NEW DEVELOPMENT OF EPICS-BASED DATA ACQUISITION SYSTEM FOR MILLIMETER-WAVE INTERFEROMETER IN KSTAR TOKAMAK

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Abstract

After successful achievement of the first plasma in 2008, Korea Superconducting Tokamak Advanced Research (KSTAR) has performed the 4[nd] campaign in 2011. During the campaigns, many diagnostic devices have been installed for measuring the various plasma properties in the KSTAR tokamak. From the first campaign, a data acquisition (DAQ) system of Millimeter-wave interferometer (MMWI) has been operated to measure the plasma electron density. The DAQ system at the beginning was developed for three different diagnostics having similar channel characteristics with a VME-form factor housing three digitizers in Linux OS platform; millimeter-wave interferometer, H-alpha monitor and ECE radiometer. However, this configuration made some limitations in operation although it had an advantage in hardware utilization. It caused unnecessarily increasing data acquired from the diagnostics when one of them operated at higher frequency. Moreover, faults in a digitizer led to failure in data acquisition of the other diagnostics. In order to overcome these weak points, a new MMWI DAQ system has been developed with a PXI-form factor in Linux OS platform and a control application has been developed on EPICS framework like other control systems installed in KSTAR. It also includes MDSplus interface for the pulse-based archiving of experimental data. Main advantages of the new MMWI DAQ system besides solving the described problems are capabilities of calculating plasma electron density during plasma shot and displaying it in run-time. To this end, the data can be provided to users immediately after archiving in MDSplus DB.

INTRODUCTION

In the first campaign of KSTAR, only a few diagnostics including the millimeter-wave interferometer were involved in experiments, but the number of diagnostics continuously increased according to the diagnostics upgrade plan and finally almost 30 different diagnostics were operated in the 4th campaign. Among many plasma physics parameters, electron density is a primary parameter and an interferometry is a widely used diagnostic tool for a measurement of the electron density [1][2]. The first DAQ system for the interferometer was developed with a VME-form factor housing three digitizers in Linux OS platform which was shared by three different diagnostics having similar channel characteristics; millimeter-wave interferometer, H-alpha monitor and ECE radiometer. Also, the DAQ system was developed on EPICS [3] middleware like other plant control systems and diagnostic DAQ systems installed in KSTAR, and performed as a standard input output controller (IOC). However, it turned out in the operation of last campaigns that the interferometer DAQ system made some limitations although it had an advantage in hardware utilization and in terms of maintenance. It caused unnecessary increase in the amount of acquired data when one of three diagnostics operated at higher frequency and resulted in a longer waiting time to read data stored in MDSplus [4] DB [5] Moreover, faults in a digitizer led to failure in data acquisition of the other diagnostics. In order to overcome these weak points and to increase the number of diagnostic channels, a dedicated DAQ system for the ECE radiometer was first developed before the 3[rd] campaign in 2010. Next, a Millimeter-wave interferometer (MMWI) DAQ system has been newly developed to measure electron density for the experiment of the 4[th] campaign in 2011 (see Table 1).

The MMWI DAQ system has been developed with a different H/W form-factor, PXI, and achieved more accurate timing and operation availability by adopting a new timing board and a standard software framework. Particularly, it can display raw data and calculated electron density data at once during plasma shot in real-time, and this feature is useful for longer pulse plasma operation. Same as the previous system, all the interferometer data are archived using MDSplus, while some of data is shared via EPICS Channel Access (CA) and displayed by using EPICS strip. The OPerator Interface (OPI) for the MMWI was developed using KWT, which stands for KSTAR Widget Toolkit and is a set of libraries developed in house using Qt [6].

Table 1: Channel Configuration in DDS#2 [5] (Old DAQ System)

Diagnostics	2008	2009	2010	2011
MMWI	4 ch	4 ch	4 ch	New DAQ (2 ch)
H-Alpha	30 ch	30 ch	30 ch	30 ch
ECE	8 ch	40 ch	New DAQ (48 ch)	76 ch

UPGRADE OF MMWI DATA ACQUISITION SYSTEM

The new MMWI DAQ system has been developed with PXI form-factor digitizers in 32-bit Linux OS platform to solve the described problems and improve performance.

The PXI system should use the NI-DAQmx library to interface EPICS device/driver in Linux OS. NI-DAQmx library supports only x86 32-bit architecture for Linux and support only some of NI devices.

H/W Upgrade

The MMWI data acquisition system consists of a 2.53Ghz dual-core PXIe embedded controller running on Linux,a home-made Local Timing Unit (LTU) and a Analog-to-Digital Convertor module[7]. The NI (National Instrument) PXI-6123 ADC module has 8 analog input channels, 16bit resolution, 4 configurable input ranges from ±1.25 to ±10V, and 64MB onboard memory. Although the input signal from a phase comparator to the ADC module varies from 0 to 5V, the operating input range is ±10V in order to avoid input saturation. The sampling rate in normal operation is 100kS/s per-channel. The bit-resolution of the new MMWI DAQ system was downgraded from 24bit to 16bit but the sampling rate was upgraded from 216kS/s to 500kS/s.

The MMWI data acquisition sequence is synchronized with KSTAR experimental cycle using the LTU and a dedicated timing network like other installed diagnostic DAQ systems. The LTU is configured with a pre-programmed scenario before plasma shot, and generates triggers and clock signals according to the scenario as soon as it receives a shot start signal from a Central Timing Unit (CTU) thru the optical timing network [8].

Specifications of the new MMWI DAQ system are as followings:

- NI PXIe-8108: 2.53Ghz dual-Core PXI Express, 4GB DDR2 RAM, up to 1GB/s system bandwidth and 250 MB/s slot bandwidth.
- NI PXI-6123: 8 simultaneously sampled analog inputs, 16-bit resolution, max 500 kS/s per channel, input ranges from ±1.25 to ±10 V.
- NI BNC-2011: BNC connectors for analog I/O, Shielded enclosure.
- LTU: accuracy < 5ns, resolution 5ns, output clock (1Hz ~ 200MHz), max 8 configurable multi triggering sections 2Gbps Optical communication speed, max 8 Trigger/Clock outputs

Figure 1 shows the configuration of the new MMWI DAQ System and network connections to the infrastructure of the KSTAR control system.

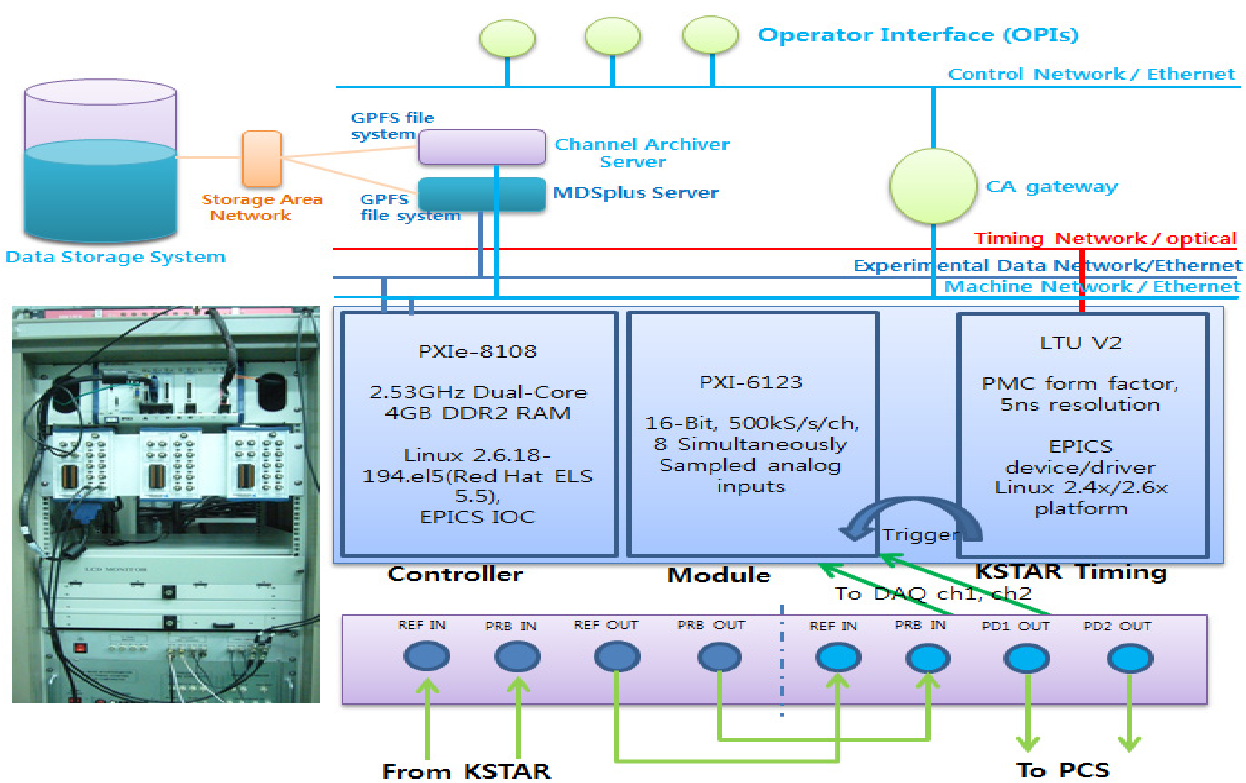

Figure 1: Configuration of MMWI DAQ System and network connections to the infrastructure of the KSTAR control system.

S/W Development

As mentioned above, the MMWI DAQ system is running in Linux OS platform, RedHat ES 5.5 (kernel – 2.6.18-194.e15). In general, all the data acquisition systems in KSTAR adopt a standard Software Frame-Work (SFW) that is developed and continuously improved in-house to reduce development time and improve system reliability. The SFW utilizes the IOC core software provided by EPICS and includes driver and device support software in common used with many other data acquisition systems in KSTAR [9]. The EPICS device/driver of the MMWI DAQ system is based on NI-DAQmx library to control National Instruments devices in Linux OS.

The SFW provides essential functions to support common records (shot number, blip time, seven states of system condition, etc), provide commonly used MDSplus interface to save acquisition data sampled at a high rate, and synchronize with a KSTAR plasma operation mechanism [9]. The OPI panels are developed by a particular set of Qt libraries named as KSTAR Widget Toolkit (KWT). They comprise of several sub-panels to configure and operate data acquisition, and to display the two types of density data in run-time; density data at 1 sec rate in AI record and full density data in a buffer in Waveform record. Additionally, the MMWI DAQ system uses common libraries of the KSTAR control system; the timestampLib to provide system time information and the sysMonLib to provide system health status of the system. Figure 2 shows the function blocks of MMWI DAQ IOC.

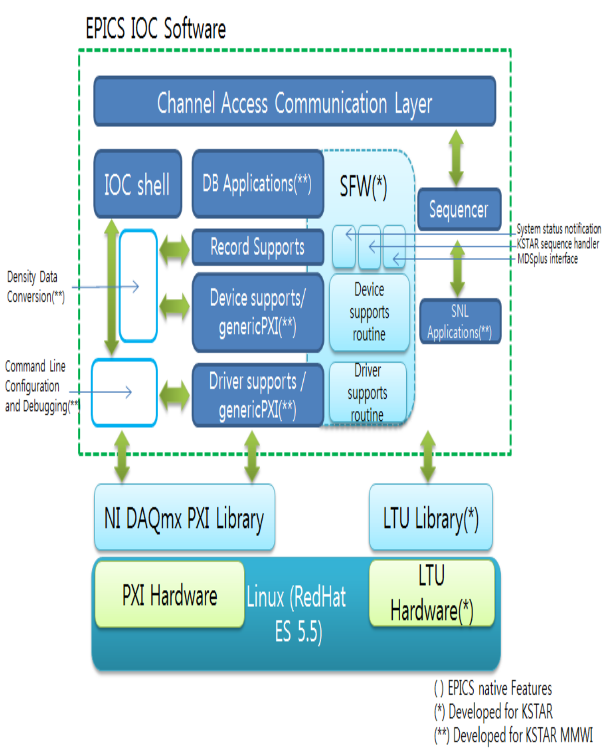

Figure 2: Function blocks for MMWI IOC.

All the programs to operate the MMWI DAQ system and archive diagnostic data are summarized as hardware driver for PXI devices (NI-DAQmx8.0.2), EPICS middleware interface program, MDSplus interface program, and Graphical User Interface (GUI) program (see Table 2).

Table 2: Environment for Software Development

Program	**Version**	**Site**
EPICS	3.14.12	http://epics.aps.anl.gov/epics
MDSplus	2.3-0	http://www.mdsplus.org
Qt	4.3.2	http://www.trolltech.com
DAQmx	8.0.2	http://www.ni.com

Calculation of Plasma Density for Real-Time Service

The millimeter-wave interferometer is a diagnostic tool to measure plasma density by using the phase changes according to density in the propagation through plasma. When millimeter-wave travels through plasma, its phase varies depending on plasma density, and the phase difference from phase through vacuum is detected and converted to voltage signal to be proportional to the measured phase by a phase comparator. If the measured phase exceeds 2π, the fringe jump phenomenon occurs and the output voltage goes back to zero. In order to provide the density value to users in real-time, the MMWI DAQ system writes the density data in AI record and Waveform record after correcting fringe jump with two raw data having the phase difference of π.

When “DMA done interrupt” from the NI device is received at every one second, the IOC first performs a fitting algorithm to compensate for a slight curvature of the phase comparator circuit. Next, the IOC averages 1000 raw data from each of two input channels and then judges which signal is closer to the center of maximum detected voltage to select better channel for calculation of density. The averaging is executed once at the start of a DMA done event.

Even though the input channel is selected, it is changed to the other to avoid the fringe jump if it’s voltage gap from the center voltage is larger than the other channel. When DMA data processing is complete, the IOC saves one calculated density data and two raw data from two input channels (without fitting) to files in the local HDD. It updates the measured density value in the waveform record and the final data in the AI record. This sequence is repeated at every DMA interrupt. After the completion of plasma shot sequence, the IOC moves two raw data and density data saved in the local HDD to MDSplus DB in the KSTAR central storage. Figure 3 shows the entire sequence of density calculation with the fringe-jump correction algorithm in IOC.

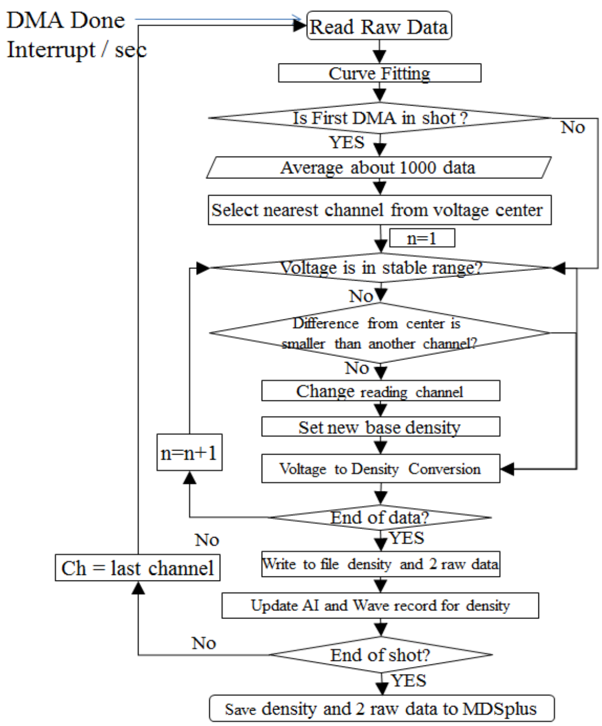

Figure 3: Sequence of density calculation with fringe jump correction algorithm.

OPERATION RESULT IN THE 4TH CAMPAIGN

After upgrading the MMWI DAQ system, both the stability and the usability of the system has increased considerably, and the amount of unnecessary data has also reduced. As shown in Table 3, just one fault occurred during the 4th campaign and even it was cause by the problem of NI-DAQmx on Linux in the case of long time operation. This problem is a big obstacle for a long time operation without system reset. Moreover, the same problem has occurred in all NI DAQ systems in KSTAR since 2008, and become the most significant fault source in the operation of data acquisition systems. We have now focused on solving it in cooperation with the manufacturer.

Table 3: Fault Counts in the Operation of the MMWI DAQ System

Campaign	DAQ fault counts	Lost shot	Total shot
1st 2008	23	23	1283
2nd 2009	4	2	1059
3rd 2010	14	17	2126
4th 2011	1	2	2002

Another deficiency is a small number of data points displayed in run-time during a shot. It displayed only 10 points data during a plasma pulse which was max 10sec in length in 2011. In the plasma experiments period, the new DAQ system operated successfully in data acquisition and density calculation only except for the case that the density changed momentarily and rapidly at the high density plasma. In addition, the heavy noise induced in the DAQ system has not been settled down.

SUMMARY AND FUTURE PLAN

In the fourth operation of KSTAR in 2011, the newly developed MMWI DAQ system was built and operated as an independent system. Add to the features of the previous system, the new DAQ system has many advantages in the views of hardware and software; the improved performance in data acquisition by adopting the standardization, more accurate synchronized operation with a new timing board, the run-time calculation and displaying density data. Also, there was a progress in the efficient data management. In the next campaign, the MMWI DAQ system will be modified to meet requirements arising in operation such as increasing the sampling counts to 10 for the effective run-time displaying and adding the function to archive the calculated data into MDSplus in real time to reduce the waiting time. Also, we will solve the problem of NI-DAQmx in the cooperation with the manufacturer.

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