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Colloidal Reservoirs: Liquid Artificial Intelligence for Scalable, Robust, and Physics-Inspired Computation

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Reservoir computing (RC) has emerged as a powerful paradigm for processing temporal data and pattern recognition, leveraging the intrinsic dynamics of complexcsystems to perform high-dimensional nonlinear transformations without the need for training highly sophisticated networks. Our recent achievements show that colloidal systems —specifically engineered suspensions of nanoparticles in fluids —offer a promising physical substrate for RC, combining the adaptability and resilience of soft matter with the functional requirements of neuromorphic computing. We obtained the experimental demonstration of several features, including electrically programmable in-memory computing in ZnO and ferrofluid-based colloids, memristive behavior, Pavlovian learning, and analog information retention, suggesting these materials can emulate key aspects of biological systems. We found that colloids can emulate synaptic-like short- and long-term plasticity, have robustness to electric disturbances and to ionizing radiations, as well as infinite endurance, making them well suited for harsh or dynamically evolving environments. We argue that these systems embody a post-digital, physically grounded Artificial Intelligence (AI) where such intelligence arises from interactions among matter, energy, and information. The ability of colloids to act as analog signal processors and perform classification tasks on binary rasterized input (e.g., digit recognition) demonstrates their viability as unconventional computing substrates. In line with the goals of physics-aware AI, colloidal reservoirs may enable robust, explainable, and energy-efficient computing architectures for applications ranging from simulation-based inference to adaptive control in fundamental physics experiments.

AI keywords

Reservoir Computing, Colloids, Robustness, Experimental Design

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