# Modeling and Characterization of Nanotechnological Environmental Sensors and Data Processing with Artificial Intelligence Techniques

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Water pollution is becoming a global issue, driven by industrial activities, urban development, and agriculture. Although traditional methods for monitoring water quality are accurate, they tend to be slow and require significant manual effort. To address these challenges, this research focuses on developing nanotechnology-based sensors combined with artificial intelligence (AI) for the real-time and automated detection of water pollutants [1].

Within this framework, we experimentally develop and characterize nanotechnological advanced sensors that use impedance and voltammetry techniques to measure pollutants. We also build circuits and electromagnetic models that simulate the behavior of sensing materials, especially focusing on materials like graphene due to their exceptional electrical and chemical properties. In parallel, we develop measurement setups to ensure reliable and accurate data acquisition. A key objective is integrating AI algorithms into the system to improve the sensitivity, selectivity, and overall reliability of the sensors. This integration enables the system to operate effectively under complex environmental conditions and deliver real-time, efficient monitoring. Graphene-based Screen-Printed Electrodes (SPEs) [2] serve as the core components of the sensing platform, offering high sensitivity and compatibility with electrochemical techniques. The SPEs are strips of nanomaterial composed of 3 electrodes as illustrated in Fig.1.a: a working electrode (where the chemical reactions happen), a reference electrode (which provides a stable reference for measuring potential), and a counter electrode (to close the circuit). We use chronoamperometry (CA) as the primary technique, where a constant potential is applied to the working electrode, and the resulting current is monitored over time. This method allows us to measure pollutants in water by detecting the current produced when substances such as Ferro-Ferri Cyanide (FFC), Hydroquinone (HD), or Benzoquinone (BQ) undergo oxidation or reduction by correlating their concentrations with the generated current.

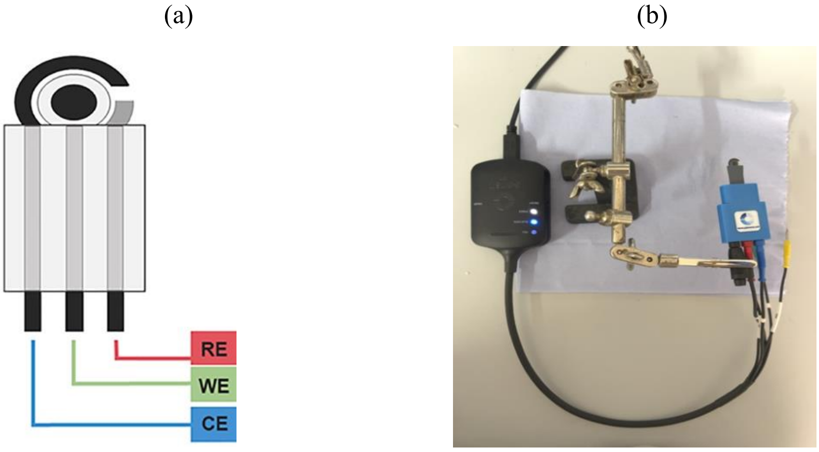

Fig. 1. (a) The SPE with the 3 connectors, and (b) The measurement setup.

Measurements are conducted for various concentrations of the substance (0.5 mM, 1 mM, 3 mM, and 5 mM), with 20 repetitions performed for each concentration using three different SPEs to ensure reliability and reproducibility. To remove background noise from the measurement data, we subtract the signal from a blank sample. The PalmSens Sensit Smart BT potentiostat [3] is used to control the voltage and measure the current accurately, as shown in the measurement setup in Fig.1. b. A MATLAB-based algorithm is developed to automate the calibration process, streamline data analysis, and enhance both efficiency and consistency. Calibration curves are constructed using the experimental data and subsequently validated with an unknown concentration (e.g., 4 mM) to assess the predictive capability of the system. The results demonstrate a consistent relationship between analyte concentration and the current measured, confirming the reliability of the method. With the help of AI, the system also successfully predicts the unknown concentration, showing that it can generalize beyond the training data.

Overall, the graphene-based electrodes exhibit strong electrochemical stability and sensitivity, although some limitations related to solvent evaporation and chemical degradation of analytes were observed. This work supports the stage for creating an automated, reliable system for continuous monitoring of water quality. By integrating AI and nanotechnology-based sensors, we can improve the detection of water contaminants, manage water resources more effectively, and respond quickly to potential pollution events.

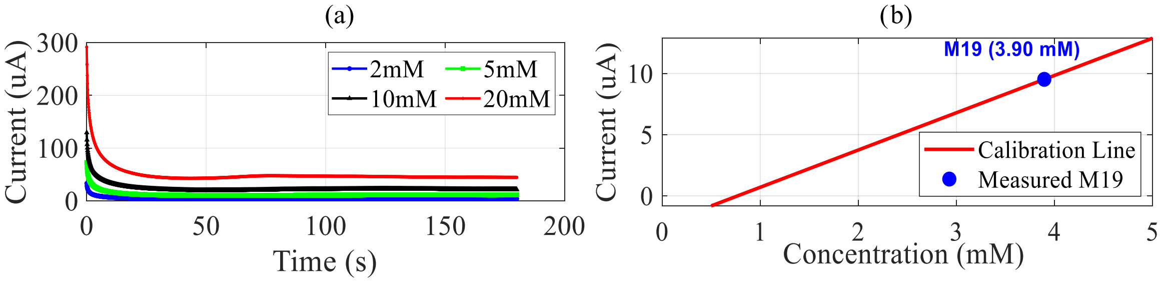

Fig. 2. (a) CA measurement response at different concentrations of FFC and (b) the calibration curves of HQ showing the corresponding measured concentrations for the 4 mM.

## ACKNOWLEDGEMENT

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