

Biosensors EEL3050

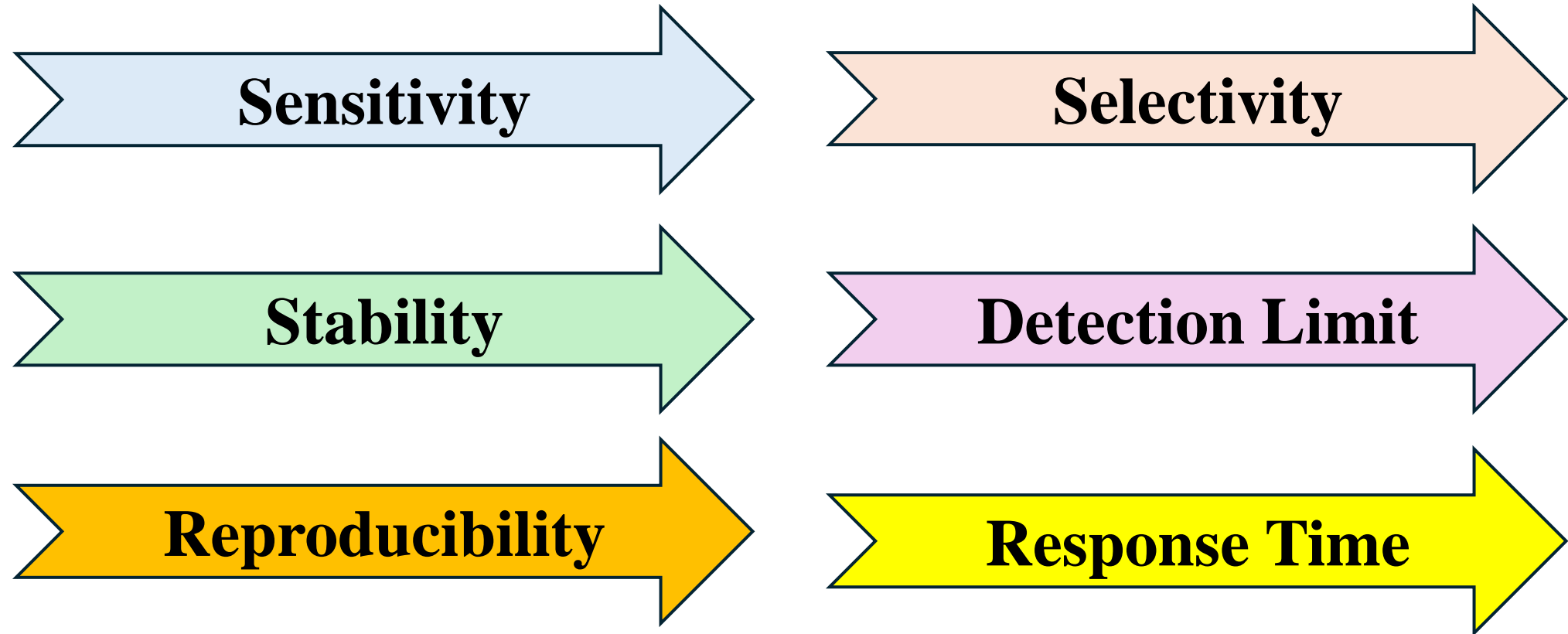


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Sensor Key Parameters

Owing to the nature of the applications in which biosensors are used in, several characteristics or parameters have to be met when a biosensor is designed. These characteristics define the performance and usefulness of a biosensor.

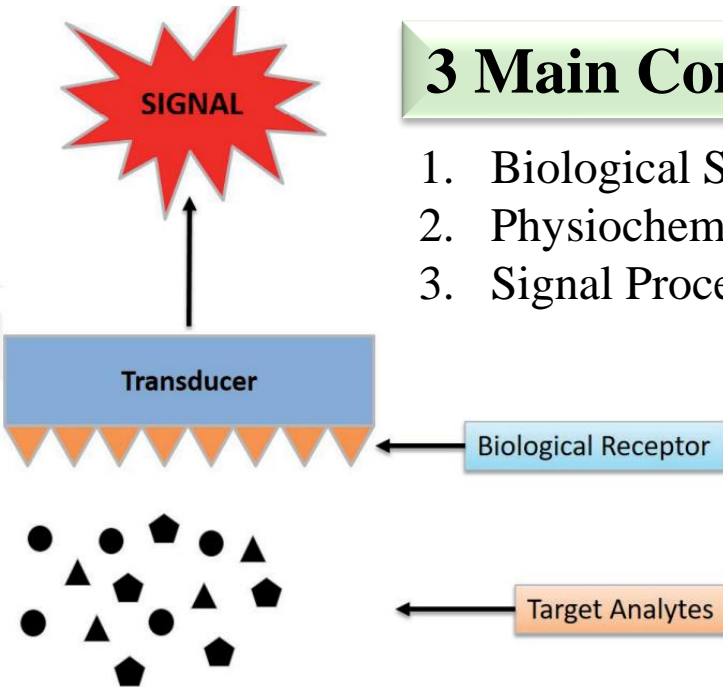


Introduction

- Ability to detect even the slightest physiological change in the human body with high sensitivity and accurately monitor processes that impact human nature, and their surroundings has led to an immense improvement in the quality of life.
- Biosensors continue to play a critical role across a myriad of fields including biomedical diagnosis, monitoring of treatment and disease progression, drug discovery, food control and environmental monitoring.
- **The sole purpose of these analytical devices is to rapidly provide accurate and reliable information about an analyte of interest in real time.**

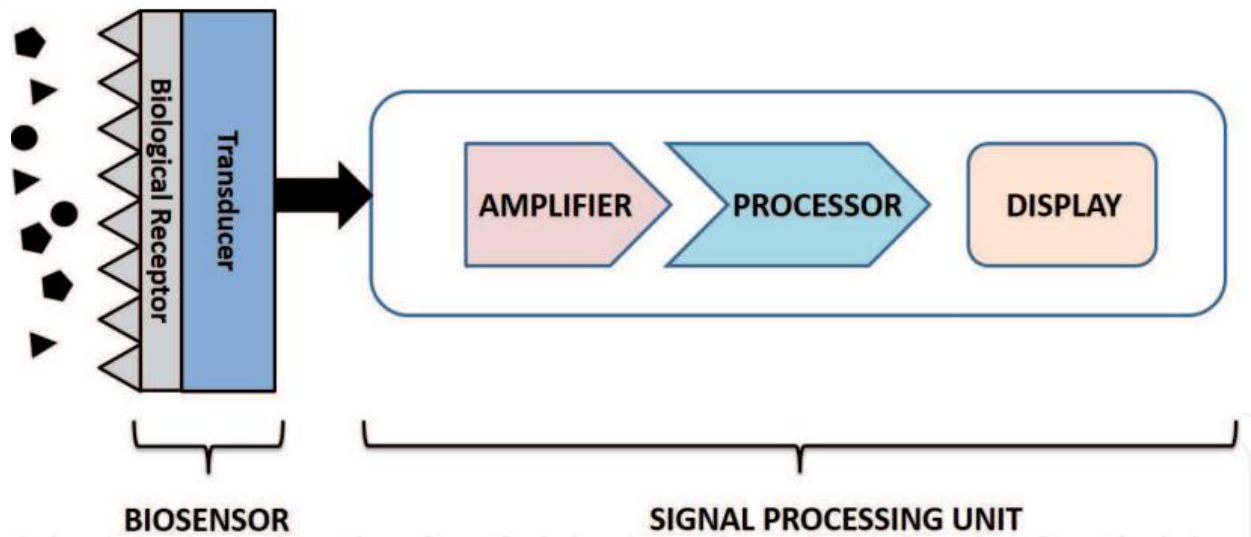
3 Main Component of Biosensor

1. Biological Sensing Element
2. Physiochemical Detector/Transducer
3. Signal Processing System



- ❖ Biological sensing elements → interact with the analyte of interest to generate a signal. Sensing elements normally include materials such as tissues, microorganisms, organelles, cell receptors, enzymes, antibodies, and nucleic acids.
- ❖ The signal generated through the interaction of the sensing element and the analyte of interest is then transformed to a measurable and quantifiable electrical signal via the transducer.
- ❖ The signal processing system therefore amplifies the electrical signal and conveys it to a data processor that produces a measurable signal in the form of a digital display.

Biosensor Design



Biological Receptors

- Responsible for sensing or detecting the presence and/or the concentration of the target analyte.
- Biological component (biochemical receptor) → specifically recognizes the target analyte.
- When the biological receptor interacts with a target analyte, it generates a signal in the form of light, heat, pH, charge or mass change.
- This material should be highly specific, stable under storage conditions and must be immobilized.
- Biological receptor should be capable of selectively detecting the target compound or analyte in the test sample.
- Biological receptor determines the sensitivity of the entire device through the generation of the physicochemical signal that is monitored by the transducer

Biosensor Design

Biological Receptors

- Component can be a tissue, microorganism, organelle, cell receptor, enzyme, antibody or nucleic acid etc.
- Grouped into two categories, namely **catalytic and non-catalytic receptors**.
- **Catalytic group of biological receptors** → used in devices intended for continuous monitoring of substances at **millimolar or micromolar concentrations**. These include enzymes, tissues and microorganisms.
- **Non-catalytic group** → used mainly in biosensor devices that measure analytes such as steroids, drugs, and toxins etc. which usually occur at very low concentrations (**micro to picomolar range**).

Transducers

- Transducer is a material that is capable of converting one form of energy to another.
- Responsible for converting the biochemical signal received from the biological receptor, (result of the interaction between the target analyte and the biological receptor), into a measurable and quantifiable signal which can be piezo-electrical, optical, electrochemical etc.
- Transducer detects and measures the change that occurs during biological receptor – analyte interaction.
- Example of a transducer is a pH sensor in a glucose biosensor.
An enzyme, known as glucose oxidase, is used as a biological receptor which binds glucose and converts it to gluconic acid in the presence of oxygen. The pH sensor (transducer) then detects the change in pH (due to production of gluconic acid) and converts it into a voltage change.

Sensor Key Parameters

Sensitivity

- Most important characteristic of a biosensor.
- Determines the biosensor's ability to detect small changes in the concentration of the target analyte, reflecting the efficiency and precision of the device.
- Highly sensitive biosensor can detect even minute fluctuations in analyte concentration, providing accurate and reliable data.

Importance of Sensitivity: High sensitivity is crucial in many applications where detecting low concentrations of an analyte is essential.

- **Medical Diagnostics:** Ability to detect trace levels of biomarkers (e.g., proteins, hormones, or nucleic acids) is vital for early diagnosis and monitoring of diseases. For example, detecting cancer biomarkers at ng/ml or fg/ml levels can lead to earlier intervention and improved patient outcomes.
- **Environmental Monitoring:** Detecting pollutants or hazardous substances at low concentrations is important for ensuring environmental safety and compliance with regulatory standards. High sensitivity allows for the detection of contaminants before they reach harmful levels.
- **Food Safety:** In the food industry, sensitive detection of pathogens or toxins can prevent foodborne illnesses and ensure product safety and quality.

Sensor Key Parameters

Selectivity

- Selectivity is a crucial parameter in the design and application of biosensors, particularly in complex sample matrices.
- Ability of the biosensor to specifically recognize and respond to the target analyte while minimizing interference from other substances present in the sample.
- The biosensor's ability to selectively bind and respond only to the desired analyte, even in the presence of other molecules or substances. This ensures that the sensor produces a signal only in response to the target analyte and not due to interactions with non-target substances.

Importance of Selectivity: High selectivity is essential in applications where samples contain a mixture of compounds, such as:

- **Medical Diagnostics:** In clinical settings, the ability to distinguish between similar molecules is critical. For example, a biosensor designed to detect a specific hormone in blood or urine must not cross-react with other similar hormones to avoid false positive results, which can lead to misdiagnosis or inappropriate treatment.
- **Environmental Monitoring:** Selective detection of specific pollutants or toxins is important to accurately assess environmental quality and ensure regulatory compliance.
- **Food Safety:** In food testing, selectivity ensures that the biosensor can accurately detect harmful pathogens or toxins without interference from other food components.

Sensor Key Parameters

Stability

- Biosensor's stability is a very important characteristic especially for biosensors used for continuous monitoring.
- Determines the ability of the biosensor device to resist change in its performance over a period of time in response to interruptions arising from temperature, humidity or other environmental conditions.
- Such interruptions have the potential to induce inaccuracies in the output signal during measurement, thereby affecting the precision and accuracy of the biosensor device.

Impact of Environmental Conditions: Q. Impact of Temp & Humidity?

Temperature: Many biosensors are sensitive to temperature changes because both the electronic components (like transducers) and the biological receptors can be affected. Temperature fluctuations can lead to:

1.Drift in sensor signals: Electronic components may experience shifts in their baseline or sensitivity due to temperature changes, affecting the accuracy of the readings.

2.Degradation of biological components: Biological receptors or enzymes used in the sensor can lose their functionality or degrade, altering their ability to interact with the target analyte accurately.

Humidity: High or variable humidity can impact biosensor performance in several ways:

1.Corrosion: Humidity can lead to corrosion of electronic components, which may affect their reliability and longevity.

2.Biofouling: Increased moisture can promote biofouling on the sensor surface, which can interfere with the sensor's ability to detect the target analyte accurately.

Sensor Key Parameters

Detection Limit

- A detection limit is defined as the lowest concentration of the target that is able to elicit a measurable signal or response.
- The detection limit of a biosensor is defined as the lowest concentration of the target analyte that produces a measurable signal or response that can be distinguished from the background noise. It is essentially the threshold below which the sensor cannot reliably detect or quantify the presence of the analyte.

Importance in Medical Applications

- 1.Early Diagnosis:** In medical diagnostics, some diseases or conditions are detectable only when specific biomarkers are present at very low concentrations. A biosensor with a low detection limit is crucial for the early detection of such conditions, allowing for timely intervention and treatment.
- 2.Sensitivity:** The ability of a biosensor to detect low concentrations of an analyte is directly related to its sensitivity. A lower detection limit implies higher sensitivity, which is essential for accurate and reliable diagnosis in clinical settings.
- 3.Precision and Accuracy:** Biosensors with lower detection limits can provide more precise and accurate measurements of analytes at low concentrations. This is important for avoiding false negatives and ensuring that any health issues are detected and monitored effectively.

Sensor Key Parameters

Reproducibility/Repeatability

- **Repeatability**, which is a key aspect of biosensor performance. Repeatability, also known as **precision**, is the ability of a biosensor to produce consistent and reproducible results under the same conditions over multiple runs.
- The capability of the biosensor to meet this criteria relies on the transducer which is required to perform in a precise and accurate manner.

Importance of Repeatability in Biosensing

- 1.Reliability:** High repeatability ensures that the biosensor provides consistent results across multiple measurements, which is essential for the reliability of the data. This is particularly important in both research and clinical diagnostics, where consistent results are needed for accurate decision-making.
- 2.Accuracy:** Repeatability is closely tied to the accuracy of the biosensor. If a biosensor consistently produces the same results for the same concentration of an analyte, it indicates that the sensor is accurately measuring the target substance.
- 3.Quality Control:** In applications where precision is crucial, such as in medical diagnostics, having a biosensor with high repeatability helps in maintaining quality control and ensures that results are trustworthy and actionable.

Sensor Key Parameters

Response Time

- This property determines the time it takes for the biosensor to generate a signal or response following the interaction of the biological receptor with the target analyte.
- **Response time**, also known as **reaction time** or **time-to-result**. It is a critical parameter for biosensors and describes how quickly a biosensor can generate a signal or response after the biological receptor has interacted with the target analyte.

Importance of Response Time

1.Timeliness of Results: A shorter response time is crucial in applications where quick results are needed. In medical diagnostics, for example, rapid detection of biomarkers can be vital for timely decision-making and treatment.

2.Operational Efficiency: For continuous monitoring applications, such as in environmental sensing or industrial processes, a fast response time ensures that the system can quickly adapt to changes in the analyte concentration, improving overall efficiency.

3.User Experience: In point-of-care testing or other user-facing applications, shorter response times enhance user convenience and satisfaction by providing quick results.

Considerations for Biosensor Design

Selection of a Biological Receptor

- The specificity and selectivity of a biosensor to the analyte of interest is dependent upon the biological receptor used.
- A suitable receptor with high affinity for the analyte is thus recommended.
- Having knowledge of the advantages and disadvantages of various biological receptors in different biosensor applications is very important in selecting a suitable receptor.

Selection of a suitable immobilization method:

- For any biological molecule to operate reliably as a biological receptor, it requires attachment onto the surface of a transducer. This process is known as immobilization.
- Various methods have been used for this task and include adsorption, entrapment, covalent attachment, micro encapsulation and cross linking.

Selection of a transducer element:

- Transducer element greatly influences the sensitivity of the biosensor device.
- Employing the right transducer will result in a device with increased sensitivity while the sensitivity is more likely to be compromised by the use of an ineffective transducer.