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LIGHTWEIGHT ACQUISITION SYSTEM FOR ANALOGUE SIGNALS

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Abstract

In a complex machine such as a particle accelerator there are thousands of analogue signals that need monitoring and even more signals that could be used for debugging or as a tool for detecting symptoms of potentially avoidable problems. Usually it is not feasible to acquire and monitor all of these signals not only because of the cost but also because of cabling and space required.

The Radio Frequency system in the Large Hadron Collider (LHC) is protected by multiple hardware interlocks that ensure safe operation of klystrons, superconducting cavities and all the other equipment. In parallel, a diagnostic system has been deployed to monitor the health of the klystrons.

Due to the limited amount of space and the moderate number of signals to be monitored, a standard approach with a full VME or Compact PCI crate has not been selected. Instead, small embedded industrial computers with Universal Serial Bus (USB) oscilloscopes chosen for the specific application have been installed.

This cost effective, rapidly deployable solution will be presented, including existing and possible future installations as well as the software used to collect the data and integrate it with existing CERN infrastructure.

OVERVIEW OF AVAILABLE SOLUTIONS

As a large organization CERN has multiple different systems for data acquisition. Some of them are older and being phased out and some are still developed and new hardware support is added. Much of the data acquisition is performed directly in the equipment groups' hardware and available via associated software. In this section we focus on standalone systems that can be used to sample signals that are not digitized by other means.

The biggest and most well known acquisition system for analogue signals at CERN is Open Analog Signals Information System (OASIS) [1] created and supported by the Controls Group of the Beams Department. OASIS supports many different hardware platforms (mostly VME crates and Kontron's PCs), digitizers from different vendors, analogue multiplexers and provides a software that allows configuring acquisition and plotting acquired traces.

This system is highly specialized and allows operators and experts to monitor all critical signals in the accelerator complex and correlate them using the system-wide triggers based on the CERN Central Timing. With use of wideband multiplexers it is possible to reuse the same precise and expensive digitizers for multiple signals. This system is perfectly suited for permanent and frequently used installations. The initial deployment cost is high but it can benefit from the scale.

From a technical point of view OASIS uses standard Front-End Computers (FECs), the Front-End Software Architecture (FESA) [2] framework and an abstraction layer for hardware. It is well integrated into the Control System and it is possible to read out values using standard tools.

On the other side of the spectrum from this central service there are acquisition systems built into devices developed by the equipment groups themselves. The Radio Frequency Group has a common way of retrieving diagnostic information from all the cards designed in-house via a standardised hardware and a set of FESA device properties. This solution, although always available, is not flexible. If a parameter was not designed to be acquired a change of hardware and/or firmware would be needed to make it accessible.

There is another acquisition system designed by the RF Group — the ObsBox [3]. It is a high throughput system that is able to monitor the longitudinal and transverse positions of bunches in a bunch-by-bunch manner and is a crucial part of the LHC Transverse Damper. The acquisition cards are connected using gigabit serial links to a powerful server fitted with a large amount of RAM.

There are many other domain specific acquisition systems which are often tightly coupled with domain specific hardware.

The Lightweight Acquisition System for Analogue Signals described here started as one of these custom solutions.

THE LIGHTWEIGHT ACQUISITION SYSTEM FOR ANALOGUE SIGNALS

The system started as a custom tool built for monitoring the health of the LHC klystrons. The sixteen klystrons are arranged in four groups, each consisting of four klystrons powered using a separate power converter installed on the surface. There are four airtight bunkers underground, from which the power is distributed to the klystrons.

Klystrons are sensitive devices and can be easily damaged by for example an electric arc. To protect against such situations the distribution point in the bunker monitors the current consumed. When the protection is triggered it switches off the power supply and fires the crowbar, which short circuits the smoothing capacitor and the power supply output to ground using a large thyristor stack in order to remove their residual stored energy and prevent damage to the klystron. After each such event the gathered data is analysed and the reasons for the fault are determined.

The first version of the system consisted of a pair of PicoScope 6000 series oscilloscopes triggered in parallel with the thyristor. The scopes were then connected via a USB-over-Ethernet bridge to a remote PC running Windows XP. On this machine LabView would read out the acquired data. The reliability of the acquisition chain was quite low and often people trying to investigate cause of a crowbar would find the PC to be off or with no data available. It was decided

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that this tool should be upgraded to something more robust, reliable and secure.

The oscilloscopes, as the most expensive part of the system, were retained and are still used. The USB-over-Ethernet device that had drivers only for Windows has been replaced with a small industrial PC in each bunker.

HARDWARE

Any device capable of booting from the network, with USB 2.0 or newer ports and able to run Scientific Linux CERN 6 can be used. So far we have used two different types of computers, one of them being the Kontron KISS 2U PC. It may be possible in the future to use something more compact, such as one of the Intel NUC computers supported by the CERN IT Department.

The oscllopscopes that were used are manufactured by Pico Technology [4], a company that specializes in USB connected measurement devices.

Two device families that are currently supported by the software and are in use are the PicoScope 3000 and the aforementioned PicoScope 6000. The PS3000 is a moderately priced equipment with 8 bit ADCs, 2 or 4 channels, up to 200 MHz bandwidth and up to 512 MS memory. PS6000 series devices are used where bandwidth requirements are higher. The ones we use have a bandwidth of 250 MHz but it can be as high as 500 MHz in high-end devices.

The other families have some other special features: PS2000 devices are compact and PS4000 and PS5000 devices specialize in higher resolutions — up to 16 bits. Some other features that are worth mentioning are:

- built-in signal generators[1]
- storing of multiple traces from consecutive triggers,
- programmable triggers as a boolean function of channels' triggers,
- live streaming of data.

SOFTWARE

The company provides software development kits (SDK) for several platforms: Windows, Linux (via their own repositories) and OS X. A separate SDK for each family of devices exists and provides C headers and a set of dynamic libraries. On Linux the driver depends only on libusb [5] which runs in user mode and makes it independent of the kernel's USB application programming interface (API).

Unfortunately each SDK has a slightly different API including `#defines`. This is a reason why a C++ wrapper [6] has been written which provides a layer of abstraction, unifies the interface and intentionally resembles the OASIS abstraction layer. As already mentioned at this moment two families are already supported: PS3000, PS6000 but it is possible to extend this layer and add more devices.

This abstraction layer is used by two FESA classes, a class representing a channel and a class that manages the triggers and sampling rates. This separation allows to change channels' settings and read out data independently. This solution also makes the design cleaner when devices with different numbers of channels are used. The full software stack is depicted in Figure 1.

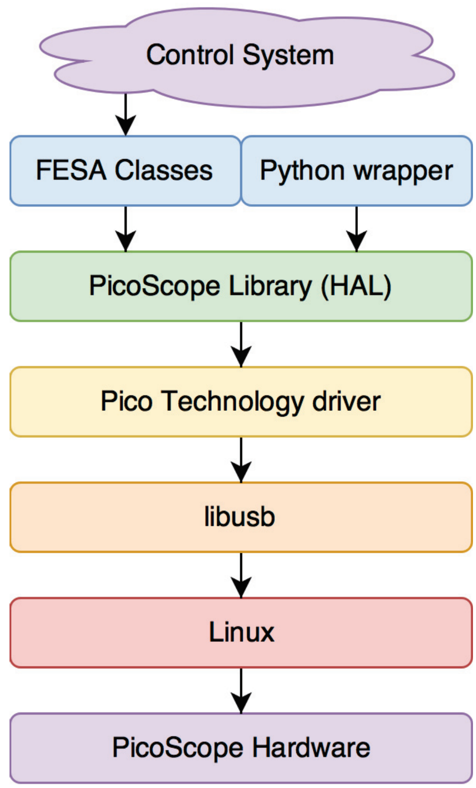

Figure 1: Software stack

Additional tools

Together with the library and FESA classes a small set of tools was created. The first tool is a Python wrapper over the library. It was generated by Simplified Wrapper and Interface Generator (SWIG) [7], a well know open-source tool that can semi-automatically generate bindings to many different languages including but not limited to D, Go, Java, Lua, Perl, Python and R.

A simple code that connects to a device, configures it and then reads acquired data is presented below:

```
from picoscope import *
from time import sleep

s = PicoScope(PS3000)

#configure channel 1
channel, enabled, termination, fullScale, offset
    = 1, True, DC1MR, 10.0, 0.0
cs = ChannelSettings(channel, enabled,
    termination, fullScale, offset)
s.setChannelSettings(cs)

#configure trigger
level, edge = 1, True, 1.0, RISING
ts = TriggerSettings(channel, enabled, level,
    edge)
s.setTriggerSettings(ts)
```

[1] some models

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```
s.addTriggerCondition({channel: True})

preTriggerSamples, postTriggerSamples = 1024,
    1024
s.runSingle(preTriggerSamples,
    postTriggerSamples)

while not s.isDataReady():
    sleep(0.1)

s.readData()
data = s.getChannelData(channel)

#do the processing here
```

The Python wrapper was used to create a crude command line "oscilloscope" that can be used as soon as soon the library and wrapper are available; a screen shot of the tool can be seen in Figure 2.

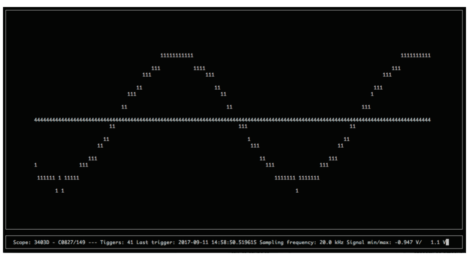

Figure 2: Command line based oscilloscope tool.

When the FESA class is running it is possible to configure the device and aquire data using any of the exising interfaces to CERN's Control System. To make data more accesible to anyone, a tool called Inspector [8] has been created in the Beams Department. Using this tool, graphical interfaces can be created and used without writing any code. A "panel" — that is a description of an interface — resembling a real scope has been designed. A screen shot of this GUI can be seen in Figure 3. Several other expert panels with customized controls and views have been created for dedicated systems such as Crowbar Monitoring and Arc Detection.

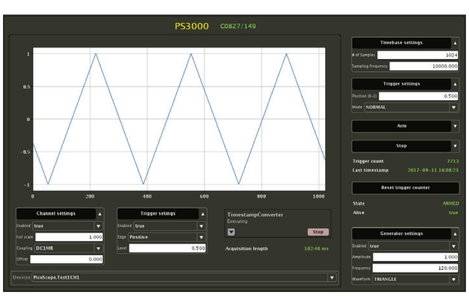

Figure 3: End-user graphical tool built with Inspector.

CURRENT DEPLOYMENTS

Currently the RF Group has two deployments of the system. The first one is the upgrade of the original system for monitoring crowbar events. It consists of 4 industrial PCs and 8 PicoScope 6204A oscilloscopes. The system has now been operational for two years and it has proven to be very stable. The devices are spending most of their time armed and waiting for the trigger and not doing actual measurements. On Figure 4 an expert application showing a crowbar event recorded on 25 August 2017 can be seen. The hardware that acquired the data is shown in Figure 5.

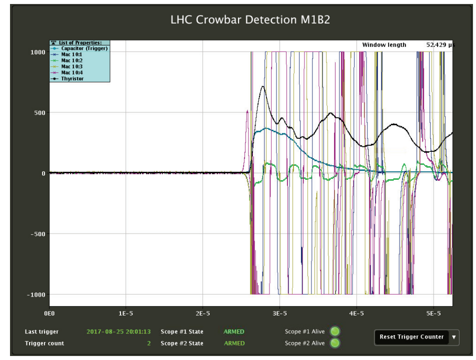

Figure 4: Crowbar event visualized by an expert app.

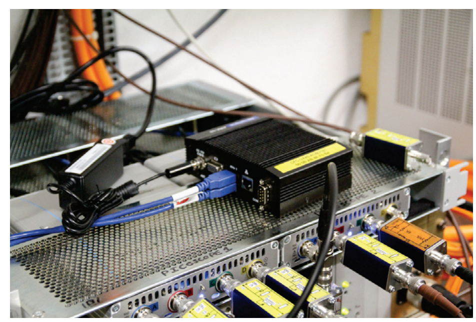

Figure 5: Equipment used to capture crowber events.

The material cost of the upgrade was quite low as only PCs had to be replaced — at current prices a single Intel NUC computer mentioned before can be acquired for less than 600 CHF [2]. If new oscilloscopes would need to be bought it would increase the cost by about 4300 € [3] for a pair. This sum would still be below a cost of a VME crate with a MEN A20 CPU alone which amounts to about 6000 CHF.

The second system is also deployed in LHC and records signals from arc detectors in klystrons and wave guides. All 16 klystrons are covered by 4 Kontron KISS 2U computers with 8 PS3403D (32 channels in total) connected. The system may be extended at any time by adding another 8 oscilloscopes. These oscilloscopes are installed in klystron racks underground in LHC Point 4 as can be seen in Figure 6.

Requirements for this installation were relaxed as the events recorded are happening at microsecond time-scales. The selected model was the lowest one fulfilling all the needs but it still exceeds them by a large margin. A cost of a single oscilloscope of this type (50 MHz bandwidth, 4 channels, 64 MS memory) is 620 € [4].

[2] Price from CERN Stores
[3] Price from external supplier via CERN Stores
[4] Price from external supplier via CERN Stores

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Figure 6: FEC and oscilloscopes used for arc detection in LHC.

It has been verified that the scopes from the crowbar monitoring could be replaced with the ones from the arc monitoring if necessary without reducing the system's effectiveness. This would allow us to have only one type of spares and would reduce potential repair costs.

FUTURE PLANS

The system, as it is now, is fully functional. We have already been asked in the past to deploy a FEC with a single scope to monitor some signals over several days in order to help debug some issues with the machine.

In the future we could design a stand-alone system that would be always ready to be rapidly deployed wherever and whenever it is needed. It would consist of a small industrial FEC with an oscilloscope connected, probably closed in a chassis and exposing only the required connectors.

The two oscilloscope families that were chosen cover our needs when it comes to acquiring analogue signals. In future it may be that a client for a 12–16 bit system appears and then the support for the PS4000 series would be added although at the moment we have no such plans.

At the moment of creating the PicoScope class, OASIS was still using FESA2 and an upgrade to the modern FESA3 framework was anticipated within a year. Our abstraction library code has been influenced by OASIS's abstraction layer and it could probably be easily integrated if such need arises.

CONCLUSION

A simple system for acquiring analogue signals of moderate bandwidth using commercial-off-the-shelf equipment has been described. Because of the simplicity and low cost we believe it could be used in places where monitoring some extra signals was previously deemed not economically viable. The other niche in which we think such system could flourish is where a rapid and temporary deployment is needed when some additional acquisition can help diagnose machine problems.

If this solution starts being adopted more widely and there is a need for low-cost acquisition of several analogue channels it could be possible to integrate it into OASIS and make use of all the infrastructure this larger system provides.

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