



# **Nationwide Geodetic Adjustment of Integrated GPS Networks in Korea**

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## **1. INTRODUCTION**

The method of national control point network that constructed in 1910s is to set up the control points of high order and then to integrate that of lower order and results of practical applications have been estimated by baseline measurement and triangulation surveying. Since over 70 % of the geodetic control points were unfortunately destroyed during the Korean War, recovery operation for the 3<sup>rd</sup> and 4<sup>th</sup> triangulation points was carried out by Korean and US military engineering corps just after the war. Besides in coordinate of 1910s, the control points of various orders were combined, making it difficult to ensure homogeneous geodetic network because the observations were made by forward intersection and graphical method.

In order to solve the problem of the Korean geodetic network, the observation of precise primary control point network with EDM surveying began in 1974, and that of precise secondary control point network began in 1987. In addition, GPS technology has been introduced to this country in the mid of 1990s, which led to increase efficiency and accuracy of geodetic surveying and made it possible to connect global geodetic datum (e.g., ITRF and WGS84). Therefore, GPS has replaced EDM as a main geodetic observation technique since 1996. GPS campaigns had been carried out on the existing EDM networks from 2007 to 2008 to improve its accuracy compatible with that of GPS.

The National Geographical Information Institute of Korea (NGII) carried out the first GPS network adjustment from 2005 to 2006 for the nationwide densification of the Korean Geodetic Datum 2002 (KGD2002) which is a geocentric geodetic datum adopted in the early 2003. Instead of simultaneous adjustment, each of block networks was successively adjusted and combined together due to laborious works on verification and cleaning of all the observations as well as computation burden. Hence, this approach resulted in a limitation of not establishing homogenous single geodetic network. [Lee et al., 2006; Lee et al., 2007]. In order to remedy the limitation of the current geodetic network in Korea, this research has carried out a simultaneous network adjustment by processing all available GPS baseline vectors at the same time. After reviewing a brief history of the Korean geodetic networks with emphasis on GPS network adjustment performed to implement KGD2002 in 2006, the

adjustment procedure adopted in this research will be presented, which simultaneously performs without any classification of the network orders, so as to ensure its consistency. This is followed by providing results of the adjustment which indicates its overall accuracy of  $\pm 1.5\text{cm}$  and  $\pm 3.0\text{cm}$  in the horizontal and the vertical component, respectively. Finally, future works on maintenance and management of the geodetic network in Korea are summarized.

## **2. HISTORICAL BACKGROUND OF KOREAN GEODETIC NETWORK**

Korea conducted many stages of national control point network adjustment for practicality and estimation of national control points. KTN1910(Korean Triangulation Network of 1910) is the result of triangulation points established by the National Land Survey of Korea between the years of 1910~1916, which was constructed by baseline measurement triangulation surveying method. KTN1957 is the result of urgent restoration work by examining the existing triangulation points post liberation and Korea war, and method of forward intersection based triangulation surveying method was used then. After then, KTN1987 was estimated via the data secured by observation of precise primary control point network that started in 1974 and precise secondary control point network started in 1987[NGII, 2006].

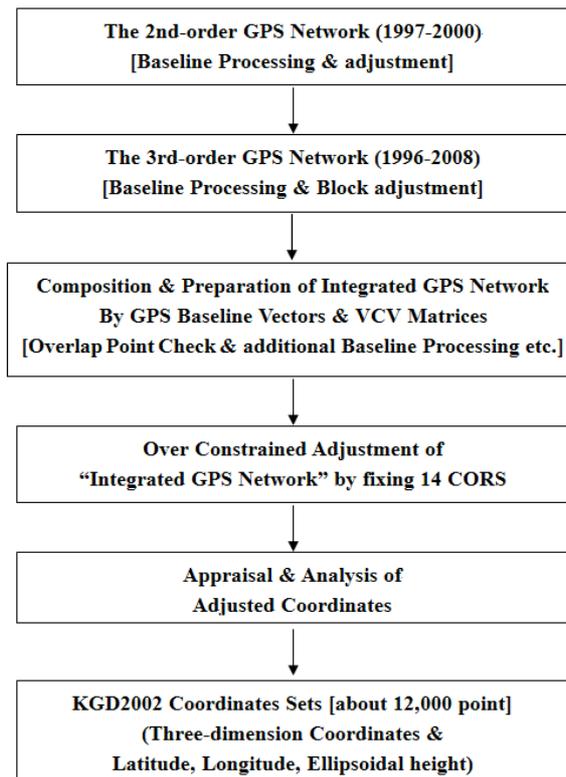


Figure 1. General procedure for KGD2002 coordinate sets

With the diffusion of GNSS surveying method in the country, about 12,000 pieces of national control points were observed by GPS surveying in the state of being divided into GPS 2<sup>nd</sup> network surveying and GPS 3<sup>rd</sup> network surveying from 1996 to 2008. GPS block network adjustment that combined the campaigns was conducted in 2006. As the results, the coordinate of national control points were estimated as geocentric 3-dimensional coordinate, latitude/longitude coordinate, plan coordinate by TM projection based on the world geodetic datum[NGII, 2006; NGII, 2008]. But, this method is problematic due to its lack of work efficiency and constant accuracy supply of national control points.

Eventually, integrated GPS network that combining total 28 GPS blocks was constructed and simultaneous adjustment of national control points through integrated GPS network adjustment was conducted in 2008. As the results, about 12,000 pieces of Korea national control points were re-estimated as the results based on world geodetic datum, resulting in the completion of KGD2002 project[NGII, 2008; Jung, 2009]. Figure 1 is the general procedure for KGD2002 coordinate sets.

### 3. INTEGRATED GPS NETWORK FOR KGD2002 project

Total 275 pieces of GPS 2<sup>nd</sup> networks were surveyed by 2000 from after the starting of the survey of nationwide 31 triangulation points in 1996 including overlapped points. Over 8 hours of observation with receipt interval of 30 seconds was conducted to unify the working way and norm in GPS observation and to secure necessary accuracy.

GPS 3<sup>rd</sup> network surveying was conducted at 17,000 pieces (total 92 campaigns) of triangulation points including temporary points connected with BMs and eccentric points, overlapped points with campaigns from 1997 to 2008. GPS observation was conducted over 4 hours with 30 seconds' storage interval for overlapped points observation of the neighboring area to connect between campaigns. Besides, GPS 2<sup>nd</sup> network connected observation for hierarchical construction of national control points was achieved. Fig 2 is the distribution illustration of national control points observed by GPS surveying.

2<sup>nd</sup> order network and 3<sup>rd</sup> order network were adjusted in the way of being divided prior to integrated GPS network adjustment. GPS 2<sup>nd</sup> network adjustment was carried out in the way of setting the total campaigns as nationwide single 2<sup>nd</sup> network and then estimated total 200 pieces of adjusted results by fixing 14 CORS of NGII [Lee et al., 2007]. Furthermore, for 3<sup>rd</sup> order network adjustment, total 93 campaigns were fixed into total 28 adjusted blocks for separate GPS block network adjustment, and the results of GPS 2<sup>nd</sup> network within GPS block and overlapped points between blocks were used as fixed points. 3<sup>rd</sup> order network was adjusted firstly in 2006 and 2<sup>nd</sup> estimation was conducted in 2008 for GPS network observed after 2006 as seen in Fig 3 and Fig 4 [Lee et al., 2007; NGII, 2008].

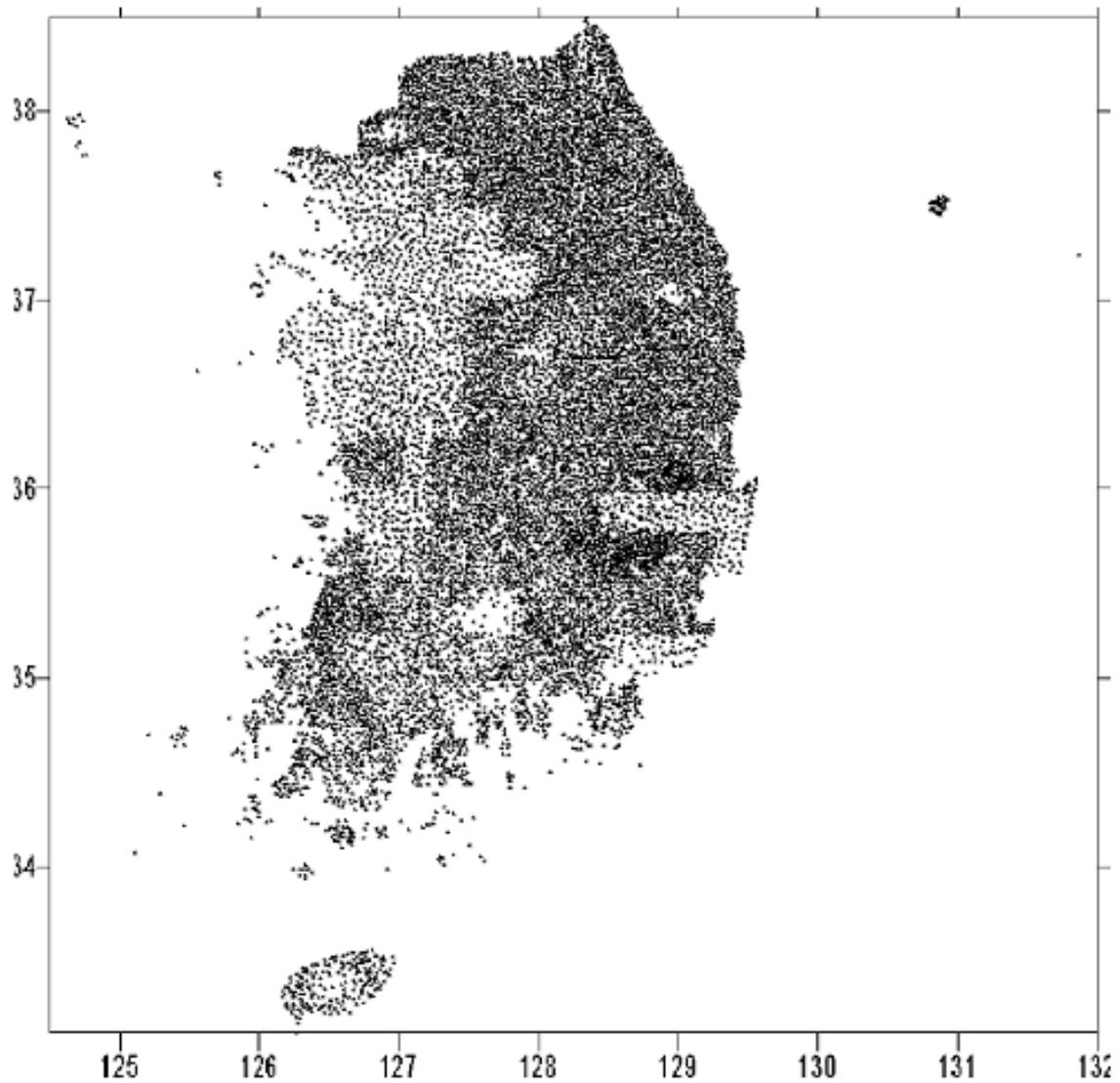


Figure 2. Control points observed by GPS(unit:degree)

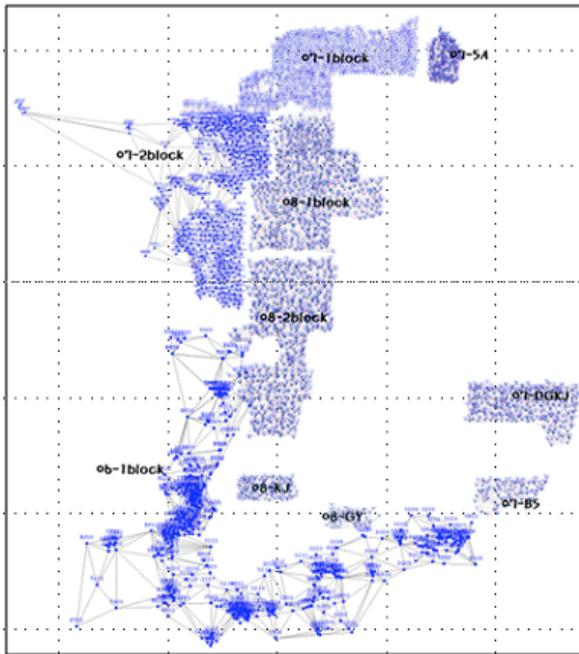


Figure 3. GPS block adjustment in 2008

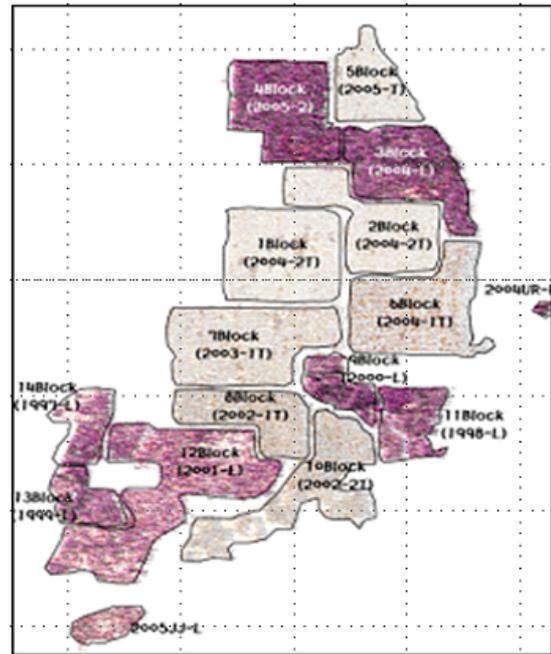


Figure 4. GPS block adjustment in 2006

In 2008, GPS-INT-EAST in east area blocks and GPS-INT-WEST in west area blocks were integrated into 2-section integrated GPS network for simultaneous adjustment of nationwide single national control point network. East area is consists of 40 campaigns including Dokdo and Ulleung island, and west area is consists of 53 campaigns including west sea islands and Jeju island. The magnitude of relative error ellipsoid between points was estimated with 95% probability based on the results of minimally constrained adjustment to estimate the propriety and accuracy of stochastic modelling and integrated GPS network. The results of the estimation were within 0.0056m in horizontal direction, and within 0.0128m in vertical direction on average.

Over constrained adjustment for integrated GPS network was conducted by fixing the bulletin results of 14 CORS run by NGII, and then final results of national control points was estimated Fig 5. Table 1 is the summarized adjustment results of integrated GPS network indicating fulfillment of redundant observation, and it's noticeable that the adjusted coordinate was estimated as the accuracy of  $\pm 1.5\text{cm}$ (95% in horizontal direction,  $\pm 3\text{cm}$ (95%) in vertical direction considering the mean and RMSE of magnitude of absolute error ellipsoid of the point estimated for 95% probability indicating absolute accuracy of adjusted coordinate.

Table 1. Summary of adjustment results about over constrained adjustmt

		GPS-INT-EAST	GPS-INT-WEST
Number of Station(Pt.)		7,231	7,425
Number of Observation		85,563	86,073
Degree of Freedom		65,217	63,837
Average and RMSE of 95% absolute error of observation points	Hor.(m)	0.0059, $\pm$ 0.0013	0.0073, $\pm$ 0.0027
	Ver.(m)	0.0136, $\pm$ 0.0029	0.0161, $\pm$ 0.0058

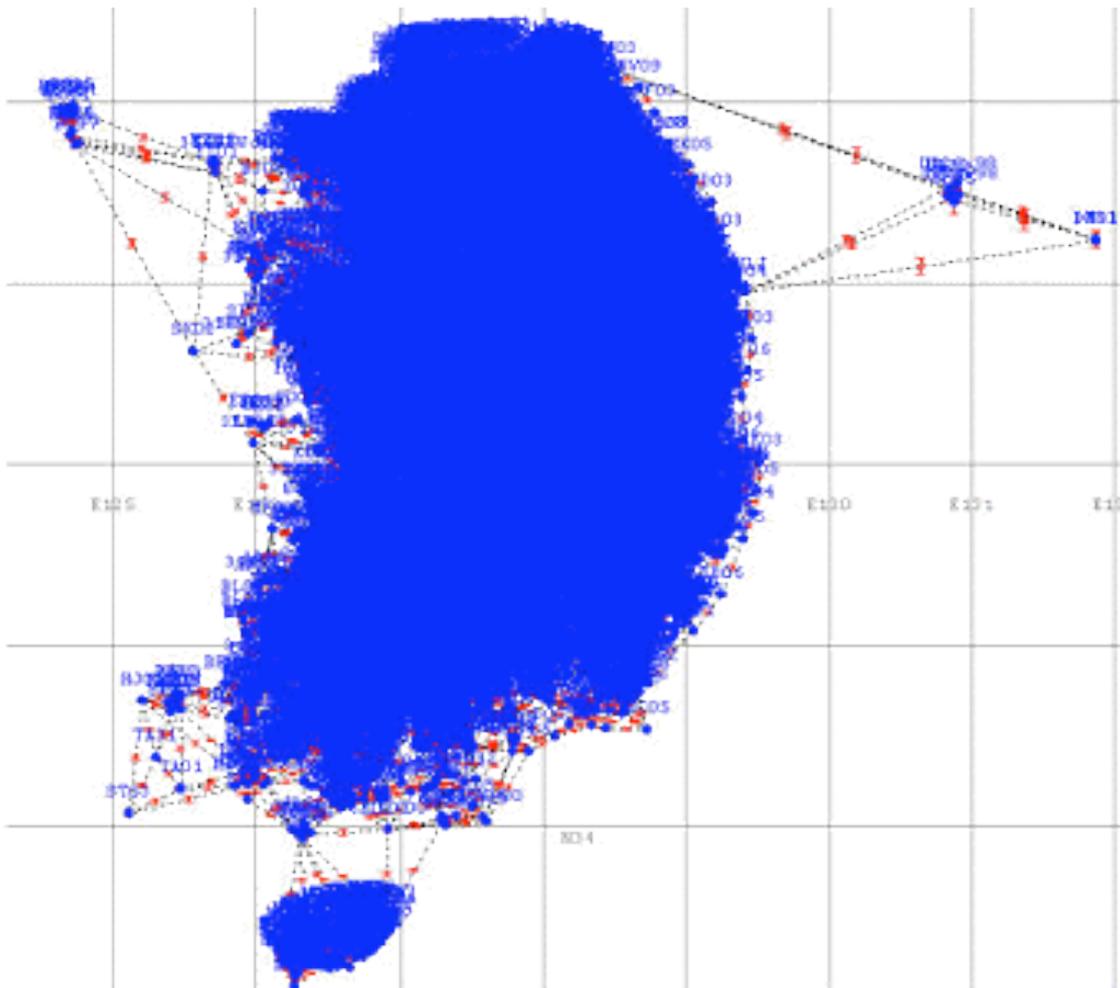


Figure 5. Over constrained adjustment of Integrated GPS adjustment

Total 473 coordinate of overlapped points which have been through network adjustment by fixing bulletin result of CORS that included in integrated GPS network divided into two areas

to check up the accuracy of GPS network adjustment, were compared. Table 2(a) is the results of stochastic estimation for the differences of overlapped points coordinate showing latitude of 0.003m, longitude of -0.025m on average, and 0.012m in ellipsoidal height.

The adjusted results estimated from integrated GPS network and block network adjustment were compared as another way to check up the adjusted result of integrated GPS network. And the comparison showed that not a great coordinate difference caused by network adjustment error, but only with differences of -0.011m in horizontality and -0.040m in verticality as seen in Table 2(b).

Lastly, the differences of coordinates of 2nd GPS control points estimated from integrated GPS network and 2nd GPS order network adjustment respectively were compared and then stochastic estimation was carried out. And its results were -0.010m in horizontal direction, -0.038m in vertical direction on average in Table 2(c).

Table 2. Comparison of coordinate difference with check result

(a) coordinate difference of overlapped points between integrated GPS network				
	Ave.	SD	RMSE	Max
Latitude(m)	0.003	0.020	0.020	0.084
Longitude(m)	-0.024	0.034	0.042	0.130
Ellipsoidal Height(m)	0.012	0.037	0.039	0.134
(b) coordinate difference of GPS block and integrated GPS network				
	Ave.	SD	RMSE	Max
Horizontal(m)	-0.011	0.017	0.020	0.115
Vertical(m)	-0.040	0.027	0.048	0.172
(c) coordinate difference with results of GPS 2 <sup>nd</sup> order control points				
	Ave.	SD	RMSE	Max
Horizontal(m)	-0.010	0.015	0.018	0.094
Vertical(m)	-0.038	0.028	0.047	0.140

#### 4. BEST PROCEDURE OF GPS NETWORK ADJUSTMENTS

We like to hold out the optimal procedure(best practice) of GPS network adjustment to estimate the results of unknown points observed by GPS surveying based on empirical methods and theories progressed for KGD2002 estimation as seen in Fig 6 as below.

(a) Acquisition and check of GPS observation data

GPS observation data necessary for baseline processing and precise ephemeris of GPS satellite necessary for baseline processing of long baseline should preferentially be secured for GPS network adjustment. Besides, for accurate estimation of unknown point coordinate with GPS network adjustment, the process of checking the quality of observation data such as observed antenna height, observed station name, receipt interval of data & receipt time, receipt state of data is indispensable. Especially, in antenna height case, check up of the location that measured APC(Antenna Phase Center), ARP(Antenna Reference Point), and of offset of antenna receiver by manufacturer is necessary. And a check up of receiving time and state needs to be done by all means for the minute application of mathematical difference in difference to the observed value of carrier value obtained from the two points while baseline processing. A check up of receipt time & receipt state is required for the minute application of mathematical double difference to the carrier wave observed value gotten from the two points while baseline processing.

(b) GPS baseline processing

GPS network is adjusted by using 3-dimensional baseline vector between two points generated from observed GPS data processing and VCV matrix. Baseline vector and VCV matrix can be calculated through GPS processing, a mathematical method and procedure estimating baseline vectors  $\Delta X$ ,  $\Delta Y$ ,  $\Delta Z$  between two points by least square method passing through the determination of integer ambiguity process after the application of mathematical double difference to the carrier wave observed value obtained from the two points at the same time effect of ionospheric and tropospheric, error of satellite track need to be fully checked up to raise the accuracy of baseline processing, and baseline processing S/W should be selected suitable for the purpose for use. Besides, after GPS processing, miscloser of baseline vector needs to be examined if there exists outlier in baseline vector or not.

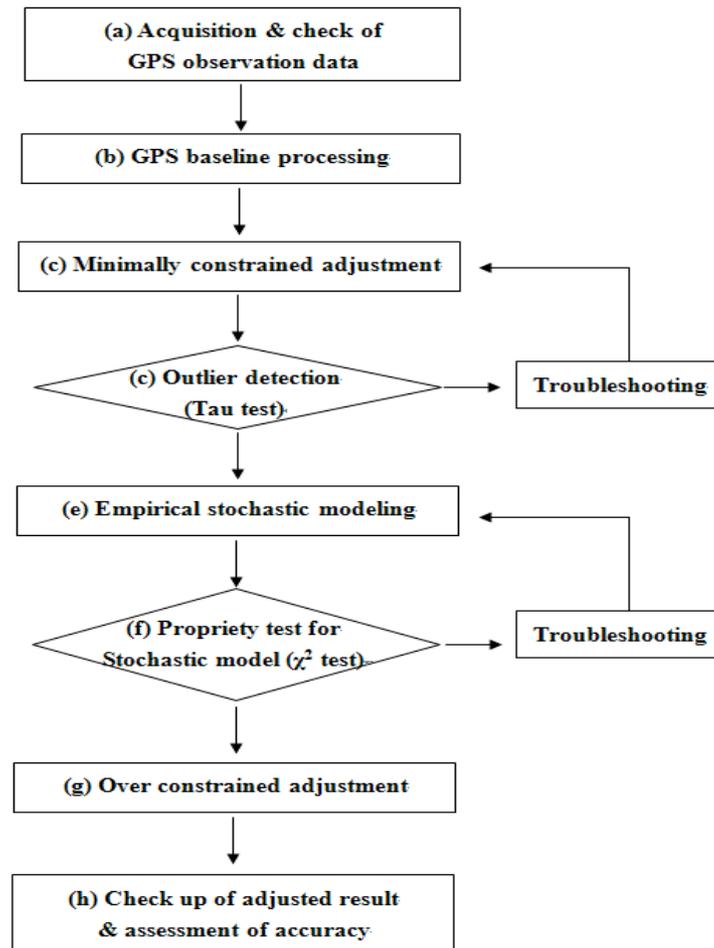


Figure 6. Optimal procedure of GPS network adjustment

### (c) Minimally constrained adjustment

Minimally constrained adjustment is conducted to detect outlier in GPS network that hasn't been detected in the discloser check up that carried out after baseline processing, and to calculate approximate accuracy of GPS network, and to determine the statistical model of GPS network that will be used in the final adjustment. One point fixed adjustment and free adjustment are mainly used for minimally constrained adjustment, approximate accuracy of GPS network is assessed through RMSE or arithmetic mean through calculation of the size of relative error ellipse between points obtained after minimally constrained adjustment for certain probability(generally 95%).

### (d) Outlier detection(tau test)

In order to check up outlier within GPS network, standardized residual should be calculated under the assumption that VCV matrix of measured value is unknown and then compare them with critical value determined by confidence interval and degree of freedom supposing they conform to students' distribution and then tau test was used for outlier detection. Tau distribution is used to estimate the confidence interval of the average of comparatively small mother group, and mainly used to check up the propriety of the average for certain part after comparison with the mother group average[Lee et al., 1987; Paul et al., 1997].

#### (e) Empirical stochastic modelling

Random error components could be included in the corrected VCV matrix, but the errors included in the estimation of effect of atmosphere and antenna height estimation that haven't been fully modelled in baseline processing S/W couldn't be included in stochastic model, and so stochastic model is determined through Empirical stochastic modelling which corrects the variance, the diagonal element of VCV matrix by recalculating it for reflection of actual accuracy of GPS network. Empirical stochastic modelling was done in the way of changing  $a$  and  $b$  in (1) by dividing it into horizontal(N, E) and vertical(H) until it passed  $\chi^2$  test, a fidelity test for model.  $S$  is standard deviation of baseline vector,  $a$  is absolute error different to the points observed,  $b$  is relative error of ppm unit in proportion to baseline length,  $L$  is baseline length[Rizos, 1996].

$$s_{E,N,H}^2 = (\alpha_{E,N,H} + b_{E,N,H} \cdot L) \quad (1)$$

#### (f) Propriety test for stochastic model( $\chi^2$ test)

Stochastic test for variance factor is necessary for the propriety of mathematical model and stochastic model that used for estimation or detection of outlier, and for this test, attest for certain confidence needs to be carried out. The result can't pass the  $\chi^2$  test if inappropriate mathematical model or stochastic model was used or the measured value contains outlier.

$\chi^2$  test is the density function for the distribution of variance estimated from the degree of freedom selected by mother group, a critical value of distribution should be arranged into a stochastic table for distribution use and stochastic test to determine confidence interval for the variance of mother group[Paul et al., 1997].

#### (g) Over constrained adjustment

Over constrained adjustment is a way of determining the coordinate of unknown point and final adjustment results by using the coordinate of unknown point and the size of baseline vector between points & variation of VCV matrix. Function model, determined by relational expression of coordinate difference for each baseline made up of baseline vector is used for the determined coordinate of unknown point by over constrained adjustment. Function model could be formulated as observed equation and in case, the number of observed equation exceeds that of unknown quantity, solution could be obtained by least square method principle[Lee et al., 1998; Leick, 2004; Rizos, 1996].

#### (h) Check up of adjusted result and assessment of accuracy

The comparison of check result with reliable accuracy and coordinate difference needs to be conducted along with comparison with individual applied point, and stochastic calculation such as RMSE, standard deviation, mean for the coordinate difference needs to be carried out for the check up of adjusted results. Besides, the assessment of adjusted results accuracy is available through estimation of absolute error ellipsoid generated from GPS network adjustment. The accuracy of horizontal location of absolute error ellipsoid could be seen considering the correlation of east and west (E) and south and north (N), and the size and shape of error ellipsoid varies to the size of standard deviation of measured value and covariance between components.

### **5. CONCLUDING REMARKS AND FUTURE PLAN**

This paper presents a nationwide GPS network adjustment for the densification of the Korean Geodetic Datum 2002 (KGD2002) which is a geocentric geodetic datum adopted on 1<sup>st</sup> January 2003. After providing brief history of the Korean geodetic networks with emphasis on GPS network adjustment performed to implement KGD2002, the geodetic network adjustment procedure adopted in this research will be presented, which simultaneously processing all available GPS baseline vectors in Korea without classification of the network orders, so as to ensure its consistency. This is followed by providing results of the adjustment which indicates its overall accuracy of  $\pm 1.5\text{cm}$  and  $\pm 3.0\text{cm}$  in the horizontal and the vertical component, respectively.

For effective and systematic management and operation of CORS network, it seems to be advisable to divide the area into central, south east, south west areas, and entrust NGII with the operation and management of the whole CORS network. The stress of the CORS data

service should be focused on the supply of real time correction data along with the offering of the data for post treatment for the use to network based RTK. Precise estimation of correction data and smooth supply of them are necessary for real time correction data. Continual study is required for precise estimation of correction data and various communication mediums such as cell phone, modem, wireless internet, DMB and environment for smooth communication between the central station that supplying correction data and users. Besides, continuous study is necessary for the solution to the lack of accuracy testing method for result calculation one of weakest point in network RTK surveying.

Currently, NGII is offering correction data for VRS, but the data quality have to be improved by calculating RTK correction data of CORS with diverse ways including SmartNet method, and the data must to be offered in data format method applicable to all the receivers made by many manufacturers. Besides, the correction data of CORS network needs to be classified into precise surveying, DGPS, real time location service for the grade and fee according to the use purpose and accuracy like German, Japan, the UK.

Triangulation points needs continues result renewal and service as it has to take the role of alternative control points and of control points for the measurement method other than GPS surveying when the service of constant GPS observation point is unexpectedly stopped. Consequently, integrated national control point network got to be established for the supply of the result of Dynamic datum based national control points, and the study on calculation of motion vector quantity for variance of control points is necessary for the semi-dynamic datum based renewal of the result of national control points.

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