New Development of EPICS-based Data Acquisition System for Millimeter-wave Interferometer in KSTAR Tokamak

October 11, 2011, Taegu Lee

KSTAR Research Center
Outlines

◆ Introduction
  • KSTAR control system and diagnostic DAQ systems
  • What is Millimeter-wave Interferometer?
  • First date acquisition system for the diagnostic
  • Why need new DAQ system?

◆ Upgrade DAQ system
  • What are the considerations in design?
  • Details about system hardware and software
  • How to calculate the density in real-time?

◆ Operation Result in the 4th Campaign

◆ Summary
# Features of KSTAR Control System

<table>
<thead>
<tr>
<th>Structure</th>
<th>2 Tier</th>
<th>•Control --- Interlock+Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Layer</td>
<td></td>
<td>•Central --- Local</td>
</tr>
<tr>
<td>Middleware</td>
<td>EPICS</td>
<td></td>
</tr>
<tr>
<td>Operating system</td>
<td>Linux</td>
<td>•Plant monitoring &amp; control</td>
</tr>
<tr>
<td></td>
<td>VxWorks</td>
<td>•Feedback control</td>
</tr>
<tr>
<td>H/W Platform</td>
<td>Slow control</td>
<td>•PLC, cFP</td>
</tr>
<tr>
<td></td>
<td>Fast control</td>
<td>•VME, PXI, cPCI, PCI, VXI, (ATCA)</td>
</tr>
<tr>
<td>Interface (Networks)</td>
<td>Machine</td>
<td>EPICS CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experimental Data</td>
<td>MDSip</td>
</tr>
<tr>
<td></td>
<td>Real-time</td>
<td>Shared-memory</td>
</tr>
<tr>
<td></td>
<td>Interlock</td>
<td>(ControlNet)</td>
</tr>
<tr>
<td></td>
<td>Timing</td>
<td>Home-made protocol</td>
</tr>
<tr>
<td>OPI</td>
<td>Qt (open source)</td>
<td></td>
</tr>
<tr>
<td>Data Managements</td>
<td>EPICS Channel Archiver</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MDSplus</td>
<td></td>
</tr>
</tbody>
</table>
### Diagnostics in KSTAR

#### Data Acquisition Systems for Diagnostics

- Continuously increasing diagnostics campaign by campaign
- Almost 30 diagnostics operate in the 4th campaign

<table>
<thead>
<tr>
<th>DAQ System</th>
<th>Diagnostic System</th>
<th>CH</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>Rogowski Coil</td>
<td>3</td>
<td>1 cPCI crate with 2 independent backplane</td>
</tr>
<tr>
<td></td>
<td>Flux/Voltage Loop</td>
<td>45</td>
<td>2 Linux servers with PCI expansion</td>
</tr>
<tr>
<td></td>
<td>Magnetic Field Probe</td>
<td>232</td>
<td>Total 576 channels on 6 digitizers</td>
</tr>
<tr>
<td></td>
<td>Diamagnetic Loop</td>
<td>8</td>
<td>max 500KSPS (digitizer itself)</td>
</tr>
<tr>
<td></td>
<td>Saddle Loop</td>
<td>40</td>
<td>Streaming data acquisition</td>
</tr>
<tr>
<td></td>
<td>Vessel Current Monitor</td>
<td>3</td>
<td>Full EPICS and MDSplus integration</td>
</tr>
<tr>
<td></td>
<td>Halo Current Monitor</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Probe system</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>MMWI</td>
<td>MMW Interferometer</td>
<td>2</td>
<td>PXI, Linux host, max 500kHz</td>
</tr>
<tr>
<td>HALPHA</td>
<td>H_Alpha Monitor</td>
<td>30</td>
<td>1 VME crate with SBC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 digitizers(max 100KSPS)</td>
</tr>
<tr>
<td>ECE_HR</td>
<td>ECE Heterodyne Radiometer</td>
<td>76</td>
<td>1 VME crate with SBC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 digitizers (max 100KHz)</td>
</tr>
<tr>
<td>TS</td>
<td>Thomson scattering Diagnostic</td>
<td>45</td>
<td>Single Linux host and VME crate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Current charging digitizer</td>
</tr>
<tr>
<td>ER</td>
<td>Edge Reflectometer</td>
<td>4</td>
<td>PXI, max 200MHz</td>
</tr>
<tr>
<td>MC</td>
<td>Mirnov Coil</td>
<td>40</td>
<td>VXI, Linux host</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 digitizers (1 ~ 800kHz)</td>
</tr>
<tr>
<td>SXR</td>
<td>Soft X-ray Array</td>
<td>64</td>
<td>PXI, Linux host</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 digitizers (max 500KHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PSU control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Timing distribute board</td>
</tr>
</tbody>
</table>
First DAQ System for MMWI

● **What is Interferometer?**
  - Interferometry is a widely used diagnostic tool for measuring electron density which is a primary plasma parameter
  - In KSTAR,
    - ✓ A 280GHz single-channel horizontal MMWI is installed
    - ✓ It is suitable for low line-integrated electron density
    - ✓ Electron density ~ about $10^{19}$/m²

● **First DAQ system for MMWI**
  - The first DAQ system was developed for 3 difference diagnostics having similar channel characteristics for H/W utilization
    - ✓ MMWI, ECE Radiometer and H-Alpha monitor
  - Features of DAQ System:
    - ✓ VME-form factor with 3 digitizers, totally 96 channels
    - ✓ CPU : SVME-183 (1.2GHz) (Curtis-wright)
    - ✓ Digitizer : Pentek M6802 (24-bit, 32CH, max 260kSPS)
    - ✓ O/S : Embedded Linux 2.6.20
    - ✓ Data stored in a local SATA disc thru FPDP
      - SATA HDD throughput : write (50.33MB/s)
First DAQ System for MMWI

● Some Limitations of First DAQ system

• Limitation in storing data to local HDD
  ✓ At 200KHz sampling, data rate = 200k*96CH*4Byte=74MB/s
  ✓ At 100KHz sampling, it takes a long time for storing

• Inefficient data management
  ✓ When one of three diagnostics obtains data at higher frequency, the others have to acquire unnecessary data

• Un-isolated fault propagation in operation
  ✓ When a fault occurs in one diagnostic, it propagates to the others
  ✓ Therefore, it reduces system availability
Upgrade DAQ System for MMWI

**System Composition and Specification**

- **Considerations in design:**
  - Does it support Linux OS? KSTAR standard OS is Linux
  - Is it stable for long-time operation without system reset?
  - Is it suitable for reducing development time and improving system reliability? Do we have experiences to develop?
  - Is the price reasonable?

- **We chose PXIe form-factor**
  1. **Controller**: PXIe-8108 (NI)
     - 2.53GHz dual-core PXIe embedded controller with 4GB DDR2 RAM
     - up to 1GB/s system bandwidth and 250MB/s slot bandwidth
  2. **Digitizer**: PXI-6123 (NI)
     - 8 simultaneously sampled analog inputs
     - 16-bit resolution, 500kS/s per channel, from ±1.25 to ±10 V input range
  3. **Time synchronization**: LTU (Local Timing Unit) (Home-made)
     - Resolution and accuracy 5ns, output clock (1Hz ~ 100MHz)
     - Multi-triggering section: max. 8 (configurable)
     - 2Gbps optical communication using a dedicated Timing Network
Development Environment

- **OS**: RedHat Linux 5.5 (kernel – 2.6.18-194.e15)
  - Control application, device/driver for PXI
- **MDSplus** (2.3-0) : Pulse-based archiving of experimental data
- **Qt** 4.3.2
  - To develop operator interface panels
  - Use in-house developed Qt libraries, KSTAR Widget Toolkit (KWT)
- **NI-DAQmx** (8.0.2) : Hardware driver for PXI
- **SFW** (Software Frame-Work):
  - in-house developed standard template
  - To reduce developing time and improve system reliability
- **sysMonLib** : To monitor system health status
- **LTULib** : Hardware driver for in-house developed local timing unit (LTU)
  - To synchronize with KSTAR experimental cycle
Upgrade DAQ System for MMWI

Configuration

Operator Interface (OPIs)

Control Network / Ethernet

Channel Archiver Server

Timing Network / home-made

LTU Controller

Experimental Data Network/Ethernet

CA gateway

Timing Network / home-made

Controller

PXle-8108
2.53GHz Dual-Core
4GB DDR2 RAM
Linux 2.6.18 (Red Hat 5.5), EPICS IOC

Digitizer

PXI-6123
16-Bit, 500kS/s/CH, 8 Simultaneously Sampled analog inputs

LTU

LTU V2
PMC form factor, 5ns resolution
EPICS device/driver Linux 2.4x/2.6x platform

Trigger

From KSTAR

phase comparator circuit

To PCS
Upgrade DAQ System for MMWI

Functional Block Diagram of IOC

EPICS IOC Software

Channel Access Communication Layer

IOC shell

DB Applications(**)

Record Supports

Device supports/genericPXI(**)

Driver supports/genericPXI(**)

SFW(*)

Sequencer

SNL Applications(**)

Record Supports

Device supports routine

Driver supports routine

Density Data Conversion(**)

Command Line Configuration and Debugging(**)

NI DAQmx PXI Library

LTU Library(*)

PXI Hardware

Linux (RedHat ES 5.5)

LTU Hardware(*)

(*) Developed for every DAQ system

(**) Developed for MMWI

( ) EPICS native features

MDSplus interface

System status notification

KSTAR sequence handler

• KSTAR sequence handler
How to Measure Plasma Density?

Features of Interferometer Signals

- When millimeter-wave travels through plasma, its phase is changed in proportional to the plasma density.
- A phase comparator measures the phase difference and outputs a voltage signal.
- If the measured phase difference exceeds $2\pi$, the fringe jump occurs and the output voltage goes back to zero.
How to Calculate Density in Real-time?

Data Processing Sequence

- DMA done Interrupt / sec
- Fitting to compensate for a slight curvature of the phase comparator circuit
- Select nearest channel from voltage center
- Density conversion with the selected channel
- End of data process in buffer
- Write data to file: density and 2raw data
- Update AI/Waveform record with density data
- This sequence is repeated at every DMA interrupt
- 2 Raw & density data transmitted from local HDD to MDSplus DB in the central storage
Operation result in the 4th campaign?

- **Operation Panel and Density Signal**

(a) OPI Panel

(b) Plasma density
Operation Results in the 4th campaign?

● What are improved?

- Increase data sampling frequency
- Improve system stability and reliability
  ✓ system fault has occurred just one time
- Optimize data size
- Implement additional function
  ✓ Displays density data on real-time
- Enhance density calculation procedure

<table>
<thead>
<tr>
<th>Campaign</th>
<th>Fault counts</th>
<th>Lost-shot counts</th>
<th>Total shot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st 2008</td>
<td>23</td>
<td>23</td>
<td>1283</td>
</tr>
<tr>
<td>2nd 2009</td>
<td>4</td>
<td>2</td>
<td>1059</td>
</tr>
<tr>
<td>3rd 2010</td>
<td>14</td>
<td>17</td>
<td>2126</td>
</tr>
<tr>
<td>4th 2011</td>
<td>1</td>
<td>2</td>
<td>2002</td>
</tr>
</tbody>
</table>

● What will be modified next?

- A small number of data points displayed in run-time during a shot
  ✓ One density data at every 1sec, 10 points for a plasma pulse in 2011
  ✓ It will be increased to 10 data at 1 sec
Summary

- In the 4th operation of KSTAR in 2011, the newly developed MMWI DAQ system operated as an independent system.
- Add to the solving the problems of the previous system, the new DAQ system has a few advantages in the views of hardware and software
  - Improved performance in data acquisition by adopting the standardization
  - More accurate synchronized operation with a new timing board
  - Run-time calculation and displaying of density data
- Also, there was a progress in the efficient data management
- The MMWI DAQ system will be modified to meet requirements arising in operation such as;
  - Increasing the DMA event counts for the effective run-time displaying
  - Real-time data archiving to reduce the waiting time in MDSplus DB