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Experimental optimization of orbital angular momentum beams generated by coherent beam combining digital laser

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Abstract: We experimentally implemented a genetic algorithm to improve the uniformity of a Laguerre-Gaussian beam generated with a 61-channels coherent beam combining digital laser. © 2023 The Author(s)

1. Introduction

Coherent Beam Combining (CBC) is a promising technique to scale up peak and average powers of fiber laser systems with beam shaping capabilities. XCAN is a 61-tiled channels CBC-femtosecond Yb-fiber digital laser. Each channel is seen as an individual pixel where amplitude and phase are controlled independently. The 61 beams are coherently combined into a single Gaussian or Laguerre-Gaussian (OAM: Orbital Angular Momentum) beam through collective focusing and a phase-locking scheme [1]. Such OAM beams offer a wide range of applications like filamentation control and the generation of energetic needle beams. However, the generated OAM beams could deviate from the desired beam quality and energy distribution. Many iterative computing approaches like deep learning and genetic algorithms (GAs) allow the required phase and intensity to be applied in the near field to produce a predefined target, and correct or optimize the far-field energy distribution. Lemons *et al.* implemented a GA to optimize a simulated CBC system [2]. Burger *et al.* recently proposed a wavefront optimization method of OAM beams through adaptive optics and GA-guided feedback [3]. In this paper, we assess the capability of a GA to homogenize the radial energy distribution of an OAM beam generated by a CBC femtosecond digital laser.

2. Method, simulations, and experimental results

We derive an optimization approach relying on a GA based on natural selection of the most adequate individual with respect to our defined goal: beam radial homogenization. An individual is a set of 61 phases (called genes based on the genetic analogy) to be applied to every channel (Fig. 1). The Figure of Merit (FoM) is defined as the ratio of the minimum over the maximum of the intensity along a circle fitting the OAM beam far-field (Fig. 2a).

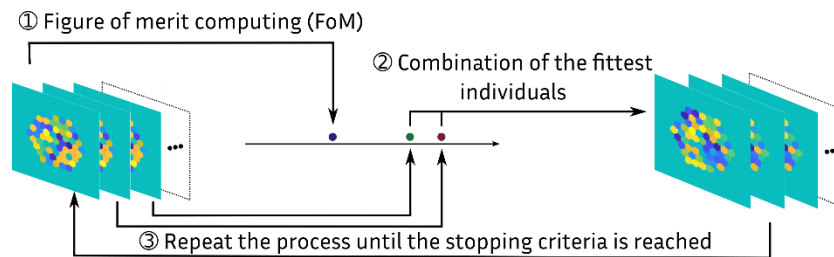


Fig. 1. Block diagram of the genetic algorithm applied to the XCAN laser.

The optimization process starts with a defined number of individuals, the initial population, while each individual's genes are initialized with random values. After being all evaluated against the FoM, individuals are ranked by proximity to the unit value (higher values being favored). Then, a number of individuals is selected for the reproductive phase consisting of two types of operations on the genes to produce a new individual: (1) crossing – the fusion of a given number of individuals' genes, and (2) – mutation: the random change of a given proportion of the individual's gene. This succession of ranking and reproductive phases is repeated until a satisfactory state is reached.

This collection of phases is called a generation and is then applied to XCAN's 61 phase modulators. The smallest phase shift between two phase values is selected to be $\pi/5$ not to hinder the CBC phase locking, thereby conserving the far field structure. The GA is first applied through simulations on an array of 61 beams, where amplitudes and phases are controlled independently. Each beam gets collimated and truncated by a dedicated microlens leading to a simulated composite near field, which is then Fourier transformed to a simulated far field. The generated OAM beam is defined by a helicoidal phase $\exp(in\theta)$ characterized by its topological charge n . The simulated far field without

correction (Fig. 2a) exhibits 6 peaks visible on the radial lineout (in white, Fig. 2a). One can observe in Fig. 2b and Fig. 2e-green that the peak-to-peak intensity is reduced but not eliminated.

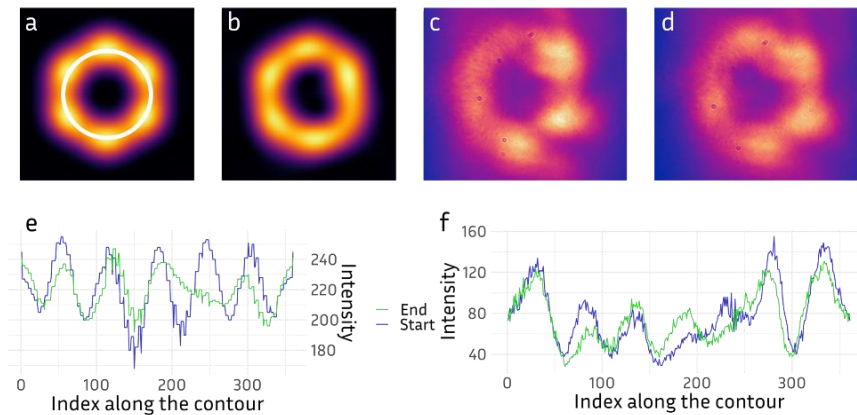


Fig 2 (Top) simulated (a - b) and experimental (c - d) OAM beam far-field before (left) and after (right) GA correction. (Bottom) Intensity lineout for the simulated (e) and experimental (f) beams (before in blue and after in green).

In the particular case of $n = 3$, Fig. 2c-d, one can observe the experimental far field before correction (2c) and after correction (2d). The plot in Fig. 2f demonstrates that the peak-to-peak variation has been reduced between the start (blue curve) and the end (green curve).

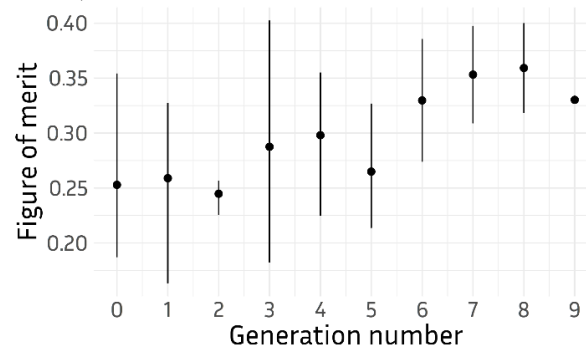


Fig. 3. Experimental evolution of the FoM; generation 0 is the beam without any optimization. Error bars represent (top to bottom) the maximum, average, and minimum values obtained over several runs.

Figure 3 depicts the evolution of the FoM and confirms the ability of the algorithm to be successful in improving the OAM beam quality. Even after regressions on generation 2, the algorithm ends up finding a higher optimum consistently. The non-monotonicity of the variation can be explained by two main factors: (1) experimental fluctuations allow the same individual to produce a slightly different FoM on subsequent generations, and (2) each point being the result of statistics (see Fig. 3's caption), variability of the average value is expected in each generation. As the number of runs through the generations is reduced due to the stopping criteria, we observe a reduction in the error bars, particularly for the ninth generation (also due to a uniformization in the genes).

3. Conclusion and future work

We demonstrate online optimization of an OAM beam on a CBC digital laser through a GA. The method being stochastic brings variability to the result of optimization. Other optimization algorithms will be explored to alleviate the probabilistic nature of the optimization. Further experimental results will be presented at the conference.

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[1] M. Veinhard, S. Bellanger, L. Daniault, I. Fsaifes, J. Bourderionnet, C. Larat, E. I© 2023 The Author(s) J.-C. Chanteloup, "Orbital angular momentum beams generation from 61 channels coherent beam combining femtosecond digital laser," *Opt. Lett.* 46(1), 25–28 (2021).

[2] R. Lemons and S. Carbajo, "Phase retrieval and reconstruction of coherent synthesis by genetic algorithm", *J. Phys. Photonics*, 4 (2), 2022.

[3] M. Burger, J. M. Murphy, L. A. Finney, N. Peskosky, J. A. Nees, K. Krushelnick, and I. Jovanovic, "Iterative wavefront optimization of ultrafast laser beams carrying orbital angular momentum," *Opt. Express* 30, 26315-26323 (2022).