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Experimental Analysis of Kinematic Network-Based GPS Positioning Technique for River Bathymetric Survey

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ABSTRACT

This paper deals with performance assessment of the kinematic network-based GPS positioning technique with a view to using it for ellipsoidally referenced bathymetric surveys. To this end, two field trials were carried out on a land vehicle and a surveying vessel. Single-frequency GPS data acquired from these tests were processed by an in-house software which equips the network modeling algorithm with instantaneous ambiguity resolution procedure. The results reveals that ambiguity success rate based on the network model is mostly higher than 99.0%, which is superior to that of the single-baseline model. In addition, achievable accuracy of the technique was accessed at ±1.6 cm and 2.7 cm with 95% confidence level in horizontal and vertical component respectively. From bathymetric survey at the West Nakdong River in Busan, Korea, 3-D coordinates of 2,011 points on its bed were computed by using GPS-derived coordinates, attitude, measured depth and geoid undulation. Note that their vertical coordinates are aligned to the geoid, the so-called orthometric height which is widely adopted in river engineering. Bathymetry was constructed by interpolating the coordinate set, and some discussion on its benefit was given at the end.

Keywords: kinematic positioning, mathematical modeling, integer ambiguity, GPS, bathymetry

1. INTRODUCTION

A waterway where topographical surface water is flowing from higher to lower geopotential is called a river and hydraulic characteristics of the flow is closely related to geometric shape in the longitudinal and cross sections. Note that the river shape keeps changing according to topography and flowing water actions. Due to this reason, a study on periodical river bathymetry is necessary for maintenance that reflects a flow characteristic of rivers. In particular, a variation in local river bathymetry caused by large-scale river improvement projects and hydraulic structures could affect the stability and functions of hydraulic structures, which should be monitored accurately through periodical surveys (Lee & Lyu 2015).

A river bathymetry represented by gridding coordinate and water depth can be acquired efficiently through simultaneous observations of global positioning system (GPS) receivers and echo sounders installed in a surveying vessel (Wolf & Ghilani 2006, Yun & Cho 2011). Since a water level, a bathymetric survey reference, is variable depending on an observation period, monitoring of mid- to long-term changes in the river bathymetry is limited. As a result, the need to represent a river bathymetry by an orthometric height with a level of centimeter accuracy has been raised after determining an ellipsoidal height through high-precision positioning techniques such as GPS real-time kinematic (RTK) or post-processed kinematic (PPK) and then applying a precise geoid model. Here, an ellipsoidal

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height refers to a normal line distance between reference ellipsoid and a point in topographic surface, while an orthometric height refers to a vertical line distance from the geoid. Since an ellipsoidal height does not guarantee a water flow from higher to lower places at all times, it should be converted into an orthometric height (Hofmann-Wellenhof & Moritz 2005).

A centimeter level of accuracy in the river bathymetric survey can be guaranteed via leveling error correction in echo sounders and antenna offset as well as accurate determination of GPS carrier-phase integer ambiguity. To do this, dual-frequency GPS receivers and a motion sensor to determine an attitude are used in the surveys (Meyer 2010, Sickle 2015). Lee & Lyu (2015) proposed a method that used multiple single-frequency receivers at each of the reference and rover stations rather than using a river bathymetric survey based on dual-frequency GPS receiver and motion sensor. This method was to constraint a geometric distance between antennas at the multiple baseline model in which a number of baselines formed between the reference and rover stations were defined with a single function relationship. Thus, since an antenna network inside a surveying vessel is moved constantly, this method is also called a “GPS kinematic network model”. Through the modeling, not only performance improvements on integer ambiguity resolution but also determination of positioning and attitude of survey ship could be achieved simultaneously. However, their implementation of the algorithm evaluated positioning performance only through simulations in consideration of different vessel trajectories, antenna arrangement, and geometric structure of satellites thereby having a limitation of real-world applicability.

In the present study, GPS data acquired from field trials using a land vehicle and a boat were processed on post-mission mode thereby analyzing integer ambiguity resolution performance and positioning accuracy to overcome the limitation of previous studies. Based on the result, river bathymetry was constructed using water depth data measured around the West Nakdong River in Gangseo-gu, Busan Metropolitan City and precise geoid model and the results were investigated. This paper is organized with four sections: Section 1 presents an introduction and Section 2 introduces a calculation procedure in the precise three-dimensional (3D) river coordinate based on orthometric height and kinematic network modeling technique with regard to GPS observation data. In Section 3, an overview of the field experiment using land vehicle and surveying vessels as well as analysis on data processing results are presented. In Section 4, results obtained through the study are summarized.

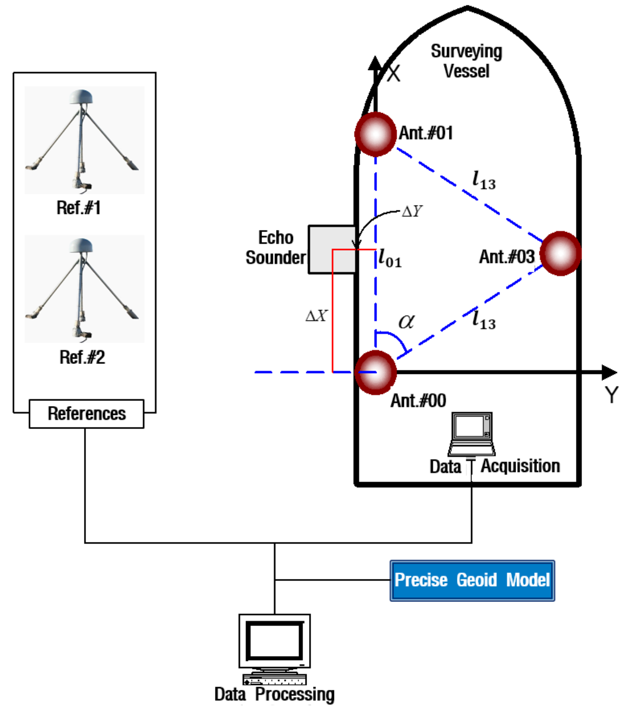

Fig. 1. Architecture of bathymetric surveying based on multiple GPS receivers: *ΔX* and *ΔY* is offset between rover antenna#1 and reference point of echo sounder; l_{ij} is geometric length between rover# i and *j*.

2. BATHYMETRIC SURVEYING WITH MULTIPLE GPS RECEIVERS

2.1 Concept

Fig. 1 shows a river bathymetric survey system, which consists of five single-frequency GPS receivers, an echo sounder, and geoid model. Compared to general cases, the main difference is that this system employs multiple GPS reference stations and rover receivers. This is aimed at improving performance in integer ambiguity resolution as well as determining an attitude and position at a centimeter level through the kinematic network modeling scheme to which geometric constraint conditions are applied to single-frequency GPS data.

An echo sounder calculates a water depth by observing an arrival time of sound wave but it cannot arrange a center axis in the gravity direction due to survey vessel movements. Thus, it measures a slant depth. A 3D location of the river was defined as orthometric height and map gridding coordinates of cross points when a line was dropped in the gravity direction from a reference point in the echo sounder. Therefore, a GPS estimation coordinate of Ant.#00 in Fig. 1 should be converted with regard to a reference point in

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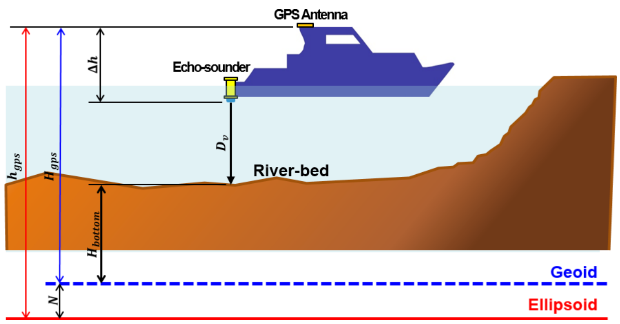

Fig. 2. Orthometric height determination of river-bed by simultaneous observation of GPS and echo-sounder.

the echo sounder using offset and attitude information with regard to the antenna coordinate, and it is necessary to correct a leveling error using pitch and roll when a water depth is deep or survey vessel movement is severe (IHO 2005).

Fig. 2 shows a procedure of orthometric height (H_{bottom}) determination in the river bed during river surveying that employs GPS and echo sounder. A GPS estimated ellipsoidal height ($\boldsymbol{h}_{GPS}$) is converted into an orthometric height (H_{GPS}) primarily using geoid height(N). Then, orthometric height in the river bed can be calculated by subtracting an offset (Δh) of GPS antenna and echo sounder and corrected water depth (D_v) in the vertical direction. To do this, a precise geoid model is needed to measure Δh before and after sensor installation and determine N.

2.2 Kinematic network-based GPS positioning and attitude determination

It is a well-known fact that accuracy of carrier phases-based GPS positioning is significantly dependent on successful integer ambiguity resolution (Hofmann-Wellenhof et al. 2001). In particular, performance of the ambiguity resolution in GPS single-frequency is no higher than that of dual-frequency theoretically (Teunissen 1997). This is because real-valued ambiguity estimation accuracy is low due to insufficient observation data and a correlation between them is high. This problem can be improved through integrated algorithm implementation of GPS and inertial navigation system (Grejner-Brzezinska et al. 1998, Lee et al. 2005), geometric distance constraint in multiple antenna system (Lu 1995, Park & Kim 1998), or method that constraints specific coordinate components in consideration of positioning environment (Ueno et al. 2000).

In this study, GPS data from two reference stations and three rover station receivers as shown in Fig. 1 were used simultaneously to estimate unknown coordinates

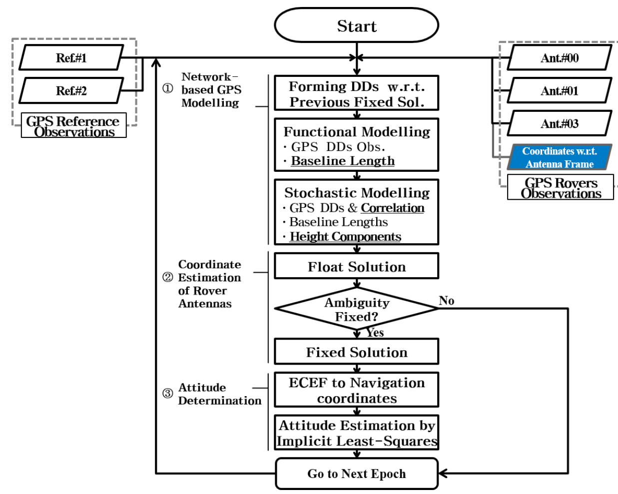

Fig. 3. A procedure of precise coordinate and attitude estimation by GPS kinematic network-based measurement modeling scheme.

of antennas with improving the ambiguity resolution performance of GPS single-frequency receivers. This method is to constraint geometric conditions with regard to antennas in the multiple baseline model (Hofmann-Wellenhof et al. 2001) that defines all GPS data into a single mathematical relationship, performing rapid search and reliable validity test of the ambiguities (Lee & Lyu 2015). A constraint condition in the present study is a previous epoch-estimated ellipsoidal height, which is characterized by no significant change in a short period of time, and baseline lengths between the multiple rover antennas, in which an installation frame was assumed as a rigid body. This GPS mathematical modeling scheme is called “kinematic network model” since a multiple antenna network formed over the navigation body is continuously moving. Lee et al. (2016) verified the reliability of positioning solution and performance improvements on integer ambiguity resolution through simulations to which various conditions were applied with regard to monitoring on large-scale social infrastructures to analyze the effect of the GPS network model.

Fig. 3 shows a procedure of surveying vessel location and attitude determination based on the kinematic network model, which consists of three main steps: (a) mathematical modeling; (b) precise coordinate estimation; and (c) attitude determination. A coordinate system for constraint of geometric distance between antennas and attitude estimation can be set by a total station, a 3-D surveying instrument that simultaneously measures vertical and horizontal angles and slope distance. The formation of GPS double-differencing data and its linearization is performed with regard to previous epoch estimation ellipsoidal height and horizontal coordinates obtained by the standard point

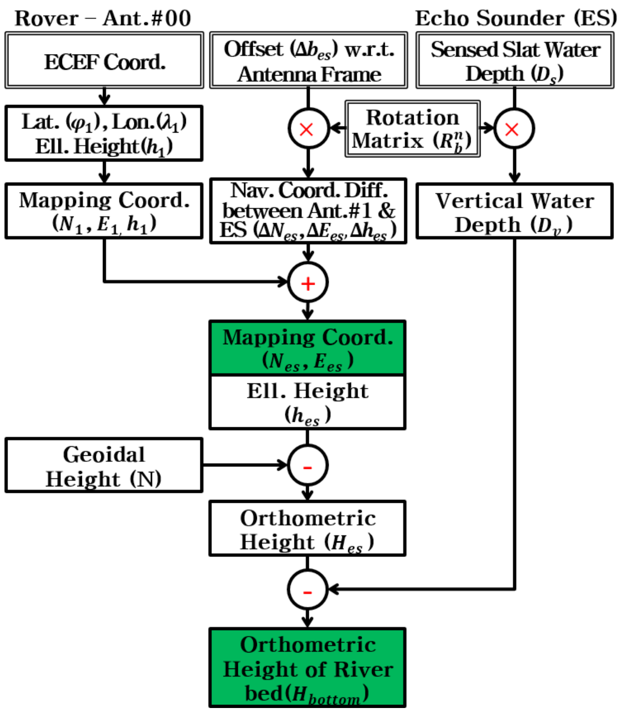

Fig. 4. A procedure of 3-D coordinate computation at a point on river bed.

positioning (SPP). In the stochastic model, uncertainties of antenna geometric distance and ellipsoidal height were reflected based on the "satellite angle dependent model" to which mathematical correlation between GPS baselines are taken into consideration. A 3-D coordinate set of rover antenna is estimated through the integer-constrained least-squares with an application of the so-called instantaneous ambiguity resolution (Han 1997).

The attitude determination is achieved through conversion of earth-fixed and earth centered coordinate of three rover antennas into that in the navigation coordinate system whose origin is Ant.#00 followed by using a correlation equation with antenna coordinate (or body frame coordinate). Here, a method of estimation on attitude was employed through implicit least-squares in the mathematical model linearized with regard to results calculated directly using navigation coordinate as shown in Fig. 3.

2.3 3-D coordinate determination for river bathymetry

Fig. 4 represents a procedure of 3-D coordinate computation at a point on river bed using GPS-estimated Ant.#00 coordinates and attitude as well as echo sounder measured water depth and geoid model. First, ECEF coordinate of the Ant.#00 was expressed to the geographic coordinates such as latitude, longitude, and ellipsoidal height, and then latitude and longitude are converted to a map gridding coordinates using the Gauss-Krüger (GK) mapping function (Hooijberg 1997). After this, 3-D coordinates of reference point of the echo-sounder is calculated by adding its navigation coordinates in the gridding coordinates and ellipsoidal height of the Ant.#00. Here, the navigation coordinates are obtained through conversion of antenna coordinate using a rotation matrix (R_b^n) composed by the estimated-attitude. The map gridding coordinates in the river bed are equal to that of the reference point but an its orthometric height is computed by subtracting geoidal height and measured water depth from the ellipsoidal height of the reference point as shown in Fig. 2. To do this, the present study employed KNGeoid14, which was a precise hybrid geoid model (Lee & Kwon 2015). If a water depth of measured target is deep or sounder leveling error is large due to vessel motion, a measured water depth should be converted to a vertical water depth by correcting a pitch and roll (IHO 2005). To do this, a plane in the antenna coordinate system of the GPS rover antenna and the center axis of the echo sounder should be orthogonal to each other.

3. FIELD TRIALS AND RESULTS

3.1 Introduction

In order to examine the performance of the integer ambiguity resolution and the positioning accuracy of the GPS kinematic network modeling scheme and its applicability to river bathymetric survey, field trials using land vehicle and surveying vessel were conducted. In the experiment, SOKKIA GRS2600 and GRS2700 were employed as a reference station and three GRX1 receivers were operated as a rover station. The GRX1 receiver is an integrated type of antennas and receivers. It was installed at a square-shape steel frame as shown in Figs. 5 and 6. In particular, echo sounder measurements were conducted simultaneously to acquire a 3-D coordinate in the river bed as shown in Fig. 6. The rover antenna coordinate was calculated by measuring a horizontal angle α and geometric distance l_{ij} 10 times after installing the total station at origin point Ant.#00, and a prism at Ant.#01 and Ant.#03 in Fig. 1. In addition, safety factor was considered in standard deviation calculated from measured distances thereby reflecting ±3 mm to the stochastic model.

All of the GPS receivers used in the experiment were originally double-frequency receivers but single-frequency pseudo-ranges and carrier-phases were used in data processing to which the kinematic network algorithm was applied. The above operation of receivers aimed to

Fig. 5. GPS receivers on roof of trial vehicle.

Fig. 6. Survey boat equipped with GPS receivers and eco-sounder.

analyze positioning accuracy by generating a reference trajectory through dual-frequency GPS data processing and comparing the results with that obtained via the kinematic network method. For this, Waypoint GrafNav GNSS post-processing software (version 8.6) was used to determine coordinates of the reference station and generate reference trajectories.

3.2 Land vehicle trials

Land vehicle trials were conducted at the outside and track in a playground where elevation level was almost constant as shown in Fig. 5 so as to examine the accuracy of height component in the estimation coordinates and to reflect the characteristics of river positioning environment sufficiently, in which a water level height was not changed significantly over time. The trial was conducted at three divided sections as presented in Table 1 and data were acquired from six to seven GPS satellites during the test

Table 1. Summary of land vehicle trials.

Trial ID	Period (GPST)	Duration (sec.)	No. of SVs	Remark
Land-1	06:05:00.0 to 06:35:29.0	1,830	7	on the track
Land-2	06:38:00.0 to 07:02.29.0	1,500	6 - 7	on the track
Land-3	7:11:00 AM.0 to 7:20:59 AM.0	600	7	off the track

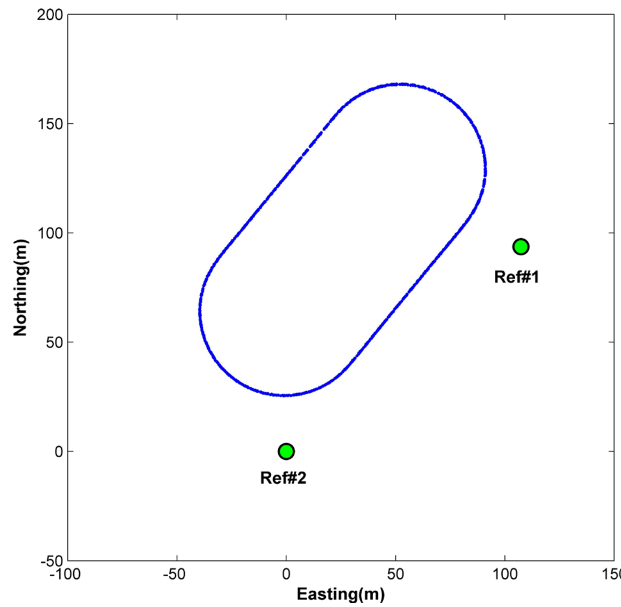

Fig. 7. Trajectory of the vehicle from Land-1 trial.

period. In particular, a vehicle was run over the track in Land-1 and Land-2, and a vehicle was run over the outer track thereby having a relatively large difference in elevation over the path, which was noticeable. Using in-house software that implemented the procedure of the kinematic network model, GPS single-frequency data was processed thereby estimating 3-D coordinates of rover antennas simultaneously (Lee & Lyu 2015). Fig. 7 shows an example of plane trajectory of Land-1 trial (Ant.#00) and reference station location in the experiment, which verified it was highly matched with a track shape of the playground.

In order to investigate the effect of the kinematic network model with respect to GPS single-frequency observations on integer ambiguity resolution performance, a separate processing of the single baseline model, in which Ref.#1 is a reference station, was performed and the results were compared. Since the field experiment was conducted on a path without no significant elevation change, whether integer ambiguity resolution was accurate or not could be verified through the analysis on coordinate of height component. This method judges whether the integer ambiguity resolution is accurate or not. It is accurate if an absolute value of difference between a mean ellipsoidal height estimated for all sections and an estimated value

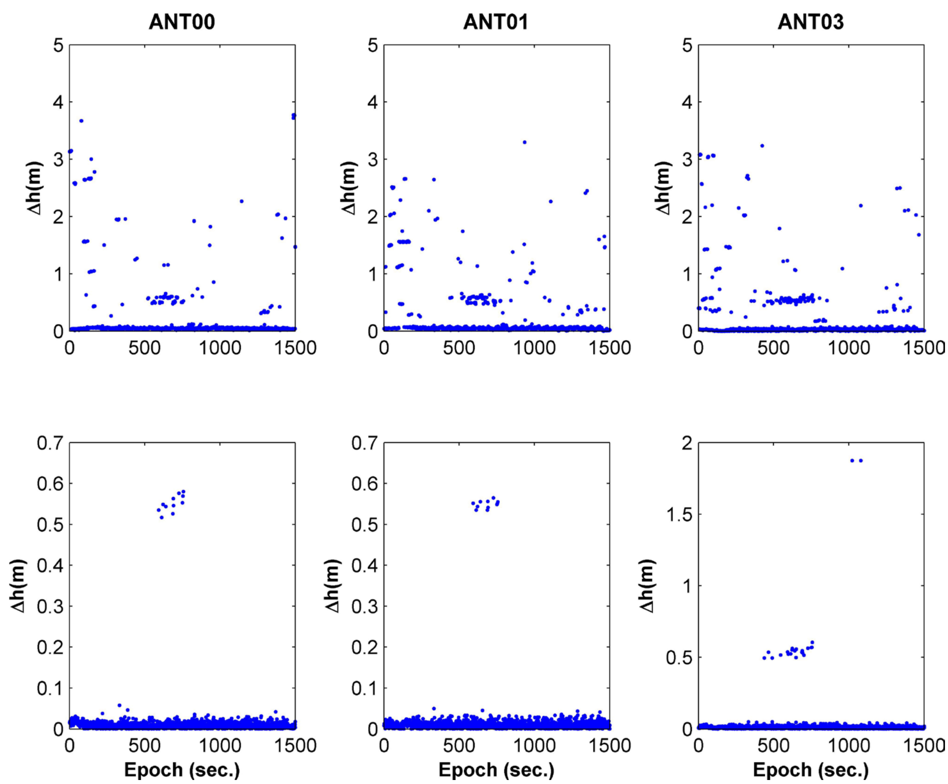

Fig. 8. Performance of instantaneous integer ambiguity resolutions: the upper graph presents differences between baseline processing estimated heights between their mean values, while the lower graph shows those of network processing.

Table 2. Summary of instantaneous integer ambiguity resolutions from baseline and network processing.

Trial ID	Antenna	Baseline processing			Network processing		
		Correct epochs	Wrong epochs	Success rates (%)	Correct epochs	Wrong epochs	Success rates (%)
Land-1	ANT00	1,533	297	83.8	1,822	8	99.6
	ANT01	1,676	154	91.5	1,822	8	99.6
	ANT03	1,658	172	90.6	1,822	8	99.6
Land-2	ANT00	1,316	184	87.7	1,490	10	99.3
	ANT01	1,262	238	84.1	1,490	10	99.3
	ANT03	1,289	211	85.9	1,479	21	98.5
Land-3	ANT00	566	34	94.3	599	1	99.8
	ANT01	579	21	96.5	599	1	99.8
	ANT03	550	50	91.7	598	2	99.3

of individual epoch is three times or less (3σ) of standard deviation. Fig. 8 shows a time-series of the GPS estimated ellipsoidal height in Land-2 trial. The upper graphs show the result of the single baseline model and the lower graphs show the result of the kinematic network model. The rapid increase in estimated height component in the figure was due to inaccurate integer ambiguity, in which height difference in the lower graphs was much lower than that in the upper graphs. This means that performance on the single-frequency GPS integer ambiguity resolution was improved through the kinematic network model. Table 2 summarizes results of the integer ambiguity resolution accuracy to which the single baseline and the dynamic network models were applied. An integer ambiguity success rate was ranged between 83.8 and 96.5% in the conventional baseline methods whereas it was all 98.5% or higher when the network model was applied, indicating a significant improvement.

According to the previous analysis result, the 3-D estimation coordinate of the epoch where the accurate integer ambiguity resolution was done is divided into horizontal and vertical components and calculated as shown in Fig. 9 (example of the Land-2 trial). A range of estimated ellipsoidal height in Land-1 and Land-2 where a

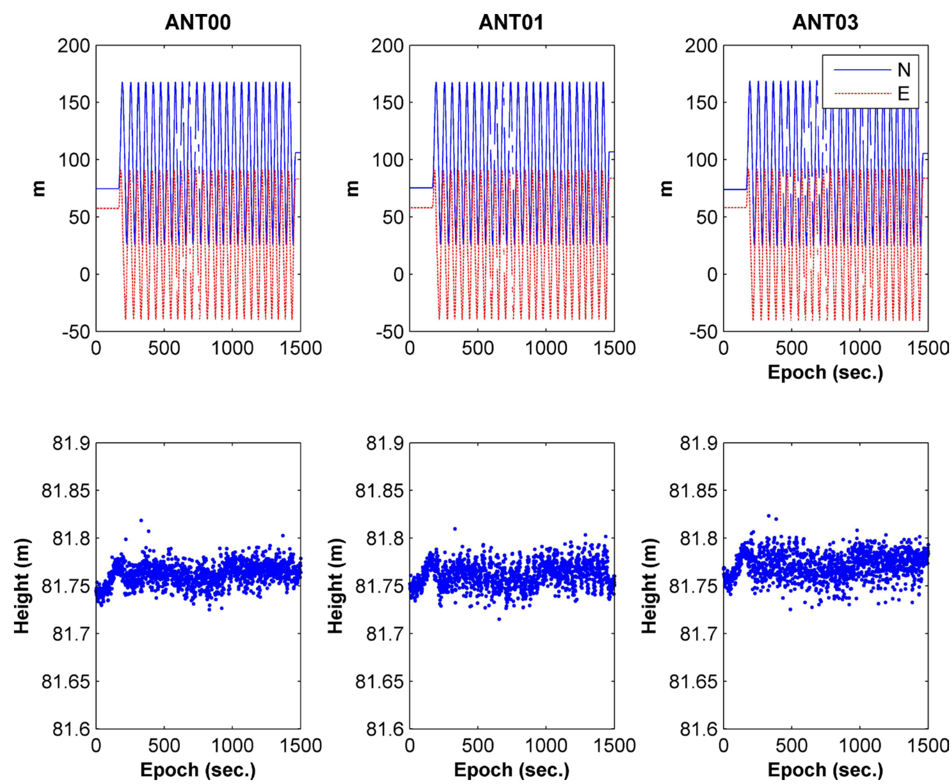

Fig. 9. Estimated 3-D coordinates of Land-2 trial if ambiguities are correctly resolved: the upper graphs show horizontal positions, while the lower ones depict those of vertical component.

Table 3. Root mean squares errors of single-frequency network solutions with correct ambiguities under 95% confidence level (unit: centimeter).

Trial ID	ANT00		ANT01		ANT03	
	Hor.	Ver.	Hor.	Ver.	Hor.	Ver.
Land-1	0.7	1.2	0.7	1.7	0.8	1.8
Land-2	0.9	1.5	1.2	1.4	1.1	1.5
Land-3	0.7	1.5	0.7	1.5	0.7	1.1

change in elevation was relatively low when a vehicle drove a track in the playground during the experiment was ±2.2 – ±3.0 cm with a confidence level of 95%. Since a difference in elevation over the track is relatively small in reality, an estimated accuracy of ellipsoidal height will have a larger range than the above result. In addition, considering an accuracy of the height estimation in the GPS positioning was two to three times lower than that of the horizontal component, accuracy in the horizontal direction in the fixed solution of integer ambiguity can be evaluated indirectly as ±1 cm approximately. The accuracy was analyzed by comparing a reference trajectory obtained through processing of the dual-frequency data and 3-D coordinates estimated by the kinematic network model proposed in the present study, which is shown in Fig. 10 (example of Land-3 trial). To do this, a root-mean-squares error (RMSE) with regard to the reference trajectory was calculated with a confidence level of 95% by dividing the trajectory into horizontal and vertical components as presented in Table 3. It can be seen from the results that the positioning accuracy of the kinematic network model was about ±1 cm in the horizontal component and ±2 cm or higher in the vertical component, respectively.

3.3 Surveying Vessel Trial

As shown in Fig. 6, a field trial of the river bathymetric survey was conducted at a boat using GPS receivers and echo sounder. In this experiment, the same GPS receivers used in the land vehicle test were employed and for echo sounder, SeaBat 7125 model of Teledyne Reson was used. The echo sounder was synchronized with the GPS time (GPST) by the pulse per second (PPS) signal from an additional GPS receiver. A steel frame for installation of GPS antennas was fixed using a spirit level to make it level and a center axis of the echo sounder was installed orthogonally as much as possible with the steel frame using a total station. Then, a total station was installed at Ant.#00 and antenna coordinate [▪(-0.990&-0.880&-2.110)] of reference point in the sounder was determined by applying a traversing technique.

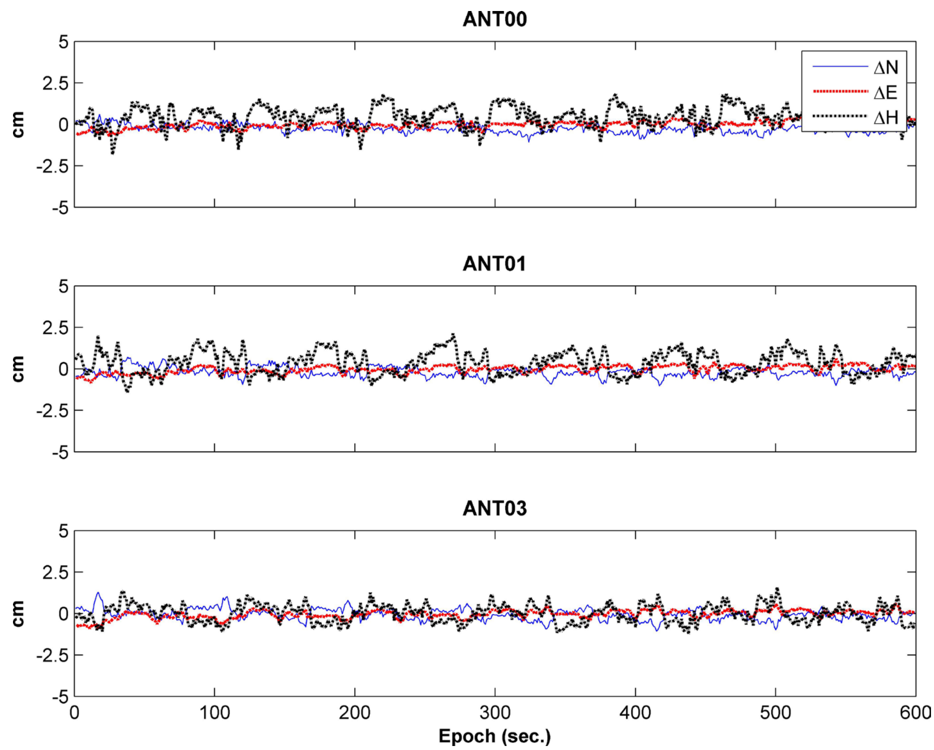

Fig. 10. Temporal variation of 3-D coordinate differences between single-frequency network solutions and those of dual-frequencies baseline processing, example of Land-3 case from correct ambiguities.

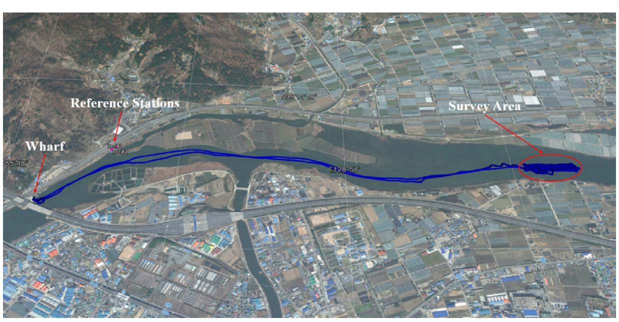

Fig. 11. Full trajectory of surveying vessel on google earth.

Fig. 11 shows the full trajectory of the surveying vessel along with the installation location of GPS reference station via Google Earth. This trial was conducted on July 25 in 2016 at the West Nakdong River in Gangseo-gu, Busan Metropolitan City for about two hours and 40 min. Fig. 12 shows the trajectories in the bathymetric survey for 65 min, in which GPS data processing and analysis was performed in the present section. A range of bathymetric survey was about 300 m in the east-west direction and about 50 m in the south-north direction. Note that an irregular section is shown in Fig. 12, which was sailed intentionally in order to determine the effect of dynamics of surveying vessel on positioning, and a water depth was not measured during this period. Excluding this section, an observation of echo sounder was done for approximately 37 min.

The first graph in Fig. 13 shows the number of satellites observed, in which most sections had more than eight satellites but in some section, the number was decreased. As can be verified in the trajectories in Fig. 12, interruption of satellite signals by the vessel or attached structures can be inferred as one of the reasons for rapid change in dynamics in the surveying vessel. An absolute value of difference between mean value of height component in the ambiguity fixed solution and its estimated value is shown in other graphs in Fig. 13 to examine the accuracy of the instantaneous integer ambiguity resolution. In the figure, a consistent correlation between the number of satellites and peaks induced due to the inaccurate ambiguity estimation can be seen. Whether integer ambiguity resolution was accurate or not was determined based on absolute value of difference between a mean of ellipsoidal height estimated with all experiment sections and individual epoch estimated value and comparison with threshold value 3σ as conducted in the vehicle experiment. The analysis result on accuracy of integer ambiguity resolution is summarized in Table 4, in which all three receivers had high success rates of more than 99.1%.

Fig. 14 shows a time-series of each component in the 3D estimation coordinate of the rover antennas in the epoch where the integer ambiguity resolution was correctly resolved. As mentioned in the above, water depth survey

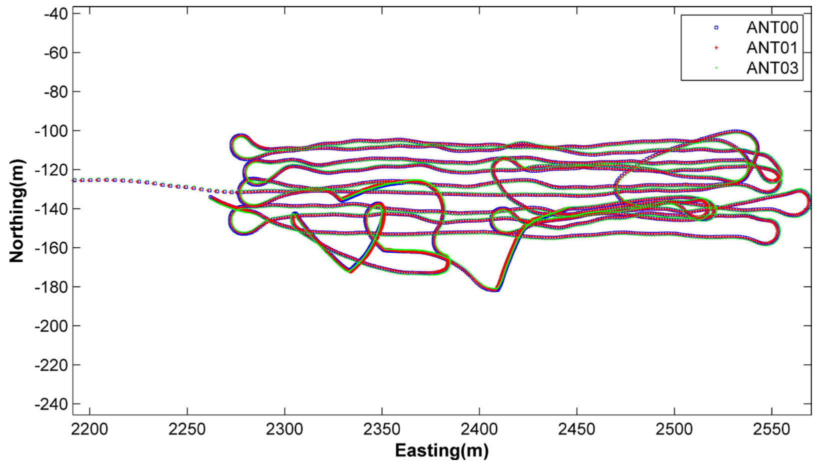

Fig. 12. Trajectories of three GPS antennas during bathymetric survey.

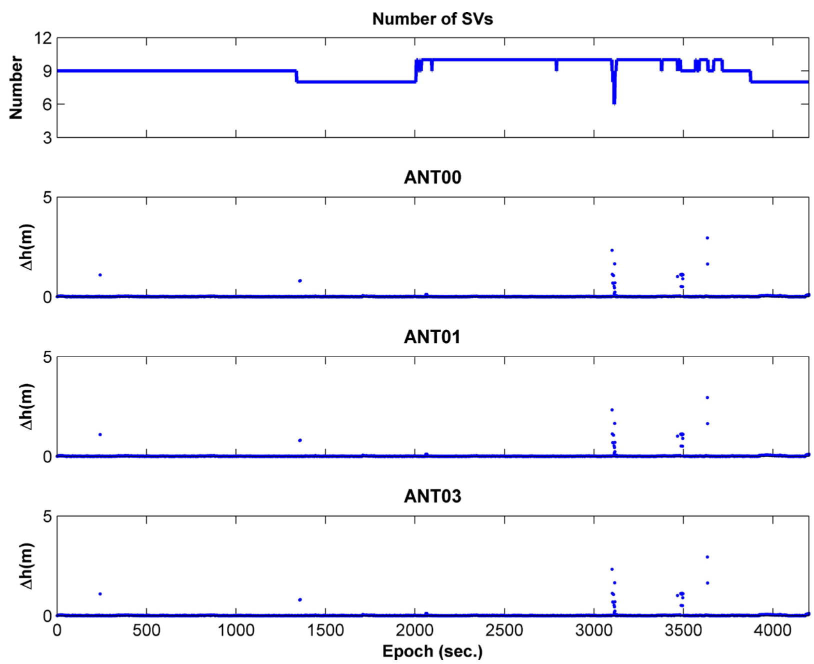

Fig. 13. The number of SVs and performance of instantaneous integer ambiguity resolutions which is depicted by differences between estimated heights and this mean values.

Table 4. Summary of instantaneous integer ambiguity resolutions by network-based processing.

Antenna	Correct epochs	Wrong epochs	Success rates (%)
ANT00	3,865	35	99.1
ANT01	3,867	33	99.2
ANT03	3,868	32	99.2

was conducted at a starting point where coordinate component in the east-west direction revealed a regular change of 300 m approximately for a section of about 2,000 sec. Ranges of changes in three GPS antenna ellipsoidal height during the observation experiment were 3.1 cm, 3.3 cm, and 3.7 cm, respectively at a confidence level of 95%. Considering the characteristics of water level in the river that is not changed significantly in a short period of time, a variance in coordinate component in the height direction was generated due to the vessel heaving and GPS errors so that accuracy of estimation of ellipsoidal height was expected higher than the above range results. Fig. 15 presents a time series of the 3-D coordinate differences between the single-frequency network solutions and those of the dual-frequencies baseline processing in order to evaluate the accuracy of multi-antenna 3D coordinate estimation to which GPS single-frequency dynamic network model was applied. Table 5 presents RMSEs calculated at a confidence level of 95%. The positioning accuracy of

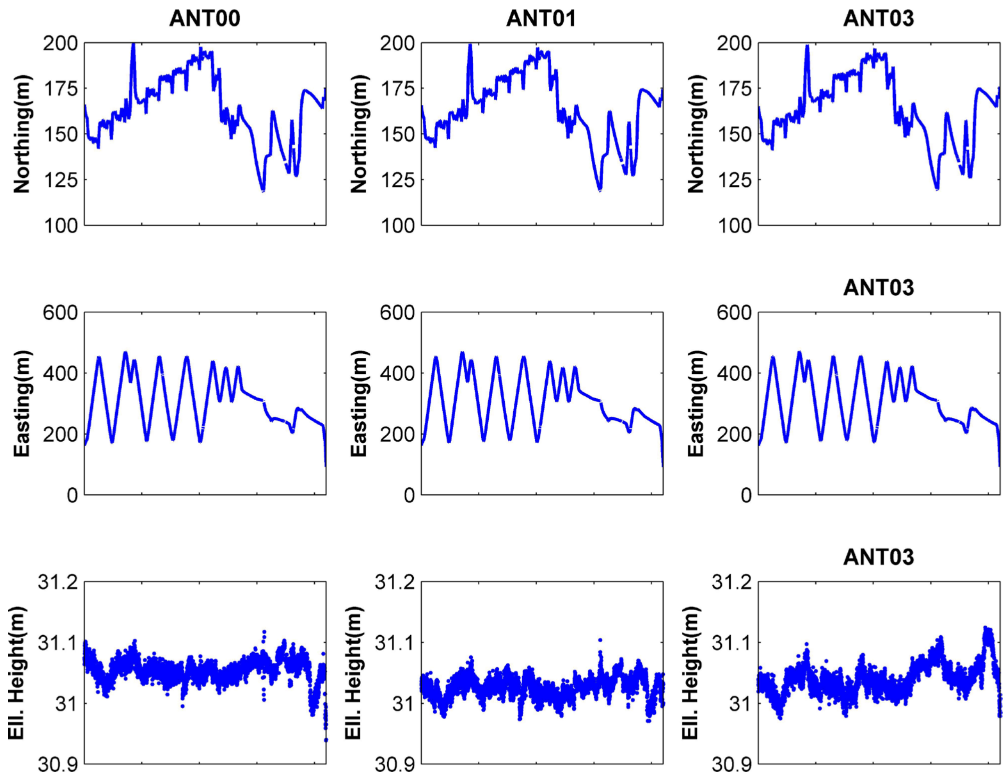

Fig. 14. Time series of 3-D coordinates of Land-2 trial with correct integer ambiguities.

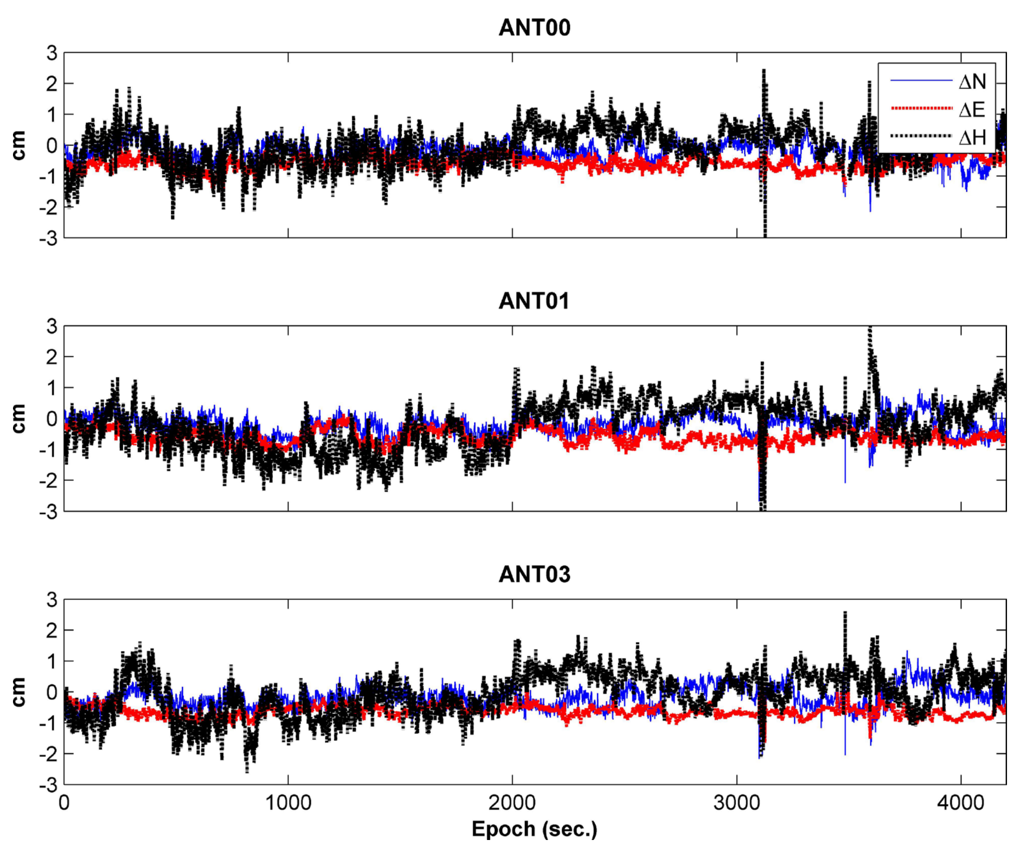

Fig. 15. Time series of 3-D coordinate differences between single-frequency network solutions and those of dual-frequencies baseline processing.

Table 5. Root mean squares errors of single-frequency network solutions with correct ambiguities under 95% confidence level (unit: centimeter).

Antenna	Horizontal	Vertical
ANT00	1.2	1.3
ANT01	1.3	1.7
ANT03	1.3	1.4

the survey vessel test to which the GPS kinematic network modeling scheme was applied was analyzed, and the results were ±1.5 cm and ±2.0 cm in the horizontal and vertical directions, respectively. The GPS dual-differential model in the present experiment is corresponded to a short baseline so that most common errors were removed through forming the double-differenced measurements. As a result, main residual error is caused by multipath. Accordingly, geometrical distances between antennas calculated from the GPS-estimated coordinates are subtracted by mean values to determine the effect of the error on positioning solution, which is shown in Fig. 16. A standard deviation of geometric distance between antennas in the figure was ±2.9 mm, ±3.5 mm, and ±3.2 mm, respectively. The above changes in distance indicated that the effect of the multipath on positioning solution was highly limited considering that GPS carrier wave noise at a few millimeters or complex effect of multipath and observation noise as well as considering that the GPS observation data model is short baseline.

When accurate integer ambiguity resolution was conducted, their attitude angles were estimated and 3D coordinate of 2,211 points existed at the river bed was determined by applying the procedure in Section 2.3. A mean water depth in the target area was 2.95 m, and a vertical correction amount due to a pitch and roll was at a few millimeter levels, which can be negligible considering an orthometric height in the river bathymetry, which was expressed at a centimeter level. Fig. 17 shows a bathymetry of the surveyed area using a grid of 2 m gap in a range of 196,420 – 196,720 m in the east-west direction and in a range of 292,010 – 292,060 m in the south-north direction in the map projection coordinate through Kriging interpolation of the above 3-D coordinate. An orthometric height of the survey area was distributed over a range of -2.57 m to -3.26 m, and a mean and standard deviation were -2.91 m and ± 0.12 m. An orthometric height whose sign was negative in Fig. 17 indicates that a bottom of the river was located below the geoid and the topography revealed a gradual slope in the direction of upper stream (i.e., east) to the downstream (i.e., west). Note that regular protrusion in every 50 m in the flow direction in the river was discovered and a certain elevation difference occurred around them. Considering the regular change in the bathymetry, they were built by dredging work at the construction of repair and renovation projects artificially. The river bathometry in Fig. 17 is shown at a few centimeter level in the absolute coordinate system. If an additional survey is conducted, more detailed change

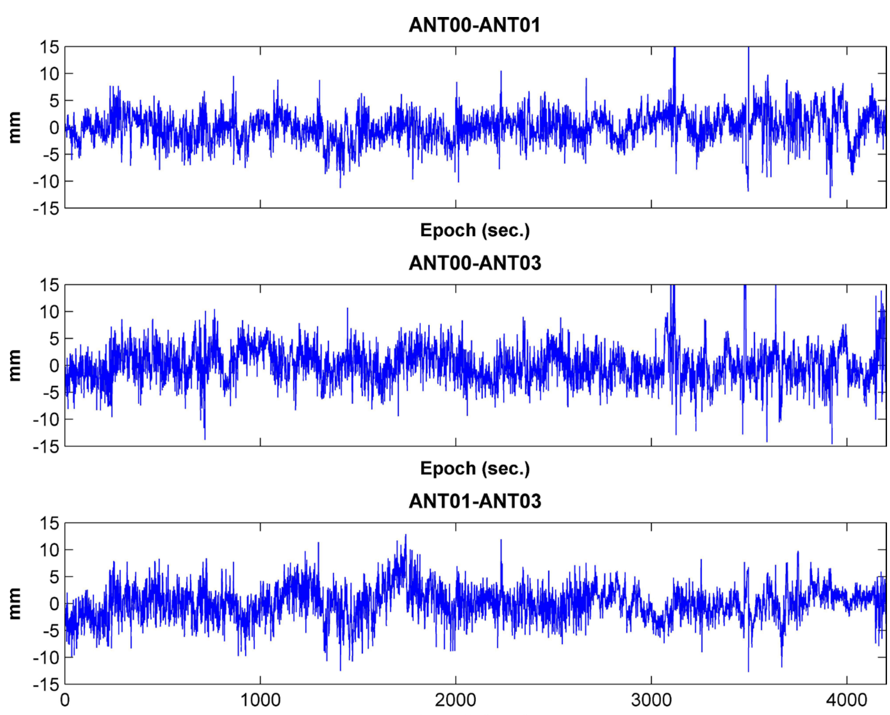

Fig. 16. Time series of estimated antenna baseline lengths subtracted by mean values.

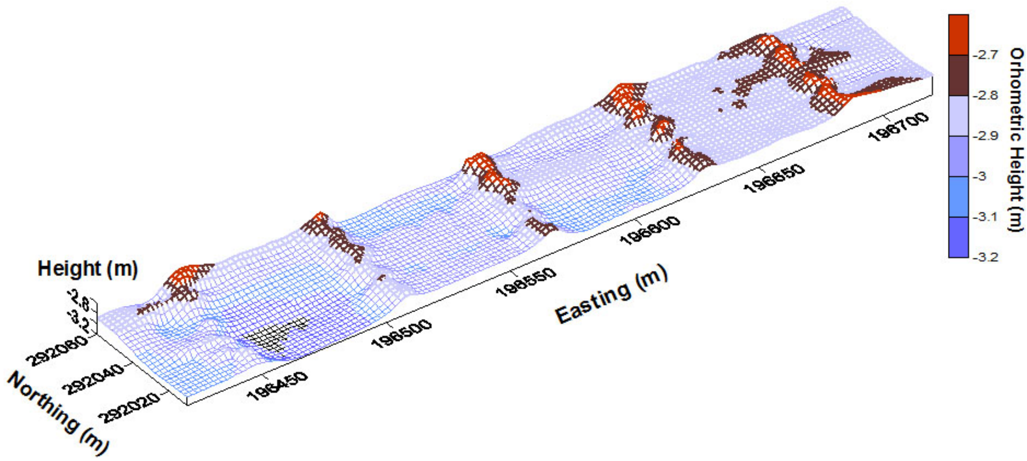

Fig. 17. Time series of estimated antenna baseline lengths subtracted by mean values.

in the bathymetry can be monitored through overlapping analysis.

4. CONCLUDING REMARKS

The present study summarized field experiments, which were conducted to investigate performance of precise GPS positioning based the single-frequency kinematic model and its applicability to the river bathymetric survey. The tests were carried out by dividing a case into land vehicle and survey vessel. The land vehicle experiment was performed at a track in the playground whose elevation was almost constant to evaluate a positioning accuracy in the height direction with a reflection of the characteristics of water level of the river which had no significant difference over time indirectly. The processing result of instantaneous integer ambiguity resolution using the modeling of GPS data with the kinematic network model indicated that success rates of the resolution were 99.9% or higher, which were significantly improved than that using the conventional baseline model. In order to examine the kinematic positioning accuracy, a distribution range of estimated ellipsoidal height was investigated and RMSEs with regard to reference trajectory, which were data processing results of GPS dual-frequency data, were calculated. The positioning accuracy with regard to reference trajectories at a confidence level of 95% showed that a horizontal component was ±1.2 cm and ellipsoidal height was ±1.8 cm on average. Assuming that uncertainties of reference trajectory in the horizontal and height directions were ±1 cm and ±2 cm, respectively, accuracies of coordinate estimation in the dynamic network model processing of GPS single-frequency were expected at ±1.6 cm and 2.7 cm. A map gridding coordinates and orthometric heights with regard to 2,211 points in the river bed were determined by using the GPS-estimated coordinates and attitude angles as well as water depths and geoidal heights in the survey vessel test These coordinates were interpolated at a 2 m interval and visualized to express the characteristics of the river bathymetry in the target area. The most advantage of the bathymetry that applied an absolute coordinate system was that variation in the river bed can be monitored according to dynamics of the river. Therefore, it is necessary to continue the study on applicability of how to acquire river topographic information as conducted in the present study through periodical surveys in the target area.

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