Comparative Analysis of Enzymatic and Immunological Biosensors in Biomedical Applications

Abhishek Saxena[1], K Praveena[2*], Manjunatha[3], Vijay Kalbande[4], Irfan Khan[5], Preeti Maan[6], Rahman S. Zabibah[7]

[1]Department of Mechanical Engineering, ABES Engineering College, Ghaziabad-201009, UP, India
[2]Institute of Aeronautical Engineering, Dundigal, Hyderabad, India
[3]Department of Mechanical Engineering, New Horizon College of Engineering, Bangalore, India
[4]Department of Mechanical Engineering, Nagpur Institute of Technology, Nagpur, India
[5]Lloyd Institute of Engineering & Technology, Knowledge Park II, Greater Noida, Uttar Pradesh 201306
[6]Lloyd Institute of Management and Technology, Greater Noida, Uttar Pradesh, India-201306
[7]Medical Laboratory Technology Department, College of Medical Technology, The Islamic University, Najaf, Iraq

*Corresponding author: *k.praveea@iare.ac.in*

Abstract. Biosensors are essential for transforming biological signals into electrical ones and have a wide range of uses in the biomedical, agricultural, and environmental fields. A biosensor is a device that combines biological and physicochemical elements to detect changes in physiological or biochemical states. This paper provides a comprehensive overview of the development and application of enzymatic and immunological biosensors, emphasizing their significant role in environmental, agricultural, and biomedical sectors. By leveraging the unique properties of natural polysaccharides, particularly cellulose, for their construction, these biosensors offer enhanced biocompatibility, robust mechanical strength, and cost-effectiveness. This study discusses the principles underlying biosensors, including their biological recognition elements, transduction mechanisms, and output systems. Enzymatic biosensors, characterized by their use of enzymes as bio receptors, and immunological biosensors, utilizing antibodies or antigens for the detection of immunocomplex formation, are evaluated in detail. Through comparative analysis, the paper highlights the diverse functionalities, sensitivities, and applications of these biosensors, ranging from glucose and hydrogen peroxide detection to monitoring of protein markers and E. coli bacteria. The study underscores the biosensors' ability for facilitating rapid, incredibly sensitive, and specific detection capabilities, critical for advancing scientific diagnostics, environmental surveillance, and food protection.

Keyword-: Enzymatic Biosensors, Immunological Biosensors, Natural Polysaccharides, Cellulose, Biocompatibility.

1 Introduction

Over the past few decades, the biological sensing industry has been rapidly investigated for novel uses and industries. Examples include medication screening, Alzheimer's diagnosis, sequencing of genomes, and blood nutrition tracking. In actuality, the vast majority of companies want to reach consumers in industrialised nations. On the other hand, nations that are developing are an orphan situation. Although the requirements of the latter group are apparently very different from those of the former, numerous of these requirements are still unmet, which suggests that biosensor technologies may yet have untapped potential. The inadequacy of medical facilities and frequent requirements for decentralised testing in remote locations to shorten turnaround times are two critical challenges that can be addressed by technology that provide such evaluations at the point of care. Biosensors play a critical role in changing biological signals into electric ones, finding numerous applications across environmental, agricultural, and biomedical domain names. Natural polysaccharides stand out within the biosensor arena, leveraging their stunning structural and practical trends like biocompatibility, film-forming abilities, and ability to construct complicated 3-dimensional matrices. Cellulose, the most considerable natural biopolymer, gives a plethora of wonderful capabilities, consisting of amazing capability, flexibility, sturdy mechanical strength, biodegradability, hydrophilicity, and price-effectiveness [1]. A biosensor is a tool capable of detecting physiological or biochemical modifications via the integration of organic and physicochemical components, Fig. 1 shows the working principle of biosensors. Normally, it incorporates a biomolecule, a transducer, and an output device. The specificity of biosensors predominantly hinges on the biomolecule hired, which may additionally consist of enzymes, nucleic acids, antibodies, cells, or tissues. Biomolecules remarkable selectivity permits them to recognize analytes, with the biochemical signal generated at some stage in popularity sooner or later transformed into a detectable signal by using the transducer. This signal is normally manifested as an electrical signal through the output machine.

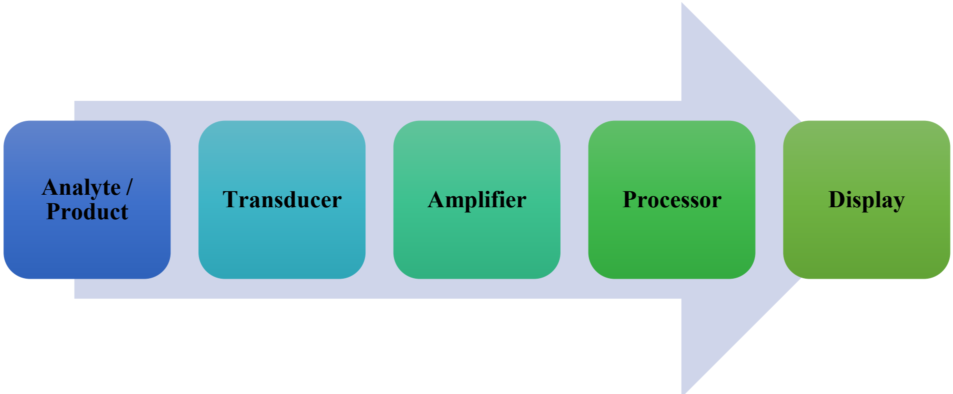

Fig. 1 : Working principle of biosensor

Biosensors are crafted in numerous styles and sizes, utilising an array of transducers which include electrochemical, optical, piezoelectric, thermal, or ion-selective electrodes. Amongst these transducers, electrochemical and optical ones are often favoured due to their inherent advantages. Various sorts of biosensors exist, consisting of mobile-based [2], microbe-primarily based, enzyme-based [3], electrochemical [4], immune sensor [5], protein, genetically encoded biosensors, DNA [5], tissue-primarily based, magnetic, optical, piezoelectric biosensors, and thermal editions. Every of these biosensors possesses precise production approaches and applications. However, they all function on the essential principle of analysing and recognizing samples, followed with the aid of transduction and amplification. in spite of this commonality, those gadgets bring in a new generation in scientific sciences, with their capability to hit upon even minuscule sample portions progressively escalating their demand [6].

2 Biosensors Based on Biological Recognition Element

2.1 Enzymatic Biosensors

An enzyme is used as a bio-receptor in enzymatic biological sensors, which are instruments for analysis that produce a continuous or discontinuous digital electrical/optical signal according to the concentration of the analyte in the material, as depicted in Fig. 2, being studied. The sensor that produces the signal also known as transducer can be integrated within the biosensor or closely related to it. A flexible electrochemical biosensor made of laser-induced graphene as well as laser direct engraved onto a polymer substrate is described in the publication that was published in [8]. On a polyimide substrate in the solution, a laser-induced graphene electrode was produced using a 450 nm UV laser. Following the engraving manage, a chitosan and glucose oxidase (GOx) combination was immobilised on the LIGE surface to create a biosensor for detecting glucose. The LIGE biosensor provided excellent responses over a broad linear range of up to 8 mm. The GOx/chitosan-modified LIGE biosensor demonstrated great sensitivity (43.15 µA mm-1 cm-2) and a relatively small limits of detection of 0.431 mm. The research presented in [9] proposes an enzymatic biosensor for amperometric identification of peroxide that contains hydrogen, which uses direct electrochemistry of myoglobin (Mb) on a porous cerium dioxide (CeO_2) nanotechnology layer. The CeO_2 film, electrodeposited on an indium tin oxide (ITO) substrate, has a wide expanse of surface and distinct nanostructures.

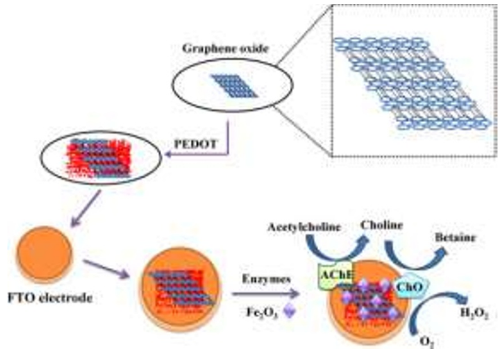

Fig. 2: Enzyme based biosensors [8]

Electrochemical experiments employing cyclic voltammetry (CV) and differential pulse voltammetry (DPV) demonstrate a simple, direct electrochemistry of molecules of biosensors immobilised on the CeO_2 film, which exhibits good electrocatalytic performance despite the absence of electron mediators. The biosensor is stable and sensitive, detecting H_2O_2 at concentrations as low as 0.6 μm with uniformity up to 3 mm and a response time of around 8 seconds. Particularly, the sensor exhibits low influence from intermediates molecules, demonstrating its suitability for catalytic sensors or devices. Electrical spinning was used to create a partially aligned and free-standing carbon nano-fiber (CNF) mat impregnated with silver nanoparticles, or Ag NPs, using a polyacrylonitrile (PAN) and silver nitrate blend, followed by carbonisation in [10]. The fibre diameters of the synthesised CNFs ranged from 130 to 190 nm, while the impregnated Ag NPs measured about 30 nm. The existence of Ag NPs increased the conductivity of electricity and encouraged the graphitization process of CNFs. To identify triglycerides, these substances were produced electrophoretically on indium tin oxide electrodes. After oxygen plasma treatment, the loading of lipase and glycerol dehydrogenase bienzymes increased on the surfaces of CNFs and Silver carbon based nano fibres. Ag-carbon-nano-fibres transported electrons more quickly than CNFs, according to both cyclic voltammetry and electrochemical impedance spectroscopy measurements. Nanoporous CNFs with covalent functionalization increased the long-term viability of the biosensor. Over a wide identification range (25-500 mg/dL), Ag-carbon-nano-fibres demonstrated a four-fold greater sensitivity (1.232 μA mg/dL^{-1} cm^{-2}) than CNFs (0.33 μA mg/dL^{-1} cm^{-2}). The biological sensors in consideration showed quick response times of 10 seconds, good selectivity, and reproducibility.

2.2 Immunological Biosensors

Immuno-biosensors detect the creation of an immunocomplex by using an antibody or antigen as a bioreceptor. Michael Heidelberger and Oswald Avery were the first to discover that an antigen and an antibody can bind together to generate a precipitate. In [11], a hybrid-biosensor system was designed to perform immunoassays for protein indicators (e.g., C-reactive protein (CRP) and procalcitonin (PCT) as well as enzyme tests for metabolic constituents (e.g., lactate) in sepsis-based samples. This device combines an enzyme-reaction zone onto the signal pad of a standard immunostrip, allowing for quick two-dimensional chromatographic testing. To reduce interference, a specified membrane location with a biological reaction pad allows the sample to enter and generate a coloured signal during the immunoassay. Signals from each experiment are detected and measured with a smartphone-based detector. Under ideal conditions, the dynamic ranges span clinical ranges with a total coefficient of variation of 8.6% to 13.3%. The hybrid biosensor shows strong correlation ($R^2 > 0.95$) with reference systems for target markers. To tackle the problem of infections caused by bacteria in biomedical, food, and environmental settings, the integration of nanotechnologies with biosensors is widely seen as a potential strategy to developing fast, highly sensitive, and specific detection systems [12]. The author proposed an electromechanical immuno-biosensor design that combines non-cytotoxic silica nanoparticles (NPs) using a two-step spin coating method. Unlike biosensors with a single antibody-based layer, this novel instrument allows for ongoing and unsaturated identification of E. coli bacteria in about 5 minutes using cyclic voltammetry. It can detect up to 103 CFU/mL within 30 minutes. Additionally, the study expands its analysis to include idealised building clusters for the duration of seismic activities, concentrating on their reactions, how they affect floor motion, and how they interact with surrounding systems and the earth. The research, which simulates the ground movement for the duration of the Northridge earthquake of 1994, reveals that the effects of soil-shape interaction (SSI) vary relying on the amount and dynamic characteristics of the homes, their distance from each other, and the impedance of the soil. Those impacts show up as variations in roof displacement, modifications in higher natural frequencies of constructing-basis systems, full-size decreases in base movement at high frequencies, and more spatial variability of floor movement. The detailed dynamics of multi-tale buildings beneath seismic and wind masses are basically discovered with the aid of this sizable look at, which additionally sheds perception on the complex interactions among structural additives, soil homes, and surrounding structures at some point of these dynamic occurrences.

An overview of the production of NiTi smart alloys using additive manufacturing techniques and their use in the healthcare sector is provided by [18]. The primary sources of heavy metal ions (HMIs) have been both natural and man-made substances. Because of its acknowledged harmful and cumulative effects on biological media and the environment, it has grown to be one of the most significant social challenges. Important steps must be taken to lessen the threats that hazardous metal contaminants in the environment cause. Using electrochemical detection methods in conjunction with tailored nanomaterials, together with stepping up research into HMI detection, is a promising and novel approach that may be able to contain heavy metal toxicity [19]. The study encompasses the entirety of the research on carbon nanotechnology development for biomedical applications. Specifically, the use of CBNs as drug delivery vehicles in carbon nanostructures is discussed [20]. Additionally included are the various CBNs' computer modelling methodologies. Prospectus, problems, and potential difficulties in this quickly evolving industry are also discussed in [21]. The overall comparison of biosensors is discussed in Table 1, which shows how enzymatic biosensors are differ from immunological biosensors.

Table 1: Comparative analysis based on biological elements [13-17].

Parameters	Enzymatic Biosensor	Immunological Biosensors
Définition & Principle	Analytical devices with enzymes as bioreceptors, producing signals proportional to analyze concentration.	Biosensors using antibodies or antigens to detect immunocomplex formation.

Materials Used	1. Laser-induced graphene on polymer substrate. 2. Chitosan and glucose oxidase composite. 3. Porous cerium dioxide nanostructured film. 4. Carbon nanofibers with silver nanoparticles.	1. Hybrid systems for simultaneous immunoassays and enzyme assays. 2. Silica nanoparticles for electrochemical immuno-biosensors.
Analyte Detection	1. Glucose. 2. Hydrogen peroxide. 3. Triglycerides.	1. Protein markers (CRP, PCT). 2. Metabolic substances (lactate). 3. E. coli bacteria.
Sensitivity	1. Glucose sensor: 43.15 µA mM^{-1} cm^{-2}. 2. H_2O_2 sensor: Detects as low as 0.6 µM. 3. Triglyceride sensor: 1.232 µA mg/dL^{-1} cm^{-2} for AgCNFs.	Variable, depending on the immunoassay; for E. coli detection, effective at 103 CFU/mL.
Detection Limit	1. Glucose sensor: 0.431 mM. 2. H2O2 sensor: 0.6 µM. 3. Triglyceride sensor: 25–500 mg/dL.	Not specified for protein markers; E. coli detection up to 103 CFU/mL.
Response Time	1. Glucose sensor: Not specified. 2. H2O2 sensor: ~8 s. 3. Triglyceride sensor: 10 seconds.	1. Hybrid biosensor: Not specified. 2. E. coli sensor: 5 minutes for detection, 30 minutes for assay.
Specific Applications/Advantages	1. Flexible and wide detection range. 2. High sensitivity and low detection limit. 3. Enhanced electrical conductivity and graphitization.	1. Rapid two-dimensional chromatography testing. 2. High correlation with reference systems. 3. Rapid, highly sensitive, and specific detection of bacteria.

3 Applications Of Biosensors

Analyte detection mechanisms known as biosensors are made up of a biological component and a physiochemical detector. These devices can be used for a multitude of purposes as depicted in Fig. 3, from environmental and utilised for agriculture to medicinal [22]-[25]. The food company also makes use of the sensors. A frequently used instance of a medically employed biosensor is the glucose monitor, which people with diabetes use for monitoring their sugar levels in their blood on a regular schedule. With the help of these sensors, which measure blood glucose levels in undiluted samples of blood, the treatment of diabetes has been completely transformed thanks to simple self-testing and tracking. In the food sector, biosensors serve a purpose, for example, in quality assurance processes for evaluating acidic substances, alcoholic beverages, and carbs [26].

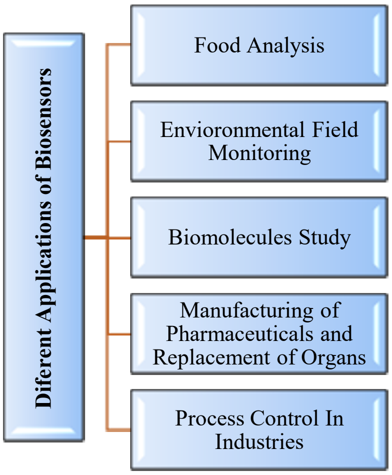

Fig. 3: Applications of enzymatic biosensors

These devices are additionally capable of being utilised to monitor fermentation while soft drinks, yoghurt, and beer are being made. Their usage in identifying pathogens in fresh seafood, poultry, or meat production is another significant purpose [27]. For the purpose of evaluating the water and air quality, biosensors are employed. These sensors can be applied, to detect wastewater levels of toxicity or to detect residues of pesticides containing organophosphates [28].

4 Ethical and Regulatory Considerations

The declaration underscores the vital role that biosensor technology, mainly whilst incorporated with improvements in nanobiotechnology, may want to play in improving international health consequences—a fundamental human right as identified by way of worldwide human rights documents [29]-[34]. Biosensors, by distinctive feature of their potential to hit upon and display various environmental and organic parameters, hold the promise of extensively contributing to public health and the achievement of the Sustainable improvement goals (SDGs) set by using the UN for 2030. Those goals emphasize the importance of proper health and well-being, clean water and sanitation, less expensive and clean energy, and climate motion, amongst others, all of which can be undoubtedly impacted by way of the deployment of biosensor era [25].
Fig. 4 shows the ability of biosensors extends to monitoring environmental changes and biodiversity, regions essential for maintaining ecological stability and human health. By means of providing actual-time statistics and analytics, biosensors can usefully resource in early caution structures, pollution manage, and the control of natural resources, thereby contributing to numerous SDGs circuitously related to fitness and sustainable dwelling [36].

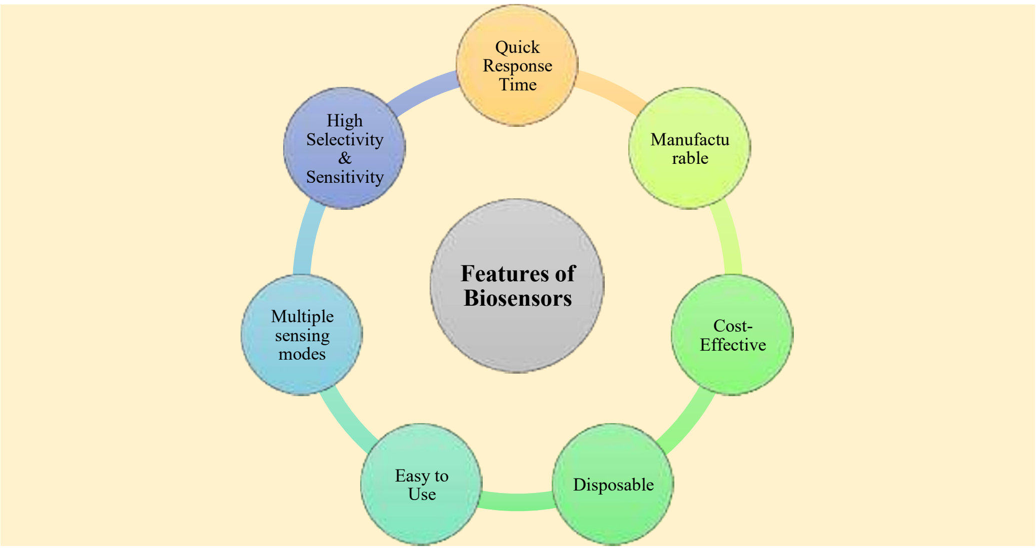

Fig. 4: Ethical consideration of biosensors in bio engineering

However, the passion for biosensor generation and nanobiotechnology is tempered through enormous moral, criminal, and regulatory challenges [37]. These challenges stem from concerns about privacy, information security, the potential for misuse of personal fitness records, and the environmental impact of nanomaterials. Moreover, the rapid pace of innovation in those fields outstrips the contemporary regulatory frameworks designed for older technologies and materials [38]. Conventional strategies for evaluation of risk factors, which focus on bulk material properties, are inadequate for comparing the specific behaviours and publicity routes of nano-enabled substances. This gap highlights the pressing need for updated regulations that could effectively control the health and environmental risks related to these superior technologies [39].
Furthermore, ethical considerations, mainly inside the industrial region, are often ignored or misunderstood. There's a pressing need for a comprehensive analysis that consists of not simply scientists and enterprise leaders however also the public, ethicists, and policymakers [40]. Such discussions must purpose to stability the capacity health and environmental blessings of nanobiotechnology with its dangers and moral dilemmas.

4.1 Ethical Considerations

Biosensors as well as biological electronic require scarce and costly materials, such as batteries made of lithium ion and metals made from rare earths. Such technologies need to be developed and applied in a way that is environmentally friendly and economically viable [41]. Patients and people in general must be entirely educated regarding the use of biological sensors and biological electronics, emphasising the benefits and hazards, prior to approval for their implementation is granted. Written authorization must be obtained before any data is collected, used, or shared. Biological sensors collect personal data about individuals, including their current state of health and healthcare histories. People must have authority over the gathering, utilisation, and distribution of their personal data, and that information must be protected from unauthorised access [42]. These sensors are more vulnerable to cyber-attacks because of their increased connectivity to the internet and network access. These attacks could undermine the accuracy of the data collected, leading to erroneous diagnoses and deceptive readings [43]. Cyber security norms like authentication and password protection must be set in order to stop unauthorised entry to these equipment [44].

4.2 Regulatory Considerations

Although the expense of the technology that underlies it is reduced to a minimum, low-resource environments typically cannot afford the items that are produced as a result of it. This occurs since the primary strategy for cost reduction in industrialised countries is continual enhancement of technologically advanced processes, as biosensors usually have been developed to fulfil business feasibility [45]. On the other hand, wealthy environments are rarely those where investments in low-cost revolutionary technologies are made. On the other hand, a bottom-up strategy centred on low-cost technology solutions could prioritise affordability first and so be better suited for focusing opportunities for nations that are developing. Cheap materials and open-source technologies can be used to support such an approach. For example, free hardware designs for microarray components and microcontrollers that might be used to build an inexpensive transporter.

5 Conclusion

In this study, the comparison of enzymatic biosensor and immunological biosensors exposes their numerous applications within various domains. Enzymatic, a particular type of biosensor have high sensitivity and specificity for identification of analyst, this offers applicability at broader aspect in identification of glucose, H_2O_2, and triglycerides. Whereas, immunological are one of the most significant groups of affinity biological sensors, they function similarly to immunoassay in that they are dependent on the particular acceptance of antigens by autoantibodies in order to create a stable complex. The functionality of polysaccharides is important for a number of applications at the same time, including additive uses. Polysaccharide-based manipulating of materials is thought to be easily accessible, workable, and equipment-light. This study shows that biosensors can also be used to monitor biological diversity and modifications to the environment, which have significant implications for preserving the balance of nature and the health of humans. Biosensors are devices that can help with early warning systems, reducing pollution, and managing resources by providing real-time information and analytics. This helps to support multiple Sustainable Development Goals (SDGs) that are indirectly related to health and sustainable living. Additionally, this study provides ethical considerations as well as regulatory considerations to ensure the proper deployment of biosensors in applications which are being summarised below:

a. Comparative analysis of enzymatic and immunological biosensors showed that enzymatic biosensors have high sensitivity and specificity for identifying glucose, H_2O_2, and triglycerides. Immune biosensors function similarly to immunoassays and depend on the acceptance of antigens by autoantibodies to form a stable complex.
b. The functionality of polysaccharides is essential for various applications, including their use as additives. Biosensors can monitor biological diversity and environmental changes, thus protecting nature and human health.
c. They useful resource in early caution structures, pollution reduction, and resource control. Biosensors guide Sustainable Development Goals (SDGs) related to fitness and sustainable living. Ethical and regulatory concerns are crucial for correct biosensor deployment

References

[1] Vigneshvar, S., Sudhakumari, C. C., Senthilkumaran, B., & Prakash, H. "Recent advances in biosensor technology for potential applications–an overview." Frontiers in bioengineering and biotechnology 4 (2016): 11.
[2] Gupta, N., Renugopalakrishnan, V., Liepmann, D., Paulmurugan, R., & Malhotra, B. D. (2019). Cell-based biosensors: Recent trends, challenges and future perspectives. Biosensors and Bioelectronics, 141, 111435.
[3] Kaur, J., Choudhary, S., Chaudhari, R., Jayant, R. D., & Joshi, A. "Enzyme-based biosensors." Bioelectronics and Medical Devices (2019): 211-240.
[4] Singh, A., Sharma, A., Ahmed, A., Sundramoorthy, A. K., Furukawa, H., Arya, S., & Khosla, A. "Recent advances in electrochemical biosensors: Applications, challenges, and future scope." Biosensors 11.9 (2021): 336.
[5] Asal, Melis, Özlem Özen, Mert Şahinler, and İlker Polatoğlu "Recent developments in enzyme, DNA and immuno-based biosensors." Sensors 18.6 (2018): 1924.
[6] Sonia, Pankaj, Jinesh Kumar Jain, and Kuldeep K. Saxena. "Influence of severe metal forming processes on microstructure and mechanical properties of Mg alloys." Advances in Materials and Processing Technologies 8, no. 3 (2022): 2405-2428.
[7] Fatima, Anab, Ishrat Younas, and Mohammad Waqar Ali. "An Overview on Recent Advances in Biosensor Technology and its Future Application." Archives of Pharmacy Practice 13.1 (2022).

[8] Maanaki, H., Xu, T., Chen, G., Du, X., & Wang, J. (2023). "Development of integrated smartphone/resistive biosensor for on-site rapid environmental monitoring of organophosphate pesticides in food and water." Biosensors and Bioelectronics: X 15 (2023): 100402.
[9] Settu, Kalpana, Pin-Tzu Chiu, and Yu-Ming Huang. "Laser-induced graphene-based enzymatic biosensor for glucose detection." Polymers 13.16 (2021): 2795.
[10] Kim, S. W., Cho, I. H., Lim, G. S., Park, G. N., & Paek, S. H. (2017). "Biochemical-immunological hybrid biosensor based on two-dimensional chromatography for on-site sepsis diagnosis." Biosensors and Bioelectronics 98 (2017): 7-14.
[11] Mondal, Kunal, Md Azahar Ali, Chandan Singh, Gajjala Sumana, Bansi D. Malhotra, and Ashutosh Sharma. "Highly sensitive porous carbon and metal/carbon conducting nanofiber based enzymatic biosensors for triglyceride detection." Sensors and Actuators B: Chemical 246 (2017): 202-214.
[12] Chen, Yanju, et al. "Nucleic acid amplification free biosensors for pathogen detection." Biosensors andBioelectronics 153 (2020): 112049.
[13] Goyal, Deepam, Rajeev Kumar Dang, Tarun Goyal, Kuldeep K. Saxena, Kahtan A. Mohammed, and Saurav Dixit. "Graphene: a path-breaking discovery for energy storage and sustainability." Materials 15, no. 18 (2022): 6241.
[14] Khor, S. M., Choi, J., Won, P., & Ko, S. H. "Challenges and strategies in developing an enzymatic wearable sweat glucose biosensor as a practical point-of-care monitoring tool for type II diabetes." Nanomaterial's 12.2 (2022): 221.
[15] Singh, A., Sharma, A., Ahmed, A., Sundramoorthy, A. K., Furukawa, H., Arya, S., & Khosla, A. "Recent advances in electrochemical biosensors: Applications, challenges, and future scope." Biosensors 11.9 (2021): 336.
[16] Otero, Fernando, and Edmond Magner. "Biosensors—recent advances and future challenges in electrode materials." Sensors 20.12 (2020): 3561.
[17] Upadhyay, K. K., Srivastava, S., Arun, V., & Shukla, N. K. (2020). Design and performance analysis of all-optical reversible full adder, as ALU. Proceedings of the National Academy of Sciences, India Section A: Physical Sciences, 90, 899-909.
[18] Farka, Z., Jurik, T., Kovar, D., Trnkova, L., & Skládal, P."Nanoparticle-based immunochemical biosensors and assays: recent advances and challenges." Chemical reviews 117.15 (2017): 9973-10042.
[19] Campuzano, Susana, Paloma Yáñez-Sedeño, and José Manuel Pingarrón. "Molecular biosensors for electrochemical detection of infectious pathogens in liquid biopsies: current trends and challenges." Sensors 17.11 (2017): 2533.
[20] Tripathi, G. P., Agarwal, S., Awasthi, A., & Arun, V. (2022, August). Artificial Hip Prostheses Design and Its Evaluation by Using Ansys Under Static Loading Condition. In Biennial International Conference on Future Learning Aspects of Mechanical Engineering (pp. 815-828). Singapore: Springer Nature Singapore.
[21] Fu, Dongmei, Zhen Wang, Yingfeng Tu, and Fei Peng. "Interactions between Biomedical Micro-/Nano-Motors and the Immune Molecules, Immune Cells, and the Immune System: Challenges and Opportunities." Advanced Healthcare Materials 10.7 (2021): 2001788.
[22] Numan, Arshid, Atal AS Gill, Saqib Rafique, Manisha Guduri, Yiqiang Zhan, Balaji Maddiboyina, Lijie Li, Sima Singh, and Nam Nguyen Dang. "Rationally engineered nanosensors: A novel strategy for the detection of heavy metal ions in the environment." Journal of Hazardous Materials 409 (2021): 124493.
[23] Swarna, K. S. V., Vinayagam, A., Ananth, M. B. J., Kumar, P. V., Veerasamy, V., & Radhakrishnan, P. (2022). A KNN based random subspace ensemble classifier for detection and discrimination of high impedance fault in PV integrated power network. Measurement, 187, 110333.
[24] Tripathi, G. P., Agarwal, S., Awasthi, A., & Arun, V. (2022, August). Artificial Hip Prostheses Design and Its Evaluation by Using Ansys Under Static Loading Condition. In Biennial International Conference on Future Learning Aspects of Mechanical Engineering (pp. 815-828). Singapore: Springer Nature Singapore.
[25] Gupta, Tejendra K., Pattabhi Ramaiah Budarapu, Sivakumar Reddy Chappidi, Sudhir Sastry YB, Marco Paggi, and Stephane P. Bordas. "Advances in carbon based nanomaterials for bio-medical applications." Current Medicinal Chemistry 26, no. 38 (2019): 6851-6877.
[26] Arora, Gurmeet Singh, and Kuldeep Kumar Saxena. "A review study on the influence of hybridization on mechanical behaviour of hybrid Mg matrix composites through powder metallurgy." Materials Today: Proceedings (2023).
[27] Alkorbi, A. S., Kumar, K. Y., Prashanth, M. K., Parashuram, L., Abate, A., Alharti, F. A., ... & Raghu, M. S. (2022). Samarium vanadate affixed sulfur self doped g-C3N4 heterojunction; photocatalytic, photoelectrocatalytic hydrogen evolution and dye degradation. International Journal of Hydrogen Energy, 47(26), 12988-13003.
[28] Karim, Mohammad Ershadul. "Biosensors: ethical, regulatory, and legal issues." In Handbook of Cell Biosensors, 679-705. Cham: Springer International Publishing, 2021.
[29] Ahmadi, Maryam, and Leila Ahmadi. "Ethical considerations of nanobiotechnology." Journal of Biomaterials and Tissue Engineering 3, no. 3 (2013): 335-352.
[30] Oksel Karakus, Ceyda, Eyup Bilgi, and David A. Winkler. "Biomedical nanomaterials: applications, toxicological concerns, and regulatory needs." Nanotoxicology 15, no. 3 (2021): 331-351.
[31] Yue, Lu, Maleraju Jayapal, Xinli Cheng, Tingting Zhang, Junfeng Chen, Xiaoyan Ma, Xin Dai, Haiqin Lu, Rongfeng Guan, and WenHui Zhang. "Highly dispersed ultra-small nano Sn-SnSb nanoparticles anchored on N-doped graphene sheets as high performance anode for sodium ion batteries." Applied Surface Science 512 (2020): 145686.
[32] Arun, V., Shukla, N. K., Singh, A. K., & Upadhyay, K. K. (2015, September). Design of all optical line selector based on SOA for data communication. In Proceedings of the Sixth International Conference on Computer and Communication Technology 2015 (pp. 281-285).

[33] Rocchitta, G., Spanu, A., Babudieri, S., Latte, G., Madeddu, G., Galleri, G., ... & Serra, P. A. (2016). Enzyme biosensors for biomedical applications: Strategies for safeguarding analytical performances in biological fluids. Sensors, 16(6), 780.
[34] Mohankumar, P., Ajayan, J., Mohanraj, T., & Yasodharan, R. (2021). Recent developments in biosensors for healthcare and biomedical applications: A review. Measurement, 167, 108293.
[35] Mohammed, Kahtan A., Kareema M. Ziadan, Alaa S. Al-Kabbi, Kuldeep K. Saxena, Rahman S. Zabibah, Ali Jawad Alrubaie, and Jalal Hasan Mohammed. "Optical, morphological, electrical properties and white light photoresponse of CdSe nanoparticles." Advances in Materials and Processing Technologies 8, no. sup4 (2022): 2289-2298.
[36] Srinivasan, K., Porkumaran, K., & Sainarayanan, G. (2009, August). Improved background subtraction techniques for security in video applications. In 2009 3rd International Conference on Anti-counterfeiting, Security, and Identification in Communication (pp. 114-117). IEEE.
[37] Basavapoornima, Ch, C. R. Kesavulu, T. Maheswari, Wisanu Pecharapa, Shobha Rani Depuru, and C. K. Jayasankar. "Spectral characteristics of Pr3+-doped lead based phosphate glasses for optical display device applications." Journal of Luminescence 228 (2020): 117585.
[38] Gupta, Tejendra K., Pattabhi Ramaiah Budarapu, Sivakumar Reddy Chappidi, Sudhir Sastry YB, Marco Paggi, and Stephane P. Bordas. "Advances in carbon based nanomaterials for bio-medical applications." Current Medicinal Chemistry 26, no. 38 (2019): 6851-6877.
[39] Jayanthi, Neelampalli, B. Vijaya Babu, and N. Sambasiva Rao. "Survey on clinical prediction models for diabetes prediction." Journal of Big Data 4 (2017): 1-15.
[40] Numan, Arshid, Atal AS Gill, Saqib Rafique, Manisha Guduri, Yiqiang Zhan, Balaji Maddiboyina, Lijie Li, Sima Singh, and Nam Nguyen Dang. "Rationally engineered nanosensors: A novel strategy for the detection of heavy metal ions in the environment." Journal of Hazardous Materials 409 (2021): 124493.
[41] Vijayakumar, Y., P. Nagaraju, Veeraswamy Yaragani, Saidi Reddy Parne, Nasser S. Awwad, and MV Ramana Reddy. "Nanostructured Al and Fe co-doped ZnO thin films for enhanced ammonia detection." Physica B: Condensed Matter 581 (2020): 411976.
[42] Singh, P., Singh, A. K., Arun, V., & Dixit, H. K. (2016). Design and analysis of all-optical half-adder, half-subtractor and 4-bit decoder based on SOA-MZI configuration. Optical and Quantum Electronics, 48, 1-14.
[43] Mehdi, Husain, Sipokazi Mabuwa, Velaphi Msomi, and Kuldeep Kumar Saxena. "Influence of friction stir processing on the mechanical and microstructure characterization of single and double V-groove tungsten inert gas welded dissimilar aluminum joints." Journal of Materials Engineering and Performance 32, 17 (2023): 7858-7868.
[44] Manohar, T., Prashantha, S. C., Nagaswarupa, H. P., Naik, R., Nagabhushana, H., Anantharaju, K. S., ... & Premkumar, H. B. (2017). White light emitting lanthanum aluminate nanophosphor: near ultra violet excited photoluminescence and photometric characteristics. Journal of Luminescence, 190, 279-288.
[45] Kumar, C. P., Raghu, M. S., Prathibha, B. S., Prashanth, M. K., Kanthimathi, G., Kumar, K. Y., ... & Alharthi, F. A. (2021). Discovery of a novel series of substituted quinolines acting as anticancer agents and selective EGFR blocker: Molecular docking study. Bioorganic & Medicinal Chemistry Letters, 44, 128118.