Korean Journal of Geomatics
Vol. 2, No. 1 / September 2002
pp. 57~64

Analysis of Coast Topography by RTK GPS and Echo Sounder

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Abstract

Measuring the depth of water is very important in ensuring the protection and safety of seaside. There are many difficulties in making the contour bathymetric map, and contour line due to the limitation of continuous measurement of water depth and collimation with the conventional measuring and positioning methods. But the real-time kinematic GPS (RTK GPS) positioning using a carrier phase enables us to decide a precise position without breaking a signal even under the condition of a moving environment. It is also possible to obtain an accurate depth of water in real time with a fathometer through the measuring of time delay between sending and receiving epochs.

This research aims at investigation of accuracy potential of RTK GPS in combination with Echo Sounder(E/S) for the coastal mapping. Apart from this purpose, the accuracy of ambiguity resolution with the OTF(On the Fly) method was tested with respect to the initialization time. The result shows that the accuracy is better than 1cm with 5-minute initialization in the distance of 10km baseline. The seaside topography was measured by the RTK GPS only, on the other hand the seafloor topography was surveyed in combination of RTK GPS and E/S. Comparing to the volume of seaside measured by RTK GPS and digital topographical map, the difference of only 2 % was achieved. This indicates that the coastal mapping with RTK GPS is successfully conducted. In addition, it is also demonstrated that the 3-dimensional perspective model resulted from the undersea topography measured by RTK GPS and E/S is very close to that from the digital map. Through this study, it was verified that RTK GPS is to be very useful method in the analysis of coastal morphology owing to its capability of getting the precise DTM for the using of harbor reclamation, dredging, and the estimation of soil movement in a river.

Keywords : RTK GPS, OTF, Coast Topography, DTM

1. Introduction

Although GPS surveying with code measurement shows excellent performance in navigation or GIS data acquisition, the accuracy level is not in millimeters (mm) but in several meters (m). Therefore, the RTK GPS surveying using carrier phase should be used in the area requiring higher accuracy such as construction, dredging, ocean surveying, seismological observation, and the taking off and landing of aircrafts.[1)]

In dredging and sounding surveys, it is necessary to measure the height of the water surface above a known level (datum). The traditional method of measuring the height of the water surface above the datum is to establish water level sensors at one or more fixed locations in the shore. These sensors record the water levels at pre-defined interval. Then, the water level at a given time at the vessel location is interpolated from these records.[2)]

For bathymetic survey, a precise three-dimensional vector is measured from the RTK GPS antenna of the reference station to the remote RTK GPS antenna. The water level measurement with RTK GPS is a satellite-based positioning method which is capable of continuous positioning of moving platforms with relative accuracy of around ± 0.1 meters.

One of the goals of this research is the improvement of 3D-positioning accuracy in RTK GPS. To achieve this goal, both an accuracy analysis of baseline vector using OTF and an investigation of important factors affecting the ambiguity resolution were accomplished.

Thereafter the real tests were conducted with RTK

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The manuscript for this paper was submitted for review on July 18, 2002.

GPS at seaside, and with the combined RTK GPS and ES at the ocean floor to assess the feasibility of RTK GPS. The test results show that RTK GPS is very useful for the acquisition of GIS DB in the field of coastal engineering.

2. RTK GPS Using OTF Method

As shown in Figure 1, the quality of RTK GPS strongly depends on the link of data transmission between the reference and the rover station. The reference receiver transmits the correction data to the rover, and then the rover calculates its position based on the received correction data. In details, the RTK GPS is performed as follows: the reference receiver computes the difference vectors between GPS observables at the reference station and its fixed known coordinates. Afterwards the correction values are transmitted to the rover receiver via a data link, and the rover receiver calculates its positions in real time comparing with its observables and the transmitted correction values because the rover's position have to be determined while the rover moves.[3),4)]

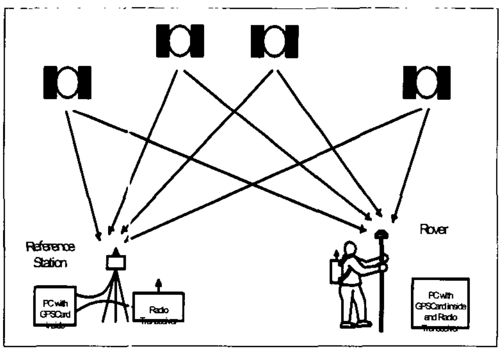

Fig. 1. Configuration of Real-Time Kinematic GPS.

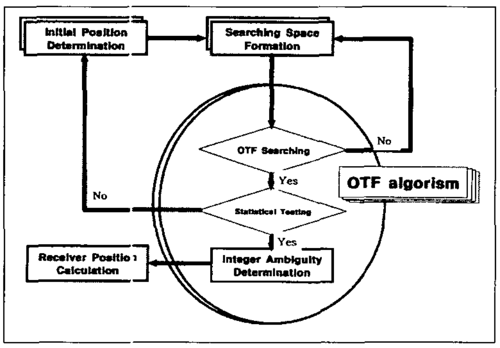

Fig. 2. Flow-chart of the OTF.

3. Principle of Echo Sounding and Correction of Water Depth

Measuring water depth from a sea surface to seafloor is called depth measuring. In measuring water depth, the situation of measuring object should be considered. A sounding rod and sounding plummet are used where it is shallow, such as an ocean or a river, whereas a fathometer is used where it is deep. When a fathometer emits the continuous supersonic waves underwater, the supersonic waves reflected from the seafloor and return to the emission position through the same path. If we measure signal travel time t which is the time difference between sending and receiving epoch of waves, and know V, underwater sound speed, the water depth D is calculated as follows:[5)]

$$D = \frac{1}{2}Vt \qquad (1)$$

In general, a fathometer is designed to have the nominal velocity of V=1,500m/sec. However, it is necessary to obtain the actual sound speed of underwater depending on the time of survey, and correct the sound speed since the actual sound speed of underwater is slightly changed by salinity, water temperature, water pressure and so on. Therefore, an experimental formula must be used under considering of sound speed, salinity, temperature and water pressure which can be only obtained through a lot of real test. There are some experimental formulas by Willson and Matthews, by Sangwon, and the KORDI formula of the Korean Institution of Oceanography. In this study, KORDI formula of the Korean Institution of Oceanography was used (2).[6)]

$$V = 1410 + 4.21\theta - 0.037\theta^2 + 1.14S + 0.0168h \ (m/sec) \qquad (2)$$

Here, V is an underwater propagation velocity (m/sec), θ is seawater temperature (℃), S is a seawater salinity (‰) and h is water depth. If an average sound speed is V_m, and the actual water depth is D,

$$D = \frac{1}{2} V_m T$$

The corrected water depth level is gained as follows.

$$D_0 = \frac{1}{2} V_a T, \quad D = \frac{1}{2} V_m T, \quad V_e = \frac{D}{\Sigma \frac{dD}{V_e}}$$

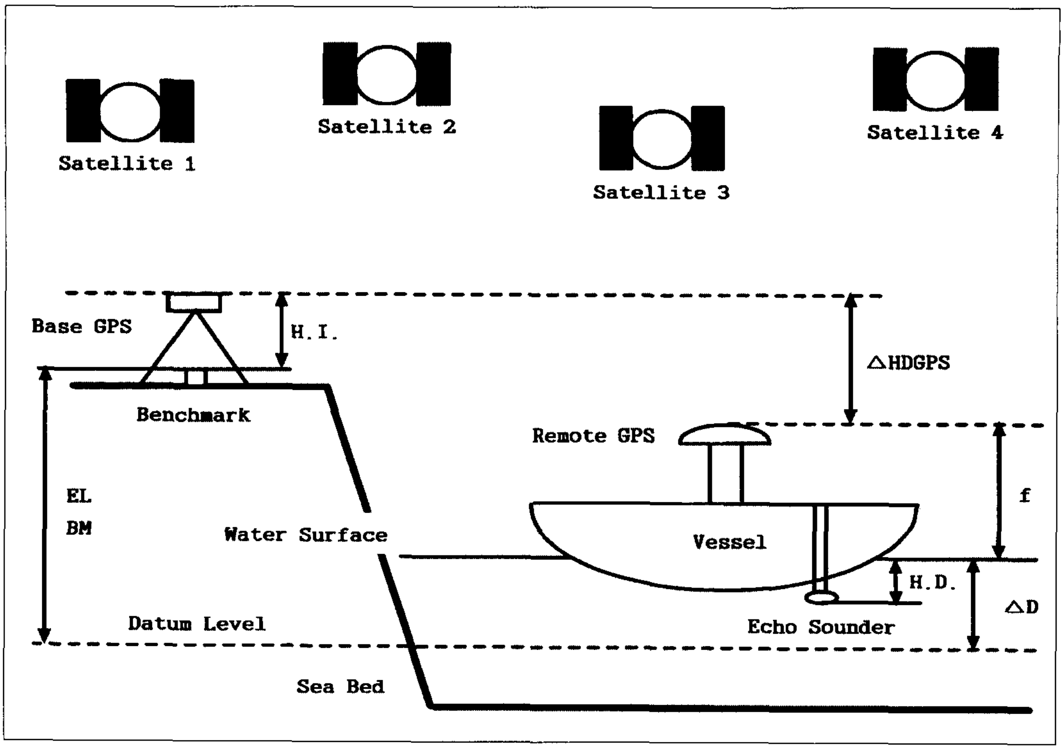

Fig. 3. RTK GPS water's surface elevation measurement technique.

where, V_a is an estimated sound speed, and V_e is the sound speed in sea water.

Therefore,

$$Corr_0 = D-D_0 = \frac{1}{2}(V_m - V_a)T$$
$$= D(1-\frac{V_a}{V_e}) = D-V_a\sum\frac{dD}{V_e} \quad (\because \ D=\sum dD)$$
$$= \sum\left\{dD(\frac{V_e-V_a}{V_e})\right\} \tag{3}$$

In case of coast sounding, there is a tide correction, which reduces water height at the time of measurement from a water depth level gained from an echo sounding and unifies to the water level under basic level surface; and a draught correction, which adds a number of draught to the record of sound measurement since it is sunk in an even depth from water surface of wave transmitter and receiver. The explanation about these corrections are shown in Figure 3, and is explained in formula (4).

In Figure 3, the desired quantity is the water level - chart data separation delta D. We calculate the elevation delta D of the water surface above or below datum at the vessel location from the following equation.[7]

$$\triangle D = ELBM + HI - f - \triangle HDGPS \tag{4}$$

where, △HDGPS is the height difference between the RTK GPS base station antenna and the RTK GPS vessel antenna, f is the height of the vessel's antenna above the water surface, and ELBM is the elevation of the benchmark above datum. HI is the height of the RTK GPS base station antenna above the benchmark. HD is the height difference between the echo sounder and the water surface.

4. Analysis of the GPS Initialization for the Ambiguity Resolution

To analyze the accuracy of ambiguity resolution using the OTF initialization method in RTK GPS survey, an observation network is established consisting of 10 stations with baseline length ranging from 1 to 10 km. After fixing of one station at HAEUNDAE Beach as a reference station to use RTK GPS, static surveying was performed for an hour with Trimble 4000SSi receivers. In data processing, L1/L2 Iono-free and L1 fixed solutions by the linear combination of L1 and L2 are used as observables to reduce/eliminate the ionospheric effect. And Hopfield model is used for the tropospheric corrections. A variance ratio of 1.5 m was set as a threshold for the fixed solutions. Table 1 contains the results of baseline analysis and its precision, initialization time and the number of tracked satellites.

Table 1. Measurement values of each point to test networks

Point	Baseline length ±Stand. dev. (m)	Initialization time	Number of Satellites
CP 01	1277.532±0.001	2 min ~ 10 min	6
CP 02	3137.538±0.002	2 min ~ 15 min	5
CP 03	5217.[illegible]62±0.002	2 min ~ 15 min	5
CP 04	7062.371±0.001	2 min ~ 20 min	5
CP 05	9802.481±0.001	2 min ~ 15 min	7

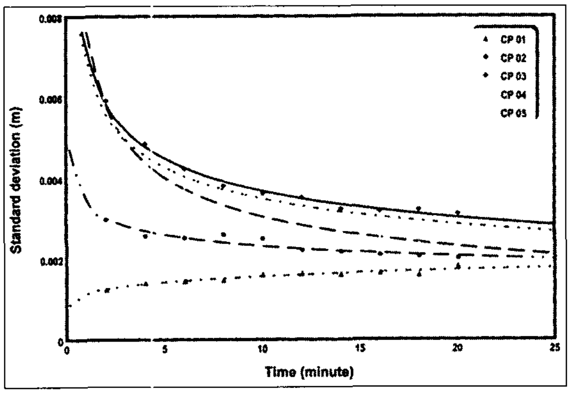

Fig. 4. Measurement accuracy according to the initialization time.

The experiment data of RTK GPS were analyzed with respect to initialization time ranging from 2 to 20 minutes and the number of observed satellites changing from 4 to 8. Theoretically, OTF does not require the initialization time, but the RMS of baseline length from the test showed that the initialization time is necessary to get a precise positions as shown in Figure 4.

In Figure 4, it was shown that more than 4 minutes of initialization is necessary to reach the accuracy better than 1cm. In this case, the RMS of baseline fixing is reduced to 0.0001(m/min) within 3km of baseline distance, and to 0.0002(m/min) with baseline length of 3 ~ 10km.

5. Topography Analysis with RTK GPS

5.1 Control Point Surveying

HAEUNDAE Beach shown in Figure 5 was selected as test area to know the possibility of RTK GPS to use for the coastal mapping. Because of a rapid development in beach area near test site, it has been lost a lot of sand. Thus several thousands tons of sand are refilled for the beach nourishment. Therefore, a submarine topography of nearby beach as well as beach itself should be surveyed in order to (exactly) understand this movement of sand. Therefore, for the standard point necessary for RTK GPS measurement, a precision of 1st control point assigned in the research area was used. And it was distributed widely as per Figure 4, and the result surveyed for 4 hours by a static survey method to these standard points was used and analyzed.

A 7-parameter transformation using Helmert equation

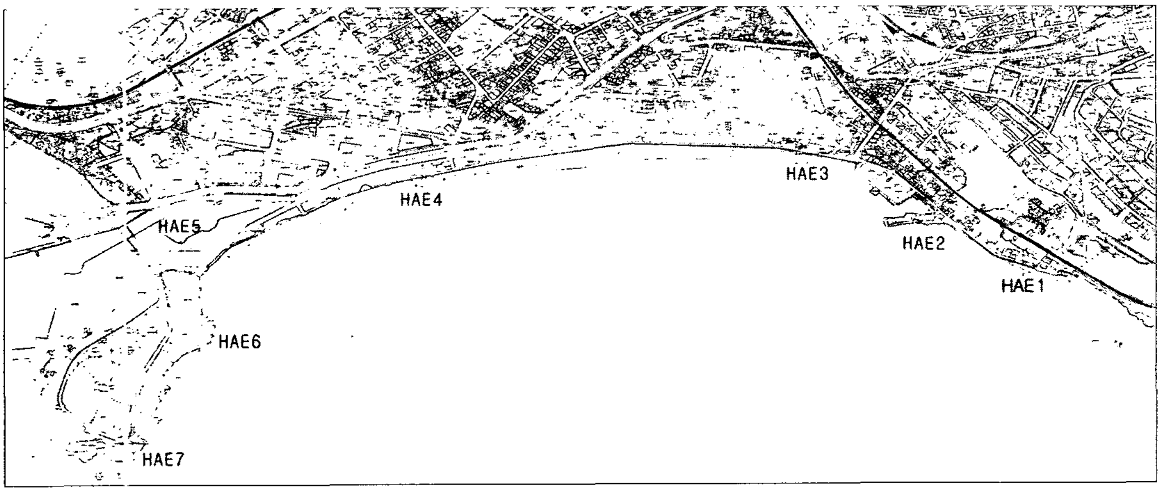

Fig. 5. Test field(HAEUNDAE) and control point.

Table 2. 7-parameters and standard deviation calculated from GPS

	△X(m)	△Y(m)	△Z(m)	ω(deg)	φ(deg)	κ(deg)	S(ppm)
Parameter	120.603	-479.898	-669.225	1.5309	-2.0836	-1.8762	5.4820
1σ	6.953	6.145	5.448	0.1867	0.1941	0.2211	0.7307

Table 3. Obtained control point for the coordinate transformation

Site	WGS 84			Korea Datum		Plan Coordinate		Ortho Height
	Latitude	Longitude	Ell. H	Latitude	Logitude	X	Y	
BASN	35-10-48.546	129-05-45.769	285.216	35-10-37.430	129-05-43.516	186776.285	208690.977	254.850
KIGO	35-09-58.205	129-09-03.690	177.421	35-09-47.058	129-09-01.467	185230.490	213701.500	147.910
HAE1	35-09-23.794	129-10-27.090	34.476	35-09-12.631	129-10-24.878	184172.877	215814.018	4.748
HAE2	35-09-27.515	129-10-18.480	33.768	35-09-16.353	129-10-16.267	184287.191	215595.899	4.040
HAE3	35-09-33.801	129-10-08.461	33.617	35-09-22.642	129-10-06.247	184480.550	215341.994	3.889
HAE4	35-09-31.816	129-09-35.064	33.278	35-09-20.660	129-09-32.825	184418.084	214496.297	3.550
HAE5	35-09-25.393	129-09-14.179	33.213	35-09-14.238	129-09-11.953	184219.365	213968.401	3.485
HAE6	35-09-18.779	129-09-16.742	36.496	35-09-07.621	129-09-14.516	184015.566	214033.579	6.768
HAE7	35-09-08.194	129-09-09.964	45.298	35-08-57.035	129-09-07.734	183689.101	213862.440	15.570

was used to transform WGS-84 to Tokyo data to acquire the local coordinates. Table 3 contains WGS-84 coordinates and the transformed coordinates acquired with 7-parameter shown in Table 2.

5.2 The Topography Analysis of Seaside

RTK GPS survey was performed for the topographic analysis of HAEUNDAE Beach for the topography analysis of its seaside. Back-hoe with tire was first used to analyze the characteristics of RTK GPS with the (moving) speed of vehicles, but because that is not fitted to the topography, backhoe with track shown in Figure 6 was used later and equipped with a 4000SSi dual frequency receiver made by Trimble Navigation.

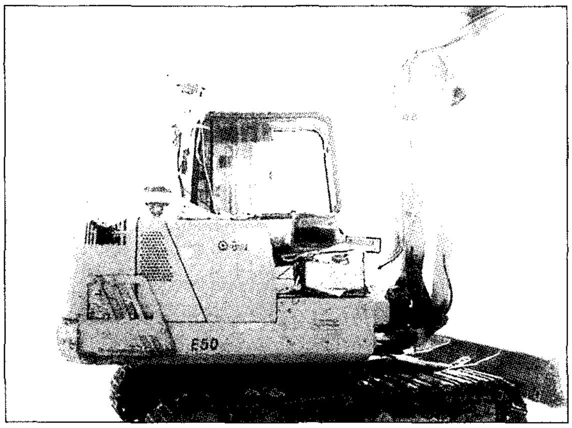

Fig. 6. Equipment setting for rover station.

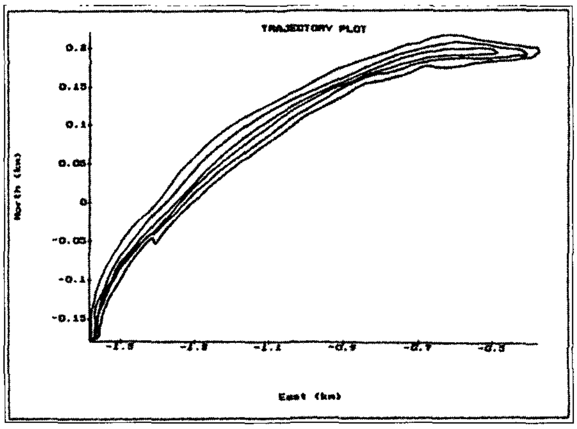

Fig. 7. Trajectory of RTK GPS rover receiver.

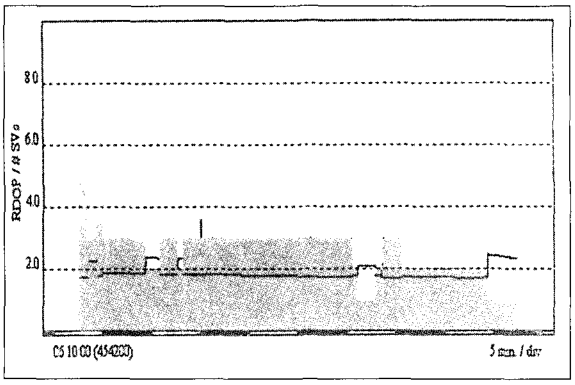

Fig. 8. RDOP of RTK GPS after post-processing.

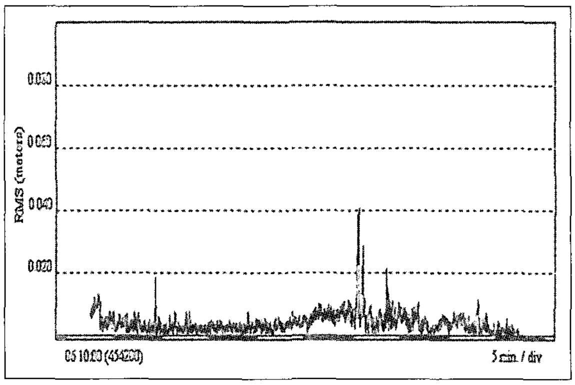

Fig. 9. RMS of RTK GPS after post-processing.

Ltd. (Also,) Figure 7 contains the moving trajectory of rover set on backhoe. Figure 8 and 9 contain RDOP (Relative Dilution of Precision) and RMS of RTK GPS surveying (i.e., average is 0.01m) at HAEUNDAE Beach.

5.3 The Topographic Analysis of the Seafloor with RTK GPS and Echo Sounder

Generally, DGPS (Differential GPS) is used for sounding the tide level surveying, but shows low accuracy for positioning, so this study adopted RTK GPS surveying. Echo sounder for sounding is E-Sea sound 103 of MARIMATECH. The installation of a depth sounder is shown in Figure 10. The information such as the offset from GPS antenna to Echo sounder,

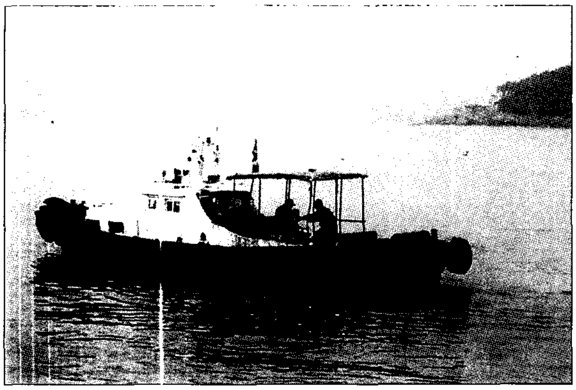

Fig. 10. Equipment setting for bathymetric survey.

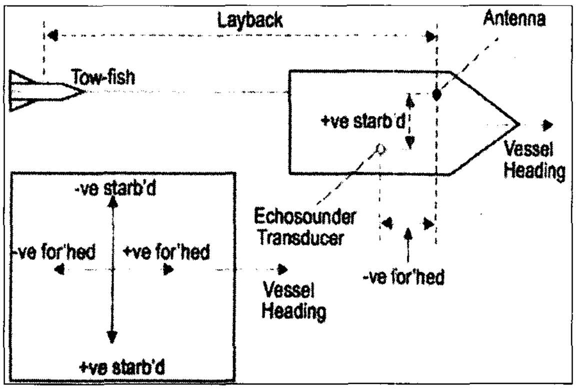

Fig. 11. Vessel offsets.

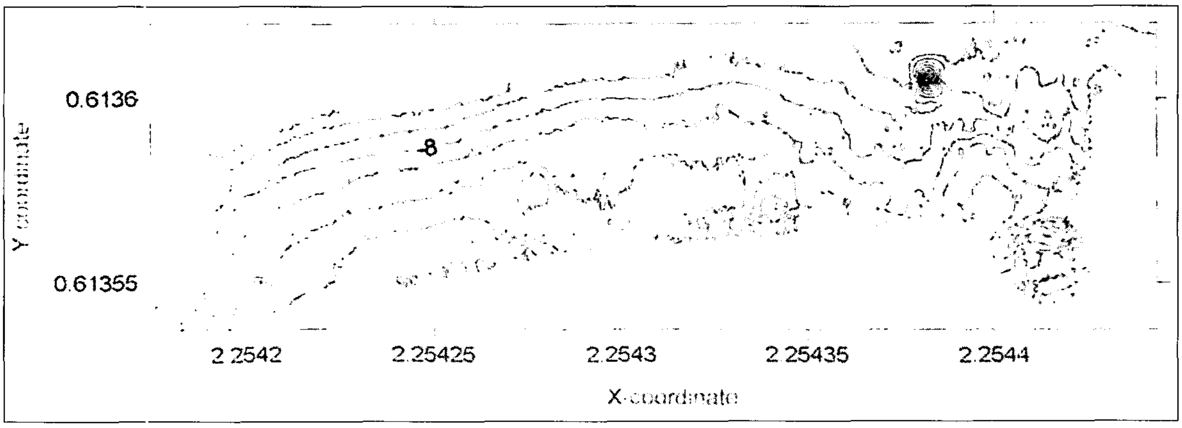

Fig. 12. Contour map of bathymetric survey with RTK GPS

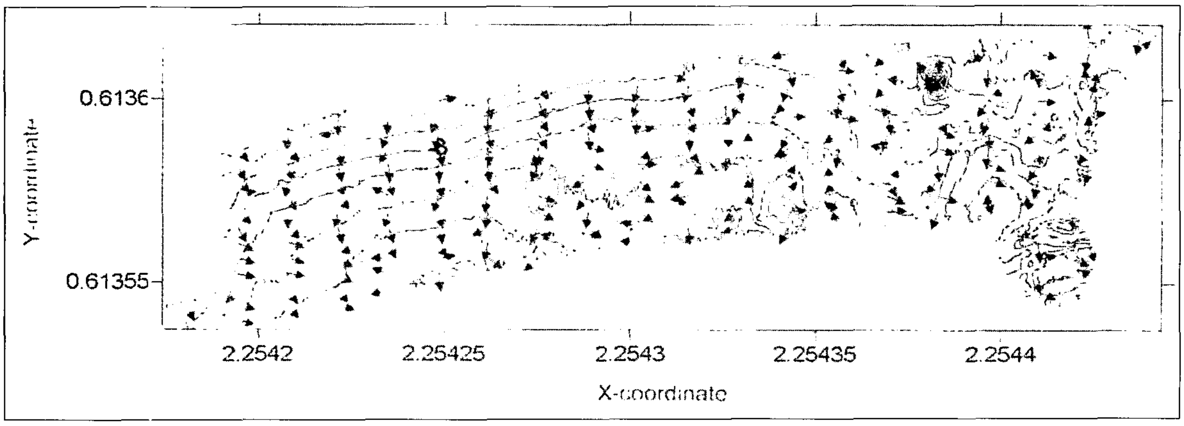

Fig. 13. Composition of contour map and slope map of bathymetric survey with RTK GPS

GPS antenna to the water surface, the offset of a transfer device below the water surface are input as a source.

The software used for the saving, the analysis of sounding data acquired in real-time was HYDROPRO made by Trimble Navigation Ltd. It is to verify the moving path of ship in real-time, predetermined the process path and the marine chart of test area, and then performed the surveying.

Also, the tide level of sea surveyed by level, and this is used as an interpolation data. The observation of GPS and Echo sounder was acquired at 1-second intervals. An isobath of test area is shown in Figure 12 and a grade of sea floor in Figure 13.

6. Analysis and Discussion

The topographic analysis of the seaside was performed using RTK GPS, the seafloor, by combined RTK GPS and Echo sounder. The DTM of digital map drawn on a scale of 1:1,200 is introduced to estimate the accuracy of seaside topography. Figure 14 contains the DTM of seaside topography by digital map, and Figure 15 contains DTM of that by RTK GPS. The volume shown in Figure 14 is 97953.9 m^3, the volume in Figure 15 is 95994.9 m^3. Therefore, the analysis shows having about 2.0% of error in the volume difference between a numerical map and the surveyed data, and it is understood that the seaside topography surveyed by RTK GPS was successful.

Also, to inspect the seafloor topography, the 3D projection map of a seafloor's bathymetric map drawn on a scale of 1: 250,000 is shown in Figure 16 and that by the combined RTK GPS and Echo sounder in Figure 17.

Since the boundary of measurement result is not identical, it is estimated that the comparison of volume and water depth is not correct. Therefore, it is found that the result shows almost similar, if a survey accuracy is compared with 3-Dimensional perspective drawing of two figures. Also, if a submarine topography measurement combined with RTK GPS and E/S is

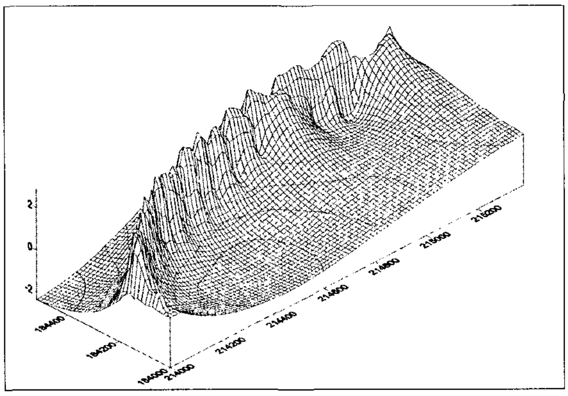

Fig. 14. DTM of Digital map.

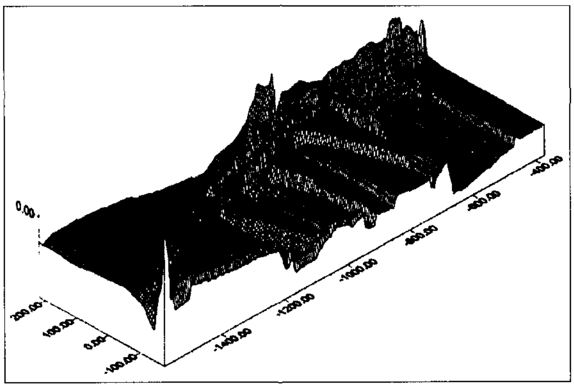

Fig. 15. DTM with RTK GPS.

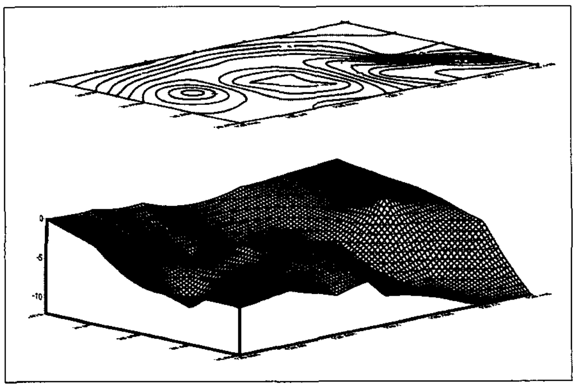

Fig. 16. 3D perspective map of seafloor's bathymetric map.

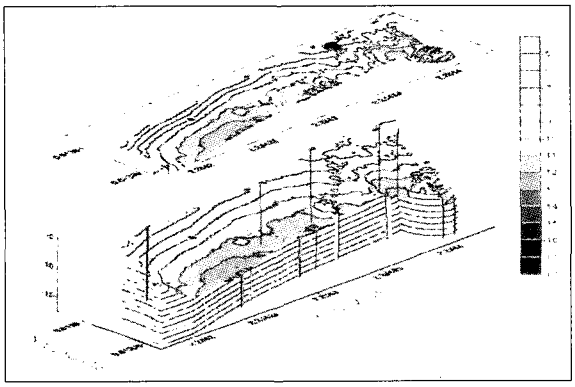

Fig. 17. 3D perspective map with RTK GPS and E/S.

carried out every year, a moving quantity of earth and sand in the tested region can be assessed, and can be used effectively for reclamation of harbors, dredging, or measuring the change of drifted sand quantity in riverbed.

7. Conclusion

In order to carry out an exact analysis of topography for the seaside region, a control point was established executing a static survey, and coordinate transformation of the control point were executed. From these control points, it was surveyed using a construction machine by RTK GPS measurement. The topographic analysis of seaside and seafloor with RTK GPS and the combined RTK GPS and Echo sounder results are as follows:

1. The precision of 10km baseline with initialization time of over 4 minutes is better than 1cm in RTK GPS. It is expected that time table showing PDOP and RDOP under 4 influencing on the positioning accuracy is good for the observation plan.

2. Comparing the contour map and DTM obtained from the topographic analysis of seaside by RTK GPS and those from the topographic analysis of seafloor by the combined RTK GPS and Echo sounder; those by digital map and the seafloor's bathymetric map are well matched and also shows a comparable numbers in volume.

3. It will be very useful for the combined RTK GPS and Echo sounder to measure the reclamation and dredging of harbor or quicksand change of riverbed and apply to the database build-up of GIS effectively.

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