Progress toward improving accelerator performance and automating operations with advanced analysis software*

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Abstract

The penetrating radiography provided by the Dual Axis Radiographic Hydrodynamic Test (DARHT) facility is a key capability in executing a core mission of the Los Alamos National Laboratory (LANL). A new suite of software is being developed in the Python programming language to support operations of the of two DARHT linear induction accelerators (LIAs). Historical data, built as hdf5 data structures for over a decade of operations, are being used to develop automated failure and anomaly detection software and train machine learning models to assist in beam tuning. Adaptive machine learning (AML) techniques that incorporate physics-based models are being designed to use non-invasive diagnostic measurements to address the challenge of time variation in accelerator performance and target density evolution. AML methods are also being developed for experiments that use invasive diagnostics to understand the accelerator behavior at key locations, the results of which will be fed back into the accelerator models. The status and future outlook for these developments will be reported, including how Jupyter notebooks are being used to rapidly deploy these advances as highly-interactive web applications.

Analysis Tools

Data Structures

A new systematic data representation of calibrated DARHT accelerator diagnostics data has been developed using Open-source Python libraries:

- Shot Based Data: Scalar data, Vector data (waveforms and spectra), 2D arrays (camera images)
- Calibration Data: Waveform attenuation, Integrator time constants, Time offsets, Scale factors
- Processing Information: Waveform filter time scale, Waveform processing time windows, Configuration information for automated warnings and alerts

Interactive Applications

- Highly-interactive applications for DARHT data analysis can be launched locally or hosted on a server and used by multiple users through web browsers.
- Apps are built using a set of high-level Python packages, in a way that allows for rapid deployment of new analysis tools.
- Apps are launched from Jupyter notebooks either locally or from a server, providing a platform for rapid development.

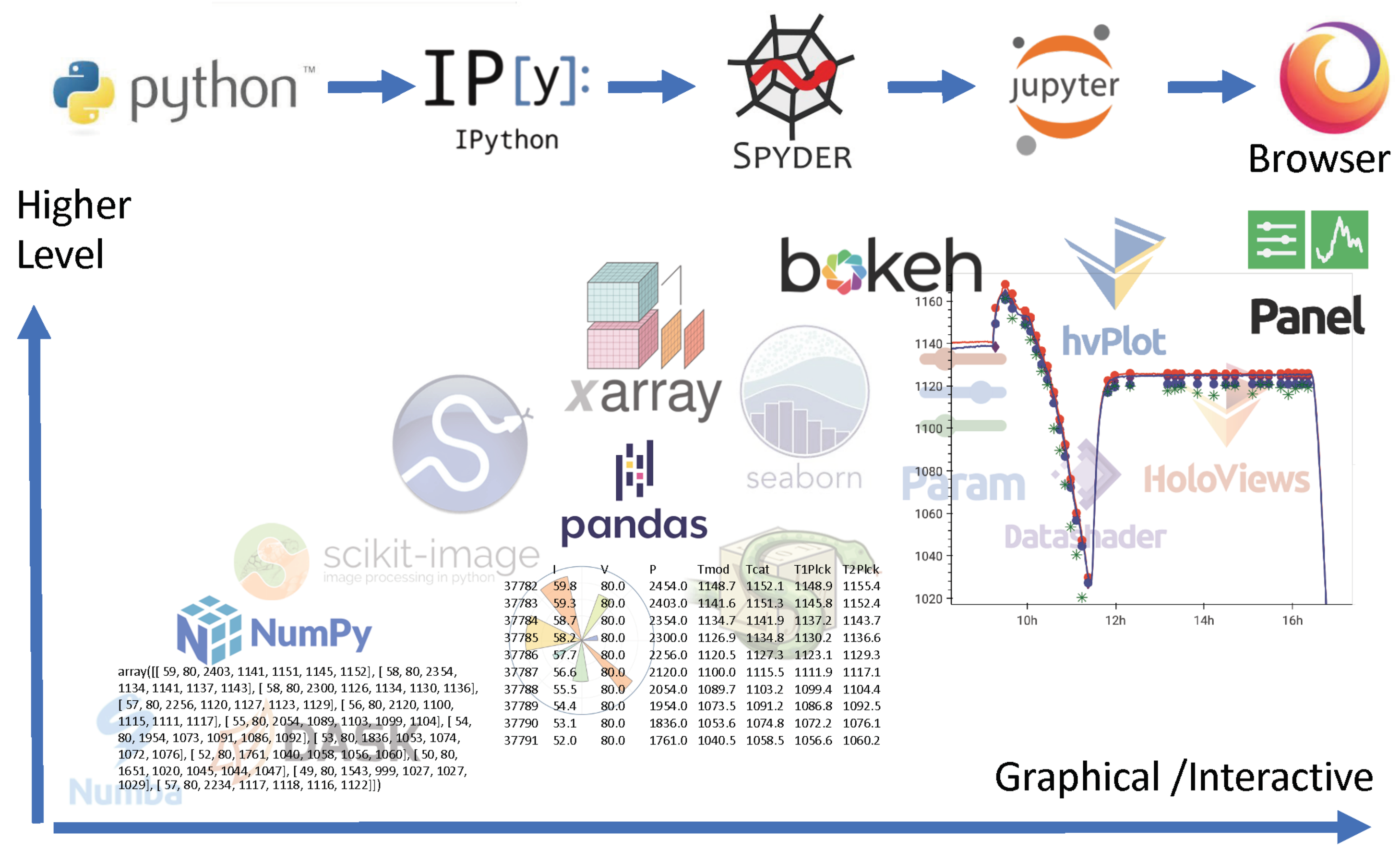

Figure 1: The graphic illustrates how increasingly higher-level packages are used to build interactive plots from named data arrays and high-level parameter objects. The apps are served directly from Jupyter notebooks either locally or from a server, providing a convenient programming plat-form for rapid development.

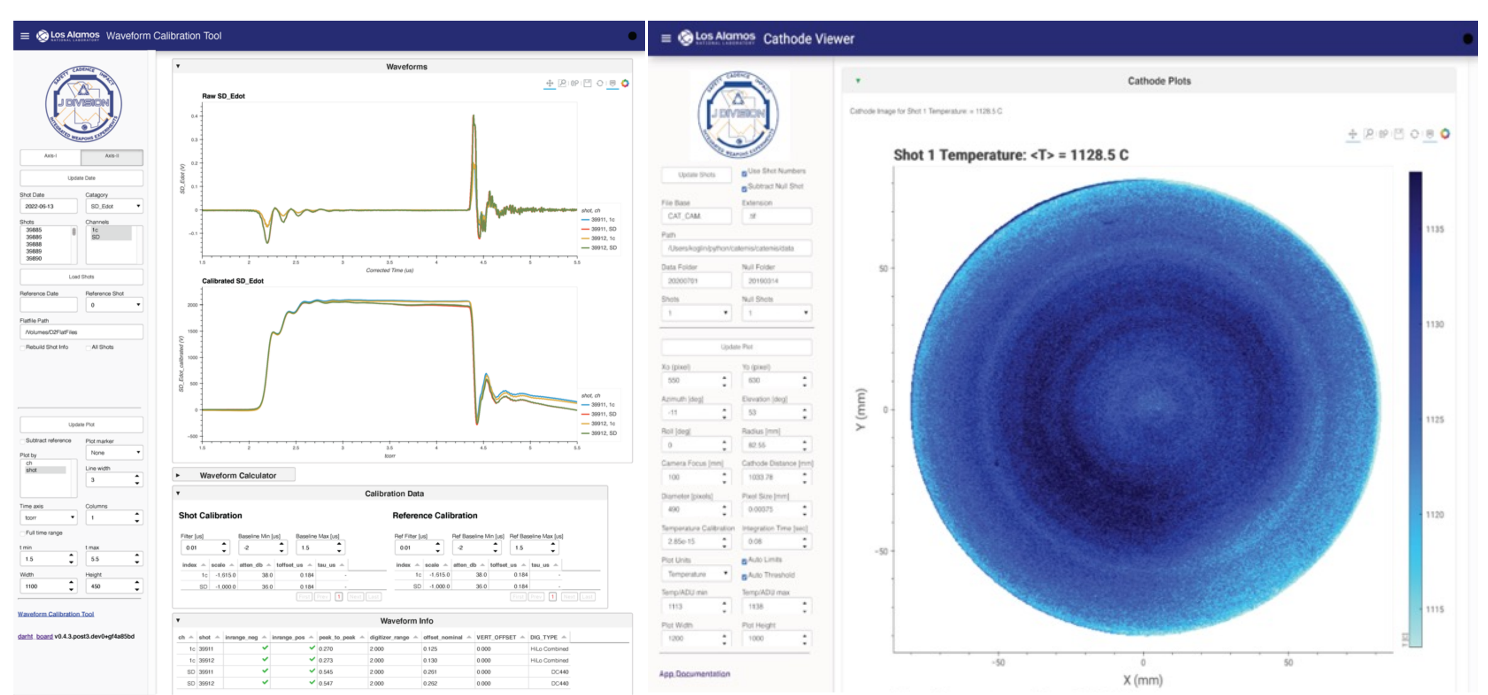

Figure 2: Examples of interactive app for waveform calibration (left) and for Axis-II Cathode temperature monitoring [https://github.com/lanl/catemis] (right)

Adaptive Signal Processing

- Waveform processing challenges include variability due to noise from pulse power systems and environmental factors as well as statistical and systematic affects.
- Diagnostic systems show signs of aging that are time consuming and often difficult to account for through component repair and/or recalibration.
- New techniques will provide:
  - Advanced baseline subtraction and numerical integration of differential signal measurements
  - Signal transmission corrections for cables, passive integrators and filters with frequency domain processing

Machine Learning

- The spot size of each of the four DARHT Axis-II pulses are characterized by a scalar metric denoted MTF.
- A neural network model allows for information from previous pulses to contribute to subsequent pulses
- Preliminary results with limited set of four pulse data: three measurements used for model verification and the rest for training data.
- The ML model used contains no actual physical model of the accelerator system and allows only enough freedom to provide a good, but not perfect, prediction
- The ML model performs nearly as well on the unseen validation data set.
- Larger datasets are being generated to further develop this predictive capability for both Axis-I and Axis-II

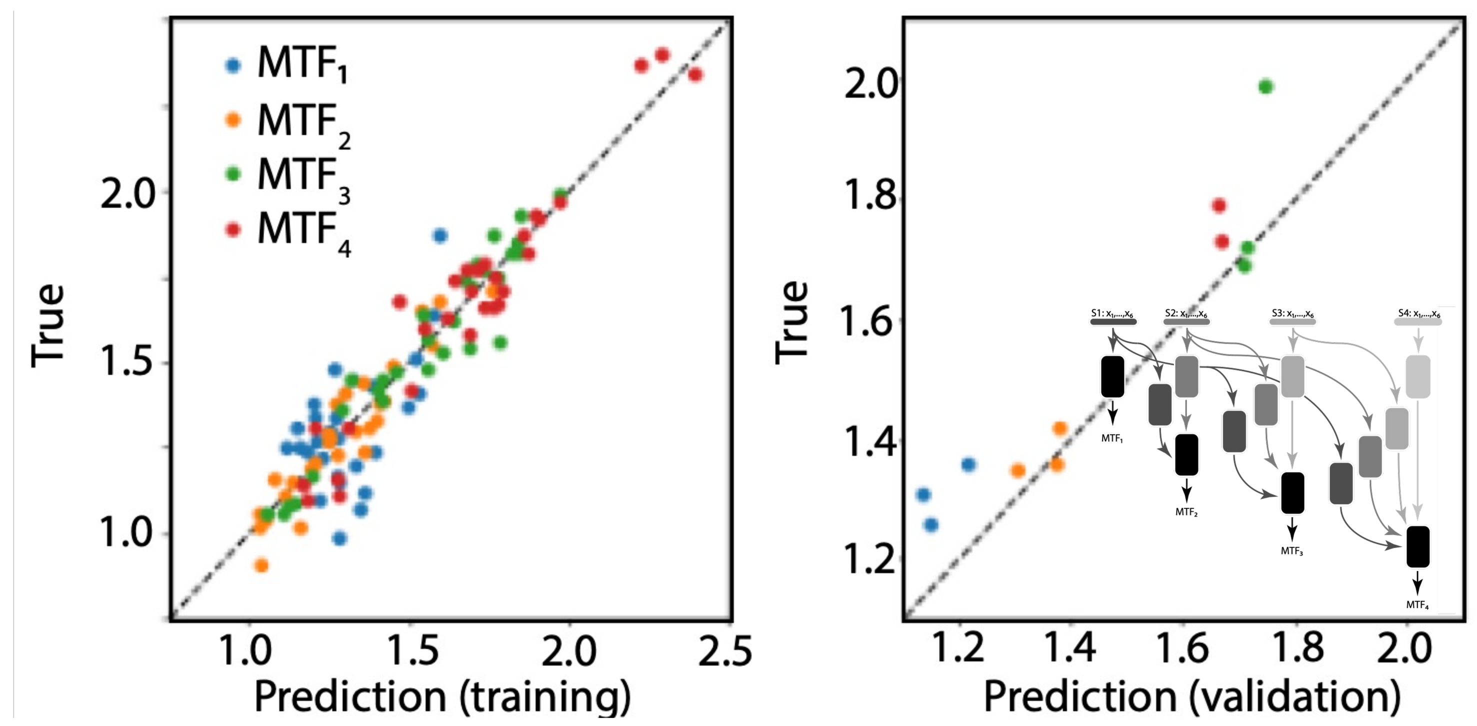

Figure 3: Spot size predictions for training (left) and validation data (right) for four pulses at DARHT based on magnet settings. Inset illustrates ML network model

Future Development

- Adaptive Machine Learning (AML) techniques are being developed to capture more complex signal propagation using large historical datasets in addition to accelerator simulations.
- Uncertainty quantification (UQ) techniques are being used to more robustly assign uncertainties to measurements.
- Automatically anomaly detection is being develop to highlight accelerator operation issues and guide troubleshooting.

→ Continued improvement to the accelerator performance and operations efficiency.

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