APS-BASED MINIATURE SUN SENSOR FOR EARTH OBSERVATION NANOSATELLITES

Marcello BUONOCORE, Michele GRASSI and Giancarlo RUFINO
Dipartimento di Scienza e Ingegneria dello Spazio - Università di Napoli "Federico II"
P.le Tecchio 80, 80125 Napoli, Italy
Phone: +39 081 7682217 / Fax +39 081 7682160/ E-mail: grassi@unina.it

ABSTRACT

This paper describes the research activity at the university of Naples concerning the study and prototype development of a low-cost APS-based miniature sun sensor for micro/nanosatellites attitude determination. In the paper the sensor architecture is described, as well as the development of its prototype and of the facility for laboratory testing. Part of the project is also the development of a numerical simulator of the sensor operation. The simulator is used to predict the sensor performance and to simulate the laboratory test of the prototype. Preliminary results show that a final accuracy better than 1 arcmin is achievable.

1. INTRODUCTION

Thanks to the evolution of MEMS (Micro-Electro-Mechanical-System) technology and micro-electronics, a number of scientific and technology demonstration missions based on the use of micro/nanosatellites have been flown by universities and space agencies. Earth remote sensing missions have been proposed and carried out, and particular efforts are being done to fly high-resolution sensors on board microsatellites. More recently, a number of studies have been performed to fly several nanosatellites in formation for remote sensing applications. The U.S. National Aeronautics and Space Administration (NASA) and Department of Defence (DOD) are studying the use of microengineered systems in space. Jet Propulsion Laboratory (JPL) uses this technology to develop “smaller, faster, cheaper” space systems for interplanetary missions. With NASA “New Millennium” and “X-2000” programs, coming years will see the development of many 10-kg spacecrafts equipped with micro-devices [1]. In 1997 the European Space Agency (ESA) identified micro/nanotechnologies as the critical technologies of future space programs [2]. Among several issues, one concerning the development and integration of micro-accelerometers, micro-gyroscopes and high-performance CCD-based sensors for navigation was identified. In fact, autonomous navigation is one of the most demanding requirements in modern aerospace systems. Autonomy means collecting a number of flight information and, therefore, integrating a number of sensors on-board the vehicle. In this ambit, the use of micro-technologies is a promising solution. Recently a number of studies have been performed to miniaturise attitude and navigation sensors. In particular, the availability of APS (Active-Pixel-Sensor) technology (in which detector and electronics are integrated on a single chip) has led to the development of advanced star sensor and miniature sun sensors for attitude determination [3-5].

In this framework, the research team at the University of Naples is developing the prototype of a miniature, low cost sun sensor. The sensor is studied in the framework of a coordinated university project, funded by the Italian Space Agency, for the design and development of four nanosatellites flying in formation for technology demonstration and remote sensing applications. Concerning satellite formations, one of the most demanding task is the study and operation of formation navigation and control. To this end, on the basis of the experience already gained with the development of a CCD-based star sensor prototype, the university team is developing the sun sensor prototype. This paper describes the sensor architecture, the sensor simulation, the sensor prototype and laboratory test facility development.

2. SENSOR ARCHITECTURE AND OPERATION

The two-axis miniature sun sensor has a field of view of 90° and an estimated final mass of about 300 g. The sensor architecture is based on an APS detector, which is an array of 512x512 25-mµ active pixels (STAR250, Fill-Factory®), and on a mask, consisting of a number of equidistant tiny holes (with diameter of 0.1 mm), placed on the top of the APS at a distance of about 6 mm (Fig.1 shows the mask schematic drawing). The sun light passes through the mask (see Fig.2 in which only one hole is shown). Images of the sun are formed on the detector plane allowing multiple measurements of the sun line direction to be performed by evaluating each image centre coordinates with an effective centroiding algorithm. Figure 2 shows the centroiding concept.

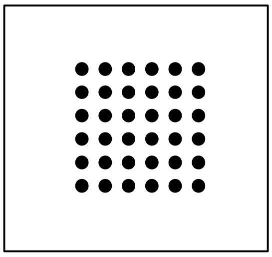

Fig.1 Sensor mask layout

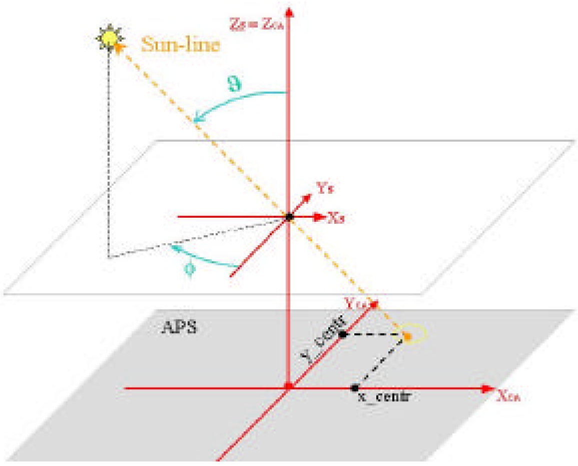

Fig.2 Centroiding concept

If the sun image on the APS is contained in a window of M rows and N columns, the image centroid coordinates are evaluated as follows:

$$x\_centr = \frac{1}{I_{Tot}} \sum_{r=1}^{M} \sum_{c=1}^{N} x_r \cdot I(r,c)$$
$$y\_centr = \frac{1}{I_{Tot}} \sum_{r=1}^{M} \sum_{c=1}^{N} y_c \cdot I(r,c) \qquad (1)$$

where r is the row index, c is the column index, I(r,c) is the intensity value of the (r,c) pixel and:

$$I_{Tot} = \sum_{r=1}^{M} \sum_{c=1}^{N} I(r,c) \qquad (2)$$

From the centroid coordinates the sun-line co-elevation and azimuth in the sensor reference frame (Xs,Ys,Zs) can be finally evaluated.

3.SENSOR SIMULATION

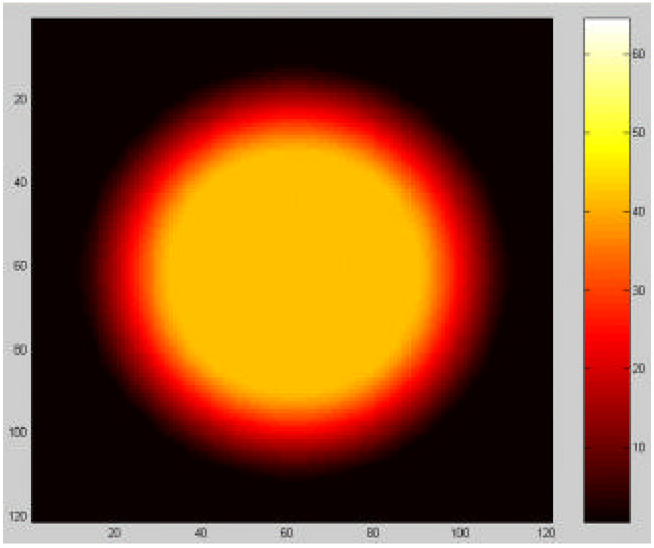

Fig.3 Sun image simulation

An ad-hoc developed simulation program has allowed preliminary analysis of the sensor performance. The numerical code, running in Matlab®, simulates each pixel response (in terms of number of generated photoelectrons) to the sun radiation by accurately modelling the sensor architecture, the APS spectral response and technical characteristics, and the sun spectral emission and illumination geometry. Figure 3 shows a Matlab® simulation of the sun image on the APS detector.

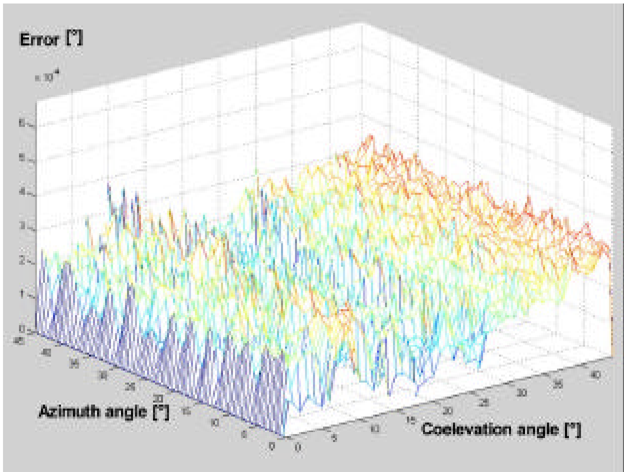

Fig.4 Error surface

Preliminary simulations have been performed mainly to evaluate the influence of the centroiding algorithm on the sun line direction estimation error (the APS noise was not simulated). The estimation error behaviour is shown in Fig. 4. The error is defined in terms of the angle between the true sun-line direction and the one estimated from the sensor measurement. Results show that a mean systematic error of the order of 10^{-4} deg. is produced by the centroiding algorithm. The irregular behaviour of the error surface is caused by the sun image moving through the pixels of the APS. Preliminary APS noise effect estimates show that an accuracy better than 1 arcmin is achievable.

4. SENSOR PROTOTYPE AND TEST FACILITY

In order to validate the sensor concept, a prototype of the sensor and a test facility are under development at the university of Naples as part of the project. To limit costs, the prototype is based on a low-cost APS detector, which is a 1280x1024 array of active pixels (Fill-Factory® IBIS4 demo-board, see Tab.1 and Fig.5). In order to perform measurements with an increasing number of holes several masks are being developed together with a mask holder/adapter to assemble the masks on the detector board. The 0.1-m thick iron mask prototype consists of equally-spaced 0.2 mm-diameter holes and it is placed at a distance of about 3 mm from the APS plane, allowing a field of view of about 90 deg. to be realised. The mask prototype has been manufactured by a low cost process (electron discharge machining) which allows a precision of 0.01mm in the hole design diameter.

Pixel size	7 mμ
FF x QE	>30% (FF=60%)
Capacity (e-)	70000 e-
Linear range within ±1%	50000 e-
ADC	10 bits
DARK CURRENT	800 e-/s

Tab.1 IBIS4 main characteristics

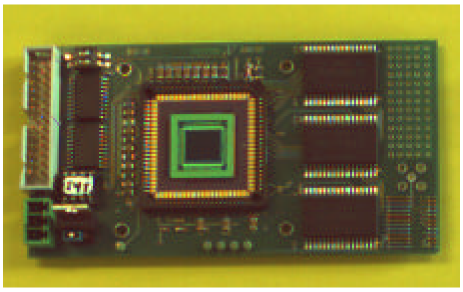

Fig.5 IBIS4 demo-board

The sun simulator consists of a 1000W- XENON ARC LAMP **(**ORIEL Instruments® **)**, whose power output is driven to an integrating sphere (ORIEL Instruments®) by an optical fiber, and of a collimating lens. The APS demo-board with the mask holder is assembled on a precision rotating stage **(**PHYSIC INTRUMENTE®**)** in order to reproduce different sun aspect angles. The distance of the sensor prototype from to the solar source is regulated by a micro-positioning system. The whole system is being assembled on an optical bench at the University of Naples laboratory.

5. CONCLUSIONS AND ACKNOWLEDGEMENTS

The paper describes the work carried out at the University of Naples concerning the study of a miniature APS-based sun sensor for micro/nanosatellite precise attitude determination. The sensor is designed in order to minimize cost, mass and power consumption, as well as to simplify space qualification procedures by the use of CMOS technology. Preliminary results of sensor numerical simulations show that the centroiding algorithm determines a sun-line estimation error of about 10^{-4} deg. and that a final accuracy better than 1 arcmin is achievable. On-going activities aim at improving the simulation software by accurately modeling the APS noise and at developing a sensor prototype and a facility test for ground validation of the sensor concept. The study is funded by the Italian Space Agency.

7. REFERENCES

1. D. Collins et all, Miniature, Low Cost, Highly Autonomous Spacecraft-A Focus on New Millennium", IAF Paper 95-U.2.06, *46th International Astronautical Congress*, Oslo, Norway, 1995
2. Proceedings of the 2nd Round Table on Micro/Nanotechnology for Space (ESTEC, the Netherlands, 15-17 October 1997) ESA WPP-132
3. V.S. Kouzmin et all, Miniature Sun Sensor, *SPIE*, Vol.2739, pp.407-410, 1996
4. J. H. Hales and M. Pedersen, Two-axis MOEMS Sun Sensor for Pico Satellites, 16th Annual AIAAA/USU Conference on Small Satellites, 2001.
5. C.C. Liebe et all, Micro Sun Sensor, IEEEAC paper #274, 2002.