Design & Development of Real Time Parallel Stream Processing System for KSTAR L/H Transition Detection

Giil Kwon ¹, Gi Wook Shin², Sang Hee Hahn ¹, Sang Won Yun ¹ and Jae Sic Hong ¹

¹ National Fusion Research Institute, Daejeon, Republic of Korea
² University of Science and Technology (UST), Republic of Korea

giilkwon@nfri.re.kr

3rd IAEA Technical Meeting on Fusion Data Processing, Validation and Analysis
Outline

• Introduction
• System Overview
• System Configuration
• L/H transition Detection Algorithm
• Software architecture
• Real Time LHML
• Performance test & results
• Summary & Future works
Introduction

- H-mode operation is much more desired than L-mode.
- The density control method need to changed as the plasma mode changes.
  - The fuel from gas injector does not absorbed into plasma due to the edge transport barrier.
- Determining the plasma mode in real time is necessary.
  - The density control devices and algorithm need to be changed as the mode of plasma changes.
- We have developed L/H Transition detection system using ML(LHML).

- KSTAR: Korea Superconducting Tokamak Advanced Research

- Plasma image at KSTAR
• L/H transition detector system using ML(LHML)
ITER Synchronous Databus Network (SDN): the real-time network based on a UDP multicast over a 10-GbE cut-through packet-switching infrastructure

ITER Time Communication Network (TCN): PTP, IEEE 1588, the network for absolute synchronization that is also synchronized with the KSTAR timing system

ITER Plant Operation Network (PON): Industrial Ethernet

ITER Data Archiving Network (DAN): 10 Gb Ethernet for data archiving
L/H transition Detection Algorithm[1,2]

- Phenomena at L→H Transition
  - $H_\alpha$ amplitude abruptly changes
  - Increase of line-averaged density $n_e$

- Long-Short Term Memory (LSTM)
  - LSTM can learn from sequential data and predict the class of data sequentially. (# of hidden units = 300)
  - Input data point is [$H_\alpha$, $n_e$] pair.
  - Down-sampled signals to 10kHz
  - No preprocessing (only rescaling)
  - 78 shot for training/ 26 shots for test set comes from 2017 campaign
  - input layer => LSTM layer => Fully connected layer => softmax layer => classification layer (output)
  - Test set accuracy : 97.8 %

Figure courtesy of Gi Wook SHIN[1]

L/H transition Detection Algorithm[1,2]

- Phenomena at $L \rightarrow H$ Transition
  - $H_\alpha$ Amplitude change timing of signal
  - Increase of line-averaged density $\overline{n_e}$

- Long-Short Term Memory (LSTM)
  - LSTM can learn from sequential data and predict the class of data sequentially. ( # of hidden units = 300)
  - Input data point is $[H_\alpha, \overline{n_e}]$ pair.
  - Down-sampled signals to 10kHz
  - No preprocessing(only rescaling)
  - 78 shot for training/ 26 shots for test set comes from 2017 campaign
  - Network layer
  - Test set accuracy : 97.8 %

Software architecture

- **Architecture**
  - **RT-ParaPro** was used to implement LHML.
    - RT-ParaPro is homemade C++ real time data processing library.
    - RT-ParaPro has a jitter of about 8 usec in 10kHz control cycle rate
  - **Consumer and producer pattern** was used.
  - **MRG-R kernel** was used to get real time performance.
  - Each thread is controlled by Finite State Machine (FSM) thread which control other thread according to KSTAR shot sequence information.
• Architecture
  • EPICS channel access is used to control FSM thread and set parameters.
  • OPI was implemented by using Control System Studio (CSS Boy)
  • LHML work with KSTAR central control system with EPICS channel access
  • LHML is automatically executed in accordance with KSTAR shot sequence from KSTAR central control System.
Multiple Data Stream Processing Unit (C++)
- ITER SDN was used to send and receive the data stream.
- Data stream processing unit consists of thread and buffer pair.
- Multi-thread was used to process data in parallel.
- FSM thread control all the other thread life cycle.
- LSTM also implemented in C++ (Eigen library).
Data transfer cycle matching module

- LHML and MMWI diagnostic system run at 1kHz.
  - These systems send/receive the packet at 1kHz.
- The $H_\alpha$ diagnostic system sends the packet which has 8192 data at 25Hz ($\approx 25.6$Hz).
- To achieve the real-time performance, Resampling thread resamples the data from $H_\alpha$ diagnostic system.
  - Duplicate the first data from $H_\alpha$ diagnostic system 39 ($\approx 1$kHz/25.6Hz) times into the buffer to fit the cycle of 1kHz.
  - $H_\alpha$ Data resolution degraded.
Performance test & results

• Experiment result
  • 186 shot at 2018 campaign at KSTAR was used
    • Due to the degradation of $H_\alpha$ data resolution, Accuracy is lower than test set result.
    • Due to the Signal level of MMWI changes
      • Density diagnostic DAQ machine changed after training.
      • Retraining and experiment are schedule for 2019 campaign

• Real time performance
  • All RT thread period is consistent.
    • $H_\alpha$ sub thread and $H_\alpha$ resampling thread run at 125Hz (period is 8000 $\mu$sec)
      • all the other thread run at 1kHz (1000 $\mu$sec)
    • LSTM takes 56 $\mu$sec.
      • LSTM run in the process thread.

Tab 1. Confusion Matrix

<table>
<thead>
<tr>
<th></th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>True</td>
<td>97</td>
<td>37</td>
</tr>
<tr>
<td>False</td>
<td>48</td>
<td>4</td>
</tr>
</tbody>
</table>

Tab 2. Performance of Classifier

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>0.72043011</td>
</tr>
<tr>
<td>Precision</td>
<td>0.66896552</td>
</tr>
<tr>
<td>Recall</td>
<td>0.96039604</td>
</tr>
<tr>
<td>F1 Score</td>
<td>0.78861789</td>
</tr>
</tbody>
</table>

Tab 3. Performance of RT Thread

<table>
<thead>
<tr>
<th>Thread</th>
<th>$\mu$sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_\alpha$ Sub</td>
<td>7961.0 1.22 49.0</td>
</tr>
<tr>
<td>$\bar{n}_e$ Sub</td>
<td>999.9 0.37 39.3</td>
</tr>
<tr>
<td>$H_\alpha$ resamp</td>
<td>7959.8 4.89 225.8</td>
</tr>
<tr>
<td>Process</td>
<td>954.8 1.17 73.9</td>
</tr>
<tr>
<td>L/H pub</td>
<td>942.5 3.13 929.2</td>
</tr>
</tbody>
</table>
Performance test & results

• Experiment result

By using H-alpha and MMWI signal, LHML effectively detects the L/H Transition.
• LHML detect the moment when,
  • $H_\alpha$ amplitude changes.
  • The degree of increase of $n_e$ (line-averaged density) changes.
Summary & Future Works

• Summary
  – We have developed real time L/H transition detector system.
  – LHML uses $H_\alpha$ signal, line-averaged density $\overline{n_e}$ signal from H-alpha system and MMWI to estimate L/H mode.
  – LHML uses Long Shot Term Memory Networks (LSTM) to estimate the L/H modes in real time manner.
  – The LHML system receives the data stream, simultaneously processes the data, and sends the result in the form of a data stream.
  – RT-ParaPro was used to implement LHML.
  – LSTM takes 56 usec.

• Future Works
  – Real time H-alpha system (1kHz) will be developed and apply to the system.
  – Retraining with new density diagnostic data and experiment are schedule for 2019 campaign.
Thank you