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REVIEW

Nonlinear controller for the laser fiber using PID controller

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We show that a software architecture based on machine learning and adaptive control advances makes self-tuning optics possible. Commercially available optical telecom components may be combined with servo controllers to develop a training and execution software module that can self-tune the laser cavity even when it is switched off. Mechanical and/or environmental disturbances may aid in frequency comb stabilization. An exhaustive search of state space is used in the algorithm training stage to find the optimum performance areas for one or more objectively interesting functions. The technique of implementation stage starts by identifying the variable space using a sparse sensing approach, then settles on a near-optimal solution and maintains it using the extremum seeking control protocol.

Keywords: laser, fiber, communication, nonlinear control, fiber laser, deep learning.

1. Introduction

Accomplish a nearly ideal result. While designing then analysis of such organizations are quite important with regard to defining -underlying movable then area of possible behaviours, organizations, nonlinearities, and feeling to a multidimensional parameter space typically make quantitatively precise system performance forecasts challenging. This is especially correct for mode–locked lasers (1–3) wherever- the major physical effects have been understood for over three decades but a measurable predictive performance theory has eluded researchers. The basic, extremely sensitive character of man-s stochastically fluctuating fluctuations in physical factors that interact with the networked, nonlinear organization is highlighted by such quantitative discrepancy. The fact that fiber birefringence fluctuates randomly along the fiber is widely known. Mode-locked fiber lasers, for example, are an example of this. Refraction plus the consequent mode-locking show can be influenced by environmental temperature changes as well as modification of the fiber physically (bending). Fiber lasers for commercial use are linked in-to site and then insulated from environmental variations in order to maintain performance. Using a robust control method on the laser to notice parameter changes and adaptively adjust the parameter site to attain near-optimal show is an alternative to environmental shielding. In the following sections, we will explain how machine learning and adaptive control approaches may establish a new paradigm for self-tuning, intelligent systems with equation-free architectures automated systems accomplished of self-tuning, and near-optimal accomplishment in a method-locked laser in this study. We use these novel data-driven methodologies to develop an- In the algorithmic infrastructure, there are learning and execution modules. The learning module explores parameter space with rigor. Identifying areas of optimal performance and building a collection of these parameter rules. The implementation module makes use of the learned behaviour by main recognizing the current parameter regime and then fast switching to the most optimum method-locking rule. The Extremum Seeking Controller (ESC) then maintains a near-optimal amount of mode locking. A numerical typical of a laser power mode-locked by a series of wave plates and polarizers is used to show the algorithm-s success.

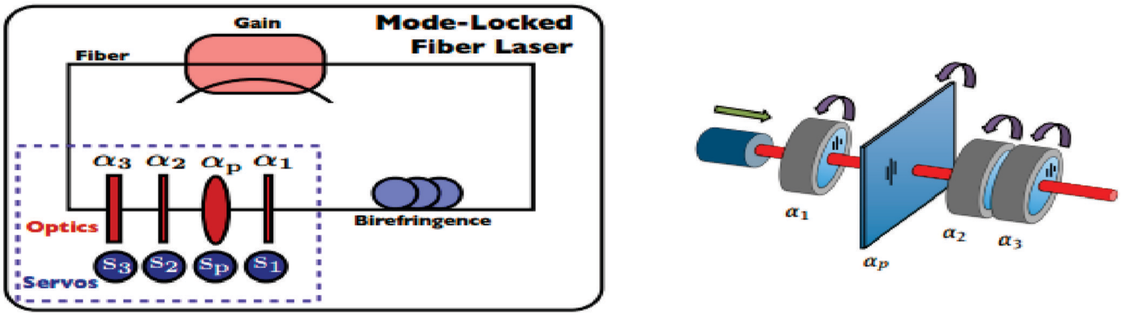

FIGURE 1 | Schematic diagram for the mode-locked fiber laser, ADAPTED (9).

2. Problem formulation

The various polarization dynamics and energy equilibration that commence the mode-locking process should be accounted for by the intra-cavity dynamics of the mode-locked laser of interest, among other things. **Figure 1** shows an example of a cavity structure utilized in experiments to create stable and durable mode-locking (1, 3). The remaining physical factors in the laser cavity are merged into an average total propagation equation that incorporates chromatic dispersion, Kerr non-linearity, absorption, and bandwidth-limited, saturating gain (4–8):

$$i\frac{du}{dz} + \frac{D}{2}\frac{d^2u}{dt^2} - Ku + \left(|u|^2 + A|v|^2\right)u + Bv^2u^* = ig(z)$$

$$\left(1 + \Omega\frac{d^2}{dt^2}\right)u - i\Gamma u \quad (1)$$

$$i\frac{dv}{dz} + \frac{D}{2}\frac{d^2v}{dt^2} - Ku + \left(A|u|^2 + |v|^2\right)v + Bu^2v^* = ig(z)$$

$$\left(1 + \Omega\frac{d^2}{dt^2}\right)v - i\Gamma v \quad (2)$$

On the left hand side of this equation are the linked nonlinear Schrödinger equations (CNLS). The non-dimensionalized averaged propagation of two orthogonally polarized electric field envelopes through a birefringent optical fiber is simulated by this system, where u and v fields are orthogonally polarized components of the electric field, (9–12):

$$g(z) = \frac{2g_0}{1+\frac{1}{E_0}\int_{-\infty}^{\infty}\left(|u|\right)^2+|v|^2\right)dt} \quad (3)$$

And linear attenuation, as well as (-cavity losses-). Models of the fiber laser cavity-s distributed loss, owing to output coupler, fiber attenuation, interconnections, and splicing. whereas g0 and E0 represent the gain (pump) strength and cavity saturation energy, respectively, in this equation. This option determines the gain media-s width. Erbium-doped fiber, for example, has a gain bandwidth of about 20–30 nanometers. The purpose of this article was to apply sophisticated data approaches, such as machine learning techniques, to help in the identification of an efficient cavity birefringence proxy. In contrast to optical communications, the laser cavity dynamics are governed by a single realization of a stochastic change in birefringence, whereas a pulse may have a numerical average across extended distances (see **Figure 2**). When there is a disturbance in the cavity, by bends, twists, orthotropic tension, and/or ambient temperature, a new realization emerges. To identify the waveplate and polarizer settings, for example, the highest energy efficiency, it is important to accurately define or detect fiber birefringence in order to improve performance. Our individuals learning subsystem-s ultimate goal is to assess the influence of birefringence on performance and find the best appropriate operating regimes given the unique birefringence, not to replicate or mimic it.

2.1. Deep learning techniques

The first step in the toroidal search is to find all of the input limits that may be used to regulate and change the behaviour of the system. The polarizer and three wave-plates that may be rotated from 0 to 2, resulting in 4-torus parameter space, are easily recognizable in the trial setup of a mode-locked fiber laser with an NPR basis. Polarization ears capable of adjusting the cavity birefringence can also be added to the cavity. For the time being, we will suppose that the average birefringence is set to an unknown number. Surprisingly, the strategy advised here could be the only practical option to train a large number of NPR laser cavities to attain optimal, high-capacity performance-.The produced parameter must be sampled or data-mined in order to do so. A spiral search algorithm is built (4N-torus). If we wish to look at this 4N-dimensional torus, we will need 4N time series made up of:

$$\theta_{j(t)} = w_{jt+\theta_{jo}} \quad (4)$$

The equation mj + nk = 0 does not have an integer solution for j [1,..., 4N], where j0 is the starting parameter value and I

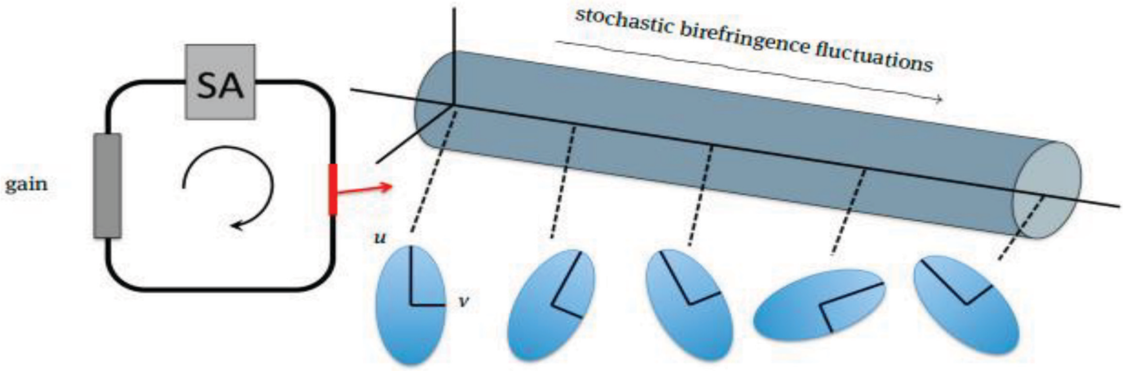

FIGURE 2 | Schematic diagram for the polarization angle effects, adapted from (13).

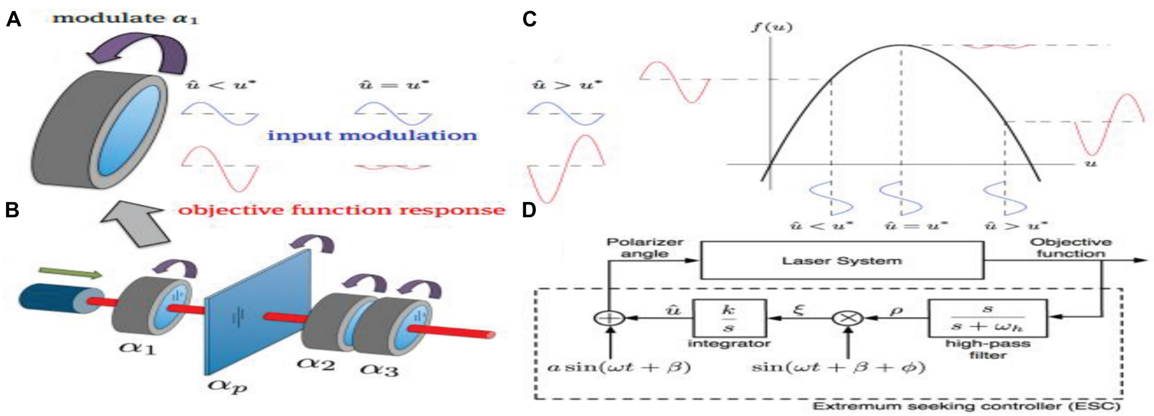

FIGURE 3 | Schematic diagram. **(A)** samples of the polarization angle, **(B)** modelling of multi -loop gain, **(C)** input- output curves, and **(D)** proposed control system.

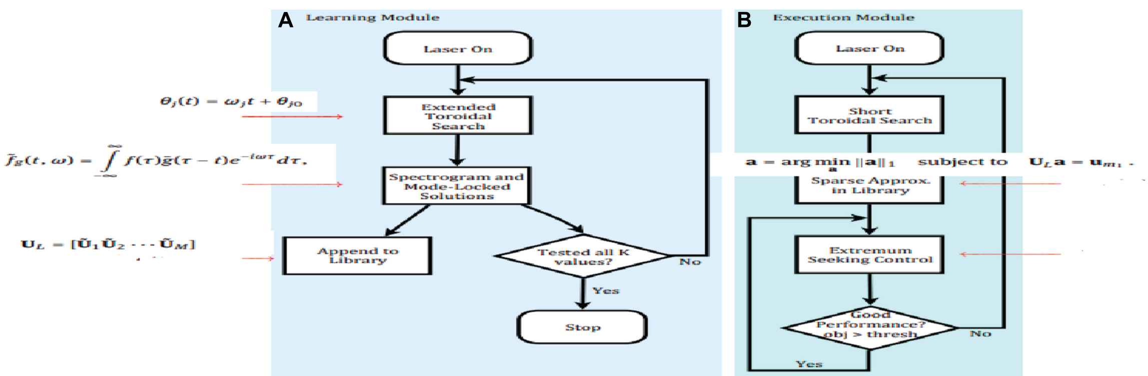

FIGURE 4 | Global searching algorithm.

is the incommensurate angular frequencies. For all j, k [1,..., 4N], j/k is irrational. It's easy to show that [1(t)...4N(t)] is dense on the torus (14) under such circumstances. On a two-torus with parameters 3 and p, Figure 3 shows how toroidal sampling works. The time series of the objective function O is displayed as the 2-torus is sampled. The goal function is aliased in Figure 3A because the torus is under-sampled. The objective function is fully created and the optimal performance may be calculated when the sampling rate rises, as illustrated in Figure 3B. The laser cavity-s ideal global maxima are in fact represented by the red dot in Figure 3C. In Figure 3D, the small shaded region surrounding this peak performance is emphasized, and a second evaluation of whether or not the solution is mode-locked is done.

The non-zero components of the sparse vector a serve act as a classifier (indicator function) for detecting which sub-library the birefringence belongs to after the L1-norm reduction. As a result, the recognized birefringence value is equal to Ki if the biggest element belongs the i-th sub-library. When paired with the unique spectrograms, this

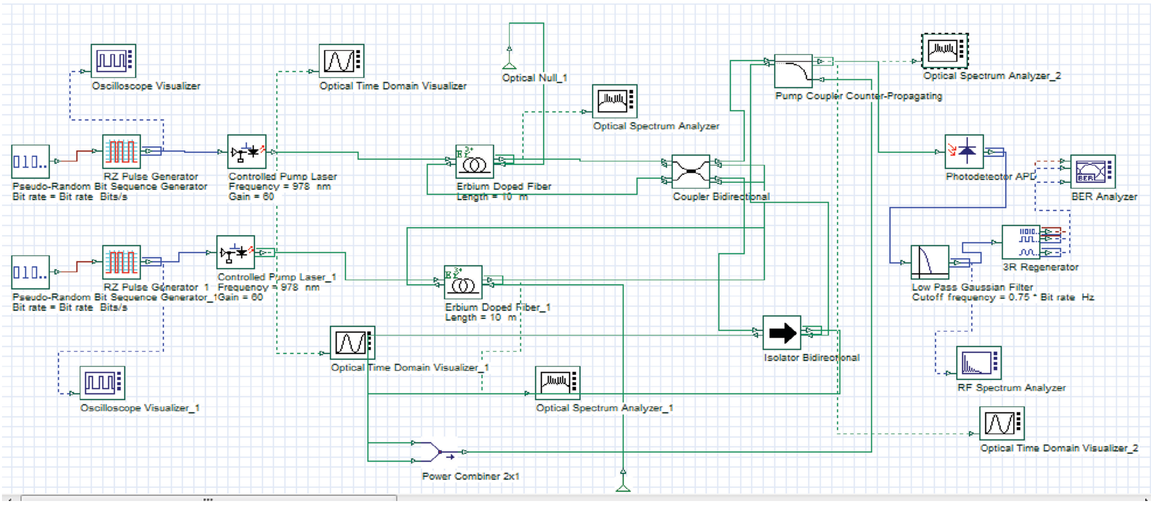

FIGURE 5 | Simulation setup of the double laser system.

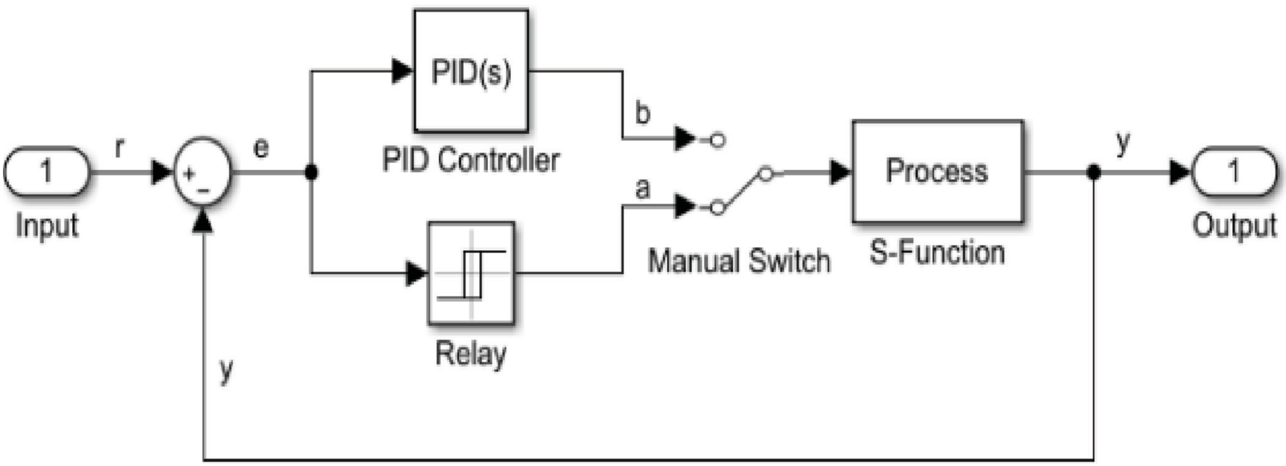

FIGURE 6 | Schematic diagram for the PID controller.

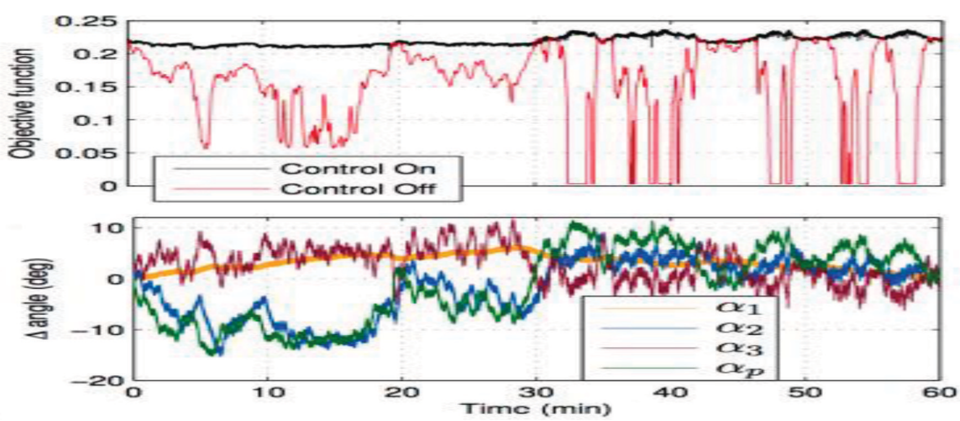

FIGURE 7 | Simulation results with control on and off.

TABLE 1 | Bandwidth 6 THZ, time between (2n–14n)-, and α_1.

Device angle	10	20	30	40	50	60	70	80	90	100	110	120	130	140
Amplitude (m)	340	230	255	400	600	760	805	720	540	340	230	260	400	620

TABLE 2 | Bandwidth 6 THZ, time between (2n–14n)-, and α_1.

Device angle	150	160	170	180	190	200	210	220	230	240	250	260	270	280
Amplitude(m)	800	840	720	540	340	230	260	400	600	760	800	720	540	340

TABLE 3 | Bandwidth 6 THZ, time between (2n–14n)-, and α_1.

Device angle	290	300	310	320	330	340	350	360
Amplitude(m)	230	260	400	620	800	840	660	540

sparsity-promoting optimization results in a fast and accurate fiber birefringence categorization method. As a result, the detection of birefringence is simple (As shown in **Figure 4**).

3. Simulation setups and results

Figure 5 illustrates the simulation system-s modeling. where the op-net software has been used to complete all the components. The controller architecture for adjusting the angles is depicted in **Figure 6**. The execution module is seen in **Figure 7**. In this experiment, the mean cavity birefringence is altered slowly (and randomly) over the period of 60 minutes. It‘s easy to utilize the execution module. The data approaches mentioned in the preceding sections can be combined to produce a reliable mode-locked laser self-tuning algorithm. The hunt for a toroid, is used to find candidate regimes for optimum mode-locking by searching for the parameter. Multiple objective functions can be used to conduct the search and assess the results; when cavity performance requirements change, optimization procedures can be tweaked to meet the new demands. The best solutions are saved (or stored) in a library structure using their spectrogram form. The body of the paper consists of numbered sections that present the main findings. These sections should be organized to best present the material.

Tables 1, **2**, and **3** list the desired value of the angles that have been used.

4. Conclusion

Since it does not need the user to have extensive, quantitatively correct knowledge about the system under examination, the technique presented in this study is interesting because it is equation-free. Rather, data from the system is collected, in this instance optical spectrum and power measurements, in order to construct an appropriate objective function. Surprisingly, the parameter space-exploring toroidal search learning method may be assessed with any number of objective functions. In mode-locked lasers and regularity comb applications, this might mean striving for the shortest, most intense, or most consistent phase-locking between round trips. Self-tuning is possible if a sufficiently large objective function can be built. Since all the technology needed to implement the method is presently accessible, our research underlines the necessity of integrating hardware, software, and algorithms to maximize technological potential. As a result, our findings. highlight the need of combining hardware with software and algorithms in order to significantly increase the potential for technological growth.

Author contributions

The author conducted a study, analyzed and implemented the system using Opti net of the types of lasers and the types of optical fibers that are meant by mods, and we saw the effect of bending. The author solved the problem of the source, the best value of the current for lasers, so that we can work on a solution for physical nonlinearity in optical fiber. Finding optimal current id1 and id2 for the laser diode and used a control system. We combined the control with the polarization angle to find the best value for the polarization. In this case, we solved a problem of gain and gave it the best value for the signal transmitter from transmitter to receiver. All authors contributed to the article and approved the submitted version.

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