Open Database from Experimental Laser Systems - Resource for Photonics Simulations

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***Abstract*-We introduce an open-access online database containing high density datasets from various nonlinear laser systems as a resource for facilitating comparisons between theory and experiment, and for answering new research questions. The database is also useful in data science and machine learning.**

I. Introduction

The largest scale projects in astronomy and high energy particle physics, with their multi-billion dollar budgets and multi-petabyte data collections, represent the high end of the "big data" revolution as it manifests in physical science. Tabletop studies of photonic systems, including nonlinear photonic systems generate more modest data sizes. Nevertheless, such studies, in common with most tabletop science, are still costly in time and money, and scientists have a responsibility to ensure the maximum scientific benefit is gained from the data collected. In a given project, experiments are completed to answer specific questions and/or test specific hypotheses. But, it can also involve ensuring the data is future proofed at the time of its collection by it being of the highest quality, volume and versatility. It should cover as much of the relevant parameter space as is practically achievable. Also, the data needs to be made more generally available so that its scientific value can be increased through it being a research resource to more scientists than those who generated it. For relevant research communities this may also involve a mindset adjustment that "new" science with "old" data can be as significant and important as science with new data. We contributed these aims, among others, to a multi-discipline research project "Big data knowledge discovery – natural science meets machine learning" supported by the Science and Industry Endowment Fund in Australia. The sections that follow describe the open science web database of nonlinear laser systems data and some of the science that this is enabling. Now that the database is live we are recommending it for research engagement by the broader community and encouraging others to adopt some of the philosophy of the approach in their own research activities. Part of demonstrating the value of our research to others is valuing our experimental data as a long term resource like our big science colleagues.

What is in the Open Science Web Database (OSWD)?

The output power dynamics of nonlinear laser systems is a main topic of our research. The data in the OSWD comes from our own experiments on semiconductor laser with optical feedback (SLwOF) systems based on free space propagation of the laser beam to an external mirror such as the system shown in fig. 1 [1]. These systems are much studied and have been a workhorse of nonlinear laser science [2]. The experimental method used to enable the collection of systematic, high-density, high-resolution, high-volume data relies on using an acousto-optic modulator for computer control of the optical feedback level (several hundred levels used, transmission between 6.5% and 75.5% accessed). The injection current is readily computer controlled (typically 45 mA to 70 mA in 0.1 mA steps). The photodiode detected output power recorded for 1 μs (20 kpts) at a sampling rate of 20 GSa/s constitutes a single time series. Typically 90,000 or so time series are collected for one, two parameter dataset. The sizes of the datasets are given in Table I which includes the other nonlinear laser systems with datasets in OSWD. These are from a photonic integrated laser with a long passive waveguide (DFB_Integrated_12GHz) as shown in fig. 2 [3,4]; an optically injected solid state laser (OISSL) shown in fig. 3 [5-8]; and a three section semiconductor laser with the optical feedback cavity being a passive waveguide using quantum well intermixing to increase the bandgap (QWI 3-section SL). The architecture of the OSWD has been designed and developed by a project partner team at Sirca. It utilises Amazon Web Services (AWS) [9].

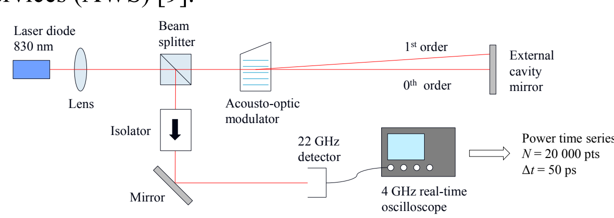

Fig. 1. Semiconductor laser with optical feedback setup [1]

TABLE I
AVAILABLE DATASETS IN OSWD & SIZE

Nonlinear Laser System Dataset	Raw Size (GB)	HDF5 Size (GB)
SLWOF_Bulk_4GHz [1]	14.7	5.0
SLWOF_Bulk_16GHz	18.9	2.2
SLWOF_Bulk_16GHz_Temperature	226.7	23.8
SLWOF_Bulk_4GHz_OSA	22.0	6.7
DFBWOF_Integrated_12GHz [4,5]	218.0	57.1
OISSL_experiment [6-9]	1.8	0.6
OISSL_simulation [7]	11.1	1.5
QWI 3-section SL	>1500	423

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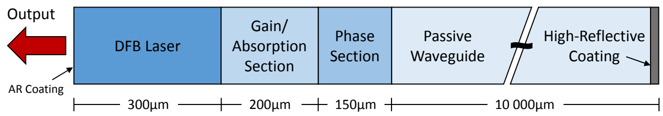

Fig. 2. Schematic of the PIC laser device that includes an InGaAsP DFB laser (λ = 1561 nm), a 200 μm gain/absorption section, a phase section and a 1 cm passive waveguide [3,4].

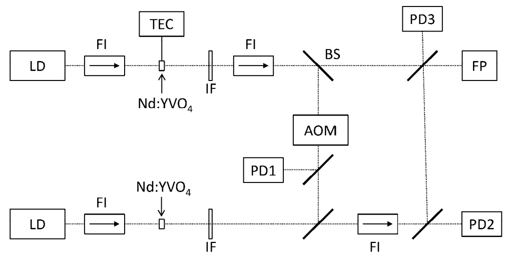

Fig. 3. Experimental setup: LD, laser diode; FI, Faraday isolator; TEC, temperature control; IF, interference filter; BS, beam splitter; AOM, acousto-optic modulator; FP, Fabry-Pérot interferometer; PD, photodetectors [5].

What of the Opportunity for Photonic Simulations?

The OSWD contains data that has already been utilised to research quantifying the complexity of chaotic laser output power time series using measures such as correlation dimension (CD) and permutation entropy (PE) [1,4,8], generating dynamical maps of the output within the relevant parameter space [1,4-6], and demonstrating the diverse range of dynamics classifications that can be observed in a single system [4,10]. To illustrate the ongoing research value that such data has we give a brief description of the research, past and ongoing, with the OISSL system (fig.3) data. Two 1064 nm solid state Nd:YVO_4 lasers were operated in a master-slave configuration. Light from the master laser was injected into the slave via an AOM allowing the relative injection power to be varied systematically. The frequency of the master laser was tuned to control the detuning. The intensity time-series of the slave laser under different combinations of injection strength and frequency detuning generated 55,440 files containing the single time series corresponding to each particular combination. In the first instance the experiment mapped the dynamical outputs of this system as a function of injection strength and frequency detuning between the master and slave lasers [5]. A rate equation model simulating the system was researched and used to show qualitative agreement between experiment and theory, including bifurcation diagrams [6,7]. Also, the comparison of experiment and simulation showed a non-zero alpha (linewidth enhancement factor) value for the laser crystals of order 0.20-0.30 is required to obtain a close match. It was then realised the data was suitable for researching the calculation of correlation dimension from the experimental time series because the chaos in the spiky output power is of a relatively low dimension and the signal to noise is high [8]. The completeness of the mapping assists interpreting the results as the CD is sensitive to fundamental and technical noise. The familiarity with the dataset then led to seeing that part of the dynamical map for this system generates a pulsed output that can be varied continuously in frequency by a single control – the injection strength [10]. Ongoing research is revisiting fractional values of correlation dimension between 0.0 and 1.0 and what this actually tells us about the dynamics of the system. Within the context of the SIEF project we are working with the NICTA team to research new techniques for inferring parameter values through directly linking the experimental data to the simulation model. These studies show which parameters are associated with sensitive dependence and the techniques are being used to test whether alpha, the linewidth enhancement factor is variable within the parameter space. Overall our experience has been that staying engaged with the experimental data and its associated theoretical model generates new research ideas over time on how the data can be re-used to answer new research questions. It is this approach which we suggest can be adopted more broadly and we welcome others using the available data in their own research.

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