NON-GAUSSIANITY FOR CONTINUOUS-VARIABLE QUANTUM BATTERIES

Beatriz Polo, ICFO
Av. Carl Friedrich Gauss 3, 08860, Castelldefels (Barcelona)
T: +34 935534138, beatriz.polo@icfo.eu
Federico Centrone, ICFO

The proposed work consists of the application of a quantum neural network, formulated within the continuous-variable (CV) framework for quantum information, to optimize precision in energy storage quantum devices.

In the CV realm, states are classified into gaussian and non-gaussian. The former have gaussian probability distributions in position and momentum spaces, and they can be fully characterized (up to a displacement) by their covariance matrix, which contains their second moments in the quadrature variables *x* and *p*. In fact, the inputs of our neural network will precisely be n-mode gaussian states, encoded in their covariance matrices. To these quantum states of light, a tunable set of operations is applied. This set is composed of squeezing of the quadratures, beamsplitting and phase shifting, each defined by parameters with respect to which we will optimize. All these operations preserve gaussianity and play the analog role to the linear part in classical neural networks. The beamsplitter and phase shifter are referred to as *passive optics*, and they are performed to create entanglement between the modes and dephasing of one of the quadratures with respect to the other. However, these operations do not suffice to explore the entire Hilbert space of CV states, and a crucial gain in expressivity of the ansatz requires the introduction of non-gaussianity (the 'non-linear activation function' in its classical counterpart). Our algorithm achieves this in a simple (both in theory and experiment) manner through single-photon additions and subtractions. Once these have been performed, the expectation value of some objective observable is computed on the photon added/subtracted non-gaussian state. Finally, the output of the neural network is the result of a classical optimization, which yields the optimal eigenvalue of the observable of interest and the covariance matrix parameters of the associated eigenstate.

$$SNR_{\mathrm{extr}}(\rho) = \frac{\langle E_{\mathrm{extr}}(\rho)\rangle}{\Delta E} = \frac{\langle E(\rho)\rangle - E_0}{\Delta E(\rho)}$$

Based on this model, we have focused on the maximization of the so-called energy signal-to-noise ratio (SNR) as our figure of merit. This observable relates the amount of energy that can be extracted or stored in a quantum state with its energy uncertainty. In the pursuit of constructing not maximally powerful but maximally precise devices, the SNR quantifies the performance of a certain state as a quantum battery.

Beyond the variational optimization, we aimed to establish a relationship between the SNR and other intrinsic quantum mechanical properties. To this end, we employed a metric of bipartite entanglement known as the SV criterion, which is monotonically decreasing with entanglement, and strictly negative for non-separable states. Our results demonstrate, on the one hand, that non-gaussian operations are necessary for the optimization, since gaussian states turn out to have constant SNR with the tuning the passive optics, and on the other hand, as is shown in Fig.1, they display a precise correlation between the parameters for optimal SNR and the local minima of the SV quantity, confirming the possibility to exploit quantum correlations to improve performance in high precision tasks.

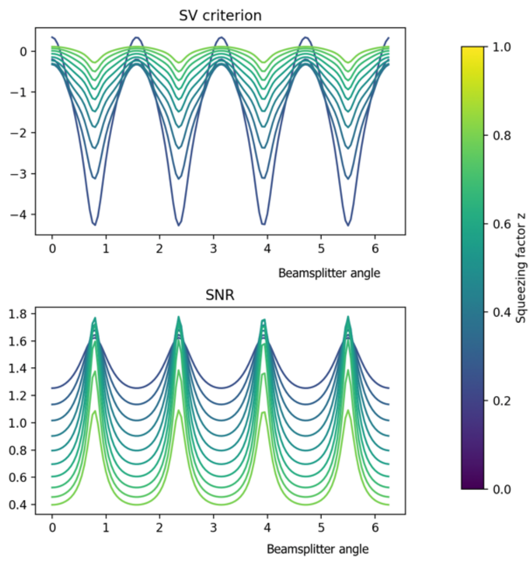

Figure 1: SV and energy SNR for the two-mode photon-subtracted state as a function of the beamsplitter angle, for different values of the squeezing parameter

[1] P. Stornati, A. Acin, U. Chabaud, A. Dauphin, V. Parigi, F. Centrone, Variational quantum simulation using non-Gaussian continuous-variable systems arXiv:2310.15919 (2023)
[2] Wang, Zhen, Heng-Mei Li, and Hong-Chun Yuan. "Nonclassicality and Entanglement of Photon-Subtracted Two-Mode Squeezed Coherent States Studied via Entangled-States Representation." International Journal of Theoretical Physics 55 (2016): 4423-4435.
[3] Friis, Nicolai, and Marcus Huber. "Precision and work fluctuations in gaussian battery charging." Quantum 2 (2018): 61.