The Test of Processing Modules of Global Positioning System (GPS) Softwares by Using Products of International GPS Service (IGS)

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Presentation Plan

1. Introduction
2. Application
3. Conclusions

Introduction

This study has been conducted to test the processing modules of Global Positioning System (GPS) softwares by using products of International GPS Service for Geodynamics (IGS) and to evaluate contributions of these products to the results obtained by GPS softwares. For this purpose, the use of IGS products, the need of ambiguity fixed solution for softwares, optimum processing procedure of all tested softwares, correlations between errors at horizontal and vertical positions and baseline length, correlation between errors at horizontal and vertical positions and height difference have been investigated.

2. APPLICATION

Choosing Test Network

Because the ionospheric effect is low in the middle of latitudes, the test network was chosen in the middle of latitudes. When test network was chosen, the following rules had been paid attention.

1. The coordinates and velocities of stations of network have to be well-known in ITRF2000 because of controlling coordinate differences perfectly and correctly.
2. The baselines were chosen between 1 and 200 kilometers increasing 10 kilometers. After 200 km, two baselines were chosen at 20-30 kilometers spacing

Choosing Test Network

- The same receiver and the same antenna have to be end of the baselines, but in relation to second item, there are a few baselines with different receivers and antennas.
- Extremely height difference does not have to be. But in relation to second item, there are a few baseline with extremely height difference

Test network, which is used in this study, consists of 19 permanent GPS stations; most of them are in Italy, and in the region between Italia-Austria-France

Information about chosen permanent GPS stations

SİTE NAME	INSTITUTION	REGION/CITY	COUNTRY	NETWORK
BZRG	GEODETICO BOLZANO RATAA	BOLZANO	ITALY	EPN+IGS
CAVA	CONSORZİO VENEZİA NUOVA	CAVALLINO	ITALY	VENICE PROJ.
CAME	ASI – TELESPAZIO	CAMERINO	ITALY	EPN
COSE	PIANO LAGO	COSENZA	ITALY	ASI
ELBA	ASI – TELESPAZIO	ISLA DE ELBA	ITALY	EPN
GENO	ASI – TELESPAZIO	GENOVA	ITALY	EPN+IGS
GRAS	OBSERVATOIRE DE CALERN- OCA	CAUSSOLS	FRANCE	IGS
HFLK	INSTITUTE FOR SPACE RESEARCH	HAFELEKAR	AUSTRİA	IGS
MATE	ASI – TELESPAZIO	MATERA	ITALY	IGS
MEDI	ASI – TELESPAZIO	MEDICINA	ITALY	IGS
NOVA	COMUNE Dİ NOVARA	NOVARA	ITALY	ASI
PADO	UNIVERSITA DI PADOVA	PADOVA	ITALY	EPN+IGS
PATK	INSTITUTE FOR SPACE RESEARCH	PATSCHERKOFEL	AUSTRİA	AUSTRİA PN.
PAVI	UNIVERSITA DI PAVIA	PAVIA	ITALY	ASI
PRAT	UNIFI- DIC	PRATO	ITALY	ASI
SFEL	CONSORZİO VENEZİA NUOVA	SAN FELİCE	ITALY	VENICE PROJ.
TORI	POLİTECNİCO TORİNO	TORINO	ITALY	EPN+IGS
VENE	ASI – TELESPAZIO	VENEZİA	ITALY	EPN+IGS
VOLT	CONSORZİO VENEZİA NUOVA	VOLTABAROZZO	ITALY	VENICE PROJ.

NETWORK*: the network name that the station has been including or operating.

Map of Used GPS Stations for Testing

Choosing Positioning Technique, Tropospheric and Ionospheric Model

The static measurement option of tested softwares was used. With the processing of static measurements baseline mode that is mentioned in Bock (1998) was chosen because of following fundamental principles and opinion.

Hopfield tropospheric model is common in all commercial GPS software packages. So this standard tropospheric model was used. If there is not this model in software, default model of software was used. The meteorological data was not used because of not existing enough in all the stations. According to Klobuchar (1991) and Odijk (2002), using ionospheric model is important to process when sun spot activities are maximum amount. Because of huge amount of sun spot activities in 2001, standard ionospheric model of softwares was used.

Collecting Stations Data

1. GPS observations in RINEX format, which is dated 27 February 2002 (58th day year, and 1155th GPS week), were used. IGS, IFAG, and ASI provided these observations.
2. Precise ephemerides of IGS in SP3 format, which is dated 26-27-28 February 2002, were used.
3. The navigation file, which is named AUTO0580.02N, was used.
4. The Earth rotation parameter file, which is named IGS02P1155.ERP, was used.
5. The coordinates and velocities of stations were obtained from ITRF2000_GPS.SNX and Caporali et al (2003).
6. The information of antenna phase centers was obtained from "Relative Antenna Calibrations" file belonging to NGS (National Oceanic and Atmospheric Administration, National Geodetic Survey). If there is software that use IGS01.PCV antenna file as Ashtech Office Suite, this file was used changing its name.

The receiver, antennas types, antenna heights, and the Cartesian coordinates of used GPS stations (epoch 2002.16)

SITE NAME	RECEIVER TYPE	ANTENNA TYPE	ANTENNA HEIGHT (m)	X (m)	Y (m)	Z (m)
BZRG	LEICA CRS1000	LEIAT504 wchokering	0.2120	4312657.5496	864634.6150	4603844.4128
CAME	TRIMBLE 4000SSI	TRM29659.00	0.0000	4542009.1897	1058964.1868	4336932.9183
CAVA	LEICA RS500	LEIAT504 wchokering	0.0274	4372204.6301	975914.9127	4524895.2585
COSE	TRIMBLE 4000SSI	TRM29659.00	0.0000	4750531.5950	1390089.5335	4010089.6189
ELBA	TRIMBLE 4000SSI	TRM29659.00	0.0000	4616533.9688	831568.6126	4307569.9520
GENO	TRIMBLE 4000SSI	TRM29659.00	0.0000	4507892.3614	707621.4288	4441603.4736
GRAS	TURBO ROGUE SNR-12RM	DORNE MARGOLIN T Wchokering	0.0350	4581690.9440	556114.7773	4389360.7478
HFLK	TRIMBLE 4000SSI	TRM29659.00	-0.0200	4248505.1055	855575.6918	4667172.2518
MATE	TRIMBLE 4000SSI	TRM29659.00	0.1010	4641949.6103	1393045.3700	4133287.4111
MEDI	TRIMBLE 4000SSI	TRM29659.00	0.0000	4461400.7980	919593.5265	4449504.7262
NOVA	TRIMBLE 4000SSI	TRM29659.00	0.0000	4431899.1764	671367.1713	4522512.2131
PADO	TRIMBLE 4700	TRM29659.00	0.0000	4388882.0857	924567.4067	4519588.6940
PATK**	TRIMBLE 4000SSI	DORNE MARGOLIN Twchokering	-0.0250	4255736.0765	862759.8746	4659191.4366
PAVI	TRIMBLE 4700	TRM29659.00	0.0000	4444603.3183	714786.0406	4503373.2105
PRAT	TRIMBLE 4000SSI	TRM29659.00	0.0280	4518264.2128	886376.6329	4399019.3025
SFEL	LEICA RS500	LEIAT504 wchokering	0.0270	4396376.7464	957869.5371	4505424.7808 7
TORI	TRIMBLE 4000SSI	TRM29659.00	0.0000	4472544.4006	601634.2918	4492545.1604
VENE	TRIMBLE 4700	TRM29659.00	0.0000	4379724.8182	957495.8327	4521605.2059
VOLT	LEICA RS500	LEIAT504 wchokering	0.0270	4390693.1715	926138.4467	4517506.9827

PATK **: The coordinates of this station were not obtained. So Its coordinates were computed in constrained adjustment using coordinates of BZRG, GRAZ, HFLK, VENE, WTZR, ZIMM stations

The softwares used in test

Software Name	Producer Company
Ashtech Office Suite 2.0	Spectra Precision Terrasat GmbH, Germany and Ashtech Inc., USA
Pinnacle 1.0	At first Javad Positioning Sytems, Russian, then Topcon Corp. Japan
Static Kinematic Software 2.3	Leica AG., Switzerland
Trimble Geomatics Office 1.5	Trimble Navigation Limited, USA

The Application Phases

At first, the vector solution types (frequency types or frequency combination) of softwares were investigated. Then, the solution type of software, which gave the best result, was used. The best solution types met by different name because of not only named by the relevant software but also results. After choosing solution type, the ambiguity fixed solutions and ambiguity float solutions were obtained separately to investigate whether fixed and float solutions affect the results or not. In addition to, the broadcast ephemerides and precise ephemerides were used separately in solutions to investigate effect on results

The Application Phases

The coordinate differences among stations were transformed to topocentric coordinate system for expressing baseline vectors in terms of horizontal (north, east) and vertical.

$$\underline{x}_{IJ} = \begin{bmatrix} n_{ij} \\ e_{ij} \\ u_{ij} \end{bmatrix} = \underline{D}_I^T * \underline{X}_{IJ}$$

The Application Phases

Table 4: The standard solutions used in application

Solution Type Number	Ephemerides	Ambiguity solution type
S.T. 1	Broadcast	Fixed
S.T. 2	Precise	Fixed
S.T. 3	Broadcast	Float
S.T. 4	Precise	Float

18 19

The Application Phases

The equations that are given in Federal Geographic Data Committee (1998) were used for computation of root mean square errors (RMSE) in horizontal and vertical positions in analysis of application results (Table 5). These equations are given as follows;

$$RMSE_H = \frac{1}{N}\sum_{1}^{N}\sqrt{(X_I - X_0)^2 + (Y_I - Y_0)^2}$$

$$RMSE_Z = \sqrt{\frac{\sum_{I}^{N}(Z_I - Z_0)^2}{N}}$$

The Application Phases

The RMSE in horizontal and vertical positions of solutions are shown in Table 5. According to Table 5, the least RMSE of each software was chosen. The chosen solution types are S.T.4 for AOS, SKI, and TGO, S.T.2 for Pinnacle. The correlation between errors at horizontal and vertical positions and baseline length and the correlation between errors at horizontal vertical positions and height difference were investigated by using regression analysis in these chosen solution types. The horizontal and vertical positions differences are shown comparing results of softwares in the following figures (Figure 2,3,4,5,6,7,8,9) according to results of solution type.

The RMSE of horizontal and vertical positions differences, which were computed in test softwares

	Root Mean Square Errors (mm)							
Software	S.T.1 Horizontal	S.T.1 vertical	S.T.2 Horizontal	S.T.2 Vertical	S.T.3 Horizontal	S.T.3 vertical	S.T.4 Horizontal	S.T.4 vertical
AOS 2.0	37.3	61.3	27.9	68.0	15.2	56.6	**12.8**	**57.0**
Pinnacle 1.0	20.2	46.3	**12.1**	**45.9**	27.3	45.6	18.8	48.4
SKI 2.3	643.7	278.2	746.9	354.4	13.5	37.5	**12.3**	**35.0**
TGO 1.5	32.3	49.3	32.4	47.4	15.9	35.3	**13.5**	**34.2**

aos pin ski tgo

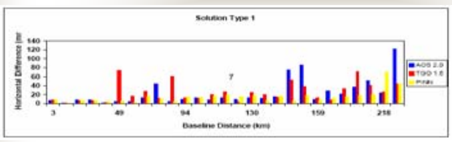

Figure 2: The horizontal differences versus baseline distance in solution type 1

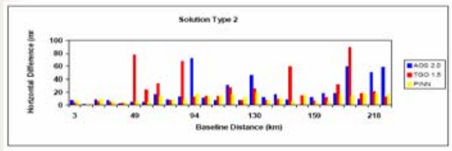

Figure 3: The horizontal differences versus baseline distance in solution type 2

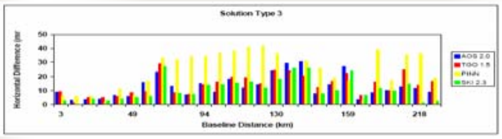

Figure 4: The horizontal differences versus baseline distance in solution type 3

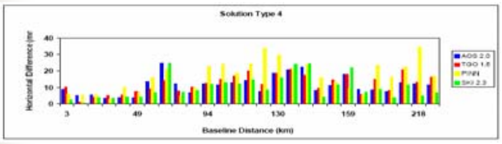

Figure 5: The horizontal differences versus baseline distance in solution type 4

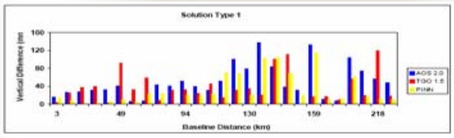

Figure 6: The vertical differences versus baseline distance in solution type 1

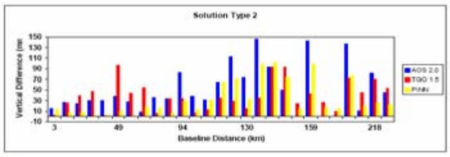

Figure 7: The vertical differences versus baseline distance in solution type 2

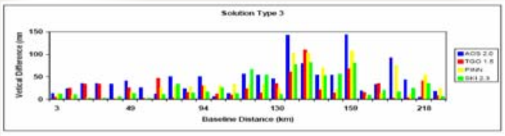

Figure 8: The vertical differences versus baseline distance in solution type 3

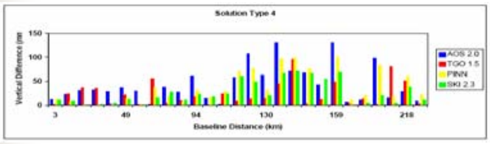

Figure 9: The vertical differences versus baseline distance in solution type 4

The Results of Ashtech Office Suite 2.0 GPS Software

1. AOS has given the best result by using precise ephemerides in ambiquity float solution (S.T.4 in RMS table). This solution is named **iono-free float** (Lc frequency option in processing options) in software The more horizontal position error (as horizontal differences are shown in graphics) than 10 mm has been reached in the solutions of baselines longer than 50 km.

The Results of Ashtech Office Suite 2.0 GPS Software

2. The mean correlation coefficient between baseline distances and RMSE of solution for every baseline solution is 0.55 in fixed solution and 0.42 in float solution. The mean correlation coefficient between baseline distances and RMSE of baseline is 0.94 in fixed solution, and 0.77 in float solution. The float solutions have reduced the correlation between baseline distances and RMSE of solution and baseline. Using the precise ephemerides in fixed solutions reduces RMSE of solution 2.29 times.

The Results of Ashtech Office Suite 2.0 GPS Software

3. It has been determined that there is a correlation between horizontal position errors and height differences of stations by 95 % confidence level and there is not o correlation between horizontal position errors and baseline distances by 95 confidence level. This situation was not being expected. So the studies about this situation have to be enlarged. There is not a correlation between vertical position errors (as vertical differences are shown in graphics) and height differences of stations, between vertical position errors and baseline distances by 95% confidence level.

The Results of Pinnacle 1.0 GPS Software

1. Pinnacle 1.0 has given the best result by using precise ephemerides in ambiguity fixed solution (S.T. 2 in RMS table). This solution is named **Wide Lane** (wide lane option of static engine in process properties) in software This solution type has a different algorithm on the contrary, usually known wide lane frequency (Topcon Corp. 2003). The more horizontal position error than 10 mm has been reached in the solutions of baselines longer than, on average, 80 km in fixed solutions, 50km in float solutions.

The Results of Pinnacle 1.0 GPS Software

2. There is so low correlation between RMSE of solution and baseline distance in float solutions. The mean correlation coefficient between baseline distances and RMSE of solution for every baseline solution is 0.55 in fixed solution. Using the precise ephemerides has reduced importantly RMSE of solution in fixed solution. Therefore, it can be said that the solution, in which the precise ephemerides is used, is so precise solutions. The investigations have shown that the mean correlation coefficient between baseline distances and RMSE of baseline is 0.86 in fixed solution, and 0.67 in float solution.

The Results of Pinnacle 1.0 GPS Software

3. In the best solution of software, it has been determined that there is a correlation between horizontal position errors and baseline distances by 95 % confidence level and there is not o correlation between horizontal position errors and height differences of stations by 95 confidence level. The height differences of stations, and baseline distances have not affected vertical position errors by 95% confidence level.

The Results of SKI 2.3 GPS Software

1. SKI 2.3 has given the best result by using precise ephemerides in ambiguity float solution (S.T.4 in RMS table). This solution is named **iono-free float** in software. This solution type is not an option of processing properties (Leica 1997). The more horizontal position error than 10 mm has been reached in the solutions of baselines longer than, on average, 90 km in float solution type.

The Results of SKI 2.3 GPS Software

2. This software has given big coordinate differences in fixed solutions. "Ambiguities will only be resolved by SKI on baselines of 20 km or less. For longer distances, the ambiguity resolution becomes unreliable. To achieve good results on baselines longer than 20km you will need to observe for longer periods of time. Note that even then ambiguities will not be resolved even though results are achieved to within the system specifications" (Leica 1997). Although mentioned information has been known, this software has been forced to search for a fixed ambiguity solution by increasing a priori rms of frequency related to baseline distances. So the investigations have shown that fixed solutions can be used in baselines of 50 km or less with this software.

The Results of SKI 2.3 GPS Software

3. The correlation coefficient between baseline distances and RMSE of solution for every baseline solution is 0.92 by using broadcast ephemerides and 0.79 by using precise ephemerides. It has been obtained that he correlation coefficient between baseline distances and RMSE of baseline is 0.73 by using broadcast ephemerides, and 0.51 by using precise ephemerides. The precise ephemerides have reduced the correlation between baseline distances and RMSE of solution and baseline.

The Results of SKI 2.3 GPS Software

4. In the best solution of the software, it has been determined that there is a correlation between horizontal position errors and height differences of stations by 95 % confidence level and there is not o correlation between horizontal position errors and baseline distances by 95 confidence level. This situation was not being expected. So the studies about this situation have to be enlarged. There is not effect of baseline distances and the height differences of stations on vertical position errors by 95% confidence level.

The Results of TGO 1.5 GPS Software

1. TGO 1.5 has given the best result by using precise ephemerides in ambiguity float solution (S.T.4 in RMS table). This solution is named **iono-free float** in software (solution type option in processing styles) (Trimble Navigation. Limited, 2001b). The more horizontal position error than 10 mm has been reached in the solutions of baselines longer than, on average, 50 km in fixed solutions, 90 km in float solutions.

The Results of TGO 1.5 GPS Software

2. The precise ephemerides have reduced the correlation between baseline distances and RMSE of solution and baseline as much as the correlation is not present. Therefore, it can be said that the solution, in which the precise ephemerides is used, is so precise solutions.

The Results of TGO 1.5 GPS Software

3. In the best solution of software, it has been determined that there is a correlation between horizontal position errors and baseline distances by 95 % confidence level and there is not o correlation between horizontal position errors and height differences of stations by 95 confidence level. The height differences of stations, and baseline distances have not affected vertical position errors by 95% confidence level.

CONCLUSIONS

- In this study, the obtained values are valid for baselines of 250 km or less. Using precise ephemerides in all tested softwares has given the best results. The observations of permanent stations coordinated by ITRF and the precise ephemerides of IGS products (if it is not important waiting 13 days,) have to be used obtaining accuracy results in GPS projects.

- Both ambiguity fixed solution and float solutions can be chosen with Ashtech Office Suite 2.0. and Trimble Geomatics Office 1.5. Firstly, it may be suggested using float solutions in these softwares. The ambiguity float solutions can be used with SKI 2.3. Investigations show that horizontal position errors are dependent on height difference and independent baseline length as results of AOS and SKI softwares. This situation was not being expected. Therefore, the more studies about this situation have to be made.

CONCLUSIONS

- Pinnacle 1.0 has a special processing algorithm in Wide Lane frequency option. This feature has been shown in all fixed solutions. The ambiguity fixed solutions can be used with Pinnacle 1.0

- According to obtained results and the results of the present written sources, it is important for the analyst to be aware of certain characteristics of double-difference solutions that could be considered "rules-of-thumb". Some of these are;

1. The chances of successful ambiguity resolution are essentially a function of baseline length, number of satellites tracked, and length of observation session.
2. The "RMSE of solution" increases with increasing baseline length. The increase in RMSE of solution is changing according to software

CONCLUSIONS

3. The coordinate standard deviations and RMSE of solution are lower for an ambiguity-float (free) solution than for an ambiguity-fixed solution
4. If there are doubts concerning the quality of the ambiguity-fixed solution, it is preferable to accept the ambiguity-float solution in its place.