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PROFINET COMMUNICATION CARD FOR THE CERN CRYOGENICS CRATE ELECTRONICS INSTRUMENTATION

R.K. Mastyna, J. Casas-Cubillos, E. Blanco Vinuela, N. Trikoupis, CERN, Geneva, Switzerland
M. Felser, Bern University of Applied Sciences, BFH, Switzerland

Abstract

The ITER-CERN collaboration agreement initiated the development of a PROFINET® communication interface, which may replace the WorldFIP interface in non-radiation areas. The main advantage of PROFINET® is a simplified integration within the CERN controls infrastructure that is based on industrial Programmable Logic Controllers (PLCs).

CERN prepared the requirements and subcontracted the design of a communication card prototype to the Bern University of Applied Sciences (BFH). The designed PROFINET® card prototype uses the netX Integrated Circuit (IC)© for PROFINET® communication and a FPGA to collect the electrical signals from the back-panel (electrical signals interface for instrumentation conditioning cards).

CERN is implementing new functionalities involving programming, automation engineering and electronics circuit design. The communication between the card and higher layers of control is based on the Open Platform Communications Unified Architecture (OPC UA™) protocol. The configuration files supporting new types of instrumentation cards, which are being developed and are compatible with the SIEMENS© SIMATIC automation environment. Some minor changes to PROFINET® PCB electronics card will be performed before launching a small series production.

It is worth to mention that all required data calculations (for example interpolation, calibration) and protocol handling (PROFINET®, OPC UA™) are performed using a multithreading application, which runs on a single netX50 chip. It allows to simplify the architecture of the control system, because there is no need for additional computing nodes in the network to execute all required calculations of the process.

INTRODUCTION

System Overview

The control system in radiation areas is shown in Figure 1. It is based on the CRATE (equivalent to a remote IO), PLC, Front End Computer (FEC), Cryogenics Instrumentation Expert Tool Supervisory Control and Data Acquisition (CIET SCADA) and Cryogenics Supervisory Control and Data Acquisition (CRYO SCADA). CIET SCADA and CYRO SCADA are connected to the DB Log (database for data logging – long term archiving and cloud data analysis). CRYO SCADA is also connected to DB Sensor (database for sensor and heater cards parameters) [1], [2], [3]. This architecture is also used in non-radiation areas.

In order to simplicity the architecture the whole functionality of the FEC was moved to the crate which is now smart device able to calculate, transform the raw input data and communicate directly with the PLC (see the Figure 2). Due to the fact that the WorldFIP protocol is not recommended for new installations the Ethernet based PROFINET® protocol is used. The communication between CIET SCADA and CRATE runs through OPC UA™, as this protocol is going to be available in the netX51 chip. OPC UA™ also allows direct connection between the CRATE and cloud data analysis module.

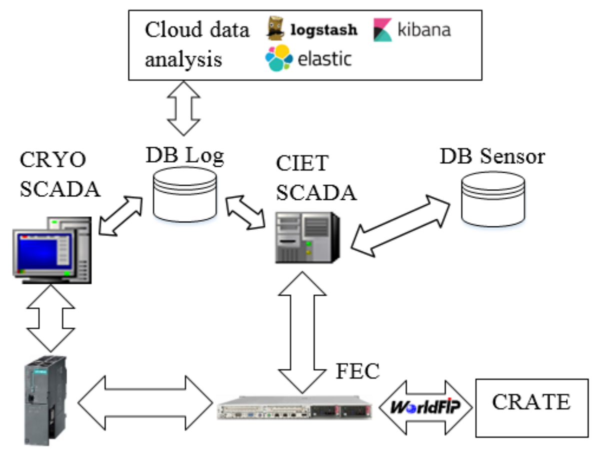

Figure 1: Current architecture overview.

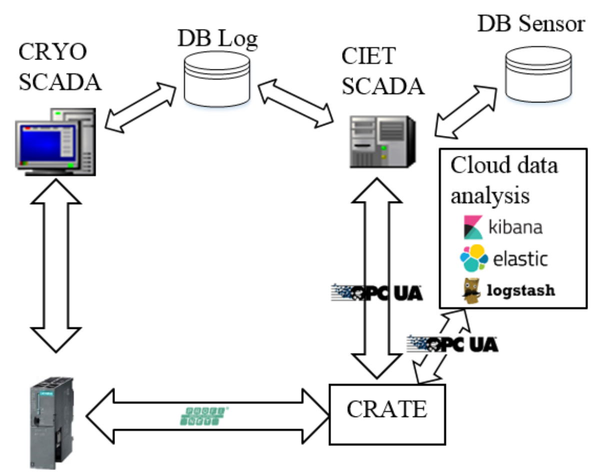

Figure 2: New architecture overview.

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CRATE Overview

The CRATE was initially developed as a radiation tolerant remote IO to be deployed in the Large Hadron Collider (LHC) tunnel at CERN. Presently more than 800 crates are operational within the LHC cryogenic control infrastructure and they provide temperature measurements with state of the art accuracy in spite of the hostile radiation environment [4]. It consists of sensor cards (for collecting raw data), heater cards (for controlling electrical heaters) and communication cards to communicate with the rest of the system [5]. It supports up to 16 sensor cards, 4 heater cards in total and each sensor card is divided into 2 sensor channels. The crate is also equipped with 2 communication cards which are the main subject of this paper (see the crate diagram in the Figure 3).

The project is focused on the communication card, which is responsible for collecting and performing required calculations on measurements from the sensor cards and sending the control commands to the heater cards. The only communication interface is 100 Mbit/s Ethernet based with support of the TCP/IP and UDP/IP Socket connections. The real-time PROFINET is used for the cyclic data exchange with the industrial PLC. The configuration and parameter data as well as the diagnostic information is controlled by the CIET through the flexible OPC UA™ protocol. A local Webserver offers some possibilities to test and commission the CRATE without an active PLC or CIET.

In order manage these tasks (especially performing calculations and simultaneous communication with several industrial protocols) the cards are equipped with a FPGA and netX50 chips.

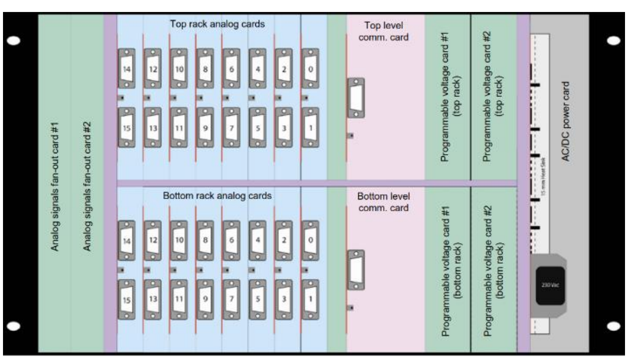

Figure 3: Overview of crate.

IMPLEMENTATION

The implementation of the logic which is responsible for data handling includes IT, electronics and automation development, because all these domains are required to correctly provide the CRATE device and incorporate it into the existing system. Figure 4 shows the most important technologies and tools used for the implementation of the project.

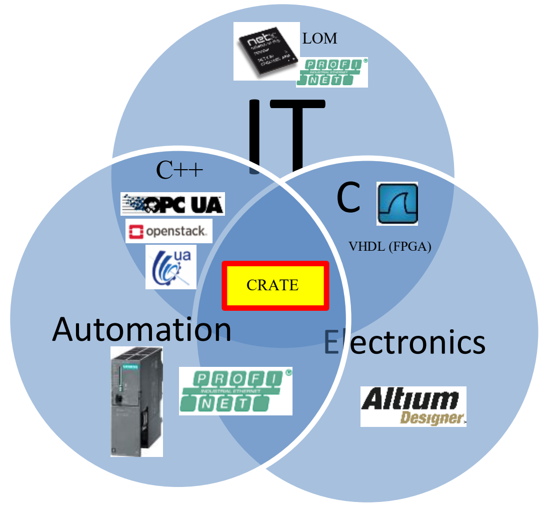

Figure 4: Domains of the development.

NETX50 BASED SOFTWARE OF COMMUNICATION CARD

The first version of the netX50 software was developed by Bern University of Applied Sciences. It is designed as a multithreading application and consists of several tasks:

- MAIN TASK – manage cooperation between other tasks
- SPI TASK – communication with the sensor and heater cards using the Serial Peripheral Interface (SPI) with the FPGA.
- PROFINET TASK – communication with the PLC using the PROFINET® protocol
- WEB SERVER TASK – web interface for the crate
- SOCKET TASK – communication with CIET using OPC UA protocol
- IO TASK – handling card's general-purpose input/output (GPIO) – LEDs and switches

The diagram of the tasks is shown in the Figure 5.

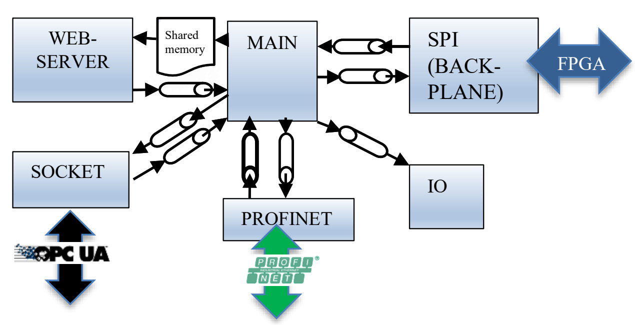

Figure 5: Application threads diagram.

The software required major data handling changes, because it assumed to be identical the sizes of the data that come from all sensor cards (see Figure 6), in practice the data size depend on the type of type of card inserted. Elastic sizes are therefore implemented with the help of the unions and structures (see Figure 7 and Figure 8). Because of

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the fact that the netX program is written in C it is not possible to use the inheritance in a straight way. The change of the data structures is important and significant as it caused many updates in the data handling, which is present in all the tasks. This deep modification took much time and required design changes but it makes the code elastic enough for easily adding a new sensor card with totally different number of parameters, because each sensor/heater channel and sensor/heater card type is now handled independently.

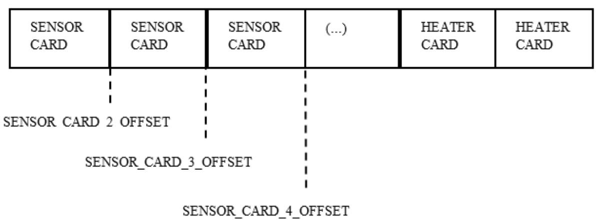

Figure 6: Previous (obsolete) sensor cards handling (using offsets).

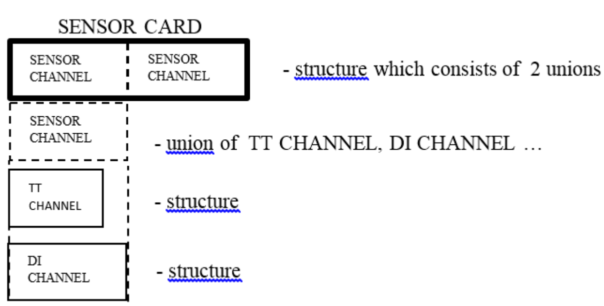

Figure 7: Sensor card structure description.

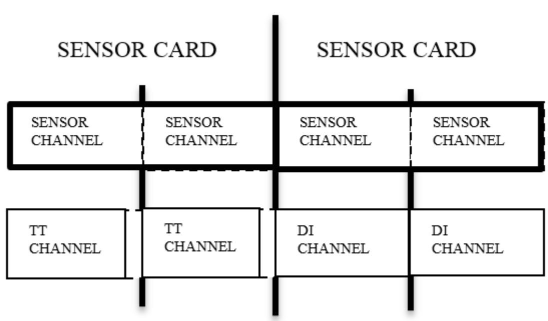

Figure 8: New sensor cards and sensor channels handling (structures and unions).

PROFINET® CONFIGURATION

The main task of PROFINET® is to allow to the PLC to receive the input data form the CRATE and send the required output data to the CRATE. For this the Engineering tool of the controller (in our case the S7-400 PLC from Siemens©) needs to know what are the possible cards available for the CRATE and what is the amount of data provided by each type of card.

The General Station Description (GSD) file has to be written in the XML format to perform the task. This allows the future users to easily use ("drag and drop" or text file edition – see Figure 9) modules structure and create a custom configuration (see the Figure 10).

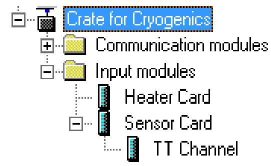

Figure 9: Structure of created crate library.

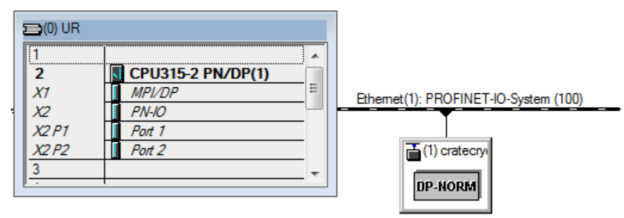

Figure 10: Siemens© Step 7 programming environment and CRATE configuration.

The general structure GSDML file proposed by the BFH was not exactly mapping the physical configuration, was not flexible and allowed to handle only one type of card (see Figure 11). It was changed by dividing each module into 2 submodules and by replacing the default, Virtual Submodules ("inline" submodule) with the classic submodules, which are not fixed (Figure 12). The submodules can now be chosen (by "drag and drop" or text file edition in SIMANTIC© software) according to the current physical configuration.

Figure 11: Obsolete sensor channel GSMDL file division.

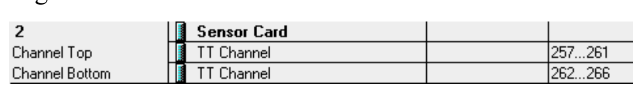

Figure 12: New sensor card GDSML file division.

OPC UA™ COMMUNICATION

In order to communicate between the netX chip and the CIET SCADA, two protocols were considered the MQ Telemetry Transport or Message Queue Telemetry Transport (MQTT) and the OPC UA™ [6], [7]. Finally, the OPC UA™ was chosen because it is easier to be incorporated into our current architecture and is a CERN supported protocol. Initially, the idea was to exchange the data directly between CRATE and CIET SCADA (this solution is shown in Figure 13), but because of the fact that LOM (Linkable

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object Model) OPC UA™ protocol stack for netX© is not available yet, the data is sent through the socket to the QUASAR server [8] which is setup on Centos 7 using CERN OpenStack (see Figure 14). The OpenStack Cloud is very convenient because it is easy accessible and available all the time without interruptions. The GNU screen program is used to keep the program running when the user logs out. In order to handle socket connection, a new module was created in the Quasar framework. The C++ Boost library was incorporated into the development and Socket and shared pointer were utilized.

The OPC UA™ communication works in both directions - - data is sent form the crate and commands and calibration curves are sent from CIET SCADA.

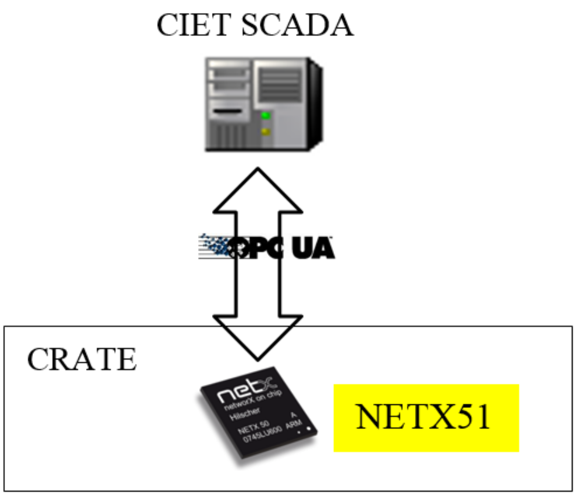

Figure 13: OPC UA™ direct communication using the LOM OPC UA protocol stack.

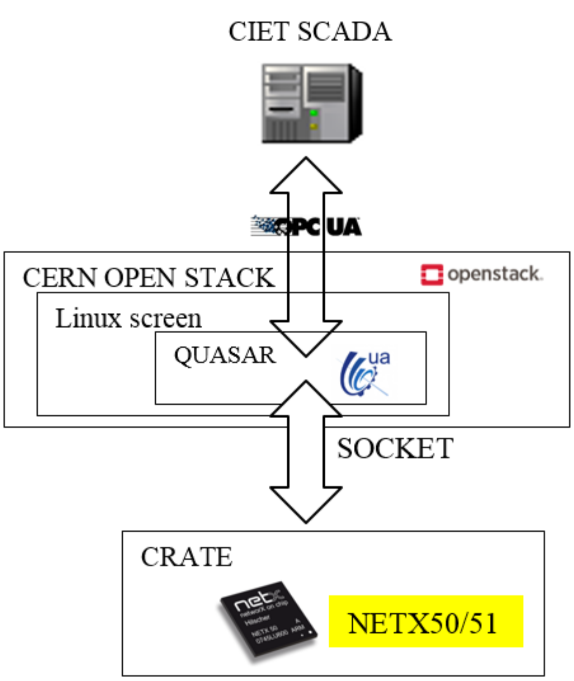

Figure 14: OPC UA™ communication using the socket.

The direct OPC UA™ communication (without the help of the Quasar) is going to be used as soon as the LOM OPC UA™ stack is available, but it is important to mention that the whole model of data stays the same from the CIET SCADA point of view – only the lower layer which is entirely in implemented in netX will be changed.

INDUSTRIAL INTERNET OF THINGS AND CLOUD BASED SYSTEMS

Currently cloud data analysis is performed with the help of DB Log as shown in Figure 1 and in more detailed way in Figure 15. The Logstash runs queries on DB Log database every morning, then the data is stored in the Elasticsearch cluster [9]. The data, which is collected, consists of:

- The number of value changes per day, for each device
- The number of alarms per day, for each device
- The number of equipment disconnections
- The equipment disconnection durations

Finally, the data is analysed with the help of the Kibana software (Figure 16).

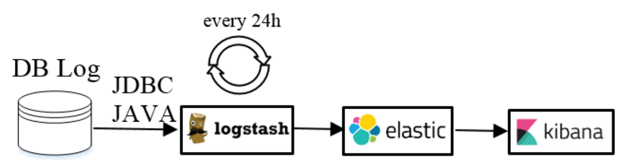

Figure 15: Current cloud data analysis.

Figure 16: Kibana analysis.

The OPC UA™ communication gives new opportunity. CRATE gains ability to communicate directly with the cloud data analysis system as shown in Figure 2 and Figure 17. The data can be sent to the Logstash through OPC UA™ channel and then can analysed as before.

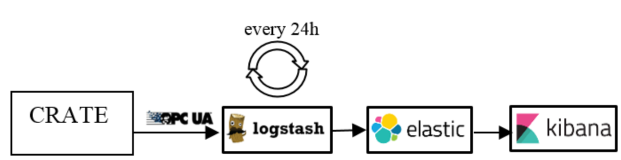

Figure 17: Possible future direct cloud data analysis.

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ELECTRONICS UPDATES

The first communication card prototype can be seen in Figure 18 and it is composed of two cards connected together (named left and right).

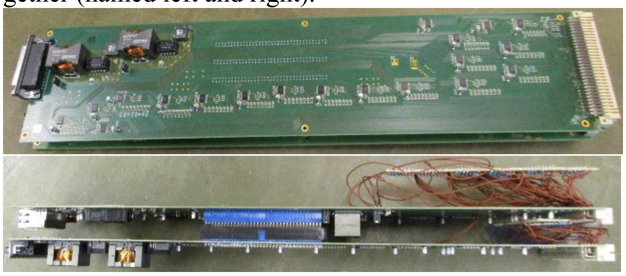

Figure 18: Communication card prototype (top/side view).

It required some minor changes to consolidate the electrical layout and avoid the use of flying wires and components:

- Left card: connector change, addition of the 1.8 V converter, addition of the pull-up resistors (see Figure 19)
- Right card - addition of pull-up resistors (Figure 20)

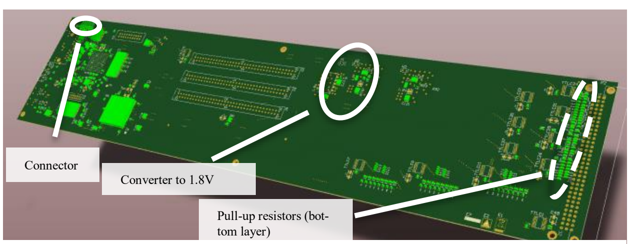

Figure 19: Left communication card modifications.

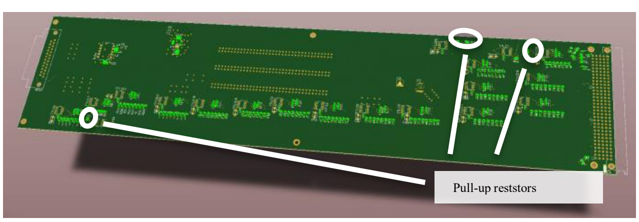

Figure 20: Right communication card modifications.

CONCLUSION

The new communication card allows to replace the WorldFIP fieldbus with PROFINET® that simplifies considerably the architecture of the system in non-radiation areas. All the software updates work correctly and makes the code more flexible and easy to maintain. The GDSML structure modification allows to add new modules in a more flexible way and is also closer to the sensor cards physical configuration. The netX software and GSDML files are more flexible and open for new sensor and heater cards. The task to create OPC UA™ communication between CRATE and CIET SCADA using socket QUASAR was completed. This solution was successfully tested and works correctly. The data is handled in both directions and because of the fact that the QUASAR OPC UA server is set on the CERN Cloud it is available without interruptions 24 hours per day. OPC UA communication will allow CRATE to connect directly to the cloud analysis system (Logstash, Elasticsearch and Kibana). The deployment of a full functioning crate with PROFINET® communication within a real cryogenic infrastructure is planned by the end of the year 2017.

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