

CONTRIBUTION OF AI AND MACHINE LEARNING IN OPTIMIZATION OF ULTRASENSITIVE BIO-SENSORS : REVIEW

David BASSIR⁽¹⁾, Ata Jahangir MOSHAYEDI⁽¹⁾, Souad TAYANE⁽²⁾, Jaafar GABER⁽³⁾, Omar EL KEDIM⁽³⁾

⁽¹⁾Smart Structural Health Monitoring and Control Laboratory, DGUT-CNAM, Dongguan University of Technology, D1, Daxue Rd., Songshan Lake, Dongguan, Guangdong Province, P.R. China

⁽²⁾University Hassan 2, Morocco

⁽³⁾FEMTO-ST, Université de Technologie de Belfort Montbéliard (UTBM), France

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Abstract

Artificial intelligence (AI) and machine learning (ML) are rapidly reshaping the design, fabrication, and deployment of ultrasensitive biosensors by enabling data-driven optimisation across the entire sensing pipeline. This review examines how ML assisted strategies enhance analytical performance limit of detection, selectivity, dynamic range, stability, and response time in electrochemical, optical (SPR, SERS, fluorescence), piezoelectric, and field-effect transistor (FET)-based biosensors. We summarize the principal ML paradigms used in biosensing, including supervised learning for calibration and multi-analyte quantification, unsupervised learning for drift correction and background separation, and deep learning for feature extraction from high-dimensional spectra, impedance signatures, and microfluidic images. Special attention is given to AI-enabled signal processing methods that suppress noise, compensate for temperature and matrix effects, and improve robustness in complex biological samples. Beyond inference, AI is increasingly adopted for sensor optimization: Bayesian optimization and active learning reduce experimental iterations in tuning nanomaterials, bioreceptor immobilization chemistry, and microfluidic parameters, while physics-informed ML and digital-twin models combine mechanistic transport/kinetic constraints with data to generalize beyond specific datasets. The review also discusses AI's role in intelligent point-of-care platforms, integrating edge deployment, smartphone readouts, and federated learning to preserve privacy while improving models over distributed clinical data. Persistent challenges—including limited labeled data, dataset shift, lack of standards for reporting, model interpretability, and regulatory validation are analyzed with recommended best practices such as uncertainty quantification, explainable AI, standardized benchmarking datasets, and rigorous cross-laboratory validation. Overall, the convergence of AI/ML with ultrasensitive

biosensing is enabling faster discovery, more reliable quantification, and scalable translation to real-world diagnostics, environmental monitoring, and food safety, positioning AI-guided biosensors as a key component of next-generation precision health and connected sensing ecosystems.