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Advancing Cellular Spatiotemporal Monitoring: Machine Learning-Enhanced Multi-Electrode Impedance Spectroscopy

Manuel Carrasco Yagüe^{1,2,*}, Gor Lebdev², Jean Gamby³ and Abdul I. Barakat¹

¹ LadHyX, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France.

² Sensome, Massy, France.

³ Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, C2N, Palaiseau, France

*E-mail: manuel.carrasco-yaguee@polytechnique.edu

Understanding how cells organize in space and time is crucial for organ development, tissue regeneration, and cancer progression [1]. Conventional methods, such as live-cell fluorescence microscopy imaging, face challenges such as dye toxicity and photo-induced cell damage. To overcome these hurdles, we propose a cost-effective, label-free solution using a micro-electrode array (MEA) and impedance spectroscopy (IS). This approach allows us to monitor different cell types and is ideal for long-term experiments, co-culture studies, and organ-on-chip applications.

Methodology and Device Overview: Impedance spectroscopy (IS) is used increasingly in biophysical and biomedical applications [2]. Cellular membrane properties and conductivity changes contribute to distinct impedance signals as a cell population develops [3]. Our newly designed MEA contains 25 pairs of electrodes and enables IS measurements across a broad frequency range. We study normal (MCF10A) and cancerous (MCF7) breast epithelial cells in separate monolayers and in co-culture. Machine learning algorithms decode electrical characteristics of the impedance spectra, while image segmentation software automates the assessment of cellular density and level of cell confluence.

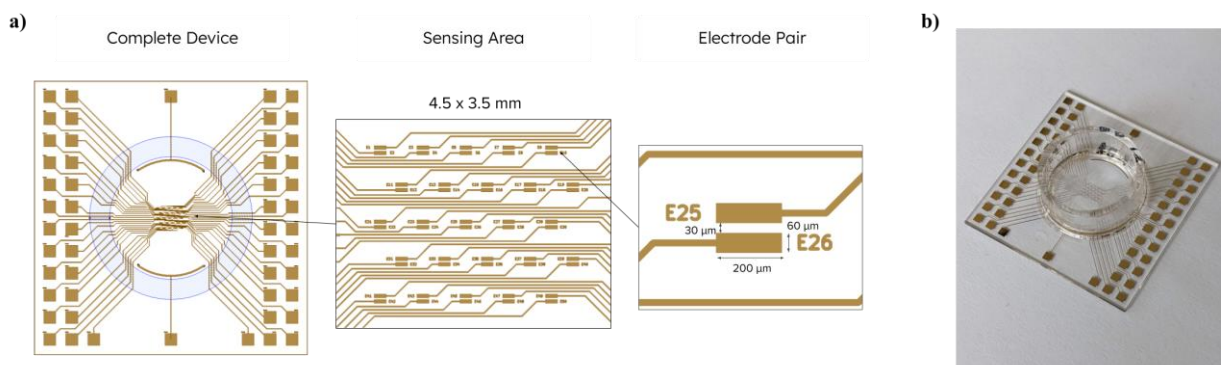


Figure 1 (a) Design of the MEA platform. (b) Fabricated sensing device

Results: We identify strong correlations between impedance signals and cell density/confluence level, revealing nuanced growth dynamics differences between normal and cancerous cells. Machine learning models provide rapid cell density estimation and accurate classification of the different cell types. These findings highlight the technology's potential in distinguishing and monitoring diverse cell lines while tracking cellular growth.

Overall Contribution and Future Directions: Our research introduces a validated MEA platform, enhancing spatiotemporal tracking of cell growth and co-culture interactions. Beyond its technological contribution, the MEA shows promise in cancer research applications. Future studies will expand co-culture experiments, offering deeper insights into the dynamic progression of cancer cells under diverse conditions. The MEA-based sensing technology described here provides a valuable tool to deepen our understanding of cellular behaviors and advance applications in biomedical research.

References

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