Photonic quantum extreme learning machine

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Abstract: We experimentally implement a quantum photonic platform exploiting single-photon quantum walks in high-dimensional orbital angular momentum. This approach, resilient to noise and apparatus imperfections, enables accurate and efficient reconstruction of polarization states and entanglement witness.

In the context of quantum machine learning, quantum reservoir computing (QRC) and its simplified version, often referred to as extreme learning machines, are emerging as highly promising approaches for near-term applications on noisy intermediate-scale quantum (NISQ) devices. In this framework, the dynamics of quantum systems is exploited to efficiently process information bypassing the need for extensive training and precise control of the system. One of the key advantages of QRC lies in its ability to handle inherently quantum tasks. Unlike classical systems, QRC naturally captures and processes quantum correlations, entanglement, and non-linearities that are challenging for classical models to replicate [1].

Building on this foundation, we develop a quantum photonic platform able to reconstruct quantum state properties efficiently and robustly [2]. Our approach exploits the dynamics of single-photon quantum walks in the high-dimensional photonic orbital angular momentum (OAM) space [3], enabling a resource-efficient and resilient method for quantum state characterization. Importantly, this approach minimizes the necessity of a precise characterization of the experimental apparatus, making it highly tolerant to noise and practical for real-world implementations.

We begin by focusing on single-qubit systems, demonstrating the reconstruction of polarization states with high accuracy. This serves as a fundamental building block before turning to more complex systems. Expanding on this, we develop a sophisticated architecture to identify one of the signature properties of quantum systems: entanglement. Using a double quantum-walk setup, we successfully train the QELM to reconstruct an entanglement witness, able to provide a clear distinction between entangled and separable states. This experimental realization highlights the capability of quantum photonic platforms to perform precise assessments of quantum properties in a manner that is both robust and scalable.

Our experimental realization demonstrates the ability of current quantum photonic platforms to precisely assess quantum phenomena, making them a powerful tool in the ongoing exploration of machine learning applications in the quantum domain.

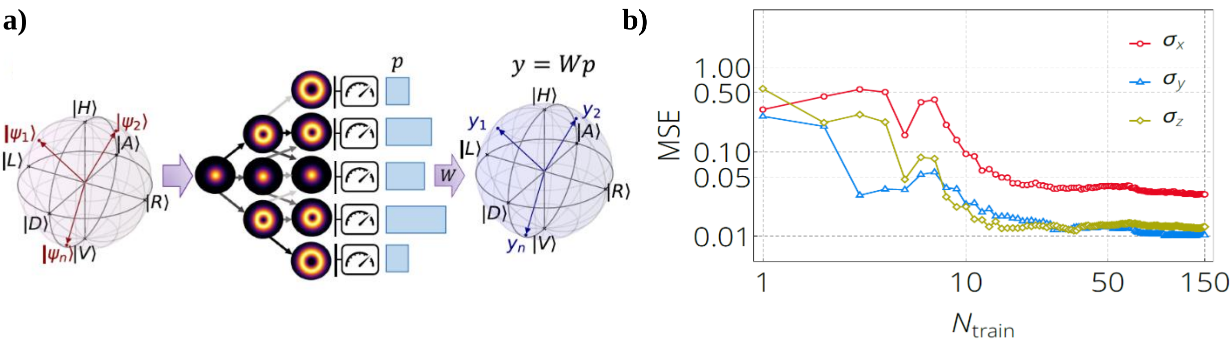

Fig. 1 a) QELM conceptual scheme. The input state evolve through quantum reservoir dynamics and the features y_i are reconstructed by training the QELM on the output probabilities. **b)** MSE of the QELM reconstruction of each observable $\{\sigma_x, \sigma_y, \sigma_z\}$ as a function of the number of training states Ntrain.

References

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