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UX FOCUSED DEVELOPMENT WORK DURING RECENT ORNL EPICS-BASED INSTRUMENT CONTROL SYSTEM UPGRADE PROJECTS*

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Abstract

The importance of usability and easy-to-use user interfaces (UI) have been recognized across many domains. However, the user-friendliness of scientific experiment control systems often lags behind industry standards in the flourishing user experience (UX) field. Scientific control systems can certainly benefit from these new UX research methods and approaches. Recent instrument control system upgrade projects at the SNS and HFIR facilities at Oak Ridge National Laboratory demonstrate the effectiveness of UX focused development work, and further reveal the need for more utilization of such techniques coming from the UX field. The ongoing control system upgrades are targeting the key facility-level priority of higher scientific productivity, and UX is one of the important tools to help us achieve this priority. We will highlight research methods and practices, introduce our findings and deliverables, and share challenges and lessons learned in applying UX methods to scientific control systems.

INTRODUCTION

Oak Ridge National Laboratory (ORNL) is home to two world-class neutron scattering user facilities: The Spallation Neutron Source (SNS) and The High Flux Isotope Reactor (HFIR). In recent years, a series of significant software/hardware upgrade projects has progressed to improve the reliability and usability of the scientific instrument beamlines at these facilities. At the core of these upgrade projects is the application of the Experimental and Industrial Control System (EPICS) [1], which has also been used for the SNS Accelerator controls systems since the beginning of the SNS project [2]. The mature EPICS toolkit has contributed greatly to the reliable and stable operation of the SNS Accelerator and has now been applied for the many individual instrument/beamline control systems. The beamlines had experienced a variety of operational challenges under the earlier legacy data acquisition system, with both reliability and user complexity issues. Based on a careful and systematic review of existing software packages and toolkits, the decision was made in 2012 to upgrade the majority of SNS beamline control systems software to use the EPICS toolkit and Control System Studio (CS-Studio) [3][4][5]. These control system overhauls have proceeded well and have greatly improved the reliability, maintainability, and data/science throughput of the beamlines [6].

The first instance of EPICS and CS-Studio being applied to the beamline control systems was for the Imaging beamline, to demonstrate more reliable, flexible, and efficient beamline operation [7]. During the past seven years, 22 beamlines at the SNS and HFIR have been upgraded to use EPICS and CS-Studio for their beamline control systems, including 17 SNS beamlines and 5 HFIR beamlines. These upgrade projects were quite successful and have subsequently freed up many resources within our group, enabling us to focus more on improving the overall user experience (UX) and ease-of-use of the user interfaces (UIs) of our beamline control systems. The past four years saw an increased number of specific UX/UI deliverables within our group, which were welcomed by our diverse scientific user community.

Our recent UX/UI deliverables have been designed and developed by applying the methods and practices of the UX [8] and Design Thinking [9] field. These deliverables empower new and external users to effectively and efficiently set up an experiment, plan and collect data, monitor experiment progress, and make informed decisions along the way. Meanwhile, the increased reliability of the control systems has simultaneously relieved the instrument staff from constant hands-on operational support. Some fundamentals of the UX/UI methodologies and practices are described in more detail in the following sections, followed by some specific examples of their use in the development of our scientific beamline control systems.

EFFECTIVE METHODS AND PRACTICES

UX and the Design Thinking process provide a new way of thinking, seeing, and doing development work based on previous research emphases, such as Human Computer Interaction (HCI), UI, User-Centered Design (UCD), and Usability. By adopting UX methods to look at the entire experience of a user interacting with our beamline control systems, we have identified opportunities for improvement, and explored solutions beyond simple user interfaces. Our goal is to decrease our users' physical effort (such as a mouse move/click and typing), mental effort (such as remembering and thinking), and emotional effort (such as perceived task difficulty), and to help them complete their tasks with a more delightful, enjoyable, and therefore productive experience.

Similarly, the Design Thinking process has proven to likewise be effective with its well-established steps, including empathize, define, ideate, prototype, and test [10]. In practice, we have discovered that the iterations of this process are more like a "spiral staircase" than that of a linear

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process; and the importance of the "empathize" step cannot be emphasized enough.

We have utilized a wide variety of UX methods, including field studies/user interviews, requirements & constraints, design reviews, task analyses, journey mapping, prototype feedback & testing, card sorting, usability bug reviews, and so forth [11]. Below are the top methods/practices that we found the most fruitful for our UX focused development work.

Field Studies/User Interviews

Going directly into the target users' work environment, observing them perform different tasks using the existing/legacy system, and asking them questions about their processes, is an obvious yet often overlooked way to gain first-hand experience during the initial phase of any new development work. Field studies/user interviews, with a beginner's mindset and an empathetic attitude, can help to see and experience first-hand the complex systems that users are facing. First, our neutron scattering beamlines often include a variety of different subsystems (such as sample environment devices, choppers, motion controls, detectors, and so forth) along with several associated support groups that work with the users. Second, the users have varying levels of background knowledge and skills regarding neutron scattering techniques, the beamlines they work on, and general computer programming experience. And third, there are many potential distractions of an operating facility with unfamiliar terminologies, operating systems, and data formats, etc. These first-hand experiences from field studies and user interviews have helped us to have a more holistic view of our users' needs and requirements. This then drives us to understand the possible reasons behind their various requests, and therefore motivates us as developers to identify and address their usability issues for improved user satisfaction. Our willingness to understand and empathize with the end user also helps us to gain trust and overcome any initial resistance, especially for any kind of unfamiliar change in the users' work environment.

Focus on Clarifying and Improving Experiment Processes

The mission of our user facilities is to support the neutron scattering users in delivering scientific discoveries and improved understanding of the structure and dynamics of materials. While our users come from a wide variety of scientific fields, on any given beamline their data acquisition needs will most likely fall into one of two distinctive types: routine needs with some established processes, or innovative needs which explore unique ways to use a beamline and incorporate new techniques. With successful outcomes and a sufficiently sized user community, some of the innovative needs may ultimately become routine needs later. By focusing on clarifying and improving processes, we empower users by making their routine tasks easy, and their innovative tasks possible during a user experiment. We also learned to examine the entire data life cycle, and to optimize globally before locally. As a result, we have provided a seamless experience to our users, by better integrating/interfacing between the data acquisition process and the subsequent data post-processing, or reduction and analysis.

Collaborating

Due to the innate complexity and diversity of the beamlines, it is impossible for any one person to master all the details and understand all the needs and requirements for our upgrade projects. Thus, we made the effort early on to gain the beamline scientists' and user's trust, to establish close partnerships with the scientists, scientific associates (SAs), and other supporting groups, and to engage all involved parties throughout the projects. Collaboration must therefore be capitalized upon both internally and externally. Internally, all of our UX/UI deliverables were built upon the previously established control system building blocks, and developers within our group worked together with beamline staff to meet the functional requirements of our users, ensuring that our system is easy to use and maintainable in the longer term. Externally speaking, one scientist's idea became a key part of the solution to help manage the complicated operating modes of one of our reflectometer instruments (one shown in Figure 1). Likewise, a postdoc's data reduction script prepared the path for a close collaboration on our CrystalAlign tool (shown in Figure 2), and an SA's passionate and tireless effort to test our new software both improved the software and encouraged the developer.

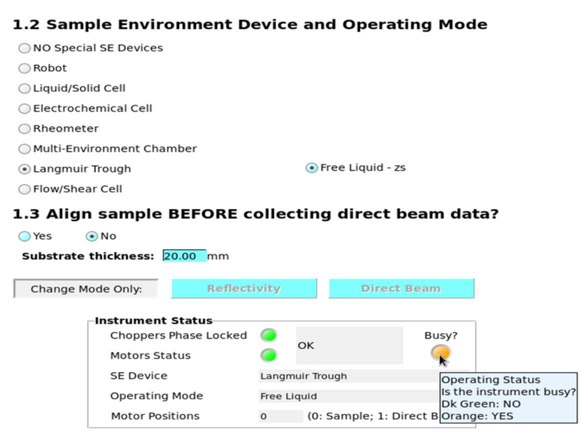

Figure 1: Example of an operating mode set up step of an experiment automation tool.

MAIN CATEGORIES OF UX/UI DELIVERABLES

Over the past four years, our UX focused development work has benefitted three out of the four main types of neutron scattering beamlines, including sample transmission on a small-angle neutron scattering (SANS) beamline, elastic neutron scattering beamlines (such as reflectometers, single-crystal and powder diffractometers, and a small-angle neutron scattering instrument), quasi-elastic/inelastic neutron scattering beamlines (such as time-of-flight spectrometers and a backscattering spectrometer), as

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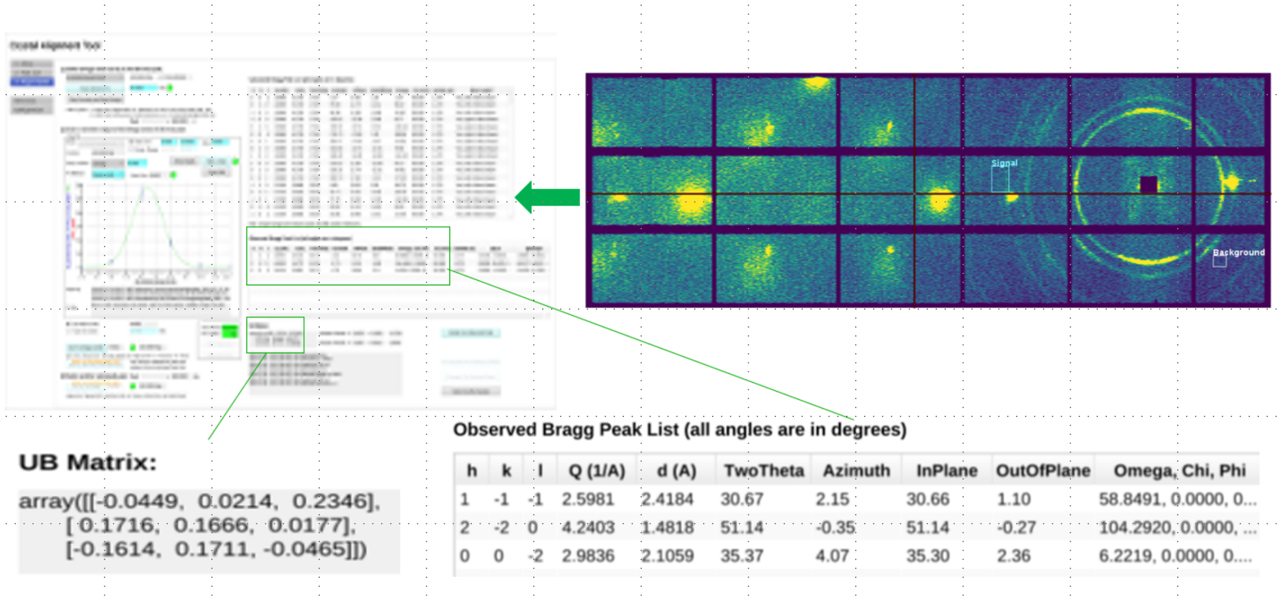

Figure 2: CrystalAlign tool's component highlights.

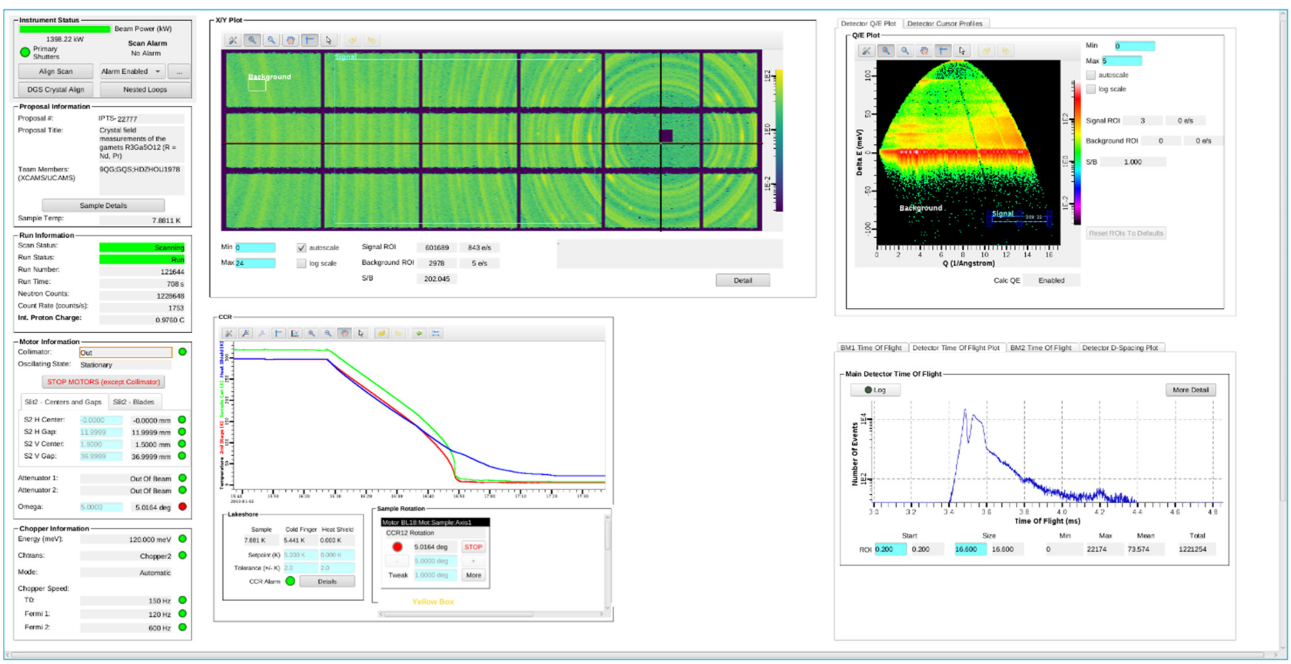

Figure 3: Example of a dashboard screen showing a 2D X/Y plot, 2D Q/E plot, and 1D Time Of Flight plot.

well as a neutron imaging beamline. Certain types of common needs were repeatedly requested, or their additional applicability discovered on subsequent beamlines, and the following three categories/themes became apparent as we reviewed our UX/UI deliverables.

Meaningful Live Displays

This category includes live 2D displays that closely represent the physical geometry of detectors, useful 1D and 2D conversions from raw data to scientific units which the users understand, and useful details within a task context (e.g. cursor information). Examples of such displays are shown in Figure 3. There were also user screens with rich meta-data/information to help users understand the current instrument configuration and status, while keeping them informed about the progress of their experiments. As Mantid [12] is the designated scientific data analysis/reduction software used primarily at our facility beamlines, we have endeavored to utilize Mantid's Instrument Definition Files (IDFs) and data processing algorithms to provide the users with familiar live 2D displays and consistent 1D and 2D conversions on the data acquisition side, for both fixed detector geometry beamlines and movable detector geometry beamlines. A specific dynamicMapping tool was developed for run-time movable detector geometry conversions. These useful displays and control screens not only help our users to make sense out of their live experiment

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data, for making informed decisions, but they also provide useful statistics that are then applied to efficiently steer the experiments.

Instrument Q Configuration Planning and Handling Tools

From our field studies and user interviews, we learned of another layer of complexity: instrument configuration for beamlines with movable detectors. For our reflectometers and SANS beamlines, users often come to study their samples within a variety of science domains. They speak the languages that are meaningful for their specific area of science, for instance, "momentum transfer" (that is, "Q"). From the data acquisition perspective, this terminology and semantic concept needs to be translated into sets of instrument configurations, mainly including wavelength and motor positions (detector distance, detector rotation, slits, etc.). It is likely that a single instrument configuration will not be able to fully cover an entire Q range that the users are interested in studying for a specific experiment. There are further complications, such as distinct instrument configurations for different types of data (such as scattering data, transmission data, direct beam), as well as ensuring a sufficient overlap of Q ranges for measurement configurations. Previously, scientists used many manual and complex Excel spreadsheets for Q range planning, or else collaborated to build limited calculation features directly into the legacy data acquisition system. Guided by our new focus on clarifying and improving the experiment processes, we collaborated with these scientists, and together built tools to standardize and simplify Q range planning. The output of these planning tools is now well integrated with the rest of our EPICS control system (one shown in Figure 4). Users can easily use different instrument configurations via our standard Table Scan tool, or via Python scripting for their data collection. Our system can then automatically manage the run time instrument configuration and visualize the progress and status for the users. These efforts have enabled users to now manage a significant amount of detailed information and various unit conversions, all without them becoming overwhelmed in the process.

Experiment Automation Tools

Besides instrument Q configuration, user experiments also often involve complicated sample alignment procedures, different types of sample environment devices (temperature, magnetic field, electrical field, polarization, etc.), sample rotation stages, sample changers, and so forth. We worked with several different beamline teams to identify gaps and opportunities in terms of various functions and usability beyond our standard Table Scan tool (which is already capable of supporting most of these functional requirements using a table abstraction). The outcomes of these efforts included a CrystalAlign tool (shown in Figure 2), a redesigned tomography beamline UI and high-level features, as well as tools to automate complex experiment modes for our users.

As a result of excellent collaborations with multiple beamline teams, we were able to clarify and optimize the single crystal alignment process, and so designed and built a CrystalAlign tool for this essential routine task (show in Figure 2). The CrystalAlign tool serves four direct geometry spectrometers and a diffractometer (both with and without movable detectors), outputting a calculated UB matrix that enables automated data reduction.

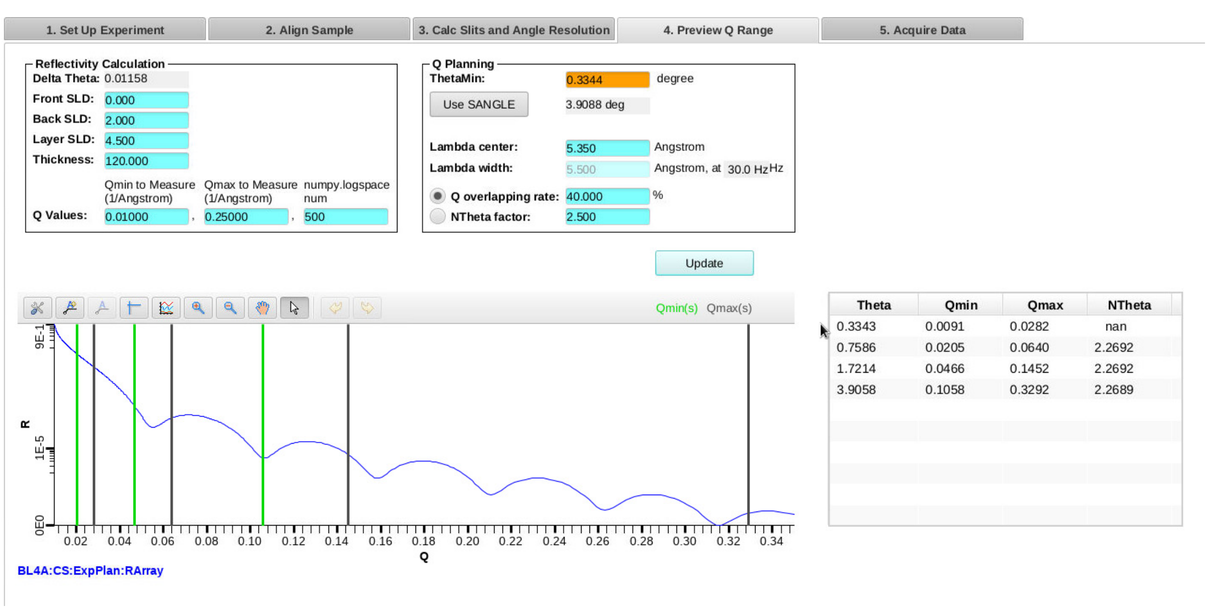

Figure 4: Example of an embedded Q range planning tool showing planned Q ranges overlaying on top of a simulated reflectivity curve.

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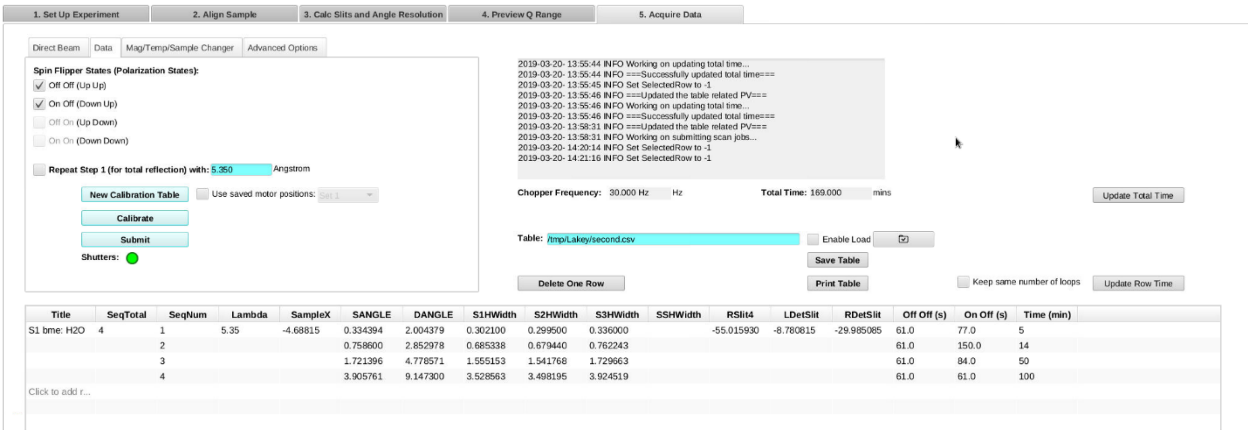

Figure 5: Example of an automatically generated data collection table.

We took the initiative to redesign the imaging beamline's user interface and high-level software features, to provide users with an improved experimental process and more automated features. More integrated tools were also developed on several beamlines to guide users through typical experiment workflows, and to plan for and automatically generate data collection tables with various operating modes (one shown in Figure 1), sample environment devices and settings, instrument Q configuration (one shown in Figure 2), sample changers, and other settings. More advanced features such as balancing the counts among different settings, predicting and estimating the total counting time, and so forth, were also added to help users plan their experiments and use their beam time more efficiently. Figure 5 shows an example of an automatically generated data collection table. By automating these routine tasks whenever possible, we successfully improved users overall experience, and helped to reduce potential beam time loss due to simple human errors.

CONCLUSION

Four years of UX focused development work has proven to be a great learning and growing experience for us all. We came to the realization that high-level control system software and user interfaces are key to helping users navigate our complex beamline control systems. It was both very humbling and satisfying to see our deliverables assist users in optimizing their beam time usage and collect high quality experiment data. We enabled the instrument staff to spend more of their time and bandwidth for science, and to better emphasize helping users with their scientific pursuits. These outcomes produced more satisfied and successful users, and directly supports the facilities' priority of a higher scientific productivity. We are grateful for all the support we have received and are excited for our ongoing work in this area, to explore new opportunities and better serve our user community.

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