AN OPTICAL ASPECT SENSOR FOR THE GAMMA RAY IMAGING DEVICE

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ABSTRACT

The function and operation of the aspect sensor for the Gamma Ray Imaging Device (GRID) is presented. Each of the aspect sensor subsystems and how they work together to determine pointing aspect of the GRID telescope is discussed. A description of the sun simulator used in laboratory testing is included as well as the methods for testing the aspect sensor in both the laboratory and in the full scale GRID mock-up.

INTRODUCTION

The Gamma Ray Imaging Device (GRID) is a γ-ray telescope [1] mounted on a balloon platform in order to observe solar activity in the γ-ray range during the 1991 solar maximum. GRID uses an optical aspect sensor to sense the direction that the telescope points relative to sun center with an rms (1 sigma) error of 0.2 arcsecond in azimuth and elevation; accurate aspect data is critical for the reconstruction of the γ-ray images. In addition, the sensor provides an error signal to the pointing gimbals in order to correct deviations in the pointing angles of the telescope. The GRID system is seen in Figure 1.

The aspect sensor determines the azimuth and elevation angles by using a lens/filter assembly to cast an image of the sun onto a detector plane [2]. The detector plane consists of four linear photodiode arrays arranged in a cross pattern. Thus, knowing the shape of the sun, the edges of the image (solar limb crossings) determine the position of the solar image on the detector plane.

Figure 1.

[1]

The photodiode arrays are scanned to determine the exact location, with respect to the optical axis, of each solar limb crossing. Using the crossing data, an on-board microprocessor calculates the position of the solar image center with respect to the optical axis. The azimuth and elevation pointing angles are then determined by using the x-axis and y-axis coordinates of the image center and the length of the telescope.

A data set consisting of up to four solar limb crossing locations is recorded every 4 milliseconds. The on-board microprocessor
determines the pointing angles from an average of ten data sets. Thus, the pointing system receives fresh azimuth and elevation pointing angles every 40 milliseconds [2]. The field of view of this aspect system will accommodate radial pointing displacements relative to sun center of up to 13 arcminutes and permit acquisition from displacements up to 22 arcminutes.

Optical Aspect Sensor

The optical aspect sensor consists of an optical telescope, a detector plane, four solar limb detectors, an 8-bit microcontroller, and two 8-bit parallel ports for communication with the recording computer and the pointing system. The optical system consists of a 6 cm diameter, 5.2 m focal length plano-convex lens located on the front end-plate of the GRID canister and the photodiode detector assembly located on the back end-plate. Figure 2 shows the optical telescope, end-plates and the solar image produced by the lens. The solar image cast on the detector plane is 48 mm in diameter.

![EXPLODED VIEW OF GRID TELESCOPE](image)

Figure 2. Optical Telescope

The photodiode detector consists of four identical photodiode line arrays each containing 1024 15-micron pixels with a total active area of 15 x 0.015 mm (11 arcminutes x 0.6 arcseconds) [2]. Each of these commercially available devices (EG&G Reticon) [3] provides a 1-dimensional positional representation of the solar image in video format. One pair of arrays overlays the other pair in the form of a symmetric cross, thus defining an x - y coordinate system on the detector plane as shown in Figure 3 [1]. The center of the solar image can be determined from the known radius of the solar image and two or more solar limb crossings whose current positions on the x - y coordinate plane are known after the arrays are scanned. Even though there is a 7 mm (4 arc second) wide dead zone in the center of the cross due to the inactive region at each end of the arrays: this detection method can measure radial displacements up to 13 arcminutes 45 degrees off any axis and up to 15 arcminutes on any one axis.

![GRID Aspect Sensor](image)

Figure 3. Detector Plane

In order to overcome the obscuration of one photo-diode array by its orthogonal counterpart, a single chip cross detector is being developed containing the two axes in one package. This package could consist of four orthogonal linear (2048 dice supplied by EG & G Reticon) [2,3], one dimensional arrays but mounted in a planar package with the angle between them precisely set at manufacture with a fiducial etched in the silicon substrate. With this design, the range of the sensor can be extended to over 16 arc minutes (one half solar diameter) with no dead zone. A plan view of the cross detector is shown in Figure 4. Two cross detectors will be used in the telescope for complete redundancy.
Measurement of the location of the solar limb is simplified by the fact that a change in brightness of the solar image over the limb is large compared to the 10% pixel-to-pixel nonuniformity between adjacent pixels. This change in brightness will occur over 2 arcseconds or 4 pixels. Therefore the nearest 0.5 arcsecond limb pixel can be identified by a binary comparison of pixel output with a fixed threshold. The rms error in this process (without interpolation) is 0.15 arcseconds. However, this error will increase when the limb is not orthogonal to the diode array. Compensating analysis options include averaging of successive measurements (since pointing is likely to vary smoothly on subsecond time scales) and post-facto compensation for the relative pixel sensitivity.

The video signal output of each array is processed by passing it through a sample-and-hold circuit and then through an envelope detector. This process smooths the signal and eliminates sensing errors. The solar limb detector circuits (SLDCs) determine the location on the photodiode array where the limb crossing occurs by counting the number of elapsed clock cycles between the start of the scan and the time that the processed video signal becomes greater than the threshold level. This process gives the number of pixels from the edge of the array to the limb crossing. Each SLDC can store one rising edge crossing and one falling edge crossing. This feature gives the aspect sensor the ability to determine if there are any dust particles or other such obstructions affecting the image. The SLDCs store this count number in a buffer until the microprocessor reads the count and places it in memory. After the microprocessor reads all of the crossing data, the SLDCs are cleared in preparation for the next scan.

The solar limb detectors are connected via address, data, and control busses to an M68HC11A8 microcontroller. This microcontroller is a Motorola 6800 based processor with on-chip features including an 8 channel analog to digital converter, a serial communications interface unit, a real time counter with input capture pins, and 5, 8-bit parallel ports [4]. The M68HC11A8 resides on an M68HC11EVB evaluation board which has an on-board operating system. Communication between the user and the evaluation board is provided by a serial link to a dummy terminal [5]. The bus system linking the microcontroller and the SLDCs allows the microcontroller to control simultaneous scanning of the four photodiode arrays and their respective SLDCs, and to gather the limb crossing information as it is needed. The bus system also allows the microcontroller to transmit both the 4 millisecond limb crossing data and the 40 millisecond pointing angle data to the storage computer and pointing system respectively.

Two 8-bit unidirectional parallel ports are used to transmit data to the storage computer and the pointing system. The first port, known as the telemetry port, sends 8 bytes of data consisting of the four limb crossings in 16-bit integer format. These numbers represent the number of the pixel at which the limb crossing occurred. This data is transmitted at the rate of 8 bytes every 4 milliseconds. The second port, known as the aspect port, sends the x and y axis coordinates of the center of the image to the pointing system in a 16-bit 2's complement format. The 2's complement format represents the position of the limb crossing, with respect to the coordinate center, in units of 10 microns.
This information is sent at the rate of 4 bytes every 40 milliseconds.

The aspect sensor operating system is written in M6800 assembly language. The operating system provides the user with the options of running the aspect sensor in three different test modes and one operating mode. The operating system also provides user control at the dummy terminal through the serial port on the M68HC11EVB. Information regarding the operation and status of the aspect sensor, as well as the solar image coordinates, is displayed on the terminal screen. This system allows friendly user interface with the sensor through the use of menu driven inputs.

Testing

A sun simulator is required to test the aspect sensor in the laboratory. The purpose of the sun simulator is to produce a 48 mm diameter image, on the detector plane, bright enough for the detectors to sense. This is accomplished by using a 300 Watt light source which projects light through a circular pinhole serving as the object source for the simulator. The size of the object source must be unreasonably small in order to produce a 48 mm image so a bi-concave lens is used to transform a large pinhole into a small virtual object source. This increases the power throughput of the simulator while still providing the correct image size. A plano-convex lens is added to collimate the light to 0.5 degree divergence angle (the same as the sun) thus causing the virtual object source to appear on the image plane of the telescope as a 48 mm diameter circle. Figure 5 shows a diagram of the sun simulator. The circular pinhole is mounted on an x-y translational optical stage. This stage enables the image to be moved in small graduated increments on the order of 10 microns in the x - y image coordinate system.

Before testing of the aspect sensor can begin the optical axis of the lens must be aligned with the optical axis (origin) of the detector arrays. This is accomplished by using the sun simulator with the circular pinhole replaced by a cross-pattern pinhole. The simulator will now produce the image of a symmetric cross on the detector plane. The alignment is performed by removing the telescope lens/filter assembly and then moving the cross pinhole on its optical stage until the image is directly over the photodiode arrays. This condition is achieved when the output of the aspect sensor is zero. Next the lens/filter assembly is replaced on the telescope causing the image to shift due to the misalignment. The lens/filter assembly is now moved on its optical stages until the aspect sensor again reads zero.

Testing the aspect sensor in the laboratory involves moving the simulated sun in known increments and recording the data at each increment. Both axes are are tested in this manner. This procedure is repeated ten to fifteen times. From this data the accuracy, rms error, and resolution can be determined.

Conclusion

In summary, the use of an optical aspect unit based on four 1-dimensional photodiode arrays provides measurement of solar offset pointing with sufficient resolution and field of view to meet the requirements of GRID. Determining the offset of the solar image is done quickly and accurately with readily available components. The aspect sensor provides two types of data: one set for post-facto processing and one set for real time aspect sensing. A user
A friendly operating system is provided to control the operation of the aspect sensor and to collect the data sets. Construction of the cross-pattern detector chip will eliminate the dead zone and increase the field of view of the device.

Future work will include mounting the aspect sensor in a full scale mock-up of the GRID telescope complete with azimuth and elevation gimbal control. The telescope will be mounted on the roof of Broun Hall at Auburn University with the purpose of tracking the sun. Testing the aspect sensor in this manner will prove conclusively that it will provide the correct aspect solutions and accurate pointing error signals under conditions similar to those experienced during the actual flight.

References
2. ---, Final Report, NASA contract NAS S-30566566