Precise Orbit Determination of GPS using Bernese GPS Software

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Abstract

The International GNSS Service (IGS) has managed the global GNSS network and provided the highest quality GNSS data and products, which are GPS ephemerides, clock information and Earth orientation parameter, as the standard for GNSS. An important part of its works is to provide the precise orbits of GPS satellites. GPS satellites send their orbit information (broadcast ephemerides) to users and their accuracies are approximately 1.6 meters level, but those accuracies are not sufficient for the high precise applications which require millimeters precision. The current accuracies of the IGS final orbits are within 5 centimeters level and they are used for Earth science, meteorology, space science, and they are made by the IGS analysis centers and combined by the IGS analysis center coordinator. The techniques making the products are very difficult and require the high technology. The Korea Astronomy and Space Science Institute (KASI) studies to make the IGS products. In this study, we developed our own processing strategy and made GPS ephemerides using Bernese GPS software Ver. 5.0. We used the broadcast ephemerides as the initial orbits and processed the globally distributed 150 IGS stations. The result shows about 6 to 8 centimeters in root-mean-squares related to IGS final orbits in each day during a week. We expect that this study can contribute to secure our own high technology.

Keywords: GPS, IGS product, ephemerides, POD

1. Introduction

GPS was developed for the purpose of the American military navigation, but the application area has been expanded, e.g. the real-time navigation for the vehicle, Earth sciences using the post-processing method and so on. IGS (International GNSS Service) was officially recognized by IAG (International Association of Geodesy) in 1993 and began officially since January, 1994 [1]. The main roles of IGS are to manage the global tracking network and to generate the IGS products. The IGS products are consist of the GPS and GLONASS satellite ephemerides, the clock information of the satellite and stations, the Earth rotation parameters, the positions and velocities. These high precision products have largely improved the precision of the processing result, so that the Earth science and many applications have grown. Especially, the improvement of GNSS satellite orbits plays an important role.

The broadcast ephemerides, transmitted by GPS satellites, have the accuracy level in about 1.6 m. This accuracy level is not sufficient to get high precision result, milli-meter level, and to research the Earth science area, because the accuracy of ephemerides affects the results [2]. Currently, IGS generates 3 types GPS ephemerides, the final, rapid and ultra-rapid orbit and the final orbit has the accuracy within 5 cm [3].

The IGS high-precise orbits are generated by the IGS ACs (Analysis Center) and combined by the IGS ACC (Analysis Center Coordinator). Finally, the products are provided by IGS and the IGS GDCs (Global Data Center) [4]. The each IGS AC, generating the products, has its own processing strategy and the best skills and techniques in the world. In Korea, the research about the techniques related to generate IGS products including the precise GPS ephemerides has studied to generate more accurate IGS products.

In this study, we made the processing strategy based on the current IGS ACs's strategies and our own experience of the processing GPS data. The 150 IGS stations are selected for our mission and the data set from 31, October, 2004 to 6, November, 2004, were used to process. The results were compared with IGS final, rapid and ultra-rapid orbits and were provided the accuracy which is about 6-8 centimeters in root-mean-squares. This study would help to secure our own techniques generating the fundamental products and to prepare the application of Galileo system which will have full constellation in 2010.

2. IGS products and the IGS ACs

2.1 The generation of IGS products

Figure 1. The Procedure of Generating IGS Products [5]

Currently, the IGS products are generated by 10 IGS ACs. Figure 1 shows the procedure generating the official IGS products. The each IGS analysis center (AC) makes its own products and sends them to ACC. IGS ACC combines the products of each AC to make the final IGS products and sends to IGS and the IGS GDCs. The final IGS products are provided by the IGS and GDC via internet for GNSS user communities.

2.2 IGS Analysis Centers

There are 10 IGS ACs which are CODE, ESOC, GFZ, JPL, NOAA, NRCan, SIO, USNO, MIT and GOP. GFZ is also in charge of the IGS ACC [6]. Table 1 shows their countries and the name of each institute. We can see that the countries, operating the IGS AC, are U.S.A., Canada, Germany, Switzerland and Czech and they are located in North America and Europe.

Table 1. The Country and the processing software of Each AC

ACs	Country	Software
CODE	Switzerland	Bernese 5.0
ESOC	EU	BAHN, GPSOBS, BATUSI
GFZ	Germany	EPOS.P.V2
JPL	U.S.A.	GIPSY/OASIS-II
NOAA	U.S.A.	Page5
NRCan	Canada	GIPSY/OASIS-II 2.6, Bernese 4.2
SIO	U.S.A.	GAMIT 9.72, GLOBK 4.17
USNO	U.S.A.	GIPSY/OASIS-II 5.5
MIT	U.S.A.	GAMIT 10.02, GLOBK 5.08
GOP	Czech	Bernese 5.0(beta)

The 3 major GPS data processing software, Bernese GPS software (developed by university of Bern), GIPSY/OASIS (developed by JPL) and GAMIT (developed by university of MIT), or their own processing sowftwares are used for generating the AC products.

Table 2 was written based on the CODE analysis strategy summary in 2002 [7]. CODE generates all IGS core products and ses Bernese GPS softaware which is used in this study.

Table 2. CODE's main processing strategy

Items	Strategy
Modeled observable	Double difference, Combination of L1 & L2
Troposphere estimation	Dry & Wet Niell
Ambiguity	QIF (<2000 km) the pseudorange, or Melbourne-Wuebbena (>2000 km)
Geopotential	JGM3
Integration interval	1 hour
Solar radiation pressure	ROCK4 and ROCK42
Adjustment	Weighted least-squares algorithm
Station coordinates	IGS00

3. The Processing Strategy

3.1 The used IGS sites and models

The key point to select the sites for the precise products is to make globally well distributed, dense network, because the performance is proportioned to the length of baselines when the double difference method is used to process the data [8]. In this processing, the globally distributed 150 IGS stations are selected like the Figure 2 and they are divided by 15 clusters.

A priori ephemeris and clock corrections are derived from GPS navigation message. The IGS ultra-rapid EOPs, predicted parts, were used to a priori information.

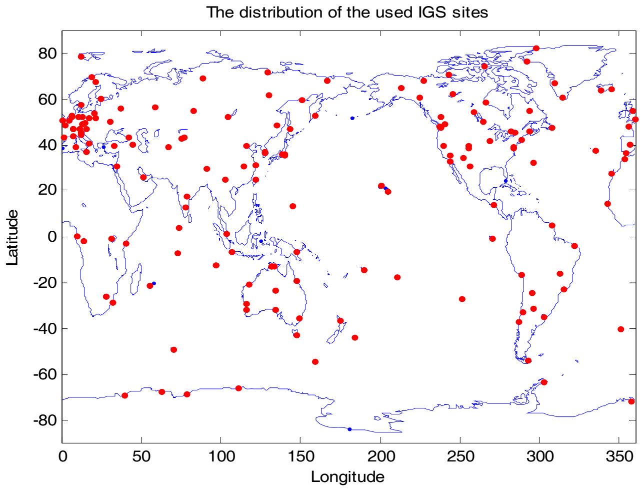

Figure 2. The distribution of the used IGS stations

The IGS uses its own realization for the reference frame of the products since ITRF97 [9]. The current reference frame used for IGS products is IGS00b since 11th, January, 2004. The used reference frame and the other models used in this processing are given in Table 4.

Table 4. The used models for KASI's processing

Items	Model
Reference system	J2000
Reference frame	IGS00b
Troposphere estimation	Dry and wet Niell
Geopotential	JGM3
Ocean loading	OT_CSRC
Subdaily pole model	IERS2000
Nutation model	IAU2000
Antenna PCV	IGS relative PCV model
Ephemeris model	JPL DE200

3.2 The procedure of the processing

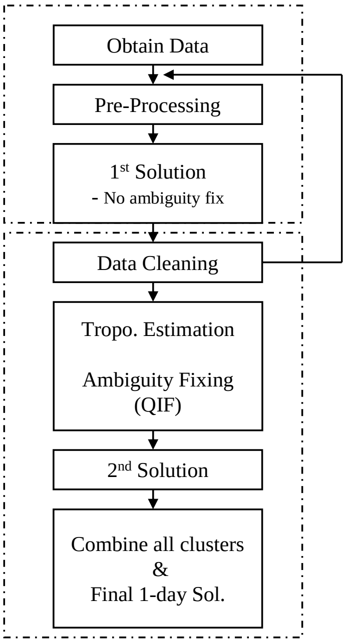

Figure 3. The flowchart of the data processing

The Figure 3 shows the flowchart of processing to get 1-day final solution. The description of the processing procedure is summarized in the next paragraph.

1. **Obtaining the required data**: the RINEX (Receiver Independent Exchange format) observation and navigation files of the IGS sites and the IGS ultra-rapid predicted EOP file are collected.
2. **Pre-processing**: This step can be largely divided by 4 small next steps. (1) Convert the RINEX files to the Bernese files. (2) Clock correction using the code data. (3) Create the single-difference observation files (baseline definition). (4) Remove the common errors between the receivers and correct the cycle slip errors using triple-difference.
3. **1st solution**: This step estimates the orbit elements and the EOP without the ambiguity resolution. The new ephemeris is generated using the estimated orbit elements and EOP.

After the third step, we can get the first improved ephemeris. The accuracy of a priori ephemeris, a broadcast orbit from the navigation message, is about 2 m, but the first solution has about 8-9 cm accuracy level in this study.
Estimated orbit elements and EOP are used for a priori ephemeris and EOP of next iteration.

4. **Troposphere estimation and Ambiguity fixing**: The troposphere parameters can be estimated with a double difference method. The ambiguities are resolved with the estimated troposphere parameters by each cluster. The method of ambiguity fixing is QIF (Quasi-Ionosphere Free) method.
5. **2nd solution**: The 5th step generates the orbit elements and EOPs with the ambiguities, generated in 4th step. The normal equation files are generated by an each cluster.
6. **Combine and Final 1-day solution**: All normal equation files are combined and the final orbit elements and EOPs are generated.

4. Results

We processed 150 IGS sites (2004.10.31~11.6, 7 days; 1295 GPS week) and estimated GPS ephemerides by 1-day arc. To compare our results, the IGS orbits are considered as the reference.

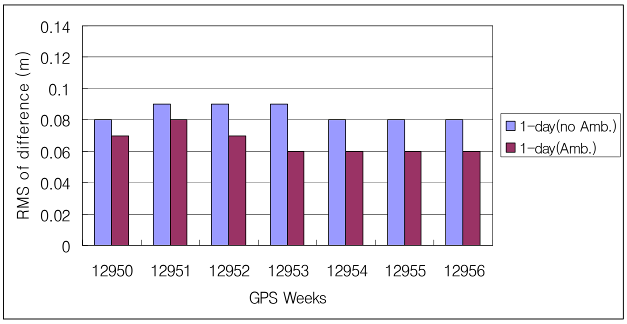

Figure 4. Comparison of 1-day solution during 1 week

Figure 4 shows the result of comparison between the estimated ephemerides and IGS final ephemerides in everyday during GPS week 1295. The Y-axis means the root-mean-squares (RMS) of the range differences from the geocenter to the GPS satellite. The result of differences is the average of whole satellites. The green bar means the difference between the 1st solutions (no ambiguity fixing) and IGS final orbit, and the blue bar means the difference between the final 1-day solution (ambiguity fixing) and IGS final orbit. We can see the 1st solution has 8 to 9 cm accuracies and the final solution has 6 to 8 cm accuracies in difference centimeters in root-mean-squares related to IGS final orbits in each day during a week.

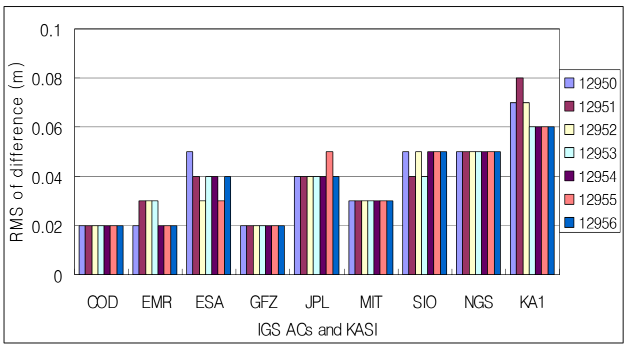

Figure 5. Comparison between KASI's and AC's during 1 week

Figure 5 compares the result with current other ACs during the same week. In this figure, the best accuracy is 2 cm and the others are 3 to 5 cm in current ACs. The differences between our estimated ephemerides (KA1) and current ACs are 1 to 6 cm. The differences are little big when compared with CODE, NRCan and GFZ, but they are small (1 cm) when comparing with SIO and NOAA.

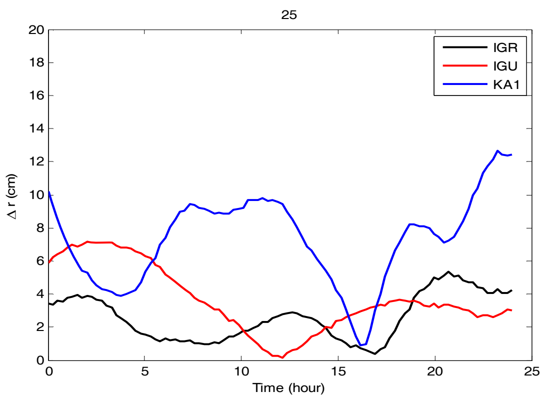

Figure 6. Comparison of the estimated ephemeris (PRN 25)

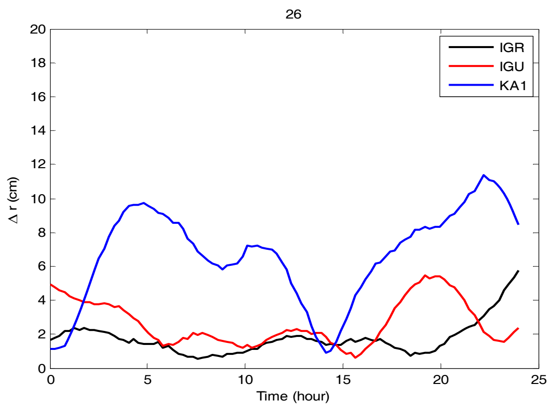

Figure 7. Comparison of the estimated ephemeris (PRN 26)

Figure 6 and 7 show the comparison between the estimated ephemerides (PRN 25 and 26) in this study and IGS orbits. The reference orbit is the IGS final orbit and the KASI's estimated orbit, IGS ultra-rapid orbit and IGS rapid orbit are compared with the reference orbit. The Y-axis means the range differences from the geocenter to the GPS satellite.

We can see that the generated orbits (KA1) in this processing have the similar differences with the IGS ultra-rapid orbit or larger differences.

5. Conclusion

The IGS has maintained the global GNSS network and provided the precise IGS products, the GNSS ephemerides, clock corrections, the Earth orientation parameter and the coordinates and velocities of IGS stations, since its foundation. The IGS products are generated by 10 IGS ACs and combined by the IGS ACC. The each AC uses the 3 major GNSS data processing software (Bernese, GIPSY/OASIS and GAMIT) or its own developed software. The GNSS ephemerides of those IGS products are important because their accuracies affect the performance of processing results.

In this study, we made our own processing strategy and generated the precise GPS orbits using Bernese GPS software Ver. 5.0. We used the broadcast ephemerides to a priori information and processed the globally distributed 150 IGS stations. The processing results show about 6-8 cm RMS accuracies. This result is about 5 cm larger accuracies than current IGS final orbits, but it shows the feasibility of the processing strategy and the possibility to improve the result.

Reference

1. URL: http://igscb.jpl.nasa.gov/overview/viewindex.html
2. U. Hugentobler, R. Dach, P. Fridez and M. Meindl, "GNSS Satellite Orbits," *Chapter 2 of Bernese GPS Software Vernsion 5.0 Draft*, Printing Office of the University of Bern, 2005, pp. 16
3. URL: http://igscb.jpl.nasa.gov/components/prods.html
4. URL: http://igscb.jpl.nasa.gov/organization/acccharter.html
5. J. Baek, H. Lim and J. Park, "Preliminary Study on the System Development for IGS Products," *Proceeding of the 12th GNSS Workshop*, Dec. 2005
6. URL: http://igscb.jpl.nasa.gov/organization/centers.html#ac
7. URL: http://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn
8. H. Lim, P. Park, J. Park, J. Cho and Y. Ahn "Precise Orbit Determination of GPS Satellites for Real Time Applications," Journal of Astronomy and Space Science. Vo. 18, No. 2, 2001, pp. 129-136
9. J. Kouba, J. Ray and M. Watkins, "IGS Reference Frame Realization," *Proceedings of the 1998 IGS Analysis Center Workshop*, Feb. 1998