Experimental neural network enhanced quantum state tomographye

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Quantum tomography is currently ubiquitous for testing any implementation of a quantum information processing device. Various sophisticated procedures for state and process reconstruction from measured data are well developed and benefit from precise knowledge of the model describing state preparation and the measurement apparatus. However, physical models suffer from intrinsic limitations as actual measurement operators and trial states cannot be known precisely.

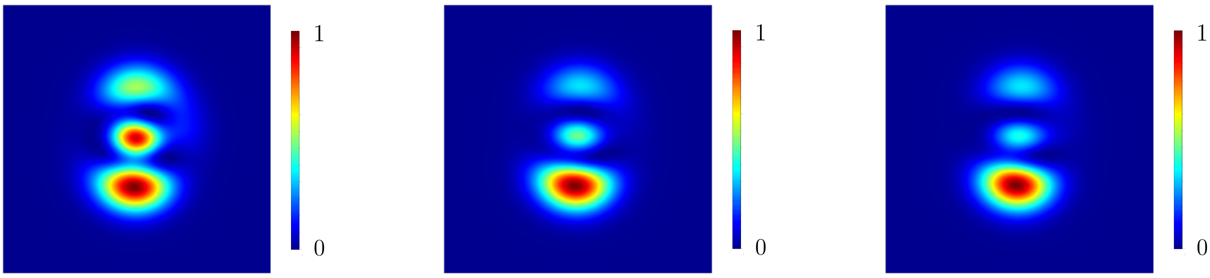

Figure 1: On the left, the spatial probability distribution of an exemplary state picked from the test set calculated using the raw measured data. Experimentally, a set of $N = 10500$ Haar-random pure states $\mathcal{D}_N = \{|\Psi_i\rangle\}_i^N \in \mathcal{C}^6$ were generated. In measurement phase, 36 SIC-POVM were employed. This projectors are close to optimal for state reconstruction and reliably realized for states spatial modes. As expected, artifacts and blurring effects due to noise corruption can be recognised inside, as compared to fig. (2) and (3). Central, spatial probability distribution reconstruction from the apriori known theoretical values of an exemplary test state. Right, state reconstruction by use of the *filtered* values processed by the neural network. The comparison qualitatively gives a prompt insight on how much the network can deal with noise corruption.

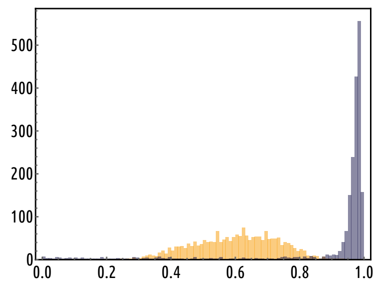

Figure 2: Fidelity histogram for the 2000 experimentally test-set states, with no Gouy phase correction for the states, reconstructed as mixed ones working out maximum likelihood estimation. Orange bar for fidelity from raw data, blue bar for fidelity using the neural network *filtered* values. In this *completely agnostic* scenario, we have achieved average estimation fidelities of $F_{nn} = (0.81 \pm 0.19)$ as compared to $F_{raw} = (0.54 \pm 0.12)$.

This scenario inevitably leads to state-preparation-and-measurement (SPAM) errors degrading reconstruction performance. Here we develop and experimentally implement a machine learning based protocol reducing SPAM errors. Similarly to neural quantum states approach [1, 2], we trained a supervised neural network to filter the experimental data and hence uncovered salient patterns that characterize the measurement probabilities for the original state and the ideal experimental apparatus free from SPAM errors. We compared the neural network state reconstruction protocol with a protocol treating SPAM errors by process tomography, as well as to a SPAM-agnostic protocol with idealized measurements. The average reconstruction fidelity is shown to be enhanced by 10% and 27% , respectively. The presented methods [3] apply to the vast range of quantum experiments which rely on tomography.

References

[1] G. Carleo, Y. Nomura, and M. Imada. Constructing exact representations of quantum many body systems with deep neural network. Nature Communications **9**, 5322 (2018).

[2] G. Torlai et al., Neural-network quantum state tomography. Nature Physics **14**, 447 (2018).

[3] Experimental neural network enhanced quantum tomography. arXiv:1904.05902 (2019)