Real-Time Deep Learning for Label-Free Imaging Flow Cytometry

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Rare-cell detection, such as the identification of circulating tumor cells in liquid biopsies, remains a major challenge due to their extremely low abundance among large populations of blood cells. This work presents a label-free imaging flow cytometry platform that combines real-time neuron networks, a high-speed motion-sensitive (event-based) camera with interferometric phase microscopy, enabling real-time deep-learning-based rare-cell detection and classification. Cells flowing through a microfluidic channel are continuously monitored by the event camera, which captures sparse temporal information at very high acquisition rates while generating minimal data for real-time spiking neural network classification. When a potential rare cell is detected, the event camera triggers a slower interferometric imaging module that acquires a single-shot quantitative phase measurement for detailed analysis. The acquired raw interferograms are processed directly in real time by a deep neural network to classify rare cells, reducing computational complexity and eliminating the need for extensive image reconstruction. The system was demonstrated using a blood model containing colorectal cancer cells, where common white blood cells were separated from rare cancer cells, followed by grading of the detected cancer cells into primary and metastatic phenotypes. By combining high-throughput screening with sensitive interferometric analysis, the proposed architecture significantly reduces data volume and processing requirements while maintaining high classification performance. Neuromorphic computing hardware and spiking neural networks can enable ultra-low-latency and energy-efficient processing. This hybrid approach provides a scalable framework for label-free rare-cell analysis and has strong potential for future imaging flow cytometry and liquid-biopsy applications.

[1] E. Dotan et al., Lab Chip, 25(22), 5856-5862, 2025.