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User control interface for W7-X plasma operation

Anett Spring *, Heike Laqua, Jörg Schacht

Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, Wendelsteinstr. 1, D-17491 Greifswald, EURATOM-Association, Germany

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Abstract

The configuration of the W7-X control system follows two major design principles. It reflects the strict hierarchy of the machine set-up with a set of subordinated components, which in turn can be run autonomously during commissioning and testing. Secondly, it links the basic machine operation (mainly given by the infrastructure status and the components readiness) and the physics program execution (i.e., plasma operation) on each hierarchy level.

The complexity of the control system implies great demands on appropriate user interfaces: specialized tools for specific control tasks allowing a dedicated view on the subject to be controlled, hiding complexity wherever possible and reasonable, providing similar operation methods on each hierarchy level and both manual interaction possibilities and a high degree of intelligent automation.

Subject of this article is the description of the operation interface for experiment control: 'Xcontrol' will be designed both for running plasma discharge experiments at W7-X and for components' or diagnostics' operation during autonomous mode or even laboratory experiments.

The necessary background information about the control system is given. The main 'Xcontrol' features, such as program composition and validation, manual and automatic control instruments, and process monitoring, will be presented. The implementation principles and the underlying configuration will be discussed.

Keywords: WENDELSTEIN 7-X; Segment control; Plasma discharge control; User interface

1. Design principles of WENDELSTEIN 7-X control

The WENDELSTEIN 7-X fusion experiment will be a highly complex device operated by a likewise complex control system. Strictly mapping the machine hardware configuration, the W7-X control system is based on two fundamental design principles: (1) the

* Corresponding author. Tel.: +49 3834 88 2757; fax: +49 3834 88 2509.
E-mail address: anett.spring@ipp.mpg.de (A. Spring).

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hierarchical structure constituting a 'project' of subordinate components, so called 'groups' and (2) the coexistence of three basic columns: safety control, operational management and segment control [1]. Each of the three columns has a counterpart at the corresponding hierarchy level. The connection between these columns on each hierarchy level, as well as between the central and subordinated parts of the control system is realized by standardized control signals.

These design principles applies for each control subsystem at W7-X, even in laboratory experiments. This ensures the use of common modules, and guarantees realistic tests and a smooth integration of new components, e.g., diagnostics into the W7-X experiment.

Naturally the safety system is an overall independently operating mechanism. It supervises the machine state by enabling or blocking the operation of every involved system and handles interlocks and critical faults.

The operational management is responsible for all slow control actions, machine wide or components' related, respectively. Between the hierarchy levels the control rights are negotiated by a standardized switch module. Thus, components can be operated either subordinated by the central control system (i.e., by the operation staff in the central control room) or autonomously by a local operator (the component's owner). The implementation of the operational management is based on industrial-suited PLC technique and a dedicated visualization providing the engineer's point of view onto the machine operation.

The segment control constitutes the basis for customizable physics program execution. By means of the segment control a long-term W7-X discharge is split into time-slices with all hierarchically ordered components operating synchronously according to a given scenario [2]. The same mechanisms can be used for laboratory experiments, for autonomous operation during commissioning, testing or calibration independently from a plasma discharge.

The 'segment control' is control by computers, generalized called 'control stations'. Precondition is the implementation of the necessary software modules for timing/segment switching, communication and of course control functions. Where strict real-time is required computers running the real-time operating system VxWorks are deployed, otherwise Java implementations can be adequate.

2. W7-X segment control basics

The complexity of the W7-X experiment demands both advance planning and straightforward user intervention. Thus, segment control is implemented as a combination of predefined automatic control and manual interaction at run-time.

The (software) background for all segment control actions lies in a central configuration and segment database. Mirroring the experiment hardware structure it determines the settings of the whole system at a given time. The database holds both the invariant settings (so called 'configuration') which do not change at run-time, and the variable settings (so called 'segment programs' and 'scenarios' as a reasonable sequence of them) which constitute the physics program. The specialized object editor 'ConfiX' [3] serves as the database front-end to define these settings.

At boot time every participating control station reads its configuration and herewith knows its role within the experiment hierarchy. It also reads its 'Idle segment' and a predefined list of segment programs. From now on a control station remains in 'Idle' state and waits for a message to activate one of the pre-loaded segments. These segment switch commands will be sent by a sequence controller, generally a specialized control station. Dependent upon a component is currently operated in subordinated or autonomous mode the segment switch command either from the super ordinate instance or the component's local sequence controller has to be followed and commands from the other source have to be ignored, respectively. For a deeper insight into the details of implementing real-time software control modules from database content refer to Ref. [4].

The user interface for presetting the control stations with a pool of segment programs, initializing the sequence controller with an experiment program as a reasonable list of segments, and monitoring the program processing – therewith the main tool for segment control handling – is 'Xcontrol'. The detailed description of the Xcontrol features is the subject of this article.

A conceptional overview about all user tasks related to preparation, execution and monitoring of a segment based experiment program is given in Ref. [5].

3. Xcontrol as segment control user interface

Xcontrol is the front-end for W7-X segment control and complements the operational management and safety control front-ends. Following a requirements' analysis concerning the underlying control mechanisms, the user groups, the expected supervising tasks on a fusion experiment and during test and commissioning, Xcontrol is implemented as a widely flexible tool. The application title 'Xcontrol' indicates the use for 'W7-X control' as well as for 'experiment control' in laboratories. Xcontrol adapts its features with regard to the set-up of the function group to be controlled, the related control rights and the operating mode. Thus, the same interface will be used by W7-X session leaders, experiment planning physicists, and the components' or diagnostics' operators, both for controlling and monitoring, both on a control room display wall or even in remote offices. In this way the approach differs considerably from control interface implementations for other fusion experiments, as in Refs. [6,7].

In the following the Xcontrol features are exemplified by means of a typical workflow. Pre-condition is a proper project/group configuration as part of components' set-up and a reasonable definition of segment programs.

3.1. Function group and user mode selection

In the Login dialog the user selects a function group for control and/or monitoring. Control rights will be granted depending on the user's authorization. Only one Xcontrol instance at a time can hold control rights for a function group.

Login for 'monitoring only' is allowed for everyone without authorization. In this case all control actions are disabled. However, segment database selections and workspace manipulations (see below) are allowed. This mode is intended to prepare experiment programs and to monitor a running experiment program executed by another Xcontrol instance with control rights. The number of monitoring instances is not limited. Hence Xcontrol will be the instrument to propagate the experiment progress to all interested participants at distributed locations.

Part of Xcontrol is a static state monitor – the upper part of the Xcontrol application window (Fig. 1) – providing status information about the function group currently logged in. The function group status regarding readiness for segment operation and the machine state of the projects operational management (n/a for stand-alone group not belonging to a project, e.g., in a laboratory experiment) are displayed as well as the status of the subgroups or stations, respectively.

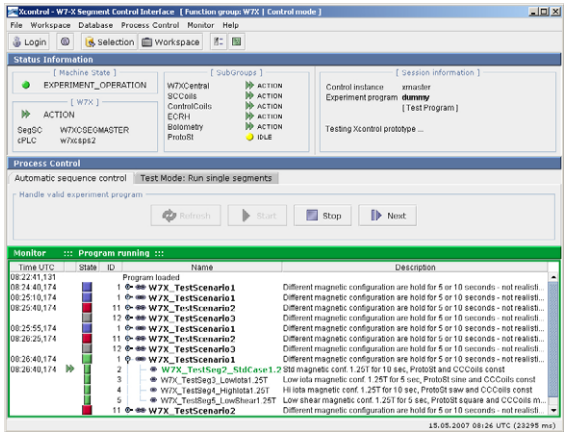

Fig. 1. Xcontrol prototype while processing an experiment program. Application main window with Status Panel, Control Panel, and Monitor.

3.2. Experiment program preparation using workspaces and resource check

An experiment program is a set of physics scenarios, which in turn are an ordered sequence of segments. The procedure is to select scenarios from the segment database using a query dialog (Fig. 2) and to arrange the scenarios within a so-called 'Workspace' (Fig. 3).

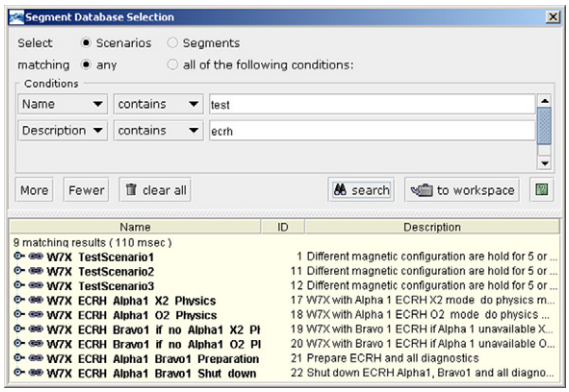

Fig. 2. Xcontrol Selection Panel.

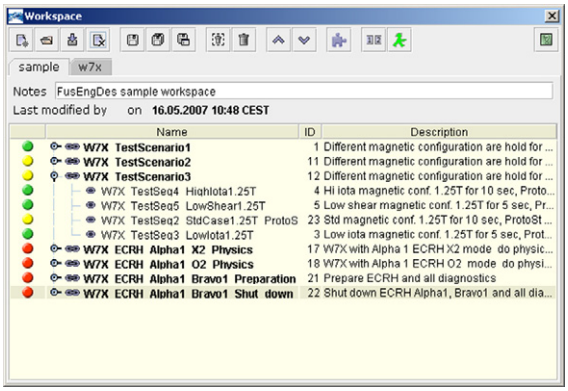

Fig. 3. Xcontrol Workspace Panel.

The database query dialog enables the user to restrict the database output by different rules: basically by segment/scenario properties, life cycle state and ownership. The query result or parts of it can be transferred into a workspace.

Operating with workspaces is a major design approach of the Xcontrol application. All Xcontrol operations start with an appropriate filled workspace. Since the database editor ConfiX follows the workspace concept, too, the user is given a familiar instrument to work with both main segment control applications. An Xcontrol workspace can only contain segments and scenarios. It is filled by segment database queries or imports from other workspaces, even ConfiX workspaces. All entries are displayed with name, description and status information (according to the offline resource check—see below). Scenarios can be expanded to present the included segments.

Several workspaces can be handled simultaneously. They can be saved as single plain text files thus ensuring easy ways to share workspaces with other colleagues, e.g., via email or commonly used directories.

Preparing an experiment program means first to sort the physics scenarios within a workspace as planned for the task and secondly, to check the feasibility of the program. While a logical check, e.g., ensuring smooth transitions, is done during editing, the proper resources' status has to be examined before executing.

Segments give a full description of each module's behavior belonging to the function group and define their own resources by declaring components as 'mandatory', 'optional', or 'unwanted'. Using this and the Xcontrol status information of all participating control stations, a resource inspection can be done. In contrast to the run-time check [8] during program execution, the offline resource check allows a deeper component examination and can be done for all segments within the program (not only the next few). This 'Segment Checker' is presently under development.

3.3. Experiment program execution and monitoring

Assuming sufficient control rights, a 'Valid Experiment Program' is declared from a prepared workspace and announced to the function group's sequence controller, which in turn permanently reports the currently running segment and the result of the online resource check. The valid program's status is displayed in the 'Monitor Panel': the bottom part of the Xcontrol main window.

The current valid program is announced by the Xcontrol control instance, thus synchronizing all listening monitoring instances for this function group. Additional information about the experiment can be edited by the control instance user (e.g., the session leader). It is spread the same way and displayed in the Status Panel.

The valid program can be handled using the 'Control Panel', the center part of the main window. By pushing the 'Start' button the sequence controller is assigned to send the first segment switch command to the associated control stations. All Xcontrol instances' monitors are updated by the reported status messages from the sequence controller, thus following the program's progress and displaying quality information about processed and future segments.

The Control Panel provides buttons for further program manipulation, e.g., for immediate program stop or switching to the next feasible scenario within the valid program. With further developments of the segment control and deeper knowledge of the machine more manipulation elements will be added, as changing a running valid program at run-time, or holding a discharge in a predetermined stationary 'Wait' state. Physicists insist on the implementation of manual control facilities for changing parameters within certain preset boundaries at run-time. Possible ways of implementation are under discussion.

Besides monitoring, the Xcontrol control instance records the actual segment flow into an archive database.

3.4. Xcontrol test mode

In order to use segment control features even without having a full project installation, Xcontrol provides two test modes:

(1) A 'Single segment test mode' is implemented as a panel with configurable segment switch buttons, which can be allocated with segments, manually or from a suitable filled workspace. By clicking a button an immediate segment switch action in all control stations of the function group is performed using the same mechanism as a sequence controller would do while processing a segment switch within a valid program.
(2) For components and laboratory experiments which do not implement a dedicated group sequence controller Xcontrol can emulate a "light version" sequence controller: a time triggered only processing of predefined scenarios in autonomous mode. Naturally Xcontrol cannot fulfill real-time conditions.

Both test mode features require the implementation of key features of the run-time resource check [8].

4. Implementation

4.1. Programming

For the development of Xcontrol as universal tool for experiment program execution and monitoring platform independency and uncomplicated distributed access will be a significant advantage. The foreseeable permanent enhancement can be handled easier by an object oriented design ensuring unproblematic ways to add new modules for user actions or monitoring tasks.

Taking all this into account, Java is the choice for application development.

4.2. GUI design

Designing a graphical user interface (GUI) is not only a programming task. The GUI is the user's first impression of an application and – if he goes to use it more often – the key point in his personal decision about the quality of the software, thus benchmarking the application at all.

The conception is to give the user specialized tools for specific tasks within the control system [5]. Since the respective user is an expert regarding the specific action, this narrows down the target group and the GUI design requests.

Xcontrol is restricted to segment program execution tasks and its GUI shall reveal this at first view. This is realized by a clear partitioning of the Xcontrol main window into three parts mirroring the three main tasks in a workflow oriented order: the Status Panel for static monitoring, the Control Panel for process control, and the Monitor Panel for progress monitoring. The experiment preparation tasks are performed in separate sub-windows: the Workspace Panel for handling workspaces and the Selection Panel for database queries. Both can be hidden after work is done.

All user actions can be triggered from the main menu. Additionally, selective features are provided by toolbar buttons in the respective sub-windows and context sensitive popup menus. The policy is to provide functionality at the point where it is needed and expected.

Another essential rule is not to peeve the user with procedures which can be automated or even hidden. Such often-called convenience features are not cosmetics but put the user in a position to concentrate on his business instead of fiddling around with the application. This is realized by offering sensible pre-settings in dialogs, by preventing maloperation through disabled functions which are not sensible at this point, or by restoring session specific settings with the next login.

By avoiding application specific quirks, where the user is puzzled about the meaning, the GUI is largely self-explaining: Xcontrol uses well known icons, same icons for same tasks, and follows well known quasi-standards to order and name menu items.

A structured help system is provided. It offers a general workflow overview, basic background information about segment control as well as detailed descriptions of all Xcontrol features and user tasks. It can be called from the main menu and context specific from sub-windows or dialogs.

Last but not the least a permanent, local file based activity logging in the background can be helpful for

troubleshooting. Only critical errors, such as failed commands or communication timeouts are directly announced to the user.

Because usability is always a subjective impression comprehensive testing and ease-of-use inspection by real users in realistic environments is unavoidable. Fortunately, both are given during the W7-X building phase.

4.3. Function group specific set-up

All function group specific set-up information is explicitly defined in the configuration database: the configuration as project or group, parameter settings, function group specific communication paths, associated groups or control stations, respectively.

During the login procedure the configuration is loaded and the control rights are negotiated (if necessary). Subsequent the communication paths have to be reset and parts of the GUI have to be redrawn or even exchanged: the Status Panel has to be updated regarding the function group hierarchy and the respective members, the Monitor Panel is cleared.

As part of the W7-X segment control system but sharing information with the operational management, too, Xcontrol has to implement both the communication with the participating segment control stations and with the respective PLCs which publish operation state information. All Xcontrol relevant control information is distributed by UDP messages via Ethernet. The sending mode differs from the messages purposes: generally speaking status information is spread periodically (herewith stating a shared memory) and commands are sent on demand. In the case of several receivers messages are sent as multicast, otherwise unicast. While the parsing algorithms for the messages are unique, the destination addresses are defined function group specific during the respective configuration set-up.

4.4. Current implementation status

The Xcontrol development takes place as an iterative and co-operative design process parallel to the permanent enhancements of the segment control software for which it serves as front-end.

A prototype is running since several months and is actually deployed during component commissioning, e.g., of the W7-X coils' power supplies, and for diagnostic preparation in laboratory.

The use in realistic environments ensures quality control at a very early stage and permanent user feedback on the subjects of usability and ergonomics—the best condition to develop stable and user-friendly software.

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