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Transitioning from Manual to Automated Control: Mode-Locked Ultra-Fast Fiber Lasers via Machine Learning and Genetic Algorithms

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Mid or Near-IR Mode-Locked Lasers offer several advantages over simple Continuous-Wave (CW) Lasers due to their unique operational characteristics and significant commercial applications. Mode-locked lasers typically generate ultra-short and ultra-fast pulses with very high peak powers and repetition frequencies, which are essential for a wide range of applications such as nonlinear optical processes, high-resolution imaging, precision material processing, micro/nanomachining, optical coherence tomography (OCT), and frequency comb generation.

In CW lasers, the amplification of light through stimulated emission is easier for longer wavelengths, making it more challenging to generate high-frequency lasers. Mode-locked lasers, on the other hand, offer advantages in these areas but come with increased complexity in their design, construction, and operation. A key challenge is achieving and maintaining precise cavity alignment, which is crucial for ensuring stability in this highly complex nonlinear optical system.

Traditional methods, such as the Split-Step Fourier Method (SSFM), rely on compact numerical calculations and multiple trial experiments. However, these conventional approaches often face limitations when confronted with the intricate challenges of achieving stable mode-locking.

Artificial Intelligence (AI), an emerging technology centered around data-driven analysis, offers new perspectives on improving the stability of mode-locked lasers. This research article explores the integration of a feedback controller-based fast controller with the Genetic Algorithm of Machine Learning, aiming to achieve stable ultra-fast and ultra-short pulses in the shortest possible time through an automatic mode-locking process. The inclusion of AI accelerates the convergence of optimal solutions, reducing the time and complexity required for manual cavity adjustments, thus paving the way for more efficient and scalable laser technologies.

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