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ABSTRACTS AND MEETING MATERIAL

12th IAEA Technical Meeting on Control, Data Acquisition and Remote Participation for Fusion Research

Daejeon, Republic of Korea, 13–17 May 2019

indico/event/180

Preface

Nuclear fusion is recognised as a long-term energy source. The International Atomic Energy Agency (IAEA) fosters the exchange of scientific and technical results in nuclear fusion research and development through its series of Technical Meetings and workshops. The 12th IAEA Technical Meeting on Control, Data Acquisition and Remote Participation for Fusion Research (CODAC 2019) aimed to provide a pre-eminent forum to discuss new developments and perspectives in the areas of control, data acquisition, data management and remote participation for nuclear fusion research around the world.

The CODAC 2019 was organized by the IAEA, in cooperation with the Government of the Republic of Korea through the National Fusion Research Institute in Daejeon, Republic of Korea, 13–17 May 2019. Previous meetings in this series were held in **Garching, Germany (1997)**, **Lisbon, Portugal (1999)**, **Padova, Italy (2001)**, **San Diego, United States of America (2003)**, **Budapest, Hungary (2005)**, **Inuyama, Japan (2007)**, **Aix-en-Provence, France (2009)**, **San Francisco, United States of America (2011)**, **Hefei, China (2013)**, **Ahmedabad, India (2015)** and **Greifswald, Germany (2017)**.

The main topics of the meeting were plasma control; machine control, monitoring, safety and remote manipulation; data acquisition and signal processing; database techniques for information storage and retrieval; advanced computing and massive data analysis; remote participation and virtual laboratory; and fast network technology and its application.

This document has been assembled from the information submitted by the contributing authors via the IAEA-Indico conference management platform. Layout, editing, and typesetting was done by Pierre-Marie Brieda (France). The IAEA officer responsible for this document was M. Barbarino of the Division of Physical and Chemical Sciences.

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ITER Operation Application Systems for plant system integration and commissioning

Mikyung Park

ITER Organization

ITER CODAC system from a software perspective is mainly composed of two software suites for the different purposes; firstly CODAC Core System (CCS) for plant system development and operation, and secondly CODAC Operation Application System (OP App) for orchestrating ITER operation and experiment executions. In aligned with the ITER project milestone, ITER CODAC team has lately more endeavored on the development of Operation Application System (OP App) and released a set of tools especially for plant system commissioning while covering functions of supervision & automation (SUP & AUTO), plant configuration (PSPS), real-time control framework (RTF) for PCS, data handling using Unified Data Access (UDA), remote participation (ORG & ODG), which were tested and evaluated at an operating tokamak, KSTAR following a whole sequence from pulse preparation to data service. This paper will describe the first delivery of ITER Operation Application System for plant system integration and commissioning and evaluation results as well as a future planning for plasma operation.

Keywords: ITER, CODAC, Operation, Tokamak

EAST research activities on control and data toward CFETR

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Chinese Fusion Experimental Tokamak Reactor (CFETR) started its engineering design since early 2018. A set of R&D aiming at establishing the technical basis for CFETR has also started recently. To meet CFETR design requirements, the domestic specific CFETR network and the design database has been established to facilitate the team data and design sharing and consistency. The document management system has been adapted from EAST which is originally from an open source sharing.

For the plasma control, EAST is more and more focusing on the future CFETR needs. The fully separation of the vertical stability control with the shape, current and position control was demonstrated which is ITER and CFETR relevant. Multi-input and Multi-output control for the plasma shape and coil current was conducted, aiming at enhancing the control robustness. For the future CFETR and even DEMO scale reactor, traditional magnetics will inevitably meet the accuracy problem arising from neutron radiation and long-term drift. Optical shape reconstruction of the plasma shape will be one of solutions. A real-time data acquisition and reconstruction scheme has already primarily established and the optical setup has just initiated. To demonstrate the heat flux reduction to the divertor target which is one of the challenges for a fusion reactor, a set of control efforts have been conducted on EAST. The control of the flux expansion or an advanced plasma shape such as quasi-snowflake has shown a good heat flux reduction toward the divertor target. The radiation control on the SOL and divertor effectively reduced the total heat to the divertor target with the limited influence to the core plasma confinement. Moreover, plasma detachment control has been demonstrated by using the ion saturation current measured from Langmuir probe as the detachment indicator.

For the plasma control system, a proposal has been given aiming at establishing a software base for the next generation PCS which meet the future CFETR requirements and catch up with information technology rapid growing.

Design and Development of a Cost Optimized Timing System for Steady state Superconducting Tokamak (SST-1)

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SST-1 timing system is a real time event based trigger generation and distribution system used for the synchronized operation of its various heterogeneous and distributed sub-systems during the plasma discharges. The VME based platform dependent old timing system is exhausted with spares inventory during long period of its existence and also had interface issues with the hardware advancement at subsystems end. The timing system physically consists of two types of modules i.e. central module and sub-system module. The timing and trigger distribution from central module to sub-systems are carried out by a star topology based optical fiber network. A platform independent, stand alone, 1U rack mountable timing system is designed, developed and tested based on Xilinx's Artix-7 FPGAs for real time event (trigger) distribution amongst different sub-systems of SST-1. The new system design's objectives being, to adopt same star topology as the old timing system, to support existing optical fiber network, to provide single interface to the heterogeneous sub systems and to have performance parameters, comparable to the old timing system with the minimal modifications on hardware as well as on software part at sub systems end.

As stated earlier, in this new system, single central timing system module can support an interface of maximum of eight (8) subsystem modules in star configuration over optical fiber network. The central timing system module can generate pre-defined experiment event (trigger) sequence in real time with a resolution of 10µs and facilitates event logging at a resolution of 1µs. Each sub-system module can support eight (8) TTL inputs for asynchronous event generation and eight (8) TTL outputs for trigger pulse generation with a resolution of 1µs. Each experiment sequence on central timing module and trigger information on sub system timing modules are configured over Ethernet interface through TCP/IP protocol. Maximum of 255 different events information can flow between sub-system timing system modules through central timing system module. Event latency is observed to be in the range of $\sim$ 4µs over 3m length of optical fiber cable.

Timing system modules are designed using Xilin's Artix-7 FPGA for the programmable resources like RAM, DPRAM using IP cores, implementation of glue-logic timing as well as implementation of serialization-deserialization logic based on asynchronous serial communication protocol for event (trigger) information distribution over fiber optic network. The use of FPGA has helped in minimizing the use of dedicated discrete hardware resources such as memory ICs, high speed serializer, de-serializer ICs and other glue-logic ICs. This platform independent standalone design helped, in avoiding designing and testing of multi-platform cards for VME, PXI systems.

Further development is underway to extend the capability of the timing system, to provide clock synchronization for the sub systems using the same timing system modules and to incorporate GPS based IRIG-B time synchronization interface. This completely new in- house design will be advantageous, as it can be easily be adapted for the time synchronization applications in any small, medium size tokamaks or experimental devices irrespective of their the hardware/ software platforms.

Introduction of ITER CODAC Relevant Technologies on JET and MAST

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The JET control and data acquisition system (CODAS) is an integrated system that provides all the pulse based and continuous data acquisition, real time and slow control and control room interfaces for JET. It has a long history, dating back to the beginning of JET in 1980. It utilises both commercially available hardware along with many in-house modules. The software has grown up and evolved largely independently of other developments in big science. Similarly, the data acquisition system on MAST has a long history of evolution from previous facilities at Culham (COMPASS). It utilises commercially available and in-house

hardware (some shared with JET CODAS) and software that has developed largely independently of JET and other external developments. More recently, we have begun to

adopt some ITER CODAC relevant technologies on both JET and MAST, in part, to also introduce some standardisation between the two facilities. This started with a pilot project

to create a cubicle and environment monitoring system using commercial hardware and EPICS monitoring and HMI. We have since gone on to implement several camera and

spectrometer filter controllers, several types of turbomolecular pump controller, and various radiation protection monitors in EPICS on JET. We are also implementing a central information display system for MAST that links the OPC interface on the machine control through to several display screens showing the machine state using EPICS. We have several MARTe based real time applications on JET and are now developing an application to provide real time proceeding of high-resolution Thomson scattering data using MARTe V2 (an ITER/F4E initiative to improve the robustness of this real-time framework). We are also considering upgrading the existing MARTe applications to this version. On JET we have also started to use another ITER CODAC technology – SDN to supplement the ATM based real time control network on JET. Initially, as a proof of principle, a real time plasma profile display was implemented. This system is now being extended to include several real time data sources which will feed their data back into the ATM network and on to the real time controllers. Looking forward, we anticipate extending the JET real time network with a purely ITER CODAC/SDN connected real time control system and provide a richer ITER CODAC interface to the JET CODAS to accommodate the possibility of ITER diagnostics testing and provide a real stress test for ITER archiving technologies.

Advances and challenges in KSTAR plasma control toward long-pulse, high-performance experiments

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An overview of advances and progress on the KSTAR plasma control improvement is given. The enhancement of the plasma control system continues in order to enable implementations of more sophisticated control algorithms and capabilities of integrated controls on magnets, gas, heating and off-normal event handling. Features and functionalities are constantly added for integration of various real-time controls that are desired for the operation space expansion, mainly regarding recent achievements of higher plasma current up to 1.0-1.2MA, high-performance long pulse up to 90s, and discharges relevant to ITER. Technical challenges on the plasma control of superconducting devices are discussed, based on experiences of KSTAR operations. Prospective upgrades and expansion of advanced control functionalities in the near future are described as well.

Current State of DIII-D Plasma Control System

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The DIII-D Plasma Control System (PCS) is a comprehensive software and hardware system used in real-time data acquisition and feedback control of numerous actuators on the DIII-D tokamak. It regulates hundreds of plasma characteristics including shape, position, divertor function, and core performance. The custom software developed at DIII-D provides an expandable platform from which new control algorithms can be incorporated. PCS has been expanding with the needs of the DIII-D research program, national, and international institutions that have adapted the PCS for use on their devices.

The DIII-D PCS group in collaboration with many national and international groups have been instrumental in steadily improving the effectiveness and capability of the system. Recent hardware improvements have been made to enhance real-time connectivity using a 40Gbit/s InfiniBand network, and to increase computational performance with additional real-time computing cores and a new GPU. Real-time data acquisition capabilities have also been enhanced through upgrades of PCS digitizers that double the acquisition rate and increase the range between signal source and digitizers. The range increase allows additions of signal sources from dispersed laboratories in the facility. New control capabilities have also been added, including machine protection algorithms (e.g. disabling ECH power in case of high plasma density) and more granular feedback of Neutral Beam control. A new GPU with 61,400 computing threads has been included in one of the PCS real-time nodes to run new Resistive Wall Mode feedback algorithms (Columbia University). Novel capabilities have been added, including the machine learning-based Disruption Predictor via Random Forest algorithm (MIT) and the ability to display real-time PCS signals beyond the control room.

In this paper, we will describe enhancements to PCS system, their motivations, results, and impact to enable the mission of the DIII-D program.

Work supported by US Department of Energy under DE-FC02-04ER54698 and DE-SC0010685

The first implementation of active divertor heat flux feedback control in EAST PCS

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The divertor heat flux is one of the major concerns for high performance and long pulse plasma operation, since it may lead to unacceptable heat load and thus damage the divertor target material. EAST has achieved a total power injection up to 0.3 GJ with ITER-like water-cooled tungsten (W) mono-block divertor. The active divertor heat flux feedback control is urgently needed in EAST.

EAST has a number of impurity seeding systems, including gas puffing in the upper and lower divertor volumes, super molecular beam injection (SMBI) and pellet injection systems at the outer mid-plane, which can be commanded by PCS [1,2] and facilitate the heat flux control. The signals from Langmuir probes are also acquired by PCS in sampling rate 10KHz and then calibrated to provide either the divertor particle flux or electron temperature. The feedback control algorithm, similar to that developed in JET [3], has the flexibility to control the main density or the particle flux to reach partial detachment, which is a promising method for steady-state divertor heat flux control. The control algorithm based on the divertor particle flux worked effectively during the 2018 EAST experiments with D2 fuelling through low field side (LFS), SMBI-injection or divertor impurity seeding from the divertor volume in H-mode plasmas, without significant degrade of the core-plasma performance, i.e., exhibiting good core-edge-divertor integration. The algorithm implementation in PCS and experimental results will be reported in this paper. Further efforts will be made to extend active feedback control towards long-pulse H-mode detachment maintenance in the near future, which will benefit the high power, H-mode operation for ITER.

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MARTe2 and MDSplus integration for a comprehensive Fast Control and Data Acquisition System

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MARTe is a framework for real-time control that has been used in several fusion experiments. Recently, a new version named MARTe2 has been developed adhering to software quality standards. The framework supervises data movement and component interaction in real-time and is based on configuration information specifying the involved threads, the computation and the data management components. MDSplus is a data system widely adopted in the fusion community. MDSplus provides fast data acquisition and access to pulse files and is intended to provide a complete interface both for the configuration of the experiment and the experimental results.

MDSplus and MARTe2 are already integrated via a set of components that are able to (1) store a data stream originated in real-time in the pulse file, (2) get experiment set-up information, such as reference waveforms, from the pulse file to be used afterwards in real-time, (3) synchronize MARTe2 components with other MDSplus components via MDSplus events. Even though the use of the above three components covers all the needed requirement for the integration of fast control and data acquisition, further integration is desirable. In particular, the configuration of MARTe2 applications is based on a very flexible set of components, either specified in a configuration file, or created on the fly by a supervisory application. Adhering to the MDSplus design pattern that states that all the configuration information should be specified inside the pulse file template, called Experiment Model, it is possible to store configuration information in the experiment model together with the other experiment configuration parameters in order to let a given pulse file fully describe the associated experiment, including its configuration. A better integration is proposed here, that is, using the Device abstraction provided by MDSplus to specify the components involved in the data acquisition process and MDSplus expressions to specify data relationships, in order to describe also the real-time components and the associated data flow. Following this approach, the whole real-time configuration would be described exactly as the rest of the other non real-time data acquisition components. All the required MARTe2 configuration information would be exposed to users via the configuration fields of the associated MDSplus devices, for which graphical interfaces can be readily developed using the MDSplus Java Beans framework. Once the real-time components and the associated data flow have been described in the MDSplus experiment model, the corresponding MARTe2 configuration will be generated on the fly, integrating all the required consistency checks.

Besides exposing to users a much less complicated and more intuitive configuration interface, the proposed approach minimizes the possible errors that could arise from a manual specification of the MARTe2 configuration that, when expressed via a text file, can be composed of thousands of lines for a non trivial configuration. A use case involving EQUINOX equilibrium computation in a MARTe2 application, currently used in simulation, but adaptable for real-time control will be presented to demonstrate the feasibility and the advantages of the proposed approach.

The Implementation and operation of the 4th version of KSTAR Fast Interlock System

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In order to increase the safety, it is more important than ever to generate a signal to turn off the device even when the abnormal situation occurs during the plasma discharge. KSTAR has built the Fast Interlock System (FIS) since achieving first plasma in 2008, and built and operated the 4th version of FIS which using NI c-RIO technology in 2018 [1].

We moved the safety related functionalities such as heating stop, soft-landing, and etc. of the Central Control System (CCS) built on the existing Versa module Europa bus (VME) to FIS [2]. The EPICS irio driver enables complete control and monitoring of the Field Programmable Gate Array (FPGA), and the distributed interlock information can be integrated in the FIS Input Output Controller (IOC) via Experimental Physics and Industrial Control System (EPICS) [3]. Hardwired signals processed by FPGA are connected to each of dedicated systems, and informational signal is published and subscribed by EPICS.

The FIS Operator Interface (OPI) panel is developed using Control System Studio (CSS), which allows an operator can easily understand FIS operation status and KSTAR shot progress status at a glance. It displays the event occurrence and sequence status on the screen, records event occurrences in the log file, and makes possible to operate with minimal operator's intervention. The FPGA, which is responsible for signal processing at high speed, implements the event counter logic to record the event occurrence time. The counter values are synchronized with the Central Timing Unit (CTU) start time of 1 second later of shot start and show relevant time from blip 0. The event generated in the FPGA is displayed in 10 microseconds resolution by the 100 kHz operation period. The start-up failure is judged within 250 milliseconds after the plasma discharge. In case of abnormality, generating the fast interlock is the most important function of the fast interlock system. In this paper we will describe the detail implementation and operation results.

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WestBox: an object-oriented software component for WEST CODAC

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Control, Data Acquisition and Communication (CODAC) real-time software codes are key elements for the operation of a fusion device as they can play a key role both for the machine protection and for the optimization of the experiments. In 2013, following the WEST project (W -for tungsten-Environment Steady-state Tokamak) upgrade, the whole legacy acquisition system has been refactored.

The WEST CODAC framework which inherited the older implementations used over 20 years on TORE Supra has been cut into primary software pieces called components, corresponding to basic technical features, such as Database Access, Inter-process Communications, Real-time Device Management, Synchronization Network, States Machine, and Shared Memory Network. In addition, a new component has been developed to integrate non-native and cross-platform data acquisition hardware and software from guest collaborators.

The paper describes this software component named WestBox implemented in an object-oriented approach and based on Qt framework for enhanced code portability. This allowed using new standard software technologies, notably Web based, from industry. It includes a modular Message Oriented Middleware (MOM) interface based on the Internet of things (IoT) connectivity. It also provides support for the integration of National Instruments LabVIEW controllers using normalized WebSocket protocol. It will further propose a control panel for remote monitoring of the data acquisition units through a web browser and remote logging of events.

The WestBox software component has been successfully operated over two years on WEST experimental campaigns. Current developments aim at including support for ITER data storage standards as MDSplus, and IMAS inside the WEST CODAC framework.

Low-risk Beginning of the Density Feedback Control in KSTAR

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During the early campaigns of the KSTAR projgect, feedback control of plasma density has been successfully commissioned at the very first attempt by using a transfer function analysis. A stable and robust discharge was chosen as a test-bed i.e. a 300 kA (I_p) 2.0 T (B_t) ohmic circular limited plasma. Before direct feedback control, pre-programmed fueling modulation was carried out by puffing the deuterium gas. Line-averaged plasma density was measured in real-time by a 280 GHz interferometer system. From the open-loop experiments, both the density decay time (τ_i^*) and the external fueling efficiency (f_{ex}) were obtained approximately : 3.0 to 5.0 s and 10 to 20 % respectively. By transfer function analysis, several transient responses such as rising time, settling time and overshoot ratio were estimated in a certain range by the measured ranges of τ_i^* and f_{ex}. It is found that τ_i^* has little effect on those response characteristics while f_{ex} plays primary role together with magnitude of the proportional gain K_p. This is due to predominance of valve response whose characteristic time τ_v was approximately determined as 60 ms by dusing D_{α} signal, which is much shorter than τ_i^*. Considering these values, K_p for closed-loop control were initially set 2.5 as minimum and followed by stepwise increment to reduce steady-state error without any integral gain K_i to avoid any uncertainty. The small K_p was chosen being concerned on excessive fueling if any unexpected result happens. Similarly the target density waveform was also set low initally liniearly increasing until a flattop period for one second before current ramp-down. In this way the first density feedback control was successfully finished although the transient responses were far different from the experimental result while the predicted steady-state error was in good agreement with the experimental undershoot. By replacing τ_v with arbitrary characteristic time τ_a two different settling time in the two subsequent feedback experiments were both matched well with a single $\tau_a\sim120ms$. This is due to a digital low-pass-filter included by a plasma control system (PCS) acting as 50 ms delay of response. Including the filter, transfer function becomes 3-pole system and no more simple analytic expression of response characteristics were avaliable. Instead, they were fully numerically computed. The changed settling times including the digital filter matched well with $\tau_a\sim50ms$ which became much closer to the original τ_v. In summary, response characteristics in longer period (settling time and steady-state error) are evaluated well with the transfer functions in considering simple particle balance model with fixed τ_i^* and f_{ex} and fueling delay estimated by D_α signal including digital filter. However rising time and overshoot still does not agree with any values of τ_a, which implies the density feedback system is not simply the second or third order or even linear system. For more accurate prediction of response, therefore, nonlinear or time-varying numerical model will be necessary especially in dealing with the recycling coefficient R that underlies in $\tau_i^*\equiv\tau_i/(1-R)$ where τ_i is particle confinement time.

Real-time classification of L-H transition and ELM in KSTAR

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It has been widely accepted that a high confinement mode(H-mode) operation is necessary for advanced tokamaks or ITER. However, when plasma is in H-mode, the edge localized mode (ELM) occurs at the plasma edge, which release particles and energy [1]. In case of ITER, a full tungsten divertor cannot tolerate the heat load from the type-I ELM [2]. Besides, in terms of plasma density feedback control, the fuel into the plasma cannot be absorbed by gas puffing only due to the edge transport barrier(ETB) and the diagnostic values of the real-time plasma density are abnormally observed by the ELM burst. In order to help to control these problems, an algorithm for classification of L-H transition and the first ELM burst in real-time has been developed with KSTAR campaign data. The algorithm has been firstly verified through off-line version using processed experimental data. After the verification, we found that the algorithm can work in real-time using raw experimental data. In order to classify the L-H transition and the first ELM burst, we applied a method of Long-Short Term Memory(LSTM) [3] which is a special kind of neural network for storing long sequence. D_α, a deuterium spectral line of Balmer series, and $\bar{n_e}$, line averaged electron density, in KSTAR [4-6] are used for pattern recognition and learning. The time area in which the algorithm will classify is from ramp-up phase to the ELM phase in the whole plasma discharge because typically, there is no L-H transition in the ramp-up phase and we did not make the algorithm learn H-L back transition. In addition, we tested our trained LSTM network in ITER-compatible environment as part of the ITER-CODAC experiment during 2018 KSTAR campaign [7]. Although the trained network was tested in the different environment, the network worked properly. In conclusion, the result of off-line version showed that the LSTM can remember the sequence of plasma discharge related to L-H transition and ELM. In the real-time version, we found that the algorithm can classify the L-H transition and the first ELM although the raw data is noisier than the processed data.

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The MAST Upgrade Plasma Control System

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MAST has undergone a substantial upgrade [1], featuring among other things several new poloidal field coils mostly distributed around the new closed-throat divertor structure and an enlarged centre column. The considerable changes have required the plasma control software to be substantially re-written.

The MAST digital plasma control system [2] was based on an architecture developed by General Atomics [3]. The legacy hardware presented in the original publication has already been replaced so only some additional I/O was required for MAST-U. The generic software infrastructure from GA has been retained for MAST-U but the tokamak-specific algorithm software has been completely reimplemented to provide the necessary flexibility to support the additional capabilities of MAST-U, especially in the areas of coil current control and gas injection control.

MAST Upgrade has very many gas injection nozzles, driven from 48 Piezo actuator valves, which are arranged in 11 toroidally symmetric groups and supplied with gas via 6 separate plena. The design brief was to provide the flexibility to perform multiple simultaneous gas injection control tasks, any of which can be mapped to any of the 11 valve groups or a combination thereof. Gas flow in a group should be symmetrically balanced whilst taking account of the calibrated flow capability of each active valve for the given plenum pressure and species. The software was also required to prevent usage conflicts or inconsistencies between the gas species assigned to the control task and that present in each of the plena supplying the assigned valve groups. This design requirement was fully met by defining a set of categories (which provide placeholders for pluggable algorithms) for each control task, all making requests to a central gas algorithm that manages the configurable mapping of tasks to valve groups. Details will be presented.

Since the primary focus of the upgrade is to support divertor research, many of the additional PF coils are to control the X-point and/or the trajectory and expansion of the divertor leg. The software architecture for controlling all these coils was partly inspired by the solution chosen for the gas system, where coils can be combined into virtual circuits according to the plasma property to be controlled by that circuit. Multiple control categories have been defined to allow each category to support a choice of control schemes for the virtual circuits it manages independently of what the other control categories are doing. Again, details will be presented.

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Design and development plan for control and data acquisition system of Thailand Tokamak 1 (TT1)

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Control and data acquisition systems of Thailand Tokamak 1 (TT1) are designed and developed as tools for researchers and students in Asian country. The control and data acquisition systems is designed base on the PXI platforms and synchronized with a precision time protocol (PTP), defined in the IEEE 1588 standard. The PXI6683 cards are used as a timing module in PXI cases, time resolution up to 100 ns. This protocol is similar to what is planned for ITER. TCP/IP network is used to connect between the central control and PXI cases while fiber optic is used for interlock, triggering and data systems. The data acquisition system is consisted of 192 channels that are installed in 2 PXI case. A bandwidth of this system includes 20 kHz; for poloidal flux loop, Rogowski coil, 2D magnetic probes and voltage loop, 100 kHz; for saddle/locked loops, and 1 MHz; for MHD probes.

Development of high-current power supplies for the TCABR tokamak

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An upgrade is being conducted on the TCABR tokamak, which is a small-size tokamak (R0 = 0.62 m and a = 0.2 m) operated at the University of São Paulo, Brazil. An important part of this upgrade is the installation of additional poloidal field coils to allow for the generation of various divertor configurations such as single-null, double-null, snowflake and x-point target divertors. The control of these various magnetic configurations requires the development of 15 robust and high-performance power supplies. To identify the most appropriate solution, different power electronic topologies are being considered such as thyristor-based, IGBT full-bridge, and resonant converter power supplies. In this work, a comparison between these topologies in terms of controllability, complexity and cost will be presented.

Development of a new CODAS for the TCABR tokamak

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An upgrade is being conducted on the TCABR tokamak, which is a small-size tokamak (R0 = 0.62 m and a = 0.2 m) operated at the University of São Paulo, Brazil. This upgrade consists mainly in the installation of (i) graphite tiles to cover entirely the inner surface of the vacuum vessel wall, (ii) new poloidal field (PF) coils to allow for the generation of various divertor configurations such as single-null, double-null, snowflake and x-point target divertors, (iii) in-vessel HFS and LFS non-axisymmetric control coils for ELM suppression studies, and (iv) a coaxial helicity injection system to improve plasma start-up. Among other goals, this upgrade will allow for studies of the impact of RMP fields on advanced divertor configurations, such as the x-point target and snowflake divertors. The creation of the various plasma scenarios that are envisaged for TCABR will require a robust and flexible plasma control system. The new TCABR plasma shape and position control is being designed and will be based on a feedback PID technique. The design of the new PID controllers will be carried out using the so-called RZIp model [Coutlis et al., Nuclear Fusion (1999) 39 663]and, in this work, the algorithms, programs and codes used to tune the plasma control system will be presented. Experimental data for the TCABR tokamak is currently stored in MDSplus (Model Driven System Plus) database and together with the data acquisition system, remote access (CODAS) [W.P. de Sa, G. Ronchi, Fusion Eng. Des.(2016) 112 1034] will be upgraded to fit the plasma control presented above and it will also be discussed.

Preparations for the control of HL-2M first plasma campaign

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This work mainly describes the progress and preparations for first plasma control in HL-2M, a medium-size copper tokamak currently under construction in China, with 16 poloidal field coils and one central solenoid (CS) coil (or Ohmic coil). Significant progress has been made in plasma control system (PCS), first plasma scenario. The proposed framework of PCS is consisted of plasma discharge scheduling platform, feedback control system, timing control system and central interlock system. The discharge scheduling platform has been completed and tested successfully by experiments, it incorporates a platform for the preset of discharge parameters which is based on eXtensible Markup Language (XML) and contains a software tools for preprogrammed discharge waveform based on MATLAB. The most frequently used RZIP control algorithm for first plasma campaign has been developed and preliminary results have been obtained, further development and verification of feedback control algorithm is on the way. Plasma shape and position feedback control in HL-2M is achieved by implementing control algorithm in RT-LabView with 1ms control cycle to adjust the current of control actuators (16 poloidal field coils), plasma current is sustained via the control of CS current. Device protection strategy, detection and response to off-normal events have been identified and implemented in the newly developed central interlock system (CIS) based on WinCC and PLC, both hardware and software of CIS is ready for first plasma campaign, integrated system test is required in the future. Timing control system generates the trigger according to the desired sequential defined in the timing XML, 96 output channels of 5V TTL trigger are provided for subsystem by Field-Programmable Gate Array (FPGA). In order to minimize the risks and difficulties of first plasma control, only small parts of PF coils are used in first plasma campaign. Two scenarios including one limiter and one divertor configuration, for first plasma are designed by using a MATLAB-based tool for tokamak modeling and plasma scenario development. Initial magnetization is not exploited, zero-crossing of PF current is not allowed and no VDE is expected in these two scenarios.

Use of Actuator management in ASDEX Upgrade control

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The control experiments on ASDEX Upgrade so far were only able to use one gyrotron per controller to perform a control action (for example supply power for Te control). The power provided by one gyrotron is not sufficient for the control tasks described below. In order to overcome this issue, we have introduced a virtual actuator which combines arbitrary number of gyrotrons and is responsible for the controller command distribution. The concept of the virtual actuator is described in [1]. This contribution will discuss the use of the virtual actuator in the ASDEX Upgrade experiments, where it proved to be a powerful and useful method.

The first application of the virtual actuator is the ßp control in the I-mode experiment. In this case, ßp was controlled by a group of gyrotrons combined to a virtual actuator heating the plasma center.

The virtual actuator was also used in the Te profile control experiments [2]. This is important for example in fast particle studies or experiments studying the effect of He plasma confinement. In this case, the controller actuated the ECRH power at two different poloidal location to control the temperature profile. For this purpose, we have used two virtual actuators with 3-5 gyrotrons each (depending on the discharge settings) pointing to the desired poloidal locations.

The next application is the H-Mode density limit disruption avoidance experiments reported in [3], where the virtual actuator was used to supply central heating to keep the discharge away from the disruptive area.

Last, but not least, the virtual actuator is useful in gyrotron replacement strategies. Traditionally, the gyrotrons tripped during the discharge were replaced by the next gyrotron in the priority list. However, this approach does not guarantee that the replacement gyrotron will have similar features, such as power deposition or current drive efficiency. The virtual actuator concept allows to define more sophisticated replacement groups which contain gyrotrons with similar properties.

References:

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[3] B. Sieglin et al, Rapid prototyping of advanced control schemes in ASDEX Upgrade, this conference.

An overview of the upgrade of the TCABR tokamak

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This work provides a general overview of an upgrade that is being conducted on the TCABR tokamak, which is a small-size tokamak (R0 = 0.62 m and a = 0.2 m) operated at the University of São Paulo, Brazil. This upgrade consists mainly in the installation of (i) graphite tiles to cover entirely the inner surface of the vacuum vessel wall, (ii) new poloidal field (PF) coils to allow for the generation of various divertor configurations such as single-null, double-null, snowflake and x-point target divertors, (iii) in-vessel HFS and LFS non-axisymmetric control coils for ELM suppression studies, and (iv) a coaxial helicity injection system to improve plasma start-up. Among other goals, this upgrade will allow for studies of the impact of RMP fields on advanced divertor configurations, such as the x-point target and snowflake divertors. Different aspects of this upgrade will be presented, with emphasis on preliminary studies of the different plasma configurations that will be generated in TCABR with the new PF coils and the magnetic diagnostic system needed for the plasma control. These studies are being used to design the PID plasma controllers and also to determine the required voltage/current wave forms that shall be supplied by 15 high-current power supplies that are being designed. Additional power supplies are also being designed to allow for toroidally rotating RMP fields. An important aspect of this upgrade is that it will serve to pave the road towards the establishment of a national laboratory that will be constructed in Brazil to concentrate and coordinate studies on nuclear fusion across the country.

Determination of Radiated Power Density Profile Using Bolometer Data for DT Baseline Scenario at JET

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The experimental data obtained from the campaign dedicated to Baseline scenario for DT (deuterium-tritium) at Joint European Torus (JET) is being investigated in the frame of EUROfusion's programme. The development of reliable ~4.0 MA scenario at q95 ~ 2.7-3 compatible with DT operation and pulse length of 5s together with the optimization of the scenario for high performance at 4.0 MA to achieve Pfus = 15MW in DT are the main experimental goals for the study related to "Baseline scenario for DT" at JET. For this purpose, data analysis of the experiments of the DT campaign needs the bolometric measurements of the energy losses with electromagnetic radiation and neutral particles, which is the essential diagnostic tool for hot plasmas.

At JET, where the plasma has a complex shape, the measurement of the spatial distribution of radiation losses employs several multichannel bolometric arrays with different directions of sight (horizontal and vertical) installed in a poloidal cross-section. Moreover, additional channels are used for obtaining the radiation loss distribution in the region of the divertor for radiative experiments. Tomography is used for reconstruction from the set of line-of-sight integrated measurements of brightness (in W · m–2) to the local emissivity (in W · m–3) profiles.

As the result of the data analysis, the radiated power in tokamaks are provided by JET bolometer tomography reconstruction. In addition, energy balance as well as reliance on discharge and the time evolution of radiation loss profiles are delivered for investigation of the plasma and impurity transport in baseline scenario for DT.

Automatic recognition of anomalous patterns in discharges by recurrent neural networks

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Anomaly detection refers to the problem of finding patterns in data that do not conform to expected behavior. These off-normal patterns are often referred to as anomalies, outliers, discordant observations, or exceptions in different application domains. The importance of anomaly detection is due to the fact that anomalies in data frequently involves significant and critical information in many application domains. In the particular case of nuclear fusion, there are a wide variety of anomalies that could be related to particular plasma behaviours, such as disruptions or L/H transitions. In the case of unknown anomalies, they probably represent the major proportion with respect to the total anomalies that can be found in fusion. Whether the anomaly is known or not, all the anomalies in a nuclear fusion device should be detected by using the same approach, i.e., the physical state of the plasma during a shot should be reflected in some of the thousands acquired signals.

The amount of data per discharge is huge, with up to 10GBytes of data per shot in JET (or the estimation of 1TBytes in the case of ITER). This involves that the detection of anomalies in the massive fusion databases could be hardly possible without any machine learning technique. In this article, we study the application of Deep Learning and a particular recurrent neural network called LSTM to detect anomalies in a discharge. LSTM has emerged as a success way to learn sequences, and in specifically, to perform forecasting of a waveform based on the values of their past samples. Our approach proposes firstly to train the LSTM with a set of discharges in order to learn regular waveforms of different signals acquired in a shot. After that, the LSTM can be used to perform forecasting during a discharge. Thus, an alarm could be raised when there is a significant difference (greater than a given threshold) between the prediction and the actual value of the waveform. The detection of an anomaly could be confirmed when there are several alarms for different signals at the same time (or at a given interval time) in a shot. This approach has been tested in the database of the nuclear fusion device TJ-II (located in Madrid, Spain). The main results regarding the application of the approach and the effects of the parameters such as the threshold of difference and the width of the interval time are discussed in detail.

Automatic recognition of plasma relevant events: implications for ITER

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Big data analytics deals with heterogeneous, complex and massive datasets to identify patterns that are hidden inside enormous volumes of data. ITER is expected to acquire more than 1 Tbyte of data per discharge. This amount of data comes from hundreds of thousands of signals acquired in each discharge. Signals can be time/amplitude series, temporal evolution of profiles and video-movies (infra-red and visible cameras). Therefore, the ITER database satisfies the conditions of heterogeneity, complexity, size and hidden patterns to use big data techniques.

ITER is a device not focused on basic research on plasma physics. Its aim is to produce high performance plasmas to approach the operation to reactor regimes. Vast amounts of hidden information will remain in the ITER databases and it will be worth to extract as much knowledge as possible from the data. Due to the large number of signals per discharge and the shot duration (30 minutes), automatic methods of data analysis will be necessary.

This work puts the focus on the use of big data algorithms for the automatic recognition of plasma relevant events in huge databases of nuclear fusion devices. A relevant event can be any kind of anomaly (or perturbation) in the plasma evolution. This is revealed in the temporal evolution signals as (more or less) abrupt variations (for instance in amplitude, noise, or sudden presence/suppression of patterns with periodical structure). Examples of events can be the input of additional power, gas injection, confinement transitions or diagnostic perturbative methods. Obviously, the automatic searching process for relevant events will have to find the above examples but the most interesting cases will be those ones whose temporal location is not explicitly related to known phenomena.

A first step to perform automatic data analysis is to recognise anomalies in individual signals. A second step is to determine characteristic times of anomalies. A third step is to identify the set of signals that show interesting patterns in the same intervals. As mentioned, the phenomenology behind these patterns can be unknown and it will be necessary to put together signals and time intervals that can correspond to the same type of physics event. To accomplish this, the fourth step is to use unsupervised clustering techniques to assign labels to each class of physics event. Once the clusters are formed, the fifth step is the creation of supervised learning classifiers for the automatic recognition of physics events. After having determined the different groups, there will be available sets of common signals and temporal locations where the same patterns appear. Therefore, there will be statistical relevance to look for a physics interpretation of the different labels found. It should be emphasised that after an off-line analysis, steps 1, 2 and the classifications resulting from step 5 can be carried out in real-time.

Specific details about these 5 steps will be given with emphasis on techniques of steps 1 and 2.

Disruption Predictor Based on Neural Network and Anomaly Detection

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Existing disruption predictor based on machine learning techniques, have good prediction performance but all these methods need large training datasets with many disruptions to develop successful predictors. Future machines are unlikely to provide enough disruption samples since they cause excessive machine damage and these models cannot extrapolate to machines other than it was trained on. In this paper, a disruption predictor based on deep learning and anomaly detection technique has been developed. It regards the disruption as an anomaly, and learns on non-disruptive shots only. The model is trained to extract the hidden features of various non-disruptive shots with a convolutional neural network and a LSTM(Long Short-Term Memory) recurrent neural network. It will predicted the future trend of selected diagnostics, then using the predicted future trend and the real signal to calculate a outlier factor to determine if a disruption is coming. It is tested with J-TEXT discharges and can get comparable if not better performance to current machine learning disruption prediction techniques, but without requiring disruption data set. This could be applied to future tokamaks and reduce the dependency on disruptive experiments.

Real-time ELM recognition system based on deep learning

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Based on the deep learning method, this paper introduced a set of ELM real-time recognition system on HL-2A. The system uses 5200 shots data (about 241,900 data slices) for learning. After more than 70 adjustments, a 22-layer convolutional neural network is obtained. The network can recognize whether a 30ms data slice contains the ELM signal, After smoothing, the system can recognize the ELMy H-mode and output the start/end time of H-mode.

The system has recognized all historical data of the HL-2A since it achieved stable H-mode discharge in 2009. A total of 1665 shots of H-mode has been recognized, of which 35 shots were misidentified, with the false positive rate (FPR) was 2.10%. In the actual 1634 shots of H-mode, the system missed to recognize 4 of them, with the false negative rate (FNR) was 0.24%. In a total of 25,321 shots, the recognition accuracy rate was 99.85%. For the data of latest years, the system obtains good results with a FPR of 3.69% and a FNR of zero. In the correctly recognized shots, the error of the H-mode start/end time less than 20ms. The data quality of HL-2A in different discharge periods has a certain correlation. These results demonstrate that the system has good generalization ability and recognition precision to fulfill the requirements for applying to new data.

In this experiment, a total of 14,900 data slices were used to test the speed of the neural network in the simulated real-time environment. The average calculation time of a single slice is 0.46ms less than PCS control cycle which is 1ms. This result show that the system can satisfy the calculation speed requirements of the real-time ELM recognition.

Since the HL-2A experimental has not yet ended, the system has not been transplanted to PCS, but the recognition precision and the calculation speed of the system have satisfied the requirements of real-time ELM recognition and real-time ELMy H-mode control.

This research introduces the deep learning method into the fusion research of HL-2A, and obtains the results that can satisfy the actual production requirements. It proves the feasibility and advantages of the combination of artificial intelligence method and fusion research field represented.

New decimation method for fusion research data

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New fusion research experiments will generate massive experimental data. For example, ITER will have above one million of variables from control signals and diagnostic systems. Some of these variables will produce data during long pulse (about 30 minutes) experiments and other will generate data continuously. Just to have a clearer idea of the problem, ITER estimates more than 10 GBytes/second of data flow during experiment pulses. In this context, fusion research appears in the scope of the big data where both search and access functions require new approaches and optimizations.

One common data access functionality is decimation. It allows to retrieve a limited number of points of the total. One classical mechanism of decimation is downsampling by an integer factor called step. It consists on selecting a value every 'step' number of values. The main characteristic of classical decimation is that selected values are uniformly distributed along the total. However, in case of time evolution experiment signals, the relevancy of data is not uniform. There are some intervals where the provided information is more complex and richer, and usually more interesting from user point of view.

The contribution presents a new data decimation technology for unidimensional time evolution signals where the limited number of accessed points are distributed based on data interest level. The new method implements, on one hand, a heuristic function which is able to determine the level of interest of an interval based on its data characteristics, and on the other hand, a selection algorithm where points are distributed based on weighted intervals. The work includes detailed explanation of this new decimation method, results of its application to real experiment signals with different sampling rate and frequency, and comparatives with classic decimation method.

A database dedicated to development of machine learning based disruption predictors

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Machine learning based disruption prediction method have exhibited good prediction performance with higher success rate, low false alarm rate and earlier warning time than physics based methods. One important thing pushed recent advances in machine learning field is high-quality training data. So a database with rich set of accurate disruption related labels is crucial to the development of a high performance disruption predictor. On J-TEXT in order to fast and iteratively develop machine learning based disruption predictors, a database dedicated for machine learning disruption prediction is built. This database provided not only disruption related labels, interfaces for querying the data based on user proved filter and auto generation of train and test data but also interface for benchmark the predictors. Its modular design allow us to plug-in various shot analyze modules which scan the diagnostic database and generate different labels automatically. These modules can be scheduled and run parallel on a cluster which speed up the shot analysis process. The generated labels are inserted into a MongoDB NoSQL database for later querying. But one major hurdle for machine learning disruption prediction is they perform un-acceptably poor on devices other than they are trained on. It requires data from many different tokamaks to possibly develop a cross machine predictor. So this database also has a data import module which reads diagnostic data from different data source such as MDSplus and store them as HDF5 files with unified data structure on a parallel file system. Now it has J-TEXT data, but it is easy to import data from different machines and provide unified data access interface.

Implementation of an FPGA-based DAQ and Processing system for Neutron-Diagnostics using Nominal Device Support, OpenCL and MTCA

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Thanks to their flexibility, FPGA-based Data Acquisition (DAQ) and processing systems are well suited to develop applications that are standard, modular, maintainable and scalable. There is currently a variety of FPGA-based solutions implementing DAQ systems and there are different approaches to design the hardware inside the FPGA. Each approach has its advantages and drawbacks, in terms of ease of the design cycle, performance, and portability among technologies. The solutions chosen by ITER CODAC use traditional HDL-based tools for MTCA-based systems or LabVIEW/FPGA and IRIO open source tools for PXIe systems (FlexRIO) and cRIO. The purpose of IRIO is to simplify the development cycle and the integration with EPICS. The main drawback is that LabVIEW/FPGA is only valid for hardware targets developed by one manufacturer. In this work, we evaluate a new approach valid for DAQ devices of multiple hardware architectures and manufacturers. This approach relies on the use of a new framework, which combines the power of software driver standardization provided by ITER with Nominal Device Support (NDS v3) with the portability and short development cycle provided by hardware description using OpenCL standard for FPGAs. NDS creates an abstraction layer, which separates the control system interface from the device driver implementation. The hardware description is done in OpenCL by means of Kernels that are managed by the host using the OpenCL runtime library. With these tools combined, the device driver is independent of the control system, while also being compatible with any hardware supporting OpenCL. Besides, we gain the heterogeneous processing capabilities of OpenCL.

In this work, the advantages of this approach, called IRIO-OpenCL, will be demonstrated. A use case for data acquisition and processing system is implemented to estimate the fusion power through the average neutron flux emitted by the plasma. Measurements for this use case originate from detectors on a fission chamber. The DAQ system digitizes the pulses produced by the neutrons in the fission chamber and, applies hardware signal processing algorithms such as filtering to increase the signal to noise ratio, or the three most used algorithms to estimate the neutron flux: Pulse Counting, Campbelling, and Current counting. All the high-performance tasks of acquiring and processing involved in the algorithms are carried out by hardware executing the OpenCL kernels.

On the hardware side, the system uses a MTCA chassis with a carrier hub, which provides an optical PCIe interface, connected to the host computer. The acquisition and processing device is the N.A.T Advanced Mezzanine Card (AMC) module NAMC-Arria10-FMC board. This board consists of an IntelFPGA ARRIA10 and includes a FMC (FPGA Mezzanine Card) connector where the AD-DAQ2FMC-EBZ module providing two 1GS/s ADC channels together with two 1GS/s DAC channels is installed.

Real-Time Processing the MSE data with GPGPU in KSTAR

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The KSTAR has MSE (Motional Stark Effect) diagnostics devices for measurement of plasma current density distribution. Real-time MSE is an essential diagnostic for advanced control over the q-profile in tokamaks [1]. The KSTAR MSE diagnostic data measurement system measures and stores a total of 25 signals and 2 reference signals at a rate of 2MHz sample per second. The KSTAR has developed the uTCA.4 form factor controller, KMCU-Z35 and KMCU-Z30, for KSTAR digitizer standardization, it has been used in some diagnostic data acquisition systems from 2016. The KMCU-Z30 can simultaneously transmit the same data in three directions from a single ADC digitizer (one PCIe and two SFP+), allowing device configurations to be configured individually for real-time control without interfering with raw data storing device system. In the 2018 KSTAR campaign, we plan to apply the KMCU-Z30's data branching function and digital lock-in algorithm for real-time MSE which we plan to implement using GPGPU for fast data processing of high sampling data. This paper introduces a detailed design concept of real-time MSE DAQ system using GPGPU and their performance results. This paper will describe the overall structure of the MSE DAQ system and performance of the real-time MSE data in KSTAR.

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Exploring MDSplus data-acquisition and analysis software with JupyterLab

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MDSplus is a software tool dedicated to data acquisition, storage and analysis used for complex scientific experiments. MDSplus has been used for data managment for fusion experiments for years, and this paper will demonstrate it can be used for a wide variety of systems as well. We will show how to set up a very simple experiment, manage data retrival, storage and consumtion using MDSplus and Python.

A custom device is used as the data provider. This device is an open-source electronics platform hardware that consists of a microcomputer and sensors. It will be able to read inputs from the sensors and the data collected will then be stored in the MDSplus tree structure for future analisys and processing.

JupyterLab is used as the interactive development environment. It allows for code development, notebooks and data visualization. In it, our MDSplus device will be defined, executed and the results will then be visualized and explored.

Fast scenario design for alternative magnetic diverted discharge on EAST

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Like any advanced tokamak devices, high heat flux to the divertor target is always a crucial issue for EAST to operate in high performance and steady sate [1]. Advanced magnetic diverted configuration, like snowflake (SF) and X-divertor, is one of the attractive methods to spread the heat fluxes over divertor targets in tokamak because of enhanced scrape-off layer transport and an increased plasma wetted area on divertor target. Exact SF configuration for EAST is only possible at very low plasma current due to poloidal coil system limitation. EAST can be operated in quite flexible plasma shapes like double null (DN) or signal null (SN) divertor configurations, but the external poloidal coils location was not optimized for the advanced diverted configurations. However, an alternative magnetic diverted configuration [2], characterized by two first-order X points where one is located in the primary separatrix and the other is outside the vacuum vessel, can be optimized to satisfy EAST constraints, like maximum current on poloidal field (PF) coils. In order to build the alternative magnetic diverted discharge in EAST, a fast scenario design tool based on EFIT & F2EQ code has been developed. A series of coil currents can be calculated and optimized based on a given alternative magnetic diverted configuration and desired pulse length. These coil currents will be offered to plasma control system (PCS) as feedforward coil currents. Then desired alternative magnetic configuration will be achieved at the scenario with specified time slice with the help of the designed feedforward and the feedback coil currents by RZIP or ISOFLUX algorithm control. This scenario design tool can provide a fast way to operate a new configuration discharge without using time-consuming TSC code, and reduce the operation runtime requirements for a new diverted configuration discharge. This method can also provide a fast scenario development for further new diverted configuration like negative triangularity shape or ITER-like SN configuration on EAST.

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Rapid prototyping of advanced control schemes in ASDEX Upgrade

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The integration of advanced control schemes is becoming more important as the development of fusion experiments progresses.

The ASDEX Upgrade discharge control system (DCS) is designed to be adaptable via configuration, no recompilation is necessary to change the behaviour of the control system.

In order to enable advanced control schemes the required information has to be available during the discharge.

With the DCS satellite concept the control system can easily be extended by including e.g. diagnostics, actuators and data processing nodes.

In this paper the extension of DCS for rapid prototyping of control schemes is discussed.

For tokamak operation disruptions are posing a major threat especially for large devices such as ITER.

Therefore disruption avoidance is an active field of research and the inclusion of avoidance schemes into DCS as part of exception handling is ongoing.

For the case of H-Mode density limit disruptions an avoidance scheme using central heating has been implemented and successfully tested on ASDEX Upgrade.

To easily add and modify input signals used for the avoidance scheme a new application process (AP) has been implemented which uses the C++ Mathematical Expression Toolkit Library (ExprTk), which enables the inclusion of run-time mathematical expressions into DCS.

The AP is operated separate from the central DCS as a DCS satellite, which allows modular inclusion of e.g. diagnostics, actuators and data processing nodes.

This is done to be able to test and validate the calculations without having to make changes to the central DCS.

For the disruption avoidance scheme the calculated signals, namely the confinement scaling $H_\mathrm{98,y2}$ and the empirical critical edge density fraction $n_\mathrm{e,edge}/n_\mathrm{e,edge,crit}$, are evaluated in a state space which defines an \textit{area of disruptivity} which the scheme tries to avoid.

In case the discharge approaches this area central auxiliary heating is requested from actuator management.

The heating is continuously increased with decreasing distance up to full allocated heating power when the border is reached.

The avoidance scheme has been successfully demonstrated on ASDEX Upgrade exploiting these new features for rapid development and testing.

It is envisioned to apply the same methods for testing and demonstrating of other control schemes before they are included into e.g. exception handling.

Real-time MHD Analysis Computer System Design, Architecture, and Integration with PCS

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PPPL and Columbia University are together building a solution for analyzing rotating magnetohydrodynamic (MHD) mode measurements in real-time on KSTAR for use in new KSTAR Plasma Control System (PCS) algorithms supporting disruption prediction and avoidance research on KSTAR. The KSTAR PCS is based on the General Atomics (GA) PCS and uses the same software infrastructure with a Reflective Memory (RFM) interconnect between the existing real-time computer and the acquisition devices. A new real-time computer currently being configured in-house will complement this design, providing a second system with additional capability connected via RFM to the existing real-time computer in a passive way so as not to disturb ongoing operations. The system has localized data acquisition that can acquire 16 signals at 300 kHz and 16-bit resolution using differential inputs. These channels will connect to an existing toroidal array of Mirnov coils via a buffer chassis and operate both autonomously as well as synchronously with the existing PCS. There are algorithms that will run on the real-time computer hardware PCIe-based FPGA alongside companion algorithms running on the CPU as part of a new PCS category specific to real-time MHD system operation. The computer will provide 16 cores at 3.5 GHz each, and communication within the computer, and between the computer and the hardware FPGA will utilize shared memory for fast, efficient, and low latency data propagation.

Integrated Data Acquisition, Storage and Retrieval for Glass Spherical Tokamak (GLAST)

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GLAST is a series of small spherical tokamaks with an insulating vacuum vessel of major and minor radius of 20 and 10 cm respectively (for GLAST III). It is installed in NTFP, Islamabad, Pakistan. The purpose of these experiments is to understand different aspects of tokamak operation such as startup phase and then sustaining tokamak plasma for a sufficiently long time. In case of a non-metallic chamber, plasma is prone to many instabilities due to absence of passive stabilization which is only provided by metallic chamber of tokamak. In this situation, measurement and correction of various type of currents and magnetic fields responsible for plasma generation becomes very important. An efficient data acquisition system serves the purpose of acquiring the raw data from all diagnostics ranging from magnetic diagnostics to plasma diagnostics and storing this raw data for post processing by different connected users.

The data acquisition (DAQ) system of this tokamak is in evolving process and is built from scratch. It integrates different data sources as an assortment of data acquisition hardware and software. It is based on the novel data acquisition technology using National Instruments' data acquisition cards. This paper presents the evolution of the hardware setup and software implementations of the DAQ system for GLAST tokamak. This system includes all the sub-systems required for successful acquisition of a signal from the transducer to the DAQ hardware and then to database. The hardware for the DAQ system comprises of National Instruments USB DAQ Cards, i.e., NI6363 USB X series. The software layer for front and back end handling is developed using LabView and Matlab for acquisition, storage, data retrieval and post processing purpose. The main features of the systems include system configuration, shot implementation, data saving and data sharing between the connected users. In addition to the evolution of DAQ system, future directions about control system of GLAST tokamak experiments has also been highlighted.

From Tore Supra to WEST : Evolution of CODAC infrastructure

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Since 1988, the Tore Supra limiter tokamak at CEA Cadarache has been in operation, and obtained the record of the longest plasma duration of 6 minutes 30 seconds and over 1000 MJ of energy injected and extracted. In 2013 Tore Supra went through major changes to become the WEST tokamak (Tungsten Environment in Steady state Tokamak). The tokamak was upgraded into an X point divertor device. Taking advantage of its long discharge capability, WEST's goal is to minimize technological and operational risks of the actively cooled tungsten divertor for ITER.

Concerning data acquisition, the "Control, Data Access and Communication" (CODAC) system has been redesigned in order to satisfy the performance and evolutions needed by researchers. A new architecture has been developed and deployed on major plant systems all around the fusion reactor allowing to fulfill the performance requirements of acquisition units, and for greater maintainability.

This paper describes the WEST CODAC system created in 2013 and evolving since. The introduction briefly presents Tore Supra and the original CODAC based on VME technology. The main section exposes the upgrade of Tore Supra into WEST and the architecture evolution. The diskless Linux system and the attached PXI or VME systems are described with the tests realized for the CODAC system. During three WEST experimental campaigns, the new CODAC infrastructure ran over major plant systems like magnetics or power plant diagnostics. Results from those systems are shown in the last section leading to conclusion and prospects.

After two years of operation, three experimental campaigns and more than 4000 pulses, the WEST CODAC infrastructure has proven its efficiency and reliability, while the CODAC team still working on possible improvements.

State-full Asynchronous Event Server and Clients

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The co-ordination of many processes/threads across many machines is a task intrinsic to plant, acquisition and machine control for all sufficiently complicated experimental devices. Although Inter-Process-Communication protocols have been developed for many applications, following decades of Tokamak operations at the Swiss Plasma Center, we decided to ask what specific messages, specifically state-changing messages, were helpful in synchronising and/or monitoring a heterogeneous set of collaborative computers that surround such experiments such as our TCV tokamak.

This contribution presents the design criteria of our CESIS server/client software that was inspired from the simplicity, yet high usefulness, of the MDSplus UDP event-packet broadcast approach. CESIS was implemented as a C-language shareable library client and server together with a Python calling class. Particular attention was taken to aim at thousands of events able circulate per second and to permit many such servers to co-exist, even on the same machine. A preliminary installation to monitor the plant and acquisition systems on the TCV tokamak is presented and simple extensions to integrate state-changes with local program stacks explained. Simplified to require minimise dependencies, the design, and example code run well on very minimal hardware employing state-less UDP packets with error checking and reporting.

Application of LHD Post Data Analysis Systems to the KSTAR Project

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The authors have been porting post data analysis systems used for the LHD project to the KSTAR project. The first one is AutoAna, or Automatic Analysis System. It is a system to manage programs to produce physical data for the LHD experiment. All the physical data for the LHD experiment is stored in the Kaiseki Server, or Analysis Server. Until the end of the fiscal year 2018, the Kaiseki Server handles 800 diagnostics, and the total number of the physical data is about 12 million. There are dependencies among these diagnostics, and physical data of some diagnostics are calculated from other diagnostics data. For example, in order to execute the transport analysis programs, it requires various source data, such as the distribution of electron temperature and pressure. Sometimes, these source diagnostics data may be modified, because of correction of diagnostics devices or modification of the programs. When one data is modified, it is required to recalculate all the physical data that use the modified data as source data. AutoAna automatically executes the calculation programs to keep the dependencies among the physical data. When one data is registered into the Kaiseki Server, it checks if there exists physical data that uses the newly registered data. If such data exists, AutoAna starts the analysis programs to produce the dependent data. AutoAna is also useful for the post data analysis because it runs the analysis program right after the necessary data is available. A typical LHD experiment is a repetitive plasma discharge experiment carried out every 3 miniates. Within the short break of the repetition, the AutoAna provides the important information of the on-going experiment.

The other system is MyView2. MyView2 is a python-based data visualization tool, and it has developed mainly for the visitors so that they can use MyView2 to retrieve and analyze the necessary data for their study soon after they arrive at NIFS. Because it is written in Python, it supports various OS such as MacOS, Windows and Linux. Therefore, the visitors can run MyView2 in the computers that vistos bring. The graph layout and the data source can be flexibly customized using a GUI operation. However, using the configuration files prepared in advance, the visitors don't bother customizing MyView2 to visualize the necessary data.

Basically, both AutoAna and MyView2 are developed so that they can be used for generic experiments and do not depend on LHD experiment too much, they can be relatively easy to use for other experiments. By porting to the KSTAR project, the authors demonstrate the utility of the tools for other experiments.

Design for the Distributed Data Locator Service for Multi-site Data Repositories

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In modern fusion experiments, the remote data access has already come into wide use in both domestic and international research collaborations. SNET mutual data exchanging platform in Japan interconnects four fusion experimental sites, LHD, QUEST, GAMMA10, and TST-2, over 1 000 km distance and enables the remote collaborators access each site's data seamlessly as if they were in local site. Also, ITER plans to replicate the full dataset to the REC, over 10 000 km distance, which will equip massive computer resources to analyze the ITER physics data off-site. The outcome results would possibly be shared with international collaborators of other sites. In such multi-site data repository environments, the data location informing service will be essential to find the nearest repository from which users can retrieve the data most efficiently. Considering the latency time becomes more than 100 milli-seconds for inter-continental network transactions, it is more preferable to distribute not only the data repositories but also the locator servers to multiple sites in the world. Since the data locations will be served by a relational database (RDB), such as PostgreSQL, real-time data synchronization between multiple locator RDBs will be necessary to provide a consistent service over the world.

PostgreSQL 9.0 and higher has a mechanism to replicate the database from a single master to multiple slaves, which is called as "streaming replication." Since PostgreSQL 9.4, it has been equipped with the multi-master bi-directional replication (BDR) capability. To register the analyzed outcome results at each site, BDR of data indexes will be necessary for the worldwide distributed data indexing services.

From the viewpoint of the data consuming clients, the most important thing is to find out the best data locator and repository site with which the clients can communicate at the highest speed through the network. There are some methods to find the neighbor place on network; typically, the DNS top domain shows the country region but have some exceptions like "iter.org." GeoIP is another network service to know where the site IP address exists geographically, however, it is also reported that the precision is not necessarily so high. It must be also noted that geographical distance does not corresponds to the network neighborhood.

Therefore, this study proposed to use the ICMP echo reply (ping) or TCP SYN+ACK response (tcpping) to measure the network distance to each data replication site and then decide which site the client can reach with the minimum latency. The latency measurement should be once made before requesting the data, and the values can be stored for some while in each client. The combination uses of the BDR of locator RDBs and the site pre-selection by latency measurement have been tentatively implemented and verified. The test proved that the client can automatically choose the nearest data site, and the newly inserted record was replicated to the other locators within a definite delay. We can conclude that this method is effective for the multi-site data environments, such as SNET in Japan and also ITER with the REC.

Control system of Neutral Particle Analyser in energy sweeping mode.

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The energy-sweeping mode was recently used for measurement of the charge exchange flux energy distribution every 3-5ms via single-channel electrostatic neutral particle analyzer (NPA) in stellarator U-3M [1].The magnetic mass-separation (MS) part of NPA was omitted during these energy-sweeping measurements.The MS part is required for some experimental conditions in a case of presents of different masses in plasma and as the efficient suppressor of parasitic influence of plasma radiation on the NPA measurements (due to geometrical factor). The MS magnets of about 10 Henry are used in our NPA diagnostics. A variation of current troughs MS magnet from zero to 0.3 A is required for energy-sweeping mode application in the energy range of 0-2keV. The 3-5 ms duration of this variation is required for U-3M. The L/R time constant of the MS magnet is about 200 ms. Required variation speed can be achieved by application of rather high voltage to the MS magnet. The voltage applied to electrostatic part of NPA should be varied from zero to 500 V (measured energy is 4.5 times higher then applied voltage). The dependence of electrostatic voltage on MS current is nonlinear, and should correspond to the NPA calibration curve. The problem of simultaneous variation of the voltage at electrostatic part and current in MS magnet in accordance with NPA calibration is solved in our work. In some cases, in particular in high voltage and power applications [2] or in the high inductance case under consideration simple square wave pulses (without pulse width modulation) are used for the control. We use STM32F100 microprocessor as a control unit. Square wave 310 V pulses of variable duration are used for control of MS magnet current. The IGBT bridge is used as a power unit of MS magnet. One pair of the bridge is used at the current rise stage; another pair is applied reverse voltage for fast decay of the MS magnet current. The digital to analog convertor unit of STM32F100 microprocessor is used for the electrostatic voltage formation. Since parameters of MS magnet and electrostatic parts of NPA are fixed, no feedback is required in our system. The predefined set of durations for MS current control and waveform of electrostatic voltage are stored in the internal memory of the microprocessor. The direct memory access unit of the STM32F100 microprocessor is used for synchronized output of two control signals.

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Design of the Interlock System for MITICA

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MITICA is the prototype of the ITER full-size Heating Neutral Beam injector (HNB). It is being installed in the Neutral Beam Test Facility established at Consorzio RFX in Padova, Italy. The operation of MITICA requires the integrated collaboration of a large set of plant systems, including high-voltage power supply (-1MV / 60 A), radio frequency power supply (4 generators, 0.9 – 1. 1 MHz / 200 kW), extraction grid (12 kV/ 140 A) and plasma grid filter (15V / 5 kA) power supply, vacuum pumping and gas injection, cooling system, and cryogenic plant. A dedicated Interlock System will be in charge of the integrated investment protection of the MITICA experiment during operation. It will implement cross-protection actions to avoid that faults generated in single plant systems could propagate to other plant systems and evolve into system-wide faults. Personnel and nuclear safety is taken care of in a dedicated safety system and, therefore, is not part of the MITICA interlock system.

The main requirements of the interlock system can be summarized as follows:

- Reaction to faults within predefined time constraints. Fast and slow protection actions will be implemented. Fast protection shall be capable to intervene in less than 10 us, from fault detection to commands of protection actions, whereas slow protection shall operate in less than 20 ms.

- Two-layer system architecture structured in central and plant system interlock System. Two plant systems interlock systems (PIS) will be implemented: the HNB PIS that is the prototype of the ITER HNB PIS and the MITICA PIS that will manage the protection of the MITICA-specific plant systems such as the cooling and the cryogenic systems.

- Fast prototyping to be ready for the upcoming MITICA power supply integrated commissioning that is expected in the first part of 2020.

The paper will initially present the fault analysis carried out on MITICA from which the Safety Instrumented Functions (SIF) are derived. The allocation of SIFs to the Safety Integrity Levels as per IEC 61508 technical standard is then presented

The hardware and software architecture will be then discussed in detail, with reference to a two-stage implementation approach, aiming the first one to realize a prototype for the power supply integrated commissioning, the second one to provide the entire system where the HNB PIS complies with the ITER requirements for plant interlock systems.

An efficient MHD equilibrium solver for control oriented transport models

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Successful reproduction of advanced tokamak scenarios in burning plasmas like ITER will strongly rely on sophisticated plasma control systems. Among the novel control physics challenges required to accomplish the control needed for scenario execution, the internal profile regulation plays a fundamental role [1]. The non-linear dynamics involved in current profile control are described by the resistive magnetic diffusion equation (MDE) expressed in flux coordinates. These coordinates are constructed out from the magnetic geometry imposed by the MHD plasma equilibrium condition. During a tokamak discharge the plasma equilibrium, its internal profiles and the magnetic geometry change, therefore, the flux coordinates should be updated during this evolution. However, the equilibrium is held fixed and the update of the flux coordinates is not yet performed by the newest control-oriented transport codes [2,3].

This simplification is made for practical reasons. On one hand, the solution of the Grad-Shafranov equation for general axisymmetric equilibria involves two nested loops (one inner loop to treat the non-linearity and one outer loop to treat the eigenvalue nature of this equation [4]) that make standard equilibrium solvers unacceptably expensive and poorly convergent. On the other hand, the resulting inconsistency is, in many cases, not severe and effective feedback control of the current profile has been achieved for some relevant scenarios [2]. Despite this partial success, an efficient method to couple the equilibrium problem with the MDE solver in control-oriented transport codes would represent a significant improvement. With such self-consistent approach, more accurate feedback controllers could be designed, better feedfordward controllers for scenario planning would be available and a fast and reliable control-oriented predictive simulation tool could be developed.

In this work, a new flux mapping method that allows a rapid estimation of the RHS of the Grad-Shafranov equation, including the eigenvalue, is introduced. This method significantly accelerates the outer loop and improves the convergence properties of the solver. In particular, equilibria with arbitrary prescribed safety factor and pressure profiles can be obtained with few outer iterations (less than five for low-beta plasmas). Moreover, the change in the equilibrium and the magnetic geometry during a control-oriented transport simulation can be recovered without the outer loop, using only few Newton iterations in the inner loop to treat the non-linearity. We show that the new mapping method can also be used to compute the internal plasma equilibrium using only the total plasma current, the shape of the separatrix and the spatial profile of the field line pitch angle. This approach differs from the traditional equilibrium reconstruction method (which uses the pitch angle information as a constraint [5]) and have many potential applications in the design of control systems requiring spatial information of the plasma parameters.

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Validation of the Fenix ASDEX Upgrade flight simulator

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Fenix [1] is the ASDEX Upgrade (AUG) flight simulator based on the 1-D ASTRA transport code coupled with the 2-D SPIDER equilibrium solver [2] and Simulink (simulation platform from MATLAB). Fenix is designed to simulate, prior every discharge, the entire discharge starting from ramping the Toroidal Field coils (TF), plasma start-up, flat-top and ramp down and finishing with ramping down the TF coils. Currently, controllers for position, shape, fuelling and heating are implemented in the same manner as the controllers used at AUG. A model of the Poloidal Field coils and their corresponding power supplies is also included, as well as basic models of heating actuators such as Electron Cyclotron Resonant Heating, Neutral Beam Injection and fuelling using either pellets or gas.

For a first assessment of the quality of simulation models, Fenix simulations have to be validated against already executed discharges. This contribution compares the measured behaviour of various ASDEX Upgrade discharges with their corresponding Fenix simulations. It also describes the implementation of more realistic gas valve and heating actuator models.

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Navigational Data Management - A general approach to representation and exploitation of relationships in scientific data sets

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Across research disciplines, the size, complexity, and heterogeneity of data sets is growing rapidly. Large projects are often long-running collaborations between evolving groups of researchers. Integrating and documenting these large heterogeneous data collections is a requirement for these data to be exploited, and for them to retain their value and meaning over time. The traditional approach to these data management problems has been to have hard- coded, application-specific solutions. The Navigational Data Management (NDM) project provides a general solution that can be applied regardless of the science domain. NDM represents data and annotations as generalized objects, with relationships stored as labeled property graphs. Universal Resource Identifiers (URIs) provide a mechanism to refer to external data objects like files, MDSplus records, or drawings. The system stores metadata and data schemas and application behaviors as first class objects, allowing them to be modified, added to, and even annotated as the needs of the research group evolve. This new toolset is being applied to initial projects at several institutions as its development continues. NDM is coded as a single page application (SPA) using modern javascript front-end tools and a graph database as the back-end.

NDM was developed using an informal agile, prototype and iterate methodology. We will lay out the overall project design and how it changed in response to both technical challenges and initial user input. As the set of use cases, objects and relationship types grows, we revisit and generalize the software to accommodate them. This process will continue in order to become a system that can be applied across science domains and applications.

Dockerizing MDSplus for use with custom data collection devices

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Advancements in data collection techniques call for the use of MDSplus not just as a centralized server, but running close to the data collection devices as well. To facilitate this, a set of Docker images are being developed to deploy miniature, self-contained installations of MDSplus. The goal being that every device could run alongside a small computer for processing and inserting the data into the MDSplus tree.

The use of MDSplus in its distributed mode allows for small, easily replacable processes running to collect and report only the data relevant to its device. This would decouple the needs of one device from the rest, and allow a more infrastructure-as-code approach to data acquisition.

We will detail the methods we used to dockerize MDSplus, along with any common mistakes one could run into. In addition, we will describe the process of configuring an MDSplus image to work with your own device, and provide the example resources we have created for our own use. Finally we will include a comparison of performance between regular and dockarized MDSplus, noting any potential pitfalls.

A full stack data acquisition, archive and access solution for J-TEXT based on Web technologies

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Flexible and fast deployable data acquisition system has been always demanded by tokamak facilities. This work proposes a full stack data acquisition, archive and access solution for J-TEXT based on Web technologies. This solution is based on a single unified software. This software can be configured into data acquisition software, data archiving server as well as data access and management server. All of the above systems are using the same communication interface: HTTP RESTful API which unifies the status monitoring, command sending even diagnostic data accessing. A working system on J-TEXT ware built using this solution. It consists of data acquisition system for ECEI and an archiving system build on HDF5 files. A data management system and a unified data access interface are also implemented using this solution. User can access data from the HDF5 or MDSplus server without noticing which data source is providing the data. All the user interfaces in this system are built as web pages which can be accessed using web browser on various devices. It is integrated into J-TEXT CODAC system which is based on EPICS CA and MDSplus. This solution provides unified data access interface and unified software for deployment.

Strategy for diagnostics integration into W7-X CoDaC for OP2

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The superconducting stellerator Wendelstein 7-X has successfully concluded its third operation phase in October 2018. The machine will see substantial changes during the next two years, when an actively cooled divertor will be installed, as well as many new diagnostic systems. The W7-X Control, Data Acquisition and Communication (CoDaC) group is responsible for the integration of all new diagnostics into the W7-X control ecosystem (around 10 Systems) as well as carrying out significant upgrades to the I&C and data acquisition of another 15 systems. Some of those have been operating autonomously with only minimum integration into the central infrastructure up to now. This was due to time and resource constraints during the previous operating phases.

This paper will present an overview of the integration challenges for OP2 both from a technical perspective as well as highlight the strategy employed by the W7-X CoDaC group to meet those challenges within the time and resource budget. The cornerstone for this strategy is standardization as far as possible to minimize individual integration effort. One example is the development of a generic, flexible and scalable camera acquisition framework based on µTCA hardware for cameralink, camerlink HS and GigEVision. This will enable CoDaC to compartmentalize the specifics of any individual camera - provided it is compliant with the aforementioned standards – and treat all cameras virtually identically for integration purposes.

A standardized software interface has also been developed (GeRI), which will greatly simplify the software interface of systems not yet fully integrated into the CoDaC infrastructure. These currently only rely on the supply of an external hardware trigger to start data acquisition.

Siemens PLCs already handle general slow control throughout the project. However, the integration work is still done fully in-house. In order to handle the large scope of work within the time budget, CoDaC will have to be in a position to outsource a significant part of the work. Efforts are undertaken at present to design and implement the necessary testing and simulation infrastructure such that external partners can develop and test according to the W7-X needs and deliver fully functional and fully tested systems limiting the risk of major refactoring work after delivery.

Development of real time framework for parallel streaming data processing

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This paper presents the KSTAR (Korea Superconducting Tokamak Advanced Research) real time framework for parallel streaming data processing framework (RT-ParaPro). RT-ParaPro is a framework used to develop programs that simultaneously process streaming data transmitted over a real-time network and send data over a network and archive them in real time. In most fusion experimental devices, each device processes the data needed for real-time control and transmit them to the PCS in real time via the network. In KSTAR, Reflective Memory (RFM) and ITER Synchronous Databus Network(SDN) are used as a real-time network. Through these network, KSTAR devices acquire the data for real-time control, process it, and share processing results with other devices through this network. By using RT-ParaPro, it is possible to simplify the configuration of a program that performs a series of processes and shorten the development time. As opposed to other real-time frameworks that focus on real-time control, RT-ParaPro is specialized in the parallel data processing, archiving and transmission of data over a real-time network. This framework consists of pairs of thread and buffer which implements parallel producer/consumer design pattern. Each thread is able to set the attributes needed to have real-time properties (CPU affinity, period, policy etc). Each thread is configured to share data using a ring buffer. Control thread controls each thread in accordance with user command or shot sequence. Control thread also manage life cycle of each threads by using control Finite State Machine (FSM). This framework is configured to send parameters and commands via EPICS channel access. and each thread is configured to be synchronized through an event for thread synchronization. By using this framework, LHML, which determines whether plasma is L-mode or H-mode in real time by using machine learning, and RFM Archiving system, which stores various RFM channel data to Mdsplus, has been developed and operated in KSTAR. To evaluate the real time performance of this framework, we tested the consistency of thread period by varying the period of the thread (1kHz,2kHz,5kHz,10kHz,100kHz). The test shows that the thread control period is consistent. The period of the thread has a jitter of about 176 usec not only in the low control cycle rate (1kHz) but also in the control cycle rate of 100kHz.

Evaluation of the Backup Signal-Processing System of the KSTAR Quench Detection System

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The KSTAR Quench Detection System (QDS) has been operated to protect the superconducting coil system of the KSTAR device in the last decade. The QDS discriminates a normal voltage of ∼100 mV on NbTi or Nb₃Sn Cable-in-Conduit Conductors (CICCs) in the event of quench, while the Poloidal Field (PF) coils are applied with voltages of up to some kV by pulsed operation of the Magnet Power supply System (MPS). The high induced voltage is compensated by using analogue circuits with 10–15 kV class isolation and digital signal processors, which consist of 3 aged VME systems.

The QDS mainly consists of high voltage signal interfaces with 83 channels of voltage taps, 3 sets of the VME systems with a host computer, and 1 set of a logic solver. Spare parts of the QDS components have to be always prepared; however, these VME systems are difficult in replication due to particular tailor-made modules. Thus the VME systems are going to have a backup signal-processing system mostly using Commercial-Off-The-Shelf (COTS) devices. The backup signal-processing system may take over the total functions of the VME systems along with newly introducing optical repeaters to split digital communication signals and a superior logic solver at a nuclear safety grade. Both the VME systems and the backup signal-processing system simultaneously operate in normal operation, and interlock signals are voted by 1-out-of-2 (1oo2) logic.

A prototype of the backup system for the PF1-PF4 coils had been developed and integrated with the KSTAR QDS; and then, this prototype was being operated in the KSTAR campaign 2018. On the other hand a supplementary part, which is used for the PF5-PF7 coils and the Toroidal Field (TF) coils, of the backup signal-processing system was completed after the last campaign. This paper describes the development and experimental evaluation of the backup signal-processing system of the KSTAR QDS.

Realization of the requirements for a safe operation of Wendelstein 7-X

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The Wendelstein 7-X superconducting stellarator is a fusion experiment designed for processing of short plasma discharges in the range of some seconds up to long discharges up to 30min in a quasi-steady state operation mode. The first plasma experiment was conducted in December 2015. Since this first plasma experiment within three operational phases were successfully performed more than 100 experimental days with about 3500 plasma experiments.

The operation of W7-X requires the handling of many different sources of danger and with different hazard potentials for persons and for the plant. To identify hazards, risk analyses and risk assessments are performed out at an early stage in the development process for all W7-X technical components and diagnostics, so that measures for risk reduction in design can be taken into account. The main objective of this process is to ensure safe operation for the personnel and to protect the investment in the W7-X plant.

In this work, we present the safety model for operation of W7-X. After a brief introduction to the architecture of the W7-X control system, the process of capturing safety requirements will be discussed. In addition, the multi-shell safety model for the technical implementation of risk mitigation functions at the various levels of the W7-X control system is described. The experiences with the implemented safety concept made at W7-X during the previous operating phases will be described.

Finally, a preview of the enhancements and modifications of the safety systems for the next operational phase OP2, which will start in mid-2021, will be given.

First experience with the W7-X Fast Interlock System

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The safety related PLC in the central safety system (cSS) of W7-X with its corresponding periphery ensures occupational safety and the basic protection of investment. Because its reaction time in the range of some 100 ms is not sufficient to protect components in the plasma vessel from overloading by plasma heating (up to 14 MW), the fast interlock system (FIS) was installed. It can respond to the signals of any diagnostics in 1 ms.

The very first practical experiences with the FIS have been gained during the operation phase 1.2b in summer 2018. Next to the proof of a satisfactory reaction, scalability and operability, the focus also was on the assessment of the reaction times of the various safety-relevant plasma diagnostics.

The paper describes the basic system components and the behavior of the FIS during several experimental situations in the operation campaign 1.2b. A couple of planned measures to improve and extend the FIS, will be presented.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Development of the JT-60SA Experiment Database System

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A new database system for the JT-60SA tokamak [1] has been developed. This system meets the following requirements: to hold all the JT-60SA data and prevent loss of data, to be easily available the data to the researchers without knowing internal configuration and structure of the database, to manage revision of the data so that the stored data can be traced back to an older revision at any time. In the experiment of JT-60SA, various experimental data are acquired by all systems constituting JT-60SA, such as diagnostic systems and heating systems. Depending on timing of data transfer for storage or reference, these data are categorized into three types: (i) discharge data, (ii) plant monitoring data and (iii) unprocessed data. The discharge data, e.g. plasma current and plasma parameters, is acquired in a discharge sequence. This data needs to be referred to immediately after the plasma discharge in order to analyze the discharge and to determine operation parameters of the next discharge. The plant monitoring data is acquired continuously 24 hours a day, which represents operating status of the JT-60SA systems such as vacuum vessel temperature and pressure. This type of data was not managed to the database system in the JT-60U tokamak. This data might be used to monitor the status of the JT-60SA systems for a long duration irrespective of discharge sequences. The unprocessed data is raw data to be processed into physics data and a primary source of the discharge data. This data with fast sampling frequency and/or high resolution could be used to analyze a discharge more in detail after the experiments. This data will also be used for re-processing it into discharge data when, for example, calibration data is updated. Therefore, this data needs to be associated with the corresponding discharge data and program used for the processing. Currently, we are carrying out linkage tests between the database system and other JT-60SA systems. This paper reports details about the hardware configuration and the software functions of the new JT-60SA database system.

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Reliable Local Controller for ITER Coil Power Supply

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In this paper, we propose improved control systems which meets ITER (International Thermonuclear Experimental Reactor) requirements.

Among the various devices delivered by Korea, the controller (local controller) for AC/DC Converter, which supplies power to ITER superconducting coil, should control AC/DC converter to supply direct current of up to 68 kA continuously for few weeks to months. In this case, the superconducting coil stores maximum energy of gigajoule units. In addition, it also is needed to control in extreme environments, such as high level of electromagnetic disturbance. For these reasons, the local controller for ITER AC/DC Converter should not only be designed as highly reliable system but also reliably communicate various data for diagnosis and research as a large-scale fusion scientific experiments device. Therefore, the local controller's Conventional system, Interlock system and Safety system need to operate with high reliability and to transmit accurate measured/calculated data through the optimized design for each system feature.

Conventional system is consists of Interface Controller, Alpha Controller and Analog-to-digital converting Controller. It is configured 5 kHz UDP and 10 Hz TCP communication redundancy method and the digital fault recorder function is applied to improve performance of data transmission. Also, it is designed able to accurate diagnosis by delivering timestamped data to the parent system using Precision Time Protocol in accorded with specification of IEEE 1588.

Interlock System is consists of Slow / Fast Local Interlock Controller (S-LIC / F-LIC). S-LIC is configured by redundant power supply and redundant communications as well as highly reliable (SIL-3) PLC for system reliability. F-LIC is designed with analog board without processor and configured redundant power supply for the fast and accurate action for protection.

Safety system is consists of redundant power supply is configured and highly-reliable (SIL-3) PLCs to monitor the safety relevant signals and to transmit them to parent system for protection of worker.

In this paper, the above designs have been applied to each system to meet the requirements of ITER and to ensure the improvement and high reliability of the system.

This work was supported by the National R&D Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science & ICT (No. 2007-2006995, Development and Procurement of ITER Superconducting Magnet Power Supply).

W7-X Logbook REST API for processing metadata and experiment data enrichment at the Wendelstein 7-X stellarator

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Wendelstein 7-X (W7-X) is a stellarator experiment located in Greifswald, Germany. In the first operational phases (OPs), the W7-X team has been already working on a variety of research topics with about 40 diagnostic systems in operation. In these OPs, many plasma discharges (50 per day/1000 per OP) with durations of up to 100 s were conducted, producing about 500 terabyte of experiment data. For demonstrating steady-state operation, longer experiment durations of up to 30 min are planned for upcoming OPs. Therefore, a large flexibility is needed to satisfy the different use cases and requirements of such an experimental environment, esp. for data processing and analysis.

For this reason, several essential functions for W7-X research are available as web services. The services can easily be combined and integrated into other software due to the usage of standard protocols and common web techniques, such as representational state transfer application programming interfaces (REST APIs). A new central logbook was implemented for working with W7-X experiment metadata via web browser and REST API. Since its introduction, many enhancements have been implemented according to user feedback. For effective research and processing of experiment data, the bulk data of W7-X experiments can be enriched with additional information, such as comments and tags for categorizing. For W7-X experiments, a majority of metadata is extracted automatically from the planned program by the central control software, while the team members complete these logs manually or via software. The logbook also provides search functionality with a powerful search syntax and millisecond response times. By using the REST API, users can integrate logbook searches into their own software and programmatically add new comments or tags. In combination with other W7-X web services, such as a magnetic coil database or the experiment data archive, additional W7-X resources can be utilized for the creation of new tags and further metadata. In this way, all team members were able to contribute to the creation of comprehensive experiment overviews. The logbook quickly became a crucial tool for W7-X operation and is now considered a central hub for experiment related information.

This contribution shows the principles and usage of the W7-X logbook REST API for data enrichment in combination with other W7-X web services and applications.

EAST MDSplus Log Data Management System

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With the increasing of data storage and data access in EAST experiment, standardized data access and user behavior monitoring become even more important. Therefore, a perfect EAST MDSplus logging system is required, and a mature log data management system is built on this basis. The EAST MDSplus log data management system architecture includes four parts: the log data collection layer, the data storage layer, the data analysis layer and the data application layer. (1) The data collection layer uses MDSplus hook function to improve the log system, and adopts log rotate mechanism for log rotation cutting, which effectively avoids the problem of excessive log storage. (2) The data storage layer uses HDFS for distributed offline data storage to support data multi-copy backup, which improves data security performance and non-volatileness. Moreover, Kafka is also used as the stream data storage middleware to ensure the release and subscription of log messages with high throughput. (3) The data analysis layer uses MapReduce to clean the offline data and establish the log data warehouse belonging to EAST. In addition, Spark Streaming is used to calculate log stream data to ensure the quasi-real-time nature of log data. (4) The data application layer is designed to visualize analysis layer data and intuitively reflect the entire EAST log data access status. Each layer of the log management system framework provides a corresponding interface, which reduces the coupling degree of the system. The EAST MDSplus log data management system aims at providing a standardized management solution for the whole EAST log data and it will be implemented in the next campaign of EAST experiment.

Methodology to standardize the development of FPGA-based intelligent DAQ and processing systems on heterogeneous platforms using OpenCL

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The usage of FPGA-based DAQ systems has been growing in instrumentation and control systems for Big Science experiments over the last years. The combination of flexibility and performance that FPGAs give to DAQ and processing systems for diagnostics is unrivaled. Moreover, the tasks for which FPGAs are used have been increasing in number and complexity, for instance, data acquisition, processing algorithms, complex timing and triggers mechanisms, interlock operations, or machine-learning algorithms. The ITER hardware catalog for fast-controllers defined by CODAC includes FPGA-based PCIe devices for PXIe and MTCA platforms. Nevertheless, design cycles for FPGA based applications are still complex and costly. At present, three options exist to develop for FPGAs: hardware description languages (VHDL, Verilog/SystemVerilog), graphics languages like LabVIEW/FPGA; and high-level languages such as HLS languages or OpenCL. From these, HDLs are the most complex to use, but they offer the highest flexibility and control over the implementation, while not being bound to a particular hardware manufacturer. Alternatively, LabVIEW/FPGA is easier to use, but it is constrained to specific hardware (ITER uses LabVIEW to develop for FlexRIO and cRIO devices). Lastly, HLS languages and OpenCL enormously simplify the hardware description using high-level languages like C/C++ which are also hardware agnostic. Additionally, standardization adds value to high-level languages, reducing the development times, to the extent that modules or complete software layers can be reused.

The work presented here is a set of methods and tools that allow developing applications for FPGA-based instruments in a standardized way, using the following elements: an OpenCL compliant Board Support Package for a PCIe device; an OpenCL interface to communicate with high-speed AD/DA converters using the JESD204B standard; a set of OpenCL Kernels to support common DAQ functionality, capable of acquiring and processing at high sampling rates; and a standardized software interface, including the NDS software layer supported by ITER that integrates the whole solution with EPICS.

The methodology has been validated with the implementation of an estimator of the fusion power through the average neutron flux on a MTCA FPGA-based DAQ and processing platform. A discussion is provided on how this methodology simplifies integration and improves maintainability compared to other development languages and tools.

Design of GPU-based Parallel Computation Architecture of Thomson Scattering Diagnostic in KSTAR

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Thomson Scattering (TS) System is a diagnostic system to measure electron temperature and density profiles of tokamak plasma. TS Data Acquisition (DAQ) system converts analog optic signals to digital data in order to calculate the profiles. In this poster, we propose a design of architecture for GPU-based parallel computation to accelerate the diagnostic calculation with a large amount of TS raw data (1024 data per channel * 140 channels). First, we applied the machine learning technique of artificial neural network to the calculation of the electron temperature profile which established method had been the -square test by referencing lookup table of the calibrated data. The learned neural networks can maintain accuracy of the outputs as well as their computation time can be significantly reduced. Second, we implemented the learned neural networks on the GPU-based parallel computation architecture. Each point of output values on the profile can be independently calculated by the corresponding neural network; thus, the parallel computation for each neural network is appropriate. Furthermore, we integrated the GPU-based parallel computation architecture into EPICS which has been the main framework of control and DAQ systems in KSTAR. The TS diagnostic data with the proposed architecture can be used for an online streaming services during plasma shot operation as well as development of a plasma feedback control algorithm.

Recent Diagnostic Developments with the ASDEX Upgrade Standard Data Acquisition System using the FPGA implemented Serial I/O card „SIO2“

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ASDEX Upgrade (AUG) since many years is using a built to purpose FPGA based PCIe computer interface with fast serial interconnects to external DAQ (data acquisition) devices as in-house standard. The renewal of large physics measurement systems („diagnostics“) for the Mirnov probes, the Soft-X-Ray cameras and others have been successfully conducted as planned. These diagnostics have also undergone the transition from Solaris 5.11 to Linux CentOS-7 expanded by real-time kernel extensions. These diagnostics receiving the stream of measured samples from the SIO2 periphery via DMA (direct memory access) in real-time can directly provide data for plasma control via sharing the DMA memory with dedicated DCS APs (discharge control system application processes) running on the same node as part of the AUG distributed DCS (discharge control system).

The SIO DAQ concept is further applied to a Thomson-Scattering system located in the AUG Divertor („DTS“ Divertor Thomson-Scattering). New 1 GigaSample ADCs developed for this diagnostic expand the range of measuring periphery into the GHz time resolution range. The same ADCs are planned to be used to refurbish and real-time enable the main chamber Thomson-Scattering systems as desired by AUG plasma control.

The talk will describe briefly some specifics of the diagnostics mentioned above. It will further emphasize on modifications of the SIO2 FPGA features introduced to address these specifics and it will give a short description of the main features of the developed GigaSample ADCs.

Plasma Diagnostics in the Optical and X-Ray Regions on the IEC Plasma Device

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The design and construction of first Egyptian inertial electrostatic confinement IEC fusion device has been studied [1]. It consists of 2.8 cm stainless steel cathode, 6.5 cm anode diameter with 10 cm diameter 20 cm height vacuum chamber. The operation of IEC experiments has concentrated on pulsed operation to achieve the high currents required to generate increased reactions rates. The discharge voltage waveform with peak voltage 12kV with a full width half maximum (FWHM) of 10 nanoseconds and current pulse waveform has been registered using pick-up coil with peak current about 170mA. Experiments are performed with nitrogen and hydrogen as operating gases at different pressures and voltages. Time resolved of x-ray radiation signals are obtained using fast radiation detector.

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Multi-channel analog lock-in system for real-time motional Stark effect measurements

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A Motional Stark Effect (MSE) diagnosis system was developed to measure the plasma current density distribution in the KSTAR tokamak. Currently, the MSE diagnostic system performs data analysis by applying Fourier transform algorithm by using the IDL (Interactive Data Language) software after measurement and digital archiving. However, in order to realize advanced plasma control aiming at the development of high performance tokamak operations, there is a demand for the MSE diagnostic system capable of real-time pitch angle measurement associated with a plasma control system (PCS). For real-time, multi-channel, and high-speed MSE data processing with high precision, an analog lock-in technique has been proposed and its feasibility has been demonstrated through the take-top tests using the photoelastic modulator. The prototype multi-channel analog lock-in system is ready for the plasma commissioning and the integration with the PCS

Integration of data acquisition devices in the ITER Real-Time Framework using Nominal Device Support

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The implementation of control algorithms for nuclear fusion requires a real-time environment to ensure the correct operation of the device. Although several alternatives have been used in the fusion community during the past decades, ITER has committed to develop a new generation real-time framework for control, the ITER Real-Time Framework (RTF). The ITER-RTF has been developed taking into account the experience gained with the use of the previously existing frameworks and addressing the new requirements derived of ITER needs (e.g. long-pulse operation, integration of heterogeneous systems developed by several domestic agencies).

The control algorithms in RTF are implemented using function blocks. Each function block can have input and output signals, which are the most basic form of data communication among function blocks. Therefore, control applications are built by simply connecting function blocks. There is a set of already implemented function blocks providing basic functionality, as file reading, simple data processes, and logging. Advanced users can also implement custom function blocks to address functionality not covered with the provided function blocks. In a control algorithm, some of these function blocks must manage the data acquisition devices to provide the necessary inputs to the control algorithms. However, the lack of non-standardized software interfaces with data acquisition devices requires developing custom function blocks for each device. This leads to a high cost in terms of development time and maintainability.

One proposal to standardize such data acquisition devices integration in control systems is Nominal Device Support (NDS). In NDS v3 applications, there are two main components, device drivers and control systems. The interface between both is accomplished using an abstraction layer, so every device driver implemented using NDS can be managed with any control system with an interface to NDS. ITER is using NDS for the implementation of instrumentation and control systems for diagnostics. Currently, there are several PXIe and MTCA data acquisition and timing devices in NDS, but the only control system integrated so far is EPICS.

In this paper, the first integration of NDS device drivers in RTF is presented. The objective of this work is to propose a methodology for the inclusion of NDS in RTF that allows reusing all the devices integrated with NDS to develop control applications using RTF.

Development of Local-Imaging and High-Speed Visible Diagnostics for Real-Time Plasma Boundary Reconstruction of EAST

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Fast plasma boundary reconstruction is usually used for real-time control of tokamak plasma. In EAST experiment, the time consuming for boundary reconstruction should be within 1ms to meet the need of real-time control. Fast evolution of cameras in recent years has made them promising tools for diagnostics of Tokamak. The solution presented in this paper consists of a prototype of high-speed visible image acquisition and processing system (HVIAPs) dedicated for EAST shape and position control. The optical system can be applied in high-speed camera diagnostics, due to its large relative aperture (1:1.5). Three visible cameras, which are mounted outside the EAST at a distance of 3.4 m, are all controlled via optical fibers over QSFP+ (40 Gbit/s data rates) interfaces. As each new frame comes in from the camera, it is stored in main memory of the server by direct memory access (DMA). In order to meet the needs of real-time storage, the acquired image data is cached in main memory and written to Solid state drive (SSD) after one shot discharged. 16 frames per second are chosen from the cached data and sent to another server for displaying by using website. GPUs and FPGAs are typically used as accelerators and co-processors in addition to a CPUs. Such a heterogeneous computing system can combine the advantages of its individual components. The offline image process results are compared to offline EFIT, with an average error of 1.5 cm. The total processing time for one frame is less than 0.2 ms.

Standardization of software device driver implementation for data acquisition and timing devices in ITER CODAC Core System: Nominal Device Support

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The standardization of device driver's implementation in distributed control systems is essential to reduce the development and integration effort. Nowadays, there are multiple distributed control systems and high-level applications used in the scientific community. Due to the lack of standardization in the interfaces with the device drivers, it is required to integrate each hardware device separately in each control system. However, a clear model of how different software applications should manage the device drivers could reduce development efforts and ease the maintainability of such complex systems. The Nominal Device Support initiative is an open source project, promoted initially by Cosylab, for the standardization of data acquisition and timing devices. The first implementations of NDS (version 1.x and 2.x) were oriented to simplify the implementation of EPICS device supports. NDS v3 is more ambitious and is built as an abstraction layer for any control system or software application.

This work is focused on the third version of NDS which distinguishes two main software elements needed to develop a NDS Device Driver. First, NDS-Core provides a hierarchical tree organization of the so-called nodes. Along with this work, most potential applications have been identified, defining a set of nodes for such applications with the aim of providing a common skeleton that eases the drivers development and unifies styles. Thus, every node is matched to specific hardware functionality by means of its predefined NDS Process Variables (NDS-PVs) that support the configuration, operation, and monitoring of the hardware. NDS device drivers are libraries built using NDS-Core, and the NDS-PVs defined in the nodes act as interface between the device drivers and the control system.

On the next layer, the NDS-Control System Interface loads the driver's libraries and manages the interactions with the control system. Current development provides an EPICS interface and a simulated Control System interface for testing purposes, although it could be extended to support interfaces with other frameworks (MARTe, TANGO, ITER Real-Time Framework, etc). The NDS-EPICS interface uses the EPICS asynDriver module.

NDS offers several advantages. Firstly, the use of a unique NDS-EPICS interface for all the device drivers simplifies the development and maintenance and reduces to the minimum user effort in the EPICS/asynDriver development. Secondly, NDS-core provides a node structure traced to common hardware functionality, saving development time and increasing the homogeneity of drivers. Finally, the possibility of reusing the same NDS device driver with different software applications or control systems shall be highlighted, as it effectively reduces development and integration costs.

Currently, NDS approach is used in ITER for diagnostic applications, and different NDS Device Drivers have been implemented for data acquisition and timing cards available in the ITER fast controller hardware catalog for PXIe (PXIe6683 PTP timing card, X-Series multifunctional DAQ Devices and FlexRIO/NI5761) and MTCA (PTM1588) form factors.

Framework for development of software for laboratory equipment and experimental setup subsystems integrated into large scale DAQ systems (LabBot)

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Development of software for small- and medium-sized experimental setups and custom laboratory equipment differs from the software production for large-scale experiments or commercial applications. Everyday work of research group involves different types of jobs with equipment control and data acquisition ranging from manipulation with distinct parts of equipment to operation with complete experimental setups with complex automation architecture.

Main research topics of our laboratory involve development of laser-aided plasma diagnostics, including Thomson Scattering and Laser Induced Fluorescence for ITER divertor. Among other tasks, we design and build experimental setups and industrial-grade equipment. To simplify the development of software and firmware, a specialized framework has been created, meeting the following requirements:

- Simple transition between different stages of equipment development: playing around with dedicated parts, assembling prototypes and preparing full-fledged experimental setups

- Integrating custom-made equipment without standard control interface protocols

- Having specialized tools for implementation of high-level logic scripts, data storage and mathematical toolkit for online data processing

- Accessibility. Members of research group have different approaches and preferred tools for data processing – jupyter, IDL, matlab, etc., demanding unified data access interface

- Straightforward integration with major large-scale control systems like EPICS/CODAC

- Out-of-the-box remote participation and experiment control support

- Operation of scientific equipment in stand-alone mode during debugging, calibration and adjustment

- Utilization of the most modern industry-approved programming techniques, tools and methodologies

- Various platforms support. It is essential to provide similar API for full-fledged x86_64 machines, an ARMv7-based devices or other hardware architectures. Ready-to-use GNU/Linux-based images for popular built-in platforms such as RaspberryPi, Atlas-SoC/DE0-nano-SoC simplify implantation of control system and network interface into equipment being developed

The LabBot framework is intended for small/medium-sized research teams to assist the implementation of industrial-grade equipment software, while reducing to zero the necessity of design of standard features like message passing, database interaction, etc. Modular system, flexible uniform messaging format, set of standard modules for data storage, host control, user notification, event-driven system architecture enables to solve vast range of laboratory automation tasks with humble programmers resources.

Examples of successful LabBot application are as follows: polychromators for Thomson scattering diagnostics, test bench for research on sputtering and deposition processes in RF-discharge, assistance for a study of dielectric mirrors for laser resistance, etc.

Open repository of ready-to-use modules and drivers permits user to install various components to the system in a one-click manner. This repository allows to combine efforts of all platform users and improve code reusability. LabBot is licensed under GPLv2.0 and introduced to public on May 10, 2019.

Remote Experiment with WEST from ITER Remote Experiment Centre

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Remote experiment with WEST tokamak in CEA Cadarache France from the ITER Remote Experiment Centre (REC) in Japan was successfully carried out on November 2018. The construction of the REC was carried out at the Fusion Energy Research Centre (IFERC) under the agreement between the Government of Japan and the European Atomic Energy Community for the joint implementation of the Broader Approach (BA) activities in the field of fusion energy research.

First, WEST and REC sites were connected via broad band networks, that are SINET5 (Tokyo-London: 20 Gbps), GÉANT (London-Paris: 100 Gbps) and RENATER (Paris-Cadarache: 10 Gbps), over about 10000 km of transmission path length. The partners network (Partners Zone) for remote participants was used on the WEST side. It is accessible through a firewall and is separated from WEST internal networks by a second firewall. The WEST Portal in the Partners Zone allows accessing a set of information and tools such as the machine status and the experiment logbooks. The Pulse schedule editor is also available by login onto the Partner Zone server (Altair). The remote experiment was devoted to test the ITER plasma-facing components and their shaping under high heat flux. It started by the pulse preparation in REC, where the remote session leader edited the pulses schedule based on the communication between REC and WEST control room via VC system. After the approval of the Pulse Schedule by Engineer in Charge in WEST, discharges were successfully executed repeatedly with modified scenario based on intershot analysis. The large video wall (LVW) in the REC room, displayed the near-real time countdown of the plasma discharge, a video of plasma generated in WEST tokamak, the live data of the time trace of the main parameters of the plasma, such as the current and the plasma density, in addition to the view of the video conference system. In the intershot period, data analyses were carried out on Applications server located in the Partner Zone.

Full functions required for the remote experiment were successfully demonstrated, which are the pulse preparation, communications between local and remote sites, live monitoring of the data and post-pulse data view and analyses. In order to become more effective for these functions, it was clarified that adequate data transferring methods and system are required, especially for the live data and the large volume result data. It was also clarified that the LVW in the REC was very effective to share the information between REC and WEST.

The first test of remote experiment with WEST, ∼10000 km away from REC, like ITER, has been successfully completed. By this test, technical requirements emerged for more effective remote participation. Those are how to get the near real time data to show the live data in REC, how to view and analyze the large volume data through the limited network capability, and how to communicate with the on-site colleagues. This paper will discuss these issues.

RUSSIAN PROTOTYPE OF ITER REMOTE PARTICIPATION CENTER

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Russian Domestic Agency has nine plasma diagnostics Procurement Arrangements with ITER Organization (IO). Before integrated commissioning at IO Site, it is necessary to test these diagnostics with most of the interfacing systems connected. As the process can be long-lasting, remote means of access should be implemented. In addition, it will be useful to develop and test remote participation functions of the subsystems in scope of ITER Operations Network (ION) program. For this reason, Project Center ITER (RF DA) designed and deployed the Model of Remote Participation Centre (RPC) to communicate with supplied diagnostics and participate in ITER Main Control Room (MCR) activities.

Main RPC tasks are: Test of Remote Participation Functions; Test of ITER remote participation interfaces (Unified Data Access, Data Visualization and Analysis tool, etc.); Investigation of the long distance high-speed data transfer via existing public networks (reliability, speed, accuracy, latency); Implementation of Local Large-capacity data storage system (Using CERN and JINR experience, taking into account ITER services requirements (storage capacity 10 TB and disk I/O speed 300 MB/s)); Access to ITER S3 zone IT infrastructure (S3 – XPOZ (External to Plant Operation Zone) in accordance with the requirements of information security and IEC 62645 standard.

The RPC has to participate in ITER Main Control Room (MCR) activities using audio and video links for direct communications, remote copy of MCR screens and plasma diagnostics HMIs, access to experimental data and data processing. While ITER MCR is under construction, the RPC has to participate in ITER Temporary MCR activities using above-mentioned features.

Dedicated data link (IEEE 802.1Q) between ITER XPOZ and RPC private network with some limitation on outside communication was created for communication purposes. Trusted hardware, virtual machines, zero clients etc. are used in this subnet. Personnel role-based access is possible to these machines under control of ITER Organization.

Video conferencing and person-to-person communication is allowed outside ITER S3 zone, Polycom and MS Skype for Business solutions are used.

RPC infrastructure can perform data processing or connect to Kurchatov Institute Supercomputer Cluster.

Work done under contract .4 .241.19.18.1027 with ROSATOM and Task Agreement C45TD15FR with ITER Organization.

Graphic interactive environment for remote data analysis and visualization with a view on ITER

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Each ITER discharge (30 minutes long) is expected to produce O(10**5) signals. This vast quantity of data must be stored and analyzed using computers with large storage capacity and fast processing units. Also, it is important to note that these powerful computers and data centers will be usually situated in remote locations from the scientists. Both access to data and some type of analysis may also be restricted by security issues. On the other hand, scientists must be able to explore the data with great flexibility and to have available diverse possibilities for analysis and visualization. For general purposes, several suitable platforms exist, providing a large variety of libraries for this work. Furthermore, the fusion community is constantly producing new techniques and algorithms, specific to this topic. Learning all the programming involved and keeping track of new developments can be a very time-demanding task.

We introduce a client-server software tool that separates the tasks of handling data, coding algorithms, doing the computation and preparing visualizations (handled by the server and specialized software engineers), from those of conducting the exploration, designing the analysis and interpreting the results (reserved for fusion specialists).

A web-accessible server, run by the institution hosting the data and offering the service, grants access to authenticated scientists and provides a variety of fusion-specific software algorithms for handling, processing, analyzing and visualizing the data. These algorithms are encapsulated in visual elements with customizable parameters that can be connected to create a graph defining a flow of data. Once the graph is completed, the server runs the (automatically generated) underlying code to produce the analysis, returning an HTML page with results.

A modern HTML client, runnable on different devices, allows scientists to connect to this service remotely. The user builds the graph selecting among the well-documented elements (elements and data offered may depend on the task or security access), adjusting their properties and connecting the output of one element with the input of another to form the correct data flow. But this task does not require writing code, relieving scientists from knowing the precise syntax and all the possible parameters for a given algorithm, and minimizing syntax errors which may result in wasted execution time.

Once the graph is completed, scientists click the run button and the server does the rest. Users can even disconnect and wait for a server message when the process has completed, receiving the results in HTML format. Repeating the process with different parameters or adding new elements to improve it only requires editing the graph, not a long code.

We show our tool and display examples of non-trivial analysis of data using simple graphs of elements, producing advanced analysis and visualizations with no (client-side) programming. In particular, we present the results of image classification from the TJ-II Thomson scattering, which implements a five-class classifier.

Web-based Streamed Waveform Display using MDSplus events and Node.js

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Streamed data visualization is a new requirement for long lasting discharges and more in general for every long lasting related experiment, such as the ITER Neutral Beam test facility. A prerequisite for live visualization is the ability of the underlying data system to support streaming in data acquisition. Data streaming is supported in MDSplus, a widely adopted data system in fusion research, by means of segments. A signal in MDSplus is stored as a sequence of segments that can be saved individually as soon as the associated data chunk is available. In this way, at any time during the experiment sequence, segments stored so far are readily available and can be used for on-line analysis and visualization. On-line visualization is routinely performed during long lasting experiments, but implementing streamed data visualization, such as strip charts, would overload the data system, especially if a large number of charts are being displayed. A different approach for streamed data visualization is proposed here, using MDSplus events, rather than directly accessing stored data. MDSplus events are used to synchronize components during the experiment sequence, using a multicast organization. A listener can register for a given event name and it will be notified when an event with that name is generated. Events can bring data and are implemented as UDP multicast packets. A data acquisition program can therefore, in addition to using MDSplus for streaming data segments, generate MDSplus events bringing the most recent chunk of samples. In order to make data carried by events available to Web applications, a Node.js server has been developed, listening for the UDP packets and updating the connected Web clients using HTML5 Server Sent Events. In turn, Web client will update the displayed waveforms using chart js.

Compared with other approaches for streamed data visualization, the presented one offers several advantages. Firstly, MDSplus events represent a much lighter solution in respect to repeatedly accessing stored data in pulse files. Then, Node.js proved a very effective environment for originating the Web pages and to implement the bridge between MDSplus events and HTML5 Server Sent events, resulting in an amazingly low number of lines of JavaScript code. Finally, chart js proved an effective tool for waveform display in Web pages, with a stunning performance in animation.

The Information Technology tools for remote participation and remote experiment control of WEST

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WEST is a full metallic environment tokamak, with an X-point divertor configuration. It is targeted at testing ITER like divertor prototypes made of actively cooled bulk tungsten units, in tokamak conditions during long pulse operation. Several partners around the world contribute by

providing various elements like parts of the divertor, ICRH antenna, and diagnostics, or by contributing to the scientific program. Like a few other fusion devices, the experimental program is open to the participation of these WEST partners. Since the C1 campaign, two years ago, the WEST experimental sessions are prepared and conducted in a collaborative way with remote access to several IT tools developed for this purpose. Each user needs a unique account to access all these tools:

· A Web Portal giving access to various web applications. These applications are:

1. A wiki to manage all scientific task forces information: experimental proposals, results,

meeting and related documentation.

2. A structured web site where the content of all pages are fully editable by any users. That site provides the description of all the WEST sub-systems, their operational limits and their status, the user guides for available computing systems and information for visitors.

3. The West Operation Management Software Suite [1] that gives access to all operation information (timeline, roster, logbook, physics summary, system status and real time

control room screens). Depending on their role and rights, users may update information.

4. A virtual Pinboard that allows every participant to share their scientific publication projects.

5. An online helpdesk to manage technical issues reported by the participants.

· Remote Computer Access is provided by a set of Linux servers fully implemented with data access and visualization and computation software. On one of them, the Pulse Schedule Editor [2] is also available (with some restricted functionalities) and has been used for the

first demonstration of WEST operation from the ITER Remote Experiment Center of Rokkasho-Mura in Japan [3].

· Implementation of IMAS (ITER Integrated Modelling & Analysis Suite) [4]: after each plasma shot, raw and processed data are produced in the IMAS format.

The WEST partners are routinely using all these tools when they are working remotely from their laboratory. This paper will present a brief description of these tools, their use and the perspectives for further development.

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Summary

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MDSplus Workshop