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Study of an FPGA-based temperature measurement using open source software

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1. Introduction

The Korea heat load test facility using electron beam (KoHLT-EB) [1,2] is in operation to conduct the high heat flux tests for the plasma facing components (PFCs) development. In this facility, an FPGA-based data acquisition system that can analyze the characteristics of a thermos-hydraulic and performance tests was implemented. In particular, there are many temperature sensors and a method for measuring them have been considered.

2. FPGA-based temperature monitoring system

The implementation of FPGA-based data acquisition systems in large physical experiments is widely used nowadays. The combination of analog and digital front-ends with FPGAs in industrial form factors such as PXIe, uTCA, or ATCA, allows the implementation data acquisition systems with processing capabilities that run with deterministic behavior. FPGAs provide developers the option to change continuously the functionality of their applications using a well-known development cycle and using VHDL-based tools. One of most innovative development cycle for advanced instrumentation systems in PXIe platform is the combination of LabView for FPGA and FlexRIO/cRIO/RIO devices from National Instruments. IRIO software has been developed with the goal of simplifying the interface with FlexRIO/cRIO/RIO devices, development of advanced data acquisition applications and their integration with EPICS. IRIO software source and IRIO Design Rules has been distributed through github repository [3].

Table 1. Comparison of thermocouple module with screw terminal type

Model	CHs	Max Sample Rate			Accuracy
		scanned (S/s)	simultaneous (S/s/ch)	filtered (Scans/s)	
NI-9210	4	14	-	2.3	0.8℃
NI-9212	8	-	96	7.1	0.39℃
NI-9213	16	100	-	1.0	0.77℃
NI-9214	16	100	-	0.96	0.37℃

cRIO temperature input modules provide up to 16 channels of temperature input from 6 types of thermocouple or 7 types of RTDs. This module may include anti-aliasing filters, open thermocouple detection, and cold junction compensation. Unlike typical analog input modules, these function can be enabled selectively and the conversion time can be changed accordingly. The "design-rules" described earlier have standardized terminal identification according to their functionality and it will allow application developer to access the physical resources using this enumerated data types. Although the original IRIO design rules defined the function for standard analog input module, there is no function definition for the conversion mode used by the temperature input module where the conversion time is determined.

IRIO classifies the different types of applications implemented in the FPGA by means of "profiles" linked to cRIO, FlexRIO and R-Series hardware platforms. Table 2 summarizes the profiles implemented and supported in original IRIO software library.

Table 2. Platforms and profiles

Platform	Profile	Functionality
cRIO	DMA	Analog Data Acquisition and I/O
cRIO	I/O	
R Series	DMA	Analog Data Acquisition and I/O
R Series	I/O	
FlexRIO	DMA to HOST	Analog/Digital and I/O
FlexRIO	DMA to HOST	Image Data Acquisition and I/O
FlexRIO	DMA to GPU	Analog/Digital and I/O
FlexRIO	DMA to GPU	Image Data Acquisition and I/O

Another thing to consider is that using DMA profile is meaningless because the conversion time in the temperature module is slower than that of analog input processing.

2. Implementation of Software

IRIO software also provide the examples using a NI cRIO chassis and seven NI cRIO I/O Modules hosted in the chassis. However, it does not explicitly support the modules specified in Table 1 described above. In order to use these modules, it is necessary to modify the source code, and so far, two methods have been considered and applied.

Table 3. cRIO device supported by IRIO software

HW ID	Description
cRIO 9159	CompacRIO Chassis with Virtex 5 FPGA
cRIO module NI9205	Analog input Module
cRIO module NI9264	Analog output Module

cRIO module 9401	TTL Digital I/O
cRIO module 9477	Digital Outputs 60V sinking
cRIO module 9476	Digital Outputs 24V sourcing
cRIO module 9425	Digital Input 24V sinking
cRIO module 9426	Digital Input 24V sourcing

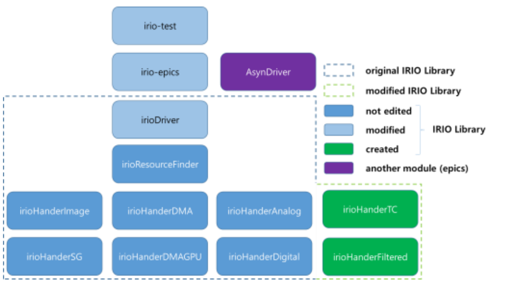

Fig 1. Concept diagram of the modified IRIO Software

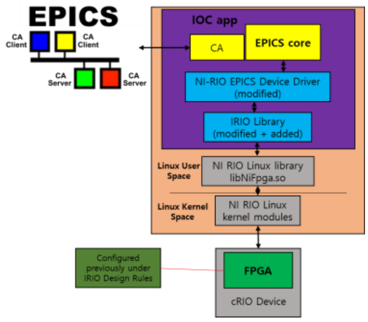

Fig 2. Modified library used for implementing and EPICS

The first method applied is to write the source code for each newly added module and include it when building the IRIO library as shown in Figure 1 and Figure 2.

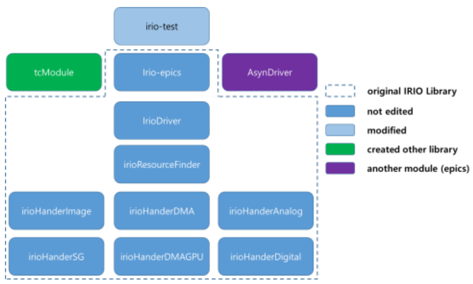

Fig 3. Concept diagram of library independent of IRIO

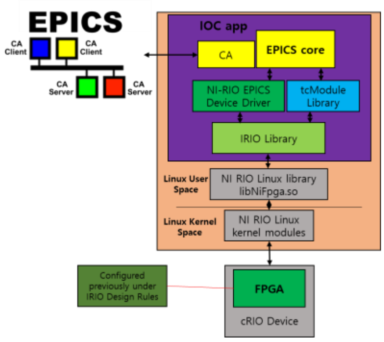

Fig 4. Independent library used for implementing and EPICS

Another way is to use the mandatory and optional resource definitions defined by the original IRIO Design Rules. However, if the function of the module to be newly added is out of range of the previously defined function, a separated library is created and used when building the EPICS application as shown in Fig 3 and 4.

3. function of Temperature library

In order to calculate temperature from thermoelectric voltage, inverse polynomial functions calculate the temperature based on the thermocouple voltage. The equation for inverse polynomial functions are of the form shown as follows,

$$t_{90} = d_0 + d_1 E^1 + d_2 E^2 \dots + d_i E^i$$

Where E is in microVolts and t_{90} is in degrees Celsius.

However, FPGA does not provide a method to calculate polynomial equation directly, so application developer need to take thermoelectric voltage data from higher application and calculate it like the flow diagram in Fig 5.

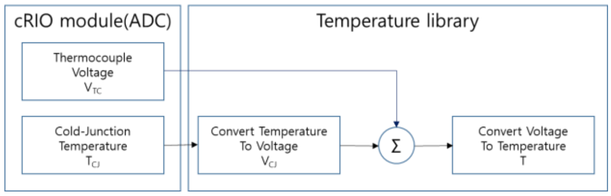

Fig 5. Thermocouple and Cold-Junction Measurement Conversion to Temperature

4. Conclusion and future works

A study has been conducted on methods that can be used when adding a module that is not a typical analog input module characteristic. Therefore, the FPGA-based data acquisition system for KoHLT-EB can be a device that satisfies the IRIO Design Rules.

REFERENCES

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[2] Suk-Kwon Kim, Hyung Gon Jin, Kyu In Shin, Bo Guen Choi, Eo Hwak Lee, Jae-Sung Yoon, Yang-Il Jung, Dong Won Lee, and Duck-Hoi Kim, "Manufacturing and Examination for ITER Blanket First Wall Small-Scale Mockups with KoHLT-EB in Korea," IEEE Transaction on Plasma Science, vol.42(5), pp.1438-1442, 2014.
[3] https://github.com/irio-i2a2/iriolib