Application of GPS/GLONASS Combination to the Revision of Digital Map

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Key words:

ABSTRACT

GPS in the United States and GLONASS of the old Soviet Union are used currently as satellite navigation systems. Plans are being made to use the Galileo satellite system in Europe, and these plans focus on a combined application of the satellite navigation systems. In this study, we examined the possibility of effective application of a combination of GPS/GLONASS to Digital Map revision of urban areas, where 3-dimensional positioning is impossible with GPS alone. We analyzed the 3-D coordinate deviation of a GLONASS satellite by integration interval and compared it with GLONASS satellite coordinates in precise ephmerides by transforming it into WGS84. We also programmed DGPS/DGLONASS, analyzed 3-D positioning accuracy by static surveying and kinematic surveying with Ashtech Z18 receivers and Legacy receivers, and then compared it with GPS surveying.

As a result, we are able to decide the integration interval for producing GLONASS satellite coordinates in navigation and geographical information and construct a GPS/GLONASS data processing system by developing a DGPS/DGLONASS positioning program. If more than four GLONASS satellites are observed, the accuracy of DGPS/DGLONASS is better than that of DGPS positioning. As a result of kinematic surveying in a congested urban area with skyscrapers, we discovered that DGPS/DLONASS combination is very effective. The Galileo system can be used to revise Digital Maps in cities effectively.

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INTRODUCTION

With the advent of computers, information can be spread rapidly. Satellite surveying systems like GPS and GLONASS for fast and accurate revision of Digital Maps becomes important. GPS is used widely enough to verify its effectiveness in positioning and in automobiles, airplanes, geodesy and surveying. However, we have some difficulty with 3-D positioning since it cannot trace more than four satellites in a congested urban area with skyscrapers continuously.

The time for observing more than four satellites is limited because GLONASS, a satellite navigation system which is similar to GPS, does not form complete satellite positioning currently. Therefore, it has a defect which does not allow us to do continuous 3-D positioning with GLONASS alone. We can expect a reduction of the observation time or better accuracy, since we can observe more satellites when GPS and GLONASS are combined than when GPS is used alone. However, to combine the two satellite systems, we should solve the problems that arise from the difference in the coordinate system of each system, as well as the time and operation frequency systems to combine the two satellite systems.

In this study, we examined the standard coordinate systems of GPS and GLONASS, the characteristics of the time and frequency systems, and developed a DGPS/DGLONASS combination program by solving the problems related to the difference in coordinate systems and frequency between them. We also suggest the possible application of the GPS/GLONASS combination to Digital Map revision of urban areas by analyzing the accuracy of GLONASS satellite coordinates and positioning accuracy of DGPS/DGLONASS.

THEORY OF GPS/GLONASS COMBINATION

Comparison of GPS and GLONASS

Although GLONASS contains L1 and L2 carrier phases of GPS and satellite signals corresponding to C/A and P codes and has much in common with GPS, there are difference in satellite positioning, frequency, and ephmerides. The satellite altitude of GLONASS is lower than that of GPS, and its satellite have a short lifespan. Each satellite of GLONASS has its own frequency because it uses a frequency spilt system. Information regarding the GLONASS satellite orbit consists of coordinate, velocity, and acceleration every 15 minutes and 45 minutes. This is unlike GPS which is recorded as a function of time of Kepler orbits and perturbation. To combine the two systems, a transformation of time and coordinate systems is basically necessary.

Time Transformation. There is a difference of a leap second in time between GLONASS time, set on the basis of UTC(SU) around Moscow, and GPS time. Broadcast ephmerides of a GLONASS satellite is described in GLONASS time and should be transformed into GPS time by using formula (1).

t_GPS = t_GLONASS + τ_c + τ_u + τ_g + τ_r (1)

with

τ_c = t_UTC(SU) - t_GLONASS
τ_u = t_UTC - t_UTC(SU)
τ_g = t_GPS - t_UTC
τ_r = receiver clock bias between GLONASS and GPS observations

Transformation of Coordinate System. Broadcast ephmerides of GLONASS is indicated with a PZ-90 earth-fixed coordinate system. The PZ-90 coordinate system is an earth-centered earth-fixed Cartesian coordinate system(ECEF) which is similar to the WGS84 coordinate system, but it is differs in setting the control or axis. In this study, the GLONASS satellite coordinate is transformed into WGS84 by using a coordinate transformation relation (2) of WGS84 and PZ-90 which Vladimir V. Mitrikas announced.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \mathrm{WGS84} = \begin{bmatrix} -0.47\mathrm{m} \\ -0.51\mathrm{m} \\ -1.56\mathrm{m} \end{bmatrix} + (1 + 22\times10^{-9}) \begin{bmatrix} 1 & -1.728\times10^{-6} & -0.017\times10^{-6} \\ 1.728\times10^{-6} & 1 & 0.076\times10^{-6} \\ 0.017\times10^{-6} & -0.076\times10^{-6} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} \mathrm{PZ-90} \qquad (2)$$

Principle of DGPS/DGLONASS positioning

The principle of 3-D positioning of GLONASS is equal to that of GPS. In observing more than four satellites, we can produce the 3-D coordinates of the receiver with a pseudo-range equation with coordinates of satellite.

$$P^i_k = c \cdot \tau^i_k + c \cdot \Delta t_k - c \cdot \Delta t^i \qquad (3)$$

$c \cdot \tau^i_k$ includes the distance between satellite and reception time. The refraction of ionosphere and troposphere is delayed in the case of code survey, and its formula is as follows.

$$c \cdot \tau^i_k = \rho^i_k + \Delta\rho^i_{k,ion} + \Delta\rho^i_{k,trop} - \Delta\rho^i_{k,re} \qquad (4)$$

with, $\Delta\rho^i_{k,ion}$ = ionospheric refraction, $\Delta\rho^i_{k,trop}$ = tropospheric refraction, $\Delta\rho^i_{k,re}$ = relativistic correction.

In the case of DGPS/DGLONASS, we can fix the observed pseudo-range correction at an unknown point by using pseudo-range correction at the control point produced as in the following formula (5), and calculate the exact 3-D coordinates by the least squares method taking the time error of 3-D coordinates and receiver as an unknown quantity.

- Pseudo range correction at control point = observed pseudo range –

satellite and real distance during reception time. (5)

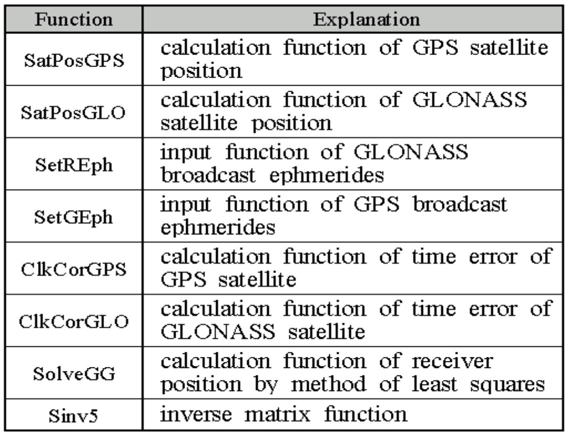
- Corrected pseudo range = observed pseudo range - Pseudo-range correction at control point.

In the case of DGPS/DGLONASS, with the formula (5) we can produce the exact 3-D coordinates taking time difference between 3-D coordinates, time error of receiver, GPS and GLONASS as an unknown quantity after correcting the pseudo-range distance.

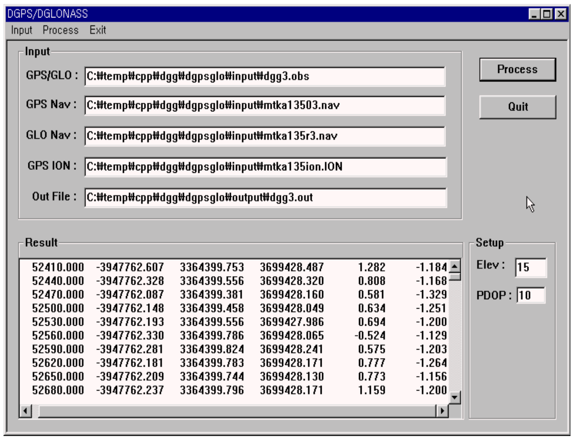
DEVELOPMENT OF A DGPS/DGLONASS PROGRAM

In this study, we invented a DGPS/DGLONASS surveying program with Visual C++ 6.0, an object-directed program.

Table 1. Constitution function of CstdAlone_GPSGLO class



Function	Explanation
SatPosGPS	calculation function of GPS satellite position
SatPosGLO	calculation function of GLONASS satellite position
SetREph	input function of GLONASS broadcast ephmerides
SetGEph	input function of GPS broadcast ephmerides
ClkCorGPS	calculation function of time error of GPS satellite
ClkCorGLO	calculation function of time error of GLONASS satellite
SolveGG	calculation function of receiver position by method of least squares
Sinv5	inverse matrix function



GPS/GLO : C:₩temp₩cpp₩dgg₩dgpsglo₩input₩dgg3.obs

GPS Nav : C:₩temp₩cpp₩dgg₩dgpsglo₩input₩mtka13503.nav

GLO Nav : C:₩temp₩cpp₩dgg₩dgpsglo₩input₩mtka135r3.nav

GPS ION : C:₩temp₩cpp₩dgg₩dgpsglo₩input₩mtka135ion.ION

Out File : C:₩temp₩cpp₩dgg₩dgpsglo₩output₩dgg3.out

Elev : 15

PDOP : 10

```
52410.000  -3947762.607  3364399.753  3699428.487   1.282  -1.184
52440.000  -3947762.328  3364399.556  3699428.320   0.808  -1.168
52470.000  -3947762.087  3364399.381  3699428.160   0.581  -1.329
52500.000  -3947762.148  3364399.458  3699428.049   0.634  -1.251
52530.000  -3947762.193  3364399.556  3699427.986   0.694  -1.200
52560.000  -3947762.330  3364399.786  3699428.065  -0.524  -1.129
52590.000  -3947762.281  3364399.824  3699428.241   0.575  -1.203
52620.000  -3947762.181  3364399.783  3699428.171   0.777  -1.264
52650.000  -3947762.209  3364399.744  3699428.130   0.773  -1.156
52680.000  -3947762.237  3364399.796  3699428.171   1.159  -1.200
```

Figure 1. Main Window of DGPS/DGLONASS program

For absolute positioning of GPS and GLONASS, we made CStdAlone_GPS and CStdAlone_GLO class, and created CStdAlone_GPSGLO class(Table 1) by inheriting them. We included a function to correct errors of troposphere and ionosphere. We created CRk4 class to calculate the position of GLONASS with the 4th order Runge-Kutta technique. In addition, we made DGPS, DGLONASS, and DGPS/DGLONASS programs by inheriting CStdAlone_GPS and CStdAlone_GLO classes. The main screen of the eveloped DGPS/DGLONASS program is shown in Figure 1.

ACQUISITION AND PROCESSING OF DATA

Acquisition of Static Surveying Data

To acquit GPS/GLONASS combination data, we chose the stations of TSKA(Tskuba) and MTKA(Mitaka) in Japan of continuous positioning of IGEX. We received observation data of May 14, 2000 from the Global Data Center of IGEX.

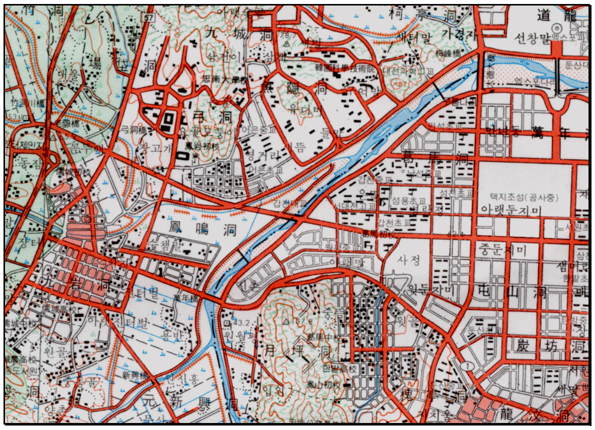


Figure 2. Position of Data Acquisition Point **Figure 3**. Object Area of Kinematic Survey

Acquisition of kinematic Survey Data

In this study, we selected Dunsan-dong in Daejeon as an object area, as shown in Figure 3. It was expected to be subject to a restriction of continuous 3-D positioning with GPS alone, since there were many roadside trees and high apartments. As shown in Figure 4, we installed the GPS/GLONASS receiver in a vehicle, performed a two hour kinematic survey by fixing CNU0 point equipped in Engineering Building #2 of Chungnam National University at 16:20 on August 7, 2001, and then saved data every one second. The GPS/GLONASS receiver installed in the vehicle was the Leagacy L1 receiver of JAVAD as shown in Figure 5.

Figure 4. GPS/GLONASS Receiver Installation **Figure 5**. Legacy GPS/GLONASS Receiver

Data Processing

We transformed the observed data at the IGEX station into RINEX form by using the CRX2RNX.EXE program, since it is compressed in a unique form and the kinematic survey data, observed with the Javad receiver, into RINEX form by using the JPS2RIN.EXE program. By dividing RINEX observation data into GPS and GLONASS data respectively with TEQC of UNAVOCO, we made observation data for GPS and GLONASS. In this study, the result of data processing of the developed DGPS/DGLONASS surveying program (CNUGG) and a commercial program (GeoGenius 2000) were compared. We had the data processed only in cases where there was more than 15 degrees satellite altitude, and seven or less in PDOP.

RESULTS AND REVIEWS

Analysis of Accuracy of GLONASS Satellite Coordinates

Production of GLONASS Satellite Coordinates by Integration Interval . Figures 6(a),(b) and (c) show the difference in position for the GLONASS satellite number 1 after integrating the equations of motion for GLONASS satellites. The broadcast ephmerides of July 3, 2000 were used. The initial positions at 15 minutes and 45 minutes were used for forward and backward integration over 15 minutes. The resulting positions at 0 and 30 minutes were calculated from two different periods.

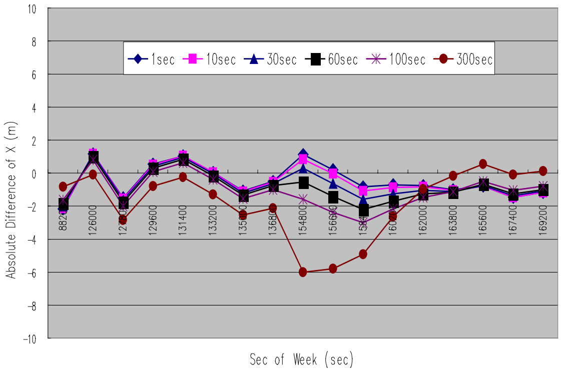


Figure 6(a). X Deviation of GLONASS SV1

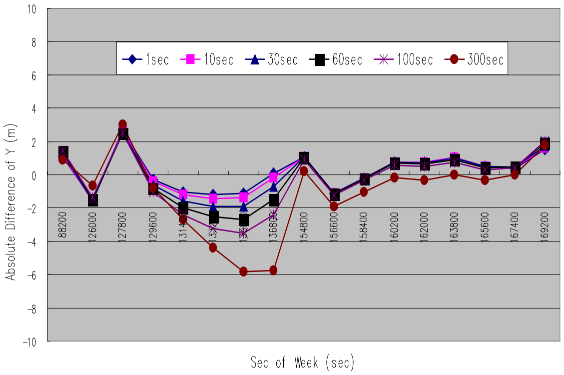


Figure 6(b). Y Deviation of GLONASS SV1

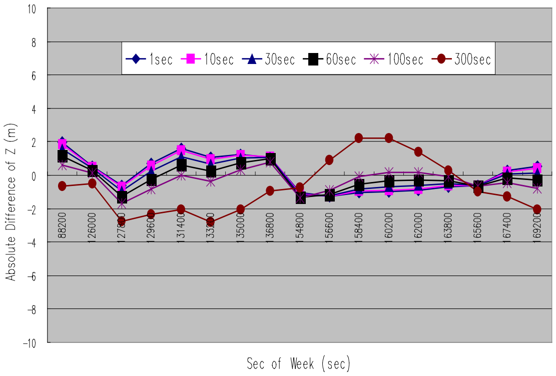


Figure 6(c). Z Deviation of GLONASS SV1

The result of integration at 10 seconds was very similar to that of integration at 1 second. However, in the case of the 300 second interval, there was a difference by maximum 6m in x and y-axises. In the case of the 100 second interval, there was more than a 2m difference in a certain section than when integrated at the 1 second interval. Therefore, we discovered that there is no difference between the results of integration by 60 second intervals and that by 1 second intervals, and the calculated coordinates of a satellite are correct when integrating at 1 or 10 second intervals.

Table 2. Errors of Satellite Coordinates by Coordinate Transformation Method

Method SV		Method 1	Method 2	Method 3	Method SV		Method 1	Method 2	Method 3
SV 1	dx	3.551	4.176	2.817	sv15	dx	4.451	4.125	4.893
	dy	2.310	3.218	3.124		dy	4.385	5.014	4.952
	dz	6.035	5.278	5.278		dz	10.928	11.123	11.123
	ds	7.373	7.460	6.749		ds	12.588	12.880	13.122
SV 11	dx	5.616	6.244	4.936	sv16	dx	4.050	4.042	3.896
	dy	5.298	3.576	6.977		dy	1.801	3.583	2.146
	dz	9.578	7.589	7.589		dz	4.614	6.141	6.141
	ds	12.302	10.458	11.429		ds	6.398	8.179	7.583
sv13	dx	5.840	7.603	4.620	mean	dx	4.702	5.238	4.232
	sy	5.410	6.535	6.032		dy	3.841	4.385	4.646
	dz	8.327	9.994	9.994		dz	7.896	8.025	8.025
	ds	11.520	14.156	12.555		ds	10.037	10.626	10.288

※ Method1 : Valdimir V.Mitrikas et.al
Method2 : Roβbach et. al. 1996.
Method3 : Misra et. al. 1996

***Analysis of Accuracy by Method of Coordinate Transformation* .** PZ-90 coordinates of GLONASS satellites observed on July 3, 2000 were calculated by integration of a 1 second interval with the Runge-Kutta technique taking coordinates, velocity, and acceleration included in broadcast ephmerides as initial values. We transformed PZ-90 coordinates into WGS84 coordinates with a coordinate transformation formula, and compared coordinates of IGEX precise ephmerides and accuracy. The error of each satellite to transformation method is shown in Table 2.

Although method 1 demonstrates less accuracy than method 2 in the x-axis, it indicates the values which are closer to precise ephmerides than any other method because it shows better accuracy in y-axis and z-axis.

Analysis of the Accuracy of DGPS/DGLONASS

Analysis of Accuracy of DGLONASS. The time that more than four GLONASS satellites were observed on May 14, 2000 is less than 3 hours. If altitude is more than 15degrees, more than 4 satellites can be observed. If the PDOP is less than 7, it is just 96 minutes (192 epoches). The result of DGLONASS data processing of the MTKA station is illustrated in Figure 7. Towards North, East, and Up the accuracy (1 sigma) was 0.578m, 0.486m, and 1.499m respectively.

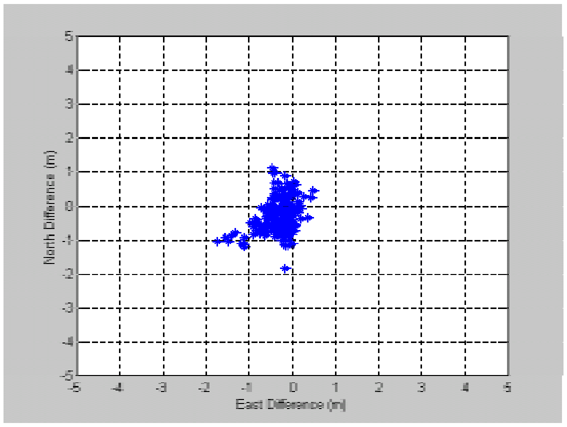


Figure 7(a). Results of Data Processing of DGLONASS (East-North)

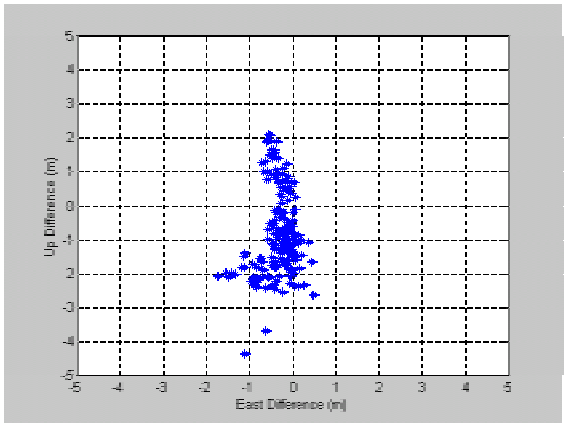


Figure 7(b). Results of Data Processing of DGLONASS (East-Up)

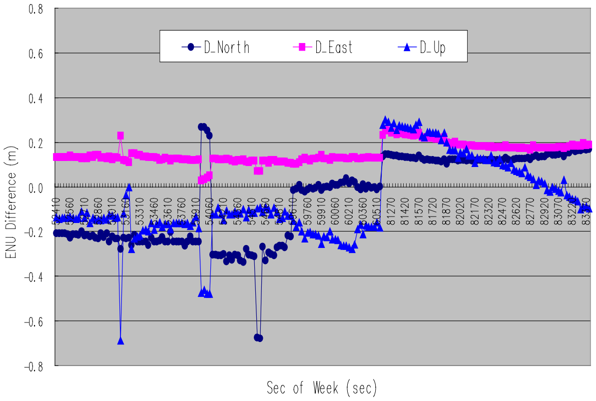


Figure 8. Result Comparison of Data Processing of GeoGenius 2000 and CNUGG

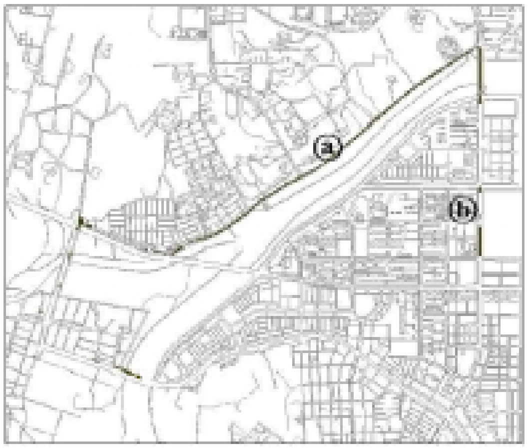


Figure 9. Results of the DGLONASS Kinematic Survey

As a result of processing the same data with the commercial program GeoGenius 2000, the accuracy (1 sigma) was 0.596m to the North, 0.611m to the East, 1.496m in the Up direction (1 sigma). Figure 8 shows the comparative results of data processing with the commercial program and developed program (CNUGG). Largely, there is less than 40cm difference for each direction.

In addition, Figure 9 shows the results of the kinematic survey in the Dunsan-dong area in Daejeon. Since 4 to 5 GLONASS satellites were located in the southeast, we could observe the northern street side of Gapcheon (area ⓐ) with little obstruction. It was impossible to receive the signals of more than four satellites in urban area (area ⓑ) with skyscrapers, therefore only 773 values were data-processed out of total 7538 observation values.

Analysis of Accuracy of DGPS. Figure 10 shows the results of DGPS data processing on the MTKA station with the TSKA station fixed by choosing a time zone when more GLONASS satellites are observed. Five to eight GPS satellites are processed at more than 15 degrees satellite altitude, and 3-D coordinates of 370 epochs are produced as a result of including only cases where the PDOP is less than seven. As a result of setting coordinates of the MTKA station as a control and analyzing the accuracy of North, East and Up, the accuracy (1sigma) was 0.261m, 0.184m, and 0.673m respectively.

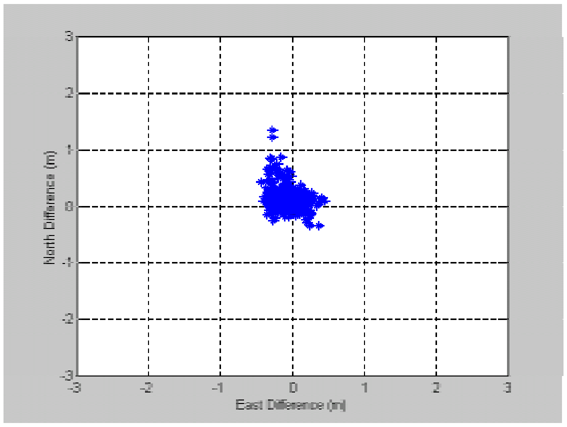


Figure 10(a). Results of Data Processing of DGPS (East-North)

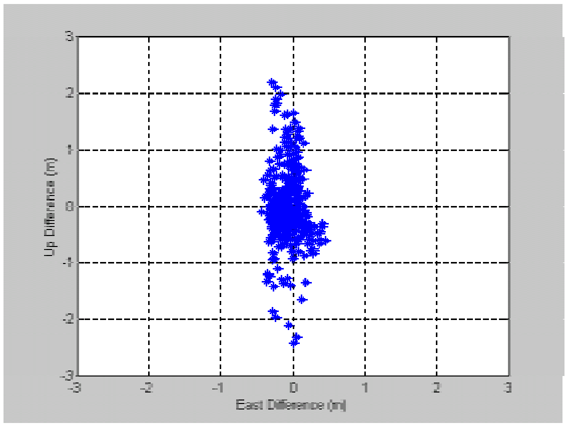


Figure 10(b). Results of Data Processing of DGPS (East-Up)

Performing data-processed with GeoGenius 2000 under the same conditions, the accuracy (1sigma) of North, East, and Up were 0.222m, 0.212m, and 0.666m respectively. Figure 11 shows the compared results of data processing with the commercial program and the developed program (CNUGG), and indicated that there was mostly less than a maximum of 80cm difference to each direction.

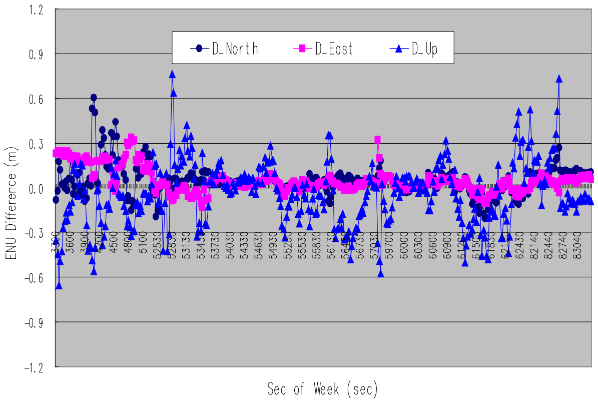


Figure 11. Comparison of Data Processing Results of GeoGenius 2000 and CNUGG

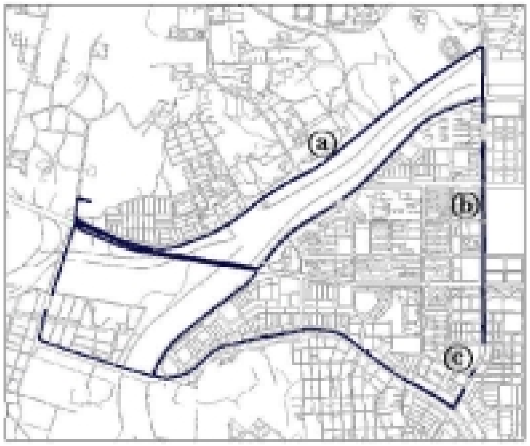


Figure 12. Results of the DGPS Kinematic Survey

The results of the kinematic survey for the Dunsan-dong area in Daejeon is shown in Figure 12. Since five to eight satellites were observed, signal reception of more than four satellites was possible even in an urban area with skyscrapers (area ⓐ) as well as in a 2-lane one-way road along Gapcheon with street trees (area b). However, the continuous 3-D positioning was impossible in the area with skyscrapers standing close together (area ⓒ), and 6188 3-D coordinates were created out of 7538 observation values.

Analysis of Accuracy of the DGPS/DGLONASS. We used the combined GPS/GLONASS data and Figure 13 shows the results of DGPS/DGLONASS data processing on the MTKA station with a control of the TSKA station. Nine to twelve satellites were used in data processing, and the accuracy (1sigma) of North, East, and Up were 0.216m, 0.226m and 0.693m respectively.

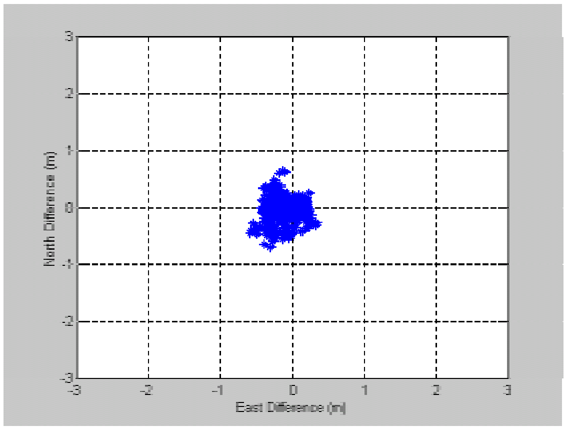


Figure 13(a). Results of Data Processing of DGPS/DGLONASS (East-North)

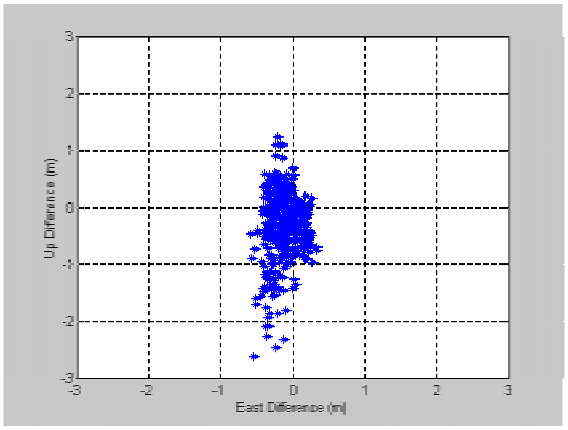


Figure 13(b). Results of Data Processing of DGPS/DGLONASS (East-Up)

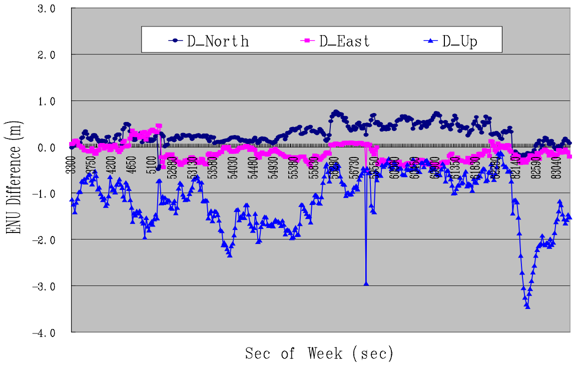


Figure 14. Comparison of Data Processing of GeoGenius 2000 and CNUGG

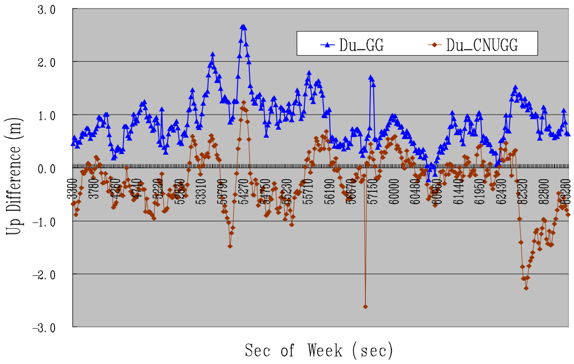


Figure 15. Comparison of Up Direction of GeoGenius 2000 and CNUGG

As the results of data processing with a commercial program of GeoGenius 2000 S/W under the same condition, the accuracy of North, East, and Up were 0.337m, 0.194m, and 0.995m respectively (1sigma). Figure 14 shows the difference between the results with GeoGenius 2000 and those with the developed program in this study. While there is less than 0.8m difference in horizontal direction, 3m difference in height. Figure 15 shows the results of comparing the difference in height with the GeoGenius 2000 S/W and with the developed program in the study, setting the control as the height of the MTKA station. We can observe that the developed program is proven, since the program demonstrates a closer result to the actual conditions.

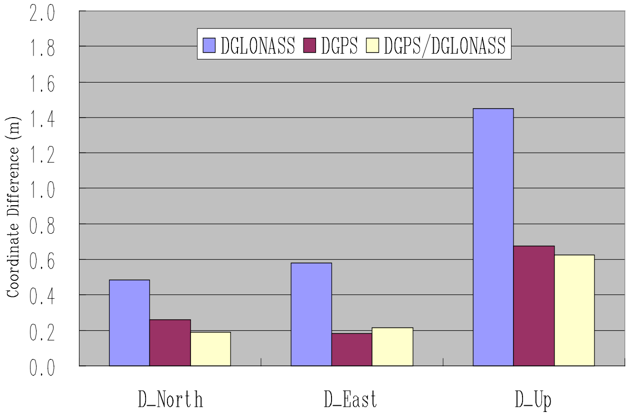


Figure 16. Comparison of the Accuracy of DGLONAS, DGPS and DGPS/DGLONASS (1sigma)

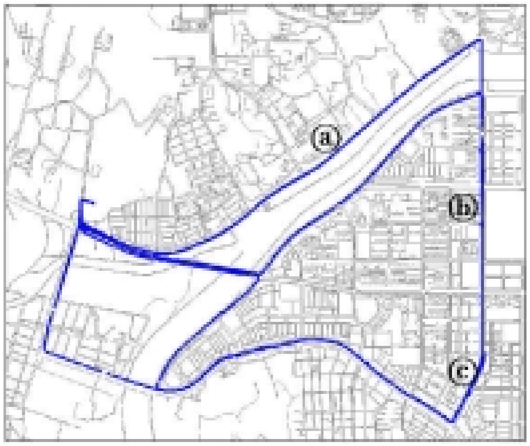


Figure 17. Results of the DGPS/DGLONASS Kinematic Survey

Figure 16 shows the comparative result of accuracies of DGLONASS, DGPS, and DGPS/DGLONASS. The accuracy of DGLONASS was the lowest due to the use of fewer satellites. The accuracy of DGPS/DGLONASS was better by 3.3cm in horizon and by 4.7cm in height than that of DGPS. Figure 17 shows the result of the DGPS/DGLONASS kinematic surveying for the Dunsan-dong area. Even in area ⓒ with clustered skyscrapers, kinematic surveying was possible to some degree. A total of 6690 observation values out of 7538 values were data-processed, 6.7% more of the data acquisition rate increased than with DGPS alone.

CONCLUSIONS

We can obtain the following results after examining the characteristics of a control coordinate system and time system on GPS and GLONASS, and analyzing 3-D positioning accuracy by developing the GPS/GLONASS combination program.

As a result of producing the coordinates of the GLONASS satellite with the Runge-Kutta technique, it is desirable to set the integration interval to less than 10 seconds for the more correct positioning of a satellite and to less then 60 seconds in the field of vehicle navigation.

By developing the DGPS/DGLONASS combination program and analyzing the accuracy, we can obtain an accuracy corresponding to a commercial program. When more than four GLONASS satellites are observed, DGPS/DGLONASS positioning accuracy is better than when only DGPS is used.

The DGPS/DGLONASS combination method is more efficient than that DGPS in urban areas where it is difficult to position with DGPS alone.

If the Galileo system is also applied, it will be useful for revising Digital Maps of urban areas.

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