ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV027

EXPANDABLE AND MODULAR MONITORING AND ACTUATION SYSTEM FOR ENGINEERING CABINETS AT SIRIUS LIGHT SOURCE

P. H. Nallin†, J. G. R. S. Franco, G. F. Freitas, R. W. Polli
Brazilian Center for Research in Energy and Materials, Campinas, Brazil

Abstract

Having multipurpose hardware architectures for controls and monitoring systems has become a need nowadays. When it comes to modular and easily expandable devices, it brings together a system which is easy to maintain and can reach many applications. Concerning Sirius accelerators, which is a 4th generation light source, monitoring environment variables becomes crucial when it comes to accelerator stability and reliability. Several cabinets make up engineering infrastructure, therefore, monitoring, and acting over their environment such as internal temperature, pressure, and fan status, increases overall system reliability. This paper presents an inexpensive hardware topology to deal with multiple sensors and actuators mainly designed to monitor cabinets and prevent beam quality losses due to equipment faults.

INTRODUCTION

Sirius accelerator, the new 4th generation Brazilian synchrotron light source, has been under commissioning since 2019. Some improvements and maintenance have been accomplished for increasing machine performance and reliability in various subsystems.

Although the machine has not reached its project parameters yet, internal, and external scientists can run their experiments in available beamlines infrastructure, along with commissioning and maintenance shifts.

Both commissioning and user shifts require subsystems to work properly. For this purpose, it is necessary to have more information about the environment where equipment is located. The more scalable andeasier to expand the solution is, the more useful it will be regarding future needs. The concept of a multipurpose monitoring and actuating system, which will be initially installed in the Engineering Area, leads to acquiring a large variety of signals, making it easy to prevent, detect or even predict misfunction of a specific device.

OVERVIEW AND MOTIVATIONS

In order tohave a bright and stable photon bean, it is also necessary to keep the accelerators' installation area stable and reliable, which leads to the monitoring of some environment variables, such as the temperature of many different locations, the humidity where each equipment is located, the ambient pressure and several other data.

Sirius' monitoring network, an in-house project called SIMAR (Cabinet Monitoring and Actuation System), has been under development and its main purpose is to obtain data information from the cabinets, which store a large variety of equipment used in Sirius subsystems, such as vacuum, diagnostics and power supply equipment.

SYSTEM ARCHITECTURE

SIMAR is a multipurpose project, based on a Beagle Board single board computer, widely used in Sirius Control System [1]. It aims to handle multiple modular hardware, each one designed to run independently, making it possible to use various sensors and actuatorsin the same system and, also, flexible enough to operate in different conditions. The figure 1 shows the structure of the SIMAR project.

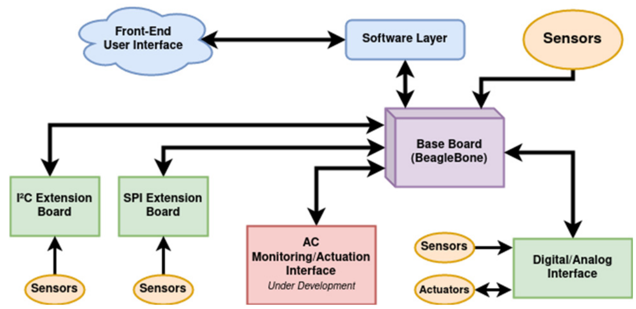

Figure 1: SIMAR conceptual design. It can integrate multiple devices, extend digital communication and easily scalable.

According to the environment to be monitored, additional stacked boards may be added as well as addressable splitters for multidrop digital communication channels. Every board must be hardware-configured prior to any new installation, in order to have a unique address identification.

Considering BeagleBone software integration, it is quite satisfactory to have one single disk image for all nodes in Controls Network, based on Debian. For that purpose, SIMAR has also been integrated into the BeagleBone-functionality-discovery service, which runs at initialization and gets information about hardware and equipment connected to a node. Then, all necessary applications are run.

HARDWARE DEVELOPMENTS

Base Board

The base board is the SIMAR main stack hardware project. It is responsible for functioning as a master on the communication buses and input/output pins. It also integrates the Programmable Real-time Units (PRUs) [2] into SIMAR interface for real-time data processing.

†patricia.nallin@cnpem.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV027

Four serial protocol signals (SPI, I²C, UART and 1-wire) are available on the base stack and they can be used for communication with several devices and sensors.

Digital and Analog Interface Stack

The first auxiliary board for SIMAR project is a general-purpose input/output digital and input analog data interface. This board makes it possible to write and read an 8-bit digital word and read up to six analog signal channels. This interface stack is controlled by the base board, as shown in figure 2, through SPI communication. Among the transmitted data, one byte is used to select the interface board, according to its unique address and to select the functionality inside of the interface board (for example, read or write digital data). If necessary, one byte for updating the digital outputs.

To write or read digital data, SPI registers (serial-in/parallel-out and parallel-in/serial-out) are available on the board.

For reading analog signals, the BeagleBone's internal 12-bit ADCs are used. Since the original input range is from 0V up to 1.8 V, signal conditioning and protecting circuits are included in order to increase voltage range and, also, prevent over voltage on BeagleBone pins.

In addition to communicating with external signals, this stack has an integrated SPI EEPROM memory, making it possible to store the latest output values to be recovered after a power outage, general board information and further necessities. The interface board is compatible with-many SPI EEPROM models.

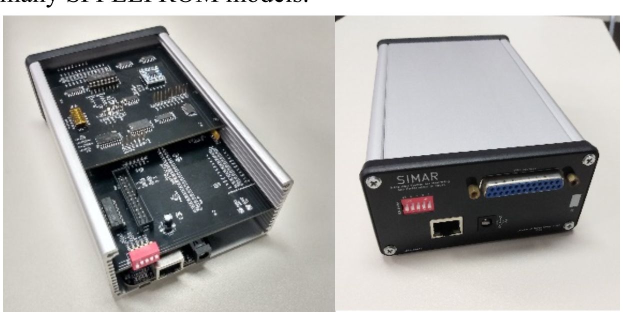

Figure 2: SIMAR base board and interface stack prototypes assembled, together, minimal unit installed in Sirius cabinets.

SPI and I²C Extender Modules

Another auxiliary device for SIMAR is a SPI extension, which aims to split and enable communication with up to six other devices. Device selection is performed by decoding four bits, which address the chip-select signal to the correspondent device. These bits get into the SPI expander as a configuration word.

Similarly, an I²C extender has been designed.

DATA ACQUISITION AND MONITORING

Acquiring Sensor Data

In order to increase system performance and allow it to work with multiple sensors, all coding is in C/C++ and Python modules may be created from these libraries.

With the base board only, SIMAR communicates through up to 4 different I²C channels, making it possible to monitor multiple cabinets with a single unit, greatly reducing costs. Switching is done through memory mapped input/output, diminishing switching times and increasing maximum polling frequencies. This strategy is also applied to other interfaces, such as SPI and digital inputs/outputs.

Currently, SIMAR supports the BMx280 family of sensors, automatically detecting and naming up to 8 different sensors (2 sensors per channel). Communication speed and sampling rates are limited by I²C channel switching delay and minimum reading/standby times for the sensors, which result in a maximum sample rate of approximately 800 Hz per sensor when all channels are active. If only one sensor per channel is active, it is possible to reach a theoretical limit of 1200 Hz for sample rates, given that only basic system and SIMAR processes are running on the main core.

For other sensors and auxiliary boards that require a faster communication solution, the BeagleBone's PRUmay also be used as some of its pins are mapped on SIMAR bus, allowing higher polling rates and predictability [3]. For example, it could count multi-purpose pulses, up to 10 MHZ, in 4 channels, while simultaneously performing other functions in the main core. Functions could be communicating with 8 different sensors, an external ADC, processing remote commands. One of the expected featuresconcerning PRUs and SIMAR is to measure duty cycles of a digital waveform in the order of tens of MHz.

Even though a containerized Redis database [4] is running in Controls cluster, latest values for any variable are stored on a local database running on each BeagleBone. Data transfer is fast, reliable and dumps to disk are easily configurable. Output signals are recovered from this database after either a cold or warm system boot. Yet, if needed, a copy of all logged sensor data is also written to any USB storage device connected to SIMAR automatically.

Deduction Algorithms for Door Status

Through the BMx280's family high accuracy and sensitivity to pressure changes (with its IIR filter disabled), it is possible to eliminate the need for a door status sensor such as a switch. By monitoring pressure moving averages, sustained and significant (> 0.3 hPa) pressure changes are counted as door status changes.

Thanks to the use of a Redis database, power outages and unplanned shutdowns do not affect the pressure moving average comparisons. When any of these situations happen, the moving average is automatically adjusted based on external pressure changes which accompany the expected pressure changes inside the cabinet since the last time it was connected. The system has shown itself to be resilient against false positives.

Wireless Connection

A very special SIMAR use-case, under software development and integration tests, is using a wireless connec-

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV027

tion to share data values between sensors and a remote Redis database. In this case, SIMAR connects to the cluster and retrieves data from the containerized database, so that static BeagleBone IPs are not mandatory to access acquired data.

It also allows the possibility to have portable SIMAR units, which are powered and start data acquisition on startup and data streaming automatically once a compatible wireless network is available.

EPICS INTEGRATION

Sirius' Control System is EPICS based, which leads to the need to translate SIMAR Redis variables into EPICS Process Variables (PVs). The EPICS IOC for this application runs atop a custom auto-failover Asyn driver [5], developed in collaboration with Dirk Zimoch, from Paul Scherrer Institute (PSI). With this driver, it automatically switches to alternative servers in case of any disconnections, which is especially useful when coupled with high availability solutions, as a cluster or systems with hardware redundancy.

The IOCs are containerized and run on the Controls System cluster, querying Redis databases for data updates, utilizing a custom auto generated Redis IOC [6]. This approach reduces overheads resulting from hosting an additional communication channel for each SIMAR unit, since Redis is already present on the default Sirius BeagleBone image.

Performance-wise, the IOC solutions applied to SIMAR make for high-frequency polling that accompanies the performance of the main program running on all SIMAR units, reducing data losses. Utilizing Redis also allows holding the data for as long as possible while the IOC catches up, in case that ever occurs. The conceptual design of the software stack is shown in figure 3.

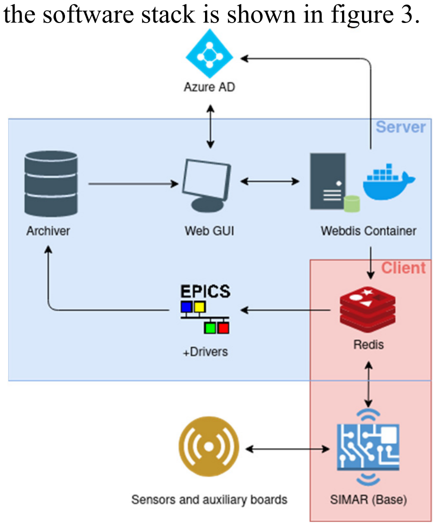

Figure 3: SIMAR's software stack.

USER INTERFACE

The user interface for SIMAR (figure 4) is web-based and responsive, allowing access from mobile devices and desktops alike. Based on the Vue framework, it features real-time data updates, graphical configuration menus, granular permissions, and safe authentication, based on Microsoft Azure's technology [7], which is the default authentication for CNPEM collaborators.

Fetching information is also trivial, since the designed GUI makes use of "Epics2Web" [8] API, utilizing web sockets to communicate in an efficient and quick manner with the EPICS server. In addition, the GUI supplies dynamic links to the EPICS Web Archiver Viewer, allowing users to quickly view historic data for each device.

Communication also occurs through a custom version of Webdis [9], an HTTP interface for Redis database. Added functionalities regarding default applications are server-side logging and authentication for additional security. In order to increase performance, Redis' script cache functionality is used, bundling together batch requests.

Authentication was added to restrict interaction with outlet actuation and custom alert limit functionalities. No user credentials are stored, and all communication is compliant with OAuth2and HTTPS standards, with only a token being received by the Webdis server, which is used to confirm the user's identity.

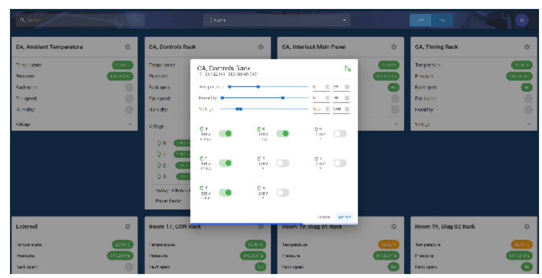

Figure 4: SIMAR's web-based graphical user interface.

In addition, in-house tools are available which allow users to be notified whenever a limit is exceeded, transmitting notifications through email and Telegram instant messages, for example.

INITIAL INSTALLATION

Currently, SIMAR prototypes have been applied to monitor some critical environments, such as 12 default cabinets from various subsystems in a high-density area subjected to higher ambient temperatures. A base board acquires data from sensors located inside each cabinet, positioned on the most critical region.

Figure 5: Sensor unit placed inside a cabinet.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV027

A wireless unit, initially connected to the corporate network due to connectivity availability, has been in operation for some months in order to acquire environmental data (ambient pressure, humidity, and temperature) outside the building for metrology refinements.

Dedicated cabinets (timing system, controls servers and interlock system) have recently started being monitored by SIMAR, acting as a replacement for a system that required physically dismounting the sensor to retrieve data and recharge batteries, figure 5 demonstrates a sensor installation in a cabinet. The graphs shown in figure 6, figure 7 and figure 8, exemplify how the environment data is being presented to the user.

Figure 6: Temperature measurement of special cabinets and environment temperature at Connectivity Area.

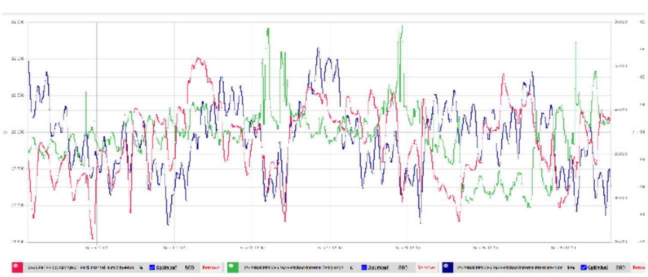

Figure 7: Temperature, pressure and humidity measurement for a pulsed-magnet cabinet.

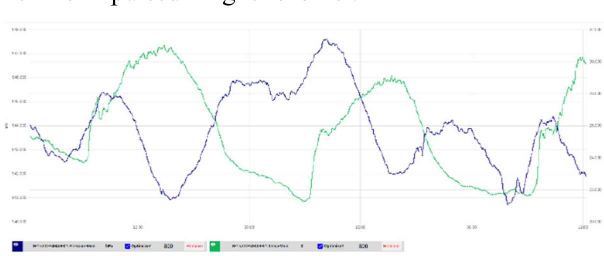

Figure 8: External (out of building) measurements, helping with subsystem stabilities.

The data provided by SIMAR allows new or existing HVAC installations to be tailored to the needs of each individual room, subsystem, or cabinet. They also help with narrowing down possible issues with airflow and humidity-sensitive equipment, as well as making it easier for operators to monitor engineering cabinets health and status. It is also important for detecting unusual temperature variations (both internal/external cabinets and outside the building), thanks to its high precision, data acquisition rate, ease of installation and high mobility.

FUTURE APPLICATIONS AND IMPROVEMENTS

Many improvements are planned, and some are already in progress. The next application under development considers power outlets switching and monitoring (voltage, current, frequency and power factor), which will greatly increase system added value and expand actuating possibilities.

Other features are also planned, such as sound signature analysis in order to predict and prevent failures more reliably, local alarms and support for more sensors. Powering through PoE would reduce the number of cables anda dedicated IoT wireless network would eliminate communication weak points.

CONCLUSION

As part of Sirius' engineering team effort to continuously improve and reach new standards of reliability, efficiency, and stability, SIMAR has demonstrated that it is quite essential for on analyzing environmental and operational data and act over it whenever it is necessary.

Such data can be used to predict failures, schedule preventive maintenance, and help members to planout upgrades in advance, while remote actuation provides a channel of interaction for otherwise inaccessible devices and systems. If environment data is acquired and all the necessary interfaces to actuate over it are available, analyzing that data along with specific subsystem variables might lead to a better environment that increases overall stability and reliability.

Although SIMAR is still in its commissioning phase, it is currently expected to be installed in all Sirius Engineering cabinets, along with other locations and systems as requested, since it is highly versatile, easy to set up and a low-cost solution compared to commercial ones.

These developments are part of the many steps to guarantee that Sirius' commissioning and operation are efficient, stable, and reliable, achieving the expected research output.

REFERENCES

[1] J. Franco *et al.*, "Software and Hardware Design for Controls Infrastructure at Sirius Light Source", in Proc. 17th Int. Conf. on Acc. And Large Exp. Physics Control Systems (ICALEPCS2019), New York, USA, Oct. 2019, pp. 263-267. doi.org/10.18429/JACOW-ICALEPCS2019-MOPHA031

[2] P. Nallin, J. Franco, R. Ito, A. Rodrigues, "Exploring Embedded Systems' Dedicated Cores for Real-Time Applications", in Proc. 17th Int. Conf. on Acc. And Large Exp. Physics Control Systems (ICALEPCS2019), New York, USA, Oct. 2019, pp. 1036-1040. doi.org/10.18429/JACOW-ICALEPCS2019-WEMPR003

[3] M. Watkins and C. Betancourt. Ensuring real-time predictability: Leveraging TI's Sitara Processors Programmable Real-Time Unit. TI Whitepaper, 2014.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV027

[4] S. Chen, X. Tang, H. Wang, H. Zhao, and M. Guo, "Towards Scalable and Reliable In-Memory Storage System: A Case Study with Redis," 2016 IEEE Trustcom/BigDataSE/ISPA, 2016, pp. 1660-1667, doi.org/10.1109/TrustCom.2016.0255

[5] Asyn Failover, available in https://github.com/cnpem-iot/asyn-failover

[6] Redis IOC, available in https://github.com/cnpem-iot/redis-ioc

[7] V. Bertocci. "Modern authentication with Azure Active Directory for web applications", 1st ed., USA, 2016, Microsoft Press.

[8] R. Slominski, T. Larrieu. "Web Extensible Display Manager", in Proc. 17th Int. Conf. on Acc. And Large Exp. Physics Control Systems (ICALEPCS2017), Barcelona, Spain, Oct. 2017, pp. 852-856. doi.org/10.18429/JACOW-ICALEPCS2017-TUPHA181

[9] A Redis HTTP interface with JSON output, available in-https://github.com/nicolasff/webdis