ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA208

EVOLVING A LABVIEW END-STATION SOFTWARE TO A TANGO-BASED SOLUTION AT THE TWINMIC ELETTRA BEAMLINE

R. Borghes*, G. Kourousias, V. Chenda, A. Gianoncelli
Elettra Sincrotrone Trieste, ITALY

Abstract

Developing and deploying software systems for data acquisition and experiment control in a beamline laboratory can be a very challenging task. In certain cases there is the need to replace and modernize an existing system in order to accommodate substantial beamline upgrades. DonkiOrchestra is a TANGO-based framework for data acquisition and experiment control developed at Elettra Sincrotrone Trieste. The framework is based on an advanced software trigger-driven paradigm developed in-house. DonkiOrchestra is meant to be general and flexible enough to be adapted to the development needs of different laboratories and their data acquisition requirements. This presentation outlines the upgrade of the LabVIEW-based TwinMic beamline control system which hosts a unique soft X-ray transmission and emission microscope. Other than the technical demanding tasks of interfacing and controlling old and new instrumentation with DonkiOrchestra, this presentation discusses the various challenges of upgrading the software in a working synchrotron beamline.

INTRODUCTION

The 2.4/2.0 GeV Italian third-generation synchrotron Elettra operates for users since 1994, 24 hours/day, seven days a week delivering more than 5000 hours/year of synchrotron light from IR to soft x-rays to 28 experimental stations. A substantial facility upgrade, named Elettra 2.0, is currently planned [1]. Every year scientists and engineers from more than 50 different countries compete by submitting proposals to access and perform scientific experiments on these stations. Synchrotron beamlines consist of a complex network of devices, such as sensors, detectors, motors, but also computational resources. The setup is not static and the data acquisition systems are constantly challenged by continues changes and upgrades, so a constant evolution of software technologies is necessary. Within the facility's organisation, the *Software for Experiments* team and the *Scientific Computing* team manage a set of core services spanning from beamline control and data acquisition systems to algorithms for data analysis. These are often deployed in Cloud computing system and advanced storage resources. Moreover a set of web based services for e-Science and Scientific Business management act as the backbone for a complete ICT service.

The present paper reports on the upgrade of the control and acquisition system of the TwinMic beamline, a soft X-ray transmission microscope working in the 400-2200 eV energy range that combines full-field imaging and scanning X-ray microscopy in a single instrument. The extreme versatility of the Twinmic beamline allows it to be utilised for a wide range of scientific experiments and applications; however the existing LabVIEW-based control system is not flexible enough to easily integrate new instrumentation or introduce custom experimental strategies. The age of the existing control system is another good reason for planning its upgrade: it is in use since 2007 when the beamline was opened to the users and is still deployed on an outdated Windows platform. Besides this, the lack of documentation and its monolithic architecture are two serious issues for the maintainability and the upgrades of the code. With the arrival of new instrumentation, like a new advanced sample stage, we took the chance of developing a new data acquisition and control system more flexible, more reliable and fully supported by the IT group. Next sections provide the reader with a technical overview of the upgraded control and acquisition system, that takes advantage of the flexibility and efficiency of DonkiOrchestra, an experiment oriented scheduler designed and developed for the Elettra and Fermi end-stations.

TWINMIC BEAMLINE

The TwinMic beamline at Elettra synchrotron light source hosts the European twin X-ray microscopy station [2], a unique instrument that integrates the advantages of the two typical X-ray microscopy configurations: the transmission X-ray microscopy (TXM) and the scanning transmission X-ray microscopy (STXM). The TwinMic beamline was built in 2006 and the microscope end-station was installed one year later. In the last 10 years the initial setup has been upgraded with the addition of a Low-energy X-ray fluorescence system (LEXRF), and with the availability of some coherent diffractive imaging modalities such as ptychography. The particular Twinmic experimental setup covers a wide range of applications in diverse research fields such as biology, biochemistry, medicine, pharmacology, environment, geochemistry, food, agriculture and materials science.

STXM Operation Mode

In STXM mode, a Zone Plate (ZP) focuses the incoming photon beam, and the specimen is raster-scanned across the microprobe as shown in Figure 1. An order-sorting aperture (OSA) is placed downstream of the

* roberto.borghes@elettra.eu

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA208

ZP to discriminate unwanted diffraction orders, while a central stop on the ZP absorbs most of the zeroth-order radiation. Since each scan typically includes a few tens of thousands of pixels, a fast read-out transmission detection system is essential. The TwinMic setup uses an Andor Ixon DV860-BV electron-multiplied fast-readout CCD (FRCCD) camera, 128x128 pixels with 24x24 μm^2 pixel size. Since the CCD chip provides excellent sensitivity and low-noise operation for visible light, a Phosphor Screen (PS) is installed in front of a group of high-numerical aperture lenses. The FRCCD detector system allows simultaneous acquisition of absorption and differential phase contrast imaging, and is potentially suited for ptychographic imaging.

When the sample is illuminated by the primary X-ray beam, characteristic X-ray fluorescence lines are emitted. The emitted fluorescent photons, detected by the Twinmic LEXRF system, provide information of all elemental constituents excited by the incident X-ray beam. The LEXRF system consists of eight silicon drift detectors (SDDs) mounted circularly around the specimen.

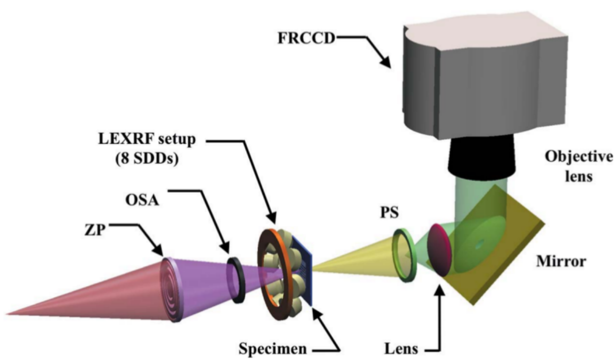

Figure 1: STXM mode as implemented on TwinMic.

TXM Operation Mode

In raster scan Transmission X-ray microscopy (TXM) mode, as shown in Fig.2, a condenser beamshaper (CBS) illuminates the specimen through an order-sorting aperture (OSA). Downstream an objective zone plate (OZP) magnifies the image of the specimen onto the detector: a directly illuminated slow-scan Princeton EEV 1300 x 1340 B CCD camera (LECCD) with pixel size 20x20 μm^2.

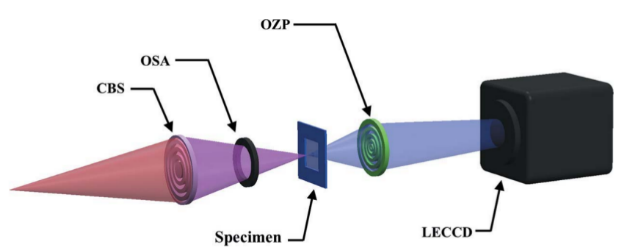

Figure 2: TXM mode as implemented on TwinMic.

CDI High-Resolution Imaging Mode

Thanks to the flexibility of its design, new imaging opportunities such as coherent diffractive imaging (CDI) can be performed at the TwinMic end-station. X-ray spectromicroscopy experiments using ptychography with a randomly phased illumination have been recently carried out [3]. With this technique, using a ZP monochromatised microprobe beam is possible to quantitatively reconstruct both amplitude and phase with a spatial resolution much higher than the probe size. Diffraction images are collected by the 1300x1340 pixel Princeton CCD and this high-resolution imaging modality is about to become standard operation mode available also to non-specialist users.

The LabView Twinmic Control System

The original control system solution for TwinMic has been developed using NI LabView on Windows machines. Stepper motors are controlled using National Instruments NI 7334 PCI cards. Digital and analogue signals are interfaced using National Instruments NI 6280 and NI 6030E PCI cards. The sample stage piezo controller is a RS232 PI E500. The LECCD Princeton camera is acquired using a Princeton Instruments ST-133 PCI card. The FRCCD Andor camera is acquired using an Andor Technologies PCI CCI-22 card. Finally the LEXRF X-ray fluorescence data is collected using two XGLab Multi Channel Analyzers XGL-MCSH-3400 connected via USB interface.

Four industrial PCs running Windows XP and Windows 2000 are dedicated to the control of the above instrumentation. They are physically located in various places of the beamline and can be accessed from the experimental hutch using remote desktop technologies (VNC) and hardware KVMs (Adder Technology). The experiment related activities, such as data acquisition, instrumentation control and data visualization are integrated in a single LabView program whose complexity is in continuous growth over the past 10 years. Unfortunately this software is lacking in documentation and any upgrade becomes really difficult. Another big issue comes from the outdated operating system that are not any more supported nor reliable. The latest instrumentation upgrades and the need for new experimental techniques pushed for an improved control system with high reliability, easy inclusion of new instruments and rapid hosting of custom experimental requirements.

THE CONTROL AND ACQUISITION SYSTEM UPGRADE

The project of the upgrade of the Twinmic control and acquisition system is an ongoing process started in 2015 with clear targets:

- choice of a new control system framework efficient, reliable and supported by the scientific community;
- the architecture should facilitate the easy integration of new instruments;
- the experiment control should be highly flexible and customizable;
- the collected data should be organized in a structured scientific data format.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA208

Developing and deploying such a system for a beamline laboratory is always a challenging task, but for Twinmic it was even harder because we had to avoid any beamline downtime. New developments had to be tested during the machine shutdown period or any other available in-house experimental shift. In the first part of the project we focused the attention on the upgrade of the instrumentation control, later we approached the development of the experiment control and the user interfaces.

Instrumentation Control

As a standard for ELETTRA and FERMI end-stations we adopted the TANGO framework[4], a robust and easy to use distributed control system. TANGO is operating system independent and supports Java, C++ and Python for all its components. There are major benefits in using TANGO: it is actively supported by an international scientific community and gives support for a wide range of scientific instrumentation. TANGO has been installed on Linux CentOS 6.4 on the existing Twinmic computers. These machines have been modified with a dual boot setup in order to preserve the current control software and avoid any downtime for the beamline activities. For some instruments, for example the National Instruments PCI boards, it was necessary the development of brand new C++ software drivers. In other cases, like the piezo controller PI E500, we could use the existing Tango code provided by the international community.

In order to coordinate the pool of beamline PCs, another Linux machine has been added to the control system. It is a CentOS 6.4 virtual machine, hosted in the ELETTRA server room, running the central TANGO Database System and other high level TANGO devices. At Twinmic, as other beamlines, we are currently planning to increase the use of virtualisation technologies and reduce the number of physical control PCs. For this reason we are gradually replacing the existing instrumentation with a network controllable one and we are introducing the use of serial-to-ethernet and gpib-to-ethernet converters.

The on-going development of the TwinMic graphical interfaces is based on the Taurus python framework [5]. Taurus widgets are implemented using the PyQt library, they extend related Qt widgets with the capability of transparently connecting to a TANGO device and display and/or change its data. Taurus framework allows the drag and drop creation of user interfaces using a customized version of Qt Designer.

Experiment Control and Data Acquisition

Due to historical reasons there is a variety of autonomous data acquisition systems installed on the end-stations of ELETTRA. Nevertheless the number of end-stations asking to be fully supported by the IT group has grown considerably in the recent years. The experience taught us that our team efficiency can be remarkably enhanced by using common software solutions highly configurable and scalable. A noticeable example is FermiDAQ, an in-house data acquisition framework adopted on all the FERMI end-stations [6]. With the same idea of a dynamic and reusable software we've focused our efforts on a new framework dedicated to experiment management and data acquisition, employable in a wider spectrum of scientific end-stations and facilities. The design of the new framework, called *DonkiOrchestra*, started with few fundamental goals:

- maximize scalability and customizability;
- allow for synchronized parallel operations;
- minimize data communication overheads.

In the DonkiOrchestra approach any experiment is organized as a sequence of independent phases individually started by a synchronization software trigger. The system acts as a *orchestra* in which a scheduler, called *DonkiDirector* organizes the execution of multiple *instruments*/tasks. Each task is performed independently and in parallel by a *DonkiPlayer*. In the DonkiOrchestra schema, each DonkiPlayer belongs to a priority group and has a specific task to execute. For each step of the sequence, a trigger event is simultaneously sent by the Director to the pool of Players with the highest priority, then to the next priority group and so on. Each Player executes a different action upon the arrival of a trigger event and sends back to the Director an acknowledge event. A data acquisition Player, after the execution of the readout task, tags the datum with the actual trigger number and sends it back to the Director that stores the incoming data in suitably structured archives. In Figure 3 is schematically shown the DonchiOrchestra architecture.

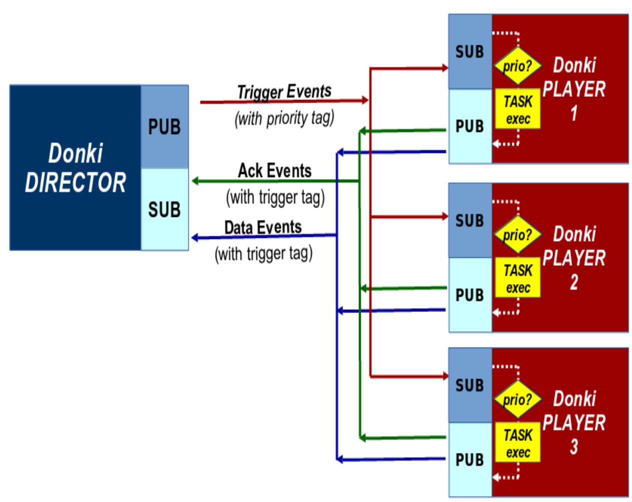

Figure 3: DonchiOrchestra schematic architecture.

The DonkiDirector, core of the DonkiOrchestra system, is an in-house Python software highly configurable, scalable and reliable. The architecture can be divided in three main sections: i) the Scheduler, ii) the Data Collector, and iii) the Information Server.

The Scheduler manages the initialization and the conduction of the train of trigger events. It uses the ZeroMQ [7] messaging system because of its asynchronous I/O model that perfectly fits the need of

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA208

having a scalable and distributed application. Each ZeroMQ trigger message sent by the Scheduler is composed by a progressive index number and a priority tag. For each phase of the experiment the Scheduler sends simultaneously a trigger to all the Players with the highest priority, waits for the acknowledge messages, then proceed with the next priority group. In addition to the main sequence all the Players receive two special trigger events: one before starting the main sequence and one after its ending. These two special events are used by the Players to perform any preparatory or closing procedure.

Concurrently to the experiment execution, the Data Collector receives and stores asynchronous data messages coming from the acquisition Players. Data is organized and stored in HDF5 [8] binary archives.

The Information Server completes the DonkiDirector structure. It takes care of collecting and sharing information between the Director and the Players. Thanks to the Information Server any change in the pool of Players is automatically detected by the system. Technically the Information Server has been implemented as a TCP server that accepts custom ASCII commands and uses a TinyDB [9] database for persistent storage.

The TANGO dependency of DonkiOrchestra in its first version [10] has been completely removed in the actual one, so it can be easily utilized in a wider range of applications. For example it has been already used for the distributed data streaming simulator for the European Spallation Source [11] within the BrightnESS European project [12].

One of the first applications developed with the new control system at TwinMic was a two dimensional raster scan with concurrent acquisition of CCD images and XRF spectrum. To be mentioned that even the developed PyQt interface (Figure 4) fully exploits the event-based infrastructure of DonkiOrchestra: it waits ZeroMQ messages directly from the running DonkiPlayers, correlates incoming data by mean of the trigger index and updates the 2D scan plot. Data collected during the scan are stored by DonkiOrchesrtra in HDF5 archives containing piezo stage positions, CCD images, XRF spectrums and some useful metadata. Using the trigger index information, data belonging to different sources may be easily correlated by a post-processing analysis software in order to produce scientific results.

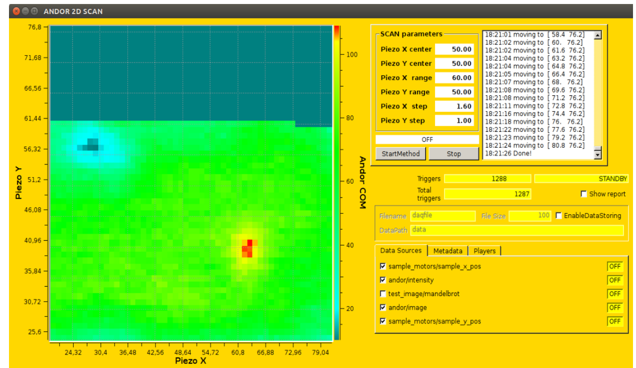

Figure 4: PyQt interface for the two dimensional scan implemented with DonkiOrchestra framework.

CONCLUSIONS

The present paper describes the upgrade of the TwinMic beamline control system from the original LabVIEW-based architecture to a more flexible and reliable solution based on the TANGO framework. The project has been carried out without affecting the beamline activities and reusing the existing instrumentation. All the control machines have been equipped with a dual boot Windows/Linux. This solution allowed us to proceed with our tests during the shutdown period without affecting the beamline availability for the users. By using a modern CentOS Linux distribution in place of unsupported Windows 2000 & XP operating systems, has increased the reliability of the infrastructure and facilitates any remote operation. Upgrading the current undocumented software to a new TANGO based version makes easier the future inclusion of new instruments and the hosting of custom experimental requirements. For the experiment management has been adopted the DonkiOrchestra framework, an in-house product fully configurable and scalable, designed to be reused on different end-stations and facilities. DonkiOrchestra exploits the powerful ZeroMQ messaging system to maximize the opportunity of performing parallel operations and sensor readouts. The strength of the new control system resides in its design choices: a dynamic and portable language like Python, a reliable distributed control system like TANGO and a fully configurable acquisition framework that permits a high degree of customization.

ACKNOWLEDGEMENT

The authors thank the IT Group and the TwinMic beamline staff of Elettra Sincrotrone Trieste. Moreover they acknowledge the importance of advanced technologies and open source software like that of the distributed control system TANGO and ZeroMQ messaging system.

REFERENCES

[1] Karantzoulis E, “Elettra 2.0 – The next machine”, Proceedings of IPAC2015, Richmond, VA, USA

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA208

[2] Gianoncelli A., Kourousias G., Merolle L., Altissimo M., Bianco A., "Current status of the TwinMic beamline at Elettra: a soft X-ray transmission and emission microscopy station", Journal of Synchrotron Radiation, Vol. 23, pp. 1526-1537 (2016), doi: 10.1107/S1600577516014405

[3] Kourousias G., Bozzini B., Gianoncelli A., Jones, M. W. M. Junker, M., van Riessen G., and Kiskinova, M., "Shedding light on electrodeposition dynamics tracked in situ via soft X-ray coherent diffraction imaging", Nano Research, Vol. 9-7, pp.2046-2056 (2016) doi: 10.1007/s12274-016-1095-9

[4] TANGO controls, http://www.tango-controls.org

[5] TAURUS framework, http://www.taurus-scada.org

[6] Borghes R., Chenda V., Curri A., Kourousias G., Lonza M., Prica M., and Pugliese R.. "A Common Software Framework for FEL Data Acquisition and Experiment Management at FERMI." Proceedings of ICALEPCS2013, San Francisco, CA, USA, 2013, 6–11

[7] ZeroMQ messaging system, http://zeromq.org/

[8] HDF5 data model, https://support.hdfgroup.org/HDF5/

[9] TinyDB database, http://tinydb.readthedocs.io

[10] Borghes R., Kourousias G., "DonkiOrchestra: a scalable system for data collection and experiment management based on ZeroMQ distributed messaging", NOBUGS 2016, Copenhagen

[11] BrightnESS European Project, https://brightness.esss.se/

[12] Reis C., Borghes R., Kourousias G., Pugliese R., "A Simulation System for the European Spallation Source (ESS) Distributed Data Streaming", THMPA03, this conference.