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Abstract: Keeping in mind the necessities of a modern control system for fusion devices, such as modularity and a
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***Cover Letter**

Dear

I am pleased to submit a manuscript to Fusion Engineering and Design as Special Issue of **"IAEA-TM 2011 SI"**.

This is the corresponding author of manuscript titled:

MARTe at FTU: the new feedback control

I submit the following files:

- Cover letter (CoverLetter4Elsevier.doc)

- 2 latex manuscripts: (article.tex and refs.bib)

- figures 1-6: (block2gam.eps, feedbackGAMs.eps, feedbackGui.eps, RS1_RS2_Z1_Z2_34781_white.eps, DEP_DEZ_34781_white.eps,gas_34781.eps)

Sincerely yours.

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Frascati, July 22st, 2011

Highlights

> ENEA Frascati, as an active developer for ITER, has the opportunity to participate in a global project along with international members from all over the world. The Fast Controller technologies and software frameworks are not full specified the ITER PSH , we show that the MARTe is a candidate to solve this issue.

> We have replaced the old real-time feedback software using the MARTe framework.

> We describe all the work done to integrate the new hardware and software subsystem with the pre-existent control system architecture

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MARTe at FTU: the new feedback control

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Abstract

Keeping in mind the necessities of a modern control system for fusion devices, such as modularity and a distributed architecture, an upgrade of the present FTU feedback control system was planned, envisaging also a possible reutilization in the proposed FAST experiment[1]. For standardization and efficiency purposes we decided to adopt a pre-existent ITER-relevant framework called MARTe [2], already used with success in other European Tokamak devices [3]. Following the developments shown in [4], in this paper we report on the structure of the new feedback system, and how it was integrated in the current control structure and pulse programming interface, and in the other MARTe systems already in FTU: RT-ODIN [5] and the LH satellite station [6]. The new feedback system has been installed in the FTU backup station (known as "Feedback B"), which shares the input signals with the actual feedback system, in order to simplify the validation and debug of the new controller by testing it in parallel with the current one. Experimental results are then presented.

Keywords: MARTe, realtime, control systems, nuclear fusion

1. Introduction

A modern Tokamak control system is a complex system from an engineering point of view: it should be easily adaptable to the experimental environment, standardized and simply upgradeable (in order to help new members of the fusion community to give their contribution without wasting too much time in the implementation details), modular (in order to easily add or remove experimental components) and decentralized. With this in mind, and considering the necessity of acquiring know-how to develop and maintain the control system of the envisaged FAST experiment [1], it was decided to upgrade and revamp the feedback control system of the FTU Tokamak. The ideal candidate to become the development framework on which to base the new system was the MARTe framework [2], actively developed and used on several fusion devices such as JET, COMPASS, RFX and ISTTOK [3].

The first part of this paper describes the MARTe framework, then the structure of the new feedback controller, presented in [4], will be detailed. Finally we present some results obtained with the new control system during standard FTU operation.

2. The MARTe Framework

MARTe is a framework for realtime control systems development [2]. It is implemented in C++ and relies heavily on object orientation in order to solve the most common problems faced while developing control systems (such as error handling, system configuration, etc.) in a simple and easily understandable way. A MARTe application is made by a series of small components called GAMs (Generic Application Modules), which exchange data through a Dynamic Data Buffer (DDB), and are otherwise completely independent. The GAMs are sequentially ran by a RealTimeThread which is usually completely isolated on his own processor (or core) in order to obtain the best performances with the minimum conceivable latency and jitter, for instance in the order of hundreds of nanoseconds in JET Vertical Stabilisation system [7].

In Figure 1 an example of how a feedback system in the standard block diagram form is translated in MARTe's GAMs/DDB architecture is reported.

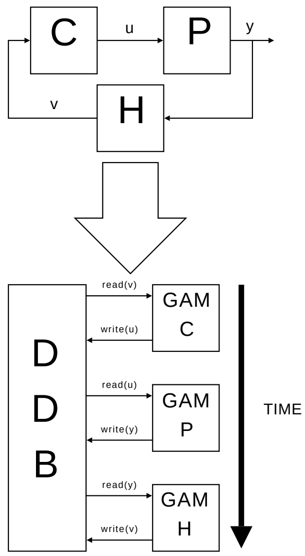

Figure 1: Conceptual translation from a standard block diagram to a MARTe application.

The deployment of a MARTe system consists basically in writing the required high-level hardware drivers, the control algorithm itself (i.e. the GAMs), and a configuration file, a text file with a proprietary structure which tells MARTe what GAMs will be used, and how they will be interconnected via the DDB.

3. MARTe at FTU

Considering the structure of the feedback system explained in [4], we tried to build a more organic structure for the system using various GAMs and limiting as much as possible the responsabilities of each one of them. The GAM subdivision is reported in in Figure 2.

Three GAMs manage the communication with the sensors and actuators (ADC and DAC), and generate the preprogrammed references requested by the physicists. The SignalCheckGAM then verifies the plasma presence and diagnoses problems such as plasma runaway, gas immission failures, and so on. The 32 magnetic measures, together with the toroidal current an the V_{loop} integral, are passed to the MomentGAM, which first evaluates and removes the pick-up toridal field offset from the

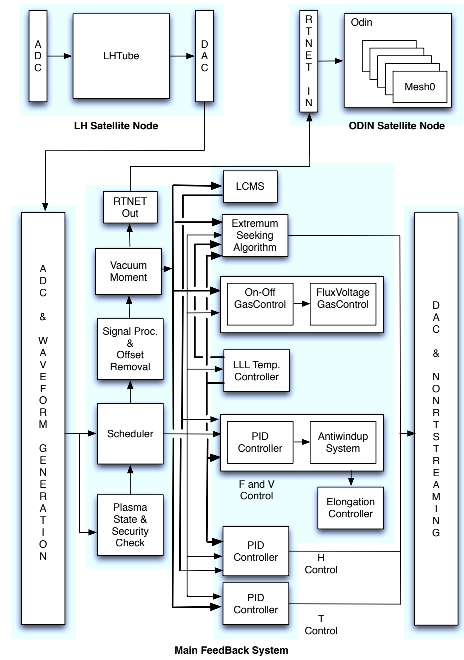

Figure 2: Block diagram of the MARTe FTU feedback system.

acquired data, and then preforms the toridal multipolar expansion described in [8]. The 12 output signals (external and internal moments) are part of the inputs for the LCMSGAM. This GAM calculates the poloidal flux on the limiter contact points, mixing the moments to the geometrical functions that describe the mesh[1]. The absolute maximum value for the flux among the contact points is the one of the last magetic surface. The reconstruction of the LCMS (Last Closed Magnetic Surface) is then carried out by iterating this process for all mesh points and stopping each time that the evaluated flux is greater or equal to the contact point one. The last set of inputs of the LCSMGAM are the preprogrammed radiuses[2], which are used to calculate the plasma position error in terms of $\Delta\Psi$ (DEP and DEZ signals, for horizontal and vertical position error respectively). These two signals, together with the plasma current, are the inputs for the CoilsControllerGAM, which holds the controllers for the three poloidal field amplifiers, and the plasma current one. Before execut-

[1] The actual mesh is made of 128 steps along the radius and 64 steps along the poloidal section

[2] Internal, external, upper and lower desidered plasma radius

ing this GAM, however, the ExtSeekGAM, if active, optimises via an extremum seeking algorithm the plasma position, in order to maximise the coupling with the LH antenna [6], patching the external preprogrammed radiuses. The CoilsControlGAM is made by four PID controller objects[3].
In FTU, the gas control is independent from the described process and is made by four GAMs: the PrefillControlGAM , the PlasmaDensityControlGAM, the SwapSignalGAM and the FluxVoltageGAM. The first two GAMs generate the gas flux request for the valves in the prefill and in the plasma phase respectively. The SwapSignalGAM schedules the control signals of the previous two GAMs, and finally the FluxVoltageGAM translates the flux request into the voltage reference for the valves amplifier using a nonlinear calibration curve.

The RTNetDrv can be used as TimeInput, Input and Output GAM, so that it can trigger, receive triggers, send and/or receive data from other systems.

The StreamingGAM is dedicated to the nonrealtime streaming towards monitoring system in the control room, see Figure 3.

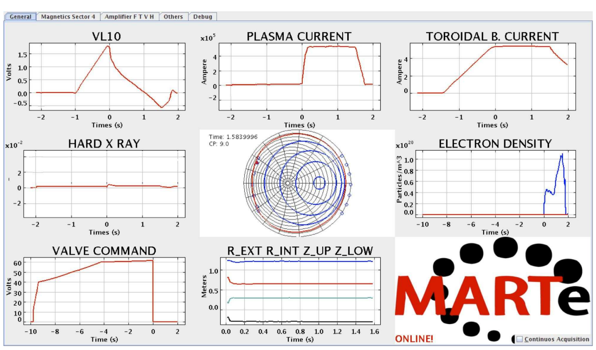

Figure 3: Feedback GUI, it show the shape evolution, and other important quantities with undreds milliseconds of latency

In FTU MARTe is being deployed using USB pendrives with a live linux distribution. This allowed to test and deploy different systems without needing to reinstall anything on the VME stations.

The integration in the real CODAS system is realized by a simple software named Feed2Marte which translates the Prometeo TCP messages into the corresponding HTTP ones and then forwards them to the MARTe StateMachine throught the HttpServer server.

4. Experimental results

The completed feedback system is being currently tested in the backup station, running in parallel with the previous feedback system. A comparison some produced signal of the old and new systems is shown in in Figures 4 and 5, while Figure 6 shows the behavior of the gas control system (in closed loop).

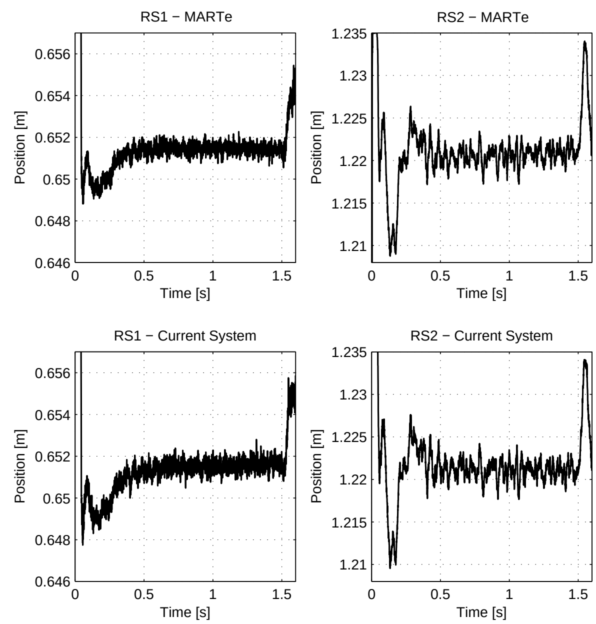

Figure 4: Reconstructed internal and external radiuses for the present controller and the MARTe-based one.

Closed loop tests of the coils control, before the final switch to MARTe, are being inserted in the FTU experimental programme.

5. Future developments

Thanks to the flexibility of the MARTe framework, many new control applications are being envisaged, such as a temperature controller for the Liquid Lithium Limiter experiment [9], an improved plasma model, using neural networks, for the F amplifier antiwindup system, and a fast equisurface reconstruction system using ECE and interferometric measures acquired and filtered by a new

[3]Note that it was necessary to merge the PIDs and the various nonlinear controllers in a single GAM, as their signals were heavily intertwined.

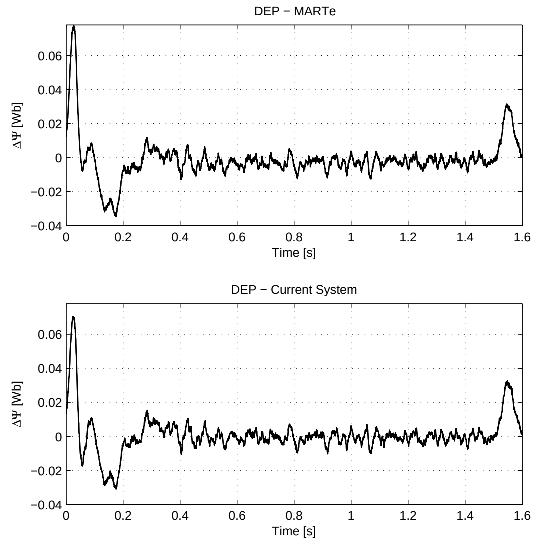

Figure 5: Magnetic flux measurement $\Delta\Psi$, used as horizontal position error for the coils control.

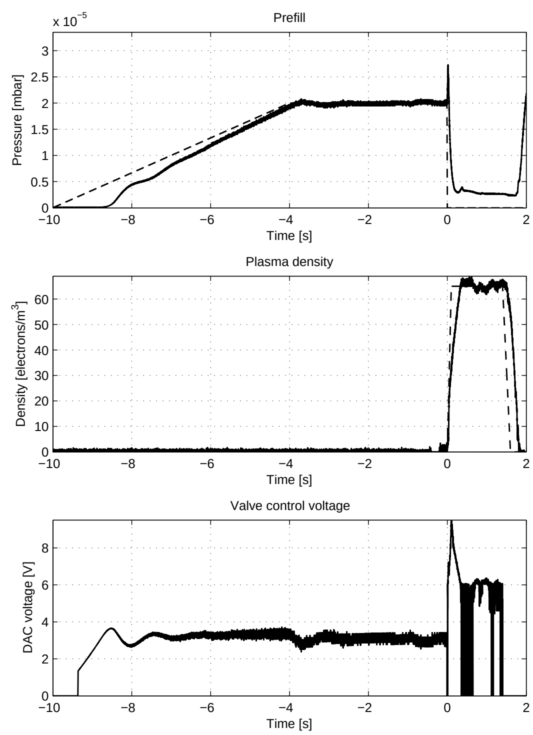

Figure 6: Pressure and pressure prefill reference , plasma density reference and interferometer density average, valve amplifier request.

MARTe system and transferred to the main station using the RTNet link.

6. Conclusions

In this work a brief introduction to the MARTe Framework has been presented. Then the architecture of the new FTU feedback control system has been described, underlining its subdivision in various independent subsystems (or GAMs). Some experimental results have also been presented.

Acknowledgment

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