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KOMPSAT-2 Orbit Determination using GPS SIgnals

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ABSTRACT

The Korea Aerospace Research Institute (KARI) has utilized the Global Positioning System (GPS) for determining the orbit information of KOMPSAT (KOrea Multi-Purpose SATellite) series, KOMPSAT-1 and KOMPSAT-2. At the circumstance of using only one ground station, the orbit determination using GPS signal is attractive area. The output of orbit determination is used for antenna tracking of ground station and information of image processing at KOMPSAT project. This paper shows two types of the orbit determination scheme of KOMPSAT-2 using GPS; the operational orbit determination and the precise orbit determination. For the operational orbit determination, the GPS navigation solutions from the GPS receiver on KOMPSAT-2 are used. The raw measurement data such as pseudo range and L1 carrier phase provided by GPS receiver on KOMPSAT-2 and GPS data generated by international GPS reference ground stations are used for the precise orbit determination. This paper describes orbit determination concept of KOMPSAT-2 and test configuration for verifying functions of the operational orbit determination and precise orbit determination. This paper also shows the experimental result of the operational orbit determination and the precise orbit determination using GPS at KOMPSAT-2.

KEYWORDS: KOMPSAT-2, GPS, Operational Orbit Determination, Precise Orbit Determination

1. INTRODUCTION

KOMPSAT-1 spacecraft was launched on 21 December 1999. The mission of KOMPSAT-1 is imaging of Korean peninsula and the resolution of KOMPSAT-1 is 6.6 m. The GPS navigation solutions from Motorola's Viceroy GPS receiver are used for KOMPSAT-1 orbit determination. The KOMPSAT-1 GPS receiver gathers worldwide navigation solutions and records it to mass memory of the satellite. And then later, it is dumped from the satellite as a primary measurement source. Because orbit determination of KOMPSAT-1 is based on navigation solutions calculating from pseudo range, the accuracy is limited but met to the mission of KOMPSAT-1.

Orbit determination scheme using GPS navigation solutions provides the static orbit information and reduce the position and velocity errors of the GPS navigation solutions. The primary errors of such as KOMPSAT-1 orbit are the errors of the geopotential model and that of the drag[1][2].

The KOMPSAT-2 will be launched in October 2005 and mission of the KOMPSAT-2 is high resolution imaging of Korean peninsula. The resolution of the satellite image is 1 m for panchromatic and 4 m for multi spectral camera.

The purpose of satellite orbit determination at KOMPSAT-2 is antenna tracking of ground stations to KOMPSAT-2 and image processing. The KOMPSAT-2 uses an Alcatel TOPSTAR 3000 GPS receiver for positioning and timing in normal operations at the satellite in orbit. GPS navigation solutions such as position and velocity, and GPS raw data such as C/A pseudo range and L1 carrier phase measurements are transmitted to the KOMPSAT-2 Ground Station(KGS) via playback of onboard mass memory. The KGS is located in Daejeon, South Korea.

Two types of orbit determination are performed at the KOMPSAT-2 using GPS data. One is the operational orbit determination using GPS navigation solutions and this is same technique to it of KOMPSAT-1. The other is the precise orbit determination using GPS raw measurement data by DGPS technique. A batch of the navigation solutions is used in the operational orbit determination, which is used for antenna tracking and image processing. A batch of the pseudo range and carrier phase data from the KOMPSAT-2 in orbit and the international GPS reference stations in ground are used at the precise orbit determination for the precise image processing.

In this paper, orbit determination for KOMPSAT-2 is described in the view of orbit determination concept, operational orbit determination and precise orbit determination. Test results using GPS simulator are described. Before KOMPSAT-2 will be launched on October 2005, the functional test for the operational orbit determination and precise orbit determination is verified. Parts of performance test are also described.

Review of test results is respected to be adapted to real orbit determination after the KOMPSAT-2 launching. It also can be a design input for GPS receiver of next KOMPSAT-3 satellite, KOMPSAT-3 will be launched in October, 2009.

2. ORBIT DETERMINATION

2.1 General Concept

Orbit determination is not simple at the mission of high imaging of low earth orbit satellite. The output of orbit determination in KOMPSAT-2 is used for the tracking of ground station antenna and image processing.

Because worldwide ground station network for satellite tracking and other tools such as laser are not used at KOMPSAT-2, orbit determination using GPS is one of good solution in this circumstance at this time. A cost and complexity for orbit determination is also decreased when GPS is used. Navigation solutions are generated by the onboard GPS receiver per 32 seconds interval. GPS raw data such as pseudo range and carrier phase are generated per 1 seconds maximum interval according to ground command. When commands are received from ground station, navigation solutions and GPS raw data are recorded on the mass memory of on board computer, and then when the KOMPSAT-2 is contacted with the KGS, the recorded data are dumped to the KGS.

Orbit determination concept is described in Figure 1. Alcatel TOPSTAR 3000 GPS receiver with two antennas of 8 channels is used for providing reference time signal, GPS navigation solution such as position and velocity, and GPS raw data such as C/A code pseudo range and L1 carrier phase[3]. The reference time signal is the time duration of 1 pulse per second and used for time synchronization between on board processors. GPS navigation solutions are used for the command reference of Attitude and Orbit Control System(AOCS) at satellite and the operational orbit determination at ground. GPS raw data are used for the precise orbit determination at ground, which is used for location information of 1 m resolution image.

There are two types of GPS navigation solutions in Earth Centered Earth Fixed(ECEF) coordinate system. One is the solution of snapshot mode and the other is the solution of DIOGENE mode using Kalman filter[4]. Generally, after navigation filter is converged, the solution of DIOGENE mode is better than it of snapshot mode.

In order to process precise orbit determination, GPS raw measurement data provided by the GPS receiver of KOMPSAT-2 and GPS data generated by international GPS reference station receiver of ground are required. GPS data generated by international GPS reference station receiver of ground are public via internet. The precise orbit determination software performs pre-processing to generate double differenced measurement data between GPS raw data of the KOMPSAT-2 and worldwide reference GPS reference station in 30 second interval. The precise orbit determination software estimates the precise orbit parameters using double differenced measurement data. The results of precise orbit determination are provided the user of image processing for the enhancement of the image quality and generation of value added products.

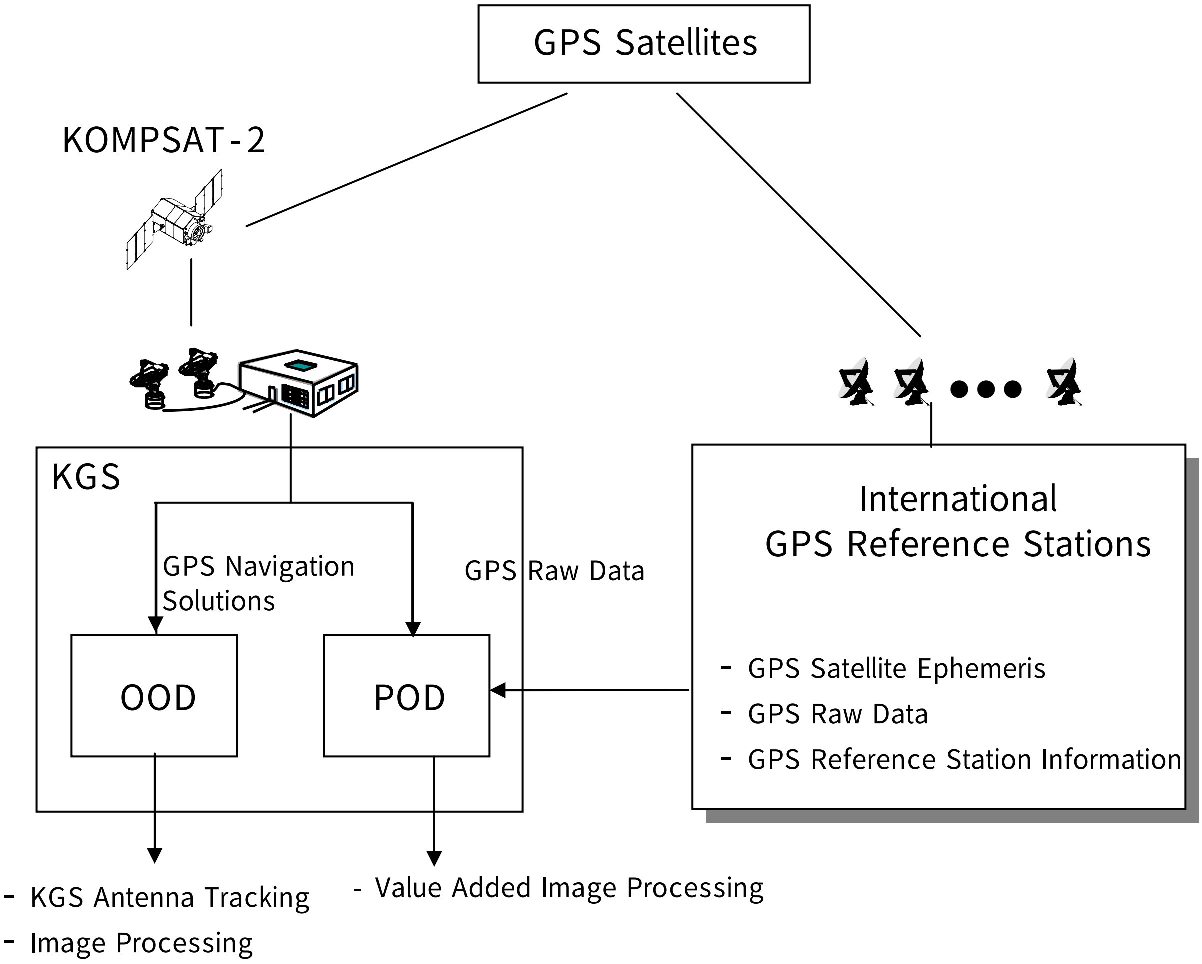


Figure 1. Orbit Determination Concept

2.2 Operational Orbit Determination

The operational orbit determination provides orbit of KOMPSAT-2 using GPS based navigation solutions from dumped telemetry. The operational orbit determination uses a batch type minimum variance estimator for deriving definitive orbit of the satellite. The operational orbit determination includes editing and smoothing the measurement data followed by a batch least square curve fit using iterative differential correction to optimize the estimated trajectory. As part of the optimization process, the corrected orbital elements are integrated in order to re-compute the residual data. GPS navigation solutions in ECEF coordinate system are transformed to True Of Date Earth Centered Inertial coordinate system.

The result of operational orbit determination is the estimation of spacecraft state for a specific epoch based on observational data obtained by GPS receiver. Gravitational, solar flux and drag error can be estimated when needed.

The operational orbit determination uses Cowell’s method, which is direct numerical integration of the satellite equations of motion in rectangular coordinates. The force models include the geopotential up to 70 X 70, the lunar solar potentials, solar radiation pressure, drag using Jacchia 71 model, and general accelerations. The numerical integration procedure is a predictor-corrector type[5].

The results of the operational orbit determination are used for antenna tracking of ground station and image processing for users.

2.3 Precise Orbit Determination

The precise orbit determination is composed of two parts. One is a pre-processing of the measurement data for error correction and double differenced data generation. The other is an estimation process based on dynamic parameters estimation and weighted least square batch filter[6].

Pre-processing performs pre-processing of measurement data for the error correction and double differenced data generation, and consists of cycle slip detection and repair, bad point detection and deletion, time tagging error correction, and differential GPS technique. Cycle slip detection and repair are forming cycle slip sensitive linear combinations of the available observable and detecting to fit a low order polynomial over the time series.

Estimation process is based on dynamic parameters estimation and weighted least square batch filter, and consists of dynamic modelling, measurement modelling, and estimation scheme. The GRAPHIC[7] and Total Electron Content(TEC) scale factor estimation[8] are used in orbit estimation process for the elimination or reduction of the ionospheric path delay in GPS measurements.

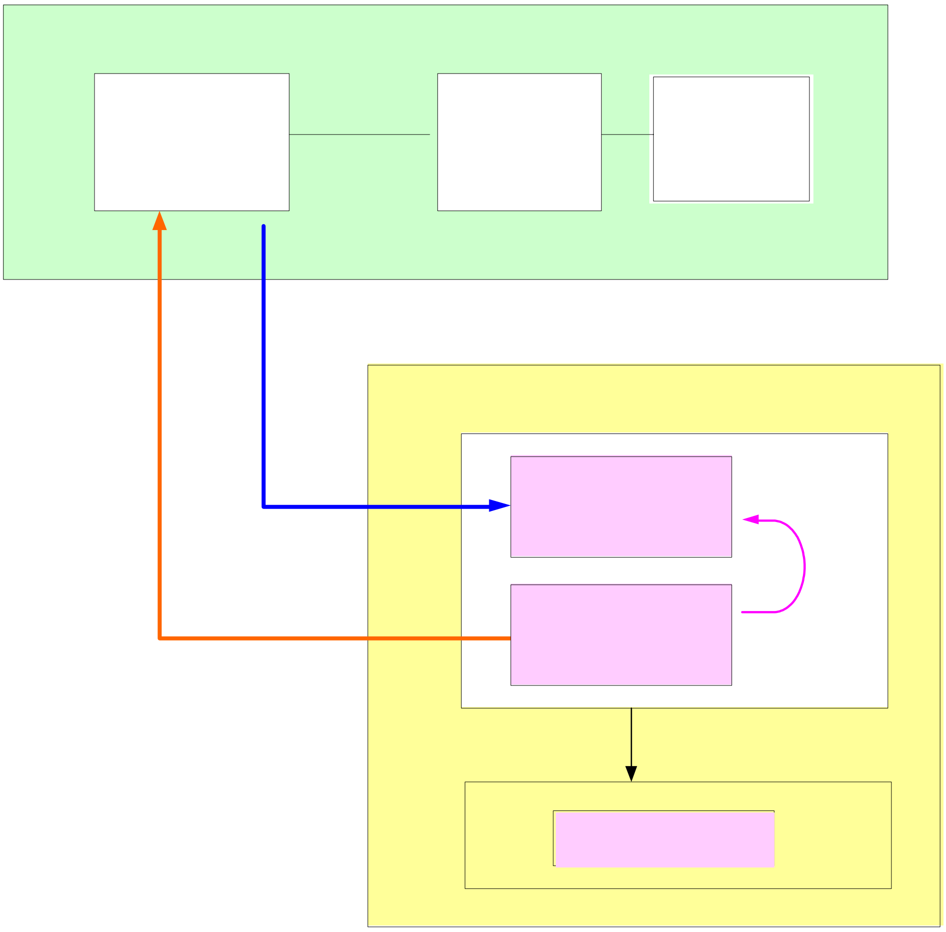
The precise dynamic models are derived as the equations of motion and variation equations of satellites and these are integrated numerically in J2000 reference coordinates. The equations of motion and the variation equations are numerically integrated using Adams-Cowell 11 th order predictor corrector method. The gravitational forces, sun and moon gravity, solid earth and ocean tides, relativistic effect, drag, solar radiation and earth radiation pressure are modelled.

GPS measurement models are composed of ionospheric delay, tropospheric delay, relativistic effect, phase center offset and variation of GPS receiver antenna, and position variation of the ground stations.

The epoch state batch filter, where all measurements obtained at different times are mapped to a single epoch in order to estimate the epoch state, has to be modified to be able to adjust the dynamic parameters such as coefficients of solar radiation, drag, and general acceleration, the measurement biases such as phase ambiguity and scale factors of TEC value, and station related parameters such as tropospheric zenith delay parameters at user specified subdivided epochs. Estimating the dynamic related parameters once per specific period has an important role on accounting for deficiencies in the dynamic models.

3. Test

Test configuration for the operational orbit determination and precise orbit determination is described in Figure 2. SPIRENT 4760 is used as GPS simulator in order to generate GPS signal[9]. TOPSTAR 3000 GPS receiver is equipped at the Engineering Test Bed(ETB). RF signal from GPS simulator is connected to TOPSTAR 3000 GPS receiver through RF cable. Validity and performance of navigation solutions from GPS receiver was verified. Position accuracy is less than 30 m, velocity accuracy is less than 0.03 m/s, and timing accuracy is less than 100 micro second at science mode. Tele Command Telemetry System(TCTS) performs communication with KOMPSAT-2 Ground Station.



The major parameters for test are as followings.

Epoch time : 2004. 05. 24. 00:00:00(UTC)
Semi major axis : 7054.203 km
Eccentricity : 0.0009071
Inclination : 98.05079 degree
Argument of Perigee : 44.60654 degree
Right ascension of ascending node : 75.28376 degree
Mean Anomaly : 313.44528 degree
Satellite mass : 798 kg
Drag coefficient : 1.5

3.1 Operational Orbit Determination

The performance of the operational orbit determination is similar to it of KOMPSAT-1 although the different GPS at the KOMPSAT-1 was used. The functional test was performed. The output of KOMPSAT-2 GPS receiver, navigation solutions are described in Figure 3 and Figure 4, respectively.

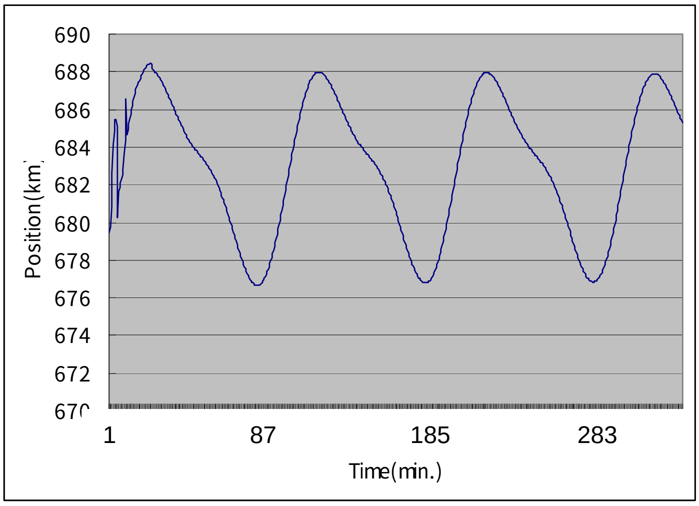


Figure 3. Position Solutions of KOMPSAT-2 GPS Receiver

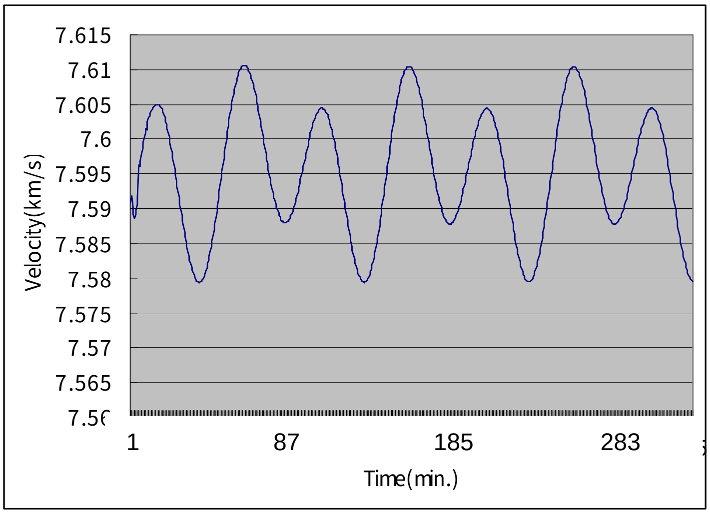


Figure 4. Velocity Solutions of KOMPSAT-2 GPS Receiver

After navigation solutions are processed at operational orbit determination software, the position accuracy is 4.45 m RMS and the velocity accuracy is 0.005 m/s RMS. According to test results, the error of along-track is most of all errors.

3.2 Precise Orbit Determination

In order to perform the precise orbit determination, RINEX-2 observation of the KOMPSAT-2, GPS satellites and international GPS reference ground station are needed. Because TOPSTAR 3000 GPS receiver doesn't provide KOMPSAT-2 RINEX-2 observation to GPS user, KOMPSAT-2 RINEX-2 generation software was developed by KARI. KOMPSAT-2 RINEX-2 generation software was verified at static circumstance of ground.
The purpose of this test is functional verification of precise orbit determination using GPS raw data of the KOMPST-2 and evaluates some performance of the precise orbit determination. Qualities of GPS raw data at the test are interested considering real operations later. Figure 5 and 6 are example of GPS raw data at KOMPSAT-2 GPS receiver of 685 km.

The value of pseudo range and carrier phase is relatively good at mission orbit. A little of cycle slips are observed.

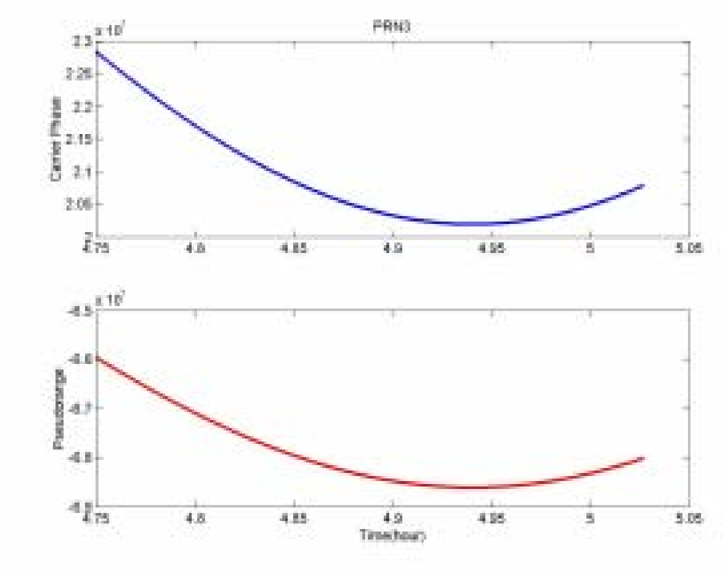


Figure 5. Quality of PRN 3 GPS Raw Data

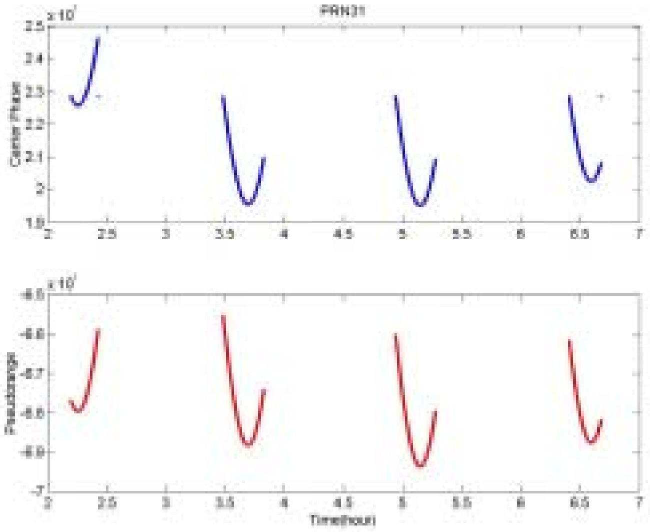


Figure 6. Quality of PRN 31 GPS Raw Data

Precise orbit determination using TOPEX/Poseidon and the CHAMP was already performed for verification of precise orbit determination software [5]. The difference between NASA GSFC Precise Orbit Ephemeris and precise orbit determination results using TEC are radial 6.9 cm RMS, along track 19.4 cm RMS, and cross track 6.9 cm RMS.

4. CONCLUSIONS

Orbit determination is an important to acquire the information for ground antenna tracking and image processing. In the case of using one ground station at a world, same as the case of KOMPSAT series, GPS based orbit determination is one of good solutions. To enhance the quality of GPS based orbit determination, precise orbit determination technique using double differenced GPS data is used at KOMPSAT-2.

Continuously, orbit determination using global navigation satellite system such as GPS and Galileo will be adapted to KOMPSAT series and tried to perform better quality and embodiment.

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