Proceedings of International Conference on Astronomy and Space Science
Celebrating 20th Anniversary of Korea Space Science Society, Jeju, 2004

OPERATIONAL ORBIT DETERMINATION USING GPS NAVIGATION DATA

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(Received September 25, 2004; Accepted October 1, 2004)

ABSTRACT

Operational orbit determination (OOD) depends on the capability of generating accurate prediction of spacecraft ephemeris in a short period. The predicted ephemeris is used in the operations such as instrument pointing and orbit maneuvers. In this study the orbit prediction problem consists of the estimating diverse arc length orbit using GPS navigation data, the predicted orbit for the next 48 hours, and the fitted 30-hour arc length orbits of double differenced GPS measurements for the predicted 48-hour period. For 24-hour orbit arc length, the predicted orbit difference from truth orbit was 205 meters due to the along-track error. The main error sources for the orbit prediction of the Low Earth Orbiter (LEO) satellite are solar pressure and atmosphere density.

Keywords: operational orbit determination, GPS navigation data, fitted orbit, predicted orbit.

1. INTRODUCTION

The purpose of operational orbit determination (OOD) is to obtain the predicted orbit solution to be used in operation scheduling. For European Space Agency (ESA)'s European Remote Sensing Satellite (ERS)-1 and ERS-2 satellites, the operational orbit showed prediction errors ranging from approximately tens of meters up to more than several hundreds meters Root-Mean-Square (RMS) after single day's prediction in the along-track direction (http://nng.esoc.esa.de/ers/predtab.html). The Ice, Cloud and land Elevation Satellite (ICESat) was required to have 15 meters normal predicted error for two days near the North Pole (Meek et al. 2003). The orbit prediction error of the Korea Multi-Purpose Satellite-2 (KOMPSAT-2) was required to have 100 meters orbit differences for the following one day after orbit determination.

The orbit prediction primarily involves errors in the along-track direction. In some application such as instrument pointing, cross-track error relative to a target on the Earth is important. In this case along-track error prediction is equivalent to timing errors and mapping into cross-track errors due to the Earth rotation. Since obtaining an accurate orbit that yields accurate predictions is extremely significant we investigate the orbit differences from the truth orbit for along-track and cross-track directions.

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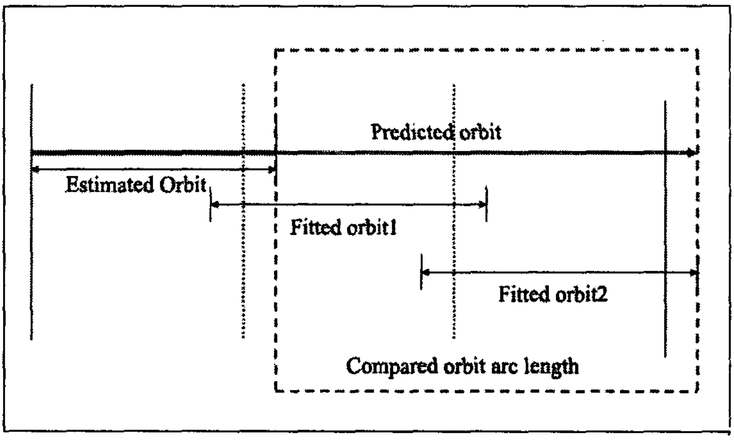

Figure 1. System design comparing the predicted orbit to the fitted orbit.

2. OPERATIONAL ORBIT DETERMINATION STRATEGY

Operational orbit used for prediction is estimated by a simpler dynamic model than is used for precise orbit determination (POD). A dynamic model approach based on continuous GPS navigation tracking data was used for the OOD in this research. The OOD for the Low Earth Orbiter (LEO) satellite was computed using MicroCosm (Martin 2000). MicroCosm uses a high fidelity dynamic model consisting of the following: 1) EGM-96 gravity model complete to degree and order 70, 2) Jacchia-71 atmospheric density model, 3) tabular data consisting of solar flux, geomagnetic data, and Earth orientation parameters (updated on a weekly basis), and 4) planetary ephemerides to account for n-body perturbations (Martin 2000, Meek et al. 2003). In addition, the position, velocity, one drag coefficient per arc and one solar pressure coefficient per arc were estimated.

The fitted orbits determined by the dual frequency double differenced carrier phase data by MicroCosm are considered as a "truth orbit" to be compared to the 48-hour predicted orbit. Data prepared for 30-hour arc length orbit solutions have 6-hour common overlapping periods. The 48-hour predicted arc is compared with the fitted orbits which have a 30-hour arc length with an overlapping period as shown in Figure 1. In the truth orbit, the estimated parameters are position, velocity, drag coefficient, solar pressure coefficient, and empirical acceleration in the along-track and cross-track directions which compensate for the mismodeled or unmodeled dynamic errors.

3. RESULTS

The orbits determined by GPS navigation data according to the different arc length were propagated for following 48-hour periods after the estimated orbit arc and compared to the fitted orbit. During the year 2002, the solar activity was high and GPS data were degraded by error factor such as ionospheric delay. Also the spacecraft was perturbed by solar activity.

Comparison of the predicted orbit and fitted orbit during the prediction period is one way to evaluate prediction accuracy. The predicted arc was generated with the estimated orbits which have 12-hour, 24-hour, 48-hour, and 72-hour arc length. Table 1 shows the orbit differences between truth orbit and the predicted 48-hour predicted orbit in a 3D sense. The orbit determined by 24-hour arc

Table 1. Two-day orbit prediction determined by LEO satellite navigation data (Units are meters).

Arc length	R	I	C	3D
12 hour arc	7.21	362.15	1.56	362.23
24 hour arc	6.58	205.35	1.87	205.46
48 hour arc	8.68	496.30	2.09	496.38
72 hour arc	6.33	607.95	2.31	607.99

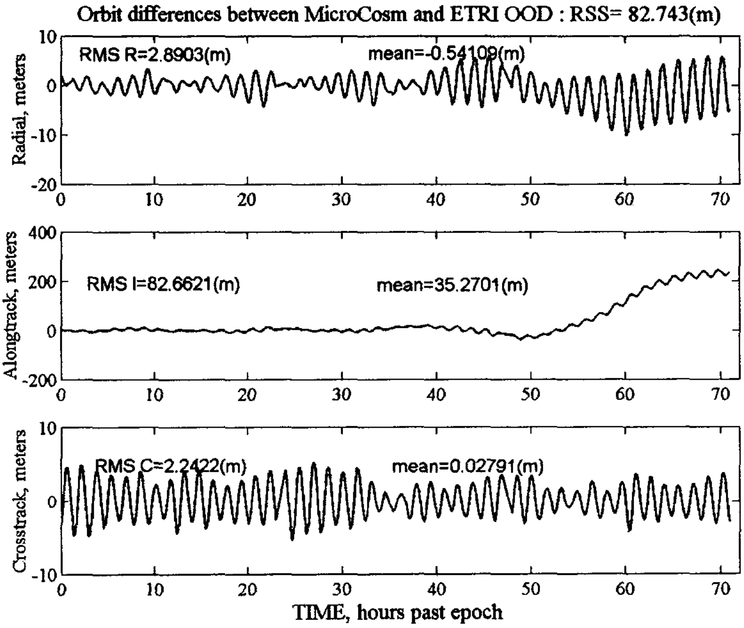

Figure 2. Orbit differences between MicroCosm OOD and ETRI OOD for CHAMP satellite from Jan 22, 2002 to Jan 25, 2002.

length shows minimum range difference by 205.5 meters, when the postfit residual of 24-hour arc orbit showed 2.2 meters RMS differences. The orbit prediction problem depends on the change of atmospheric density caused by solar radio flux (F10.7) and the geomagnetic indices Ap/Kp provided on a three-hour basis.

Figure 2 compares the propagated orbit between MicroCosm's OOD and ETRI's OOD results over three days, which includes both the fitted 24-hour arc length and predicted 48-hour periods. The orbit differences from the predicted 24-hour orbit shows consistent value within 10 meters Root-Sum-Square (RSS) in a 3D sense as shown in Figure 2. However, for 48-hour periods the predicted spacecraft ephemeris differed by more than 100 meters because the fitted measurements after 24-hour predicted orbit less affects to the orbit prediction. One of difference is due to slight differences in the polar motion models of MicroCosm and ETRI's tool in transforming the coordinates such as true-of-date or inertial J2000 frame.

Figure 3 shows the orbit differences using Differenced Range Versus Integrated Doppler (DRVID) carrier phase data between truth orbit and the predicted 48-hour orbit in a 3D sense. Although empirical acceleration estimate is helpful in generating accurate solutions for the fitting interval, they do not show consistent result during the orbit prediction periods (Lee et al. 2002). Therefore, the

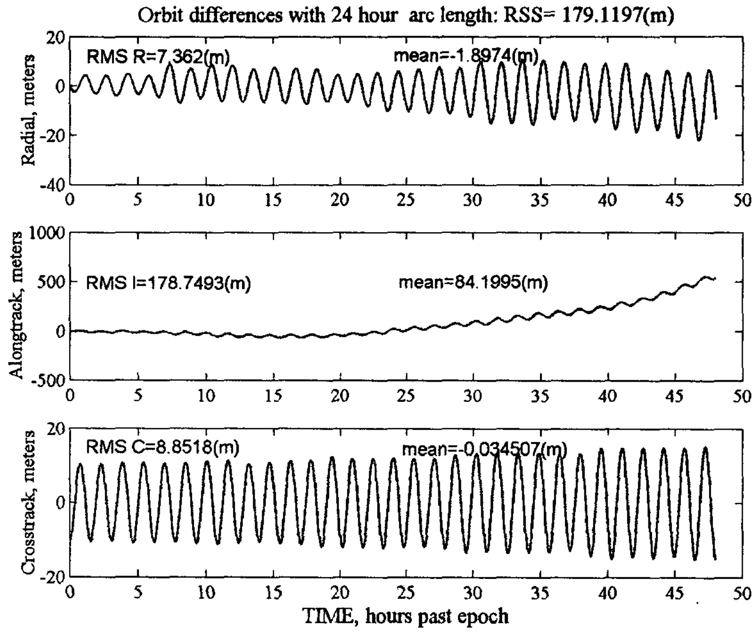

Figure 3. Orbit differences between truth orbit and 48-hour predicted orbit using DRVID carrier phase data for CHAMP satellite from Jan 23, 2002 to Jan 25, 2002.

fitted orbit was estimated by position, velocity, drag coefficient, and solar pressure coefficient.

Figure 3. Orbit differences between truth orbit and 48-hour predicted orbit using DRVID carrier phase data for CHAMP satellite from Jan 23, 2002 to Jan 25, 2002.

4. CONCLUSIONS

The maximum RSS of the along-track and cross-track prediction error for 48 hours of orbit prediction due to a one-sigma adjustment was 200 meters with 24-hour arc length during high solar activity. The requirement, which is 100 meters orbit differences for the following one day after orbit determination, of the orbit prediction error of the KOMPSAT-2 above 600 km altitude is satisfied with the simulation of the CHAMP satellite at altitude 450km when we consider that the prediction error sources for the orbit prediction are solar pressure and atmosphere density for the LEO satellite.

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