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A STAR CAMERA ASPECT SYSTEM SUITABLE FOR USE ON BALLOON EXPERIMENTS

S.D. Hunter, R.G. Baker
Code 662, NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771 U.S.A.

1. Introduction. We have designed, built and flown, on a balloon borne experiment, a star camera aspect system. This system was designed to provide offset corrections to the magnetometer and inclinometer readings used to control an azimuth and elevation pointed experiment. The solid state camera used is a General Electric TN2500 CID camera with a Nikkon Noct-Nikkor 58mm f/1.2 lens. The camera is controlled by a Texas Instrument TMS 9995 microprocessor, including commandable exposure and noise rejection threshold, as well as formatting the data for telemetry to the ground. As a background program, the TMS 9995 runs the aspect program to analyze a fraction of the pictures taken so that aspect information and offset corrections are available to the experiment in near real time. The analysis consists of pattern recognition of the star field with a star catalog in ROM memory and a least-squares calculation. The hardware, software and star catalog which make up this system are fully described in reference 1. This paper describes the performance of this system in ground based tests and as part of the NASA/GSFC High Energy Gamma-Ray Balloon Instrument (2).

2. Ground Tests. Ground based tests were performed during 1983 and early 1984 to check the operation of the star camera and aspect program. The TN2500 camera provides an 8 bit digital output, in addition to a standard analog output, which made the camera easy to interface to the microprocessor and provided a convenient measure of star intensities. In the following, ADC counts or counts refers to the digitized output of the pixel or pixels illuminatd by a star.

The intensity of several observed stars in ADC counts for a five second exposure (integration time) as a function of visual magnitude is shown in Figure 1. Each data point represents a lower bound to the intensity because some of the light from a star can fall on the inactive area of the CID chip between the pixels. Stars of magnitude fainter than about 3 illuminate single pixels whereas brighter stars illuminate several pixels. Their intensity is the sum of the response of all the pixels comprising the star image. The observed intensity of brighter stars was fairly constant except for atmospheric effects. The intensity of dimmer stars varied much more dramatically as the star image partially or completely fell on the inactive area between pixels.

For the ground tests, the CID chip was cooled to about 5°C with a thermo-electric cooler. This reduced the thermal noise by a factor of two to between 5 and 8 counts. Thus, from Figure 1, it can be seen that, for a five second exposure, stars of magnitude six were detected with a signal-to-noise ratio of about one. A signal-to-noise ratio of one and the inclusion of a few noise pixels, which are indistinguishable from star images, does not affect the operation of the aspect program other than to slow down the calculation. The aspect program, when provided with the approximate altitude and elevation of the camera, was able to calculate the aspect information for the observations.

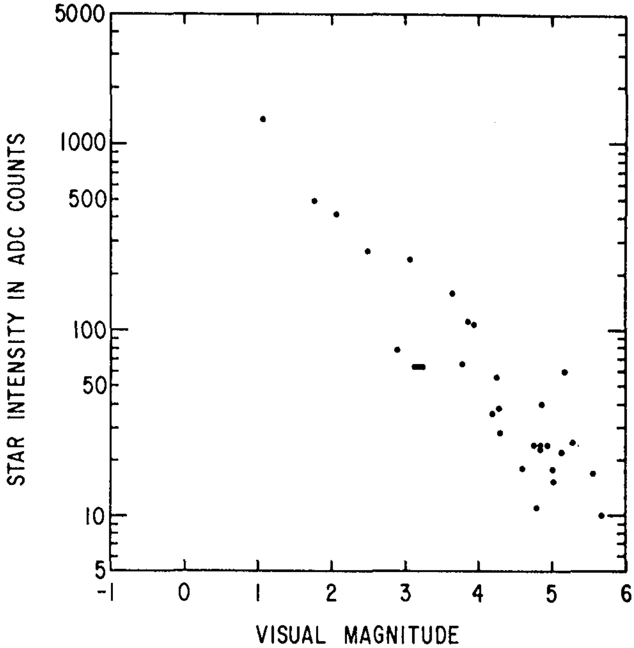

Figure 1 -- CID camera star intensity as a function of visual magnitude for a five second exposure.

3. Balloon Flights. The first balloon borne experiment to use this camera aspect system was flown on May 9, 1984. The first two hours of the flight were dedicated to tests of the aspect system. Three regions of the sky were observed in the constellations of Hercules, Ursa Major and Aquila. During the Aquila observation, 78 pictures were taken. The star Altair (53-x Aqu., Mv = 0.77) was seen in all the pictures. It was so bright that all the pixels which formed the star image were saturated. The star 50-γ Aqu, Mv = 2.7 was seen in almost all the pictures. Its single pixel intensity varied between 25 and 70 counts. The star 60-β Aqu., Mv = 3.7 was seen in only three pictures. The observed intensity was 10, 22 and 33 counts. The only dimmer star observed was 75-Her., Mv = 4.2, which had an average observed intensity of about 8 counts. The signal to noise ratio for these observations was about one although the thermo-electric cooler was not needed due to the low temperature at balloon altitudes.

The azimuth-elevation pointing system of the balloon experiment held the desired azimuth pointing direction within a 0.5° deadband. The elevation drive was powered off during the camera tests. Within the azimuth deadband the experiment moved with an azimuthal velocity between 0.08 and 0.1 degrees per second at all times. This azimuth velocity produced an effective exposure of about 0.5 second per pixel since the star images were smeared over several pixels. Taking into account this effective exposure, the above intensities are consistent with the ground based results shown in Figure 1 if scaled by a factor of ten to correct for the difference between the 0.5 second effective exposure and the 5 second ground based exposure.

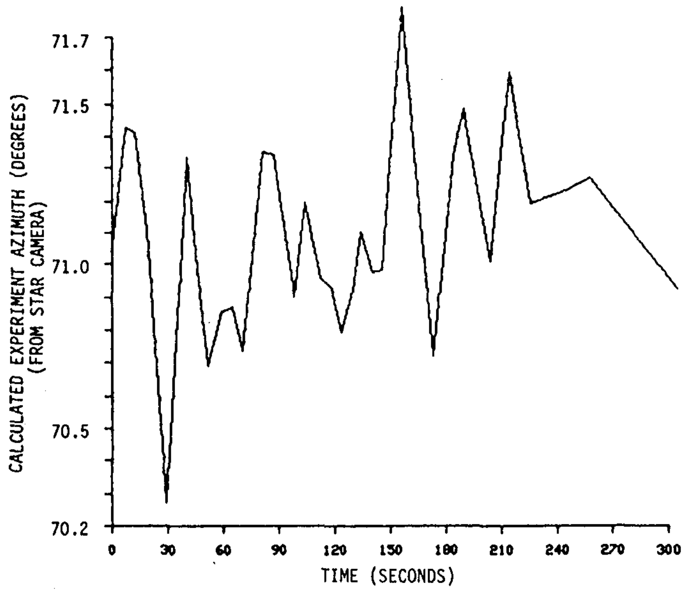

Figure 2 -- The azimuth angle calculated for the experiment by the aspect program.

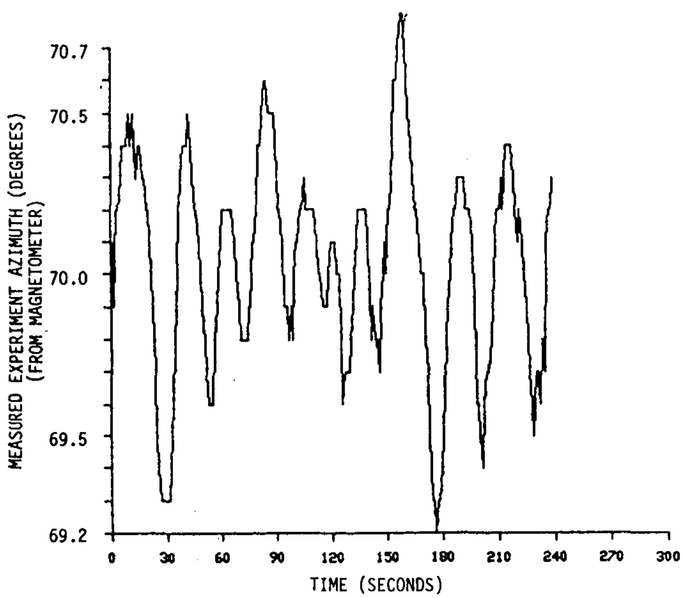

Figure 3 -- The azimuth angle measured for the experiment by the magnetometer.

During the balloon flight the aspect program was not able to analyze any of the pictures because only one in about twenty pictures is processed by the program, although all pictures are telemetered to the ground. For a picture to be processed by the aspect program, it must contain at least three stars, real or noise. To complete the analysis and determine the aspect information, the picture must contain at least three real stars. Noise pixels are treated as stars without a match in the star catalog and are ignored by the program.

During post flight analysis of all the pictures the aspect program was able to analyze the pictures that contained three real stars. The aspect program was modified to complete the analysis if only two real stars were found. The aspect information determined by this analysis is not as accurate as in the case when three or more stars are observed.

Part of the results of this modified analysis, the calculated azimuth of the experiment, is shown in Figure 2. The exposure time for the observations used for Figure 2 was five seconds for the period labeled 0 to 170 seconds and ten seconds afterward. Figure 3 shows the azimuth of the experiment as measured by the pointing system megnetometer for the same time period as shown in Figure 2. It can be seen, by comparing these two figures, that the azimuth calculated by the aspect system shows the same time variations as the azimuth measured with the magnetometer except for a discrepancy of about one degree. This discrepancy between the measured azimuth and the azimuth calculated with respect to the inertial star frame provides the offset correction needed to account for uncertainties in the latitude and longitude of the balloon, the alignment of the magnetometer and the deviation angle of the magnetic field. Similar analysis of th elevation angle would provide the offset correction for the inclinometer

4. Summary. We have shown that our aspect system can provide accurate near real time aspect information for balloon experiments if a factor of two to five improvement in the stability of the balloon experiment can be made to reduce smearing of the star images. In addition, if the calculated offset correction is averaged over several analyzed pictures, the offset correction can be determined with an accuracy of at least 0.1°.

5. Acknowledgements. S. D. Hunter also held a National Research Council Associateship at NASA/Goddard Space Flight Center and was affiliated with the University of Maryland during the period of this work. We thank the National Scientific Balloon Facility, Palestine, Texas, for their flight support.

6. References.

1. A Star Camera and Aspect Determination System for Balloon Borne Payloads, R.G. Baker and S.D. Hunter, NASA X Document, in preparation.
2. High Energy Gamma Ray Balloon Instrument, D.J. Thompson, et al., paper OG9.2-15, these proceedings.