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A highly accurate wireless digital sun sensor based on profile detecting and detector multiplexing technologies

Minsong Wei [a,b], Fei Xing [a,b,*], Zheng You [a,b]

[a] Department of Precision Instrument, Tsinghua University, Beijing 100084, China
[b] State Key Laboratory of Precision Measurement Technology and Instruments, Tsinghua University, Beijing 100084, China

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ABSTRACT

The advancing growth of micro- and nano-satellites requires miniaturized sun sensors which could be conveniently applied in the attitude determination subsystem. In this work, a profile detecting technology based high accurate wireless digital sun sensor was proposed, which could transform a two-dimensional image into two-linear profile output so that it can realize a high update rate under a very low power consumption. A multiple spots recovery approach with an asymmetric mask pattern design principle was introduced to fit the multiplexing image detector method for accuracy improvement of the sun sensor within a large Field of View (FOV). A FOV determination principle based on the concept of FOV region was also proposed to facilitate both sub-FOV analysis and the whole FOV determination. A RF MCU, together with solar cells, was utilized to achieve the wireless and self-powered functionality. The prototype of the sun sensor is approximately 10 times lower in size and weight compared with the conventional digital sun sensor (DSS). Test results indicated that the accuracy of the prototype was 0.01° within a cone FOV of 100°. Such an autonomous DSS could be equipped flexibly on a micro- or nano-satellite, especially for highly accurate remote sensing applications.

1. Introduction

The sun sensor, which measures the direction of sun vector, is an essential component of attitude determination subsystem of satellites [1–4]. Due to the employment of the charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) image detector, the digital sun sensors (DSS) are superior to the analogue sun sensors (ASS) in accuracy and stability [5–7], and consequently the DSS is in stringent demand by a precision or robust solution. Currently, the researches have been focusing on the miniaturization of DSS, especially for application on the micro- or nano-satellites, which are critical with the size, weight, power consumption and cost of the sensors onboard [8–11]. Moreover, the plug-and-play concept has been introduced and broadly employed in the sensors or subsystems onboard micro- or nano-satellites [12–14] and thus, a fully autonomous and wireless DSS with high accuracy and large field of view (FOV) could be greatly advantageous in convenience for installation and application [15–16].

Generally, traditional digital sun sensors are not quite appropriate for application on small satellites due to their large size and high power consumption which are mainly resulted from the employment of digital image detectors [17]. To reduce

* Corresponding author at: Department of Precision Instrument, Tsinghua University, Beijing 100084, China.
E-mail address: xingfei@mail.tsinghua.edu.cn (F. Xing).

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the system size and power consumption of DSS, TNO has successfully developed an application-specific integrated circuit (ASIC) chip, namely APS+ [18], and based on the customized image detector, several miniature sun sensors, including a wireless micro-DSS (μDSS), have been realized [19,20]. However, it is still costly to complete the ASIC chip since most of the micro- and nano-satellites are susceptive to the budget. Moreover, the update rate of μDSS is limited to approximately 10 Hz for the accomplishment of self-power.

The wireless DSS developed in our work employs a high- speed commercial-off –the-shelf (COTS) image profile detector to reduce the cost and improve the data update rate. The image profile detector outputs the projection information of the obtained spot, which could tremendously lower the power consumption and improve the frame frequency [21,22]. However, such image profile detector fails to identify and recovery multiple spots from tradition pattern design and accordingly, a profile detecting technology was presented. In this method, to achieve multiple sun spots output, the apertures on the mask were obliquely designed. Based on a multiple spots recovery approach, the multiplexing image detector method [23,24] could be utilized to achieve both high accuracy and large FOV. Based on the introduction of the FOV region, a FOV determination principle was presented to simplify sub-FOV and whole FOV determination. Furthermore, the plug-and-play functionality is achieved by GaAs solar cells, which is mounted on the top surface of the sensor to provide sufficient power, and a RF MCU, which is utilized to process the algorithm and manage RF data transmission. The prototype of wireless DSS is only 45 mm × 40 mm × 20 mm and 38 g. Test results indicated that the accuracy of the wireless DSS was 0.01° within a cone FOV of 100°.

2. Implementation of multiplexing image detector method based on the profile detecting technology

2.1. Principle of digital sun sensors based on the image profile technology

To reduce the cost and improve the data update rate of the digital sun sensor, a high-speed profile detecting technology was proposed, based on a COTS profile detector which could realize the pixel readout from a 2-dimensional pixel array to a row and a column. As illustrated in Fig. 1, instead of readout of all pixels of the image detector (as the full image data), the image profile detector outputs the profile data. The value summation of each pixel in the same column is output as the profile data in x axis and the value summation of each pixel in the same line is output as the profile data in y axis. As a result, the total number of output data is merely the number of pixels in one row and one column.

Based on the profile data, the centroid (x_c, y_c) of the spot with the size $n \times m$ obtained on the image plane could be determined by centroiding algorithm in Eqs. (1) and (2), with which sub-pixel resolution could be achieved.

$$x_c = \frac{\sum_{i=1}^{n} (x_i \times v_i)}{\sum_{i=1}^{n} v_i} \tag{1}$$

$$y_c = \frac{\sum_{j=1}^{m} (y_j \times w_j)}{\sum_{j=1}^{m} w_j} \tag{2}$$

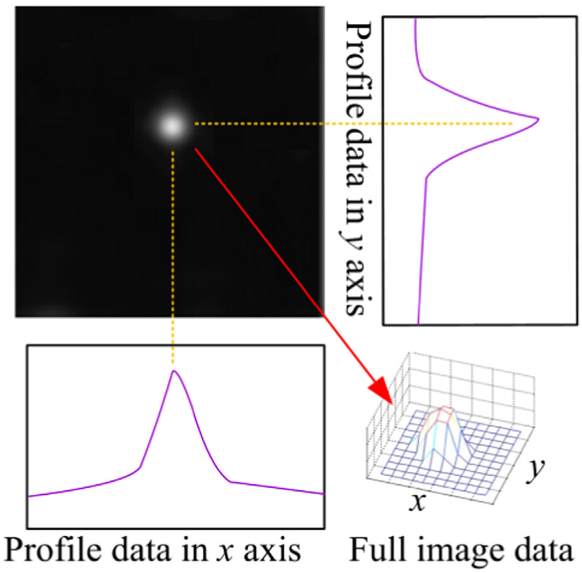

Fig. 1. Operation mode of an image profile detector.