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Development of a Prototype for an Autonomous Environmental Gamma Radiation Monitor

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1. Introduction

Within each nuclear facility, the presence of a primary accident prevention and monitoring system is necessary. It is also desirable to have a secondary environmental radiation monitoring system, in the facility surroundings. To name just a few around the world, there are the REVIRA in Spain [1], NMR in Holland [2] and RadNet in EUA. In Brazil, the Dosimetry and Radioprotection Institute possesses a few autonomous monitoring stations, in the vicinity of the Angra I and II nuclear power plants, composed of two Geiger-Müller (GM) detectors and a communication module for data transmission over GSM cellular network.

Monitoring networks are mainly used to determine the population's exposure to radiation, due to small amounts of radioactive effluents released by nuclear installations (power plants, ore extraction sites, centrifuges, tailings deposits, etc.) or carried by rain. In a second instance, in the case of an unlikely nuclear accident, followed by successive failures of the physical barriers and failure in the reactor's control and protection systems, the release of radioactive material can be significant. A large amount of radioactive material can be released in the vicinity of the plant and carried by the wind, representing a threat to life. In this case, the monitoring network shows where the radioactive material is being transported to.

In this paper, we present the development of a low-cost autonomous environmental gamma radiation monitor prototype using FPGA technology. Field-programmable gate arrays (FPGAs) have become the trend for digital signal processing. While microcontroller units are mostly used for sequential tasks, FPGAs can perform many logical operations in parallel and, therefore, are the top choice for the implementation of pulse detection algorithms [3]–[10].

Most environmental monitoring networks are based on GM counters, which makes it difficult to separate the contribution of different radionuclides. Our monitor has a multichannel analyzer (MCA) to separate the detected gamma pulses according to their energy. Then the resulting spectrum can be analyzed to identify multiple radionuclides within a single radioactive material.

2. Methodology

The basic structure of the environmental monitor is shown in Fig. 1. The monitoring station is the data acquisition side of the monitoring system. The detector and electronics are powered by a 12V battery which is charged through a solar panel. The detector is composed of a NaI(Tl) crystal coupled to a photomultiplier tube, and a pre-amplifier system with analog filters for signal conformation.

The MCA was implemented using an AVNET ZedBoard development board built with a Xilinx Zynq-7000 System-on-Chip (SoC). The detector's signal is constantly sampled by the Zynq-7000 built-in analog-to-digital converter (ADC). A simple pulse detection algorithm was written in Verilog language to detect and record pulse counts separated by amplitude.

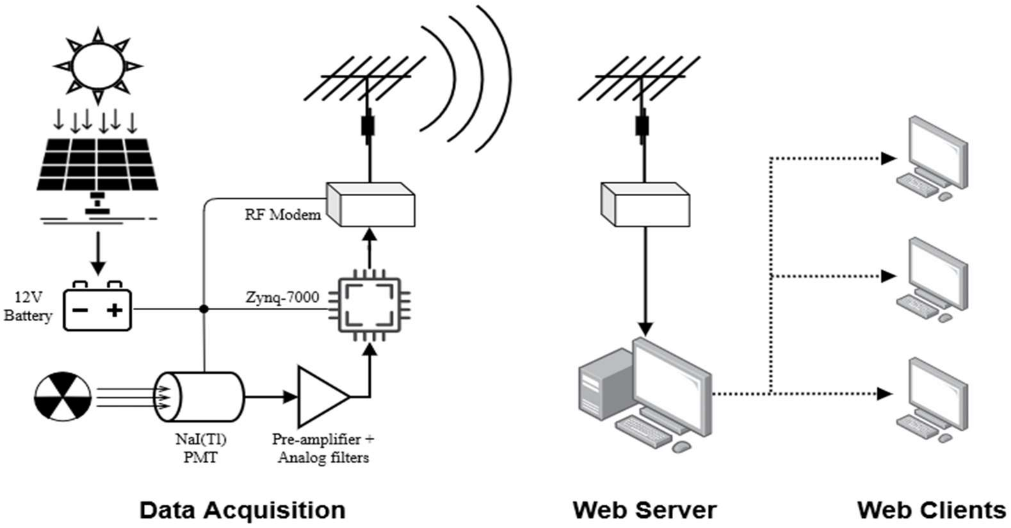


Figure 1: Basic structure of the environmental monitor station.

The pulse detection algorithm was written based on a simple finite state machine. To rule off electronic noise, we divide the amplitude range into three regions: the lower, central, and upper bands. The bands are illustrated in Fig. 2 (left). The algorithm counts a single pulse *only if* the voltage signal goes from the lower band to the central band, and back again to the lower band. Voltage signals passing through the upper band could be the result of piled-up pulses or out-of-range gamma energies and are discarded. Electronic noise can generate false counts when the voltage signal transitions between the lower and central bands. We avoid these false counts by reducing the lower band voltage level on the signal's return to ground, analogously to the hysteresis effect in analog comparators. A 3-stage analog frequency filter was designed to obtain a semi-gaussian pulse shape with approximate full-width-at-half-maximum (FWHM) of 4.5 µs.

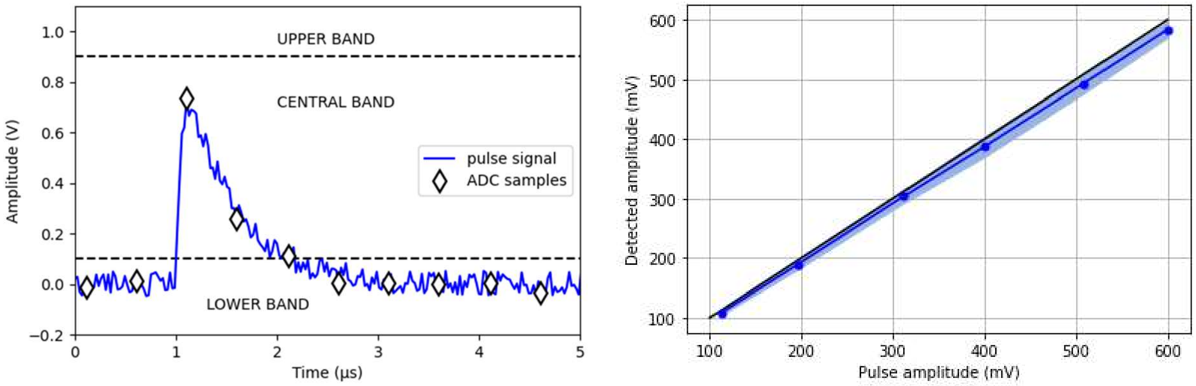


Figure 2: Pulse detection algorithm's illustration (left) and amplitude measurement test (right).

For radiofrequency communication, Alfacomp RM2060 1W 900MHz modems were chosen. Their communication range is up to 32 km. To transfer data from the Zynq-7000 to the modems, we used a Maxim PMOD MAX3232PMB1 which converts UART to RS232 standard.

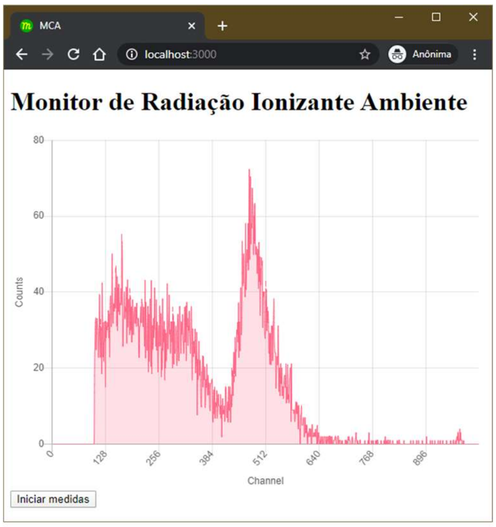
On the server side of the monitoring system, the spectrum data are received by a web server running on a computer. The web server was written in JavaScript language and runs through Node.js runtime environment. It records received spectra and displays them in HTML pages upon request from clients using web browsers on a local network or the internet.

To test whether the correct amplitudes are measured by the pulse detector algorithm, a BNC DB-2 Random Pulse Generator was connected to the preamp input and several pulses were generated at random time intervals. The pulse emission rate was approximately 480 pulses/s. Amplitudes were limited between 100 and 600 mV. Fig. 2 (right) shows the detected amplitude as a function of the input amplitudes.

To verify the server's functioning, a radioactive source of ^{137}Cs was placed next to the NaI(Tl) detector and a spectrum was measured every 10 seconds. The data were then sent from the monitor to the server, which displayed it in an HTML page to connected clients.

3. Results and Discussion

The preamp stage maps gamma energies up to 1 MeV into the approximate range of 0 to 1 V, corresponding to the Zynq-7000 ADC input range. The pulse detection algorithm was tested using a BNC DB-2 Random Pulse Generator. For input amplitudes ranging from 100 to 600 mV, the detected amplitudes are shown in Fig. 2 (right). The behavior is linear with correlation coefficient $r^2 = 0.815$. The maximum standard deviation is 44 mV/V. An additional calibration procedure, with standard radioactive sources, must map the detected amplitudes to the correct incoming gamma energies.



Monitor de Radiação Ionizante Ambiente

Figure 3: Screenshot of ^{137}Cs spectrum shown in a web browser (the web page text is in portuguese).

At every 10 seconds, the spectrum data were sent from the monitor to the server computer, which displays it in an HTML page to clients connected through web browsers. Prior to display, the server reduces the 4096 spectrum channels to 1024 in order to reduce statistical errors. A screenshot is shown in Fig. 3. This spectrum comes from a ^{137}Cs radioactive source placed next to the NaI(Tl) detector, and clearly shows the peak line corresponding to the 662 keV gamma emission of this isotope’s radioactive decay.

4. Conclusions

In this work, a prototype for an autonomous environmental gamma radiation monitor was developed. The monitor includes a fully functional 4096-channel MCA, implemented with FPGA technology. Parallel to the monitor development, a web server was written to gather data from monitoring stations and display them in HTML pages for web clients. The environmental monitor will soon be mounted on a stand for outdoor testing. Improvements can be made on the web server, such as recording spectra data in a database for further analysis.

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