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Use of Electrical and Electronic Sensors in the Chemical Industry

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Abstract: Chemical industries, particularly those operated in continuous or steady state mode, rely on sensors for continuous feedback regarding key process parameters and product specifications. For example, most Chemical Industries being polluting in nature are governed by laws regarding emission of effluents and waste, sensors thus provide real time data to control effluent parameters. Sensors also play an effective role in reduction of operating costs through detection of leakages, structural damages etc. Electrical engineering and electronics play a key role in the development of sensors. With the advancement in technologies in these fields more compact, sensitive and specific sensors have been developed which can withstand harsher environmental conditions. Simultaneous development in fields like nanotechnology, biotechnology etc. and an inter-disciplinary research approach have led to the growth of interest in multi-disciplinary fields like Bio-Electronics.
Keywords: sensor, electronics, chemical, industry, electrical

I. INTRODUCTION

Sensor is that device which detects and responds to some type of input from the physical environment. The specific input could be heat, light, motion, pressure, moisture, or any one of the myriad number of other environmental phenomena.

Examples of sensors we come across in daily life include:

A mercury based thermometer, for which the input is temperature. The liquid contained expands and contracts in response, causing the level to be higher or lower on the marked gauge, which is human-readable.

An oxygen sensor in a car's emission control system detects the gasoline/oxygen ratio, usually through a chemical reaction that generates a potential difference. A computer in the engine reads the voltage and, if the mixture is not optimal, readjusts the balance.

Motion sensors in various systems including home security lights, automatic doors etc. typically send out some type of energy, such as microwaves, ultrasonic waves or light beams and detect when the flow of energy is interrupted by something entering its path.

A photo sensor detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy.

Electronic Sensors are used in the Chemical Industry primarily for Process Control and Monitoring to primarily monitor for safety. Sensors often have a decisive influence on the quality, mechanical and energy parameters, economic efficiency and safety of the process and the product by controlling key process parameters.

A generalized electronic sensing system produces changes in the physical/chemical properties of an array of sensory devices utilized in an electronic circuit to provide an analogue signal, which can be amplified, linearized and digitized before being fed into a pattern-recognition system. The functions of a generalized pattern-recognition system can be further subdivided into those of a pre-processor, a feature extractor and a classifier. All these functional units have some local memory that can be modified by feedback from the environment or internally.

A. Use of Sensors in the Food-Beverage and Aroma Industry

Electrical and electronic Sensors have vast applications in the food-beverage as well as the aroma(perfumery) industry. The need for electronic sensors in these industries arose primarily because the mechanical and manual methods already in place proved to be inefficient, expensive and time consuming while dealing with the ever increasing volumes of production. Besides sensors also give results that are reproducible even with variations in the environment compared to manual methods which are relative to the environment.

B. Use of Sensors in the Oil and Gas Industry

Oil and gas are characterized as hazardous, their transportation through pipelines warrants proactive and continuous monitoring.

Unfortunately, there has been limited continuous monitoring of this critical infrastructure, which causes great financial losses to the industry. Also, pipelines can unexpectedly fail for several reasons including, corrosions, cracking, process upsets, and external environment influences. Electronic Sensors are utilized by Oil & Gas Industry for monitoring various features such as, i) Pipeline Integrity, ii) Tank Level, iii) Equipment Condition, iv) Pipeline Pressure Relief Value, v) Wellhead Automation Monitoring and vi) Refineries Pressure Relief Value

Condition monitoring is often carried out periodically but system failure may occur between these intervals. Different kinds of sensors such as acoustic, vibration and temperature sensors can detect wall thinning or thickness through temperature of noise measurements, leakages by analysing real-time flow, and pressure measurements etc.

C. Use of Nanotechnology

When chemicals interact directly with the sensor surface, nanotechnology is invariably involved since biomolecules and other species of interest are at the nanometre size scale. Nanotechnology is built in and essential to sensor function. However, there are many recent examples where newer forms of Nano-structured materials increase the response speeds and/ or detection limits of chemical sensors and where Nano machined mechanical elements can translate a chemical signal into an electronic one.

D. Chemical Sensors

Sensors used in the chemical industry most commonly are the chemical sensors. Chemical sensors are transducers that incorporate a sensitive layer, which transforms a chemical interaction into an electrical signal. They tend to be small, operate in real time, and are controlled by the kinetics and thermodynamics of a reaction. Chemical sensor and biosensor technologies have emerged as dynamic approaches for identifying and quantifying specific analytes. Though the chemical sensors are sometimes robust enough to sense the analyte in an adverse environment, the sensitivity and selectivity obtained at a laboratory scale isn’t necessarily achieved in field-testing. The selectivity, sensitivity, and reversibility of the sensors still remains major concern. Addressing these concerns, the increase in sensitivity can be realized by appropriate sample pre-treatment and pre-concentration techniques, whereas filters and separation units can be used to increase the selectivity, minimize cross-interference, and reduce false positives and negatives. Adopting such measures will inadvertently increase the complexity of the whole system, but learning from past experience and leveraging current technology is often more desired than developing a simple product with significant deficiencies. Future sensor systems could probably address this issue by using sensor arrays and higher order sensors with advanced signal processing techniques to provide the selectivity and sensitivity.

E. Bio-Electronic Sensors

Bio-electronic sensors are the primary drivers of bioelectronics in that cells and their components can be used as biological transducers for measurements or as components in building novel materials or circuits, i.e. components of cells have been used for novel applications outside of their primarily observed application. Cells are sensitive to many environmental phenomena. For instance, identifying the response of a cell to a known toxin could allow it to be used as a “canary in a coal mine” to detect toxic substances in the air samples. Biomolecules, in particular anti-bodies, can also be used as transducers, via their exquisite specificity. Coupling antibodies with emerging Nano-technologies could result in highly sensitive sensing methods. Bio-inspired fabrication shows promise for constructing nanoscale assemblies, which could lead to significant advances in sensor designs and material sciences.

II. REVIEW OF THE LATEST RESEARCH

A. Sensors for Mechanical Parameters

Major performances losses occur in process industries due to failures that are not identified at the incipient stage. Early detection of the faults is also critical for the safety of equipment, operating persons and the other resources. The faults at the primary stage can propagate to wreck major havoc at the later stage. The use of sensor technologies for the detection of these faults in industries, chemical plants, etc. having large scale manufacturing is now in demand. Hence, sensors placement algorithms for fault diagnosis using qualitative models in the presence of numerical simulations have been proposed. [1]

Structural Health Monitoring(SHM) sensing requirements are very well suited for the application of optical fibre sensors (OFS), as shown in [23]. To bring about an increase in productivity safety of oil wells, it is essential to obtain reliable data about both physical and some chemical parameters from the wells in the oil fields. According to oil experts, it is possible to increase the well's production by up to 30% and reduce probability of occurrence accidents by utilizing OFS. The use of OFS in the Gas and Oil industry has increased substantially in recent years. Their utilization has been mainly centred in the monitoring of the pipeline and in the downhole, in order to detect and reduce the leakage, control the pressure and temperature, etc. with the aim of maximizing the oil production. OFS could also be used for security of these Oil and Gas installations.

With the extensive use and integration of 3D micro-parts in modern manufacturing, the need for accurate and traceable metrology is becoming ever more apparent. So that micro-structures, often containing many high-aspect ratio features, can be measured, a stylus for a vibrating micro-CMM(coordinate measuring machine) probe has been designed, as seen in [25]. It was observed that the sensitivity of the tested micro-CMM probe was dependant on the overall length of the stylus and not its diameter. Two styli have been selected to be assembled with the triskelion device and dynamically tested to ascertain whether they are suitably sensitive to detect the surface interaction forces that can greatly affect measurements taken at these small dimensions.

Higher rotor-stator interaction (RSI) has resulted due to current trends in design of pumps and turbines. Dynamic loads are of specific interest having produced catastrophic failure in pump-turbines. Determining RSI characteristics facilitates the proposal of actions that will prevent these failures. Pressure measures were suitable to monitor and detect RSI characteristics. The RSI characteristics allowed inferring important conditions of pump-turbine such as static eccentricity and an excessive pressure pulsation at a particular position. Thus RSI characteristics can also be determined using vibrations measured rotation with shaft. [26]

The absolute distance or position and the displacement of the target point with respect to a reference point along a linear or a rotary axis are the fundamental quantities for measurement in precision positioning. Laser interferometers with advantage of large measurement range, high accuracy, fast measurement speed, direct linkage to the definition of meter will continue to play an essential role in ultra-positioning systems. Working in well-controlled environments such as photolithography scanners and scanning type surface from measuring instruments are highly in demand. [28]

B. Gas Sensors

Luminescence based sensing schemes for oxygen have experienced a fast growth and are in the process of replacing the Clark Electrode in many fields as observed in [12]. Unlike electrodes, sensing is not limited to point measurement via fibre optic micro sensors but includes additional features such as planar sensing, imaging and intra cellular assays sensing nano-sized sensor particles. Optical sensors for O_2 have extra features like enabling O_2 to be sensed on a nanoscale and to be imaged over a large scale. Planar sensors for oxygen are also used in glucose sensors where the consumption of O_2 caused by glucose oxidase is measured. Industries in the field of environmental sciences and water process control use optical sensors for O_2.

A gas sensor of the type seen in [29], fabricated by the simple casting of single-walled carbon nanotubes (SWNTs) on an interdigitated electrode (IDE) is useful for gas and organic vapour detection at room temperature. The sensor's responses are linear for concentration of sub ppm to hundreds of ppm. The time is on the order of seconds for the detection response and minutes for recovery. The variation of sensitivity is less than 6% of all the tested devices. An important feature of the sensor platform is the extended detection capability to organic vapours such as benzene, acetone, etc. in principle semiconducting metal oxide as well as semiconducting SWNTs are non-sensitive to many organic vapours.

Electronic noses, [30], are the devices for the automated detection and classification of odours, vapours, etc. The electronic noses are comprised of chemical sensing systems (e.g. sensor array or spectrometer) and a pattern recognition system. Because the sense of smell is an important sense to the physician, an electronic nose has applicability as a diagnostic tool. Currently the biggest market for electronic noses is food industry. Application of electronic noses in food industries include assessment in food production, inspection of food quality by odour, control of food cooking processes etc.

A flexible graphene sensor array, [32], has been constructed by in situ reduction of a graphene oxide (GO) array patterned on a paper chip. To achieve cross-reactive sensing and gas distinguishing ability, the surface of each reduced GO (rGO) spot is modified with a variety of ionic liquids (ILs), which can significantly alter the semiconductor properties and consequently the gas sensing behaviour of the paper-supported rGO sensor. Gas sensors based on nanomaterials such as gold nanoclusters provide substantial advantages over conventional metal oxide-based gas sensors in terms of sensitivity, selectivity, and room-temperature operability. Graphene is fast emerging as a superior electronic material with excellent thermal, mechanical and electrical properties. Also, the band gap of graphene can be modified by chemical doping or surface modification. For example, pristine graphene displays semi-metallic properties with nearly zero band gap, while hydrogenated graphene displays semiconductor characteristics with an energy gap of 3.5 eV. P-type doping of epitaxial graphene (EG) has been achieved by surface modulation with a molecular electron acceptor. Therefore, the ability to introduce a band gap into graphene in a simple and reproducible manner can facilitate the fabrication of graphene-based devices.

Chemical sensors based on carbon nanotubes, [31], have recently attracted a great deal of attention. Nanotubes exhibit excellent properties as transducers since they are known to exhibit charge sensitive conductance and large surface area. For certain applications, semi-conducting nanotubes play an important role and therefore field-effect transistor(FET) geometry is very convenient. It is reported that nanotube transistors are responsive to several gaseous agents e.g. NO_2 and NH_3, in addition the conductance of nanotubes is known to be sensitive to ambient environments, especially to oxygen and oxygen containing species, but for practical sensor applications it is however necessary to investigate and to understand characteristics such as reproducibility, sensitivity, reversibility and selectivity to various gas analytes.

Gas sensors based on metal-oxide-semiconductor transistor with the polysilicon gate replaced by a gas sensitive thin film have been around however these are not suitable for the emerging mobile and wearable sensor platforms due to operating voltages and powers far exceeding the supply capability of batteries. A novel approach to decouple the chemically sensitive region from the conducting channel for reducing the drive voltage and increasing reliability, as shown in [34]. This chemically gated field effect transistor uses silicon nanowire for the current conduction channel with a tin oxide film on top of the nanowire serving as the gas sensitive medium. The potential change induced by the molecular adsorption and desorption allows the electrically floating tin oxide film to gate the silicon channel. As the device is designed to be normally off, the power is consumed only during the gas sensing event. This feature is attractive for the battery operated sensor and wearable electronics. In addition, the decoupling of the chemical reaction and the current conduction regions allows the gas sensitive material to be free from electrical stress, thus increasing reliability. The device shows excellent gas sensitivity to the tested analytes relative to conventional metal oxide transistors and resistive sensors.

Incorporating gas sensing devices into wearable devices such as wrist watches, tablets, etc. will revolutionize the health of environment and the industrial safety by providing individuals with a convenient way to detect harmful chemicals in the environment as shown in [9]. The integration of gas sensors in the handheld devices requires fabrication techniques to be compatible with the CMOS (Complementary Metal-Oxide Semiconductor) sequence, the power dissipation to be suitable for battery powered technologies and a minimal stress build-up due to reliability concerns. A reliability analysis of a gas sensor with a suspended membrane and tin oxide as the sensing layer has been performed.

The study in [11] aims to explore the potential merits of palladium oxide sensing electrodes. The physical properties, morphology, chemical properties and sensing performance of synthetic PdO electrode have been characterized. An interesting phenomenon is that the thickness of the PdO electrode has an impact on the sensing capabilities. The sensor with PdO sensing electrode has a relatively high sensitivity to CO, although the selectivity is the major problem that hinders the sensor in practice. Differential electrode equilibria have been proposed for the sensing mechanism.

C. Biological Sensors

Bacterial count quantification generated by medium dielectric variation and consequent polarization material release is the basis of this method based on Dielectric Magnetic Flux in [5]. It is useful in determining the bacterial count in juice industries. The sensing mechanism works when the external magnetic field solution conductivity variation was generated from the free electrons in the conductors which produced an eddy current and the consequent release of the paramagnetic material. This technology was developed on the basis that the bacterial concentration was kept under check.

The basic mechanism of bacterial sensing technology involving nano-pore arrays prepared from electrochemically etched silicon is shown in [6]. The pores on this array are blocked due to increasing bacteria concentration and thus the alert is given due to Fourier Transformed Reflectometry Interference Spectroscopy (FT-RIS). For food and water safety, quality control purpose, the bacterial concentration has to always be kept under check. The strategy established in this work is the rapid detection of target bacterial concentration.

There is always a need for rapid, specific and sensitive arrays for the detection of bacterial indicator for quality monitoring in [8]. Rapid arrays for detection of E-Coli were developed by using MUG Protein. The data developed in this study demonstrates that the customized biosensor can function as a useful tool to directly analyse the presence of E-coli in a water sample without processing or concentration steps. A biosensor in this study can be used independently or in conjugation with other methods as a part of an array to detect E-Coli.

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Escherichia-Coli O157-H7 is a predominant foodborne pathogen with severe pathogenicity leading to increasing attention given to rapid and sensitive detection. Impedance biosensors using new kinds of series-printed interdigital microelectrodes (SPIMS) and wheat germ agglutimin (WGA) for signal amplification are used to detect E-Coli O1587-H7 with high sensitivity and time efficiency in [10]. An electrochemical impedance immune-sensor based on self-assembled monolayer detection of E-Coli with signal amplification using WGA has been studied. The utility of WGA as a signal amplifier for bacterial detection has played a key role in this study.

D. Sensors for Chemical Parameters

A standoff detection scheme for buried landmines and concealed explosives charges is presented in [7]. The detection procedure consists of the following; live bacteria sensor strains, genetically engineered to produce a dose-dependent amount of Green Fluorescent Protein (GFP). The fluorescence produced by the bacteria in response to traces of the explosives material in their micro environment is remotely detected by a phase-locked optic-electric sampling system. This method can be effectively used to detect concentrations of explosives that may have leaked in a chemical industry, thus preventing loss of life and property.

The gas-solid two phase flow has been widely applied in the power, chemical and metallurgical industries. It is of great value in determining velocity at different locations in a pipeline. Thus electrostatic sensors array using 8 arc-shaped electrodes were designed as shown in [13] were developed. The gas-solid two phase flow has been widely applied in the power, chemical and metallurgical industries. It is of great value in determining velocity at different locations in a pipeline. Thus electrostatic sensors array using 8 arc-shaped electrodes were designed. The relationship between the cross-correlation (CC) velocity and the distribution of particle velocity, charge density and electrode spatial sensitivity was analyzed. Finally, the particle velocity at different locations with different flow conditions were measured to determine the particle velocity distribution.

A composite of poly (3, 4-ethylenedioxythiophene) Polystyrene sulfonate (PEDOT-PSS) and zinc stannate has been introduced for impedance based humidity sensing in [15] owing to high sensitivity, good stability, very fast response time (~0.2s) and recovery time (~0.2s), small hysteresis, repeatability, low cost of fabrication and wide range of sensitivity. Three different ranges of 2 composite materials have been mixed and analyzed to optimize the performance of the sensors.

The potential use of audible acoustic emissions for monitoring particle agglomeration in ethylene polymerization fluidized bed reactors was investigated in [20]. Comparison was made between the agglomeration signals and power spectral centroid offset. On this basis, the acoustic signals were decomposed by wavelet packet decomposition (WPD) and the energy ratios of every sub-band were set as the voice print. Subsequently, principal component analysis (PCA) was introduced to reduce the dimension ability of the feature vector.

Inspired by the dendritic integration and spiking operation of a neuron, in [33], flexible oxide-based neuromorphic transistors with multiple input gates are fabricated on flexible plastic substrates for pH sensing applications. When such devices are operated in a quasi-static dual-gate synergic sensing mode, it shows a high pH sensitivity of the order of 105mV/pH. Results also demonstrate that single-spike dynamic mode remarkably improves pH sensitivity and reduces response/recovery time and power consumption. Moreover, we find that an appropriate negative bias applied on the sensing gate electrode can further enhance the pH sensitivity and reduces power consumption. The flexible neuromorphic transistors provide a new sensory platform for biochemical detection with high sensitivity, quick response and highly reduced power consumption.

3D-printing is a developing technology that can revolutionize the way functional devices are fabricated. Metal 3D printing is used to fabricate bespoke electrochemical stainless steel electrodes that can be used as a medium for several electrochemical applications ranging from oxygen evolving catalyst to electrochemical capacitors and pH sensors by means of a controlled deposition of iridium oxide films as shown in [35]. Excellent pseudo capacitive as well as catalytic properties have been achieved with these 3D-printed steel-iridium oxide electrodes in alkaline solutions. These electrodes also demonstrate Nernstian behaviour as pH sensors. This work represents a breakthrough in on-site prototyping and fabrication of highly tailored electrochemical devices with complex 3D shapes which facilitate specific functions and properties.

Chlorine is used in water treatment plants. Hence the water needs to be monitored before being supplied to households which is currently done using DPD (N, N Diethyl-1,4 Phenylenediamine Sulphate). A need for a robust, reliable, low-cost, and portable sensor is desired to which the aminated-graphite found in lead of a pencil offers a promising solution, as demonstrated in [4]. The most important criteria it satisfies is that it responded to only chlorine ions and insensitive towards other potential anions present. It had low hysteresis losses, quick response time and showed a linear plot for concentration of chlorine and the signal outcome. The measurements done were compared to commonly used DPD colorimeter and results were fairly close. It also satisfied the basic criterion of a sensor being reusable. Thus this low cost and portable sensor could be successfully employed in near future.

E. Nano-technology based Sensors

The use of Nano-technology derived products in the development of sensors and analytical measurements methodologies has increased significantly over the past decade. Nano-materials based sensing approaches include the use of Nano-particles (NPs) and Nano-structures to enhance sensitivity and selectivity, design new detection schemes, improve sample preparation and increase portability. [16]

The biological and chemical sensors play an important role in human disease diagnosis, treatment and life safety and other industrial areas. Owing to the characteristics of high sensitivity to external environment, compactness and easy integration, nanowires (NWs) as shown in [14] possess potential application in biochemical sensors and have achieved measurement for a variety of physical, chemical and biological variables with a high precision and resolution in recent years. NW sensors have been widely used in detection of concentration of species of proteins, DNA, small molecules, viruses and gas. The compact and highly versatile NWs sensors possess high detection accuracy and sensitivity towards the analyte.

Chemo-resistive sensors are becoming increasing important as they offer an inexpensive option to analytical instrumentation. They can be readily integrated into electronic devices and they have low power requirements, as demonstrated in [17]. Nano-wires (NWs) are a major theme in chemo sensor development. High surface area, inter-wire junctions and restricted conduction pathways give intrinsically high sensitivity and new mechanism to the transducer binding or action of the analyte.

The nano-pore sensor is a high output and low-cost technology and can detect single nano-pore particle in solution. For the study presented in [21], the silicon nitride Nano-pores were fabricated by focused Ga ion beam (FIB). The surface was functionalized with 3-aminopropyltriethoxysilicate to change its surface density. Various experiments were performed on this basis and the results suggested that chemically modified nano- pores detected not only nana-particles but also provided an effective platform for the rapid analysis of nano-particle in solution.

Recent advancements in nanotechnology are being used for temperature measurements of various phenomena. Raman scattering principle using fibre optics as remote analysers is an effective technique used in nanowires and nanotubes for strain temperature measurement, as in [2]. Thermographic phosphor thermometry uses the principle of luminescence on nanoparticles and exploits the property of spectral line dependence on temperature. Techniques for using refractive index as a parameter to gauge temperature variations called thermos-reflectance and interferometry in which temperature is quantified by analysing the optical path of light in the sensor. Non-luminescent methods use transducers of nanoscale for temperature measurement and find their application in scanning thermal microscopy, nanolithography, carbon nanotubes, and biomaterials. The energy emitted by a body in form of thermal radiations is measured by infrared measuring devices. Thermometers of nanoscale are sensitive to radiations of limited wavelength range. The conventional liquid in tube methods and resistance temperature devices can also be used.

F. Sensors inspired from Biological Sciences

The ability to detect small molecules in a rapid and sensitive manner is of great importance in the field of critical chemistry. Testosterone is an example of such a small molecule. The detection of testosterone is important in both clinical and sporting industries to prevent doping. Such a portable, rapid and sensitive test of testosterone would be of great use across a variety of analytical fields. Two sensing platforms are directly compared for the detection of testosterone based on classical SPR (Surface Plasmone Resonance) and LSPR (Localized SPR). Using a competitive assay format and functionalized gold nano-particle, testosterone detection was made successful in [18].

A cross match test is required to examine the repeatability between donor and recipient blood groups. Generally, in all cross match tests, a specific chemical reaction of antibodies with erythrocycle antigens is carried out to monitor agglutination. Despite the classical methods, modern biosensors and molecular blood typing strategies have also been considered for straight forward, accurate and precise analysis. The interfacial part of a typical sensor device could range from natural antibodies to synthetic receptor material as designed by molecular imprinting and which is suitably integrated with the transducer's surface in [19]. Such a sensor could be used in the chemical industry to match specific molecules for a particular reaction.

Wireless medical instruments are readily available commercially for a variety of applications, including diagnostics, surgical, in

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vivo, remote patient monitoring, and indoor positioning. Currently research is integrating more biosensors, electronics, and wireless capabilities into portable, low power systems that can be worn or implanted into patients. Wireless systems will play an integral role in the future of health-care technology and healthcare infrastructure with pervasive wireless networks and devices becoming a reality inside the hospital and the healthcare industry. [24]

The study of Sensitivity (S) and Limit of Detection (LOD) of microscopic based photonic biosensors as a function of the waveguide composition and dimension has been proposed in [3]. Aflattoxin, which is a toxin of major concern for South-Europe dairy industries. The sensing device is based on an array of multiple SiON micro-ring resonators. The detection of Aflattoxin in solutions of various concentrations is being performed by functionalized sensors.

The applicability of observability analysis for accelerating the development of mechanism soft sensors in the bioprocess application were performed as observed in [22]. Observability analysis can be used for identification of suitable secondary measurement combinations and can provide sufficient criteria for designing experiments that can lead to better process understanding. It is now possible to choose particular process analytically strategy based on their information content and expected measurement error. Thus the observability analysis is a useful tool for bioprocess development application.

G. Future of Sensors in the Chemical Industry

From the ground to the edge of the space, NASA (National Aeronautics and Space Administration) has applications that require passive wireless sensor technologies in extreme aeronautical environments. Sensor systems of NASA (including acceleration, pressure, temperature, shape, strain, chemical, acoustic emission, imaging, ultrasonic, eddy current, thermographs and tetra hertz waves) could benefit the chemical industry by making sensors passive and wireless. However, each of these applications has its own requirements and issues. Extreme environments offer may challenge that must be addressed such as temperature, pressure, vibration, ionizing radiations, etc. [27]

III. CONCLUSION

The recent advances in sensor technologies utilizing the latest research in electronics and electrical engineering are being used in the chemical industry to enhance the quality, quantity and life of the industrial produce. The use of sensor applications such as electronic noses, electrical sensor arrays, carbon Nano-tubes, electronic tongue etc. has greatly increased over a period of decades due to the demand of better working conditions, fast reproduction and increased quality. Also the use of sensing mechanism has not been restricted only to the technical field, but also has been used in biological sciences and their application based processes. The use of sensors for bacterial sensing applications, detecting the concentrations of bacteria etc. is mandatory due to growing usage of biological components and processes in the chemical industry. Also the demand of today's age is increased level of precision. Hence sensors are recognized as a tool for increasing the precision in chemical industries and also other industries. The fabrication of sensors from materials like Nano-wires and polymers reveal the extent of inter-disciplinary research being carried out in these fields. Hence we can conclude that sensors have played a key role in revolutionizing the chemical industry and ensuring safety and quality of the processes and products.

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Figures and Tables

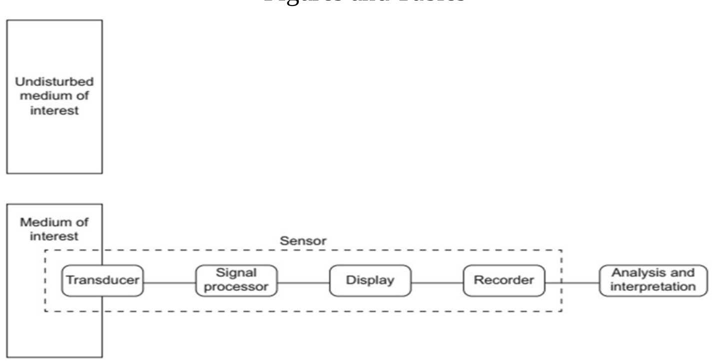

Figure 1. A comparison between the undisturbed medium and a typical temperate measurement application [2]

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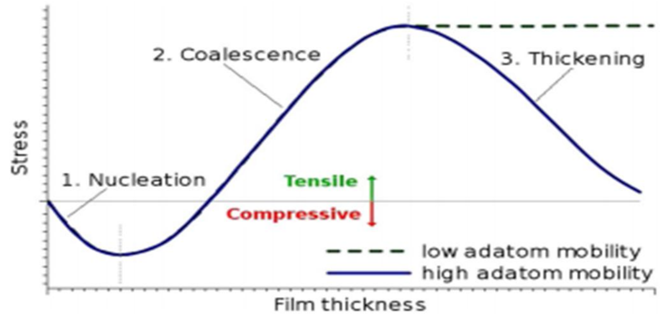

Figure 2. Stress evolution during the growth of metal and metal oxide films [9]

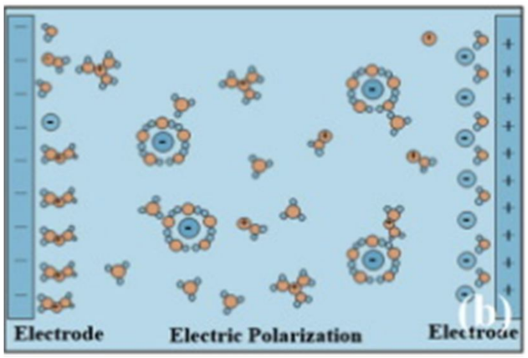

Figure 3. Electric Polarization between 2 electrodes [5]

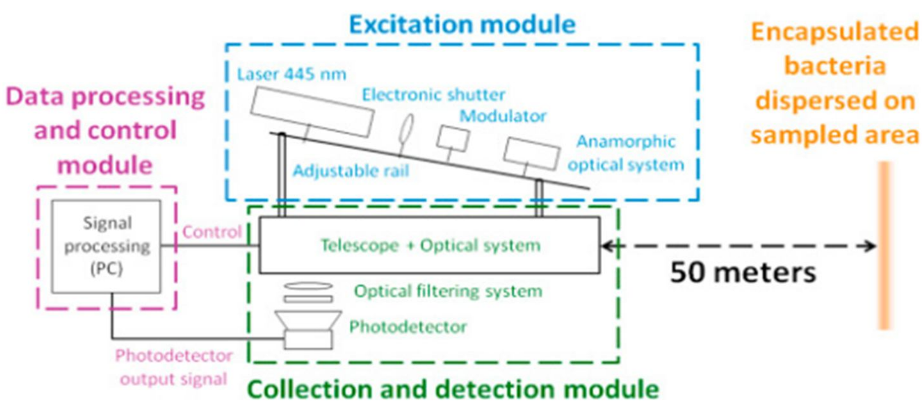

Figure 4. Schematic representation of the standoff sampling system [7]

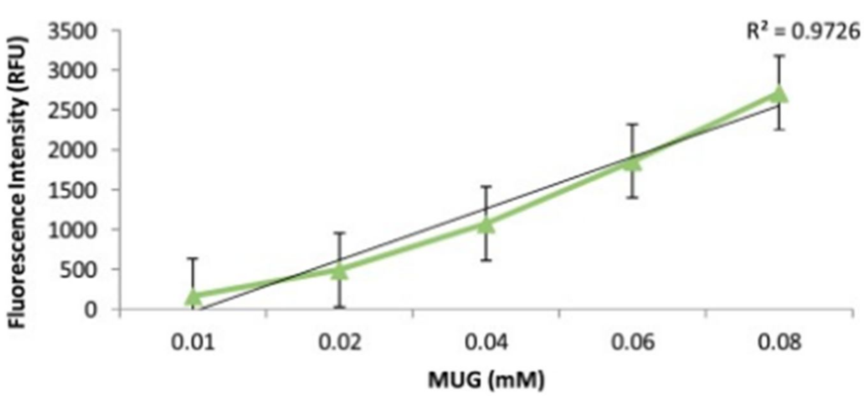

Figure 5. E. coli MUG calibration curve [8

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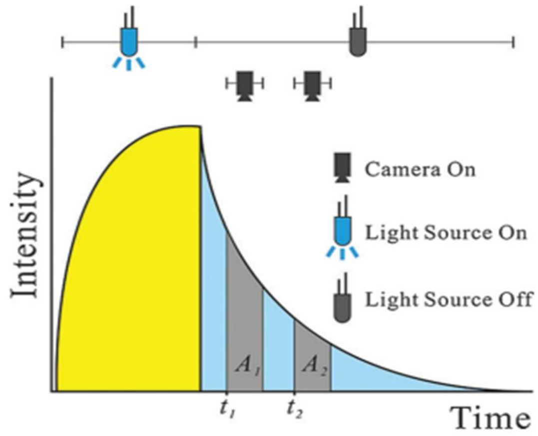

Figure 6. The RLD method for rapid determination of luminescence decay time [12]

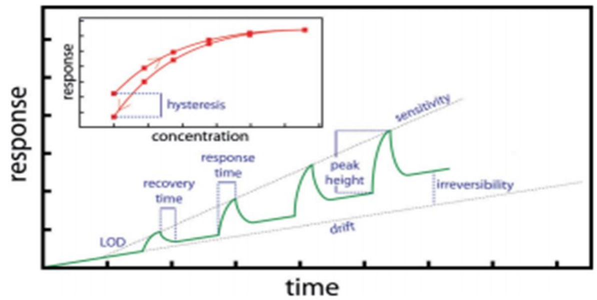

Figure 7. Graphical representation of selected performance parameters [17]

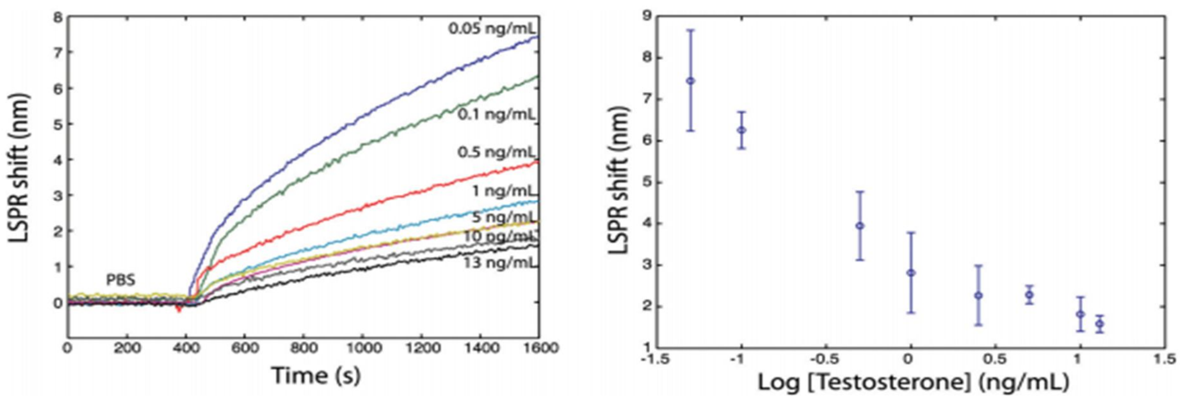

Figure 8. (Left) LSPR sensograms for testosterone. (Right) Log-scale calibration curve. [18]

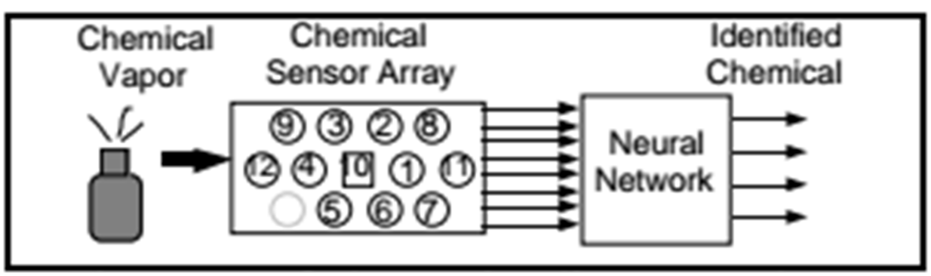

Figure 9. Schematic diagram of an electronic nose [30]

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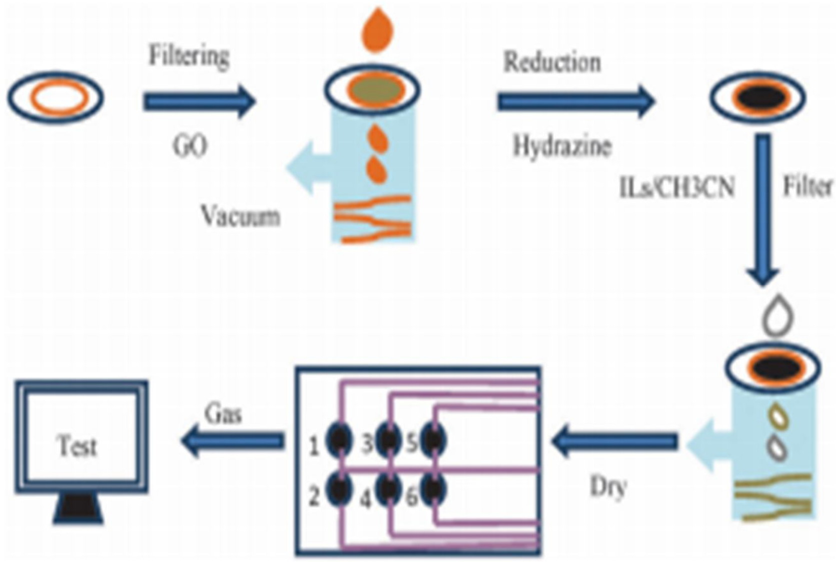

Figure 10. Procedure for preparation of paper supported rGO-IL sensor array [32]

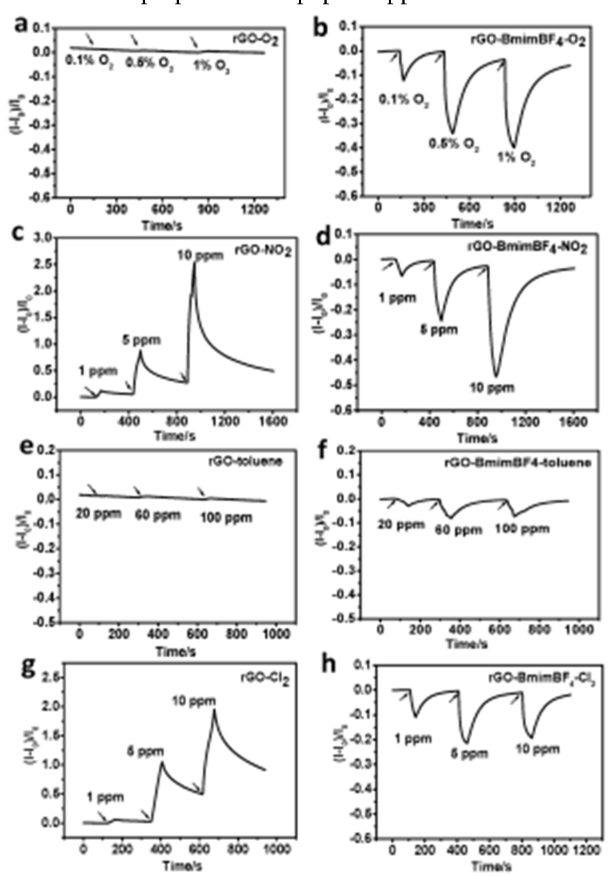

Figure 11. The conductance response of the paper-supported rGO chip to(a) diluted air sample containing 0.1–1.0% O_2; (c) NO_2 (1–10 ppm); (e) toluene vapour (20–100 ppm); (g) Cl_2 (1–10 ppm). The resistance response of the paper supported rGO–$BmimBF_4$ chip to (b) diluted air sample containing 0.1–1.0% O_2; (d) NO_2 (1–10 ppm); (f) toluene vapour (20–100 ppm); (h) Cl_2 (1–10 ppm). [32]

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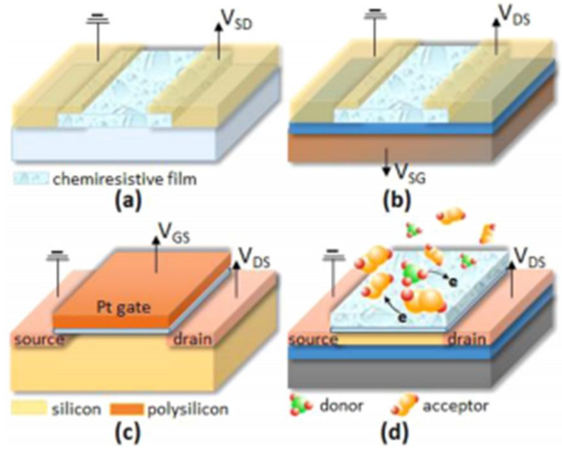

Figure 12. Schematic illustration of various gas sensor structures [34]

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