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Development of KOGD2003 Geoid Model and its Implementation by Visual Software

Suk-Bae LEE* and Yong-Woon SUH**

Abstract

It is well known that GPS technique can be used for high accuracy leveling positioning if a precise geoid model is available to use at a surveying point. In this study, KOGD2003 geoid model was developed in and around Korean peninsula and this geoid model could be achieved by combining GPS/leveling data with the formerly developed KOGD2002. To this end, the software for orthometric height obtaining and geodetic datum transformation has been implemented with the visual C++ language, what we called GPS-GeoL v.1.0. In order to evaluate the performance and the accuracy of the software, GPS field tests were carried out in the Korean second-order leveling network over Chollabukdo area. Results of the tests have shown that the mean value of the differences between outputs of the software developed in this research and officially announced orthometric heights by NGII (National Geographic Information Institute) was 0.0221 m and also those of RMS was 0.0332 m. Therefore, it was possible to conclude that the KOGD2003 and GPS-GeoL v.1.0 software could be used to determine orthometric heights for civil construction field applications with cm-level accuracy.

Keywords : orthometric heights, GPS/leveling, geoidal heights, GPS-GeoL v.1.0 software

1. Introduction

GPS (Global Positioning System) provides precise positioning in a terrestrial three dimensional Cartesian frame as like ECEF (Earth Centered, Earth Fixed) coordinates system. In addition the ECEF Cartesian referenced coordinates (e.g. X,Y,Z) can also be converted into ellipsoidal-referenced ones (e.g. latitude, longitude and ellipsoidal height). However, in order to obtain orthometric height, reduction is required with accurate geoidal height.

In Korea, the latest geoid model is KOrean GeoiD 2002 (KOGD2002) and Lee (2004) made and published the KOGD2002 gravimetric geoid model applying remove and restore technique. In the above computation of geoidal heights N by combining a geopotential model(GM), mean free air gravity anomalies $\triangle g_{FA}$, and heights (h) in a degital terrain model is based on the following formula Eq. (1).

$$N = N_{GM} + N_{\Delta g} + N_h,$$
$$\Delta g_{res} = \Delta g_{FA} - \Delta g_{GM} - \Delta g_h \quad (1)$$

The term N_{GM} gives the contribution of the GM coefficients, while the term $N_{\triangle g}$ gives the contribution of the reduced mean free air gravity anomalies with the effects of the GM, $\triangle g_{GM}$, and the terrain $\triangle g_h$, removed. N_h gives the indirect effect of the terrain reduction on N.

Computation of KOGD2002 involves a spherical approximation to conduct the Stokes' intergration by a two dimensional Spherical fast Fourier Transform (SFT) with 100% zero-padding (Lee, 1996). A terrain correction was also computed by FFT with a spherical approximation of the Residual Terrain Model (RTM) terrain correction integration. (Lee, 1996) And, then more accurate new geoid model was made on the basis of KOGD2002.

Fig. 1 shows relation of orthometric height, geoidal height and ellipsoidal height and the orthometric height can be calculated by Eq. (2) under the assumption that deflection of the vertical (θ) is zero.

$$H = h_{GPS} - N \quad (2)$$

*Member, Assistant Professor, Dept. of Civil Engineering, Jinju National University, Jinju, Korea (E-mail : sblee@jinju.ac.kr)
**Assosiate Professor, Dept. of Civil & Urban Engineering, Pohang College (E-mail : ywsuh@pohang.ac.kr)

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Where,
H : orthometric height
h : ellipsoidal height
N : geoidal height
θ : deflection of the vertical

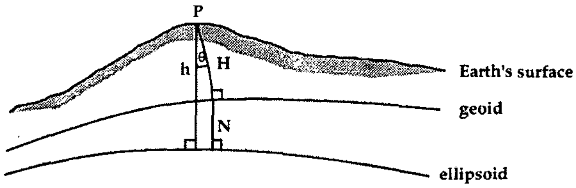

Fig. 1. Relation of H, N and h.

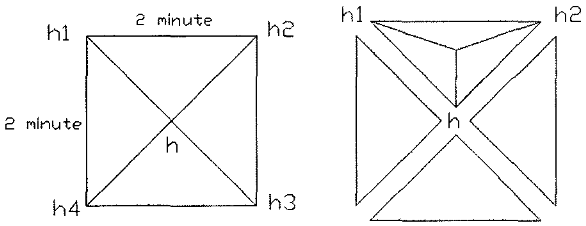

Fig. 2. Intèrpolation of geoidal height in a grid.

To achieve the orthometric height at random point, firstly geoidal height has to be determined at the same point. So, to calculate geoidal height first, geoidal height of central point of a grid is calculated based on bilinear interpolation and second, geoidal height of the random point is calculated on the multiquadric interpolation as shown in Fig. 2.

An aim of this paper is to develop a software which computes orthometric height at GPS surveyed point and geodetic datum transformation. Fig. 3 depicts outline of this research process. As shown in the figure, GPS-GeoL v.1.0 software was developed using visual C++ language to obtain orthometric height at GPS-surveyed point and geodetic datum transformation. And GPS/leveling field survey was carried out in test area for accuracy evaluation.

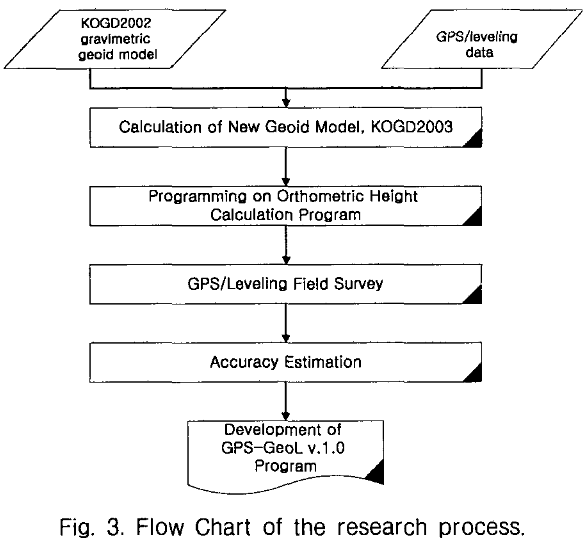

Fig. 3. Flow Chart of the research process.

2. Development of Precise Geoid Model, KOGD2003

It can be classified several ways into gravimetric method, astro-geodetic method and GPS/leveling method etc to obtain geoidal heights. And, the precision of geoidal heights can be improved if the heterogenious data are used in computation of geoidal heights because one kind of data (as like gravity data or satellite altimetery data) has the precision limit in computation of geoidal heights. The general strategy for high resolution local gravity field determination has been pointed out by a number of authors. (Tscherning and Forsberg 1986, Denker et al., 1986, Schwarz et al., 1987) The gravtity field determination is splitted up and taken from three different parts, and also, KOGD2002 was developed contribution of three different wavelength contribution as follows.

- the long wavelength contributions from a global geopotential model:
  EGM96 model was used to compute long wavelength effect by spherical harmonic analysis.
- the medium wavelength contributions from terrestrial point observations in land and satellite altimeter data in ocean as gravity anomalies:
  Point gravity data were supplied from Korean NGII and Pusan National University. Gravity anomalies in the ocean area are based on a combination of Geosat, ERS-1 and Topex/Poseidon databases made by BGI.
- the short wavelength contributions from high resolution digital elevation model:
  In order to compute the terrain correction and their contribution of geoid prediction, a $2' \times 2'$ gridded DEM was generated by means of a minimum curvatures spline from GTOPO30 digital elevation model supplied by USGS.

To improve the precision of KOGD2002, geometric geoid was added to KOGD2002. To obtain geometric geoid, 104 GPS/leveling data was taken from Korean Energy Resource Institute, SungKyunKwan University and Korean Astronomy Observatory but, only 59 GPS/leveling data was selected considering its accuracy and local density. So, the KOrean GeoiD 2003 (KOGD2003) model was made by combination of

KOGD2002, gravimetric geoid model and geometric geoid by 59 GPS/leveling data. Contour map of geoidal heights of KOGD2002 and KOGD2003 are shown in Fig. 4 and Fig. 5.

The above two geoid model consists of 89,701 point data by 2′×2′ grid spacing area of latitude from 32°N to 43°N and longitude from 123°E to 132°E in and Korean peninsula.

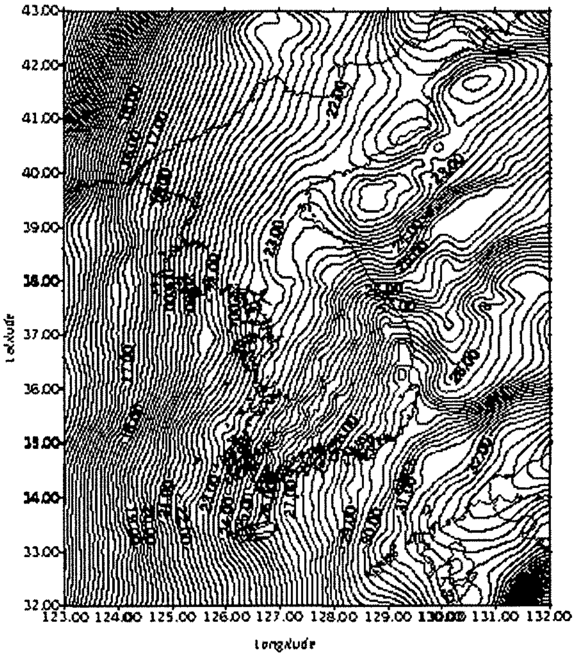

Fig. 4. Contour map of KOGD2002 geoidal heights referred to GRS80 (Contour interval = 0.25 m).

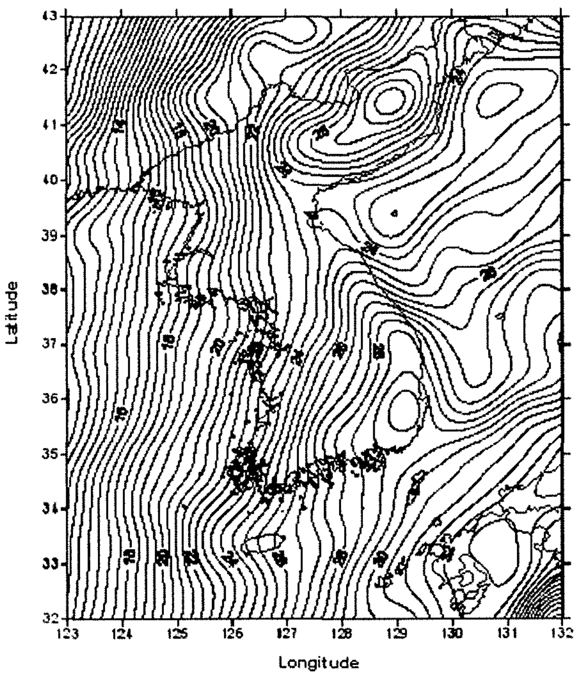

Fig. 5. Contour map of KOGD2003 geoidal heights referred to GRS80 (Contour interval = 0.5 m).

3. Development of GPS-GeoL v.1.0 Software

Orthometric height calculation software can be developed in base of interpolation because KOGD2003, precise geoid model had made. To make it user-friendly program, visual C++ language and pull-down menu were used. To develop the program, first total menu frames were determined and then works to be processed in each frame were determined. The program was designed that user could access through user-ID and password after program installation. The program was designed with two main parts, one was on orthometric height calculation and the other was on geodetic datum transformation. After completion of program development, this software was named 'GPS-GeoL v.1.0'. Fig. 6 shows main frame of first main part of GPS-GeoL v.1.0 software about orthometric height calculation.

As you can see in Fig. 6, the first main frame of the software has data input function, function on automatic calculation of orthometric heights and data storage function. Execution method can be determined by button selection between point data calculation method and totally data calculation method according to the input data amount. In point data calculation method, execution process are as like belows.

1. Data input function: Point data as like station name,

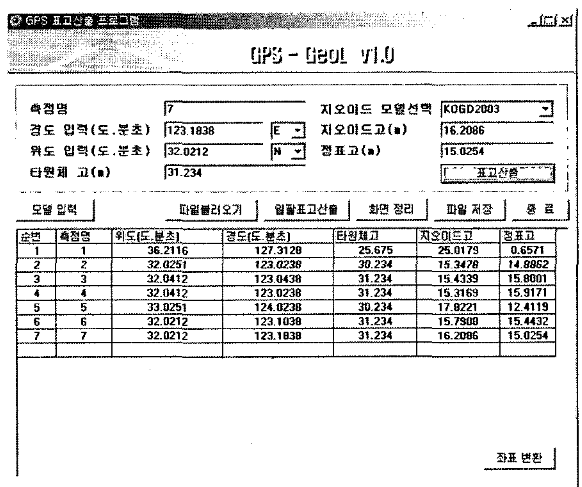

Fig. 6. A main frame of GPS-GeoL v.1.0 about orthometric height calculation.

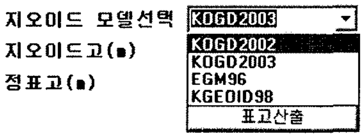

Fig. 7. Choice function of geoid model.

latitude, longitude and ellipsoidal height have to be inputted.

2. Geoid model choice function: Appropriate geoid model can be chosen in this function for extraction of geoidal height. as shown in Fig. 7.
3. Orthometric height calculation function: Orthometric height can be calculated automatically in this process. And the results as like geoidal height and orthometric height shall be displayed in each blank row.

In totally data calculation method, the basic process is similar to previous point data calculation process. But, because the data amount is so big, input, calculation and output function is accomplished by a file and excel file format (xls) is adapted for standard file format in this process. So, the functions as like calling excel file out as input data file and total calculation of orthometric height of the excel file and data file storage are added on previous method.

As like many countries have been changing their geodetic reference systems to geocentric reference system because applications of GPS have been increased, Korea also has been changing hers from local reference system to geocentric one. But, in order to prevent people's confusion caused by use of new reference system which has been used since 2003, Korean NGII notified that all survey could be accomplish at the base of both old local Tokyo Datum on Bessel 1841 ellipsoid and new KGD2002 (Korean Geodetic Datum 2003) based on GRS80 ellipsoid until 2006. So, the geodetic datum transformation between old and new geodetic reference system is necessary. Therefore, as the other main part of GPS-GeoL v.1.0 software, geodetic datum transformation frame was added. As you can see in Fig. 8, this frame have menu as like point data transformation and data file transformation with excel-file format.

In this function, geodetic datum transformation can be performed with seven parameters consist of parallel translation ($\triangle X, \triangle Y, \triangle Z$), rotation parameter ($R_x, R_y, R_z$) and scale factor between old and new datum in Korea. And, also this frame contains transformation function between geographical coordinates (ϕ, λ, h) to three

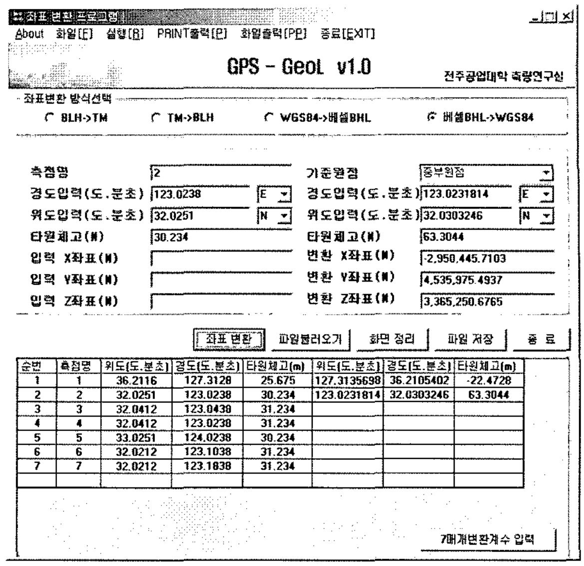

Fig. 8. A main frame of GPS-GeoL v.1.0 about geodetic datum transformation.

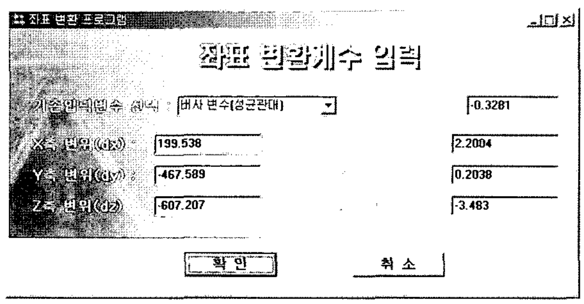

Fig. 9. Input function of geodetic datum transformation parameter sets.

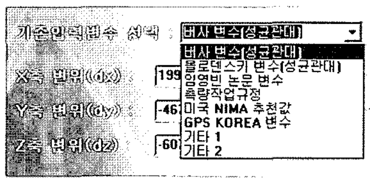

Fig. 10. Choice function of geodetic datum transformation parameter sets.

dimensional Cartesian coordinates (X,Y,Z). In addition, for the various geodetic datum transformation procedure, it can be inputted that various geodetic datum transformation parameter sets (Fig. 9) and it can be chosen among the various parameter sets. (Fig. 10)

4. GPS Field Survey for Accuracy Evaluation

For accuracy evalutation of GPS-GeoL v.1.0 software, GPS field survey was carried out by authors at 13 vertical control points distributed in 53 km Korean second leveling line and the GPS field survey area located in Kunsan and Jeonju city southwestern part of Korea. GPS field survey was accomplished in Korean official first and second order vertical control points with connection of two horizontal control points to obtain horizontal coordinates. Summary of the GPS field survey is shown in Table 1 and Fig. 11 shows location of GPS field survey points.

Data processing for 'baseline analysis' and 'network adjustment' were accomplished with Trimble Geomatics Office (TGO) after collection of all RINEX data under the 'Regulations of 1st and 2nd order control points survey by GPS' of Korean NGII. And, then geographical coordinates and ellipsoidal heights were obtained after data processing and geoidal heights was extracted in the GPS-GeoL v.1.0 for the same points. Also, official leveling results of orthometric height for 13 GPS survey points (leveling points) were issued by Korean NGII. So, comparison of optometric heights between output of GPS-GeoL v.1.0 and official results of NGII was accomplished. Table 2 shows the results and differences.

Where,

A : Ellipsoidal heights by GPS
B : Geoidal heights extracted from GPS-GeoL v1.0
C : Orthometric heights calculated in GPS-GeoL v1.0
D : Official coordinates of orthometric heights issued by NGII
E : Differences of C and D (C-D)

According to the ststistics of Table 2, comparison results are turned out a minimum value of differences is -2.84 cm, a maximum value is 10.64 cm, mean value is 2.21 cm and RMS of differences is 3.32 cm. Therefore, we can judge that GPS-GeoL v.1.0 software could be applied in civil construction field to obtain orthometric height on GPS survey point without connection of vertical control point with cm-accuracy.

Above Fig. 12 shows comparison chart of geoidal heights of KOGD2002, KOGD2003 and GPS/leveling geoid and Table 3 shows the statistics of differences between KOGD2002, KOGD2003 and GPS/leveling geoid.

Table 3 shows that KOGD2003 geoid model is

Table 1. Summary of GPS field survey.

Number of survey point	13 vertical control points and 2 horizontal control points
Receiver used	2 Trimble 5700 and 4 Topcon Legacy
Observation period and time	Nov. 12 - Nov. 14, 2002 1hour observation per session
Number of session	4
Data processing software	TGO (Trimble) and Pinnacle (Topcon)

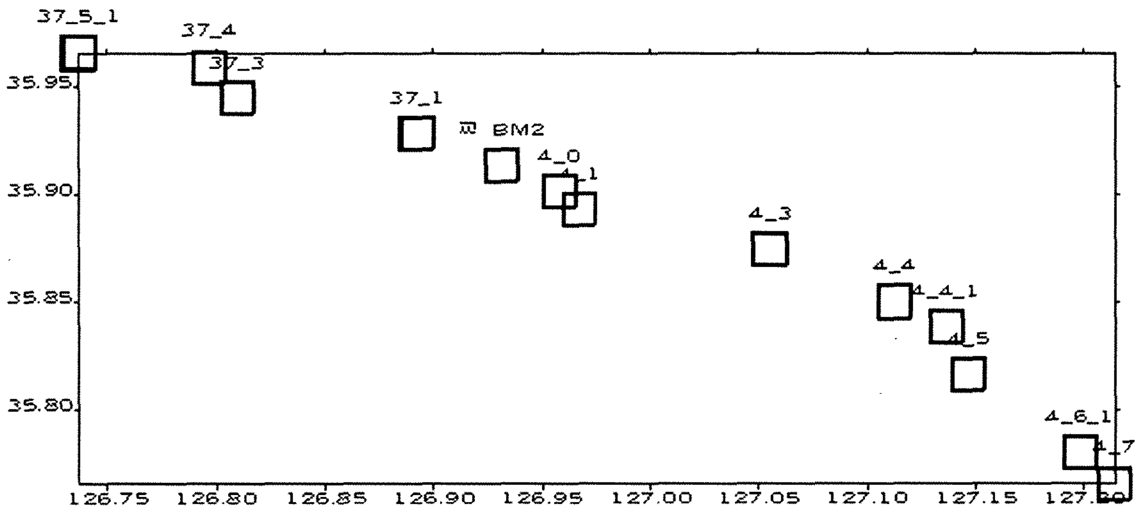

Fig. 11. Point map of GPS field survey.

Table 2. Comparison of orthometric heights.

NO.	BM NO	Longitude (°)	Latitude (°)	A	B	C	D	E
1	37_5_1	126.736930E	35.966176N	28.883	23.6573	5.2603	5.2257	0.0346
2	37_4	126.796758E	35.959321N	33.690	23.7928	9.9196	9.8972	0.0224
3	37_3	126.809901E	35.944910N	32.610	23.7948	8.7977	8.8152	-0.0175
4	37_1	126.892364E	35.928256N	29.402	24.1512	5.3572	5.2508	0.1064
5	교BM2	126.931213E	35.913427N	33.788	24.1927	9.6219	9.5953	0.0266
6	4_0	126.958376E	35.901275N	32.567	24.2303	8.3083	8.3367	-0.0284
7	4_1	126.967062E	35.893142N	33.866	24.2952	9.5747	9.5708	0.0039
8	4_3	127.055345E	35.874599N	49.760	24.5883	25.1701	25.1717	-0.0016
9	4_4	127.112949E	35.850054N	47.835	24.7959	23.0232	23.0391	-0.0159
10	4_4_1	127.136536E	35.838107N	61.446	24.9129	36.5397	36.5331	0.0066
11	4_5	127.146569E	35.815982N	65.915	24.9592	40.9449	40.9558	-0.0109
12	4_6_1	127.198336E	35.779824N	101.555	25.2061	76.3508	76.3489	0.0019
13	4_7	127.214016E	35.765394N	117.843	25.2712	92.5606	92.5718	-0.0112

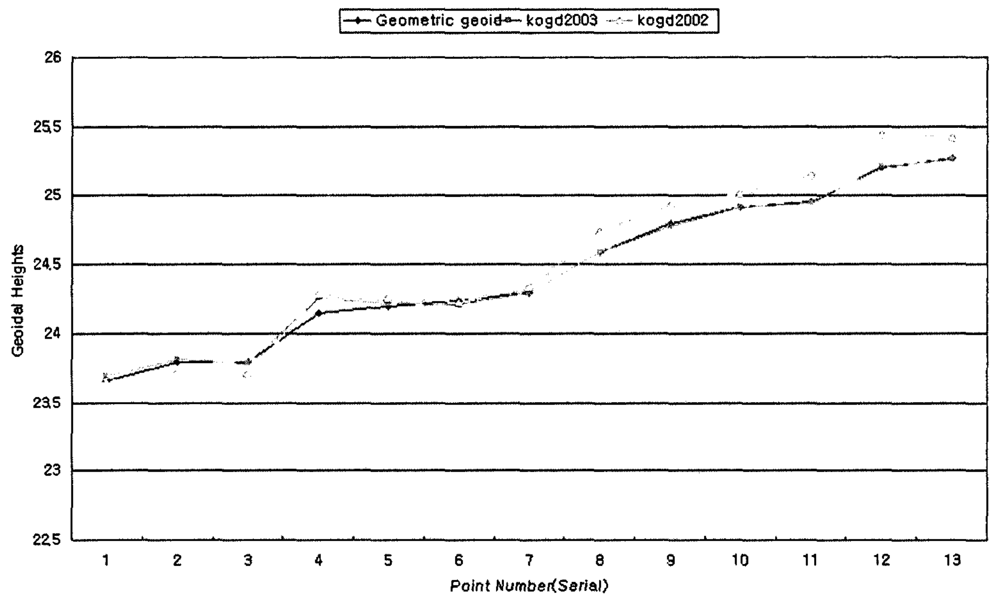

Fig. 12. Comparison chart of geoidal heights of KOGD2002, KOGD2003 and GPS/leveling geoid.

Table 3. Statistics of differences between KOGD2002, KOGD2003 and GPS/leveling geoid.

Items	KOGD2002	KOGD2003
Minium value	-0.0871 m	-0.0284 m
Maximum value	0.2296 m	0.1064 m
Mean value	0.0776 m	0.0221 m
RMS	0.0961 m	0.0332 m

more accurate than KOGD2002 gravimetric geoid model. And it can be confirmed that GPS/leveling data is efficient to improve accuracy gravimetric geoidal height as a heterogeneous data.

5. Conclusion

In order to transform ellipsoidal height differences obtained from GPS survey into national height system with cm accuracy, geoidal heights differences must be available within the same accuracy level. The goal of this research was to develop user-friendly software about orthometric height achievement at GPS survey point and geodetic datum transformation. To develop this software, precise geoid model was needed so, KOGD2003 precise geoid model was made by combination of KOGD2002 which was gravimetric geoid model by FFT and geometric geoid by GPS/leveling data. And the accuracy of KOGD2003 was improved compared to KOGD2002 geoid model. Therefore, orthometric height can be achieved in GPS-GeoL v.1.0 software at GPS survey point without connection of vertical control point. To be user-friendly software, visual C++ language was used.

And, for accuracy evaluation of the software, GPS survey was carried out at 13 vertical control points distributed in 53 km Korean second leveling line. The comparison results of orthometric heights between GPS/leveling data and GPS-GeoL v.1.0 software shows that mean value of differences is 2.21 cm and RMS of differences is 3.32 cm. Therefore, we could judge that GPS-GeoL v.1.0 software with GPS could be applied in construction field to obtain orthometric height with cm-level accuracy.

References

1. Ardalan A.A. and Grafarend E.W. (2001). "Ellipsoidal geoidal undulations (ellipsoidal Bruns formula); case studies", *Journal of Geodesy*, Vol. 75, No. 9-10, pp. 544-552.
2. Collier P.A. and Croft M.J. (1997). "Heights from GPS in an engineering environment", *Survey Riview*, Vol. 34, No. 263, pp. 11-18.
3. Denker H. and Wenzel H.-G. (1987). "Local geoid determination and comparison with GPS results", *Bulletin Geodesique*, Vol. 61, pp. 349-366.
4. Heiskaanen W. and Moritz H. (1967). *Physical Geodesy*, W.H. Freeman and Co., Sanfransico, USA.
5. Kim, K.B. and Lee, S.B. (2002). "Determination of gravity anomaly using satellite altimeter data in Great Lakes", *KSCE Journal of Civil Engineering*, Vol. 6, No. 3, pp. 313-320 .
6. Li Y., Pascoe R.W. and Brunner F.K. (1990). "Reproducibility of Height Difference Measurements Using GPS", *The Austrian Surveyor*, Vol. 35, No. 2, pp. 128-139.
7. Lee, S. (1997), *Visual C + + Programming Bible Ver. 5.X.* Youngjin Publishing Co.
8. Lee, S.B. (1996). *Precise Geoid Determination by FFT in and around Korean Peninsula*, Ph.D. Dissertation, Department of Civil and Environmental Engineering, SungKyunKwan University, Suwon, Korea.
9. Lee, S.B., Hwang, Y.J. and Lee, J.W. (2004). "Calculation of Geometric Geoidal Heights Using GPS/leveling Data in Study Area", *Journal of the Korean Society of Surveying, Geodesy, Photogrammetry, and Cartography*, Vol. 22, No. 1, pp. 45-52.
10. Takao T, Shigeo W. and Tomokai S. (1994). "Geoid undulation differences in Shikoku region, Southwest Japan, determined by GPS measurement and leveling", *Journal of the Geodetic Society of Japan*, Vol. 40, No. 1, pp. 33-44.
11. Takeyasu Yamamoto (1994). "Evaluation of geoid undulation differences using GPS/leveling and surface gravity data", *Journal of the Geodetic Society of Japan*, Vol. 40, No. 4, pp. 367-375.
12. Tscherning CC. et al. (2001). "Local geoid determonation combining gravity disturbances and GPS/leveling; a case study in the Lake Nasser area, Aswan, Egypt", *Journal of Geodesy*, Vol. 75, No. 7-8, pp. 343-348.
13. Tziavos I.N. (1993). *Numerical Considerations of FFT Methods in Gravity Field Modelling*. Report. Nr. 188, Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universitat Hannover, Hannover.