Mem. S.A.It. Vol. 79, 958

Memorie della

Optical sensors for attitude control systems on balloons

F. Nati

Physics Department, University of Rome La Sapienza, P.le A. Moro 2, 00185 Roma
e-mail: `federico.nati@roma1.infn.it`

Abstract. A brief review of optical devices used on balloon borne experiments for attitude control is given. I focus mainly on systems used for telescopes aimed to study the microwave emission of the sky, in particular the Cosmic Microwave Background and its features.
Different methods have been developed due to different flight conditions and scientific goals. We explain the advantages of the several sensors and optical devices with respect to specific requirements, i.e. night or daytime, fast spinning payloads or high resolution telescopes.
The most common solutions are star sensors and sun sensors. They make use of CCD cameras or photo-diodes arrays, coupled with mirrors or lenses, depending on the specific experiment.

Key words. Optical sensors – Attitude control systems – Balloon borne telescopes

1. Introduction

Attitude control systems (ACS) perform all the operations needed to control pointing or any other motion of the payload. An ACS makes use of motors, often brush-less torque motors placed in the azimuthal pivot, and other kind of actuators, i.e. linear actuators. ACS is a control system which needs feedback. It requires input from position and motion sensors. They can be angular digital encoders or gyroscopes, sensitive to variations of angular speed.

In order to control the pointing we need a reference frame. But of course the payload is suspended, which makes things quite difficult. But we can look at the sky, and use it as a reference frame somehow. Usually experiments mount optical star sensors and/or sun sensors. These devices can give the orientation of the payload with respect to the sky objects. Then, by combining these information with other sensors, such as GPS, magnetometer, gyroscopes, encoders, LVDTs, we can solve the pointing solution with the desired accuracy. ACSs must work also if link with ground stations is lost, and they must be very reliable systems.

2. Sensors development and implementation

The development of the sensors used in in ACSs normally depends from the specific experiment. Every single payload has different specifications about pointing accuracy, sample frequency, data rate, scanning strategy and speed, day or night conditions, not to mention all the mechanical issues. These requirements vary quite a lot among the experiments, even for experiments devoted to similar scientific goals, and even for the same experiment when used in different conditions. So, this is why at the moment there is no complete off-the-shelf solution suitable for every experiment.

As an example, on BOOMERanG (de Bernardis, 1999) for the night-time flight there were a set of 3 vibrating gyroscopes, a flux-gate magnetometer, and a CCD camera with real-time star position measurement which provided attitude reconstruction to 1 arcmin. For the same payload in the day-time flight there were a coarse and a fine sun sensor, a differential GPS, and a set of 3 laser gyroscopes. Again, the system was able to reconstruct the attitude better than 1 arcmin.

2.1. Optical sensors

2.1.1. Star sensors

Optical sensors are the most used way to look at the sky and reconstruct the orientation of the payload. Among these, star sensors are the most accurate. They divide mostly into star cameras, which use CCDs, and fast star sensors, which use photo-diode arrays. The receivers are coupled with some optics, usually mirrors or lenses. These devices are complex systems which require a dedicated on-board computer running a sophisticated software for star recognition and pointing reconstruction. The algorithms used are optimized for on-board real-time solutions or offline, slower but more accurate solutions.

Star sensors allow high pointing accuracy, up to one arcsecond. The number of visible stars limits the accuracy. This is a function of

- the field of view
- the optics diameter
- the integration time
- the receivers noise and sensitivity
- the atmospheric noise

As far as optics is concerned, we can use mirrors or lenses. Mirrors are usually used for fast sensors, needed by spinning payloads at high angular speed. The higher the speed, the lower the integration time. So large mirrors, i.e. 40 cm of diameter, can provide enough flux in order to have good signal to noise ratio and easily detect high magnitude stars (i.e. magnitudes up to 8 or 9). The main disadvantages of using big mirrors are size and weight, especially considering the whole telescope when a long focal length (i.e. 2000 mm) is used. But they are quite simple in their optics and mechanics, and should not require refocusing at float. On the other hand, lenses are suitable for more compact systems, when lower diameter are allowed. Lenses usually need auto-focus at float. Of course the suffers from daylight so they work much better during the night. They may produce high data rates.

Solutions with photo-diodes arrays are suitable for fast sensors, i.e. linear arrays work very well for spinning payload. These sensors are very low noise and require simple and fast readout. On the other hand, CCDs allow high sensitivity and resolution, but need a computer or other frame grabber, and have slower readout. They also need pressure vessels and thermal control.

2.1.2. Sun sensors

Speaking about optical sensors, we must remember that also the sun position can give a useful reference frame. Of course these devices can work only when the Sun is above the horizon. They make use of CCD, often coupled with pinhole or slit cameras.

As an alternative or as a complement we can use 4-sensors sun tracker, a sensor that can follow the Sun. The system is feedback-based and drives two motors making use a four sensors photo-diodes. When the image of the Sun moves away from the center, the current produced by the corresponding sensor will activate the corresponding motor putting back the tracker in position. Then two digital encoders (which measure the angles) and GPS information (time and position) give the direction of the Sun.

3. Examples from real experiments

3.1. Fast spinning payloads

Some experiment requires relatively high scanning speed. If also high resolution is re-

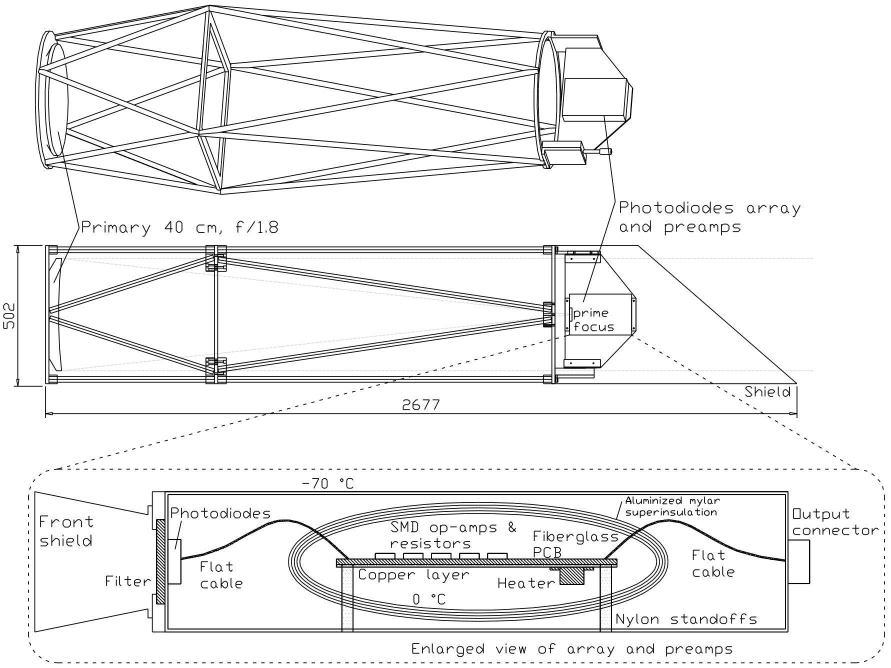

Fig. 1. Archeops Fast Star Sensor

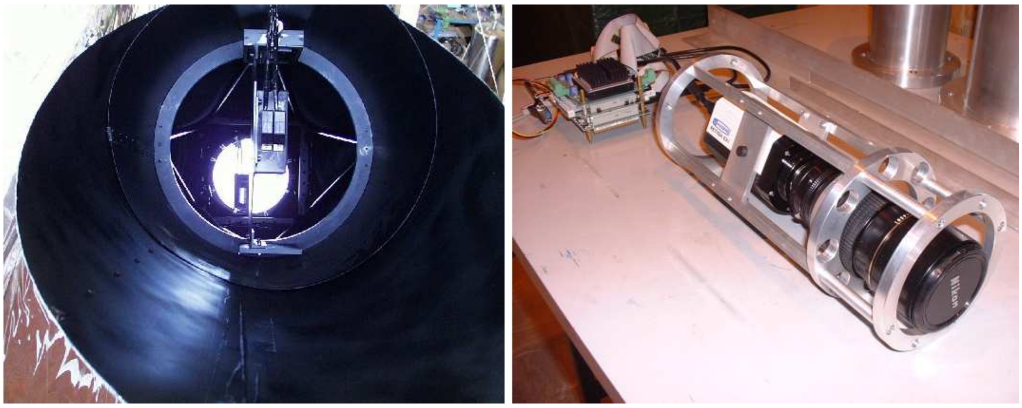

Fig. 2. Left: Photo of the Archeops Fast Star Sensor - Right: OLIMPO CCD Star camera

quired then it becomes critical to develop a specific sensor for pointing reconstruction. The Archeops experiment made use of a 10-12 arcmin resolution telescope (Benoit, 2001; Macias-Perez, 2007) mounted onto a payload which was spinning at a constant angular speed of 2-3 rpm. It flew during the arctic night. We had to develop and build a specific star sensor which had to match the main requirements of being very fast and sensitive enough to reconstruct pointing with about 1 arcmin accuracy (for details see Nati, 2003; Nati, 2001). This solution worked perfectly, allowing a pointing accuracy within requirements. Such a solution suffers from some disadvantages. Firstly it is quite big (see Fig. 1) and heavy if compared with small lenses solutions.

3.2. High resolution telescopes

We developed a star camera for the OLIMPO experiment. When not too high scanning speed is required but high resolution and pointing accuracy is critical then the best solution is coupling a high sensitivity CCD camera with a proper lens system. We are using a Qimaging Retiga Exi CCD camera connected with a PC104 (266 MHz processor running Linux OS). The system is provided by the CNR of Firenze (A. Boscaleri).

The PC-104 computer is mounted inside the star camera pressure vessel. The computer runs the software that processes the CCD images. The computer can also command the stepper motors for auto-focus, and regulates the lens temperature.

The system sends the right ascension and declination of the center of the image to the flight computer, which will communicate with the TM and the data storage system.

As far as the pointing reconstruction algorithm is concerned, see The Pyramid star identification technique from Mortari (2004). A similar system was developed for the Blast experiment (Rex, 2006).

Acknowledgements. Thanks to Giovanni Romeo, Andrea Boscaleri, Enzo Pascale for useful information and explanations.

References

Benoit, A. et al., 2001, Astropart. Phys., 17/2, 101

de Bernardis, P. et al., 1999, New Astron. Rev., 43, 289

Macias-Perez, J.F. et al., 2007, A&A, 467, 1313

Mortari, D. et al., 2004, INIST-CNRS, 51/3, 171

Nati, F., 2001, Degree Thesis, University of Rome La Sapienza

Nati, F. et al., 2003, Rev. Sci. Instrum., 74/9, 4169

Rex M., Chapin E. et al., 2006 `arXiv:astro-ph/0605039v1`