Software Development of the KSTAR Tokamak Monitoring System


National Fusion Research Center, 52 Eoeun-dong, Yuseong-gu, Daejeon 305-333, Republic of Korea

Abstract

The Korea Superconducting Tokamak Advanced Research (KSTAR) project, which is constructing a superconducting tokamak, was launched in 1996. Much progress in instrumentation and control has been made since then and the construction phase will be finished in August 2007. The Tokamak Monitoring System (TMS) measures the temperatures of the superconducting magnets and structures and hence monitors the superconducting conditions during the operation of the KSTAR tokamak. The TMS also measures the strains and displacements on the structures in order to monitor the mechanical safety. There are around 500 temperature sensors, more than 360 strain gauges, and 20 displacement gauges.

Functions of KSTAR Tokamak Monitoring System (TMS)

- Cryogenic Monitoring
  - Monitoring superconductive characteristics
  - Temperature monitoring
  - Cernox/PT-100 sensors
  - Calculate Helium properties (super-critical He)
  - Input: pressure, temperature
  - Output: density, entropy, internal energy and etc.
- Structural Monitoring
  - Monitoring mechanical safety
  - Displacement
  - Strain-Stress
  - Magnetic field: Hall sensors

Structure and functions of TMS

- TMS IOC#1: Cryogenic monitoring
  - SCXI modules: Cernox sensors & Hall sensors
  - CompactFieldPoint: PT-100 sensors
- TMS IOC#2: Structural monitoring
  - SCXI modules: Displacement, Strain-Stress
- Channel Archiver
  - Continuous data archiving
- SAN Storage
  - User Interface
  - Alarm, Stripchart
- Operator Interface
  - Communication relay between the machine network and control network
  - Reduce communication overhead on IOCs
  - CA gateway
  - Communication relay between the machine network and control network

Implementation of TMS IOC software

- EPICS IOC core software
  - Communication: Channel Access Server/Client
  - Bundled device/record supports
  - User programming environment
  - Data Archive: Graphical/Visual programming
  - State Notation Language (SNL): C like syntax / finite state machine
- Development of Software
  - PXI hardware driver & device
  - devPXIS: interface layer between NI DAQmx and EPICS device support layer
  - devPXIS: data transmit between hardware to EPICS record, data conversion, and etc
- DB Application
  - Data conversion: Raw data to Physical data (for displacement, strain-stress, Hall sensors and PT-100)
  - Database control: sampling rate, gain, filter option and etc. (by operator or by control logic)
- SNL program
  - Cooling status, Detection of abnormal status
  - Cernox Data Conversion (Special requirement)
    - each Cernox sensor has its own characteristic curve (fit the curve by Chebyshev polynomials) require a database for fitting coefficients each sensor
    - fast conversion time
    - Implement a function block in device supports with C language
    - an IOC thread
    - executed by a request from record support
    - asynchronous processing to avoid blocking of the record processing

Choice of Hard ware and Software

- Hardware
  - National Instruments PXI / SCXI
    - Cheap & Powerful CPU board
    - Multi channel 1/0: >100ch/module
    - Signal Conditioner: 15kV isolation, Low-pass filter, adjustable gain control, and etc
    - A/D converter (digitizer): PXI-6680
    - Signal Conditioner:
      - Cernox/Hall sensor: SCXI-1125
      - Displacement/Strain-Stress: SCXI-1520 and etc.
- Software
  - OS: Linux (kernel-2.6)
    - Middleware: EPICS (R3.14.8.2) - control software standard in KSTAR
  - Measurements & I/O control: EPICS IOC software
  - Data Archiving: EPICS channel archiver
  - Monitoring & User Interface: EPICS channel access library,

Reducing the calculation time

- example of the Cernox Data Conversion
  - Implemented with C and embedded into the device supports
  - Choose more faster algorithm
    - Recursion with Trigonometric function
    - Recursion with arithmetic only
    - \[ r(n) = \log_{b}(a) \]
    - \[ r(n) = 2 \times r(n-1) + \sum_{i=0}^{n-1} c_i \]
      - \[ r(n) = \sum_{i=0}^{n} c_i r(n-i) \]

Measurements of computation time

Software

Channel Access Communication Layer

- Command line Configuration and Debugging
- Sequeencer

EPICS IOC Software

- Channel Access Communication Layer
- 5th Applications
- SNL Applications

PXI/SCXI Hardware

- NI DAQmx PXI Library

Function block in EPICS IOC

(*) Developed for KSTAR TMS
How to avoid blocking of the Record processing during hardware configuration

- Sampling Rate, gain, Low-pass filter control
- To avoid blocking of Record processing: multi-threading
- Command line interface (CLI) on IOC shell

EPICS Driver Thread
Request to change the hardware configuration
Kernel module and Kernel Thread

- Command thread
- Message queue
- Resume and suspend

Extensions for IOC shell command
Debugging Features
- Report information of hardware configuration, task status, channel configuration
- List up information of sensors, counters, parameters for software internal
- Turn on and turn off the debugging messages
Configuration Features
- Create task to handle PXI hardware
- Create channel and configure properties of channel
- Destroy the channel
- Destroy the task

The driver is running on
- _main_ thread
- CA-Client thread
- Scanxx thread
- ScanOnce thread
- etc

EPICS Message Queue
Keep perform the processing chain on the driver thread

Record Processing Phase I
Terminate the phase I processing

Record Processing Phase II
Suspended until receive messages
No pay for watching events
Suspended
Resume

Record Processing Flow
For the PXISCXI control

Example of IOC shell command

Operator Interface (OPI)
- Developments
  - Graphic library: Qt/Qt Designer
  - Communication: EPICS Channel Access library
- Operation environment
  - Redhat Enterprise Linux WS4
- Network Connection
  - TMS OPiS: control network (Ethernet)
  - TMS IOCs: machine network (Ethernet)
  - CA gateway
    - relay station of Channel Access communication
    - Reduce communication overhead on IOCs (make virtual connection with OPIs)

Data Archiving & Retrieve System
- Data Archiving
  - EPICS Channel Archiver
  - Continuous archiving
  - Periodic / Event driven archiving
- Data Storage
  - SAN Storage
  - IBM DS8100 Storage
  - StorNext file system (Shared file system)
- Data Retrieve
  - by Data analysis server
  - ArchiverExport (CLI tools)
  - Web based export (apache, XML rpc, cgi )
  - Java export (graphical tools)
  - GNUplot, Excel, and etc

Pre-Commissioning
- Hardware check
  - Check for sensors, signal lines and connections
  - Calibration digitizer offset
  - Check long term drift of measurement data
- Software check
  - Check basic functions of IOCs, OPiS, and Data archiving system
  - Check software stability
  - Stability check conditions
  - Total PVs: ~1,300 PVs (10Hz processing, 13,000 events/sec) in two IOCs
  - 10 OPiS connection
  - CA gateway: 1,300 PV connection, 13,000 virtual circuits, 130,000 server events/sec
  - Channel archiver: Archive whole channels, every events.
- Results of Stability Check
  - IOCs: worked well during 2 months (no memory leak, no hang-up, less than 10% CPU loads)
  - CA gateway: passed (no hang-up, less than 5% CPU load)
  - Channel archiver: keep evaluation (less than 30% CPU load, have been crashed once )
  - OPi Application: fixing –up memory leak on graphic widget

Summary and Future Plan
- We have developed the TMS and performed pre-commissioning with room temperature conditions under which the measurements values and system performance were satisfied. The TMS also passed a 2 months aging test and was found to be very stable.
- The next step is to implement automatic gain control functions for the Cernox sensors and measurements of the helium properties to prepare for the cool down process and operation.