Enhancing Bacterial Detection by Harnessing Graphene Transistors' Latent Features with Deep Learning

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Graphene electrolyte gate field-effect transistors (GFETs) effectively detect small molecules, biomolecules, ions, glucose, deoxyribonucleic acid (DNA), proteins, and hormones and can also measure pH levels. Graphene's high sensitivity to electric fields and charges enables electrical transduction with output signals obtained at low operation voltages. Non-functionalized reusable GFETs have already shown promising results when combined with locally trained Artificial Intelligence (AI) models [1,2]. This study, however, focuses on functionalized GFETs—a more specialized class of devices. Probes integrated into GFETs serve as molecular connectors, linking target DNAs to the graphene surface. While functionalized devices have much-improved selectivity compared to non-functionalized ones and can detect extremely low sample concentrations, their high sensitivity is still susceptible to interference from other molecules and electron trapping/detrapping from defects in the underlying SiO_x substrate, causing signal drift. This disruptive technology, therefore, needs further improvement before it can seize the biosensor market.

This study examines the practical use of functionalized GFETs to detect genomic mutations in antibiotic-resistant bacteria. It assesses the real-world applicability of these devices in bacterial detection scenarios by employing a proposed data classification methodology utilizing the "V"-shaped transfer curves of the functionalized GFETs under different concentrations of mutated DNA [3], as shown in Figure 1. Figure 2 illustrates the Artificial Neural Network (ANN) architecture developed to predict concentration ratios. The model leverages Deep Learning to uncover and interpret subtle patterns within the data at different concentrations. The network is comprised of four modules: a feature extraction module based on a Siamese Network approach to assess similarities between curves; a number embedding module that captures the reading event associated with the curve; an attention mechanism module that processes a pair of feature vectors to model their interactions; and, finally, a regression module that predicts the ratio of concentration levels between the reference and unknown curves. Afterward, a proposed classification approach aggregates the predictions made by the trained model.

Biosensing in real-world applications has significant potential but faces challenges, including signal variability and drift. This work brings new perspectives on how functionalized GFETs can be employed in real-world scenarios while dealing with signal instability.

References

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Figures

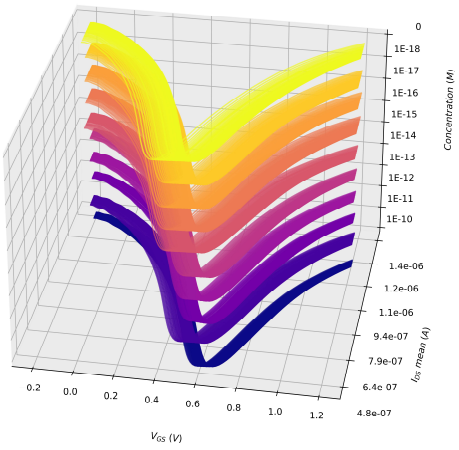

Figure 1. Example of drift phenomenon for ten concentration classes. Each concentration represents drift by seventy consecutive readings, also known as sweeps.

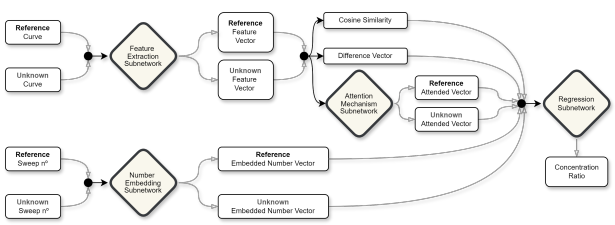

Figure 2. Artificial Neural Network architecture proposed for a regression task. A trained model is further used in a classification methodology.