A COMMON SOFTWARE FRAMEWORK FOR FEL DATA ACQUISITION AND EXPERIMENT MANAGEMENT AT FERMI*

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Abstract

After installation and commissioning, the Free Electron Laser facility FERMI is now open to users. As of December 2012, three experimental stations dedicated to different scientific areas, are available for user research proposals: Low Density Matter (LDM), Elastic & Inelastic Scattering (EIS), and Diffraction & Projection Imaging (DiProI). A flexible and highly configurable common framework has been developed and successfully deployed for experiment management and shot-by-shot data acquisition. This paper describes the software architecture behind all the experiments performed so far; the combination of the EXECUTER script engine with a specialized data acquisition device (FERMIDAQ) based on TANGO. Finally, experimental applications, performance results and future developments are presented and discussed.

INTRODUCTION

FERMI is a seeded free electron laser (FEL) operating in the extreme ultraviolet and soft x-ray region [1]. It is open to external user experiments since December 2012. The machine produces intense, short pulses of light (of the order 100 fs), with photon wavelengths from 100 nm, and pulse energies up to 300 μJ. The pulse repetition rate is 10 Hz, scheduled to be increased to 50 Hz in 2014. Light pulses are provided to three end-stations: Diffraction and Projection Imaging (DiProI), Elastic and Inelastic Scattering (EIS), Low Density Matter (LDM).

Besides the intensity and duration of the light pulses, the scientific experiments can also take advantage of unique FEL features like wavelength tuning and light polarization (linear horizontal, vertical and circular). A new generation light source like FERMI opens new horizons to the scientific community resulting to user proposals that are extremely diverse. The facility is under continuous upgrade thus the number and type of scientific instruments is constantly growing. In the past three years substantial effort has been dedicated to the design and development of a robust and adaptable software framework capable of carrying out all the scientific experiments on the existing FEL end-stations.

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SYSTEM OVERVIEW AND DESIGN

The design of the FEL data acquisition and experiment management system is based on the following fundamental requirements:

- scientific data must be acquired and tagged with the corresponding FEL pulse identification number (bunchnumber);
- number and type of data sources continuously change, the acquisition framework should be easily configurable;
- to fully meet the users experimental requirements the framework should allow for easy adaptation and implementation of new experimental procedures and sequences.

Using a top-down approach, the development has been broken up in three logical levels (Fig.1), each of them designed in order to satisfy one of the above mentioned essential requirements:

- at INSTRUMENTATION level there are multiple shot-by-shot data acquisition devices, capable of buffering and exporting data tagged with the bunchnumber;
- at DATA STORAGE level there is a single centralized, configurable software device, named FERMIDAQ, that organizes and stores data coming from multiple sources;
- at EXPERIMENT level there is a highly dynamic and flexible script engine, named EXECUTER, capable of implementing different experimental sequences in the form of Python scripts.

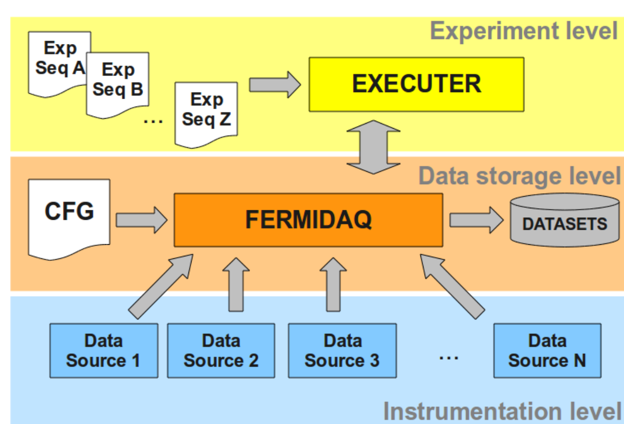

Figure 1: Block diagram of the FERMI experiment management system.

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As in the rest of the facility [2], the software development has been based on the TANGO framework [3]. A goal is that reusability and simplicity should characterize most of the system and its components. A simple linear system architecture should be easier to understand while reusable applications can reduce redundant development.

Data Source Devices

Depending on each end-station, the number of data sources acquired during an experiment may vary from 61 to 71. This number includes scientific data coming from end-station instrumentation and diagnostic data coming from the machine control system. Data type ranges from single floating values, like amplified photocurrents, to 5.5MP images coming from scientific cameras.

For each FEL instrument, a C++ Tango device has been developed following few common guidelines:

- shot-by-shot acquired data must be tagged with the corresponding bunchnumber and memorized in a local buffer;
- a Tango command must exist for retrieving data relative to a range of bunchnumbers. Hereinafter this command will be conventionally indicated as GetData(BN1,BN2), meaning that data relative to bunchnumbers in the range from BN1 to BN2 are requested;
- for each shot-by-shot datum, a Tango attribute containing the last acquired value must exist.

The bunchnumber value is shared over different acquisition machines using a software infrastructure called Network Reflective Memory (NRM) [4]. It consists of a real-time Linux device driver and a dedicated API, available in both kernel space and user space, which implement the data-transparent memory sharing among computers.

FERMIDAQ Data Storage Device

The FERMIDAQ application is the core of the data storage phase in the FEL experiment. It is a Python Tango device that continuously collects and saves shot-by-shot data and metadata coming from different Tango sources (Fig.2).

In practice, FERMIDAQ instantiates multiple acquisition threads, one for each data source. All of them independently collect scientific data using the Tango command GetData(BN1,BN2) described above. Data sources information are defined in an XML configuration file that is read at startup. Furthermore it is possible to define metadata sources, namely Tango Attributes that are stored as single values in the dataset.

Shot-by-shot experimental data and metadata are organized and saved in a binary scientific data format, HDF5 (Hierarchical Data Format) [5]. Usually an experiment dataset is composed by multiple HDF5 archives containing data relative to contiguous FEL shots. Also for the storage operation the FERMIDAQ device instantiates multiple threads, one for each HDF file.

During a data collection it is possible to enable or disable the acquisition of each data source, define the total number of shots to acquire and the size of the HDF files. Besides this, it is possible to define a "trigger action" that will be performed after each file completion and may start a post-processing pipeline. The data storage system is based on the Gluster 3.3 filesystem [6] with 250 TB homogeneously distributed over five Linux machines with a 10 GbE connection. Benchmark tests measured an achievable continuous writing speed of 800 MB/s.

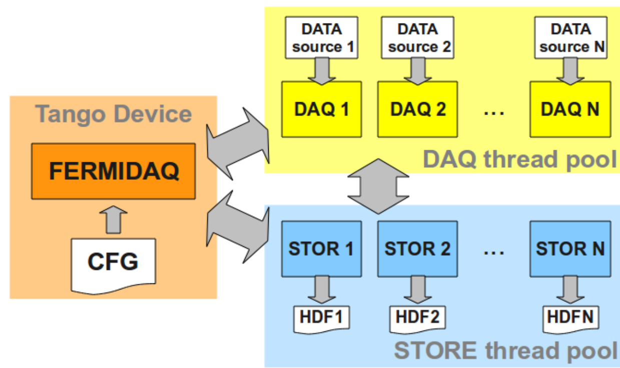

Figure 2: Structure of the multi thread FERMIDAQ Tango device.

EXECUTER Experiment Manager Device

The EXECUTER application is a highly flexible Tango device, developed in Python, capable of executing generic external scripts (Fig.3). All the scripts are written as Python functions in an external file. These scripts can call external programs and functions written in other languages too.

Additional dynamic Tango attributes can be added to the EXECUTER device structure by using an XML configuration file. This feature allows to define optional input variables for the scripts, as well as result viewers.

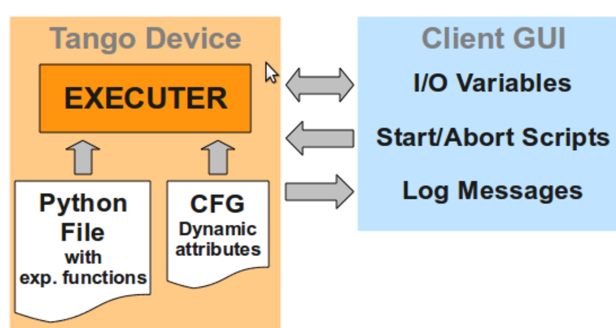

Figure 3: The EXECUTER Tango device can execute generic Python scripts, input and output variables can be defined in a XML configuration file.

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All the experiments performed at FERMI end-stations have been implemented through the EXECUTER application. Main advantages of such approach are the simplicity and the flexibility that allowed for reduced lines of code and significant speedup of any new developments.

The Graphical Interface

Like the rest of the FERMIDAQ components, the graphical interface has been developed as a configurable application so that it can be used in multiple different contexts (Fig.4). It has been developed utilizing the C++ QTango framework [7] based on the Qt toolkit for Linux.

An XML configuration file is used to define the content and the appearance of the frontend panel. Visually, the application is composed of three main sections resembling the architecture of the acquisition system:

- experiment section: consists of a tabbed panel, each tab relative to a different EXECUTER script, containing the relative I/O variables and buttons;
- data source section: a dynamic list of the FERMIDAQ data sources; it is possible to check their status and enable/disable them;
- common section: a utility common zone that can hold optional buttons or data viewers.

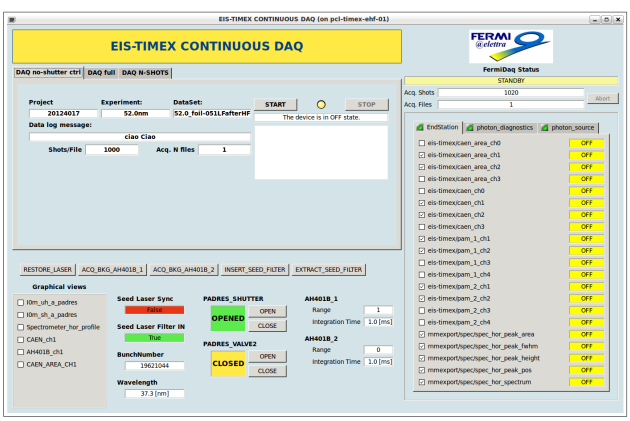

Figure 4: The configurable graphical interface used at the FERMI end-stations.

FERMI EXPERIMENTS

Some experimental techniques implemented so far will be briefly presented below.

DiProI End-station

Thanks to the high degree of transverse coherence, and the focused beam at the sample plane, single shot Coherent Diffraction Imaging experiments can be routinely performed [8]. Diffraction patterns are measured by a Princeton CCD of 2048x2048 pixels and 16 bit depth. One of the first proof-of-principle test experiments has been performed using nano-lithographic objects fabricated by depositing a 100 nm thick platinum film on Si_3N_4 windows (Fig.5).

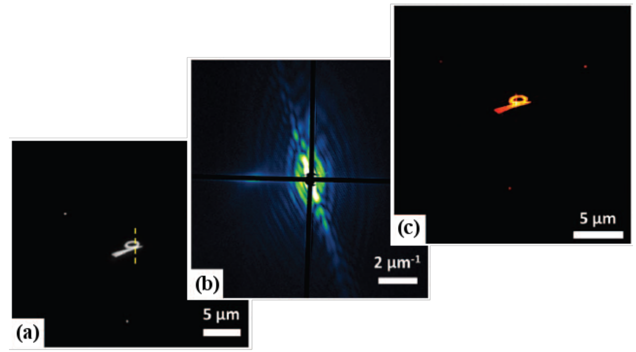

Figure 5: A DiProI CDI experiment. (a) SEM image of the sample. (b) Single shot diffraction pattern with 32.5 nm FEL pulse. (c) Phase retrieval reconstruction. [8]

EIS-TIMEX End-station

The EIS-TIMEX end-station has been designed to exploit the high intensity, energy domain and time structure of the FEL to probe fundamental properties of dense matter under extreme thermodynamic conditions [9]. Latest experiments were carried out in the field of time-resolved EUV absorption spectroscopy. Ge and Si foils (80 nm), mounted on a 5-axis manipulator, have been analyzed at different FEL wavelengths, varying the time delay between the probe (FEL) and the pump (User Laser) sources (Fig.6).

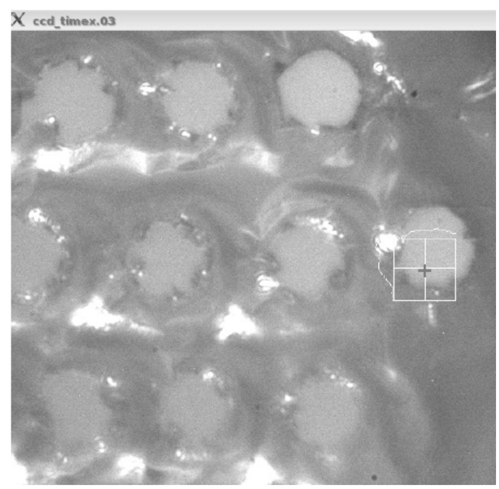

Figure 6: Sample scan at the EIS-TIMEX end-station: holes (50-100 micron diameter) produced by the pump–probe sequences in a Ge foil.

LDM End-station

The LDM end-station is a versatile instrument for the study of atoms, molecules and clusters by means of electron and ion spectroscopies [10]. Experiments carried out at LDM end-station strongly take advantage of FEL wavelength tuning and its variable polarization. One of the detection system is a Velocity Map Imaging (VMI) spectrometer (Fig.7), based on a sCMOS Andor R Neo camera, 2560x2160 pixels, 16 bit depth. Experiments at LDM may require hours of continuous data acquisition, and this end-station has by far the highest data throughput (~1TB/day).

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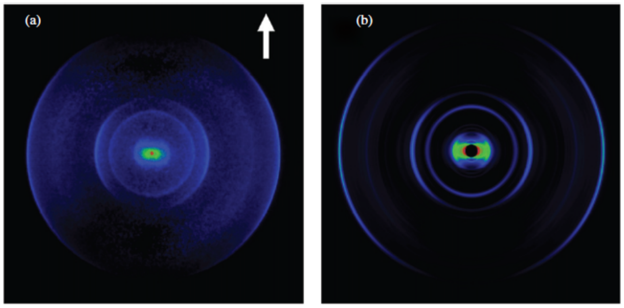

Figure 7: Example of a LDM VMI image. Photon energy 23.95 eV, circular polarization. Sample: He. (a) Raw data. The arrow indicates the direction of propagation of the light. (b) reconstructed image. [10]

FUTURE DEVELOPMENTS

The next big challenge is that of the planned upgrade of the repetition rate of the facility from 10 Hz to 50 Hz scheduled for 2014. The increment of data throughput will stress the current system that is expected to be altered to accommodate the future requirements. It is planned to minimize the communication overhead, by transforming the data acquisition devices to active UDP sources. On the other end the FERMIDAQ device will act as a UDP data receiver. Early developments and preliminary tests have yield encouraging results.

Finally, the described framework is going to be deployed on three new end-stations that are under construction: TIMER, MAGNEDYN and TERAFERMI.

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