Evaluation of KOMPSAT-1 Orbit Determination Accuracy

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Abstract: For the normal operations, KOMPSAT-1 orbits are determined using GPS navigation solutions data such as position and velocity vectors. Currently, the accuracy of GPS navigation solution data is generally known as on the order of 10~30 m with the removal of S/A. In this paper, an estimate of the current orbit determination accuracy for the KOMPSAT-1 is given. For the evaluation of orbit determination accuracy, the orbit overlap comparison is used since no independent orbits of comparable accuracy are available for comparison. As a result, It is shown that the orbit accuracy is on the order of 5 m RMS with 4 hrs arc overlap for the 30 hr arc.

Keywords: KOMPSAT-1, Orbit Determination, GPS, Overlap

1. Introduction

The KOMPSAT-1 satellite was launched into a circular, sun-synchronous orbit on Dec. 21 1999. The primary mission goals are to collect earth images, multi-spectral images of the ocean, and to collect information about particle environment of the low earth orbit. The orbit characteristics for KOMPSAT-1 are shown in Table 1.

Table 1. KOMPSAT-1 Characteristic and Mean Orbital Elements(January 2003)

Parameter	Type/Value
Orbit Type	Sun-Synchronous
Period	98.25 min
Mean Altitude	669.38 km
Inclination	98.095^{o}
Eccentricity	0.00165
Argument of Perigee	88^{o}
Spacecraft Mass	437.97 kg
Cross-sectional Area	5.871 m^2

The satellite carries a Viceroy™ global positioning system (GPS) receiver that generates point position and velocity solutions on board [1]. These navigation solutions are nominally recorded at 32-s intervals and telemetered to the ground. The dumped GPS navigation solutions data is used for orbit determination (OD) at KGS (Kompsat Ground Station). For the normal operation, the MAPS (Mission Analysis & Planning Subsystem) is used to generate the KOMPSAT-1 ephemerides. The orbit determination system in MAPS was developed by ETRI (Electronics and Telecommunications Research Institute) based on the GEODYN II. In this OD system, Batch technique is employed using the high fidelity dynamic model. Apart from the MAPS, KGS at KARI employs the MicroCosm® (MC) orbit determination software as a part of the Flight Dynamics System. For the convenience of the work of OD and analysis, the MC was used to assess the KOMPSAT-1 orbit determination accuracy.

The MC is one of the high-precision orbit determination software that has been used for many missions such as Quickbird, Quikscat, AMSAT, GPS/MET spacecraft, etc. This software package is derivative and full implementation of the GEODYN II version 8609 precision orbit and geodetic parameter determination software system developed for NASA's Goddard Space Flight Center. The major difference between the two pieces of software are the MC is specially capable of determining precise GPS satellite orbits, whereas GEODYN II is a generic POD software. Moreover, the MC software incorporates more sophisticated preprocessing software that allows for the input of GPS data. The MC software components take into account the motion of the earth, luni-solar-planetary ephemeredes, reference site information, measurement modeling and related derivatives, data processing, force model and variational equations, integration and interpolation, a statistical estimation scheme, and data input and output utilities [2].

2. Method

The most difficult point in the work of OD for spacecraft is that we can never know the true orbit of the spacecraft. However, the following methods are usually carried out in order to assess the orbit accuracy [3].

(a) check O-C (O : observation, C : calculation)
(b) check the self consistency
(c) compare with other results obtained by using different software
(d) compare with other results obtained by other groups

As for (a), if the values of O-C are distributed randomly around zero, then we think our orbital determination is good and that only the noise component is shown in the distribution of O-C. As for (c), we have not another software that is comparable to the MC at present. As mentioned above, the MC is a derivative of GEODYN II. Thus, we do not compare with each other in order to assess the orbit accuracy. Moreover, We have no independent orbits of comparable accuracy for the KOMPSAT-1. In this paper, we only use the method (b) that will still be the best method for assessing the orbit accuracy. Moreover, the overlap method of determining orbit accuracy is always optimistic because of the presence of systematic errors with longer term effects.

To assess orbit accuracy in this paper, 30-hour solutions are generated centered on noon of a given day. This results in a 6-hour overlap of consecutive orbit determination solutions, as indicated in Fig. 1. The orbits in the center 4-hours of the overlap period are differenced. To avoid the "end effects" commonly encountered with reduced dynamic orbit determination, one hour segments from each end of the two solutions are omitted. This leaves a 4-hour overlap between two consecutive days for assessment of orbit determination accuracy. The difference between the orbits is a measure of orbit precision and is a rough indication of accuracy [4].

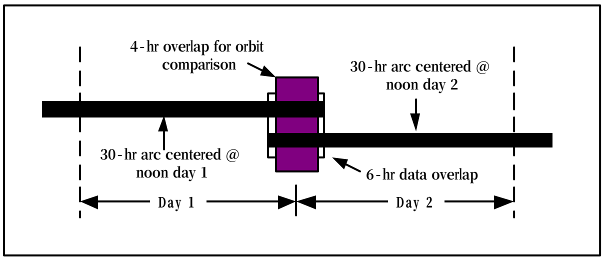

Fig. 1. Overlapping data arcs and Orbit Solutions

3. Orbit Determination Using Onboard GPS Navigation Solutions

Bayesian least squares estimation is used by MC for parameter determination. The method of least square is to minimize the mean square difference between the actual observations and computed observations of the orbit [2]. The dynamic models used in this study included gravity, point masses, solar radiation pressure, and atmospheric drag. The Joint Gravity Model field 2 (JGM-2) of degree and order 70 was used in the analysis for KOMPSAT-1 satellite. Solar and lunar point mass perturbations were included in the model as well. The Jacchia-71 atmospheric density model with 3-hourly geomagnetic indices was used and drag coefficient (Cd) was estimated as a part of the state.

The ground antenna tracking measurements, such as azimuth, elevation are collected as backup measurements. Moreover, range and range rate data are not available for the normal operation because of limited ground contact time at single ground station, KGS. Therefore, the only tracking data available from KOMPSAT-1 for the operational orbit determination at KGS, are the GPS navigation solutions.

The GPS navigation solutions are ECEF position and velocity vectors constructed internally from pseudo-range and pseudo-range rate or carrier phase information. The U.S Department of Defense deactivated selective availability (S/A) on the GPS signals on 1 May 2000. Thus, the precision of single frequency C/A code point positioning of Viceroy^{TM} receiver is expected to be about 10-30 m [1,5].

The root-mean-square (RMS) of the fit is often used to gauge the quality of the orbit solution. The solution RMS provides an indication of how well the orbit solution agrees with the tracking observations. Systematic errors in the dynamical model that are incompatible with the measurement model will results in poor RMS of fits. The "Weighted RMS" indicates the noise-only uncertainty of the solution. GPS point position data are definitely affected by systematic errors as well as noise [3].

Table 2 shows a sample of the statistics of orbit determination result with the 30 hour data set by measurement type. The results clearly indicate that the position-only solution fits much better than others in terms of 3-D Weighted RMS. It means we can achieve better orbit consistency with the position-only data than position/velocity data. It is clear in that the poor RMS and Weighted RMS of velocity-only solution indicates the quality of the GPS velocity data is not good enough to use for OD. Although the RMS of the position/velocity solution is slightly less than that of the position-only solution, it doesn't mean the accuracy is improved. Because, the formal standard deviation will be improved whenever the data of any kind are added. Table 3 shows the position difference between the position-only trajectory and other cases. The 3-D difference between the position-only and position/velocity is 16.768 m. Meanwhile, the 3-D difference between the position-only and velocity-only is 954.185 m. Consequently, only the GPS position data is used for operational orbit determination.

Table 2. OD statistics by measurement type

	3D Weighted RMS	RMS Position(m)	RMS Velocity(m/s)
Pos. Only	0.8651	0.725	0.00074
Pos. + Vel.	4.5663	0.707	0.00072
Vel. Only	2.2869	5.481	0.00564

Table 3. Position Difference by measurement type

Measurements	Radial(m)	Cross(m)	Along(m)	3-D(m)
P vs. P+V	0.363	5.289	15.908	16.768
P vs. V	6.646	155.701	941.372	954.185

4. Orbit Overlap Tests and Results

One hundred OD with the 30 hour fit span were performed for epochs between Nov. 1 2002 and Feb. 21 2003, excluding a few days where there are known problems (GPS 3-D fix loss). Consequently, 99 orbit overlaps were generated and compared. Figure 2, 3 show histograms of the RMS overlaps for KOMPSAT-1 satellite. The radial component is in the direction from the center of the earth to the spacecraft. Along track is roughly in the direction of the velocity vector and cross track completes the local orthogonal coordinate system. The statistics peak around the median values and are not normally distributed. The median RMS overlap values in radial, cross-track and along track directions are 1.5~2.0 m, 0.5~1.0 m, and 4.0~4.5 m respectively.

Most of orbit error is in the along track component. This means that the dynamic errors due to drag are expected to dominate the solution process. Meanwhile, the median RMS overlap values in position is 5~5.5 m as shown in Fig. 3. This RMS difference in position is almost same as the 3-D RMS difference in RCA Frame. As shown in Fig. 2 and 3, there exists some points apart from the median values up to 10~15m. This results from that the OD was performed using GPS navigation solutions that included more bad data than usual due to OBT (On-board Time) Jump in spacecraft.

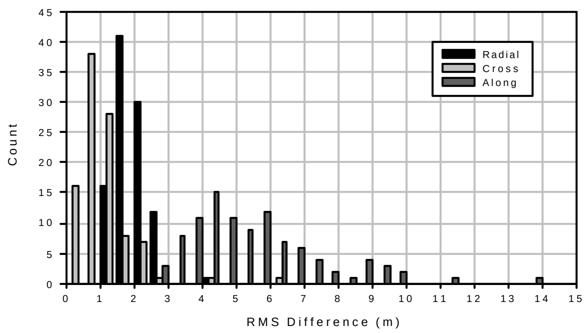

Fig. 2. RMS Overlap Statistics (Radial, Cross, and Along)

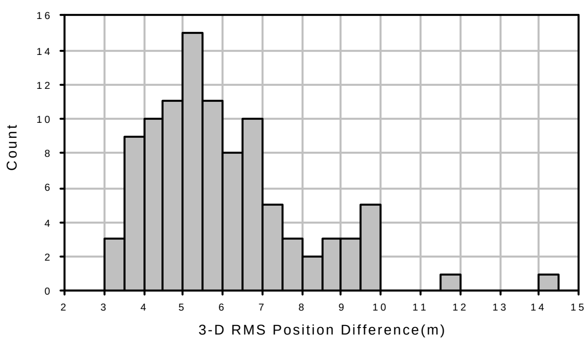

Fig. 3. RMS Overlap Statistics (3-D Position)

A sample of the orbit difference during the 4-hour overlap is shown in Fig. 4. These plots are representative of all 4-hr overlap between the 30-hr arcs that were performed in this work. The RMS difference in this case is 2.508 m in radial direction, 5.340 m in cross track direction, and 0.458 m in along track direction. As mentioned before, It is shown that the significant differences appeared in the along track direction, while the differences in radial and cross track direction show the sinusoidal curve with a slight increment. This can be attributed mainly to uncertainties and variations in atmospheric density that induces the general acceleration error in the along track direction. Thus, it is clearly that the along track component contributes to most of the error in RMS values of 3-D RMS orbit difference.

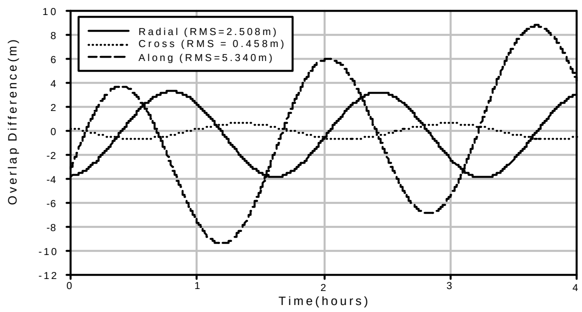

Fig. 4. 4 hour Overlap between the 30-hr arcs

5. Conclusions

Orbit determination accuracy for KOMPSAT-1 is evaluated by overlap comparisons of successive arcs. We have shown that the MC orbit determination system, using on-onboard GPS position-only data as a measurement, produced 30-h overlapping arc position errors on the order of 5 m RMS. This means that the KOMPSAT-1 position could be known to better than the original position data from GPS receiver that is expected to be about 10~30 m with the removal of S/A.

As a result, the Bayesian least squares estimation scheme employed by MC significantly improves the accuracy and precision of the orbit given by the GPS receiver.

Acknowledgement

The authors appreciate Mr. Tom Martin of Van Martin Systems, Inc. for his expert help in dealing with our questions regarding MicroCosm®.

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