PRECISE ORBIT DETERMINATION FOR ALOS AND THE ACCURACY VERIFICATION BY SLR

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Abstract
The Advanced Land Observing Satellite (ALOS) has been developed to contribute to the fields of mapping, precise regional land coverage observation, disaster monitoring, and resource surveying. Because the mounted sensors need high geometrical accuracy, precise orbit determination for ALOS is essential. So ALOS mounts the GPS receiver. This paper deals with the precise orbit determination experiments for ALOS using Global and High Accuracy Trajectory determination System (GUTS) and the evaluation of the orbit determination accuracy by Satellite Laser Ranging (SLR) data.

1 Introduction
Japan Aerospace Exploration Agency (JAXA) launched “DAICHI”, from the Tanegashima Space Center in Japan on 24 January 2006. ALOS performs Earth observation at a high resolution, which is expected to contribute to a wide range of fields such as map compilation, region observation, grasp of disaster situation and resource mapping. ALOS has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather land observation. In order to fully utilize the data obtained by these sensors, ALOS is designed with two advanced technologies: high speed and large capacity mission data handling technology and precision spacecraft position and attitude determination capability. These technologies will be essential to high-resolution remote sensing satellites in the next decade [1][2].

To achieve the high geometrical accuracy required for ALOS’s sensors, we need to determine ALOS’s orbit very accurately. For this purpose, ALOS carries a double frequency GPS receiver. Precise orbit determination for low orbit satellite using GPS receiver data has been widely studied. The orbit determination for GRACE: (Gravity Recovery And Climate Experiment, managed by National Aeronautics and Space Administration (NASA) and Deutschen Zentrums für Luft- und Raumfahrt (DLR)) and CHAMP (CHAllenging Minisatellite Payload, managed by GFZ) has been reported to achieve a few centimeters accuracy[3][4]. JAXA has developed a precise orbit determination system (GUTS) from 1995. We performed precise orbit determination experiments for ADEOS-II carrying a single frequency GPS receiver and achieved 23 cm accuracy [5]. In the experiments using GRACE’s double frequency GPS receiver data, we achieved 8 cm accuracy compared with the result of DLR [6]. And also in GPS satellites’ orbit determination, we achieved 7cm accuracy compared with the ephemeris released by the International GNSS Service (IGS).

The orbit determination accuracy required for ALOS is within one meter, which is not considered to be difficult to achieve. But the GPS receiver loses lock of GPS signals more frequently than expected, and there are long period during which the receiver locks less than four GPS satellites. In order to determine the position and time using GPS signals, it is required that the GPS receiver receive signals from at least four GPS satellites. Because of this, when we deal with ALOS’s GPS receiver data same as other GPS receivers’ data, the orbit determination accuracy is less than instances of orbit determination using double frequency receiver data. So we preformed orbit determination using as much data as possible by conducting the preprocessing appropriately.

Because the ALOS onboard GPS receiver was newly developed, we need to evaluate the data received from the receiver. For this purpose, ALOS has a Laser Reflector (LR) composed of eight Corner Cube Reflectors (CCRs ) for SLR operations. We performed orbit determination using only SLR data and compared
the SLR-determined orbit with the orbit determined by GPS data.

2 Mission Requirement of ALOS

For precise mapping using satellite imagery, it is necessary to observe the earth with high resolution and determine the geographical positions corresponding to the observation image. Thus, high positioning accuracy and pointing control accuracy are required for ALOS [7], [8], [9], [10]. The accuracy requirements for satellite attitude and pointing control are shown in Table 1. Taking these errors into account, the orbit determination accuracy is required to be better than 1 meter (peak-to-peak). There are two tools for precise orbit determination for ALOS; GPS receiver and laser reflector (LR) for Satellite Laser Ranging (SLR). ALOS’s GPS receiver was newly developed for its mission. Detailed explanation of GPS receiver is described in Toda et al [11].

<table>
<thead>
<tr>
<th>Pointing Accuracy</th>
<th>Control</th>
<th>Roll, Pitch, Yaw: ±0.1 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>Short</td>
<td>Roll, Yaw: 2.0×10-5deg/0.37ms (peak-to-peak) Pitch:1.0×10-5deg/0.37ms (peak-to-peak)</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>No DRC Drive: 2.0×10-4 deg/5s (peak-to-peak) With DRC Drive: 4.0×10-5 deg/5s (peak-to-peak)</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td>Roll, Pitch, Yaw: ±2.0×10-4 deg</td>
</tr>
</tbody>
</table>

3 System Configuration of GUTS

Fig. 2 shows the system configuration of GUTS. GUTS receives onboard GPS receiver data from JAXA Earth Observation Center (EOC) and GPS ground stations data from JAXA GPS ground station control and the IGS ftp server. The system is mainly composed of three functions: preprocessing, preliminary orbit determination, and precise orbit determination. We use GPS data (RINEX) as observation data and determine the satellite’s orbit by estimating some parameters of Dynamical Model and Observation Model. We perform preliminary orbit determination using GPS navigation data and ALOS onboard GPS data (point positioning data), and use the orbit as the initial orbit for precise orbit determination.

3.1 Preprocessing

Before precise orbit determination, GUTS Performing to collected data as follows.

- correction of clock offset of onboard GPS receiver data
- detection and correction of cycle slip of onboard and ground GPS receiver data
- correction of ionospheric delay
- smoothing and compression

3.2 Preliminary Orbit Determination

GUTS estimates the initial orbit from RINEX navigation data for GPS satellites and from point positioning data for ALOS.

3.3 Precise Orbit Determination

In GUTS precise orbit determination, we use GPS data (carrier phase measurements from RINEX) as observation data and determine the orbit by estimating some parameters of Dynamical Model and Observation
Model by SRIF (Square Root Information Filter). First, the selected GPS satellites’ orbits are estimated by using the coordinates of the ground stations published by the IGS (SINEX). Then, ALOS orbit is estimated using the determined GPS satellites’ orbits. The detail is omitted here, and the outline is described below.

3.3.1 Dynamical Model

Dynamical Model is a set of forces acting on the satellite and is used for propagating the satellite's orbits. The detail is shown in Tab.1.

3.3.2 Observation Model

The Observation data used for GPS satellites’ orbit determination is calculated from ground stations’ GPS receiver data and includes various observation errors other than geometric distances between GPS satellites and ground stations. In order to correct these errors, some factors are modeled. Modeled factors are described in Tab.2.

3.3.3 Estimation Parameters

GUTS can estimate not only orbital elements but also various parameters described above. The estimated parameters for ALOS orbit determination are shown in Tab 3. Note that in GPS satellites orbit determination, the GPS satellite position is estimated assuming that the positions of the GPS receivers (ground stations) are fixed, and in ALOS orbit determination, onboard GPS receiver’s position is estimated assuming that the positions of the GPS satellites are fixed.

4 Features of ALOS onboard GPS Receiver Data

Considering the performance of GUTS described in section 1, it is not so difficult to fulfill the requirement for orbit determination accuracy, if the ALOS onboard GPS receiver locks onto four or more GPS satellites signals constantly. However, the ALOS onboard GPS receiver frequently loses GPS satellites signals because of electromagnetic interference with other sensors. Because of this problem, the ALOS onboard GPS receiver often can not locks onto four or more GPS satellites signals.

4.1 Interference Problem

PALSAR, mounted on ALOS, is a radio wave sensor using L band. There was a concern about radio disturbance due to electromagnetic interference because the transmission frequency (1270MHz) was close to L2 frequency (1227.6MHz) of the GPS receiver. To deal with this problem, an interface was established between
Tab. 3 Estimation Parameters

<table>
<thead>
<tr>
<th>Orbital Elements</th>
<th>GPS Satellites Orbit Determination</th>
<th>ALOS Orbit Determination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Six Elements</td>
<td>Six Elements</td>
</tr>
<tr>
<td>Solar Radiation Pressure</td>
<td>GPSM.04b(Scale Factor, y bias) CODE(D0, Y0, B0, Z0)</td>
<td>Solar Radiation Pressure Scale Factor (10 minutes interval)</td>
</tr>
<tr>
<td>Atmospheric Drag</td>
<td>Receiver Clock Offset</td>
<td>Receiver Clock Offset</td>
</tr>
<tr>
<td>Clock</td>
<td>Estimate</td>
<td>Estimate</td>
</tr>
<tr>
<td>Carrier Phase Bias</td>
<td>Wet zenith tropospheric delay</td>
<td></td>
</tr>
<tr>
<td>Tropospheric Delay</td>
<td>Empirical Acceleration</td>
<td></td>
</tr>
</tbody>
</table>

PALSAR and GPS receiver so that the receiver will stop receiving L2 signal when the PALSAR signal is transmitted. As shown in Figure 3, GPS receiver stops receiving GPS signals while PALSAR is active. By this method, Electromagnetic interference between GPS and PALSAR was avoided successfully. However, another unexpected electromagnetic interference was observed between the ALOS GPS receiver and other ALOS instruments. This electromagnetic interference caused the GPS signals to be lost when the operations of ALOS sensors increased. In satellite positioning using GPS, at least four GPS signals are required to determine the position and time. So this interference problem causes a degradation of orbit determination accuracy.

As is shown in Figure 5, the number of acquired GPS satellites was four or less during the most of the period and the number of GPS satellites useful for orbit determination further decreased due to erroneous data. The maximum value of vertical axis is six satellites because the GPS receiver has six reception channels for both L1 and L2.

4.2 Parameter Tuning for Preprocessing

As shown in Fig.5, 6, the percentage of the orbit determination using four or more GPS satellites was 35.7%, when we counted the number of GPS satellites used for the orbit determination per 60-second period of GPS data. The percentage of four or more GPS satellites tracked, calculated based on RINEX data, is 56.6%. We modified the following parameters of preprocessing to use as much data as possible for orbit determination.

- maximum data loss time for pass regarded as continuous: A pass is divided if it is longer than this time.
- minimal time for pass regarded as effective: A pass is rejected if it is shorter than this time.
- time for carrier smoothing

GUTS performs carrier smoothing as follows.

- Calculate the difference between ionospheric free combination pseudorange data and ionospheric free combination carrier phase data
- Take the average of the difference over a certain period
- Make a new pseudorange data by adding the average to the ionospheric free combination carrier phase data

![Fig. 3 Interface between PALSAR and GPS Receiver](image)

![Fig. 4 Data Rejection Rate](image)
5 Experiments

5.1 Execution Condition

We used 40-hour data for orbit determination (30-sec interval data for ground GPS receiver data and 1-sec interval data for the ALOS onboard GPS receiver data). The used preprocessing parameters are shown in Tab.4.

Tab. 4 Preprocessing Parameters

<table>
<thead>
<tr>
<th>Condition</th>
<th>Time[sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum data loss time</td>
<td>2</td>
</tr>
<tr>
<td>for pass regarded as continuous</td>
<td></td>
</tr>
<tr>
<td>minimal time for pass regarded as effective</td>
<td>120</td>
</tr>
<tr>
<td>time for carrier smoothing</td>
<td>60</td>
</tr>
</tbody>
</table>

5.2 Accuracy Evaluation

The orbit determination arcs have 16-hour overlap period as shown in Fig.7. We compared the two determined orbit during the overlap period (6-hour overlap period excluding the first and last five hours) and the maximum absolute difference in the period was used for orbit determination accuracy. This evaluation is comparative, but can be used for evaluation of random errors of orbit determination.

ALOS carries a LR for SLR. We also performed absolute evaluation by taking differences between SLR-data -based range to ALOS and orbit-determination (using GPS data)-based range to ALOS (O-C). In addition, we performed ephemeris comparison between orbit determined by only SLR data and orbit determined by only GPS receiver data. In SLR-based orbit determination, we chose a period in which relatively a larger amount of data was acquired and estimated the orbit in short arc. Despite this, SLR-based orbit was less accurate during the period without SLR data. So we evaluated ephemeris comparison during the period with SLR data.

6 Results

By tuning the preprocessing parameters, the percentage of period in which the ALOS onboard receiver locked onto four of more GPS satellite signals increase from 35.7% to 49.5%. The result of overlap evaluation is shown in Fig.8. As shown in this figure, orbit determination accuracy is less than about 30-centimeters and better than before tuning.

Tab.5 Comparison with SLR-based orbit

<table>
<thead>
<tr>
<th></th>
<th>Radial</th>
<th>Cross-Track</th>
<th>Along-Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average(cm)</td>
<td>-2.98</td>
<td>-4.69</td>
<td>-5.44</td>
</tr>
<tr>
<td>Standard Deviation(cm)</td>
<td>20.54</td>
<td>38.32</td>
<td>28.76</td>
</tr>
</tbody>
</table>

Fig.7 orbit determination arc and overlap period
The result of O-C evaluation using all 14-day SLR data is that the averaged difference is -4.78-centimeter and the standard deviation is 12.03-centimeter. This means that, other than small errors, there is no inconsistency between the SLR-data-based range to ALOS and orbit-determination (using GPS data)-based range to ALOS.

The result of ephemeris comparison is shown in Tab. 5. The averaged differences are within the values of standard deviation in all directions. This result shows that the GPS-based orbit is consistent with the SLR-based orbit considering the 1 sigma error. In other words, the averaged differences can not be regarded as offsets between the GPS-based orbit and the SLR-based orbit, because the standard deviations are larger than the averaged differences. And considering the 1 sigma error, orbit determination accuracy of one meter (peak-to-peak) was achieved.

7 Conclusion

We performed orbit determination for ALOS, which carries a dual-frequency GPS receiver, and evaluated the accuracy by overlap method and comparison with SLR data. The ALOS onboard GPS receiver has a problem of electromagnetic interference with other onboard sensors and because of the problem, often loses lock onto GPS satellite signals. We performed preprocessing parameter tuning and tried to use as much data as possible. After parameter tuning, period of locking more than four satellites is not enough, but we achieved 1 meter orbit determination accuracy.

References