Optimization and machine learning algorithms applied to the phase control of an array of laser beams

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Abstract: The phase control problem is to lock and maintain of an array of laser beams on arbitrary target phase set in a fast dynamical environment. The potential application is a remote laser beam illumination. The difficulty is that direct phase measurements are not possible, but only phase modulations are available. The goal is to set the phases of the laser beams to the target values represented by a vector $\varphi \in [0, 2\pi]^n$, where n is the number of laser beams. This problem can be solved via an opto-numerical algorithm developed in [2]. The optical part of the algorithm is done by means of noisy intensity measurements from a photonic system, the numerical part is an optimization algorithm based on alternating projections. The first part of the talk is devoted to the presentation of the optimization algorithm and to the resulting experiments. In the second part, a machine learning based approach is also presented [1]. The numerical algorithm has two unavoidable requirements: robustness and efficiency. The experimental data are very noisy and the phase control must done in less than one tenth of millisecond. At the k-th iteration of the opto-numerical algorithm, a vector of noisy intensity measurements $b_k \in \mathbb{R}^m_+$, with $m > n$, is returned by the photonic system. From b_k, one has to compute a vector $x_k \in \mathbb{C}^n$, which represents the state of the n laser beams. The physical connection between these vectors is described by means of a transmission matrix $A \in \mathbb{C}^{m\times n}$, such that $|Ax_k| = b_k$, where $|\cdot|$ is computed element-wise. This model represents a scattering device with photodetectors. The problem of solving this set of nonlinear equations is called a phase retrieval problem. The alternating projection algorithm, also called Gerchberg-Saxton in this context, is frequently used for this goal because of the high speed and robustness of the iteration process. It is considered as a baseline algorithm in our work to compare with.

At first, we present a kind of Alternating Direction Method of Multipliers with adaptive restarts for solving the phase retrieval problem. It is shown numerically, under some assumptions on A, that starting from a random initial point the algorithm converges to a global solution with a high probability. The robustness of the algorithm is also shown for different levels of noise. These properties allow us to reduce the number of physical interactions with the photonic system and thus to reduce the time of the phasing process.

We also present a machine learning based algorithm [1] that could replace the optimization method of the opto-numerical algorithm. It is shown numerically that under some assumptions on the phase correction process (fixed target), a simple neural network with one fully-connected layer without a bias and with an activation function, can compute $\varphi_k \in \mathbb{C}^n$ such that $\varphi_k \to \varphi$ up to a constant for sufficiently large k. This approach is highly scalable and cheaper in comparison with the previous optimization algorithms.

These two methods are compared with the baseline algorithm numerically and tested on the experimental setup to verify the speed and robustness of the algorithms.

References:

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