Machine Learning for Parameter Estimation from Continuously-Monitored Quantum Systems

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Here we consider the problem of estimating an unknown dynamical parameter from the signal generated by a quantum system under continuous interrogation, such as the photon-counting signal of the radiation emitted by a continuously-driven atom. It has been shown that the optimum estimation strategy in this case requires a process of Bayesian inference, where the likelihood of the data is obtained by calculating conditional evolutions of the open quantum system [1,2]. These methods extract as much information from the signal as possible, but require a precise modelling of the system, and become computationally expensive in complex systems or for multi-parameter estimation tasks. Here, we demonstrate that deep learning architectures can be trained to estimate unknown parameters in this scenario, without any knowledge of the underlying model. We benchmark the performance of these models and show that they can achieve the same level of sensitivity as the optimal Bayesian inference protocols. Remarkably, the inference process using a trained network is much less computationally demanding than the corresponding process of Bayesian inference.

References

[1] J. Gambetta, H. M. Wiseman, Physical Review A 64, 042105 (2001)
[2] S. Gammelmark, K. Molmer, Physical Review Letters 112, 170401 (2014)

Figures

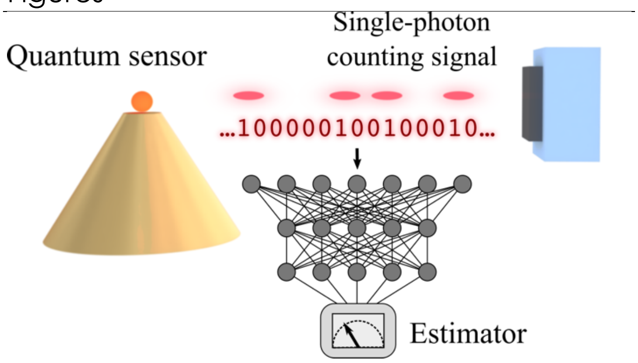

Figure 1: Sketch of a machine-learning estimator applied to the continuous measurement of the radiation emitted by a quantum sensor, e.g. a photon-counting signal with single-photon resolution.

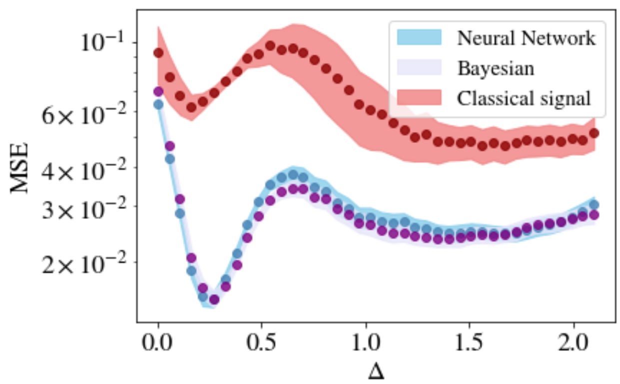

Figure 2: Mean squared error (MSE) in the estimation of an unknown detuning between an atom and a coherent drive from the analysis of a photon-counting signal with single-photon resolution. The MSE of the deep-learning estimator is compared to that of a full Bayesian inference protocol, and with the MSE of a maximum-likelihood estimator applied to a photon-counting signal without single-photon resolution, which illustrates the gain in information obtained when the signal can describe quantum correlations (in this case, photon antibunching).