SOFTWARE STRUCTURE AND REAL-TIME SIGNAL EXCHANGE FOR THE ASDEX UPGRADE TOKAMAK CONTROL SYSTEM

W. Treutterer, K. Behler, A. Lohs, G. Neu, G. Raupp, D. Zasche, T. Zehetbauer
and the ASDEX Upgrade Team,
Max-Planck Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany
R. Cole, K. Lüddecke, Unlimited Computer Systems, D-82393 Iffeldorf, Germany

Abstract

The toroidal magnetic confinement experiment ASDEX Upgrade investigates hot plasma performance and scalings in preparation of a thermonuclear fusion reactor. A new distributed real-time control has been designed for the device based on PCs and workstations under VxWorks and Solaris. As scientific progress requires frequent modification of algorithms, the system must provide flexibility to select specific sets of application processes (AP) and place these on target processors providing the necessary performance. For efficient information exchange between APs a shared memory layer for real-time signals, consisting of local ring buffers and shared memory hardware, has been developed which encapsulates signal routing and administration. The universal approach with free allocation of APs onto target processors combined with transparent real-time signal communication provides a flexible, reliable and efficient runtime infrastructure for general purposes.

INTRODUCTION

Research in preparation of an energy producing thermonuclear fusion reactor focuses on understanding, optimisation and control of the physical processes in a hot, fully ionised and magnetically confined plasma. The most advanced toroidal magnetic confinement trap is the tokamak, characterised by an axisymmetric, current carrying plasma ring in a strong toroidal magnetic field. The ASDEX Upgrade (AUG) fusion experiment is also based on that principle.

Though steady state tokamak operation is desirable, the standard inductively driven tokamak scenario inherently is a pulsed system working in a sequence of so called discharges. With magnetic field, gas valves and additional heating and fuelling devices the plasma base parameters – temperature, density and pressure – can be influenced via complex physical processes. Once these processes are sufficiently understood the plasma can be adjusted and held in optimised conditions with appropriate control methods. These methods must process a big amount of measurement data in short time, supply sophisticated control algorithms, react fast and flexibly to changes in plasma state, guarantee reliable and safe operation and should be easily extendible with new algorithms and additional feedback loops.

THE PRESENT CONTROL SYSTEM

ASDEX Upgrade started in 1991 with an ambitious control system [1] based on clusters of up to 14 transputer processors, working in parallel and connected with serial links. Input and output channels are also attached to these links with fibre optical wires. The clusters exchange information via point-to-point connections in a star-like architecture. Each cluster has a dedicated task: control of plasma current, position and shape, control of plasma density, heating, fuelling, radiation and energy confinement, monitoring mechanical and thermal loads on magnetic coil and suspension structures and discharge supervision and flow control with synchronisation of the clusters.

This control system has been continuously enhanced and extended through the years [2] and has contributed a lot to the good results of AUG fusion research.

Meanwhile, however, the capacity of this system has reached its limits while the ongoing research claims for further extensions. A hardware upgrade is not possible as transputer processors have vanished from the market. Furthermore advanced control algorithms require more knowledge on the plasma state and tend to integrate previously independent simple control loops to bigger units. A growing amount of information has to be exchanged between clusters, but this exchange is severely limited by the present point-to-point communication.

At this point it was decided to make a hard cut and develop a new control architecture from scratch.

THE NEW CONTROL SYSTEM

Guidelines for design fundamentals of the new control system were derived from the experience with the previous control system:

- It should be modular with components that can be easily exchanged or upgraded to keep pace with technological progress.
- It should focus on an efficient control framework and dedicated control algorithms but rely on third-party components where possible.
- Since reactor-like tokamaks also have considerable dimensions, it should facilitate distributed, on-the-spot data acquisition and preprocessing.
- And it should offer efficient access to process quantities for all control and monitoring applications.

The first realisation of the new control system is based on PC technology and the VxWorks operating system. All processor units, called controllers, have global access to measurement data and general plasma and control states, the real-time signals, using distributed shared memory. It comprises local buffers and a reflective shared memory network device which is built on BIT3 technology. This architecture (fig 1) is scalable in that controllers can be upgraded or new ones can be added to implement new evaluation and control activities or to increase computing power. For legacy input and output special transputer TPIO devices have been developed. Future external interfaces, however, should rather use commercial on-board converters as well as adapters to diagnostic data acquisition systems. Non time-critical user interaction, flow control, parameter database query, as well as signal visualisation are mainly sourced out to Unix workstations. Controllers communicate with these tasks through standard network protocols and the networking middleware NDDS in a protected ethernet domain [3].

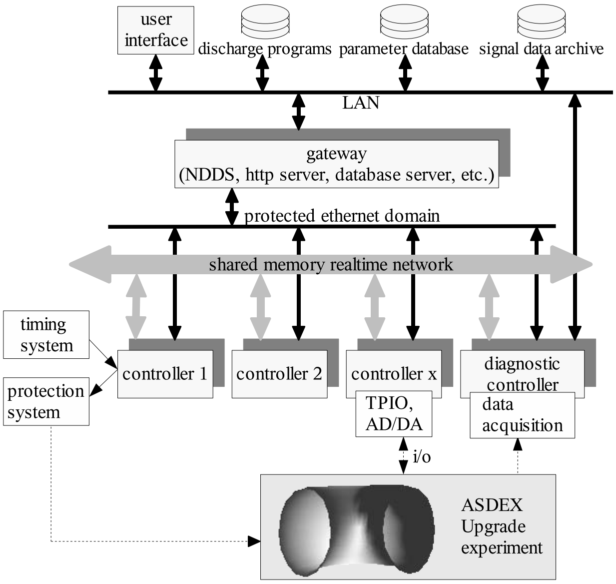

Fig. 1: architecture of the new AUG control system

The main focus of this paper, however, lies on the real-time architecture of the controllers. Real-time control action is implemented by a number of application processes (APs). They are arranged on the controllers depending on performance considerations. Time variant data that must be exchanged between APs during the real-time phase is propagated as real-time signals via shared memory as described below.

Tasks like cyclic synchronisation, shared memory handling, message logging and timeout monitoring are separated out into an infrastructure framework. This framework is complemented with a number of APs with administrative character: protocol handlers for archiving and visualising signals, input/output TPIO processes, an injector generating reference signals from an external discharge program and a supervisor determining control flow according to user-defined conditions dependent on the state of plasma and plant. On top of this structure is the bulk of actual application processes namely measurement preprocessors, plasma and device state monitors and feedback control units.

REAL-TIME SIGNAL EXCHANGE

Real-time signals stand for periodically generated samples of a changing quantity. Besides the value which may be a scalar, vector or matrix, they comprise a cycle number and a state tag. The state tag allows to grade validity of the value and to flag a stop of signal production to requestors. Signals may be single or organised in static or dynamic groups. Each signal must be uniquely provided but can be referenced by any number of requestors.

Samples are exchanged via shared memory made up of a local part for signal storage and a global part for signal transport. The local part consists of a pool of ring buffers for each used signal on a controller. These ring buffers store the sample history and decouple signal providers and requestors. The routing information is encapsulated in the shared memory administration layer.

If signals are requested on remote controllers, samples are copied to the shared memory device upon update and mirrored by reader processes to the ring buffers of those controllers. A process accesses a signal sample using handles associated with the local ring buffer. Besides the methods for sample access, the handle contains invariant signal properties like identifier, data type tag, dimensions, sample rate and required ring buffer depth.

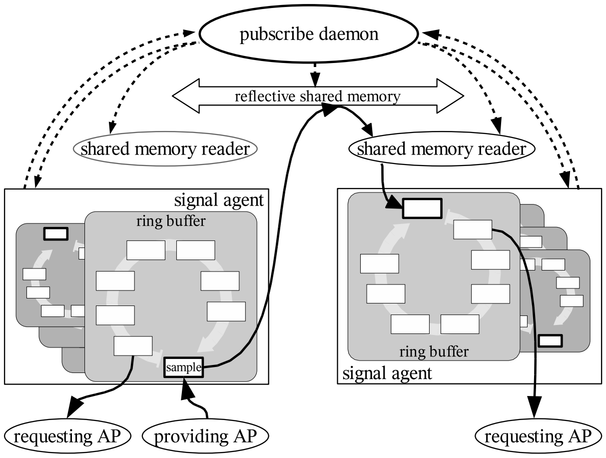

Fig. 2: real-time signal exchange via shared memory

These properties are necessary for signal administration which, however, is handled in non time-critical discharge preparation phases. The signal agent is the local administration entity where signals must be registered. All registrations are then sent to a central unit, the pubscribe daemon, which checks signal matching and consistent properties. It allocates storage location for all signals to be transferred on shared memory. The result is used to configure the shared memory readers and signal agents on the controllers. Finally the signal agents create the ring buffers and connect them to the registered process handles. During the real-time phase the signal agents are inactive as the application processes access the ring buffers directly.

REAL-TIME COORDINATION

Real-time processes synchronise each other by publishing new signal samples on which other APs are waiting in order to start or continue operation. Process pipelines may easily be built this way. For asynchronous access, requestors may also poll for a sample or subscribe for a buffered notification when a sample becomes available.

The entire chain of control processes is executed periodically in cycles. Digital control algorithms require constant sampling time and deterministic input-output latency, however. Therefore, combined peripheral input and output is performed at the beginning of each cycle. All output samples must have been produced timely before the next cycle starts. Violation of this deadline first leads to a singular short-term cycle prolongation, but, if persistent, to a protection shutdown of the discharge as then a severe error must be assumed.

To accomplish this feature, two infrastructure components closely work together. The cycle master is responsible for periodic generation of the cycle number real-time signal to which all i/o synchronise. Its partner is the house keeper, split in local representatives on each controller, to whom all application processes must report completion of their cycle action, and one central head, which in turn enables the cycle master to generate the next cycle or to trigger the protection system in case of timeout.

It is also a task of the cycle master to terminate the real-time phase of a discharge. For this it flags a production stop in the status of the cycle number signal. As a consequence all signal agents forward the production stop to the latest samples of all signals thereby releasing all processes waiting for future samples. Subsequently after some potential post-processing e.g. for signal archiving and message logging each AP must return to non-real-time operation.

NON-REAL-TIME COORDINATION

While signal data processing is the objective of the real-time phase, application parameter preparation and most administrative functions are executed in the non-real-time phase. An application management unit (AMU) is responsible to dynamically load and unload application processes. An experiment management state machine governs the sequence of non-real-time phases and the transition to the real-time phase, routing phase commands via NDDS to all application processes.

Basic actions comprise preparation of device drivers (prepare), retrieving constant parameters including signal specifications from external definition sets (getparams), informing the pubscribe daemon about published and requested signals (pubscribe), retrieving signal mapping on shared memory device and initialising shared memory (loadmap) and finally entering the real-time phase (start).

EXAMPLE IMPLEMENTATION

Figure 3 shows an example collaboration map for plasma position control. Participants are a TPIO process (io), a plasma geometry reconstructor (g), a shotprogram interpreter (ref) and the feedback controller (fb). They are assisted by the infrastructure processes shared memory reader(smr), cycle master(cm), local and central house keepers (lhk, chk) and protocol handler (ph). Processes are distributed over four controllers.

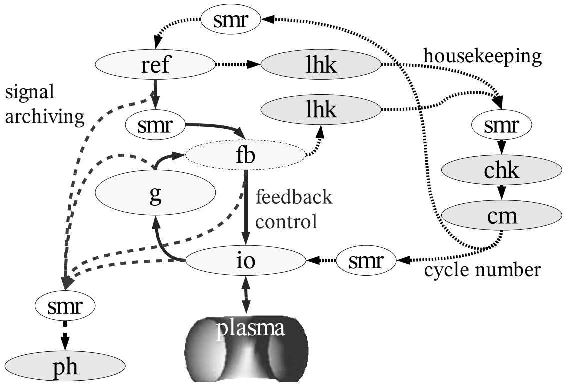

Fig. 3: collaboration map for plasma position control

OUTLOOK AND CONCLUSION

The new ASDEX Upgrade discharge control system has been completely redesigned in hard- and software. One main objective is the global availability of measured and preprocessed plasma and plant data allowing for enhanced plasma control algorithms. Information carrier for data exchange are real-time signals which are embedded in a shared memory layer.

While the hardware of the new system is already in place and the software infrastructure has been implemented, the actual plasma control applications are presently being designed. The envisaged initial sampling time for the whole system is 2 ms, and about 600 real-time signals must be exchanged.

Commissioning is planned at the beginning of year 2004.

The ASDEX Upgrade team is confident that this redesigned control system will assist its physics research activities as reliably and powerfully as the old system has done during the past 12 years.

REFERENCES

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