Optimization of femtosecond fiber laser pulses with selected machine-learning algorithms

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Abstract: We investigate the possibility of optimization of ultrashort laser pulses by spectral phase modulation using machine learning algorithms. We compare the efficiency of two algorithms: Grey Wolf Optimizer and Genetic Algorithm.

The generation of ultrashort laser pulses, with a duration of a few optical cycles, is crucial for many applications, such as multiphoton microscopy [1]. Their further development is going in the direction of miniaturization, which was significantly accelerated by the development of fiber lasers. One of their big advantages is not only their size but also their simple operation or price. Optimizing a femtosecond fiber laser for the generation of the shortest pulse is a bigger challenge – because of many adjustable parameters, finding the best settings manually can take at least a few hours, if not days. As we have shown in [2], optimization of femtosecond pulses using spectral phase modulation is possible. In this work we compare two machine learning algorithms: Grey Wolf Optimizer and Genetic Algorithm.

Figure 1 shows the experimental setup of the AI-optimized laser system. The femtosecond laser pulse with a duration of 335 fs reached the diffraction grating, then went onto the spectral light modulator (Santec SLM-200) which modified the spectral phase using a suitable mask. Next, the pulse returned to the diffraction grating and was guided to the autocorrelator for measurements. The software controlling the system served as a skeleton (frame) allowing for testing various algorithms and comparison of their effectiveness.

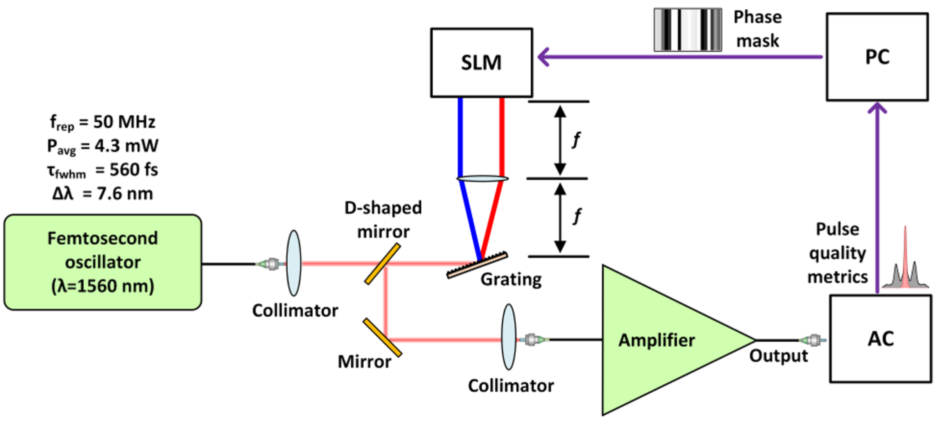

Fig. 1 Experimental setup. AC – Autocorrelator, PC – Personal Computer, SLM – Spatial Light Modulator. Taken from [2].

The first algorithm that was used to optimize the pulses was the Grey Wolf Optimizer [3]. It is a meta-heuristic algorithm that models the hunting behaviour of a pack of grey wolves. Notably, the GWO is an online machine learning algorithm that learns in real time and does not need any prior data acquisition. As it does not use any neurons, or deep learning architectures, it does not require powerful computational resources (a regular PC is sufficient). The second algorithm that we tested in this work was Genetic Algorithm [4], which is widely used for solving engineering problems, e.g., design of multipass cells [5]. It is inspired a population based search algorithm, inspired from the natural selection. The new populations are created by use of genetic operators on individuals within the current population. Key elements of GA include chromosome representation, selection, crossover and mutation. Similarly to GWO, GA does not make use of neuron structures and does not need prior data acquisition, which makes it a good candidate for our application.

Each optimization algorithm needs a well-defined optimization goal (cost function). It describes the quality of the pulse, guiding the algorithm towards the global minimum. In this case, we came up with a coefficient F that takes into consideration not only the Full Width Half Maximum (FWHM) but also the difference of areas of obtained pulse (A) and calculated fit (A_{fit}). That way, we care not only about the time duration of the pulse, but also its shape.

$$F = FWHM \cdot \left(1 + \left|\frac{A_{fit}}{A}\right|\right)^2$$

The resolution of used SLM was 1920 x 1200 pixels, but for faster optimization the spectral resolution was restricted. The display of SLM was divided into 40 vertical stripes, which were modulated by the algorithms. For 40 stripes, one stripe corresponded to 0.9 nm of spectral width. For each measurement, the number of agents (in GWO) or population (in GA) differed from 50 to 300. The results can be found in Table 1 and the convergence curves are shown in Fig. 2. Fig. 3 shows a comparison of autocorrelations of the input pulse and best results for each of the algorithms. Clearly GWO managed to find a better phase mask, that corresponds to a pulse with a FWHM 26 fs shorter than the pulse optimized with GA.

Table 1. Comparison of Pulse Quality values for GA and GWO

Agents/Population	Pulse Quality F [a.u.]	
	GA	GWO
50	135.12	147.16
150	135.11	75.70
300	118.35	70.23

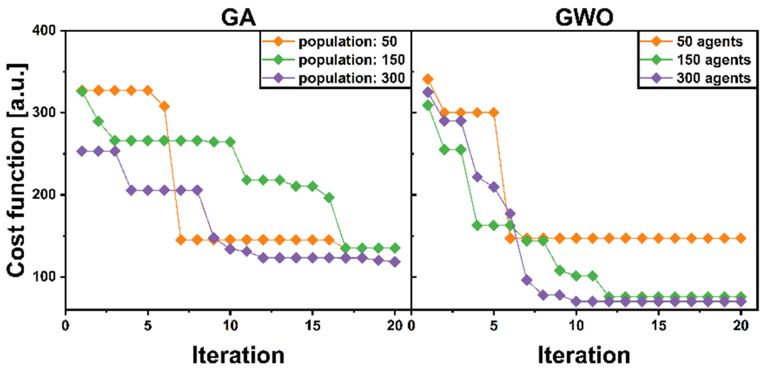

Fig. 2. Convergence curve, showing the value of fitness throughout iterations for different configurations of Genetic Algorithm (GA) and Grey Wolf Optimizer (GWO).

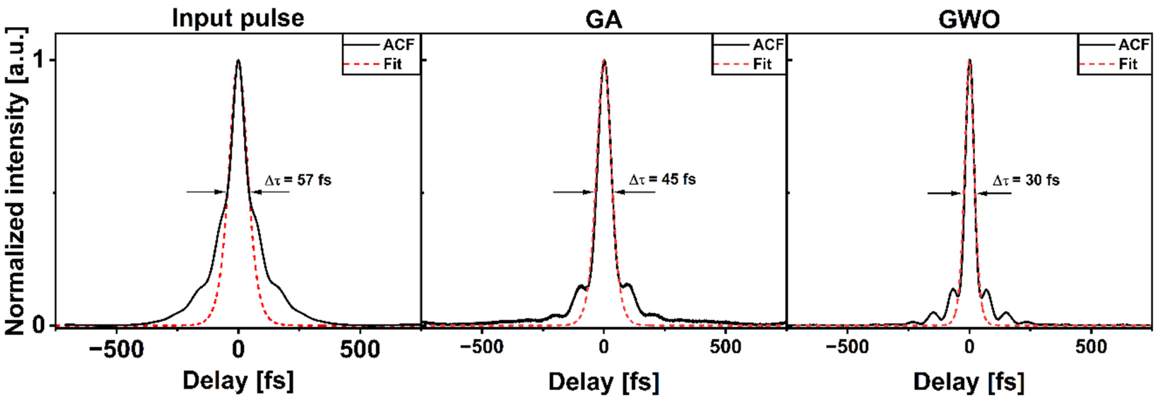

Fig. 3. Comparison of autocorrelation function (ACF, solid black line) with sech^2 fit (Fit, dashed red line) of the input pulse, pulse optimized with Genetic Algorithm (GA) and Grey Wolf Optimizer (GWO) with 40 stripes and 300 agents/population.

Results show that in majority of cases GWO proved to be better for optimization of femtosecond fiber laser pulses with spectral phase modulation. Seeing the convergence curves, it is visible that GA usually needs more iterations to find the minimum. Despite the popularity of GA, when looking for an easy to implement and effective algorithm for online optimization of laser systems, GWO is a better candidate. As was shown, despite having less adjustable parameters, it gave better results and required less iterations to find the minimum. The research was funded by National Science Centre under project no. 2021/42/E/ST7/00111.

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