A proposal of a counting and recording system for cosmic ray muon detectors

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Abstract. A multidirectional high energy cosmic ray (muon) telescope is operational at the Southern Space Observatory, in Sao Martinho da Serra, RS, Brazil. This telescope is part of the Global Muon Detector Network (GMDN) and aims to study and forecast Space Weather. This paper proposes a new counting, correlation and recording solution based on an embedded system able to interface observational data by internet for remote monitoring. It is built around a Rabbit 3000 microcontroller with TCP/IP Ethernet 10Base-T connectivity. It is able to detect and count 200 ns pulses generated by the sensor system (scintillator plastics coupled with photomultipliers) during a specified period of time (generally one second). A preliminary version of a monitoring web page was developed and it is able to show the cosmic ray (muon) data of one detector in real time. The current system is an attempt to improve the reliability of the telescope when comparing to the recording system based on a personal computer, currently under operation. One advantage is the easy maintenance, since all the counting and correlation boards currently under operation can be replaced by an embedded system. Besides, as the hardware is off-the-shelf, it is only necessary to develop software routines, which is based on royalty-free libraries.

1. Introduction
The multidirectional muon telescope of Sao Martinho da Serra (Brazil) is installed in Southern Space Observatory (geographic coordinates: 29.4° S, 53.8° W, 488 m). It has detection area of 28 m² and is multidirectional, allowing simultaneous record of the intensities in various directions of viewing. This detector has an identical design to other detectors installed in Nagoya (geographic coordinates 35.1°N, 137.0° E, 77 m) and Hobart (43.0°S, 147.3° E, 65 m), except for the detection area which is 36 m² for Nagoya and 16 m² for Hobart [2]. These detectors, combined with a muon hodoscope installed in Kuwait City, are part of a network called Global Muon Detector Network [1]. It has been shown that combining data of all stations allows the determination of the spatial gradient of the galactic cosmic ray density in three-dimensions and, therefore, to study precursors of geomagnetic storms [3,4], magnetic cloud geometry [5] and corotating interaction regions [1].

Each detector consists of two horizontal layers of plastic scintillators, vertically separated by 1.73 m, with an intermediate 5 cm layer of lead to absorb the soft component radiation in the air. Each layer comprises an array of 1 m² unit detectors, each with a 0.1 m thick plastic scintillator viewed by a photomultiplier tube of 12.7 cm diameter. An electronic amplifier circuit which converts the current...
input pulses into square pulses with duration of about ~200 ns. By counting pulses of the twofold coincidences between a pair of detectors on the upper and lower layers, we can record the rate of muons from the corresponding incident direction. The multidirectional muon detector comprises various combinations between the upper and lower detectors. The logic to determine the incident direction is described elsewhere [6].

Traditionally multidirectional muon detectors as the case of the detector in São Martinho da Serra, Hobart and Nagoya, have counting and correlation system based on conventional logic gate integrated circuits. Recently a new counting and correlation system based on the devices of Field Programmable Gate Array (FPGA) and VHSIS Hardware Description Language (VHDL) has been developed for muon detectors [6]. This system is said to allow a more complicated logical circuit with a reduced cost when compared to the logic gate. This recording system is under operation since 2006 in parallel with the traditional logic gate correlation and counting system. The recording system of both correlation and counting systems is a personal computer which also provides remote access through internet. A block diagram of the multidirectional muon detector is shown in the figure 1 by the gray and blue blocks.

Figure 1. A block diagram of the muon detector installed in São Martinho da Serra. The gray blocks indicate the signals processed by the conventional logic gate based correlation and counting system. The blue blocks indicates the correlation and counting system proposed elsewhere [6] and installed in 2006 in São Martinho da Serra. The block in orange is the new system for counting, correlation, recording and network connectivity based on the present work, which is in preliminary testing phase.

2. Objective

Our objective is to present a suggestion for a new counting, correlation and recording system for a multidirectional muon detector based on a embedded system (hereafter, this new system is referred as ES). The ES is meant to be attached to the output of the amplifiers and pulse shapers (2nd block in gray in figure 1, from left to right). Our objective is to develop a system which operates uninterruptable and which allows both local and remote monitoring from any computer connected to the internet.

The current recording system needs a specifically made application to be running on a personal computer. On the other hand, using the ES proposed, the correlation and counting boards, and the computer are not needed. A computer would be used only as an optional user interface and as a long term data storage since it would probably have more memory than the ES. The ES is an attempt to improve the reliability of the muon detector when comparing to the recording system based on a personal computer which is currently under operation. Moreover, the ES has lower cost when compared to a personal computer and has easy maintenance since the board is off the shelf and basically only software development is needed.

The input signals are 3V 200 ns square pulses generated by the amplifying board associated to each photomultiplier and detector. The connectors which will be available in the final user interface are: a) 5V or 12V DC power supply, b) RJ45 TCP/IP connector and c) connector for the input signal. A suggested user interface for the system may have only the following buttons: a) power on/off, b) reset.
and c) start/stop recording and the following on/off LED indicators: a) powered system, b) recording in progress, c) TCP/IP network, d) data transfer (upload), e) input signal connected and f) memory full. Beyond this, a LCD display is one missing step where current count rate and memory status can be checked by a local user with no need to network connection. The connectors and the suggested user interface is illustrated in figure 2.

Figure 2. An illustration of the user interface and the connections available in the correlation, counting and recording system proposed in this work.

3. Methodology and first results

For developing the present project we used a microcontroller with TCP/IP stack. Among others available off-the-shelf, we can cite the Rabbit 3000, a 8 bits device with 29.4 MHz clock. It can be programmed in high level language similar to C and has an extensive royalty-free libraries for TCP/IP application which are the core of this work [7].

The first step was implementing static HTML on which the information cannot be updated during the user access to the page. For updating the page, the user needs to reload it. In order to show muon count rate of 1 second, static webpage is not ideal. We have decided to show a dynamic webpage using scripts CGI which allow us to show directly the content of a given microcontroller variable on the page. First the variable is sent to the server buffer and after it is send to the HTML page using a library available. Up to now, the embedded system was connected to a network using a fixed IP address and could be accessed remotely through the internet. A simple webpage was developed and is able to show the last second count rate from a given detector. Although internet is not a real time system and therefore remote communication with the system is done only in nearly real time, it is not expected to be inconvenience since data is typically integrated and recorded in each hour.

The second step was creating a file system for storing the files. Basically two types of file systems are available in the code libraries to be developed with Rabbit 3000 series: FS2 and FAT. The file allocation table (FAT) is considered the industry default and its directory structure can be accessed both by DOS and UNIX systems. The FS2 file system, although, is adopted only in Rabbit embedded systems and allows us, for example, to rewrite only parts of a file, to use simultaneously two or more memory devices like flash or SRAM, partitioning devices etc. One main limitation of FS2 is the maximum number of files which is 255 and the impossibility to use names in the files and to create directories: files are identified by a number. In principle FAT would be the best choice since it allows us an unlimited number of files and it is generally compatible with personal computers. In the specific
case of Rabbit 3010, the FAT file system cannot be used, it can be used only in other Rabbit 3000
devices which already have an embedded memory card reader [7].

The algorithm created up to now has basically the following procedures: a) file system
initialization; b) partition creation; c) create a testing file and read it to check if it is successful; d) the
pointer is moved to the file which will contain the data; e) a file is created for each day and both the
count rate and current time and date are recorded.

4. Final remarks
We proposed and started the development of an embedded system for counting, correlation and
recording data from a multidirectional muon detector which can be applied to a vast range of scientific
applications, especially when data needs to be collected remotely and when a TCP/IP network is
available.

Up to now we implement a preliminary counting and recording system and a HTML interface for
data monitoring remotely. The file system used in the current system allows a maximum of 255 files
and therefore shows up a limitation for the continuous and uninterruptable data recording. The
replacement of the current FS file system by a FAT file system will allow a long term data recording
since there is no limitation in the number of files.

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