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HOW LOW-COST DEVICES CAN HELP ON THE WAY TO ALICE UPGRADE

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Abstract

Cheap, ready to install and simple to configure, minicomputer and microcontroller boards have been in use in ALICE for a few years for specific, non-critical tasks, like integrating the environment sensors network in the experimental site, and to monitor and analyse clock signals. These systems have also been installed inside the ALICE experiment, in the presence of magnetic field and radiation, and subjected to a functionality test. While the major part of these devices proved to work correctly even under the experiment conditions, finally some weaknesses were revealed, thus excluding this class of devices from usage in the production setup.

They have also played a role in the realization of scaled systems for the ALICE upgrade. With them, we have been able to simulate the presence of Front-End cards which are not yet available, allowing to proceed in the development of the software framework, of libraries and interfaces, in parallel with the production and validation of the hardware components. Being off-the-shelf and available everywhere in the world, they can be installed in remote institutes and laboratories participating to the collaboration.

Some of the systems have been realised by students and trainees hosted at CERN for short periods of time. As well as being cheap and easy to procure, they proved to be a great didactic tool, allowing young collaborators to realise a complete system from scratch, integrate into a complex infrastructure and get a hands-on approach to modern control systems.

INTRODUCTION

The ambitious upgrade plan of the ALICE experiment[1, 2] expects a complete reformulation of its data flow after the LHC shutdown scheduled for 2019. The continuous read-out of large size events at an interaction rate of 50 kHz Pb-Pb and 200 kHz pp, resulting in an impressive 3.4 TBytes/s data flow and 100 GBytes/s data-to-storage rate[3], requires the development of brand new electronic modules, together with the redesign of the trigger and online computing systems[4].

The electronics development phase started a few years ago and has already made a lot of progress. However, access to the prototypes is at present very limited and full scale prototypes of new devices are expected only very close to the time of their installation in the experiment. The lack of real hardware has a negative impact on developments of the supervision systems, including the Detector Control System (DCS)[5, 6].

To overcome the limitations caused by the lack of realistic hardware, the ALICE DCS team started building small-scale prototypes of the Front-End cards, based on low-cost commercial components: Raspberry Pi, Arduino, Intel Edison, etc.

These systems are commonly used in ALICE for environmental monitoring and to check simple electronic components and sensors. During 2016 and 2017, some of these devices have been configured and installed in the experiment areas around and inside the ALICE detector, where they were left for several months, in the presence of beam and magnetic field.

While the developments continue on the electronics part and on the overall design, these small-scale prototypes demonstrate their helpfulness to simulate the final system, allowing to understand and optimise the separation of roles, and target tools and protocols for the communications. Lastly, they represent a rather inexpensive, but realistic, laboratory, to exercise the developers' tools and environment, and to plan the deployment and integration phases.

FROM PRESENT INSTALLATIONS TO THE ALICE UPGRADE

Operational since 2014, the first minicomputer setup was installed to monitor the alignment of the LHC clocks (Fig. 1), replacing an expensive oscilloscope.

Figure 1: LHC clock monitor, able to detect misalignments of 100 ps.

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Figure 2: Weather station setup (left), installation point on the ALICE gas building (center), and a screenshot of the ALICE DCS monitoring web site (http://alicedcs.web.cern.ch/AliceDCS/monitoring/main.aspx), where temperature trends are published (right).

It’s composed of a Raspberry Pi Model A, connected to a DRS4 evaluation board by PSI[7], able to sample signals like a 5 GSPS oscilloscope. The need to monitor the LHC clock signals appeared during the ion collisions campaign in 2011: near the end of the RAMP phase of the LHC, some instabilities were observed, requiring a RESYNC operation from the central trigger. The Raspberry Pi based setup shown in Fig. 1. is running a C++ routine comparing the standard variation of the edges of the clock waves, and a DIM server[8] publishing data to the ALICE DCS, where the values are received and integrated into the WinCC OA[9] and JCOP Framework[10] monitoring and alarm system. If a misalignment is observed, and automatic resynch is not performed, an alarm is raised on the DCS shifter’s interface suggesting a manual synchronisation of the clocks.

The last system installed in ALICE is a weather station (Fig. 2). Environment data from the CERN RAMSES system[11] was used in ALICE to estimate the phase shift in clock signal transmission between the LHC site and the experiment site, over 15 km of optical fibres installed at a depth of 1 m. Due to the dependence of the quartz refraction index with temperature, the clock is subject to a seasonal drift of around 8 ns, and a diurnal drift up to 200 ps, that has to be evaluated and corrected online whenever operations permit. In 2016, when CERN discontinued the publication of environment data, we installed a simple device based on a Raspberry Pi 3 model B (Wi-Fi) connected to an Arduino board reading two analogue temperature sensors.

During 2016 and 2017, some of these devices have been configured and installed in the experiment areas around and inside the ALICE detector (Fig. 3), to verify their behaviour in the real harsh, experiment environment. The setups consisted of a Raspberry Pi minicomputer, connected to the network via Ethernet (where available) or Wi-Fi, an Arduino Uno micro-controller board and different sets of analogue and digital sensors, measuring temperature, humidity, pressure, magnetic field, noise and light.

They were configured to send regular streams of data using DIM, and archive the same data locally using RRD. Data was collected in WinCC OA, archived in Oracle database and displayed in WinCC OA panels and web pages, exactly like in the ALICE control system.

They were left in position for several months, in the presence of beam and magnetic field, and data was collected. After some time, we noticed the first failures and had to exchange parts of the setup with spares. Half of the systems resulted in broken power supplies (commercial AC to DC converters, delivering 5 V to Raspberry Pi and Arduino). The Wi-Fi connectivity weakened in time, becoming unreliable when the magnets were switched on (Fig. 4). Finally, we observed file system corruption in several microSD cards.

Even if some of the problems can be easily solved (like powering the system from a safe site and use wired connections), a more quantitative qualification needs to be done before using these systems in such environment, like irradiation and systematic tests ub magnetic field.

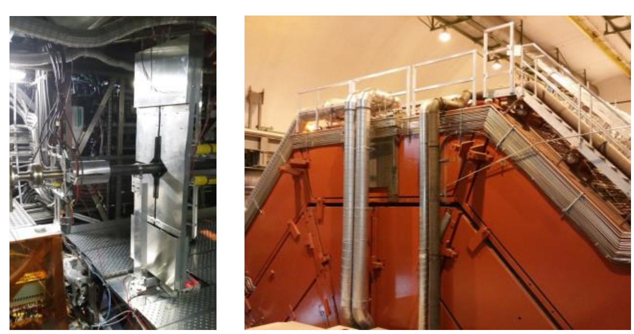
Figure 3: two installations of Raspberry Pi setups; left) near the interaction point, 1 m below the beampipe; right) on top of the ALICE L3 solenoid magnet.

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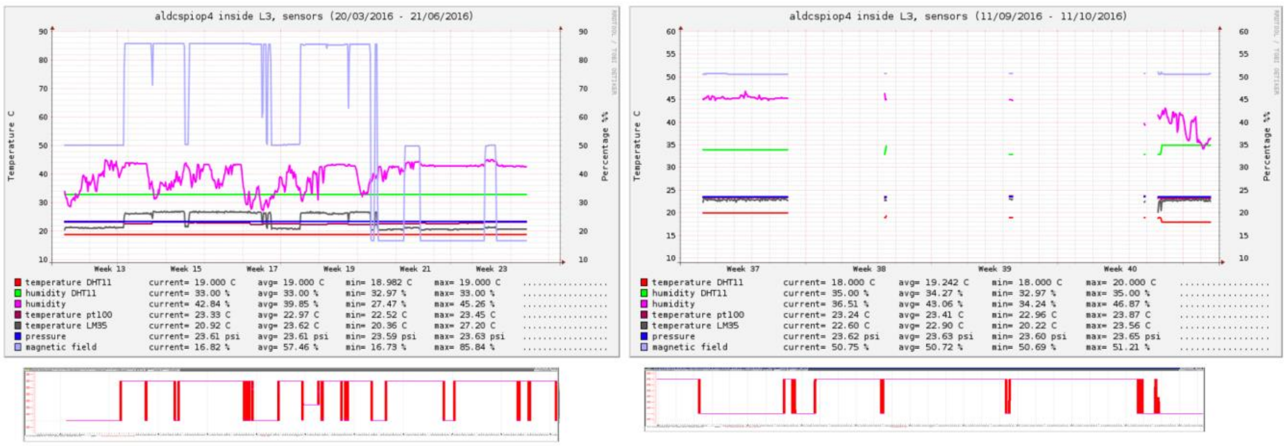

Figure 4: RRD graphs of the sensor readings (above) during 2016, showing the degradation of performances and the correlation with the on/off status of the magnet (below).

ALICE next generation front-end cards will be able to collect, filter and transfer data which will be part of a throughput of 3.4 TBytes/s. Embedded in the stream, DCS data is encapsulated and transmitted through the read-out optical lines, and eventually extracted and redirected to control systems and archives as described in the ALICE O^2 computing model[3]. Through the same line, configuration data from databases is sent to the front-end. During the development phase, DCS data coming from heterogeneous sources and with different frequencies have been successfully simulated using Raspberry Pi and Intel Edison boards, analogue and digital sensors, and DC-DC converters (Fig. 5, 6).

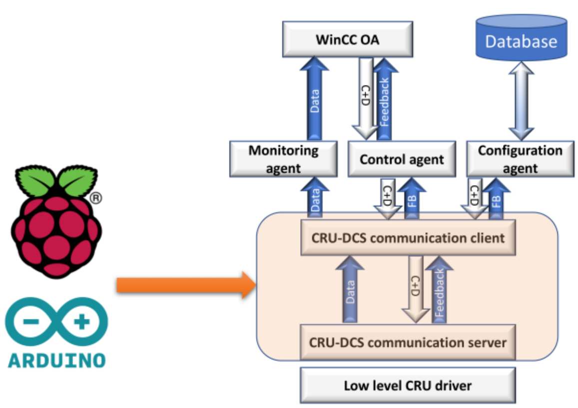

Figure 5: In absence of the CRU (Common-Readout-Unit) and Front-End cards, a Raspberry Pi and Arduino based setup is the proof of concepts for the DCS role into the new read-out chain.

The structure of the communication and control software developed for these boards is based on the architecture proposed for the future detectors. Through Arduino we have exercised the readings of sensors and the control of DC-DC converters. Data is collected on the Raspberry Pi, reformatted, and published via DIM. Software on the micro-computer is written in python and C++. All publications are subscribed to WinCC OA projects and archived on Oracle Database, exactly like in the production system.

In the other direction, configuration data is extracted from the configuration database and pushed to the Raspberry Pi to be applied on the controllers for the DC-DC converters. An example setup is shown in Fig. 6.

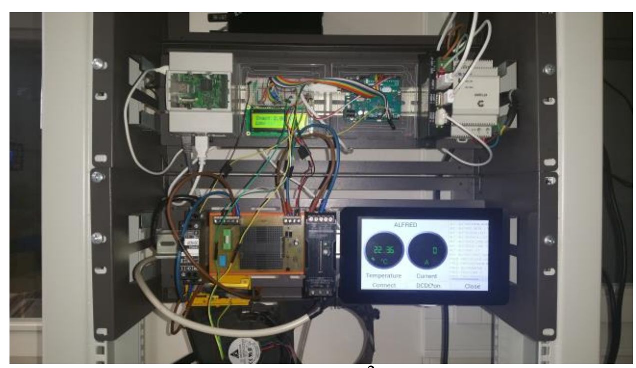

Figure 6: one of the ALICE O^2 simulator setups, with Raspberry Pi, Arduino and sensors installed on the top rail, and DC-DC converters and a User Interface touchscreen on the bottom rail.

STUDENTS PROJECTS

Every year CERN is hosting a big group of enthusiastic summer students. Some of them have participated in the ALICE DCS development working on a copy of the production setup, deployed in a lab environment. While the software framework and tools are almost the same, it is often impossible to fully duplicate the hardware devices, whilst maintaining an environment that allows them to fully exercise their projects. Some devices, like temperature, pressure and humidity sensors,

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or parts of the cooling and ventilation systems, can however be successfully substituted, or simulated, using low cost devices. Numerous setups have been deployed in the last years with the aim of exercising the integration to the main WinCC OA, DIM, and database architectures of the experiment. Mainly realized with Raspberry Pi and Intel Edison boards, these projects have been integrated in the ALICE laboratory parts of the upgrade development setup.

From time to time, CERN is also hosting short-term trainees, for periods of one to two weeks. They are mainly high-school students with very limited technical and scientific knowledge. While their involvement in the experiment activities is unrealistic, the realization of a real full setup using simple and cheap devices can be very satisfactory and rewarding for them (Fig. 7).

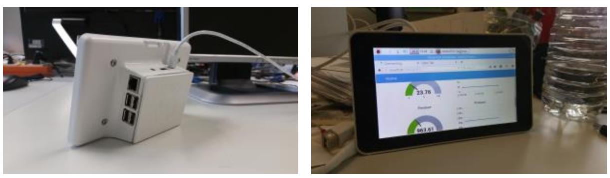
Figure 7: the last high-school students' project realized during summer 2017: a standalone setup composed by a Raspberry Pi 3 running Node-Red, a SenseHat shield with temperature and pressure sensors, a 7" touchscreen and a box enclosure.

CONCLUSIONS

ALICE is facing a challenging upgrade project. While new electronics are being developed and tested, part of the control software and infrastructure can progress in parallel thanks to small scale prototypes realized with low cost devices.

Some of the setups have been installed in harsh environmental conditions in the experimental site, but after some time failed, mainly, but not only, due to the presence of a significant magnetic field. They did prove, however, to be robust enough for test purposes, and are still a realistic test-bed for expert or beginner developers while the production of final electronics is continuing. In addition, devices based on these prototypes can be easily used in the laboratories, e.g. for environment monitoring.

As well as being useful as simulators for the future front-end devices due to be installed in the upgraded experiment, these systems proved to be an important and appreciated didactic tool for students and short term collaborators, allowing them to approach and exercise the technologies of modern control systems.

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