Realizing the Potential of Small-sized Aperture Camera (SAC) in High-Resolution Imaging Age

Young-Wan Choi, Ee-Eul Kim, Sung-dong Park
SaTReC Initiative
461-26 Jeonmon-dong Yusung-gu, Daejon 305-811, Korea
ywchoi@satreci.com; eek@satreci.com; sdpark@satreci.com

Abstract: SAC is a compact electro-optical camera for imaging in visible-NIR spectral ranges. SAC provides high-resolution images over the wide geometric and spectral ranges: 10 m ground sample distance (GSD) and 50 km swath width in the spectral ranges of 520 ~ 890 nm. SAC is designed to produce high quality images: modulation transfer function (MTF) of more than 15 %; signal-to-noise ratio (SNR) of more than 100.
The missions of SAC incorporate various imaging operations: multi-spectral imaging; super swath-width imaging with cameras in parallel; along-track stereo imaging with slanted 2 cameras.
Keywords: camera, earth observation, satellite, MTF

1. Introduction

A high-performance micro-satellite, KITSAT-3, developed by the Satellite Technology Research Center (SaTReC) was launched in May 99 into a 730 km sun-synchronous orbit. Since its launch, its primary payload, a pushbroom multi-spectral imaging system, has produced numerous images of high quality and demonstrated the potential of micro-satellites as a cost-effective tool for earth observation.

Since the successful launch of IKONOS-2, the commercial market for high-resolution satellite images has substantially increased. Consequently, several commercial "big" satellites for high-resolution imaging are under development [1]. On the other hand, a new attempt is being made to provide high-resolution images using "small" satellites EROS A1-2 that weighs 280 kg proves that such an attempt can become a valuable alternative [2]. In addition, as the cost-effectiveness of micro- or small satellites was recognized more widely, several constellation programs were suggested for environment and disaster monitoring [3].

SaTReC Initiative, a commercial venture established by key engineers of SaTReC, is developing the next generation pushbroom imaging systems for small and micro-satellites as international collaborative research and development programs. The Medium-sized Aperture Camera (MAC) [4], [5] and the Small-sized Aperture Camera (SAC), cost-effective imaging systems, will become valuable demonstration tools for high-resolution earth observation using small satellites and commercialization of its product.

2. System Overview

SAC is a pushbroom imaging system with three linear detectors aligned in parallel on its focal plane. Its ground sample distances are 10 m in multi-spectral bands at the nominal altitude. Its swath width is greater than 50 km at this altitude.

The functional diagram of SAC is shown in Fig. 1. SAC consists of two configurable subsystems: Electro-Optical Subsystem (EOS) and SAC Management Subsystem (SMS). EOS includes telescope, focal plane assembly (FPA) and processing unit. SMS performs system control and management and image data storage and maintenance.

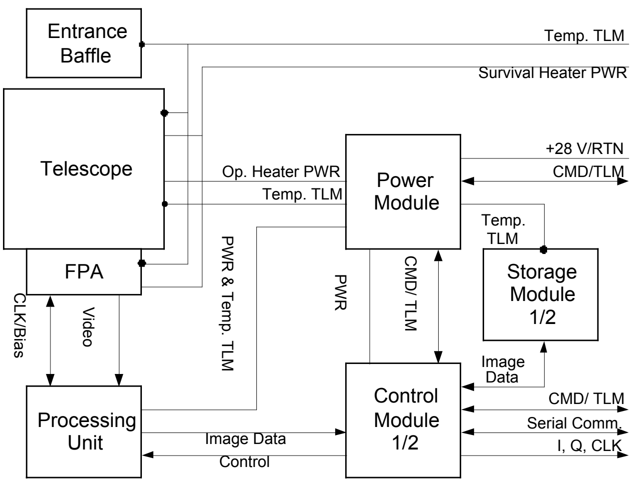

Fig. 1. Functional diagram of SAC

Key performance features of SAC are summarized in Table 1.

Table 1. System Characteristics of SAC

Clear Aperture	120 mm
Imaging channels	3 multi-spectral (MS)
Spectral bands (μm)	0.52 ~ 0.89
GSD (m)	10 (14.5 μrad)
Swath width	50 km

MTF (%)	15
SNR	≥ 100
Signal quantization	8 bits
Signal gain	Programmable
Mass storage	8 Gbits
Mass	≤ 15 kg
Peak power consumption	≤ 30 W

3. Subsystem Description

1) Electro-Optical Subsystem

The telescope is a mangin-variant optical system of five spherical lenses where two reflective surfaces are included as shown in Fig. 2. Lens is made of a low-expansion glass material, Fused Silica. The diameter of entrance pupil is 120 mm and the optical design gives an MTF value of about 38% at the Nyquist frequency as in Fig. 3.

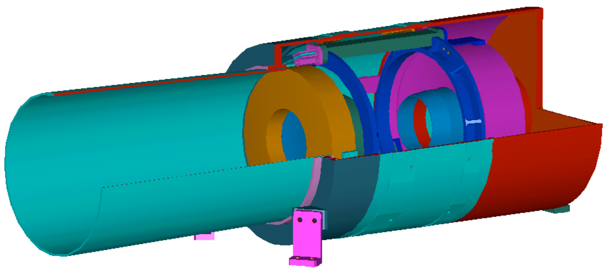

Fig. 2 Solid model of SAC EOS

Structural elements of EOS are made of different materials such as Super Invar and Aluminum to protect optical elements and to maintain the optical performance during operation.

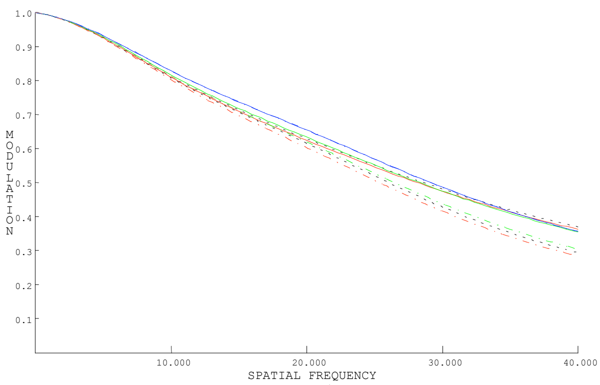

Fig. 3 Design Value of telescope MTF

The most stringent requirement given is the distance between primary and secondary mirrors during operation, which is 2 μm. To meet this requirement, metering rods made of Super Invar are used between two mirror assemblies. Special attention was paid to mechanical interfaces between metering rods and mirror assemblies to minimize the distance variation between mirrors.

For stray light control, three baffles are used: baffles for primary and secondary mirror are made of aluminum; entrance baffle is made of CFRP for mass reduction.

2) SAC Management Subsystem

SMS consists of five modules. One module for power supply provides power to different electronics modules from the bus primary power. It also includes switches for heater control and it supports control modules in telemetry collection.

SMS has two control modules in cold redundancy and a storage module. Control modules are responsible for overall management, image data storage, maintenance and transmission and communication with the command and data handling subsystem of the bus. They are capable of synchronizing the imaging operation to the pulse-per-second signal from GPS.

Storage module is designed to provide a total storage capacity of 8 Gbits. It is designed with a multiple level of fault tolerance to bypass damaged memory blocks or memory packs.

4. System Development

Preliminary integration and test has been accomplished for telescope of EOS using support equipments. The purpose of the integration and test is to verify whether the primary and secondary mirror assemblies are ready for system integration.

The procedure started with integration of primary mirror assembly. After integration of the primary mirror assembly, the secondary mirror assembly was integrated to them using alignment jigs and interferometric measurement data. Fig. 4 shows the alignment of the secondary mirror assembly to the primary mirror.

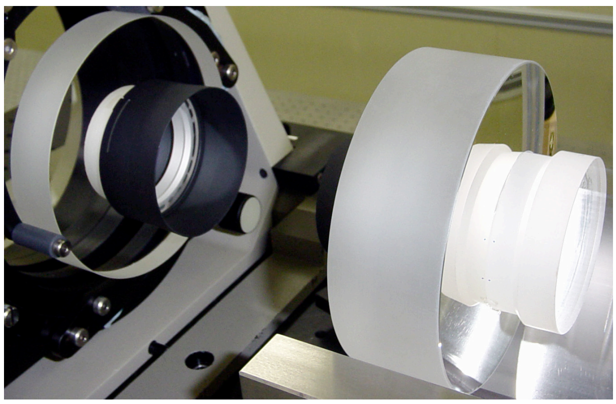

Fig. 4 Alignment of EOS using support equipments

Fig. 5 shows wavefront error (WFE) of telescope that was measured to be 0.0945 (1/10.5) λ where λ is 632.8

nm. MTF value is estimated based on wavefront error measurement. As shown in Fig. 6, the estimated value was 32 % at the Nyquist frequency, which is 0.18 of nominal spatial frequency, 1/(□ F/#).

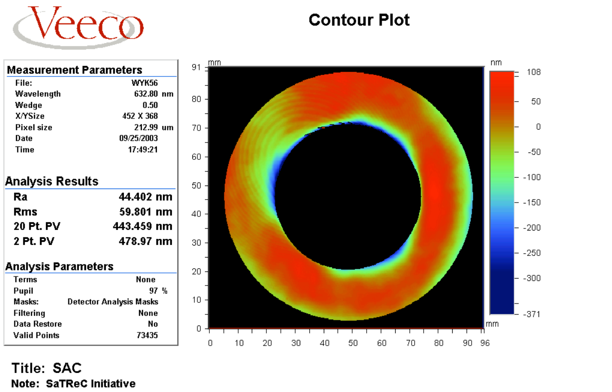

Fig. 5. Measured interferogram and WFE of telescope

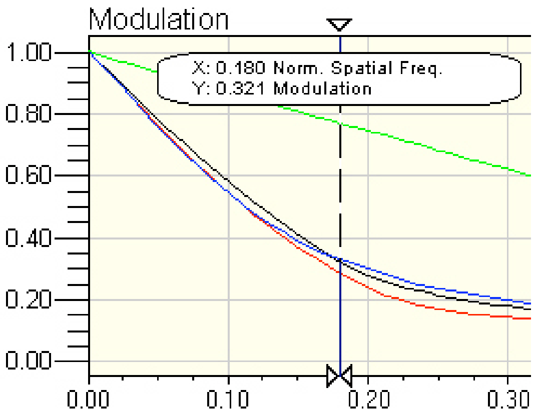

Fig. 6. Estimated value of MTF based on WFE measurement

5. Application

The missions SAC can support, incorporate various imaging operations: multi-spectral imaging to provide the images of 3 to 4 spectral bands; super-swath width imaging to provide 100 km ~ 200 km wide images with the installation of 2 ~ 4 cameras as shown in Fig. 7; along-track stereo imaging to produce digital elevation model (DEM) with the installation of slanted 2 cameras.
The potential missions with SAC-based on detector configurations, include hyper-spectral imaging and infrared imaging. Incorporating spectrometric modules, SAC can be designed to provide hyper-spectral imageries of more than 32 bands. Infrared imaging can be implemented in the spectral range of 0.9 ~ 2.5 and around 3.5 micrometers: the spectral limitation is imposed by the substrates used for optical components.

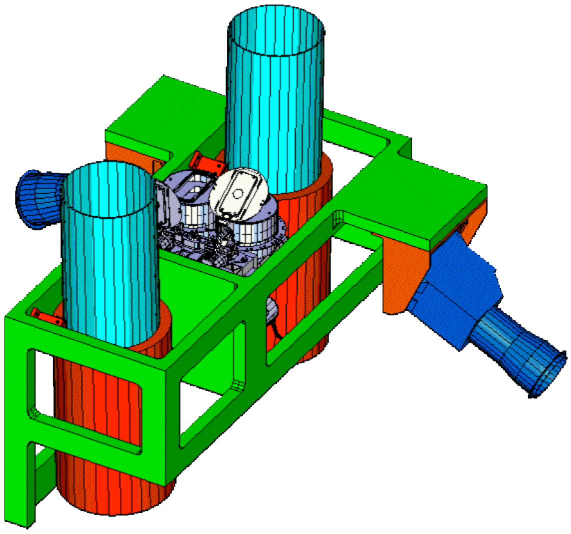

Fig. 7. Dual Configuration for super-swath imaging

6. Conclusion

In this paper, Small-sized Aperture Camera (SAC) has been introduced with design approach and performance. Even though it is developed for micro-/small satellites, the presentation of development status and test results demonstrate the potential capability that SAC can provide for world-wide remote sensing groups: short development period, cost-effectiveness, and high performance.

References

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