A Modular and Flexible Data Acquisition System for a Cosmic Rays Detector Network

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Abstract

We describe a modular data acquisition system developed as the foundation of a cosmic ray detector outreach network. Each detector setup is composed of an independent hardware device that can be controlled and read out through the Internet. This device is designed to acquire and process the signal of up to eight different detector planes. Each of these detector planes uses plastic scintillator slabs that are optically coupled to silicon photomultipliers (SiPM). The main readout is based on a programmable system-on-a-chip (PSoC), a flexible and re-configurable commodity hardware that is used to implement the trigger and timing logic.

Introduction

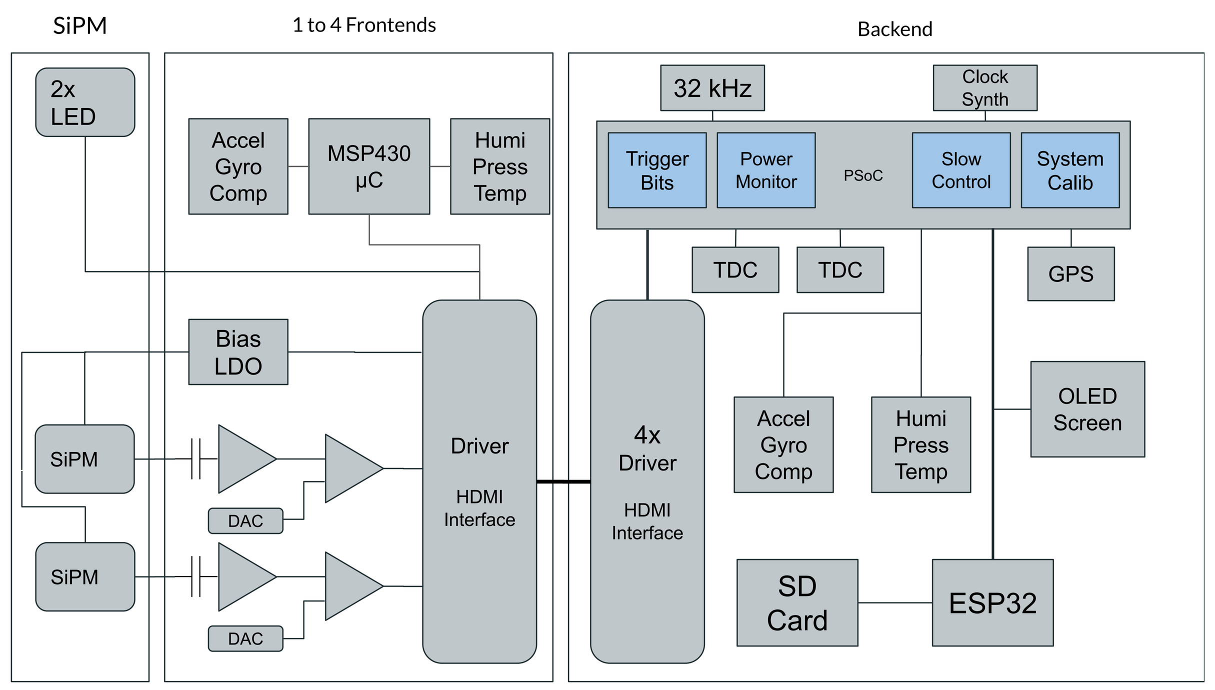
The detection of cosmic rays using simple apparatuses for quantitative data-taking has been explored over the years by several initiatives around the world for outreach and experimental High Energy Physics instrumentation teaching[1] [2] [3]. The possibility to connect geographically dispersed stations synchronized by a GPS timing signal[4] allows for a larger detection area suitable for the identification of high energy cosmic rays showers. In order for such system to be deployed in a high school or science museum environment (hence for outreach purposes), it must be safe (no flammable gases or high voltages) and ideally low cost, so the network can comprise as many stations as possible. The use of plastic scintillators, SiPMs and commodity electronic hardware allows the project to fulfill these objectives. The readout, timing and trigger implementation supports a variety of geometries and even other cosmic rays detection methods (e.g. Cerenkov) that can be easily deployed by a simple re-configuration of the system. This enables a variety of experiments to be performed with the same hardware, thus reducing the complexity and costs of the system construction and operation.

Cosmic Ray Detector

Each station is an autonomous hardware (and firmware) unity that detects cosmic ray events and transmits raw data to the software stack through the Internet. These stations are composed of up to four **Frontend modules** (FE), each housing up to two sets of scintillators and SiPMs, plus the analog section of the electronics. The information is then transferred to a **Backend module** (BE) that aggregates the trigger, timing, data acquisition, event building and network communication functions.

A disassembled Frontend Station showing the plastic scintillators slabs light-proofed and the Backend readout board.

The current system uses $4 \times 4\,\mathrm{mm}^2$ Silicon Photomultipliers (SiPM) sensors (Broadcom AFBR-S4N44C013[5]) that can be installed as an array of up to four sensors mounted on dedicated PCBs. The SiPMs are directly attached to a plastic scintillator slab (BC508) using optical grease. The FE hardware can be configured to either add the signal of the four SiPMs (when using a thicker scintillator) or to keep the two signals separated for coincidence.

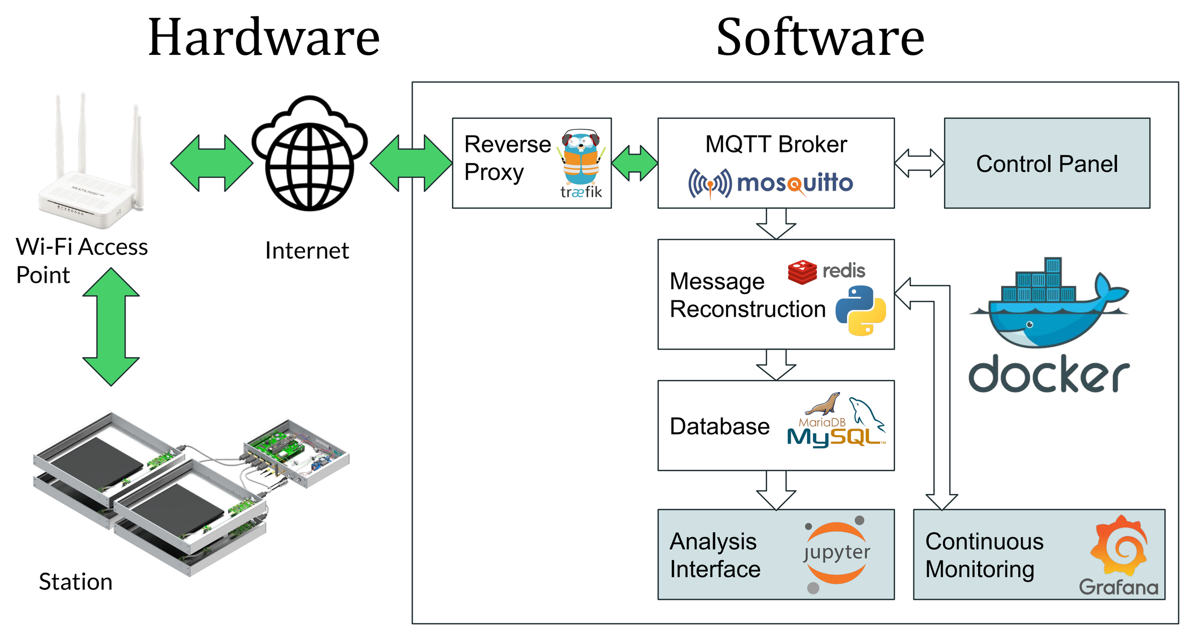


Block Diagram of a detector showing the PCBs and their internal components.

The current design is able to use scintillators slabs as thick as 20 mm. The system is sealed in a light-proof aluminum container and the connection to the readout electronics made by a flat cable. Besides this, the FE also provides calibration and environmental data for the analysis.

Data Management and Analysis

Intended as an outreach focused project, the user interface allows many educational activities, ranging from just observing the detection rate from a fixed station to the combination of several stations or angular muon distribution.



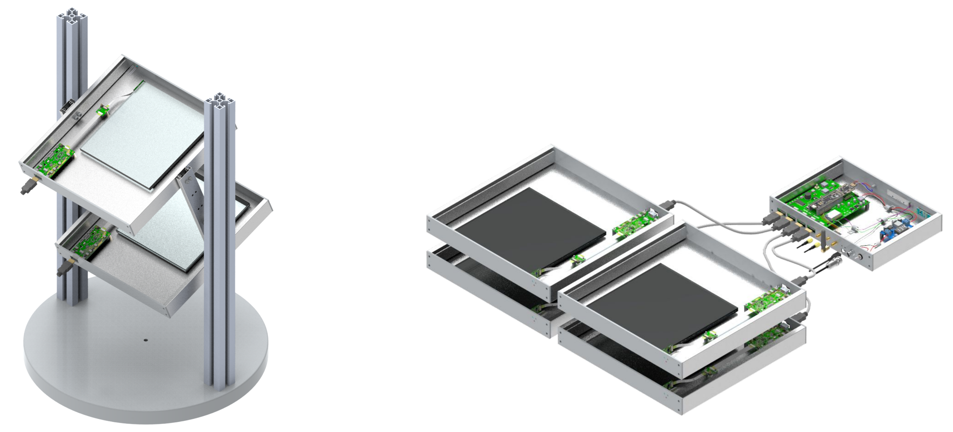
Docker containers stack deployed as part of the Data Management and Analysis (user accessible services in light grey). As part of the software infrastructure the preliminary version of the project home page is hosted at `https://raioscosmicos.gitlab.io`

The infrastructure is built as a Docker stack, with each service running in its own container. Each station has a dedicated topic in our MQTT Broker and a custom Python script offloads all messages transmitted in these topics to a fast Redis cache. This script is also responsible for some data reconstruction and the Database (SQL) storage. Two parallel services are available for the user interface: the first is a Grafana panel, intended as a read-only web page showing all monitor information predefined by the team; the second one is a Jupyter Notebook service, a web-based interactive notebook capable of running Python code with read access to the Database through the network.

Future Plans

As the stations and the network are in constant development, we are currently deploying the second version of the station. The stations can be reprogrammed on the fly and have their trigger logic, sensor bias and threshold voltage, type of timing conversion (signal time-over-threshold or absolute time) and telescope angle modified by the user in real time. All changes are logged in the database, that also keeps the inventory of the hardware and schools.

A pair of "roaming" stations will also be installed in the trucks as part of the "mobile USP" outreach project, so we can autonomously gather data across geographically dispersed sites in São Paulo state.



Left: telescope assembly - Right: custom veto and coincidence trigger assembly

Finally, profiting from the very flexible design of the whole system, we are currently instrumenting a FE to act as a cosmic ray neutron detector for monitoring water content in soil, to be presented as a nice spin-off example of the technology here presented. [6]

Acknowledgements

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