KOMPSAT-3 DIRECT GEOREFERENCING MODE AND GEOMETRIC CALIBRATION & VALIDATION

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Abstract: KOMPSAT-3 AEISS PAN data can be used various researched to investigate different aspects and experiments of mapping using KOMPSAT-3 data: geometric accuracy, DEM extraction, image content, extraction of planimetric features, and integration of raster and vector data. The first object of this research is to describe overview of KOMPSAT-3 geometric calibration, a description of the KOMPSAT-3 system, ground system and satellite system which the characteristics of the AEISS sensor and attitude GPS sensor such as star tracker, gyro, and GPS. Secondly, we explain the direct geo-referencing model of KOMPSAT-3. The KOMPSAT-3 IRPE system has two type of sensor model, one is direct sensor model based on look vector another is rational function model. Finally, we devoted to explain the geometric calibration and validation of KOMPSAT-3 ...

INTRODUCTION

The KOMPSAT-3(Korean Multi-Purpose Satellite 3) was successfully launched on 18 May 2012. KOMPSAT-3 is a lightweight Earth observation satellite developed by the Korea Aerospace Research Institute KARI. It will operate at an altitude of 685 km in a sun-synchronous orbit for 4 years and monitor the Korean peninsula using a payload capable of sub-meter class resolution. The mission objectives of the KOMPSAT-3 are to provide continuous satellite Earth observation after KOMPSAT-1 and KOMPSAT-2 and to meet the nation's needs for high-resolution EO (Electro-Optical) images required for GIS (Geographical Information Systems) and other environmental, agricultural and oceanographic monitoring applications.

The KOMPSAT-3 system consists of space segment, ground segment, and launch service segment, and various external interfaces including additional ground stations to support image data reception or launch and early operations. The space segment is a satellite consists of the spacecraft bus and payload. The main payload of KOMPSAT-3 is AEISS (Advanced Earth Imaging Sensor System). The AEISS is a high spatial resolution imaging sensor which collects visible image data of the earth's sunlit surface.
The AEISS is a pushbroom-scanned sensor which incorporates a single nadir looking telescope. The sensor is submerged and rigidly attached to the spacecraft and the optical bore-sight of the telescope is aligned with the spacecraft +Z direction (nadir). The AEISS collects panchromatic and multi-spectral images of the earth. At the nominal mission altitude with nadir attitude, the AEISS collects ground image with a ground sample distance of approximately 0.7 meter panchromatic and 2.8 meter multi-spectral data and swath width of greater than 15 km. The image telemetry data can be compressed on-board by ground command.
The Mission orbit of the KOMPSAT-3 is a sun-synchronous circular orbit with an altitude of 685.13 ±1 km. The Orbit inclination is 98.13 ± 0.05 degrees and the eccentricity from 0 to 0.001. The satellite operates with a nominal local time of ascending nodes of 13:30 AM +10/-15 min.
The major objective of this research is to describe overview of KOMPSAT-3 geometric calibration and explain the direct geo-referencing model of KOMPSAT-3. The KOMPSAT-3 IRPE system has two type of sensor model, one is direct sensor model based on look vector another is rational function model. Finally, we devoted to explain the geometric calibration and validation of KOMPSAT-3

KOMPSAT-3 SYSTEM DESCRIPTION

The KOMPSAT-3 system consists of the KOMPSAT-3 satellite including spacecraft bus and optical payload system, the KOMPSAT-3 ground segment and a launch service segment. The Table 1 and Table 2 describe orbit parameters and AEISS payload characteristics. The AEISS, payload for the KOMPSAT-3, is a high spatial resolution, visible imaging sensor that collects visible image data of the earth's sunlit surface. The AEISS can operate at up to a 10% duty cycle per orbit but maximum imaging time is limited to 10 minutes per orbit and 50 minutes per day.

Table 1: KOMPSAT-3 orbit and attitude parameters.

Parameters	Value
Nominal orbit altitude at the equator	685.13 km (Sun synchronous orbit)
Inclination	98.13°
Mean local time of ascending node	13:30
Repeat ground track	409 orbit per 28 day

Table 2: AEISS payload characteristic.

Item	Value
Design lifetime	4 years
Ground Sample Distance	Pan : 0.7 m @ altitude 685 km(nadir) MS : 2.8 m @ altitude 685 km(nadir)
Spectral Band	Pan : 450 ~ 900 nm MS1 (Blue): 450 ~ 520nm MS2 (Green): 520 ~ 600nm MS3 (Red): 630 ~ 690nm MS4 (NIR): 760 ~ 900nm
Swath Width	Pan : 15 km, MS: 15 km @ nadir
Modulation Transfer Function	System MTF at Nyquist frequency for PAN : 8% System MTF at Nyquist frequency for MS : 12% (at strip imaging mode)
Radiometric Resolution	14 bits

KOMPSAT-3 SENSOR MODEL

There are two types of sensor model for KOMPSAT-3, Direct Geo-Referencing Model and Rational Function Model (RFM). In general, a sensor model relates object coordinates to image coordinates. The direct geo-referencing model calculates the orbital parameters directly by using the position vector. Based on the collinearity condition, an image point corresponds to ground point using the employment of the orientation parameters, which are expressed as o function of the sampling time.
The RFM is a generalized sensor model that uses a pair of rations of two polynomials to approximate the condition equation.

DIRECT GEO-REFERENCING MODEL

The direct geo-referencing model of KOMPSAT-3 AEISS is realized on the co-linearity condition. The spacecraft perspective center, image point and the corresponding ground point are assumed to be on one straight line using five basic coordinate systems. The Figure 1 gives a description of direct geo-referencing model of KOMPSAT-3.

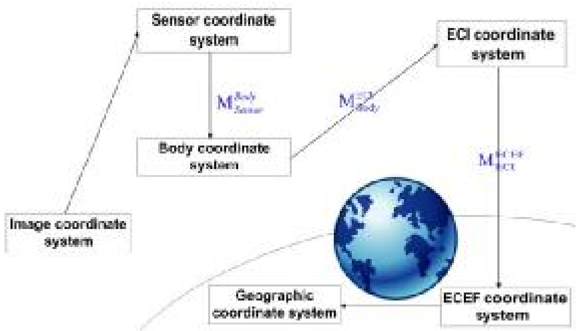

Figure 1: Direct geo-referencing model of KOMPSAT-3

- Image Coordinate System

The detector generates satellite image which consists of row and column. The image coordinate system starts from the top left corner. When imaging time increases, row numbers increases (+x). When pixel number increases, column number increases (+y).

- Sensor Coordinate System

The image coordinate (v, u) of the point in the image coordinate system to be transformed to (x, y, z) coordinate in the sensor coordinate system. The spacecraft of mass is located in origin of the sensor coordinate system. The z-axis points from the Earth center of mass to spacecraft center of mass. The y-axis is direction to the direction of spacecraft and the x-axis completes the right handed coordinate system.

- Body Coordinate System

The body coordinate system is fixed with the origin of the KOMPSAT-2 spacecraft on the center of mass. The coordinate axes are defined by the spacecraft attitude control system. The X-axis is the spacecraft axis in direction of velocity vector; Z-axis is the spacecraft toward nadir. The Y axis completes the right handed coordinate system.

- ECI Coordinate System

The Earth Centered Inertial (ECI) reference frame is an inertial reference frame having the center of the Earth as the origin of the coordinate system. This coordinate system is fixed with the reference to the stars and does not rotate with the Earth. The ECI reference frame is a right-handed Cartesian coordinate system where:

- The Z axis points along the direction of the North Celestial Pole.
- The X axis points along the direction of the vernal equinox.
- The Y axis is chosen to make the system right handed.

J2000 is one of inertial coordinate system. The epoch is 2000 January 1, noon or Julian ephemeris data 2451545.0. The origin is located at the center of the earth. The J2000 is aligned with the mean equator and equinox at the reference epoch J2000.

- The Z axis is parallel to the mean rotation axis of the Earth, at the epoch, from South to North Pole.
- The X axis points into the direction of the mean vernal equinox, i.e. the ascending node of the Earth's mean orbital plane on the mean equator, at the fixed epoch J2000.
- The Y axis is chosen to make the system right handed.

- ECEF Coordinate System

In general, the Earth Centered Earth Fixed reference frame is a rotating reference frame having the center of the Earth as the origin of the coordinate system. This coordinate system rotates with the Earth and is fixed with respect to its surface. The ECEF reference frame is a right-handed Cartesian coordinate system where:

- Origin in the Earth’s center of mass.
- Z axis points along the direction of the North Pole.
- X axis points along the direction of the intersection of the Equator and the Greenwich Meridian.
- Y axis is chosen to make the system right handed.

- Geographic Coordinate System

WGS-84 is the 1984 revision of the World Geodetic System. It defines an earth fixed global reference frame. It includes an earth model which is defined by a set of primary and secondary parameters. Each datum has been produced by fitting a particular mathematical Earth model (ellipsoid) to the true shape of the Earth (geoid) in such a way as to minimize the difference between the ellipsoid and the geoid over the area of interest.

- Geographic altitude is the distance from the point of interest to the reference ellipsoid, measured along the geodetic local vertical, and is positive for points outside the ellipsoid.
- Geographic longitude measured in the plane of the earth’s true equator from the prime (Greenwich) meridian to the local meridian, measured positive eastward.
- Geographic latitude measured in the plane of the local meridian from the Earth’s true equator to the geodetic local vertical, measured positive north from the equator.

The geodetic longitude is exactly the same as in ECEF, but the geodetic latitude is different from its correspondent spherical latitude. Geodetic latitude can differ from geocentric latitude by as much as 12 arc-minutes, which means at about 20km of northing distance.

The calculation of ground coordinates on an arbitrary image coordinate (u, v) is

$$\begin{bmatrix} X - X_s \\ Y - Y_s \\ Z - Z_s \end{bmatrix} = k \cdot M_{ECI}^{ECEF} \cdot M_{Body}^{ECI} \cdot M_{Sensor}^{Body} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (1)$$

Where,

M_{ECI}^{ECEF} : From ECI coordinate system to ECEF

M_{Body}^{ECI} : From body coordinate system to ECI coordinate system

M_{Sensor}^{Body} : From sensor coordinate system to body coordinate system

$[x, y, z]^T$: Scan line coordinate

$[X_S, Y_S, Z_S]^T$: Satellite position from ephemeris data

$[X, Y, Z]^T$: Ground coordinate

k : Scale factor

RATIONAL FUNCTION MODEL

The RPC for the KOMPSAT-3 AEISS sensor is generated from the resulted KOMPSAT-3 direct geo-referencing model using the rational function model. The RPC (Rational Polynomial Coefficients) generation in KOMPSAT-3 image processing system consists of 4 main parts as shown in Figure 2.

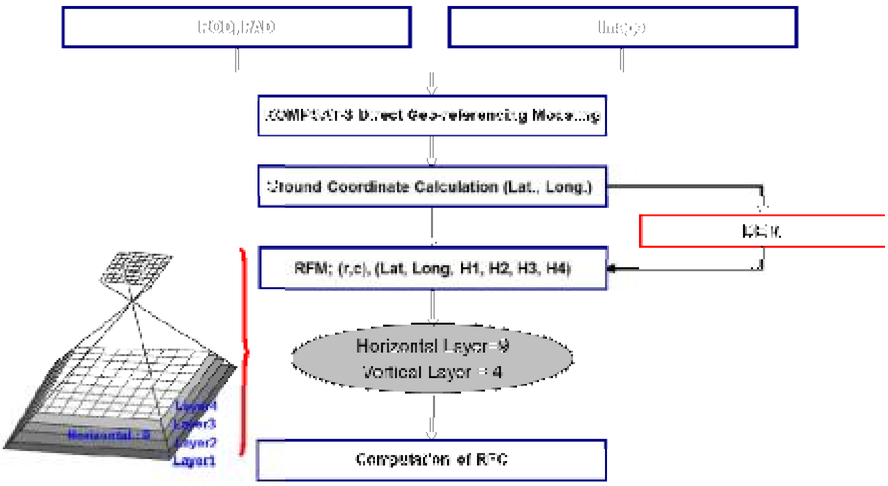

Figure 2. KOMPSAT-3 RPC generation workflow

The model uses a pair of rations of two polynomials, as shown in equation 2.

$$r_n = \frac{p1(X_n, Y_n, Z_n)}{p2(X_n, Y_n, Z_n)}, \quad c_n = \frac{p3(X_n, Y_n, Z_n)}{p4(X_n, Y_n, Z_n)} \quad (2)$$

Where,

r_n, c_n : the normalized row and column index of pixels in image.

X_n, Y_n, Z_n : the normalized coordinate value of object points in ground space.

$p1, p2, p3$ and $p4$: the polynomial coefficients

$$p1(X_n, Y_n, Z_n) = a_0 + a_1X + a_2Y + a_3Z + a_4X^2 + a_5XY + a_6XZ + a_7Y^2 + a_8YZ + a_9Z^2 + a_{10}X^3 + a_{11}X^2Y + a_{12}X^2Z + a_{13}XY^2 + a_{14}XYZ + a_{15}XZ^2 + a_{16}Y^3 + a_{17}Y^2Z + a_{18}YZ^2 + a_{19}Z^3$$

KOMPSAT-3 RFM is forward method which can be calculated from ground coordinate (Latitude, Longitude, Height) to image coordinate (Column, Row). Auxiliary file gives RPC parameters for "ground to image" location model.

A least-squares approach is utilized to determine the RPC a_n, b_n and d_n from a three-dimensional ground coordinates generated using the KOMPSAT-3 direct geo-referencing model. The basic relationship of the KOMPSAT-3 direct geo-referencing model that describes the ground coordinates in term of sensor coordinates is realized by the co-linearity condition in which the KOMPSAT-3 AEISS PAN perspective center, an image point and the corresponding ground point are assumed to be on one straight line. The 3D ground coordinates of object points in RFM are generated by intersecting the rays emanating from a 2-D grid of image with a number of constant elevation planes.

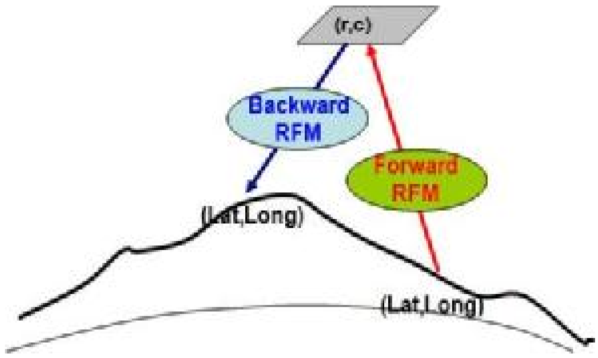

Figure 3: Rational Function Model of KOMPSAT-3

ON-ORBIT GEOMETRIC CALIBRATION AND VALIDATION OF KOMPSAT-3

The on-orbit geometric calibration of a system having as many sensors as a high resolution imaging satellite takes place over a period of time and is accomplished by the achievement of milestones events. It is this method that is used in this paper to describe the geometric calibration and validation process. The calibration and validation process have many experts involved in tuning and calibration of the sensor components that they are responsible. While a substantial amount of work is done in parallel by the geometric calibration team members on sensor components, there is also a sequential approach to bringing the system into calibration. For example: validation or calibration of satellite position and velocity, calibration of time synchronism between GPS sensor and other sensors such as star-tracker, payload etc. and the attitude determination systems must be calibrated prior to completion of the camera calibration. The milestone events of KOMPSAT-3 are following those;

- 2012 May 18 : KOMPSAT-3 launched
- 2012 May : Initial Calibration of the Attitude Determination System
- 2012 June 1 : Hybrid Orbit adjustment of KOMPSAT-3
- 2012 June 15 : Initial evaluation of location and pointing accuracy
- 2012 June 19 : Orbit maneuver and adjustment of time synchronism
- 2012 July 13 : Adjustment of PAD (precision attitude data)
- 2012 August 10 : Adjustment of sensor parameter of KPADS (KOMPSAT-3 Precision Attitude Data Sub-system)
- 2012 August 10 : Evaluation of location and pointing accuracy

CONCLUSIONS

This paper presents the KOMPSAT-3 satellite system and explains the sensor model of KOMPSAT-3. There are two types of sensor model for KOMPSAT-3, Direct Geo-Referencing Model and Rational Function Model (RFM). The direct geo-referencing model calculates the orbital parameters directly by using the position vector. Based on the collinearity condition, an image point corresponds to ground point using the employment of the orientation parameters, which are expressed as o function of the sampling time. The on-orbit geometric calibration of KOMPSAT-3 has proceeded through a series of steps concluding with the geometric camera calibration such as focal length adjustment, CCD distortion and CCD alignment.

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