Detecting cosmic rays using CMOS sensors in consumer devices

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Since the time of Victor Hess and his balloon flight that demonstrated that cosmic rays increased with altitude, new detection methods have become widely available to be used on current day flights. One such method is to utilize CMOS sensors with long duration exposures. During the exposures the CMOS sensor is exposed to cosmic rays which then leave a track. This phenomenon is caused by the CMOS's inability to distinguish between photons of light and charged particles. Such tracks can then be separated from the CMOS's background noise and classified.

I. Introduction

Cosmic rays are not actually rays. Cosmic rays are merely charged particles. This radiation, for the most part, consists of protons. Prior to interaction in our atmosphere these particles are considered primary cosmic rays. Once there is an interaction with our atmosphere a shower is created. These particles that are created are considered secondary cosmic rays. These secondaries tend to be gamma rays, muons, protons, pions, and elections. At ground level it is predominately muons that are detected.

II. Common Detection Methods

A. Citizen Scientist Grade

There are quite a few common methods of detection of cosmic rays for citizen scientists. These include cloud chambers, scintillator panels and CMOS.

1. Cloud Chamber

One of the easiest methods is the use of a cloud chamber. Cloud chambers consist of some clear sealed container that has a felt bottom and is supersaturated with alcohol. Under this chamber is dry ice to cool the alcohol. When ionizing radiation enters the chamber the alcohol vapor condenses along the track of the radiation making it visible.

2. Scintillator Panels

Scintillators are materials that, when excited by ionizing radiation, release energy in the form of light. This light is then converted into current by a photodetector and then can be recorded electronically. Using a single panel will allow detection of ionized particles, however, it does not give any information in regards to direction or velocity. By introducing a second panel it becomes possible to determine both. It is important to note that the accuracy of the velocity vector depends on the distance between the panels and the size of the panels. This means that the larger the panels are the farther apart they will need to be. Figure 1 shows

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a rough estimate of the cone that both scintillator panels will see a single cosmic ray from. By increasing the distance between them the cones theta angle decreases.

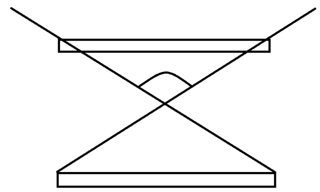

Figure 1.

3. CMOS Sensors

CMOS sensors are by far the most readily available option for citizen scientists to detect cosmic rays. CMOS sensors detect cosmic rays much the same way they detect light. When a cosmic ray enters the CMOS sensor the cosmic ray deposits a charge onto the sensor itself. If the sensor is not exposed to any sources of light, the cosmic ray will leave a track behind in the resulting image. It becomes important to mention that the CMOS sensor has to be capturing a frame at the time that the cosmic ray enters the CMOS sensor. If it is not the sensor will not detect the cosmic ray. It is also important to note that CMOS sensors are much smaller than other methods of detection (.15 cm^2) and therefore also have fewer cosmic rays enter the sensor. This means that the overall livetime of the sensor needs to be as near 100% as possible. Figure 2 Shows the basic concept of how a cosmic ray enters the CMOS sensor and how the CMOS sensor reads it as light. //

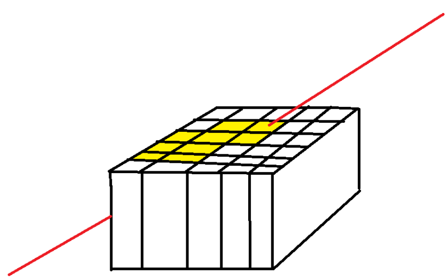

Figure 2. Red line indicates the path of the cosmic ray. Yellow indicates pixels triggered by the cosmic ray.

DECO The Distributed Electronic Cosmic Ray Observatory (DECO) (http://wipac.wisc.edu/deco) is an application that can be installed on Android powered devices. The goal of the project is to be able to detect cosmic rays throughout the world and give citizen scientists the ability to process data that their own phones produced in a user friendly manner.

III. Method Used

A. Choice of CMOS

Due to the ease of use, access and analysis CMOS are an optimal tool for detection of cosmic rays. Also due to the small size and therefore weight CMOS are an optimal choice for use on high altitude balloon launches. For this experiment a GoPro Hero HD was used (sensor area of .24 cm^2)[1] as the CMOS sensor for detection. The main alteration to the GoPro was the addition of tape to the GoPro case's lens. This was to prevent light from entering the CMOS and contaminating the data. Since the GoPro isn't looking at anything specific it can be mounted anywhere inside the box[a].

[a]This was not significantly tested to see if the mounting position had any correlation to event rates. However, at ground level cosmic rays are more vertical. The scale between the two is according to $cos^2(theta)$ theta being the zenith angle

B. Video Vs Still Captures

Livetime is one of the largest concerns when it comes to detection of cosmic rays. Due to this concern it became paramount to determine the best way of increasing the livetime. Depending on the device used, livetimes using still image capture hovered around 5%. This means that 1 out of every 20 events would be detected. Since the CMOS has relatively small surface area there is a low rate of cosmic rays that enter the sensor. By then only being able to detect 1 out of ever 20 events meant that CMOS would be nearly useless on 2 hour flights. A breakthrough came when it was realized that by switching to video mode instead of still image capture the live time increased from 5% to upwards of 95%. This, however, came at the cost of resolution. 8 MP images were reduced to 2 MP frames. This resolution degradation was deemed reasonable due to the extreme increase in livetime and thereby viability of use on a standard duration balloon flight.

IV. Results

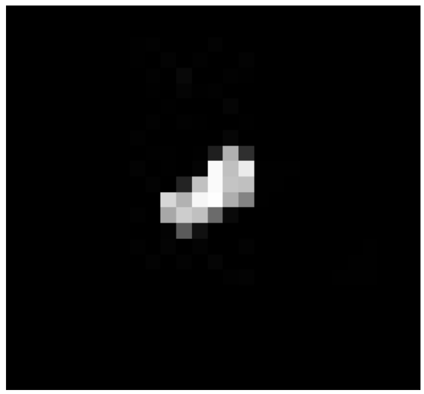

Figure 3. GoPro cosmic ray capture

Utilizing the GoPro configured as stated above results have been fairly strong. Three flights have been conduced with this system as a secondary payload. When the first flights data was processed using a basic threshold cuts. This is done by scanning through all of the captured frames and looking for pixels that R, G or B values are greater than this threshold. After this cut each image was visually checked to verify that the event is valid. Figure 3 shows . Due to the lack of GPS on GoPros it was not possible to correlate altitude to rate of events detected.

V. Conclusion

The main goal of using the GoPro was to demonstrate the viability of CMOS in a video mode. This was demonstrated, however the resolution of the frames was worse then initial thought. The issue with this will become apparent when the tracks are analyzed. Since the analysis is done using linear regression the more data points available the more accurate an approximation will be. If, however, the method was to be used purely as a detection method resolution will not matter.

VI. Future Work

A. Raspberry Pi & Data Logging

One of the main issues with using the GoPro is the lack of interaction with what the camera is doing. Digital cameras tend to have a lot of post processing and filters built into the firmware. This can lead to events being blurred out. This occurs because the camera determines these cosmic rays as noise from the sensor and wants to eliminate that noise. A second issue is the lack of EXIF data that is being written to the video. Since cosmic ray rates vary with altitude it is extremely important to have the altitude stored within the video so that the rates can be correlated to those altitudes.

One of the best and most affordable ways of achieving this is through Raspberry Pi and Raspberry Pi

Cams. By using these micro computers GPS can be tied into the image capture itself. Also since the image capture program is completely controlled by the user it is possible to prevent image filtering from taking place.

B. Long Duration Exposure

The best way to fix the resolution and data rate issue that currently befalls the video capture method is to return to still image captures. However, in order to be able to do this it becomes extremely important to again consider sensor livetime. To increase the livetime it became apparent that long duration exposures are necessary. One option for longer exposures lies in the Android operating system. With the release of android 5.0 it will become possible to set exposure times up to 2 seconds. To utilize this a new version of DECO is currently being developed at the Wisconsin IceCube Particle Astrophysics Center. This new version is capable of nearly 50% live time and would make cellphones a largely viable method of detecting events on high altitude balloons. For this reason DECO is highly recommended for future high altitude flights.

C. Track Analysis

If still image capture become viable it become possible to do track analysis. Giving some known dimensions of the sensor and the orientation of the sensor it becomes possible to trace back the direction that the cosmic ray entered the CMOS from. This also allows for classification of events based off of their image. For instance an event that goes straight through the sensor and creates a "spot" will be unable to give any track information. However, an event that takes a worm like path through the CMOS can be identified as an electron worm. There are many different ways the events can be classified the only necessity is higher resolution.

Acknowledgments

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References

[1]'GoPro HD Hero Camera Specs - CNET' Available: http://www.cnet.com/products/gopro-hd-hero-camera/specs/.
[2]Groom, D., *Cosmic Rays and Other Nonsense in Astronomical CCD Imagers*, in Scientific Detectors for Astronomy, 2004.