Software developments in Gemini

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Introduction

The Gemini laser system software consists of a network of distributed applications, used to control sections of the laser and monitor a large number of parameters, both on-shot and continuously. The main Control System, plus an increasing number of diagnostic and control sub-systems, communicate and are controllable via the EPICS (Experimental Physics and Industrial Control System) [1] protocol, originally developed at Los Alamos National Laboratory.

Over the last year there have been two significant updates to the Gemini diagnostics: a new Grenouille analysis application, and a new data acquisition (DAQ) application for the Rogowski coils monitoring the two Quantel lasers. These are described below.

The Grenouille analysis application

Pulse length (PL) is a key diagnostic when using a Grenouille device [2] (aka "frog") to characterise the beam, together with a set of phase, spectrum, temporal and auto-correlation traces. The old software consisted of a suite of applications that were awkward to use and lacked operational awareness. For example, the device's cameras were kept in an armed state, which would eventually time out, thus rendering the camera inoperative until someone happened to notice and reset it.

The new application is implemented in .NET and uses an analysis engine based on an algorithm by Sidorenko *et al* (described below), plus the OxyPlot graphics package. Tabs are available to enable the operator to view the spatial image and the temporal image, and to check or adjust the calibration and configuration parameters.

By listening to the appropriate EPICS PVs (Process Variables), the application is able to determine the current operational state. The cameras are only armed if the operators are in control, the laser is in High or Full Power, and there is light in the area (cameras disarmed if not), thus avoiding the problem of them timing out.

Other PVs provide the current shot number and BANG keyword to indicate that a shot has occurred. On a shot, the application saves the temporal (master) and spatial images; it then takes a line-out to determine whether the image is of sufficient brightness to indicate light into the device and performs the analysis if so. Each analysis run takes a few seconds, slightly longer if beam quality is non-optimal, and the resulting traces are saved. The images, traces and various other parameters are then submitted to the diagnostic data cataloguing tool, eCAT (described in previous reports).

During the beamline alignment phase, operators use the application to image the beam and check pointing. They can also use the "Calculate PL now" button to initiate an on-demand analysis and assess the quality of the beam before actually firing any shots. Diagnostic data from these analyses is also saved, but according to timestamp rather than shot number, and is not submitted to eCAT.

There are five Grenouille devices in Gemini, each containing two cameras. The manufacturer's calibration factors for these ten cameras are kept in a central Oracle database. When the

application is first run it connects to the cameras, requests their serial numbers, then retrieves the relevant calibration factors from the database server.
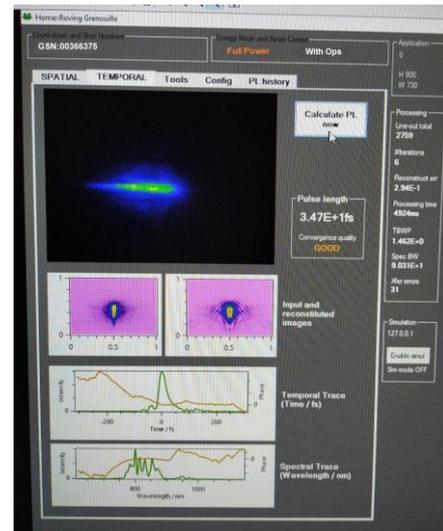

Figure 1. Grenouille application "Temporal" window showing a false-colour image of the beam, reconstructed images, analysis traces and best-convergence pulse length. The operator is poised to initiate an on-demand analysis.
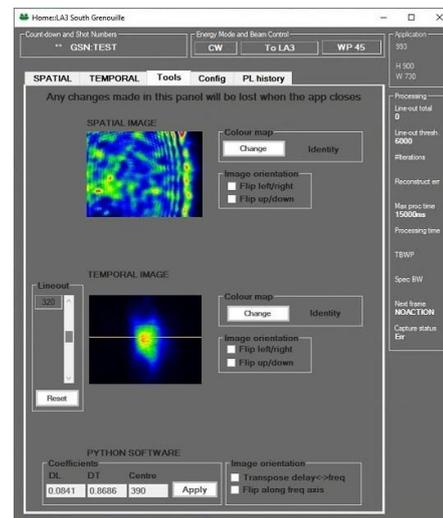

Figure 2. Grenouille application "Tools" window showing spatial and temporal images under the default colour map, line-out position and device calibration factors. There are also options to flip each image horizontally and/or vertically, and to switch to a different false colour map.

The application can be configured for use in laser or target areas, which have slightly differing modes of operation; it can also be configured to operate independently from the main control and diagnostic systems, and hence provide a roving Grenouille function. It is far more robust than the previous version, easier to use, and has greatly assisted the process of characterising the Gemini beam.

The FROG reconstruction algorithm

The FROG reconstruction algorithm is a Python implementation of the algorithm described in Sidorenko *et al.*[3] This is based on similar reconstruction techniques for ptychography, and unlike the traditional methods, it can work with incomplete traces. In fact, Sidorenko *et al* showed that it can give good results even when most of the original trace is missing.

To deal with imperfect real-world traces more robustly, it is necessary to first apply a median filter to remove noise and "roll" the trace to centre it along the delay axis. This step is crucial. The reconstructed trace is mathematically required to be perfectly symmetrical along the delay axis, so if the input trace is not close enough to being symmetrical, the reconstructed trace will never match it. What has been observed in this case is a reconstructed trace that fits in the region where the input trace and its mirror image overlap. This is narrower than the real input trace, and so will give a pulse that is shorter than the real one. A measurement of how far the trace is off-centre can be obtained by finding the centre of mass of the squared image.

The image can be centred. Omitting the squaring step does not work sufficiently well because of the significant background.
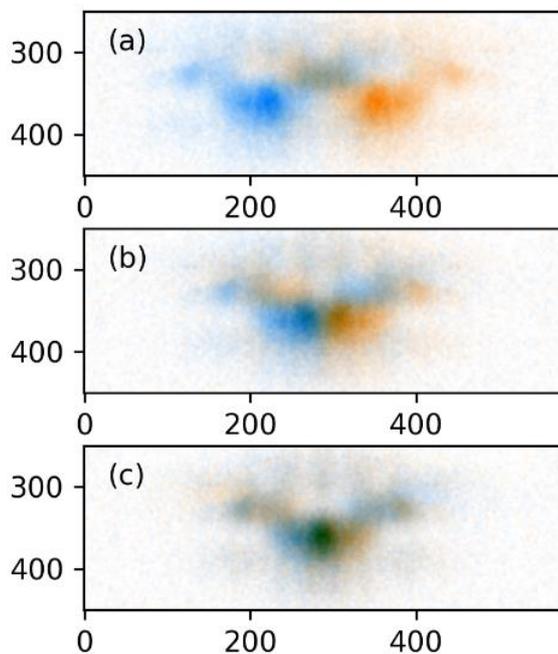

Figure 3. Symmetry plots of a FROG trace, with the original in blue and its mirror image in orange. The horizontal axis is delay (but all numbers shown are pixels). (a) Original trace recorded by camera; (b) trace centred using image centre-of-mass; (c) trace centred using centre-of-mass of squared image. Image (c) is almost perfectly centred, but the others are both noticeably left of centre.

Like most FROG reconstruction methods, this one is non-deterministic. The same reconstruction is run several times, each starting from a different initial condition; the final result selected is the one with the least difference between the input and reconstructed images.

The DTACQ2106 Rogowski application

When Gemini was built in 2008, the health of the 108 lamps in the two Quantel lasers was monitored using Rogowski coils and two 64-channel ACQ196 DAQ devices from D-TACQ Solutions Ltd.[4] Although the hardware itself was very robust, the devices were managed using software which has become obsolete and unmaintainable over the years.

At the start of this year, the two old devices were upgraded to one 128-channel ACQ2106 device. The application managing the device and performing DAQ was also rewritten. This has greatly simplified and streamlined the diagnostic process, which is concerned not so much with characterising what is working correctly, but rather with diagnosing when something has failed. In this case, a failed lamp can lead to loss of energy in the beam, which in turn compromises any experiment running at the time.

This application is implemented in .NET and uses EPICS PVs to determine the state of the system, the shot number, whether to save North and/or South beam data, and the laser mode to determine whether to arm or disarm the device. The device itself is EPICS-enabled, so makes available several hundred PVs concerning its internal state, settings and data. On a shot, the device generates 2.5 Mb of trace data, therefore it is run over a network separate from the main Gemini network.
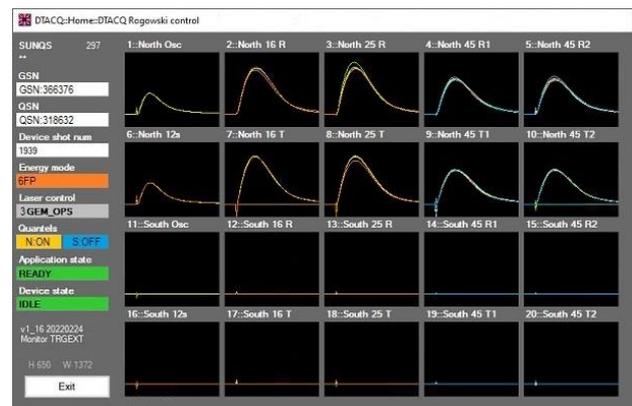

Figure 4. Typical Rogowski curves. Only the North Quantel is on, and it can be seen that a couple of the 16T and 45T2 lamps are failing.

The ACQ2106 device is located in the R7 Services Area, which also houses 48 capacitor banks. The levels of EMP generated by the capacitor banks exceed those for which the device has been designed, and so occasionally knock it out, requiring a hard reboot. There is an on-going discussion with the manufacturer to investigate EMP damping solutions, some of which have now been incorporated into devices supplied to their other customers who operate in similar, electrically noisy environments.

References

[1] https://epics.anl.gov/index.php

[2] https://www.swampoptics.com/pulse-measurement.html

[3] Sidorenko *et al.*, Optica 3 pp1320-1330 (2016) https://doi.org/10.1364/OPTICA.3.001320

[4] https://d-tacq.com/index.shtml