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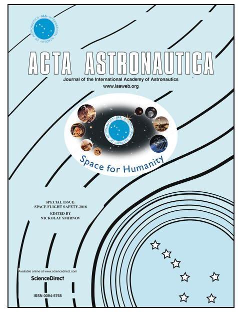

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Development of a low-cost Sun sensor for nanosatellites

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Sun sensors represent a common and reliable technology for attitude determination, employed in many space missions thanks to their limited size and weight. Typically, two-axis digital Sun sensors employ an array of active pixels arranged behind a small aperture; the position of the sunlight's spot allows to determine the direction of the Sun. With the advent of smaller vehicles such as CubeSats and Nanosats, there is the need to further reduce the size and weight of such devices: as a trade-off, this usually results in the curtail of the performances. Nowadays, state of the art Sun sensors for CubeSats have resolutions of about 0.5°, with fields of view in the ±45° to ±90° range, with off-the-self prices of several thousands of dollars. In this work we introduce a novel low-cost miniaturized Sun sensor, based on a commercial CMOS camera detector; its main feature is the reduced size with respect to state-of-the-art sensors developed from the same technology, making it employable on CubeSats. The sensor consists of a precisely machined pinhole with a 10 μm circular aperture, placed at a distance of 7 mm from the CMOS. The standoff distance and casing design allow for a maximum resolution of less than 0.05°, outperforming most of the products currently available for nano and pico platforms; furthermore, the nature of the technology allows for reduced size and lightweight characteristics. The design, development and laboratory tests of the sensor are here introduced, starting with the definition of the physical model, the geometrical layout and its theoretical resolution; a more accurate model was then developed in order to account for the geometrical deviations and deformations of the pinhole-projected light-spot, as well as to account for the background noise and disturbances to the electronics. Finally, the laboratory setup is presented along with the test campaigns: the results obtained are compared with the simulations, allowing for the validation of the theoretical model.

I. Introduction

In the flourishing small satellites market various solutions for Sun sensors are available, most of them derived and miniaturized from larger satellites hardware. Such components are therefore not optimized for small spacecraft, and present heavy requirements, in terms of mass and power consumption and price, up to several thousands of euro, that are not always balanced with good accuracy and precision. Similarly, the few sensors developed primarily for such platforms usually trade small size and reduced resources consumption with further scarce performances. In particular, one of the finest off-the-shelf sensors reaches an accuracy of 0.3° and a precision of 0.05°, with a size of 40x30 mm and a weight of 25 g.[1*]

A simplified classification of current Sun sensor solutions is here briefly reported; references are related to small satellites applications. 1-D sensors are able to give a single angular information regarding the Sun direction, and their measure can be performed with an analog[3] or a digital system[4,5] with a theoretical resolution up to 0.07°. To obtain a complete information of the Sun relative position (i.e. the Sun vector) it is possible to use two 1-D elements or implement 2-D sensors, usually employing a photosensible surface instead of a linear array of photodiodes. Their working principle is simple: Sun rays passing through a mask mounted in front of the photosensible sensor illuminate a spot that can be detected, allowing the reconstruction of the Sun vector.[6,7] In the cited case, average accuracy can reach less than 0.01°, but with a mass of 2 kg.[8]
With particular focus on CubeSat market solutions,

*In this paper, **accuracy** is defined as the measure of systematic errors, **precision** the measure of the random errors distribution (i.e. the reproducibility and repeatability of the acquisition), and **resolution** the smallest change of the acquired quantity that produces a response in the acquisition.[2]