on training session with the facilities at INUP, Indian Institute of Technology, Bombay, funded by the Ministry of Electronics and Information Technology (MeitY), Govt. of India.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Nomenclature

WHO	World Health Organization
DALY	Disability-Adjusted Life-Years
PM	Particulate Matter
VOC	Volatile Organic Compounds
IOT	Internet of Things
WSNs	Wireless Sensor Networks
PCA	Principal Component Analysis
WRSN	Wireless rechargeable sensor network
ACRL	actor-critic reinforcement learning
ACNN	augmented convolutional neural network
SVM	support vector machine
FEDS	Fair Energy Division Scheme
HC	hierarchical classifier
PLSR	partial least squares regression
PLS	partial least square
SWNTs	single-walled carbon nanotubes
DMMP	dimethyl methylphosphonate
UWSN	Underwater wireless sensor network

References

Alizadeh, T., & Soltani, L. H. (2016). Reduced graphene oxide-based gas sensor array for pattern recognition of DMMP vapor. *Sensors and Actuators B: Chemical*, *234*, 361–370. https://doi.org/10.1016/j.snb.2016.04.165

Almagrabi, A. O. (2020). Fair energy division scheme to permanentize the network operation for wireless rechargeable sensor networks. *IEEE Access, 8,* 178063–178072. https://doi.org/10.1109/access.2020.3027615

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Brauer, M., Cohen, A. J., . . . & Dandona, L. (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The global burden of disease study 2017. The Lancet Planetary Health*, 3*(1), e26–e39. https://doi.org/10.1016/S2542-5196(18)30261-4

Cao, S., Sui, N., Zhang, P., Zhou, T., Tu, J., & Zhang, T. (2022). TiO2 nanostructures with different crystal phases for sensitive acetone gas sensors. *Journal of Colloid and Interface Science*, *607*, 357–366. https://doi.org/10.1016/j.jcis.2021.08.215

Chakraborty, J., & Basu, P. (2021). Air quality and environmental injustice in India: Connecting particulate pollution to social disadvantages. *International Journal of Environmental Research and Public Health*, *18*(1), 304. https://doi.org/10.3390/ijerph18010304

Chaudhri, S. N., Rajput, N. S., Alsamhi, S. H., Shvetsov, A. V., & Almalki, F. A. (2022). Zero-padding and spatial augmentation-based gas sensor node optimization approach in resource-constrained 6G-IoT paradigm. Sensors*,* 22(8), 3039. https://www.mdpi.com/1424-8220/22/8/3039

Chen, T. M., Kuschner, W. G., Gokhale, J., & Shofer, S. (2007). Outdoor air pollution: nitrogen dioxide, sulfur dioxide, and carbon monoxide health effects. The American journal of the medical sciences*,* 333(4), 249–256. https://doi.org/10.1097/MAJ.0b013e31803b900f

Chiu, S. W., & Tang, K. T. (2013). Towards a chemiresistive sensor-integrated electronic nose: a review. Sensors*,* 13(10), 14214–14247. https://doi.org/10.3390/s131014214

Chu, J., Li, W., Yang, X., Wu, Y., Wang, D., Yang, A., Yuan, H., Wang, X., Li, Y., & Rong, M. (2021). Identification of gas mixtures via sensor array combining with neural networks. *Sensors and Actuators B: Chemical*, *329*, 129090. https://doi.org/10.1016/j.snb.2020.129090

Destaillats, H., Maddalena, R. L., Singer, B. C., Hodgson, A. T., & McKone, T. E. (2008). Indoor pollutants emitted by office equipment: A review of reported data and information needs. *Atmospheric Environment*, *42*(7), 1371–1388. https://doi.org/10.1016/j.atmosenv.2007.10.080

Doshi, M., & Fahrenthold, E. P. (2022). Functionalized semiconducting carbon nanotube arrays for gas phase explosives detection. *Surface Science*, *717*, 121998. https://doi.org/10.1016/j.susc.2021.121998

Dutheil, F., Baker, J. S., & Navel, V. (2021). Air pollution in post-COVID-19 world: The final countdown of modern civilization? Comment on: "COVID-19 and air pollution: The worst is yet to come". Environmental Science and Pollution Research*,* 28(33), 46079–46081. https://link.springer.com/article/10.1007/s11356-021-14433-0

Feng, L., Dai, H., Song, X., Liu, J., & Mei, X. (2022). Gas identification with drift counteraction for electronic noses using augmented convolutional neural network. *Sensors and Actuators B: Chemical*, *351*, 130986. https://doi.org/10.1016/j.snb.2021.130986

Feng, S., Farha, F., Li, Q., Wan, Y., Xu, Y., Zhang, T., & Ning, H. (2019). Review on Smart Gas Sensing Technology. *Sensors*, *19*(17), 3760. https://doi.org/10.3390/s19173760

Creative Market. (2019). Five senses of human. Retrieved from https://creativemarket.com/Good_Studio/3897870-Five-human-senses?ts=201909

Jain, P. C., & Kushwaha, R. (2012). Wireless gas sensor network for detection and monitoring of harmful gases in utility areas and industries. In *2012 Sixth International Conference on Sensing Technology*, 642–646. https://doi.org/10.1109/ICSensT.2012.6461759

Gardner, J. W. (1991). Detection of vapours and odours from a multisensor array using pattern recognition Part 1. Principal component and cluster analysis. *Sensors and Actuators B: Chemical*, *4*(1-2), 109–115. https://doi.org/10.1016/0925-4005(91)80185-M

Gautam, S. (2020). COVID-19: Air pollution remains low as people stay at home. Air Quality, Atmosphere & Health, *13*, 853–857. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7241861/

Guttikunda, S. K., Goel, R., & Pant, P. (2014). Nature of air pollution, emission sources, and management in the Indian cities. *Atmospheric Environment*, *95*, 501–510. https://doi.org/10.1016/j.atmosenv.2014.07.006

Hallil, H., & Heidari, H. (2020). Smart Sensors for Environmental and Medical Applications. USA: John Wiley & Sons. https://doi.org/10.1002/9781119587422

Han, G., Yang, X., Liu, L., Chan, S., & Zhang, W. (2018). A coverage-aware hierarchical charging algorithm in wireless rechargeable sensor networks. *IEEE Network*, *33*(4), 201–207.

Hasager, F., Bjerregaard, J. D., Bonomaully, J., Knap, H., Afshari, A., & Johnson, M. S. (2019). Indoor air quality: Status and standards. In R. A. Meyers (Eds.). *Encyclopedia of sustainability science and technology*, 1–28. Springer. https://doi.org/10.1007/978-1-4939-2493-6_1097-1

Hasager, F., Bjerregaard, J. D., Bonomaully, J., Knap, H., Afshari, A., & Johnson, M. S. (2021). Indoor air quality: Status and standards. In *Air pollution sources, statistics and health effects*, 35–162. https://doi.org/10.1007/978-1-0716-0596-7_1097

He, A., Wei, G., Yu, J., Tang, Z., Lin, Z., & Wang, P. (2017). A novel dictionary learning method for gas identification with a gas sensor array. *IEEE Transactions on Industrial Electronics*, *64*(12), 9709–9715. https://doi.org/10.1109/TIE.2017.2748034

Hong, H. K., Shin, H. W., Park, H. S., Yun, D. H., Kwon, C. H., Lee, K., Kim, S. T., & Moriizumi, T. (1996). Gas identification using micro gas sensor array and neural-network pattern recognition. *Sensors and Actuators B: Chemical, 33*(1–3), 68–71. https://doi.org/10.1016/0925-4005(96)01892-8

Hunter, G., Neudeck, P. G., Beheim, G., Okojie, R. S., Chen, L., Spry, D. J., & Trunek, A. (2007). An overview of wide bandgap SiCsensor and electronics development at NASA Glenn Research Center. ECS Transactions, *11*(5), 247–257. https://doi.org/10.1149/1.2783879

Ismail, A. S., Wang, X., Hawbani, A., Alsamhi, S., & Abdel Aziz, S. (2022). Routing protocols classification for underwater wireless sensor networks based on localization and mobility. *Wireless Networks, 28*(2), 797–826. https://link.springer.com/article/10.1007/s11276-021-02880-z

Jorquera, H., & Villalobos, A. M. (2023). A new methodology for source apportionment of gaseous industrial emissions. *Journal of Hazardous Materials*, *443*, 130335. https://doi.org/10.1016/j.jhazmat.2022.130335

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution*, *151*(2), 362–367. https://doi.org/10.1016/j.envpol.2007.06.012

Kaur, R., & Pandey, P. (2021). Air pollution, climate change, and human health in Indian cities: a brief review. *Frontiers in Sustainable Cities, 3*, 705131. https://www.frontiersin.org/articles/10.3389/frsc.2021.705131/full

Kumar, S., Tiwari, P., & Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: a review. *Journal of Big data, 6*(1), 1–21. https://link.springer.com/article/10.1186/s40537-019-0268-2

Li, C. W., & Wang, G. D. (2006). The Research on artificial olfaction system-electronic nose. *Journal of Physics: Conference Series*, *48*(1), 667–670. https://doi.org/10.1088/1742-6596/48/1/125

Li, Y., Zhou, W., Zu, B., & Dou, X. (2020). Qualitative detection toward military and improvised explosive vapors by a facile TiO2 nanosheet-based chemiresistive sensor array. Frontiers in Chemistry, *8*, 29. https://doi.org/10.3389/fchem.2020.00029

Lim, G. H., Bae, S., Kim, Y. J., Lee, K. S., Cho, H., Park, Y. J., ... & Son, D. I. (2022). Boron nitride/carbon nanotube composite paper for self-activated chemiresistive detection. *Sensors and Actuators B: Chemical, 355*, 131273. https://doi.org/10.1016/j.snb.2021.131273

Liu, F., Lu, H., Wang, T., & Liu, Y. (2019). An energy-balanced joint routing and charging framework in wireless rechargeable sensor networks for mobile multimedia. *IEEE Access*, *7*, 177637–177650.

Lu, Y., Partridge, C., Meyyappan, M., & Li, J. (2006). A carbon nanotube sensor array for sensitive gas discrimination using principal component analysis. *Journal of Electroanalytical Chemistry*, *593*(1-2), 105–110. https://doi.org/10.1016/j.jelechem.2006.03.056

Ma, H., Wang, T., Li, B., Cao, W., Zeng, M., Yang, J., Su, Y., Hu, N., Zhou, Z., & Yang, Z. (2022). A low-cost and efficient electronic nose system for quantification of multiple indoor air contaminants utilizing HC and PLSR. *Sensors and*

Actuators B: Chemical, *350*, 130768. https://doi.org/10.1016/j.snb.2021.130768

Madaan, G., Swapna, H. R., Singh, S., & Arpana, D. (2022). Internet of Robotic Things: Issues and Challenges in the Era of Industry 4.0. *Next Generation of Internet of Things: Proceedings of ICNGIoT 2022*, 89–101. https://link.springer.com/chapter/10.1007/978-981-19-1412-6_8

Mannan, M., & Al-Ghamdi, S. G. (2021). Indoor air quality in buildings: A comprehensive review on the factors influencing air pollution in residential and commercial structure. *International Journal of Environmental Research and Public Health*, *18*(6), 3276. https://doi.org/10.3390/ijerph18063276

Marlier, M. E., Jina, A. S., Kinney, P. L., & DeFries, R. S. (2016). Extreme air pollution in global megacities. *Current Climate Change Reports*, *2*, 15–27. https://doi.org/10.1007/s40641-016-0032-z

Mitzner, K. D., Sternhagen, J., & Galipeau, D. W. (2003). Development of a micromachined hazardous gas sensor array. *Sensors and Actuators B: Chemical*, *93*(1-3), 92–99. https://doi.org/10.1016/S0925-4005(03)00244-2

Mutunhu, B., Chipangura, B., & Twinomurinzi, H. (2022). A systematized literature review: Internet of Things (IoT) in the remote monitoring of diabetes. In *Proceedings of Seventh International Congress on Information and Communication Technolog, 2*, 649–660.

Nazemi, H., Joseph, A., Park, J., & Emadi, A. (2019). Advanced micro- and nano-gas sensor technology: A review. *Sensors*, *19*(6), 1285. https://doi.org/10.3390/s19061285

Nervous System of Human (2021). https://marivellyden.blogspot.com/2021/03/picture-of-nervus-system-nerves-plaque.html

Nikolic, M. V., Milovanovic, V., Vasiljevic, Z. Z., & Stamenkovic, Z. (2020). Semiconductor gas sensors: Materials, technology, design, and application. *Sensors*, *20*(22), 6694. https://doi.org/10.3390/s20226694

Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., Turkgulu, B., Kumar, G. A., Khare, M., Beig, G., Gupta, T., Krishnankutty, R. P., Causey, K., Cohen, A. J., Bhargava, S., Aggarwal, A. N., Agrawal, A., Awasthi, S., Bennitt, F., et al. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *The Lancet Planetary Health*, *5*, e25–e38. https://doi.org/10.1016/S2542-5196(20)30298-9

Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., Turkgulu, B., Kumar, G. A., Khare, M., Beig, G., Gupta, T., Krishnankutty, R. P., Causey, K., Cohen, A. J., Bhargava, S., Aggarwal, A. N., Agrawal, A., Awasthi, S., Bennitt, F., . . . Dandona, L. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *The Lancet Planetary Health*, *5*, e25–e38. https://doi.org/10.1016/S2542-5196(20)30298-9

Ortiz Perez, A., Bierer, B., Scholz, L., Wöllenstein, J., & Palzer, S. (2018). A wireless gas sensor network to monitor indoor environmental quality in schools. *Sensors, 18*(12), 4345. https://doi.org/10.3390/s18124345

Pasupuleti, K. S., Nam, D. J., Bak, N. H., Reddeppa, M., Oh, J. E., Kim, S. G., ... & Kim, M. D. (2022). Highly sensitive gC 3 N 4 nanosheets as a potential candidate for the effective detection of NO 2 gas via langasite-based surface acoustic wave gas sensor. *Journal of Materials Chemistry C, 10*(1), 160–170. https://doi.org/10.1039/D1TC04904F

Qureshi, B., Aziz, S. A., Wang, X., Hawbani, A., Alsamhi, S. H., Qureshi, T., & Naji, A. (2022). A state-of-the-art survey on wireless rechargeable sensor networks: Perspectives and challenges. *Wireless Networks, 28*(7), 3019–3043. https://link.springer.com/article/10.1007/s11276-022-03004-x

Rattan, S., Kumar, S., & Goswamy, J. K. (2022). Gold nanoparticle decorated graphene for efficient sensing of NO2 gas. *Sensors International*, *3*, 100147. https://doi.org/10.1016/j.sintl.2021.100147

Ravishankara, A. R., David, L. M., Pierce, J. R., & Venkataraman, C. (2020). Outdoor air pollution in India is not only an urban problem. Proceedings of the National Academy of Sciences, 117(46), 28640–28644. https://doi.org/10.1073/pnas.2007236117

Sakurai, Y., Jung, H. S., Shimanouchi, T., Inoguchi, T., Morita, S., Kuboi, R., & Natsukawa, K. (2002). Novel array-type gas sensors using conducting polymers, and their performance for gas identification. *Sensors and Actuators B: Chemical, 83*(1-3), 270–275. https://doi.org/10.1016/S0925-4005(01)01069-3

Saleem, H., Zaidi, S. J., Ismail, A. F., & Goh, P. S. (2022). Advances of nanomaterials for air pollution remediation and their impacts on the environment. *Chemosphere*, *287*, 132083. https://doi.org/10.1016/j.chemosphere.2021.132083

Salthammer, T., & Bahadir, M. (2009). Occurrence, dynamics and reactions of organic pollutants in the indoor environment. *Clean–Soil, Air, Water*, *37*(6), 417–435. https://doi.org/10.1002/clen.200900015

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., & Fisk, W. J. (2012). Is CO2 an indoor pollutant? Direct effects of low-to-moderate CO2 concentrations on human decision-making performance. *Environmental Health Perspectives*, *120*(12), 1671–1677. https://doi.org/10.1289/ehp.1104789

Shao, S., Xie, C., Xia, Y., Zhang, L., Zhang, J., Wei, S., Kim, H. W., & Kim, S. S. (2022). Highly conjugated three-dimensional van der Waals heterostructure-based nanocomposite films for ultrahigh-responsive TEA gas sensors at room temperature. *Journal of Materials Chemistry A*, *10*(6), 2995–3008. https://doi.org/10.1039/D1TA09749K

Shehzad, K., Liu, X. X., Ahmad, M., Majeed, A., Tariq, F., & Wahab, S. (2021). Does air pollution upsurge in megacities after COVID-19 lockdown? A spatial approach. *Environmental Research, 197*, 111052. https://doi.org/10.1016/j.envres.2021.111052

Shupler, M., Hystad, P., Birch, A., Miller-Lionberg, D., Jeronimo, M., Arku, R. E., Chu, Y. L., Mushtaha, M., Heenan, L., Rangarajan, S., Seron, P., Lanas, F., Cazor, F., Lopez Jaramillo, P., Camacho, P. A., Perez, M., Yeates, K., West, N., Ncube, T., & Brauer, M. (2020). Household and personal air pollution exposure measurements from 120. https://doi.org/10.1016/S2542-5196(20)30197-2

Sinju, K. R., Bhangare, B., Pathak, A., Patil, S. J., Ramgir, N. S., Debnath, A. K., & Aswal, D. K. (2022). ZnO nanowires based e-nose for the detection of H2S and NO2 toxic gases. *Materials Science in Semiconductor Processing*, *137*, 106235. https://doi.org/10.1016/j.mssp.2021.106235

Star, A., Joshi, V., Skarupo, S., Thomas, D., & Gabriel, J. C. P. (2006). Gas sensor array based on metal-decorated carbon nanotubes. *The Journal of Physical Chemistry B, 110*(42), 21014–21020. https://doi.org/10.1021/jp064371z

Staerz, A., Weimar, U., & Barsan, N. (2016). Understanding the potential of WO3 based sensors for breath analysis. *Sensors, 16*(11), 1815. https://doi.org/10.3390/s16111815

Sun, H., Tao, L. Q., Li, T., Gao, X., Sang, T., Li, Y., ..., & Li, J. (2022). TiO2–Doped GeSe Monolayer: A highly selective gas sensor for SF6 decomposed species detection based on DFT method. *Applied Surface Science, 572*, 151212. https://doi.org/10.1016/j.apsusc.2021.151212

Sundgren, H., Lundström, I., Winquist, F., Lukkari, I., Carlsson, R., & Wold, S. (1990). Evaluation of a multiple gas mixture with a simple MOSFET gas sensor array and pattern recognition. *Sensors and Actuators B: Chemical*, *2*(2), 115–123. https://doi.org/10.1016/0925-4005(90)80020-Z

Suriano, D. (2021). A portable air quality monitoring unit and a modular, flexible tool for on-field evaluation and calibration of low-cost gas sensors. HardwareX, 9, e00198. https://doi.org/10.1016/j.ohx.2021.e00198

Tatli, S., Mirzaee-Ghaleh, E., Rabbani, H., Karami, H., & Wilson, A. D. (2021). Rapid detection of urea fertilizer effects on VOC emissions from cucumber fruits using a MOS E-nose sensor array. *Agronomy*, *12*(1), 35. https://doi.org/10.3390/agronomy12010035

Tomar, A., & Jana, P. K. (2017). Designing energy efficient traveling paths for multiple mobile chargers in wireless rechargeable sensor networks. In *2017 Tenth International Conference on Contemporary Computing,* 1–6. https://doi.org/10.1109/IC3.2017.8284332.

Tyagi, B., Choudhury, G., Vissa, N. K., Singh, J., & Tesche, M. (2021). Changing air pollution scenario during COVID-19: Redefining the hotspot regions over India. *Environmental Pollution*, *271*, 116354. https://doi.org/10.1016/j.envpol.2020.116354

Van Duy, N., Thai, N. X., Ngoc, T. M., Le, D. T. T., Hung, C. M., Nguyen, H., Tonezzer, M., Van Hieu, N., & Hoa, N. D. (2022). Design and fabrication of effective gradient temperature sensor array based on bilayer SnO2/Pt for gas classification. *Sensors and Actuators B: Chemical*, *351*, 130979. https://doi.org/10.1016/j.snb.2021.130979

Wang, T., Zhang, H., Wu, Y., Jiang, W., Chen, X., Zeng, M., Yang, J., Su, Y., Hu, N., & Yang, Z. (2022). Target discrimination, concentration prediction, and status judgment of electronic nose system based on large-scale measurement and multi-task deep learning. *Sensors and Actuators B: Chemical*, *351*, 130915. https://doi.org/10.1016/j.snb.2021.130915

WHO (2021) *World Health Statistics Report*. Switzerland: World Health Organization.

WHO (2021). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Switzerland: World Health Organization.

World Health Organization. (2021). Ambient (Outdoor) Air Pollution. Retrieved from https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

World Health Organization. (2021). Air Pollution. Retrieved from https://www.who.int/

Yang, D. S., Pennisi, S. V., Son, K. C., & Kays, S. J. (2009). Screening indoor plants for volatile organic pollutant removal efficiency. *HortScience, 44*(5), 1377–1381. https://doi.org/10.21273/HORTSCI.44.5.1377

Yang, M., Liu, N., Zuo, L., Feng, Y., Liu, M., Gong, H., & Liu, M. (2020). Dynamic charging scheme problem with actor–critic reinforcement learning. *IEEE Internet of Things Journal, 8*(1), 370–380.

Zhu, L., Wang, J., Liu, J., Xu, Z., Nasir, M. S., Chen, X., Wang, Z., Sun, S., Ma, Q., Liu, J., Feng, J., Liang, J., & Yan, W. (2022). In situ enrichment amplification strategy enabling highly sensitive formaldehyde gas sensor. *Sensors and Actuators B: Chemical*, *354*, 131206. https://doi.org/10.1016/j.snb.2021.131206

How to Cite: Bandewad, G. W., Datta, K. P., Gawali, B. W., & Pawar, S. N. (2023). Review on Discrimination of Hazardous Gases by Smart Sensing Technology. *Artificial Intelligence and Applications* 1(2), 70–81, https://doi.org/10.47852/bonviewAIA3202434