Adaptive Phase Estimation using Genetic Algorithm

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ABSTRACT

Phase estimation is a framework of quantum metrology where the challenge is estimation of unknown phase shifts by developing optimal protocols that estimate the phase to maximum possible precision by exploiting minimum number of resources [1-3]. We have designed a robust search based Genetic Algorithm for the process of offline adaptive feedback based phase estimation using single photons in a Mach-Zehnder interferometer, which is able to deliver high performance using only a few resources [4]. The results of estimation show that the unknown phase can be estimated using very limited number of photons, with an accuracy close to theoretical limits. We also explored the performance of our algorithm in the presence of usual sources of errors, in order to concoct noise-robust policies that are tailored for both noisy and noiseless cases. Our results illustrate the potential of extending such methodologies to other applications in quantum metrology and for solving more general problems related to quantum information.

REFERENCES

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Adaptive Protocols

Adaptive Estimation Protocol provides rapid convergence in estimation. Simulations are performed with the algorithm to generate a policy, before starting the actual experiment. The offline adaptive protocol is looped in the following steps:

1. Introduce an external control parameter Φ_k in the system, acting as a feedback system.
2. Prepare a photon in initial state and insert into the system.
3. After interaction, make measurement on the photon state. Send outcome to control unit.
4. Find feedback parameter from the set of rules (policy) calculated by the machine learning algorithm.
5. The control parameter Φ_N of last iteration is the estimate.

Feedback update

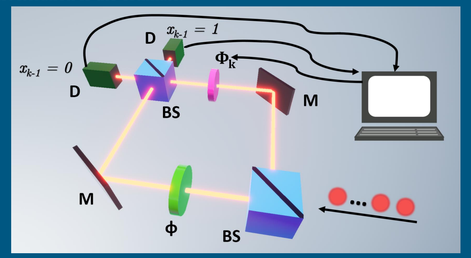
$$\Phi_k = \Phi_{k-1} + (-1)^{x_{k-1}} \Delta\Phi_k$$

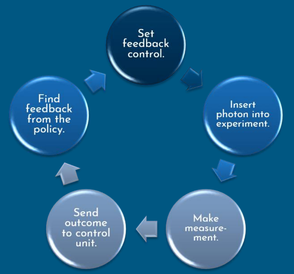
where $\Delta\Phi_k$ is the kth policy rule, and x_k is k-1th outcome [2].

Fitness – Quality of policy

$$S(\Delta\Phi) = \left| \int_{-\pi}^{\pi} p(\theta|\Delta\Phi) e^{i\theta} d\theta \right|$$

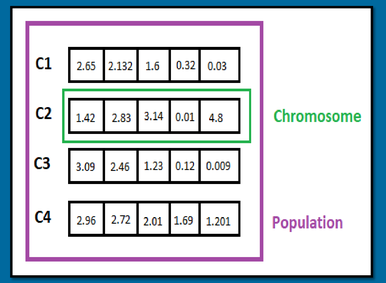
where $\theta = \Phi_{est} - \Phi$, $p(\theta|\Delta\Phi)$ is probability of getting θ using $\Delta\Phi$.

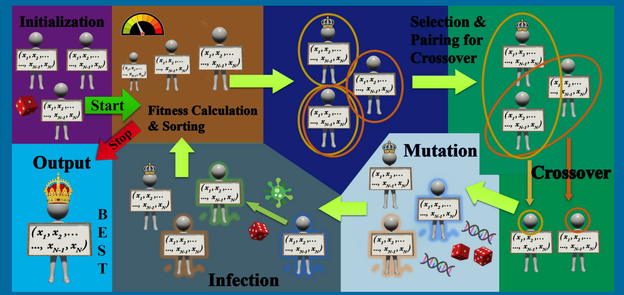




Genetic Algorithm (GA)

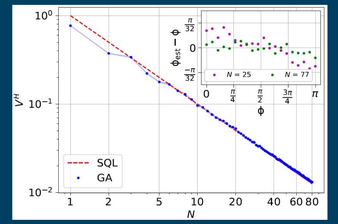
Genetic algorithm is an evolutionary algorithm based on the theory of natural selection. A set of solutions (chromosomes), containing the policy form the population. A randomly initialized population evolves by selecting best mates and coalescing their genes, according to some crossover method. The recombined solutions mutate, and the iteration continues to reach a desired fitness.

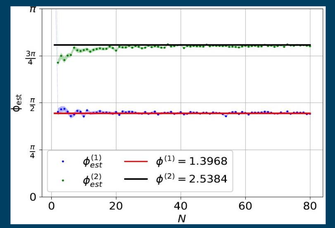




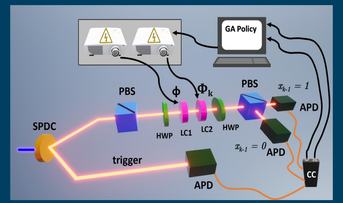
Results

Simulation : 100 Trials





Experimental Setup



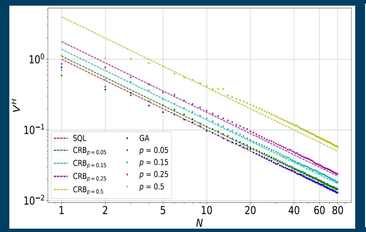
Robustness to Noise : 100 Trials

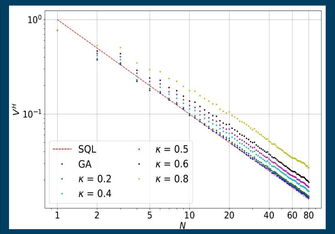
Depolarizing Noise

Photon detected with P(1-p) + p/2 probability at each step , where P is probability for detecting $x_k = \{0,1\}$ with zero noise (p = 0). Noise paramter: p.

Phase Noise

Random fluctuation in the feedback phase for noiseless policies with a variance of κ^2. Noise parameter: κ





Experimental Results