Open Database from Experimental Laser Systems - Resource for Photonics Simulations

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- Geophysics
- Ecology
- Laser physics

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Mr. Nathan Williams
Mr. Daniel Lau
Mr. Paul McCarthy
Acknowledgements - Collaborations

OISSL data, experiment completed by Simo Valling, simulations by Thomas Fordell, in the group of Dr Asa Lindberg, Dept. of Physical Sciences, University of Helsinki, Finland.

QWI 3-section SLs fabricated at the Australian National University, Canberra, Australia, by Dr Pawel Sajewicz, Dr Lan Fu, & Professor Hoe Tan, in the group of Professor Chennupati Jagadish.

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Where are we?

Macquarie University Campus
Make the high quality datasets available to more researchers
  - BDKD Open Science Web Database
    http://laser.portal.knowledgediscovery.org/

Harness higher compute power via collaboration with experts
  - BDKD Development of the Clusterous Platform
    https://github.com/sirca/clusterous
An Open Science Web Database of NLD Datasets

Background
Understanding the diversity of dynamical outputs from a broad range of nonlinear systems is a major field of research and knowledge.

Important nonlinear systems include those in acoustics, economics and finance, ecology, lasers, mechanics, physiology, etc.

Contrasting experimental and theoretical studies of nonlinear laser systems can be important examples for studying the effects of the practical and technical issues such as signal to noise, pickup, etc. These studies can in turn elucidate the effects of such issues in other nonlinear systems where there is less or no control.

High-resolution, data-dense, datasets that investigate a broad range of the relevant laser system parameters are best for prospecting for as yet undetected regions of different types of dynamics, for making careful connections between theoretical models/simulations and experimental data, can be used to establish pathways to improved theoretical models led by experiment, and will be the most versatile datasets for future use.
Photonics Dynamical Systems
https://research.science.mq.edu.au/photonics-dynamical-systems/

Photonics Dynamical Systems Group

Currently, we undertake leading research in mapping complexity and related measures using experimental data from nonlinear laser systems. Understanding complexity and chaos in a broad range of nonlinear systems is a major field of research and knowledge. Important nonlinear systems include those in acoustics, economics, finance, ecology, lasers, electronics, mechanics, physiology, etc. Photonics dynamical systems represent ones in which high quality, measured output power data from a range of different laser systems become a tool for research and testing learning strategies that may be able to be deployed in the broader range of nonlinear systems. Many of the latter are not amenable to systematic study as key parameters are set and not variable. Also, complex laser systems are capable of producing chaotic signals which have a range of potential applications including secure communications, random number generation, optical sensing and reservoir computing.

Our focus is on broad parameter space and high resolution measurement, characterisation and mapping in these systems in order to identify and classify the full range dynamical outputs which occur throughout a range of operating conditions. The boundaries between different regions of operation, and quantification of the level of complexity of the output power over time are also key aims. We have already published significant results from this.

By taking a big data approach to experiments and capturing highly sampled dynamics at the finest possible parameter resolution we are answering a range of research questions, including contrasting experiment with theory, and achieving a better overall understanding of complex system dynamics.
Open Science Web Database
https://research.science.mq.edu.au/photonics-dynamical-systems/open-science-web-database/

In order to facilitate an open and collaborative research environment, where the impact of scientific research can be improved, our industry partners, Srcsa, have established an open science web database to provide access to data collected from a range of nonlinear laser systems.

This endeavour was part of a Science & Industry Endowment Fund (SIEF) project “Big Data Knowledge Discovery: Where Machine Learning Meets Natural Science”.

The database is hosted on cloud in Amazon Web Services Simple Storage Service (S3). A web based portal provides an easy way to access the data:

Go to database

There are a range of datasets available, recorded over wide operating parameter spaces from several different types of nonlinear laser systems including:

- semiconductor lasers with optical feedback,
- solid-state laser with optical injection,
- integrated multi-section photonic chip lasers.

The data is stored in HDF5 file format. Instructions for accessing data in this format are provided here.
BDKD Data Portal  Where Machine Learning meets Natural Science
http://laser.portal.knowledgediscovery.org/

BDKD Data Portal

Big Data Knowledge Discovery

Macquarie University and The University of Sydney are joining forces with globally recognised Machine-learning experts from NICTA and leading Big Data Software Engineers from SIRCA to deliver data-led insights to ecology, physics and geosciences.

eg: laser, magnetism, land

BDKD Data Portal statistics

9 1 10 0
9 datasets found

Semiconductor Laser with Optical Feedback - Integrated 3-Section Device - 12...
Time series data of the output power of monolithically integrated 3-section InGaAs/GaAs semiconductor laser devices. Devices manufactured by Pawel Sajewicz...

Semiconductor Laser with Optical Feedback - Bulk - 4GHz Detection BW - Optica...
Output power time series and optical spectra from an edge-emitting, multiple quantum well 830nm semiconductor laser subject to optical feedback. Data recorded for different...

Semiconductor Laser with Optical Feedback - Integrated Device - 12GHz Detection...
Output power time series from a 4-section photonic integrated circuit (PIC) laser. The device consists of a 300 um long DFB laser section, a 200 um feedback control section, a...

Optically Injected Solid-state Laser - Experiment
Output power time series from an optically injected 1064 nm solid-state Nd:YVO4 microchip laser. Time series recorded for different combinations of injection strength and...

Optically Injected Solid-state Laser - Simulation
Simulated output power time series from a model of an optically injected 1064 nm solid-state Nd:YVO4 microchip laser. Time series generated for different combinations of...

Semiconductor Laser with Optical Feedback - Bulk - 4GHz Detection BW
Output power time series from an edge-emitting, multiple quantum well 830nm semiconductor laser subject to optical feedback. Time series recorded for different combinations of...

Semiconductor Laser with Optical Feedback - Bulk - 16GHz Detection BW - Tempe...
Output power time series from an edge-emitting, multiple quantum well 830nm semiconductor laser subject to optical feedback. Time series recorded for different combinations of...

Semiconductor Laser with Optical Feedback - Bulk - 16GHz Detection BW
Output power time series from an edge-emitting, multiple quantum well 830nm semiconductor laser subject to optical feedback. Time series recorded for different combinations of...

Low Bandwidth
Output power time series from an edge-emitting, multiple quantum well 830nm semiconductor laser subject to optical feedback. Time series recorded for different combinations of...

http://laser.portal.knowledgediscovery.org/
Semiconductor Laser with Optical Feedback - Bulk - 4GHz Detection BW


Data and Resources

- download
  Provides individual links to download files

- metadata
  Metadata for Semiconductor Laser with Optical Feedback - Bulk - 4GHz...

- manifest
  Manifest for resource Semiconductor Laser with Optical Feedback - Bulk - 4GHz...

optical-feedback  semiconductor-laser
### Additional Info

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Author</td>
<td>Joshua P. Toomey</td>
</tr>
<tr>
<td>Maintainer</td>
<td>Dr Joshua P Toomey, MQ Photonics Research Centre, Dept of Physics and Astronomy, Macquarie University</td>
</tr>
<tr>
<td>Version</td>
<td>1.0</td>
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<td>data_type</td>
<td>Time Series</td>
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<tr>
<td>detailed_info</td>
<td>This data is being provided to be used in the context of the SIET project 'Big Data Knowledge Discovery'. Any use of this data should cite the following reference: J. P. Toomey and D. M. Kane, 'Mapping the dynamic complexity of a semiconductor laser with optical feedback using permutation entropy,' Optics Express 22 (2), 1713-1725 (2014). This data set was recorded from an experimental semiconductor laser subject to optical feedback on 13/08/12. Laser wavelength ~ 830nm. External cavity round trip time ~ 4.5ns. During the experiment, 2 system parameters were varied: the optical feedback level and laser injection current. Optical feedback was varied by changing the voltage across the 50ohm oscilloscope input. Time series were sampled at 20GSamples/s (50ps per data point) and contain 20,000pts for a total record length of 1microsecond. For different settings of: - Injection (251 values = 45mA to 70mA in 0.1mA steps) - Feedback (351 values from 0.45V to 0.8V in 0.001V steps) The filenames consist of the AOM and INJ values at which the data was recorded; e.g. AOM_0.642V_INJ_45.2mA.h5 : feedback = 0.642 V, injection = 45 mA Each hdf5 file consists of a single dataset called 'TimeSeries'. This contains a time series of amplitude values measured as the voltage across the 50ohm oscilloscope input. Time series were sampled at 20GSamples/s (50ps per data point) and contain 20,000pts for a total record length of 1microsecond.</td>
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## Available Datasets In OSWD & Size

<table>
<thead>
<tr>
<th>Nonlinear Laser System Dataset</th>
<th>Raw Size (GB)</th>
<th>HDF5 Size (GB)</th>
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<tbody>
<tr>
<td>SLWOF_Bulk_4GHz [1]</td>
<td>14.7</td>
<td>5.0</td>
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<tr>
<td>SLWOF_Bulk_16GHz</td>
<td>18.9</td>
<td>2.2</td>
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<tr>
<td>SLWOF_Bulk_16GHz_Temperature</td>
<td>226.7</td>
<td>23.8</td>
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<tr>
<td>SLWOF_Bulk_4GHz_OSA</td>
<td>22.0</td>
<td>6.7</td>
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<tr>
<td>DFBWOF_Integrated_12GHz [2,3]</td>
<td>218.0</td>
<td>57.1</td>
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<tr>
<td>OISSL_experiment [4-7]</td>
<td>1.8</td>
<td>0.6</td>
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<td>OISSL_simulation [5]</td>
<td>11.1</td>
<td>1.5</td>
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<tr>
<td>QWI 3-section SL</td>
<td>&gt;1500</td>
<td>423</td>
</tr>
</tbody>
</table>


http://laser.portal.knowledgediscovery.org The OSWD team at Sirca includes Balram Ramanathan, Lolo Fernandez and Ben King.
The Model

\[
\frac{ds(t)}{dt} = \frac{\gamma n(t) \Gamma - s(t) + s(t)G_n(n(t) - n_0)}{\tau_{sp}} + \frac{1}{1 + \varepsilon s(t)} + FB_s
\]

\[
\frac{dn(t)}{dt} = \frac{n_{nj} - n(t) - s(t)G_n(n(t) - n_0)}{\tau_{sp}} - \frac{1}{1 + \varepsilon s(t)}
\]

\[
\frac{d\phi(t)}{dt} = \frac{\alpha}{2} G_n(n(t) - n_0) \Gamma + FB_\phi
\]

The System

The Results

Contrasting conventional optical and phase-conjugate feedback in laser diodes, J S Lawrence and D M Kane, Phys Rev A 6303, pp 3805-3814, (2001)
Semiconductor lasers with optical feedback

- 4GHz Bandwidth
- Low Bandwidth + Optical Spectra
- High Bandwidth
- Temperature Study

Optically injected solid-state lasers

- Experiment
- Simulation

Varying parameters:
- Optical feedback level
- Laser injection current

Semiconductor Laser with Optical Feedback - Now

Laser Diode
Lens
Beam splitter
Isolator
Mirror
Acousto-optic modulator
External cavity
1st order
0th order
Mirror

4 GHz real-time oscilloscope

Power time series
\[ N = 20\,000 \text{ pts} \]
\[ \Delta t = 50 \text{ ps} \]

Raw data = 14.7 GB

MACQUARIE University
SYDNEY-AUSTRALIA
“Bulk” semiconductor laser with optical feedback system

Fabry-Perot semiconductor device Access Pacific Model APL 830-40 emitting at 830 nm
External cavity length 67.5 cm, round trip length of 135 cm (222 MHz)

The high density data set of experimental output power time series is collected for:
(i) injection current 45 mA to 70 mA in steps of 0.1 mA
(ii) optical feedback level varied by adjusting the 0th order transmission of the AOM from 75.5% to 6.5% (in 351 non-uniform steps sizes).

A total of 88,101 time series covering the operating region of interest.

“Bulk” semiconductor laser with optical feedback system

Dynamics maps of (a) RMS amplitude, (b) permutation entropy as a function of optical feedback level and laser injection current. (c) Example time series and RF spectra from points in the map.
Monolithic PIC chaos generator that includes: a 300 \( \mu \text{m} \) InGaAsP DFB laser, a 100 \( \mu \text{m} \) gain/absorption section (G/As), a 200 \( \mu \text{m} \) phase section (PHs), and a 1 \text{cm} \) passive waveguide (PW). (a); internal structure of the packaging module: micro-strip lines connect the different active sections of the PIC with SMA connectors, while thermo-electric cooling of the device provides extremely stable temperature control, fiber-chip coupling is performed by a tapered-end fiber with antireflective coating (b); packaged module (c).
Photonic Integrated Chaotic Laser - optical feedback system

### Parameter space

<table>
<thead>
<tr>
<th>Section</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFB Laser Section</td>
<td>$I_{DFB} = 15 - 50$ mA in 0.1 mA steps</td>
</tr>
<tr>
<td>Gain/Absorption Section</td>
<td>$I_{GAS} = 0 - 10$ mA in 0.1 mA steps</td>
</tr>
<tr>
<td></td>
<td>$V_{GAS} = 0 - 2$ V in 0.1 V steps</td>
</tr>
<tr>
<td>Phase Section</td>
<td>$I_{PHA} = 0 - 7$ mA in 1 mA steps</td>
</tr>
</tbody>
</table>

### Detection System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscilloscope real-time bandwidth</td>
<td>12 GHz</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>40 GSa/s = 25 ps/point</td>
</tr>
<tr>
<td>Length of time series</td>
<td>$2 \mu$s = 80,000 points</td>
</tr>
<tr>
<td>Number of time series</td>
<td>42,822</td>
</tr>
</tbody>
</table>

Raw data = 217.1 GB

Nonlinear laser data available publicly on the database

Optically injected solid-state lasers
- Experiment
- Simulation

A good dataset to test the connection between published model and experimental observations.
ML research on model parameter optimisation

Results – Dynamics Maps

Varying parameters:
- frequency detuning between master and slave
- Injection strength

Raw data = 11.1 GB

OISSL 1.0 – Numerical Simulation Model

\[
\frac{da}{dt} = \left[ \frac{1}{2} (1 - i\alpha) \frac{\gamma_c \gamma_n}{\gamma_s \tilde{J}} (n - 1) - \frac{1}{2} \gamma_p (a^2 - 1) + i\Omega \right] \times a + \kappa + F_a,
\]

\[
\frac{dn}{dt} = \gamma_s (1 - n) + \gamma_s \tilde{J} (1 - a^2) + \gamma_n a^2 (1 - n)
\]

\[
\quad + \frac{\gamma_p \gamma_s \tilde{J}}{\gamma_c} a^2 (a^2 - 1) + F_n,
\]


OISSL 1.0 – Experiment & First Results

Optically injected Nd:YVO₄ solid state laser system

- Two Nd:YVO₄ solid state lasers. Light from “master” laser injected into the “slave” laser.

- Observed the slave laser dynamics while varying 2 controllable systems parameters:
  - frequency detuning
  - injection strength

- Prior work used peak amplitude to map different dynamical regions (left) and experimentally determined bifurcation lines from time series (middle) to compare with the theoretical bifurcation diagram (right).

- A map of peak intensity provides limited insight into the nature of the dynamics.
- Bifurcation lines identify where the dynamics change but does not provide any information about the complexity of the dynamics.

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Correlation Dimension

Varying parameters:
• frequency detuning between master and slave
• Injection strength

Optically injected solid-state lasers
• Experiment
• Simulation

Results – Dynamics Maps

Raw data = 1.8 GB


OISSL 4.0 and 5.0

Dynamics as dependent on initial conditions
Parameter Estimation

Unpublished results removed
Researchers are encouraged to access and use the data in any way they would like directly from the public database. 

http://laser.portal.knowledgediscovery.org/

We are inviting research questions that can be answered from the datasets in this database to be included as collaborations, that can be included in our future funding applications.

We are particularly interested to collaborate on further development of models for multi-section lasers with optical feedback for comparison with experimental results.

Those interested should contact deb.kane@mq.edu.au

Also please take a look at the Clusterous toolkit for cluster computing via an AWS account. https://github.com/sirca/clusterous
Thank you