Design of GPU-based Parallel Computation Architecture of Thomson Scattering Diagnostic in KSTAR

Seung-Ju Lee*, Jongha Lee, Taehyun Tak, Taegu Lee, Jaesic Hong

* NFRI / KSTAR Research Center / Control Team
Thomson Scattering System Intro.

Thomson system

Laser Beam

Core Lens

Edge Lens

Polychromator

Optical fiber bundle

5ea electric signal

5 spectrum

Measurement of electron temperature ($T_e$) and density ($n_e$) profiles
TS 5GSPS DAQ System

V1742(CAEN)

- 12-bit @ 5 GS/s
- Switched Capacitor technology based on the DRS4 chip (1024 capacitor cells per channel)
- 5, 2.5, 1 GS/s and 750 MS/s software selectable sampling frequencies
- VME64/VME64X (32 ch.), NIM (16 ch.) and Desktop (16 ch.) modules
- Analog inputs on MCX coaxial connectors
- 1 Vpp input dynamic range with programmable DC offset adj.
- Dead-time due to conversion: 110 μs (analog inputs only), 181 μs (TRn inputs)
- Memory buffer options: 128 events/ch; 1024 events/ch
- VME64/VME64X, USB and Optical Link communication interfaces
- Multi-board synchronization features (VME only)
- 16 programmable LVDS I/Os
The analog signal is collected in an array of 1024 capacitors with 5GHz switching. After holding the collection, voltage values of each capacitor are sequentially acquired by the ADC circuit. The information of the pulse shape and noise level is available.
Diagnostic Calculation Method

X-square method

- **Current status**
  - The diagnostic data is available after each plasma shot experiment.
  - The diagnostic calculation takes few seconds.

- **Problem: Increased data to be processed**
  - Raw data: 1 data (QDC) => 1024 data (5GSPS), signal processing, integral
  - Resolution of the lookup table: 1eV => 0.1eV

\[
X^{\square} = \min_{T_e} \sum_{i=1}^{4} \omega \left( y_{data}^i - f_{cal}(T_e)^i \right)^2
\]
Artificial Neural Network (ANN)*

ANN Feasibility Test*
- Optimized performance of ANN
  - 8 nodes of the hidden layer
  - Training cycles: $N=10^3$
- The computation time is 20 times faster than the X-square methods.

Design of Computation Architecture
- Adoption of the ANN algorithm
- Real time operation: 20ms
- Compatible with TS DAQ program
- GPU based Computation Architecture
  - Parallel computation of multiple ANNs
  - Parallel computation of integration operation for each pulse signal
  - Reduction of CPU task load

Parallel Computation Architecture

Overall Structure

- **EPICS framework**
- **Data read thread**: Receive the raw data from digitizer
- **Data write thread**: Store the raw data in file => Put to MDSPlus server
- **The GPU thread**: Diagnostic calculation
- **Queue**: Ring buffer
**Parallel Computation Architecture**

### Task Parallelization

- **Data Read Thread**: Board 1, Board 2, Board 3
  - Data read from digitizer board
  - Data queue

- **GPU Thread**: Board 1, Board 2, Board 3
  - Host Memory: Data Input
  - Host Memory: Diagnostic Data
  - GPU Memory
  - Diagnostics

### CUDA Stream

- **Memory copy**: from host to GPU, GPU kernel execution (Diagnostics), from GPU to host

- **Streams**: Stream 1, Stream 2, Stream 3, Stream 4

### Task parallelization

- **TS DAQ host PCs**: TS Core, TS Edge
- **Four digitizer boards (32ch/board)** for each DAQ host PC
- The task of each digitizer is parallelized by using its own data read thread and GPU thread

### CUDA stream

- Support the task parallelization
- Task concurrency is enabled
## Parallelization of Diagnostic Calculation

<table>
<thead>
<tr>
<th>Signal Processing</th>
<th>Diagnostics 1</th>
<th>Integral</th>
<th>Integral</th>
<th>ANN (IN→HI)</th>
<th>ANN (HI→OUT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diagnostics 2</td>
<td>Integral</td>
<td>Integral</td>
<td>ANN (IN→HI)</td>
<td>ANN (HI→OUT)</td>
</tr>
<tr>
<td></td>
<td>Diagnostics 6</td>
<td>Integral</td>
<td>Integral</td>
<td>ANN (IN→HI)</td>
<td>ANN (HI→OUT)</td>
</tr>
</tbody>
</table>

- **Total six ANNs are simultaneously calculated.**
- **Integral**
  - 1 block / channel
  - 1024 threads / block
  - Total 24 blocks
- **ANN(IN→HI)**
  - 1 block / ANN
  - 4(IN) X 8(HI) threads / block
  - Total 6 blocks
- **ANN(HI→OUT)**
  - 1 block / ANN
  - 8(HI) X 1(OUT) threads / block
  - Total 6 blocks
- **Method for signal processing is a research topic**
Feasibility Test

Test GPU

Test Conditions

- Data acquisition and execution of data read threads are simulated by reading a sample data file. (Period: 50Hz)
- We measure the time length that all data read and GPU threads are completed.
Feasibility Test

Test Results: Diagnostic Calculation Time

- **Average:** 0.312 ms, **Peak:** 2.894 ms
- **Max frequency:** [0.23, 0.286] ms
- **Expected calculation time range:** [0.118, 0.734] ms < 1 ms
Conclusion & Future Works

◆ Conclusion
  • 5GSPS DAQ system have been installed in KSTAR Thomson Scattering system.
  • Diagnostics Method: X-square => ANN
  • Task parallelization
    – Data acquisition => Diagnostic calculation
    – Multi-thread based programming
  • Parallelization of diagnostic calculation
    – Calculation of each neural network is executed concurrently.
    – GPU based architecture (CUDA programming)
  • Integration with EPICS frame work.

◆ Future Works
  • Research Topic: signal processing of raw TS data
  • New calibrated TS data => Learning ANN and evaluation
  • Implementing the architecture in the TS DAQ system.

◆ Application
  • Streaming the diagnostic data
  • Feedback control
Thank You