Title

Continuous Data Acquisition with Online Analysis for the Wendelstein 7-X Magnetic Diagnostics

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Abstract

The coupling of continuous data acquisition and continuous online analysis keeping up with the acquisition is one of the features the W7-X data acquisition system is designed for. As proof of principle of this concept the magnetic diagnostics have been implemented.
The magnetic diagnostics measure time derivatives of the magnetic fluxes and the signals have to be time integrated accordingly. Both measurement and analysis tasks are executed on a single PC based system.
The configuration of both hard- and software of the system is presented. Special focuses are the task of software integration of a user supplied online analysis function into the data acquisition system and the incorporation of the complete system into the W7-X segment concept in use by the Control System.
The complete installation has been tested at the WEGA Stellarator experiment. Because WEGA is capable of continuous steady state plasma operation the practical suitability of the installation for W7-X could be demonstrated successfully.

Keywords

Continuous Data Acquisition, Online Analysis, Wendelstein 7-X, WEGA, Magnetic Diagnostics

1. Introduction

Wendelstein 7-X will be a long running fusion experiment with plasma operation running up to 1800s. Therefore, advanced data acquisition techniques have been developed for continuous acquisition [1]. Not only acquisition of data has to be run continuously, but also online data processing. Moreover, all data analysis requires the incorporation of individual algorithms and methods supplied by the physicists.
Special attention has to be paid for online analysis that needs to keep up with the data acquisition, especially if it is suited for monitoring [2] or feedback processes.
With the magnetic diagnostics [3] these demanding requirements have been linked together and tested at the WEGA Stellarator in continuous data acquisition and data processing mode [4]. Furthermore, the integration of the magnetic diagnostics into the Wendelstein segment control system [5] will be shown.

2. Description of the W7-X magnetic diagnostics

This diagnostic has typically inductive sensors, pickup coils and flux loops, on the vacuum vessel of the fusion plasma experiment. They are measuring time derivatives of magnetic fluxes by recording induced voltages. The long pulse suited digital integrator [3] generates chopped analogous signals with chopping frequencies in the order of 1 kHz. After digitizing they have to be synchronously rectified and integrated in time to obtain flux signals. An online analysis algorithm performs this digital rectification and integration using the digitized chopper clock signal as additional input.
The diagnostics data acquisition system is treated as a single component for W7-X. Each component at W7-X will have its own control system permitting autonomous operation for commissioning and testing [5]. Moreover, controlled segmented continuous operation must be foreseen.

3. Signal Conditioning

The signals are pre processed with the in-house developed W7X-Integrator card chopping the measured signals.
This card consists of the internal chopper clock generator and external clock signal conditioning, which can be alternatively used for synchronization. The power supply is taken from the cPCI bus and converted by SMD voltage regulators. The remaining part of the card possesses 4 identical analogous chopper channels with the signal properties and circuit design as given in [3]. The analogous output is fed via the front panel to a 24 bit ADC sampling at a rate of 50 kHz. The algorithm being implemented as a “user supplied” analysis function has to detect the chopping transition, to determine the polarity of the signal in each time interval and to sum up the samples accordingly. Furthermore, an automatic offset level determination has to be performed before the integration process starts (Fig. 4, calibration segment). Such offsets are introduced by thermo voltages and creeping currents in the signal path before the chopper stage and are unavoidable.

4. Measurement setup of signals and time stamps

The hardware installation has been composed to be utilizable for both machines W7-X and WEGA as well, see Figure 1.

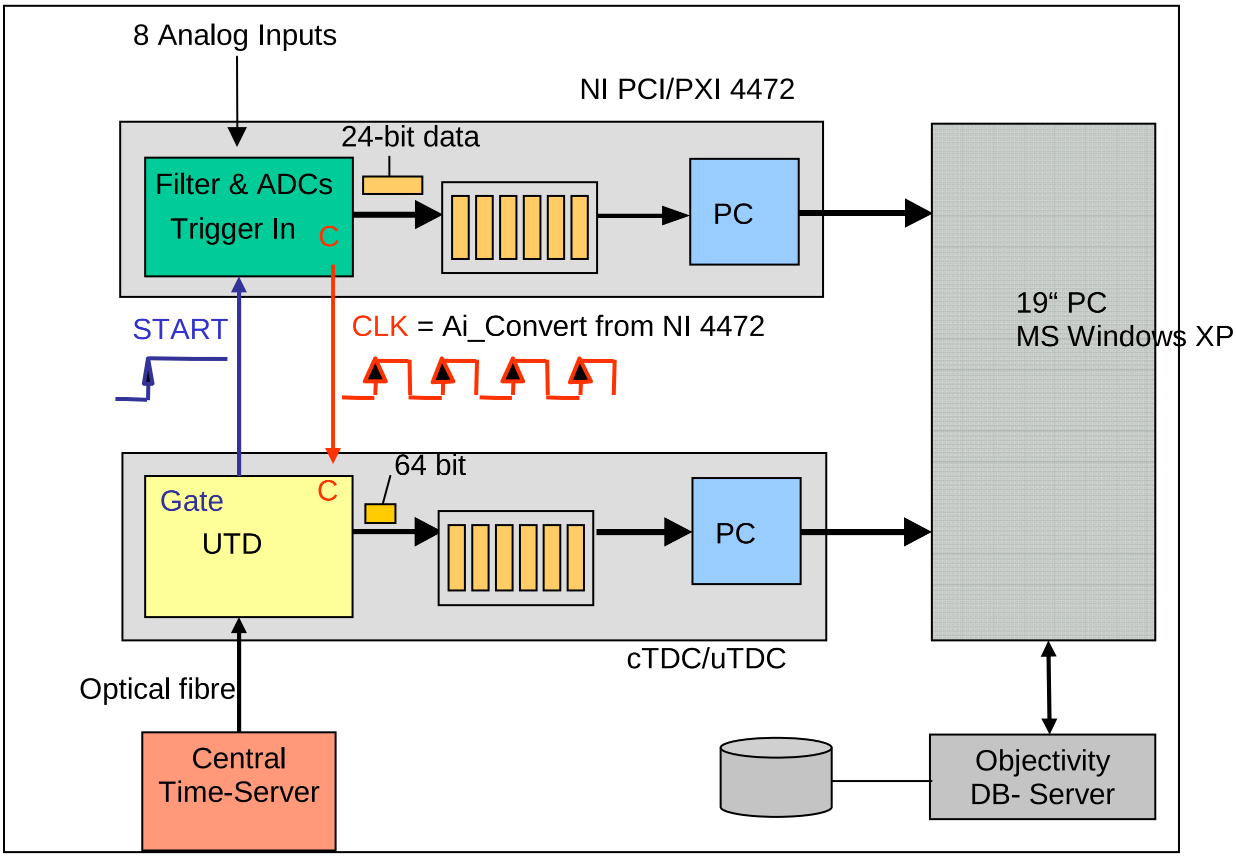

Figure 1: Data flow in the CoDa Station with sample clock synchronization of NI 4472 and UTDC

The installation consists of a 19" PC based system (Windows XP) with PXI cards in a chassis connected with a high speed electrical bridge ME-StarFabric. The ADC (Analogous-to-Digital-Converter) card NI4472 was chosen especially to allow simultaneous sampling (102 kS/s) with high resolution (24bit) and is capable of signal conditioning with anti-alias-filters. A TDC (Time-to-Digital-Converter) card cTDC is included for time synchronization [6] with the experiment. Both ADC and TDC are synchronized via a clock signal. The sample clock is generated from the ADC (AI-Convert) and routed via the PXI Real-Time System Integration bus implemented via the PXI trigger lines. To access the AI-Convert signal an additional Adlink cPCI-8301 PMC-Base board is installed in the PXI crate and connected to the cTDC by wire.

5. The Control and Data Acquisition Software

The Control and Data Acquisition (CoDa) software is described in [1]. Sampled data is time stamped in a TimeGroup, see figure 2. Both ADC and TDC are read out cyclically (typically every 100 ms, software configurable) and resulting time stamped data is queued internally and written into database piecewise (typically once per second, software configurable). After each ADC and TDC readouts the online analysis function is called. It must be ensured that the analysis does not last longer than the sample time between two hardware readouts.

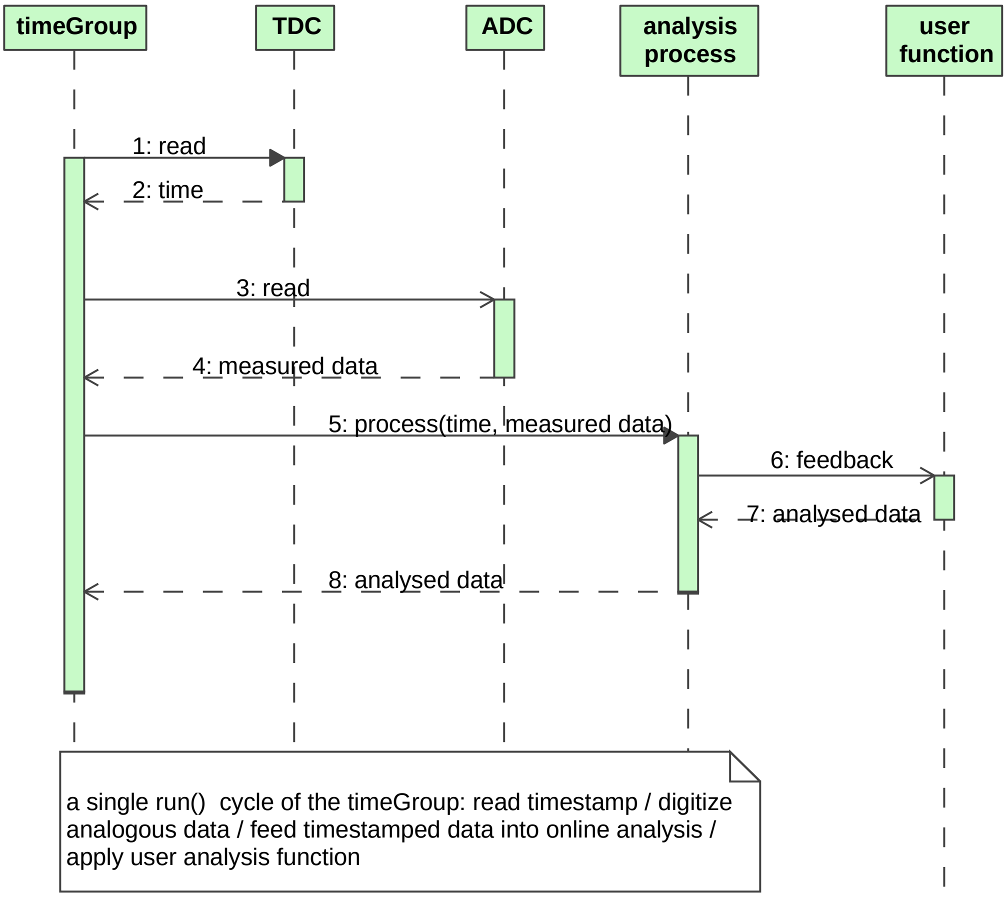

Figure 2: Sequence of cyclic data processing in a TimeGroup coupling measurement with online analysis

Within the TimeGroup concept three different kinds of processes are foreseen:
(1) Feedback Processes cyclically generating analysed data;
(2) DataReduction Processes cyclically generating data for Monitoring [2] and
(3) Pattern Recognition Processes for asynchronous event generation.
The process calls an individual function supplied by the user with the concrete algorithm.

6. Online Analysis using the Control and Data Acquisition Software User Interface

Feed back data algorithms can be implemented either in hardware or in software. Hardware solutions are predictable and reliable but are hard to change whereas software solutions are more flexible but more difficult to guarantee quality of service. At the presented system a software solution has been chosen.

All preparations like allocation of memory, pre-calculations etc have to be done in a **prepare** method before the start of the analysis. The analysis process is called cyclically invoking the **feedback** method of the user function returning the analysed data, thus allowing continuous analysis, see also figure 2. After passing the algorithm the analysed data are processed exactly the same way as sampled data, see section 5.

6.1. User supplied Analysis Function

The Integrator Function algorithm for the diamagnetic loop was already existing and well-proved [3]. It will be used for both Wendelstein 7-X and WEGA magnetic diagnostics. To integrate the algorithm some decisions were necessary:

(1) Decision to run the function online (at runtime) and not offline (after finishing acquisition) because continuous acquisition demands continuous analysis.
(2) Decision for a feedback process to allow integration of the analysed data to be used for controlling the machine.
(3) Decision to port the algorithm to Java because it was written object oriented in C++ without using external libraries. The solution was to copy and paste the code and adapt to the interface.

6.2. Data handling

Both sampled and analysed data is handled the same way as so-called **Packets**. Every packet object has a concrete type and holds a sequence of data items. The time stamped data is called a **DataPacket** and contains a sequence of time samples and corresponding data samples. The concrete type is generated at runtime via a software factory. For mixed type data a **FreeFormArrayPacket** has been developed handling any combination of simple java types.

In this component the measured data from the ADC has 24 bit per channel that is wrapped as java integer whereas the measured data from the TDC has 64 bit and is wrapped as java long. Creation of a suitable DataPacket assuming the number of channels active in the ADC is 1 and the sequence length is 4000 leading to:
`new DataPacket (new TimePacket(4000), new IntPacket(4000, 1));`
The algorithm result contains a single java long 64 bit time stamp, a byte value for the estimated synchronization signal, a byte value for the mask and per channel 3 double values for the calculated offset, mean and integrated signal: `new DataPacket(new TimePacket(4000), new FreeFormArrayPacket(4000, “2 byte, 3 double”).`

7. Segments

Wendelstein 7-X continuous plasma operation will be scheduled as a series of machine segments [5] constructed of component specific segment descriptions. It is possible to put the same segment description of the component into different machine segments. An example is shown in figure 3.

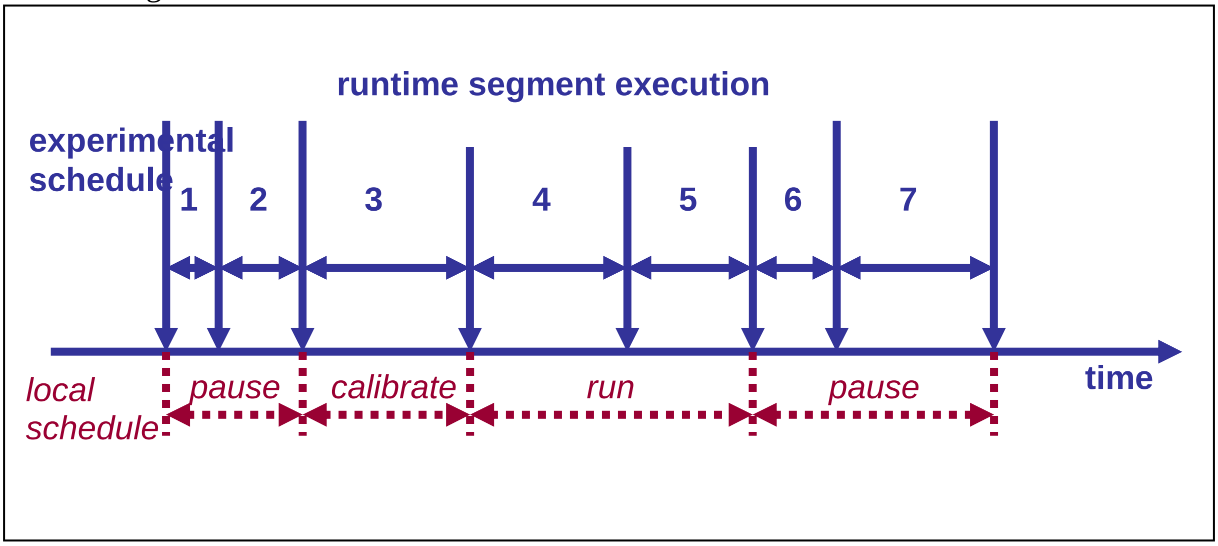

Figure 3: Example segment schedule: the experiment executes 7 different segments whereas the component specific local settings change only 3 times

This diagnostic component has three major behaviour patterns:
(1) Calibration-Segment

Is a calibration for the algorithm and has the constraint that the magnetic field is not allowed to change. In the calibration segment both measurement and algorithm calibration are running. The calibration parameters are preconfigured. The result of the calibration algorithm, the residual offset voltage, is saved in the experimental database in addition to the measurements.
(2) Run-Segment
The standard run segment does measurement with standard parameters e.g. fixed sample frequency and analysis parameters. In case of a preceding calibration segment the calibration factor for the algorithm is well-known. In case a preceding calibration is missing, the algorithm looks for the last saved calibration factor in the archive and takes this as first guess, since the calibration factors are expected to change only slightly over days or weeks.
(3) Pause-Segment
No measurement and no analysis will be done.

In experimental mode switching between the possible patterns is done via the central control system where these patterns are part of the overall segment schedule. When there is no change at the local machine no local switching is done, see figure 3. For commissioning and tests the component control software [7] schedules single segment changes where each segment equals one of the patterns.

8. Tests at WEGA

The WEGA Stellarator is used as a test bed for W7-X diagnostic systems. The described diagnostic has been mounted at the magnetic sensors at the WEGA coils.
The WEGA magnetics data is preprocessed, measured and analysed with the described installation sufficiently satisfying. The measured data as well as the analysed data is stored in the database and can be retrieved with a data browsing tool [8], see figure 4. Continuously acquired data to be retrieved is sliced with respect to smaller time intervals to fit into memory.

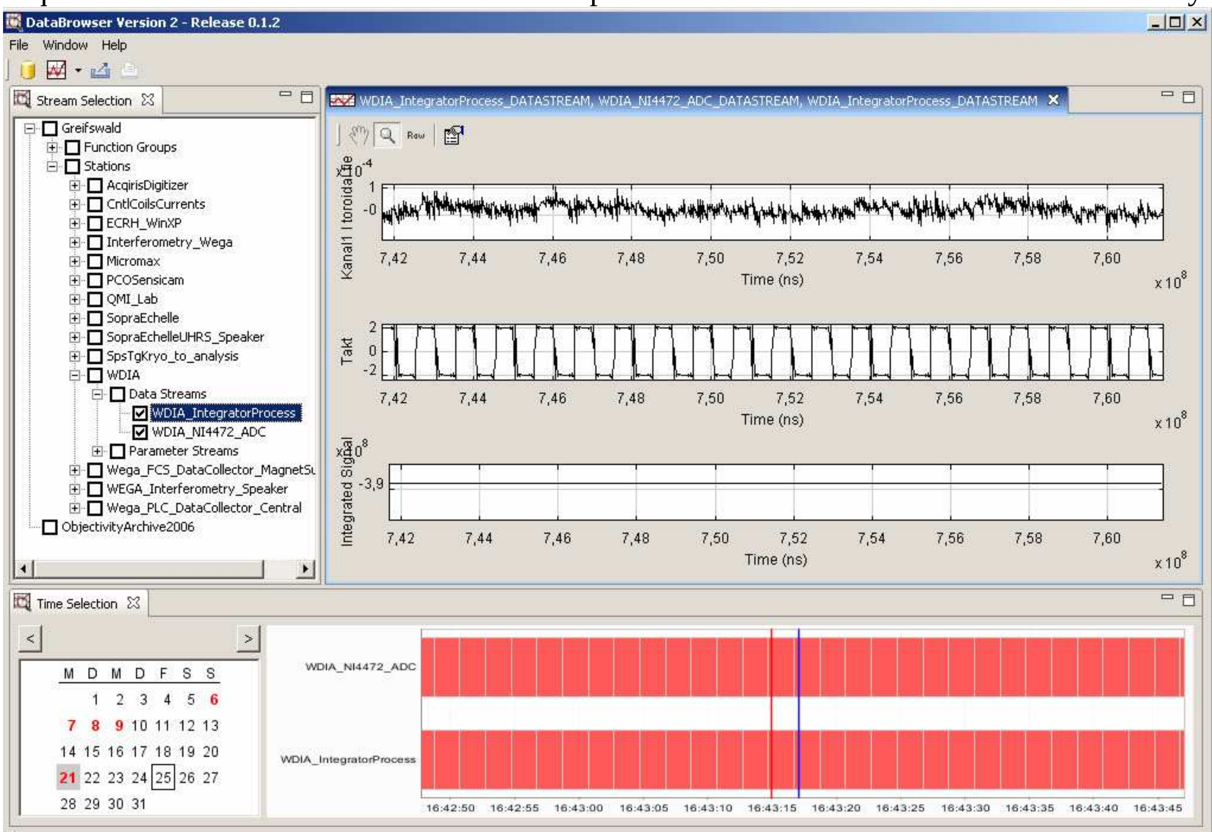

Figure 4: screenshot of measured and analysed data stored in the database visualized with the DataBrowser [8]:
The upper 2 plots show the digitized currents of the chopped toroidal field and the chopper clock.
The lower plot shows the resulting integrated signal of the toroidal field.

The Wendelstein segment control concept has been applied for scheduling and running the magnetic diagnostic at WEGA. The user control interface for W7-X plasma operation [7] has been used for segment execution and monitoring of execution. By this means execution of the pause, calibrate and run segments (see section 7) in any order and with arbitrary duration has been carried out.

9. Conclusions

The described installation shows its suitability for the magnetic diagnostics data acquisition system. The proof of principle of a user supplied online analysis function on top of data acquisition exemplified with the magnetic diagnostics digital integrator has been demonstrated.
The installation has been tested successfully at the WEGA Stellarator for continuous operation. The application of the segment concept has been demonstrated and tested as a local schedule plan. Extensions and further tests with a complete distributed Control and Data Acquisition system including many components utilized of WEGA will be done next [4].

10. Acknowledgement

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