Digital Image Simulation of Electro-Optical Camera(EOC) on KOMPSAT-1

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Abstract

Electro-Optical Camera (EOC) is the main payload of the KOMPSAT-1 satellite to perform the mission of cartography that builds up a digital map of Korean territory including a digital terrain elevation map. This paper discusses the issues of the digital image simulation of EOC for the generation of EOC simulated scene as taken by EOC at 685km altitude on orbit. For the purpose, simulation work has been performed with the sensor models of EOC and the satellite platform motions models through image chain analysis from the illumination source (Sun) to a simulated image output in digital number. MODTRAN for radiance calculation, MTF models of optics, detector and motions of EOC for system point spread function (PSF), and signal chain equations for digital number output are described. Several noise models of EOC are also considered. The final output is the EOC simulated image in digital number. The simulation technique can be used in several phase of a spaceborne electro-optical system development project, feasibility study phase, design, manufacturing, test phases, ground image processing phases, and so on.

1. Introduction

The main mission of EOC is cartography to build up the digital map of Korean territory including a Digital Terrain Elevation Map (DTEM). EOC collects panchromatic image with the Ground Sample Distance (GSD) of 6.6 meters and the swath width of 17 km at nadir view through the visible spectral band of 510nm~730nm. EOC can scan the ground track of 800 km per orbit by push broom scanning and spacecraft body tilting (roll) method. At the Image Reception and Processing Element (IRPE) of Korea Ground Station (KGS), a stereo image can be generated from a pair of images that are obtained with different roll tilt angles. KOMPSAT-1 will be launched on November 1999 at the Vandenberg Air Force Base, California, U.S.A.

In digital image simulation of EOC, several components in image chain are considered. First, for calculating radiant energy at the aperture of EOC, solar zenith, nadir viewing at 685 km altitude and ground target reflectance are used as MODTRAN input parameters. Second, for determining system PSF, the MTF models of EOC optics, detector and motion are transformed using the Inverse Fast Fourier Transform (IFFT). Diffraction and degradation (aberrations and defocusing) effects are included in optics MTF model. Spatial aperture effect, carrier diffusion effect and Charge Transfer Efficiency (CTE) effect is included in Detector MTF model. Linear motion effect due to push broom scanning, spacecraft drift and jitter effect are included in motion MTF model. Finally, digital number output as simulated image is made using signal chain equations together with random noise. The signal chain equations include Quantum Efficiency (QE) of detector, charge conversion to voltage, analog signal processing and analog to digital conversion.

Digital image simulation of spaceborne electro-optical system has been used in remote sensing area to perform image chain analysis from illuminator, medium to digital output (target image). Digital image simulation technique provides the following figure of merits at several phases for spaceborne electro-optical system development:

- Analysis of compatibility between mission and requirements in feasibility study phase of a project;
- Prediction and evaluation of performance in design, manufacturing and test phases;
- Support for ground image processing for value added image during operational phase.

Especially in feasibility and design phase, the technique with trade-off and iteration is usually performed to optimize system design parameters of instrument, and to determine orbit and operation, and so on.

2. Image Chain of Spaceborne Imaging Systems

The basic functions associated with the typical image chain of a spaceborne electro-optical system are shown in Figure 1. Sun radiation propagates through the atmosphere to ground target, the ground target reflects the radiant energy from direct sun radiance and solar scattered downwelled radiance (skylight). The reflected radiance propagates through the atmosphere and is collected by instrument aperture. In addition to the reflected radiance, path radiance (solar scattered upwelled radiance) is also collected by the aperture as a background signal. The collected total energy is spread on image plane due to optics, then sampled by detector and converted electro-optically in electronic signal inside the detector as much as QE.

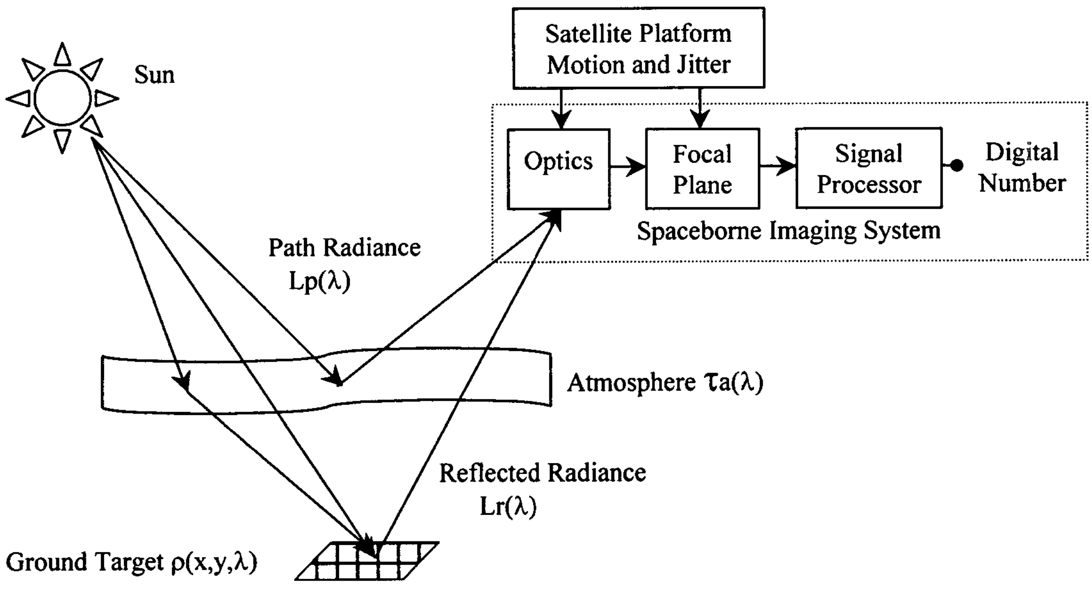

Figure 1. Spaceborne Electro-Optical Imaging System

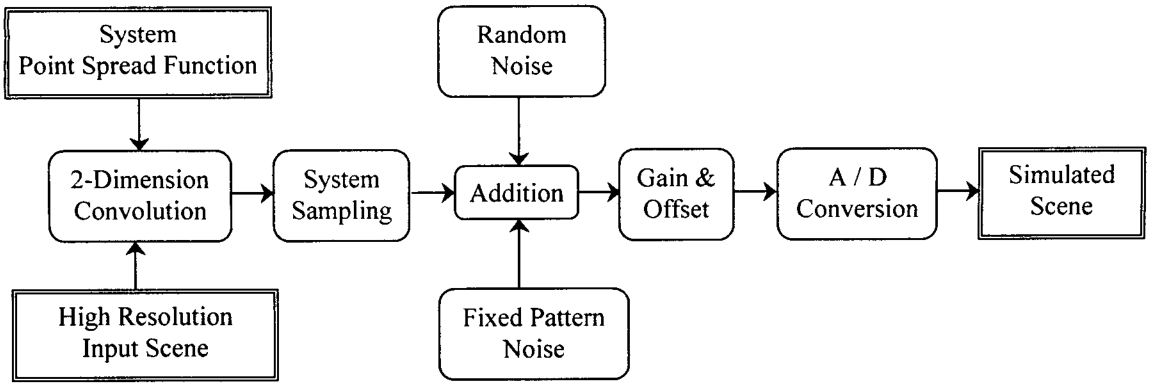

Figure 2. Digital Image Simulation Process Diagram

During sampling photons on image plane, target photons are spread due to spacecraft motions, e.g. linear motion, drift and jitter. After signal processing, digital numbers (image) are achieved.

Following the image chain as described above, digital image simulation of EOC is carried out. The image simulation process of this paper is described in the next section.

3. Method

In the image simulation process used in this paper, in sequence, the collected radiance is calculated, then system PSF is generated and signal chain equations are applied to get a simulated image. The detailed simulation process is shown in Figure 2.

3.1 Collected Radiance Calculation

The atmospheric radiative transfer code MODTRAN is used to calculate the ground-reflected radiance $Lr(\lambda) * \tau a(\lambda)$ and the path radiance $Lp(\lambda)$, as shown in Figure 1, observed by the aperture of EOC at 685Km altitude in nadir view direction for EOC spectral band in 510nm~730nm range through the atmosphere for a clear (23 Km visibility), mid latitude summer atmosphere with 45 degree solar zenith angle. The reflected radiance $Lr(\lambda)$ is calculated as a function of the direct sun radiance, solar scatter downwelled radiance (skylight) and ground target reflectance $\rho(\lambda)$. The total irradiance collected by the EOC aperture is $\Omega * (Lr(\lambda) * \tau a(\lambda) + Lp(\lambda))$, where Ω is the effective collecting solid angle of the EOC aperture, $\tau a(\lambda)$ is the upward atmosphere spectral transmittance.

3.2 MTF Models and System PSF

EOC will operate in a push broom mode with the in-scan(ram) direction, 'x' and the cross-scan direction, 'y'. EOC analytical models are described in spatial frequency domain by using MTF. The system PSF and system Optical Transfer Function (OTF) forms a Fourier transform pair. The MTF is defined to be the modulus of the OTF, and MTF can have only positive values. In symmetrical incoherent imaging systems like EOC, the components of its OTF are real but can be negative values. In this paper, MTF is referred to the same as OTF. The MTF models of EOC component, are used as shown in Table 1.

The Table 2 shows EOC parameters and values relating to the MTF models. Assuming each component is a linear system, the system MTF can be defined as a product of component MTFs. By inverse Fourier transform, system PSF can be obtained as $PSFsys(x,y) = FT^{-1}$

{ MTFsys(fx,fy) }. The PSF makes incoming energy spread on image plane.

Table 1. MTF models of EOC

IN-SCAN, Fx	CROSS-SCAN, Fy
OPTICS ● Diffraction ● Degradation (Aberration,Defocusing)	OPTICS ● Diffraction ● Degradation (Aberration,Defocusing)
DETECTOR ● Spatial Aperture	DETECTOR ● Spatial Aperture ● Carrier Diffusion ● CTE
Spacecraft Platform ● Linear Motion ● Drift ● Jitter	Spacecraft Platform ● Drift ● Jitter

Table 2. EOC parameters relating to MTF models

IN-SCAN, Fx	CROSS-SCAN, Fy
OPTICS ● F# : 8.3 ● Average Wavelength : 620nm ● Aberration & Defocusing Scale Factor : 2.8	
DETECTOR ● Pixel Size : 10 μm	● Pixel Size : 10 μm ● 2592 Pixels ● Output Taps : 2 ● CTE : 0.99995 ● Ldef : 75 μm ● Ldep : 12 μm
Spacecraft Platform ● Velocity : 6.8 km/sec ● Drift : 0.04 deg/sec ● Jitter : 1.7 μrad	● Drift : 0.04 deg/sec ● Jitter : 1.7 μrad

3.3 Signal Chain Equation

EOC sensor produces photon-electron on each pixel using linear CCD of 2592 pixels, which scans in cross direction 'y'. Analytical model of a pixel signal in a function of electron, noise signal, total signal and digital number after analog to digital conversion are,

$$P_e = \frac{\pi X_{ps}^2 T_{int}}{4F\#^2 hc} \int_{\lambda 2}^{\lambda 1} (Lr(\lambda)\tau_a(\lambda) + Lp(\lambda))\tau_o(\lambda) QE(\lambda)\lambda d\lambda$$

$$Ne = \sqrt{Pe + De + Ee^2}$$

$$Te = Pe + De + Ne*GR(0,1)$$

$$DN = INT(Te*Gconv*Gasp / LSB)$$

, where Pe denotes pixel signal in electron, Xps denotes pixel size, Tint denotes integration time, τo denotes optical transmittance, De denotes dark current noise and Ee denotes electronic noise.

Actually pixel signal is calculated taking into consideration the spread on image plane due to PSF. In equations dark current signal and path radiance signal produce an offset in the image.

The table 3 below shows EOC parameters and values relating to the signal equations

Table 3. EOC parameters relating to signal equations

Parameter	Value
Pixel Size	10 μm
Optical Transmittance	0.83
Quantum Efficiency	0.71
Dark Current Density	1 nA/cm^2
Integration Time	976.56 μsec
Gconv * Gasp	15 μV/e
Electronic noise	100 e
ADC	1.75 Volt / 255

4. Results and Discussion

The simulation result shows In-Track MTF in Figure 3, Cross-Track MTF in Figure 4, system PSF in Figure 5. The difference between In-Track and Cross-Track MTF means deferent component MTF applied as shown Table 1, in 'x' and 'y' direction. Figure 6 of next page shows high-resolution scene used as the simulation input with

845 x 845, 1-m resolution. The EOC simulated image, 128 x 128 6.6m resolution is shown in Figure 7 at next page. The simulated scene has lower contrast than high-resolution scene, it results from path radiance that contribute mainly background signal as a mount of offset at signal chain. And it is blurred by the system PSF value of EOC.

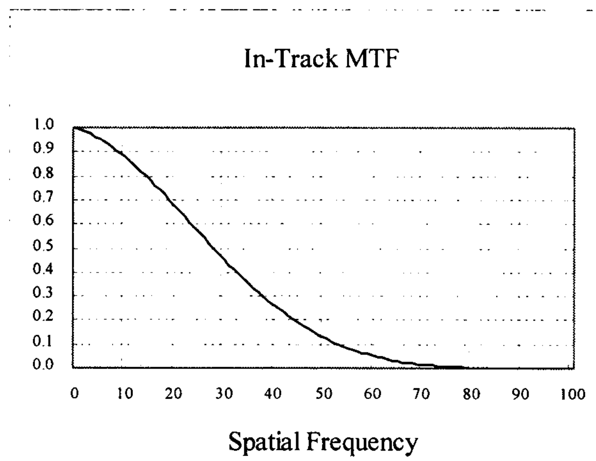

Figure 3. In-Track MTF

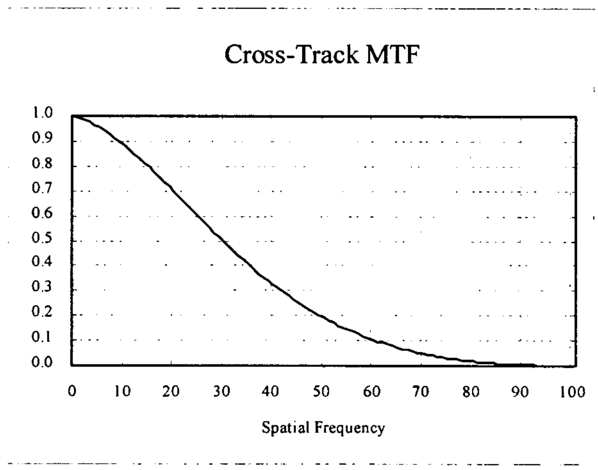

Figure 4. Cross-Track MTF

5. Conclusion

The Digital Image Simulation of Spaceborne Imaging System, EOC of KOMPSAT-1, has been addressed. This technique is useful tools from early phase to ground image processing phase by generating simulated image of a spaceborne EO system.

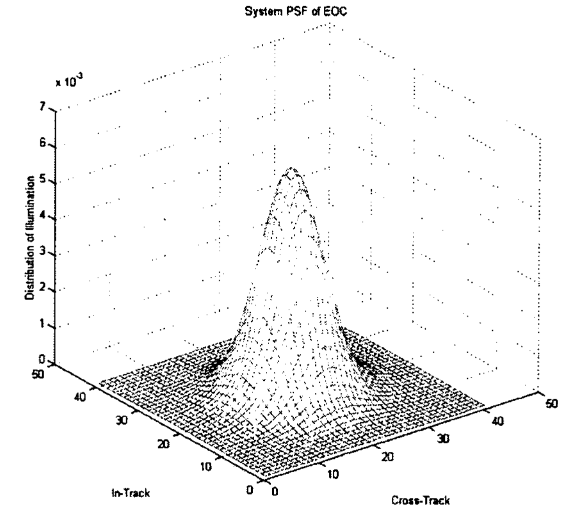

Figure 5. 2-Dimensional PSF of EOC

Acknowledgements

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Figure 6. High Resolution Input Scene

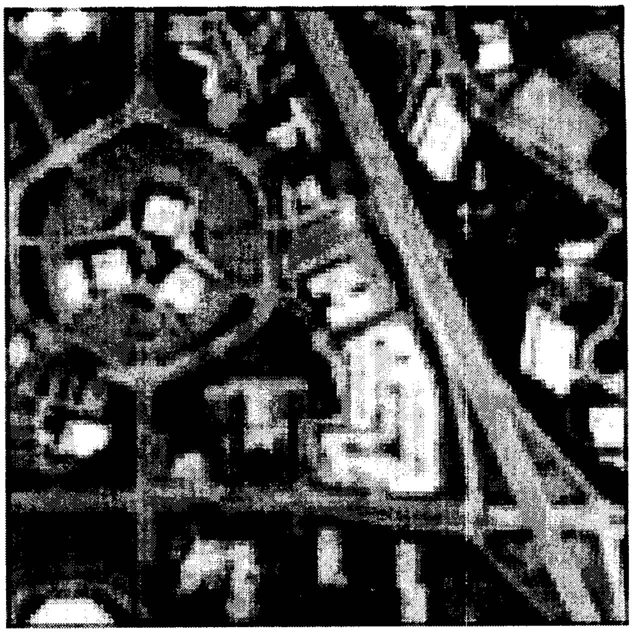

Figure 7. EOC Simulated Image

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