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Guest Editorial

Special issue on design and implementation of real-time systems for magnetic confined fusion devices

Real-time systems in magnetic confined fusion devices have followed the tremendous advances over the last two decades of new hardware technologies, software platforms and design methodologies.

On the hardware side, the availability of relatively low cost hardware with multi-core processors, together with the development of fast data acquisition boards capable of efficient and reliable on-board embedded computations have pushed the design of efficient and flexible solutions for both real-time diagnostics and control systems (see some recent examples in [1,2]). As a matter of fact, the last decade is witnessing the affirmation of non-proprietary solutions, which allow to implement real-time systems that loosely integrate off-the-shelf components with bespoke custom electronic solutions (see [3–5]).

Furthermore, the availability of reliable and effective, low latency, high bandwidth, data communication solutions, has contributed to the growth of distributed and decentralized solutions. In particular fast serial protocols, such as PCI Express, are currently starting to be commonly used as the standard interface layer between the data acquisition and the data processing stages, while full duplex Gigabit Ethernet based networks are providing the layout for distributed control architectures [6,7].

These trends are also reflected on the software side, where the number of systems running real-time extensions of the Linux operating system is increasing [8,9]. Moreover, various flexible and modular frameworks are currently in use on all the fusion devices around the world [10].

The main issue that is addressed by all these different solutions is the re-usability of the software components, which has been mainly achieved by means of an abstraction concept that is commonly used in object oriented approaches, and by a clear definition of interfaces and boundaries between the system components.

Summarizing, in the fusion community the last decade has witnessed the fall of rigid, monolithic and proprietary architectures and the rise of flexible, open and distributed solutions, commonly to what is happening also in other fields (see [11,12] among the others).

Another major driving force to develop new and more flexible solutions for the deployment of real-time systems in the fusion community is the construction of the ITER tokamak, which also adds another important requirement: the need to reliably support long-pulse experiments where plasma-driven events will play a major role in the scheduling and parametrisation of the real-time control algorithms. This function has to be supported both by the hardware and software implementations and has to take into account the fact that plant systems will be commissioned and installed over a large period of time. The need of a staged operation in the ITER machine is already shared by other existing experiments. Indeed, one very important requirement in the Joint European Torus (JET) fusion experiment is to be able to operate the device whilst non-essential plants, which are already completely integrated in the operational environment, are being safely commissioned and operated without endangering the experiment. The latest large enhancements to the JET plant [13,14] have shown that a loose coupling between plants, together with clear and well defined interfaces, is essential in guaranteeing the upgrade and installation of plant systems without majorly impacting the operation of the machine.

The papers presented in this special issue report on the recent developments and upgrades of real-time systems of some of the larger and most active magnetic confined fusion devices in the world. The various contributions focus on technological and implementation issues, presenting also experimental results.

The first set of presented papers deal with the recent upgrades that have been made to the real-time control system of ASDEX-U [15], TCV [16,17], COMPASS [18,19], ISSTOK [20], FTU [21,22] and RFX-mod [23].

The Discharge Control System (DCS) presented in [15] has evolved in order to satisfy the requirements that arose during the operations of the ASDEX-U tokamak. As of today the DCS provides a software framework for distributed real-time systems in fusion experimental reactors, linked to an infrastructure of additional services and tools. Examples are the pulse scheduler, which generates control references that take into account the occurrence of exceptions during a pulse, and a tool for the management of the experiment. These features made the DCS a possible integrated solution for plasma control systems of small and medium size tokamaks, similarly to the DIII-D PCS [24]. On the other hand, despite the modularity, such integrated solutions are more challenging to be adopted as standalone real-time frameworks and to be incorporated into existing control and data acquisition infrastructures. Indeed, the DIII-D PCS has been deployed as a whole in different machines (the latter are KSTAR [25] and

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EAST [26]), while the DCS is a possible choice, currently under evaluation, for the plasma control system of the WEST tokamak [27].

The hardware and software architecture of the Système de Contrôle Distribué (SCD) currently used at TCV is discussed in [16]. The SCD makes a step further into the separation of a real-time framework from the overall infrastructure for plasma control and data acquisition. This separation is obtained by the means of the *SCD host computer*. Furthermore, the SCD software architecture gives the possibility to the users (i.e. to the diagnostic and control specialists) to develop their algorithms using Simulink, and to rapidly deploy them on the plant. This feature, together with an overview of the control and diagnostic algorithms currently implemented in within the SCD, is presented in the paper by Felici et al. [17].

The plasma data acquisition and control system of the COMPASS tokamak is presented by Hron et al. [18]. In this case the overall system is the result of the integration of different hardware and software technologies developed in other labs, such as FireSignal [28], ATCA and the MARTe real-time framework [10]. The experimental results achieved by this architecture are presented in [19].

The technologies deployed at COMPASS have been also adopted at the ISSTOK tokamak, with the aim of improving the discharge stability and to increase the number of AC discharge cycles while maintaining stable plasma parameters throughout the discharge, as reported by Carvalho et al. [20].

MARTe has been adopted as real-time framework also for the distributed plasma control system of the FTU tokamak, as described in [21,22]. The former paper by Boncagni et al. deal with the Plasma Position Current Density Control (PPCDC), while the latter focuses on the Electron Cyclotron Resonance Heating (ECRH) controller. Also the multi-core architecture of RFX-mod relies on the MARTe framework, as reported by Manduchi et al. [23]. MARTe was originally developed to at JET to deploy the plasma shape and position control system [29], and it does not include all the tools and services required by a control and data acquisition infrastructure for fusion experiments. However, it can be easily integrated in different environments, interfacing with different hardware, and facilitating the user to test different control solutions. MARTe achieved this result mainly because it is platform independent, and because it has a modular and lightweight architecture that completely separates the control algorithms from the rest of the infrastructure. Other than at JET, COMPASS, ISTTOK, FTU and RFX-mod, MARTe systems have been integrated at a prototype level both with the ASDEX-U DCS and with the KSTAR PCS [30].

The three papers [31–33] deal with real-time systems that run at the JET tokamak and that have been upgraded for the operation with the ITER-like beryllium wall (ILW).

The enhancement to the JET Plasma Position and Current Control (PPCC) system, which is the main JET real-time control system, is described in [31]. The new features implemented in the PPCC system were mainly aimed at improving the management of the exception that lead to plasma termination, as well as at improving the plasma breakdown.

Another important JET real-time systems for operation with ILW is the WALLS system, which monitors the plasma-wall thermal load, and whose design and implementation is presented in [32] together with some experimental results.

The JET hard X-ray and gamma-ray profile monitor system is an example of a real-time diagnostic system which integrates ATCA and FPGA technologies. The hardware and software architecture of this diagnostic is described by Fernandes et al. [33].

The paper [34] by Winter et al. closes this special issue, and gives an overview about the main areas of intervention of the ITER plasma control system, as well as a summary of the interfaces and the integration into ITER CODAC.

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Gianmaria De Tommasi*
Consorzio CREATE/DIETI, Università degli Studi di Napoli Federico II, Via Claudio 21, 80125 Napoli, Italy

André C. Neto
Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal

* Corresponding author.
E-mail address: detommas@unina.it (G. De Tommasi)

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