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Infrared Earth sensor with a large field of view for low-Earth-orbiting micro-satellites

Key words: Infrared Earth sensor; Micro-satellite; Attitude determination system

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Motivation

- Infrared Earth sensors are effective components of the attitude determination and control system of satellites. Dynamic Earth sensors are often larger, heavier, and consume much more power than static earth sensors because of their movable components. Thus, static Earth sensors are more suited for micro-satellites.

- Traditional static Earth sensors have a relatively small field of view (FOV) (<60°). However, micro-satellites are used mostly in low-Earth orbit (LEO). This means static earth sensors with a large FOV are needed.

Main idea

- A novel infrared Earth sensor composed of a panoramic annular lens (PAL) and a complementary-metal-oxide-semiconductor (CMOS) infrared camera is designed. PAL is used to make FOV large enough to fully view and measure the Earth in LEO.
- To find the center of the Earth in the infrared Earth image, a computationally efficient algorithm including Hough transformation and least-squares estimation is developed.

Method

1. Hardware

The infrared Earth sensor is composed of an infrared camera, PAL, and image-processing circuits. The lens follows the principle of the flat-cylinder perspective.

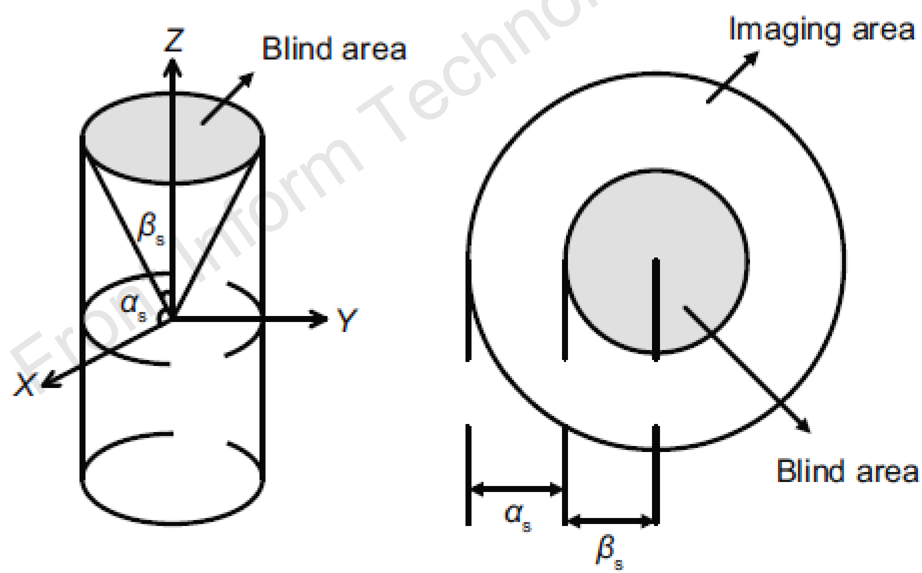
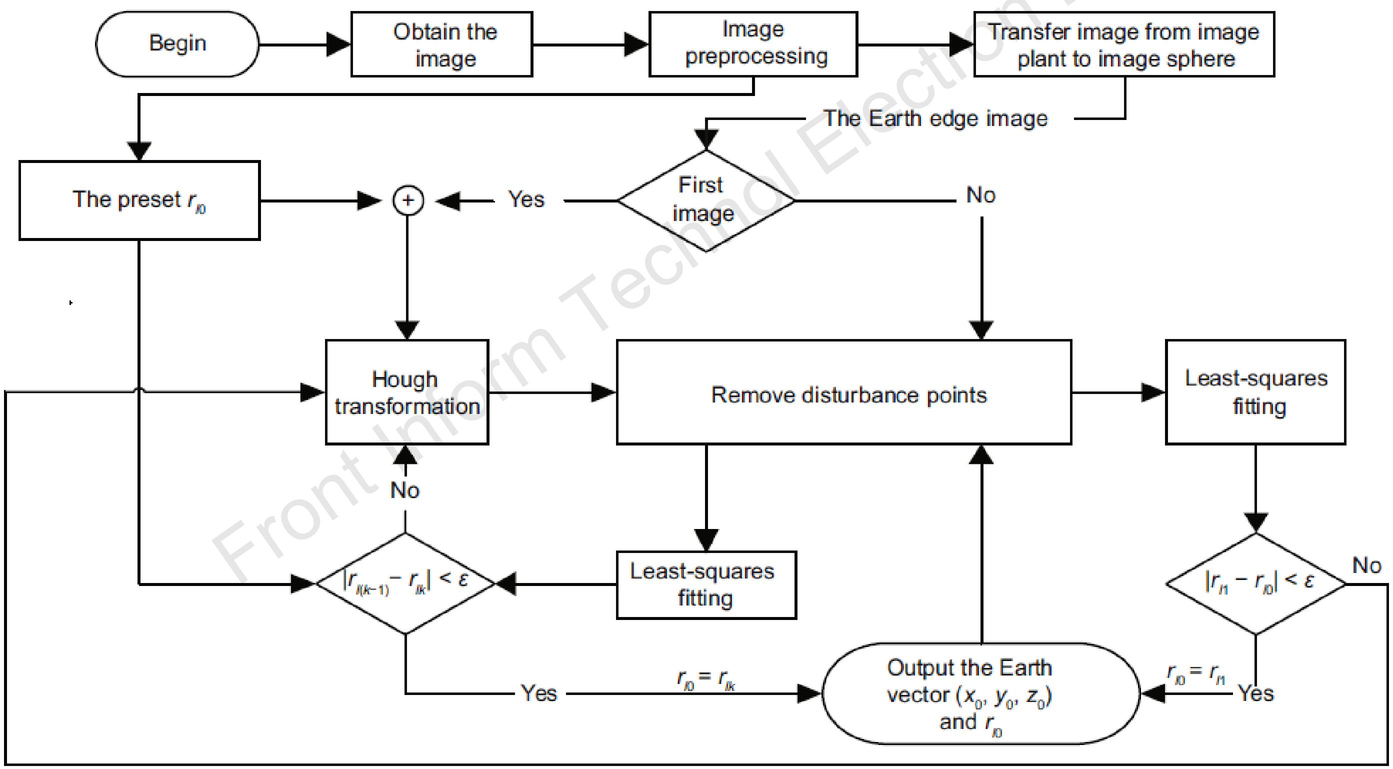


Image plane of the panoramic annular lens

Method

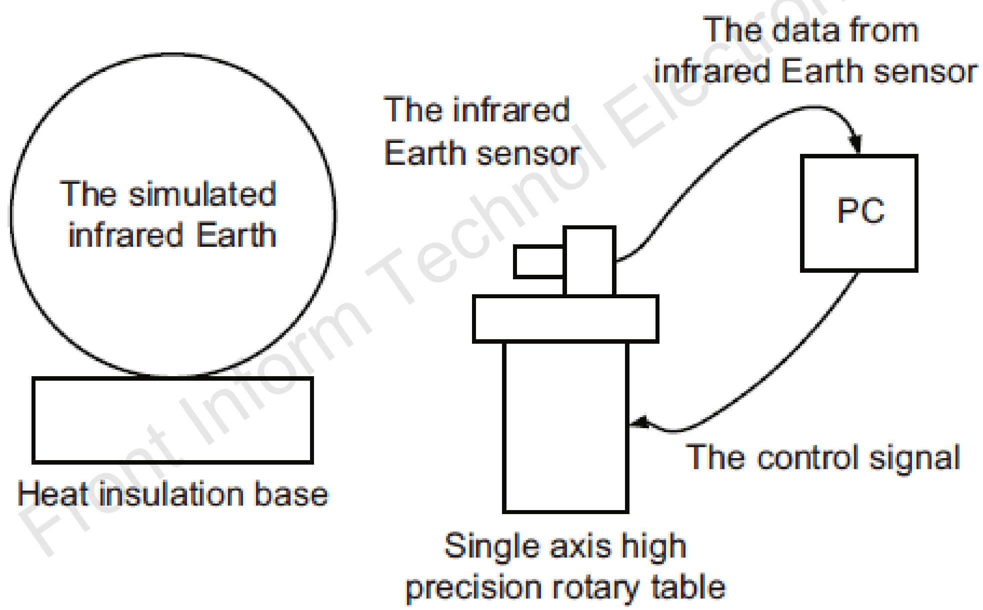
2. Image-processing algorithm



Block diagram of the Earth sensor's algorithm

Method

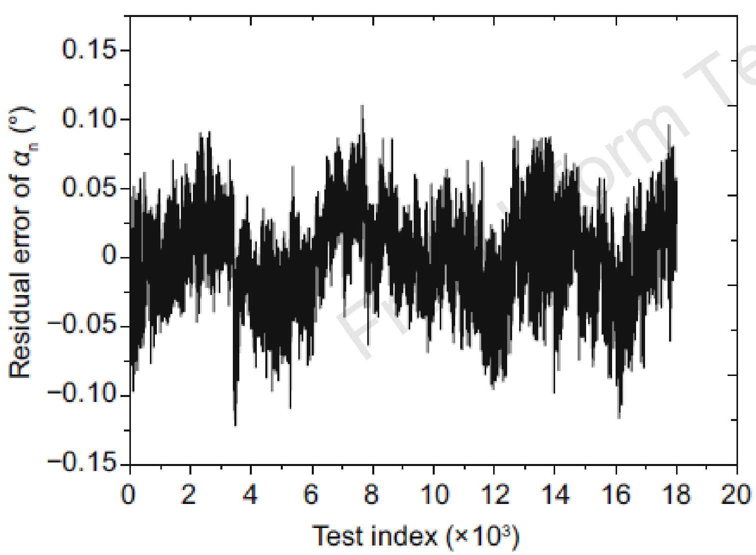
3. Experimental setup



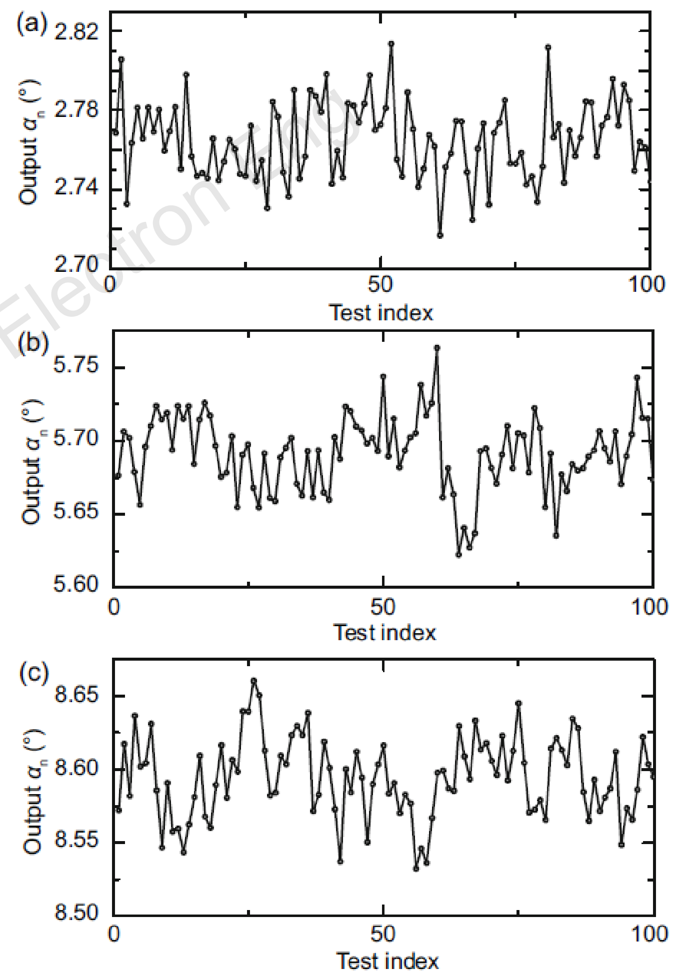
Block diagram of the Earth sensor's algorithm

Major results

According to the chi-squared test, the residual errors were normally distributed with a −0.0005° mean. The standard deviation and root mean square were both 0.032°.



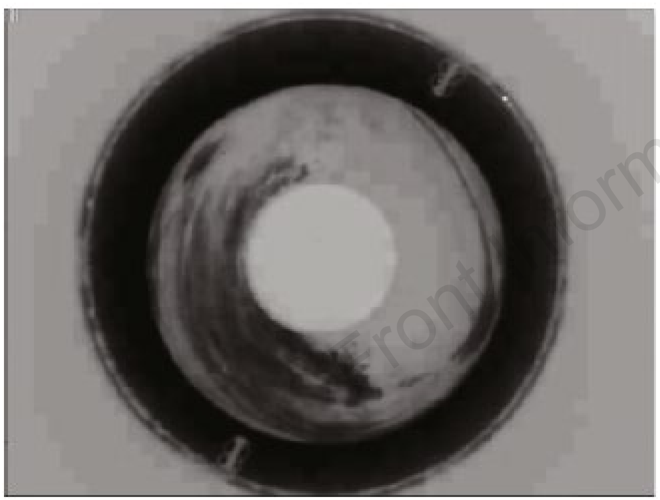
Residual error of the Nadir angle



Measurements at three different inputs with three different rotation angles

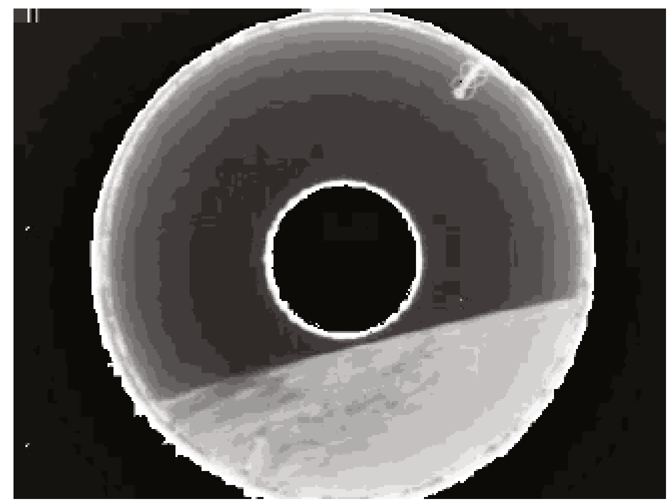
Major results (Cont'd)

The image-processing result for the calculated angle between the Earth and the satellite was 3.26°.



Infrared image of the Earth when satellite was in three-axis-stabilized mode

The image-processing result for the calculated angle between the Earth and the satellite was 100.28°.



Infrared image of the Earth when satellite was in Sun-pointing mode

Conclusions

- Advantages of traditional static Earth sensors are retained in the new Earth sensor, including small size, light weight, and low power consumption.
- A panoramic annular lens is used to meet the requirements of medium- and low-Earth-orbiting satellites.
- The measurement accuracy can be guaranteed within 1° when the inclination of the sensor is about 50° to the Earth.
- The system has high stability and precision for Nadir-pointing scenarios (the inclined angle is less than 10°) with a standard-deviation error below 0.032°.