An Analysis on Virtual-Base-Station Real Time Kinematic GPS Positioning System of e-GPS Base Station Network

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Abstract

Flourishingly developing technologies of internet and wireless communication have made Global Positioning System (GPS) Real-Time Kinematics (RTK) satellite positioning as the main stream of international survey and positioning technique. Specifically, the architecture of GPS ground network combined with the concept of Virtual Base Station (VBS) has become the RTK system that is actively established in many developed countries. Since 2004, the Land Survey Bureau (LSB) of Ministry of the Interior (MOI) has been integrating existing GPS ground stations around Taiwan to build up a national e-GPS RTK network. The e-GPS network has increased the applicable distance between the reference station and the rover, hence has enlarged the operation area of a traditional RTK system. Moreover, area correction parameters (ACP) derived from the GPSNet software of Trimble Co. have also improved RTK positioning precision and reliability

In order to assess the precision and feasibility of the above VBS (or e-GPS) RTK positioning technique, from April to December 1994, LSB carried out a series of tests in middle and northern Taiwan. The tests verified that the VBS-RTK positioning precision is about 2 centimeters in horizontal coordinates and about 5 centimeters in ellipsoidal heights. The achieved positioning accuracy is suitable for setting up all orders of control points. It is expected that the VBS-RTK positioning technique will be widely applied to the people's daily life in Taiwan, and also to disaster prevention and navigation monitoring and different kinds of scientific research in the near future.

Key Word:

Global Positioning System, Virtual Base Station, Real-Time Kinematic

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1、Introduction

Due to the low-latitude geographic location of Taiwan Island and large variations in topography, the effects of the ionosphere and troposphere contained in received GPS signals in Taiwan are significantly severer than in many other countries. Besides, frequent earthquakes and tectonic activities in the region also produce difficulties in maintaining a precise coordinate system. In order to effectively conduct all levels of control surveys using GPS, LSB utilized 24-hr continuously observed GPS data from GPS base stations installed over the Taiwan area, together with sophisticated Internet infrastructure and wireless data communication technology, to experimentally survey basic and supplementary control points with the VBS-RTK technology in 2005. The primary goals of the experiment were as follows: obtaining precise coordinates of the e-GPS network stations, analyzing achievable accuracy and reliability associated with the VBS-RTK technique, and summarizing field experiences and test results to draft standard operation procedures as well as different types of surveying and mapping codes.

2、The VBS-RTK system

2.1 Basic Principles of VBS-RTK

The basic concept for VBS-RTK technology is that a network of GPS base stations continuously receiving GPS satellite signals and connected to a control center through internet or other communication facilities, produces area correction parameters (ACP) and in the mean time, generates Virtual Base Station (VBS) measurements nearby a rover station. Within the scope of the GPS base station network, any RTK user can set up a GPS receiver on a rover station and connect to the control center through wireless communication and receive VBS data in RTCM format, followed by a traditional ultra-short-baseline RTK positioning procedure to obtain centimeter-level coordinate results.

2.2 System Components

The VBS-RTK system is composed of three major components:

(1) GPS base station network:

Continuously receiving GPS observation data and real-time transmission of raw data to the control center through the internet.

(2) Control center:

1. Continuously receiving, monitoring, processing, and archiving GPS data.
2. Continuously calculating ACP and generating VBS observations.

3. Transmitting VBS data to rover station through GSM/GPRS and/or NTRIP.

(3) User (rover station):

Transmitting navigation message in NMEA format to the control center through GSM/GPRS and NTRIP, then utilizing VBS data to perform RTK positioning.

3、VBS-RTK System of a Nationwide e-GPS Base Station Network

3.1 e-GPS Base Station Network

LSB passed a budget plan for a nationwide e-GPS network from 2004 to 2006 to complete 79 base stations on Taiwan Island and several off-shore islands, including Penghu, Kinmen, Green Island, and Lanyu. The plan was to complete 23 base stations in 2004, 20 stations in 2005, and 36 stations on off-shore islands in 2006. Basically, the distance between each base station does not exceed 50 km and the station distribution map is illustrated in Fig. 3.1.

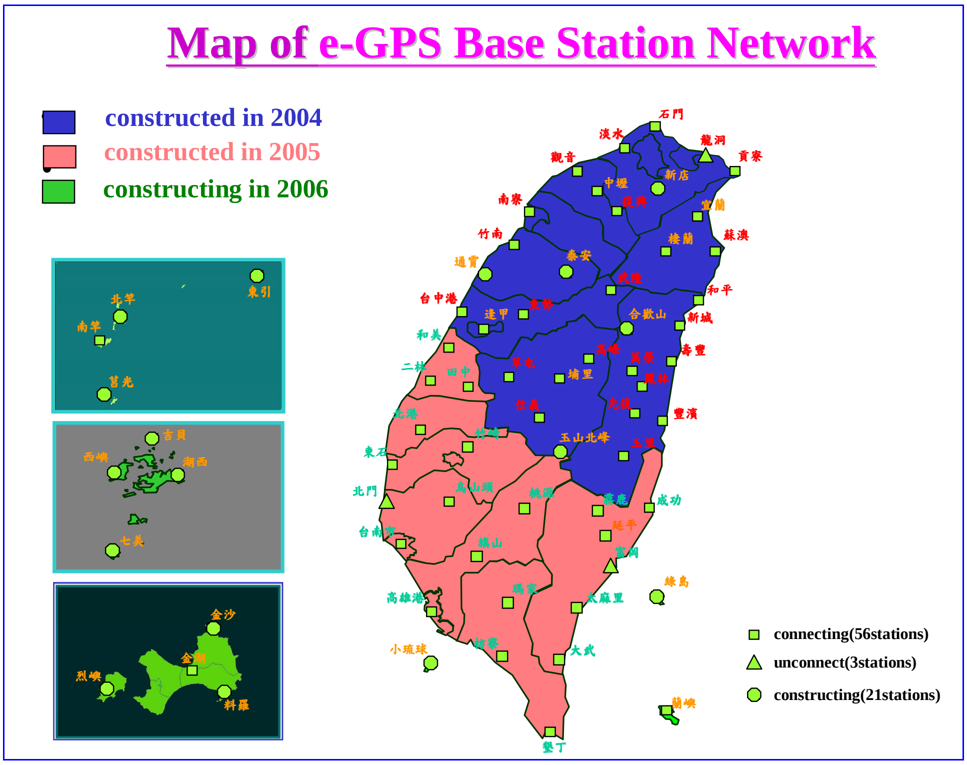

Fig. 3.1 Distribution Map of the e-GPS Base Station Network

3.2 Framework of the Control Center

The internet framework of the control center as well as of each base station is adopted from Virtual Private Network (VPN) framework of Government Service Network (GSN). Presently, the control center located at LSB has 2 fixed T1 private lines, 1 E1 private line, and 1 ADSL (2M/512K) line, and is connected to the base stations in VPN framework mode as shown in Fig. 3.2.

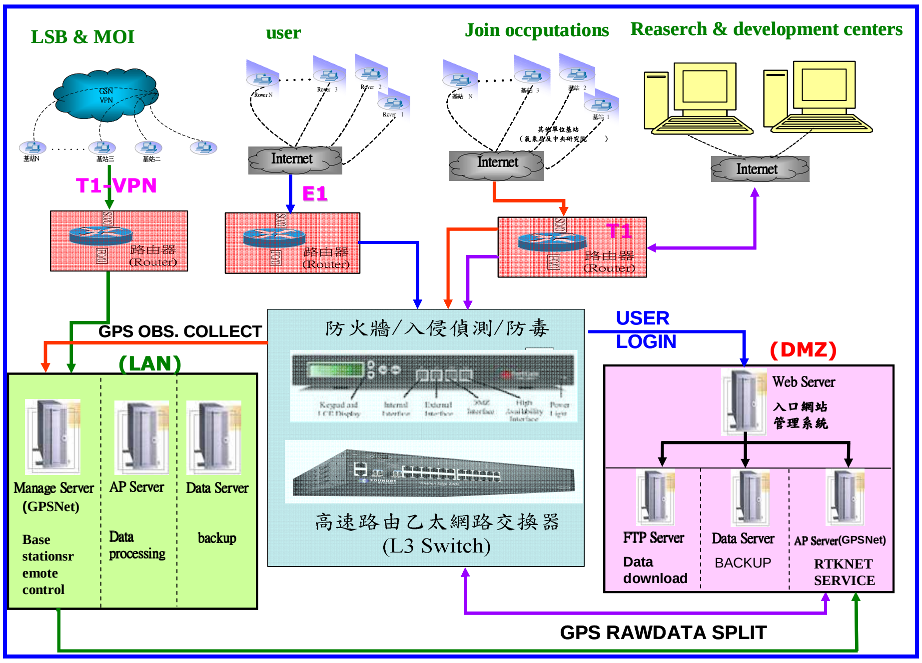

Fig. 3.2 The framework of VBS-RTK positioning system

3.3 Setting of the VBS-RTK Service Net

Due to the low-latitude geographic location of Taiwan Island, the effects of the ionosphere are rather severe. Also, frequent tectonic activities in the region also produce large relative motions of base stations. To avoid the condition of declining accuracy of the VBS-RTK system, it is very important to maintain high-precision relative positions between the base stations to ensure accurate system operation.

The VBS-RTK system is therefore divided into 8 networks (as shown in Fig. 3.3), including 7 regional service network and 1 central service network overseeing the entire area. Naturally, it is then desired to determine precise relative motions and velocities between the regional networks from continuous GPS observations collected at the base stations and from field experiment GPS data.

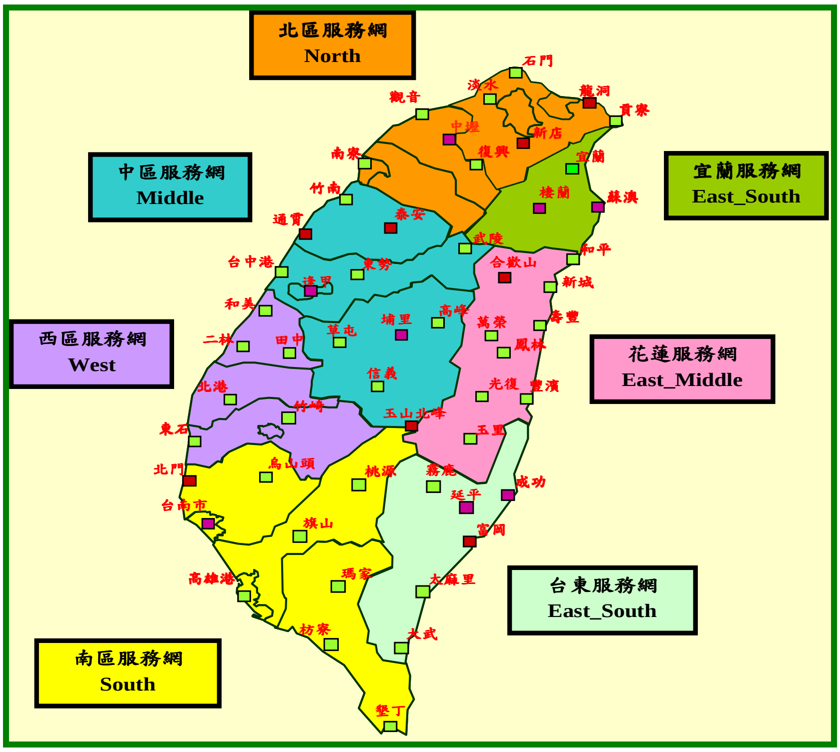

Fig. 3-3 Distribution of Taiwan Regional VBS-RTK Service Networks

4、Precision and Reliability Test Analysis of VBS-RTK

4.1 Background

The evaluation has the following items:

(1) Precise coordinate calculation and accuracy evaluation for e-GPS base stations.

(2) In conjunction with current surveying codes and standards of control surveys, analyzing the positioning accuracy and reliability.

4.2 Coordinate accuracy analysis for e-GPS base stations

Coordinate accuracy of e-GPS base stations plays an important role in VBS-RTK positioning results. The evaluation uses minimum-constraint for network adjustment of the e-GPS Network built by LSB in 2004 and 2005, the MOI GPS tracking stations (excluding Dungsha Island), and tide gauge GPS stations, to obtain displacement velocities for subsequent coordinate accuracy analyses.

4.2.1 Selection of Fixed-coordinate Base Stations.

We first fixed the TWD97 coordinates of Yang-Ming-Shan national park MOI GPS tracking station to compute the coordinates of all e-GPS base stations. Then, we selected the most stable and least displaced station as the fixed reference station for the e-GPS network. After some analysis, the station JUNA was selected as the reference station. It's coordinates and velocities are defined in ITRF94 at epoch 12:00:00, Feb. 15, 2005. The coordinates are X:-2975764.7118 m, Y:4976994.8411 m, Z:2647324.2334 m, and velocities are X:0.0083 m/yr, Y:-0.0006 m/yr, Z:-0.0129 m/yr, respectively.

4.2.2 Calculation Procedures

The Bernese software developed by University of Berne, Switzerland was used to calculate the daily coordinates of e-GPS base stations with precise GPS satellite ephemeris from IGS. The TAU test（τ-test）was used to eliminate outlier results in daily coordinates. The resulting velocities and there standard deviations (STD) of the base stations are listed in Table 4-1 and Fig. 4-1.

Table 4.1 Velocities and standard deviations of base stations (DOY 032-365, 2005)

unit: mm

	Station	Velocity of N-S	STD of N-S	Velocity of E-W	STD of E-W	Velocity of height	STD of height
1	GOLI	-15.3	0.8	2.1	0.8	-11.6	1.9
2	SHMN	-12.6	0.8	-2.8	0.9	-13.9	1.8
3	GS10	-14.5	3.1	7.1	2.5	-14.7	8.0
4	KYIN	-14.6	1.0	-0.7	0.7	-4.5	2.4
5	FUSN	-6.6	0.7	-25.4	0.9	-32.7	1.4
6	SHJU	-12.2	0.4	-5.8	0.3	-18.6	1.1
7	**JUNA**	**-9.7**	**0.0**	**-6.8**	**0.0**	**-9.7**	**0.0**
8	TACH1	-17.9	0.8	-8.1	0.8	-24.6	2.2
	TACH2	-7.7	2.6	-10.1	2.3	-2.2	6.4
9	DOSH	-8.5	0.6	-11.6	0.6	-15.3	1.3
10	WULI	-4.4	0.9	-8.0	0.8	7.0	2.1
11	CAOT	-12.8	0.6	-9.8	0.7	-15.9	1.3
12	KAFN	-1.4	0.7	-43.9	0.5	-1.0	1.6
13	SINY	-2.7	0.6	-34.1	0.7	-7.3	1.8
14	VR01	-14.4	0.7	-7.9	0.6	-11.3	1.6
15	VR02	-16.9	0.6	-11.2	0.6	-93.3	1.6
16	VR03	-13.9	0.7	-7.9	0.7	-9.2	1.7
17	PKGM	-14.6	0.7	-8.0	0.5	-29.7	1.7
18	CHYI	-14.3	1.2	1.0	1.3	-19.7	2.8
19	JHCI	-8.2	1.5	-21.7	1.8	1.4	4.9
20	WUST	-6.7	2.3	-14.1	2.0	20.3	6.7
21	KASH	-32.9	2	-60.5	2.2	-3.1	6.0
22	CISH	-15.7	1.7	-45	1.9	4.9	4.3
23	TAYN	11.6	2.2	-48.6	2.5	27.9	7.0
24	MAJA	-3.8	1.9	-56.8	2.8	1.2	6.9
25	FALI	2.4	1.6	-56.7	2.2	-11.4	5.1
26	KDNM	12.8	4.7	-74.4	8.4	13.7	17.4
27	DAWU	-0.6	1.6	-64	2	8.6	5.0
28	TMAM	11.4	4.1	-34.7	5.2	15.6	14.6

29	WULU	6.8	2.3	-25.2	3.2	24.6	8.2
30	JULI	8.0	0.6	-33.0	0.8	-30.1	2.1
31	FONB	35.7	0.8	-54.6	0.9	-25.5	2.1
32	FLNM	5.3	0.8	-32.1	0.8	-18.7	2.1
33	HUAP	-24.4	1.4	4.0	1.8	1.1	4.9
34	YILN	-1.3	8.5	-5.3	7.8	-22.4	35.3

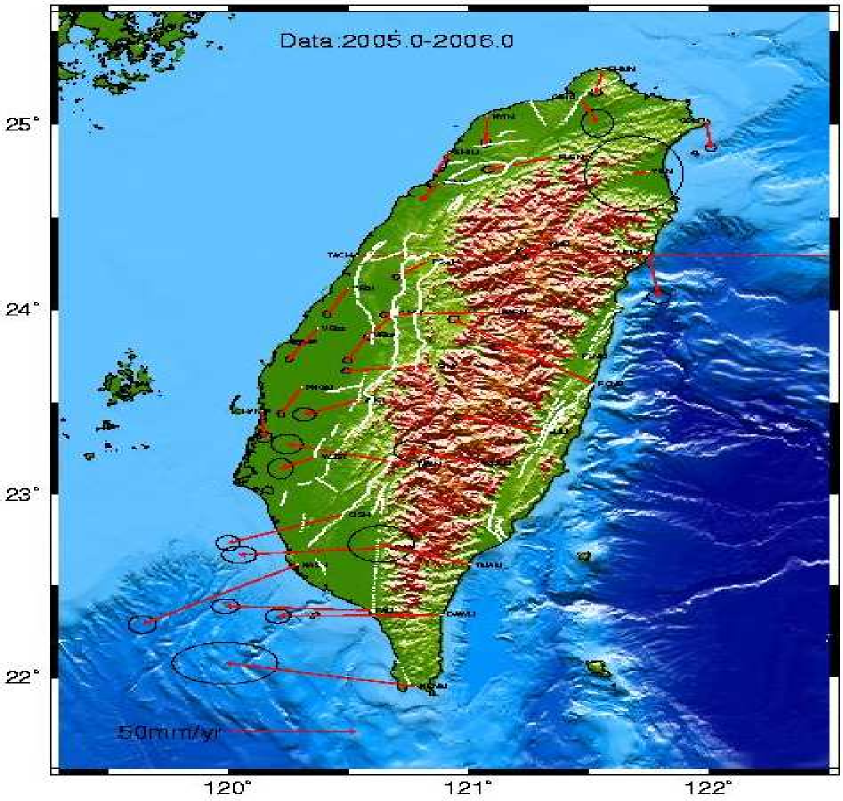

Fig. 4-1 Velocities and standard deviations of e-GPS base stations

4.2.3 Relative Coordinate Accuracy Analysis

After data analysis for a whole year (2005), it was concluded that to reach 1-cm relative coordinate accuracy between base stations requires station coordinate updates every 3 months in North, Middle, and East-North service networks, every 2 months in East-South service network, and every month in West, South, and East-Middle service networks.

4.3 Analysis of VBS-RTK positioning accuracy and reliability

Base on a fixed station (LSBA) every 24hr 1Hz continuously of VBS-RTK positioning coordinate result and simulate field kinematics real observation data, and according to collected VBS-RTK Fixed solution as statistic analysis data basis.

. Because of coverage of base station network that cause parts users are outside the service nets, our plan to anticipate evaluating and analyzing the solution, the precision, the accuracy of VBS-RTK positioning result and its relationship between external operation environment.

In order to evaluate the stability of coordinates from LSBA Station, introducing Bernese 4.2 software in associate with both LSBA station together and eleven VBS stations of Middle regional service net for proceeding minimum restriction adjustment. Between days of 121 to 271 since 2005, LSBA station coordinates maximum variation in N direction is 0.9 cm, E direction is –1.19cm and H direction is 1.55 cm (see fig. 4-2) which revealed the stability ought to stand as reference basis for general testing projects.

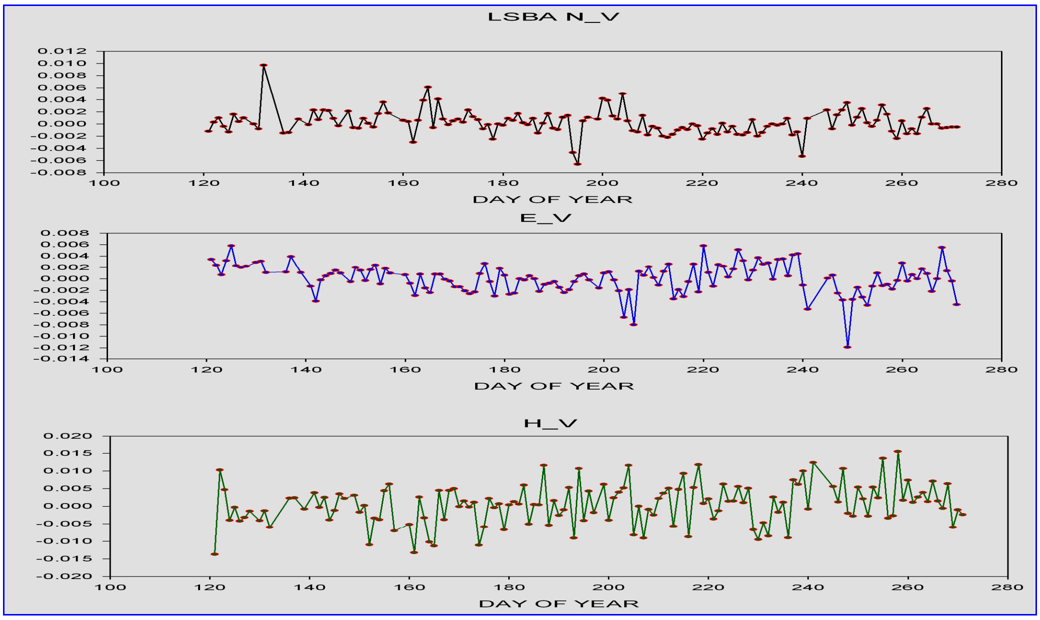

Fig. 4-2 LSBA station's daily coordinate variation (DOY 121-271, 2005)

4.3.1 VBS-RTK static positioning interpolation test results

The related tests were being proceeded in Middle region service net from Apr. 27 to Dec. 30 of 2005 for totally 157 days collection VBS-RTK positioning result. Statistic analysis test result are as following :

(1) Statistical analysis of VBS-RTK positioning solution success rate.

The analytical foundation of positioning solution success rate is base on the daily continuously positioning result daily or ratio available to solve Fixed Solution The VBS-RTK positioning test result for a period of 157 days calls for an average of 98.38% success rate. Among them, the highest solution rate is 100% while the lowest is 57.2% in a single day. As for each monthly basis, in addition to July and August solution rate 96.64% and 94.32% respectively, for the rest of months with average of above 97% . Main reason for lower solution rate in July and August probably because of bad weather conditions such as Typhoons and cloudburst etc., which not only cause the unsteady data quality transmission on some base stations and data interruption, even worse influence the solution and accuracy of the VBS-RTK fixed position data.

(2) Statistical analysis of precise VBS-RTK positioning results

The precision analysis for positioning result was according to RMS (Root Mean Square) from LSBA Station's daily 1Hz continuously position result, and being used as Statistical basis reference.

The testing project totally collects 157 days of VBS-RTK position result, deducting lower accuracy result of plane and elevation on July 8, 29 and August 17, 19 four days. The RMS average value of direction N and E is 1.44 cm and 1.48 respectively. And RMS average value of elevation direction is 3.87cm, the RMS average value in plane direction of each month is below 2 cm, and elevation direction around 3-4 cm as table 4.2 and figure 4.3.

Tab 4.2 Average Statistics of monthly VBS-RTK positioning accuracy in 2005

month		May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Sample days		26	23	16	12	21	23	15	21
Ave. Of precision (cm)	N	1.37	1.42	2.52	2.29	1.17	0.98	1.12	1.23
	E	1.28	1.58	2.33	2.36	1.33	1.06	1.33	1.21
	h	3.60	4.17	5.45	5.62	3.41	3.13	3.60	3.16

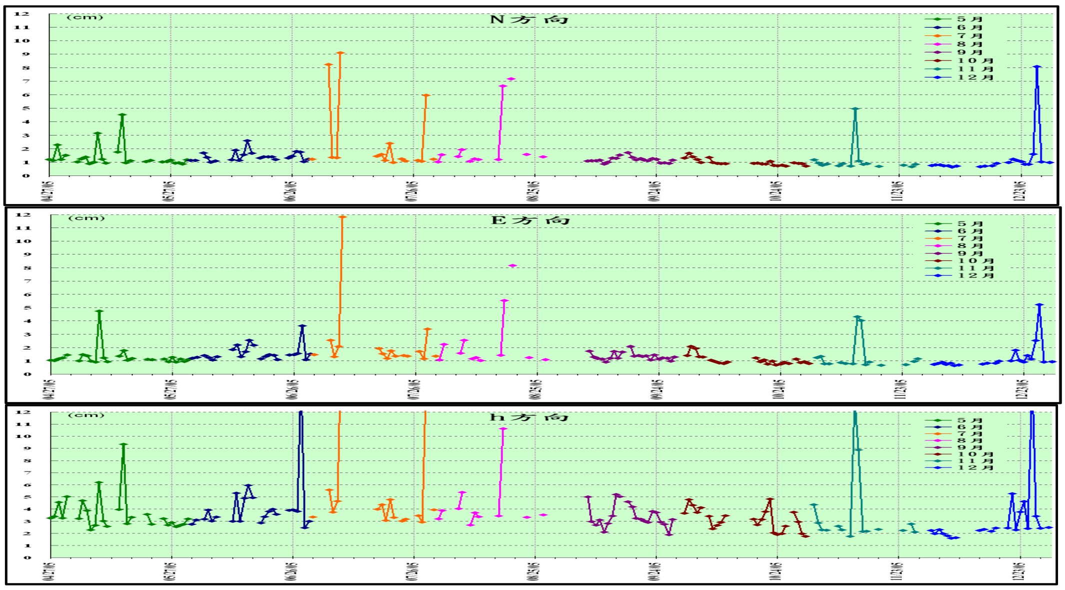

Fig. 4.3 Daily positioning accuracy map

(3) Statistical analysis of positioning accuracy

The precision analysis for positioning result is an assumption from LSBA precise coordinate as true data and the error (Root Mean Square Error) acquire from daily 1 Hz consecution fixed position result , be used as the basis of the covariance analysis, its essence puts great emphasis on the difference degree between VBS-RTK fixed position result and assumed true value.

The test project totally collects 157 days VBS-RTK position result, its N direction average error is 1.70 cm as the E direction error is 1.80 cm and elevation direction error is 4.42 cm, detailed as table 4.3 and figure 4.4.

Table 4-3　VBS-RTK positioning error of Station LSBA in 2005.

Month		May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	ave
Sample days		26	23	16	12	21	23	15	21	
Ave. of rms (cm)	N	1.74	1.76	2.82	2.56	1.35	1.22	1.40	1.35	1.70
	E	1.36	1.73	2.44	2.57	1.88	1.61	1.84	1.56	1.80
	h	4.29	4.47	5.59	6.18	3.84	4.34	4.29	3.38	4.42

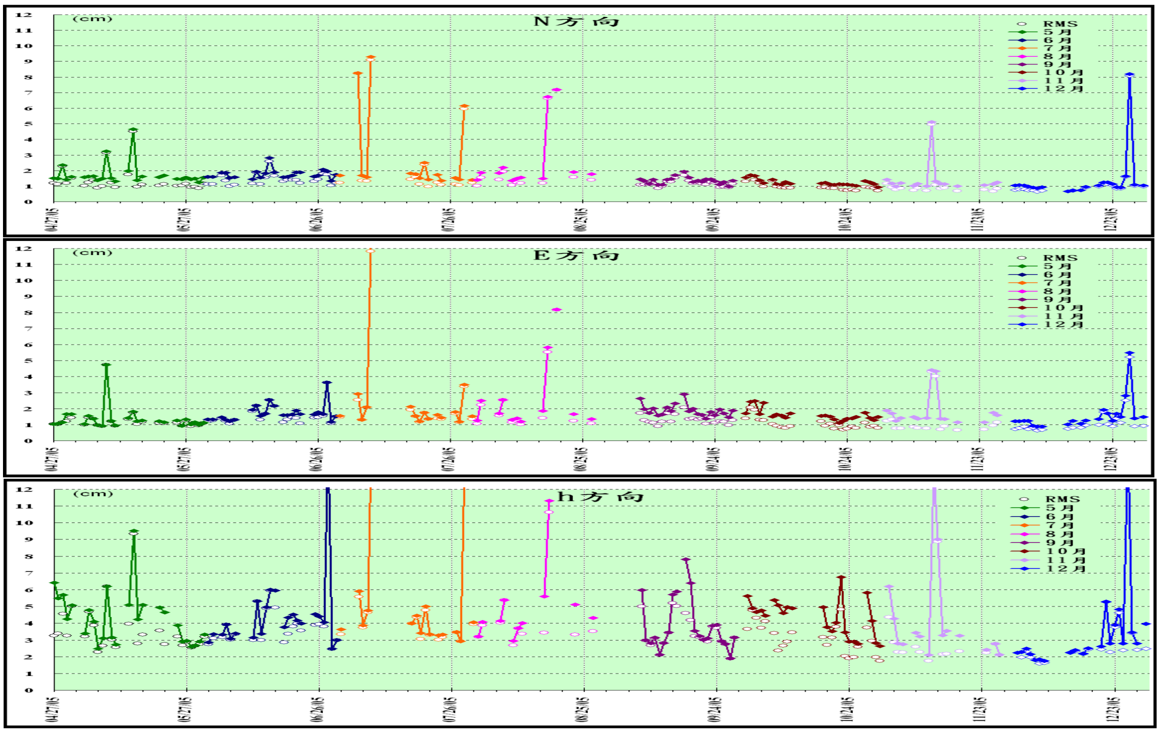

Figure 4-4 Daily VBS-RTK positioning error for Station LSBA

(4) Daily time block analysis for VBS-RTK positioning results

The VBS-RTK positions the result and everyday time block relativity analysis, is measures LSBA station everyday, take 4 hours as at that time a block, statistics the variety situation that each time VBS-RTK inside the block positions the result accuracy(RMS value), May goes to December the period to measure in the LSBA from 94 years stand a VBS-RTK fixed position accuracy and everyday time block of ratio to manifestation, in addition to July and August in 2005,because the period is several of the fixed position accuracy is up to more than 10, cause the fixed position accuracy been inferior turn the situation the outside, the VBS-RTK of rest and each month each time of everyday block fixed position the result all and mostly can match the flat surface 2 cm of, high distance 5 cm of expectation accuracy in, past VBS-RTK fixed position the accuracy first step's predicting should have no absolute relativity with everyday time block, that is move station user at everyday any time carry on the VBS-RTK fixed position solution calculate, all can acquire equal of fixed position accuracy, detailed as table 4-4.

Tab4.4 VBS-RTK positioning precision and timeframe for station LSBA (unit: cm)

	month / timeframe	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
N	0hr-4hr	1.4	1.6	2.4	1.3	0.9	1.0	0.9	0.7
	5hr-8hr	1.0	1.1	1.0	2.7	1.0	0.8	0.6	0.6
	9hr-12hr	1.4	1.6	1.2	1.2	0.9	0.8	0.7	0.7
	13hr-16hr	1.2	1.2	2.1	2.9	1.1	0.9	1.1	1.0
	17hr-20hr	1.0	1.1	1.1	2.2	1.5	1.0	1.9	1.9
	21hr-24hr	1.1	1.2	2.7	1.3	1.1	0.9	0.8	0.9
E	0hr-4hr	1.5	1.6	1.5	2.4	0.9	0.9	0.7	0.7
	5hr-8hr	0.9	1.1	1.0	2.5	0.8	0.8	0.7	0.7
	9hr-12hr	1.1	1.5	1.3	1.3	1.0	0.9	0.8	0.8
	13hr-16hr	1.1	1.4	1.7	2.6	0.9	1.1	1.0	1.0
	17hr-20hr	1.0	1.3	1.5	2.0	0.8	1.1	2.3	1.8
	21hr-24hr	1.2	1.4	3.2	1.2	0.8	0.9	0.7	0.8
h	0hr-4hr	3.1	4.7	3.6	4.4	3.2	2.9	2.1	2.0
	5hr-8hr	2.7	3.2	3.2	5.9	2.1	2.1	1.7	1.5
	9hr-12hr	4.1	3.9	2.9	2.7	2.2	1.9	1.7	1.6
	13hr-16hr	3.1	3.2	5.9	7.3	3.1	2.4	2.2	3.8
	17hr-20hr	2.7	2.7	3.5	5.1	3.3	2.8	6.0	3.8
	21hr-24hr	3.1	3.1	5.8	2.9	2.8	3.0	2.7	2.2

4.3.2 VBS-RTK static extrapolation positioning results and analysis

The VBS-RTK static extrapolation testing also adopt the fixed station of LSA in proceeding VBS-RTK solution under e-GPS RTK system for the analyze basis of precisely positioning, hence according to the distance between LSBA Station and each base stations nearby to adjust maneuverability the satellite base station group of external insertion testing net. The external distances are 14 、18、 32、 38 、52 and

64 kilometers respectively.

Because this test is similar from previous section of static internal insertion, therefore we only aim at processing the three key types positioning result (VBS-RTK's solution, precision and accuracy) for analysis as following:

(1) Analysis of solution rate for VBS-RTK static extrapolation positioning result

Over 95% solution within 38 km distance between test station and base station, until exceed distance over 50 km which solution decrease to below 90%, detail as fig. 4-5。Within the distance of 38 km in base station, the solution successfully achieve over 95%

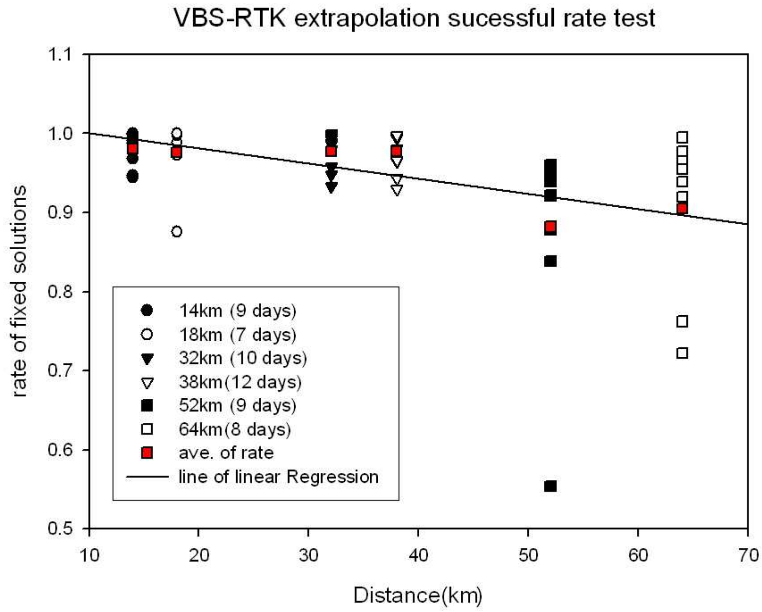

Fig. 4-5 Success rates of static extrapolation positioning

(2) Precision analysis of VBS-RTK static extrapolation positioning

When distance from test station to main base station is within 18 km, VBS-RTK static external insertion plate positioning accuracy roughly maintain within 2 cm, but the average accuracy on elevation direction is about 5cm, and the maximum error exceed 20cm; furthermore from up to distance of 32 km, both accuracy of plate and elevation will be decrease following distance increase, and the the uncertainty of elevation positioning accuracy will substantially increase comparatively.

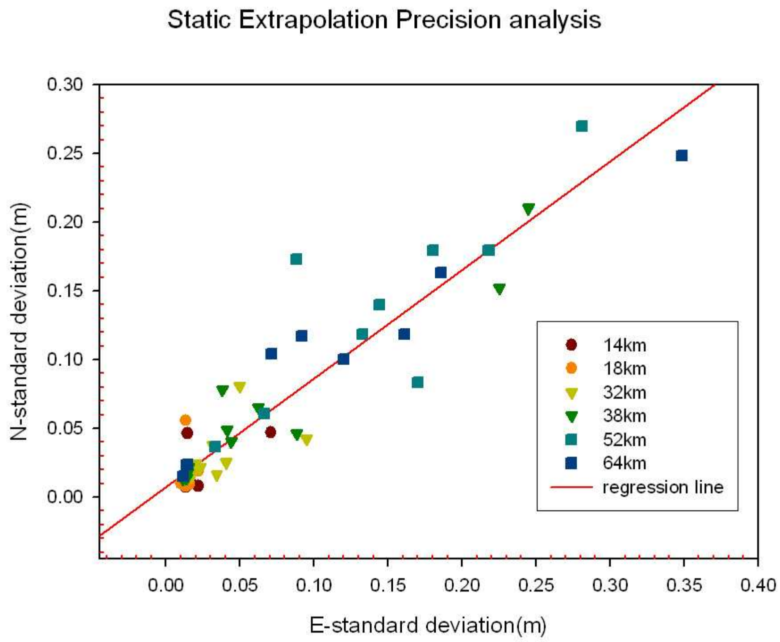

Fig 4-6 Precision analysis of VBS-RTK static extrapolation positioning

(3) The accuracy statistical analysis of VBS-RTK Static extrapolation positioning

We can see the consistent relationship with internal insert from the analysis of static extrapolation positioning result, thus there’s a highly relevance between VBS-RTK positioning accuracy and precision, as detailed in figure 4-7.

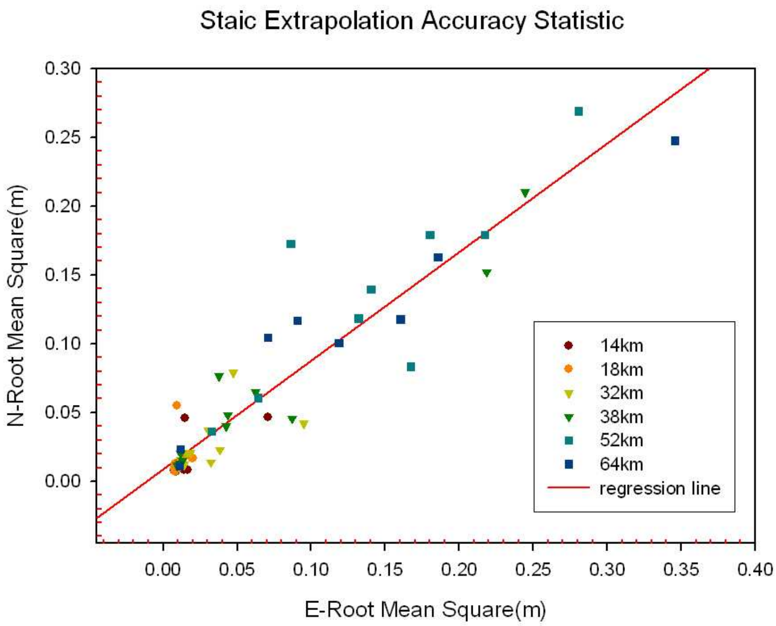

Fig. 4-7 Accuracy analysis of VBS-RTK Static extrapolation positioning

4.3.3 Statistical analysis of VBS-RTK field positioning test results

Regarding the kinetic testing of VBS-RTK positioning result is by processing real time kinetic processing from basic control point or supplementary point on field to discuss the difference between positioning test data with known information for renewing future reference on survey drafting standards.

(1)The deviation comparison analysis of VBS-RTK kinematic positioning result and control point coordinates

Because of necessary regular corrections on precise coordinates for each base stations, the comparative accuracy should maintain within 1cm, thus bring regional deviation forth with the TWD97 national coordinates system announced by Ministry of Interior (MOI)

. The purpose of deviation analysis between VBS-RTK kinetic positioning result with each point order from TWD96 coordinates is to definite the inconformity and regional cover range for this type of coordinates

The maximum inconformity data of plate coordinates occurred mostly in Keelung city, its N、E direction inconformity rate is -4.8 cm and 3.5 cm respectively, while elevation direction occurred in Hsinchu city, its coordinates deviation value is 3.8 cm; as for the middle area in Maoli, Taichung and Nantao district, the E direction possess 6-30 cm deviation value, under speculation the reason for the deviation is due to the continuously earth crust activities effected upon 921 enormous earthquake incident, Hualien district average deviation in E direction almost reach about 30 cm as tab. 4-5

Tab 4-5 Deviation comparisons of VBS-RTK positioning result with each control point

Unit : cm

縣市別	基隆	台北	桃園	新竹	苗栗	台中	南投	宜蘭	花蓮
檢測點數	10	39	131	43	11	25	5	27	120
△N	-4.8	2.4	1.2	2.2	-1.7	-0.9	3.1	-11.2	12.6
△E	3.5	1.3	-0.4	-1.1	-5.9	-6.2	-29.3	14.8	-27.8
△h	2.9	0.1	-2.0	3.8	5.2	-6.5			

(2) The transformation and integration analysis of VBS-RTK kinetic positioning result

As both the”present time” coordinate frame adopted by e-GPS positioning system and “bulletin” coordinate frame adopted by cadastral survey are under the TWD97 national coordinate system basis, however the coordinate displacements caused by factors in differential areas such as control point accuracy, crustal displacements or others will rise the difficulty in integrating different periods of cadastral results. Under the circumstances of lacking long term complete observation data and precise velocity information, post processing will be the temporarily way for integrating coordinate transformation with minimum multiple configuration to link the relation between direct solution of VBS-RTK positioning coordinates and legal bulletin coordinates.

Fig. 4-8 shows the common point of transforming integration via one second order satellite control point and three third order control point at I-Lan, Tungshan district. Within range of surveying area using Helmert 4-parameter plane coordinate transformation and least-squares collocation fitting method to counter at 20 fourth order control points and 151 supplementary points for practical data comparison of preceding and forgoing transform integration.

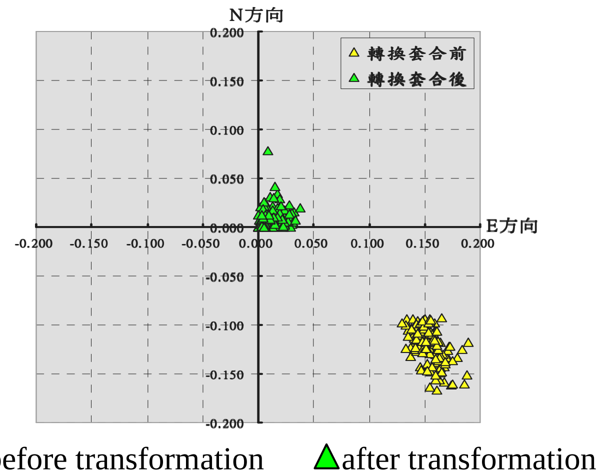

Fig.4.8 Comparison of VBS-RTK coordinates and known coordinates in Dongshan and I-Lan cadastral resurvey area

(3) Initialization time of VBS-RTK kinematic positioning

The VBS-RTK kinematic positioning time depend on adopting On-The-Fly (OTF) demand initialized time, and available to obtain centimeter accuracy of RTK-Fix coordinate per second once complete initialized. So to aim at the analysis of initialized time for VBS-RTK kinetic positioning GPS observation Net is to conclude the analysis data on 71 sites control point test in northern area, thus 64% available to complete initialized within 1 minute and over 92% within 2 minutes as fig. 4-9

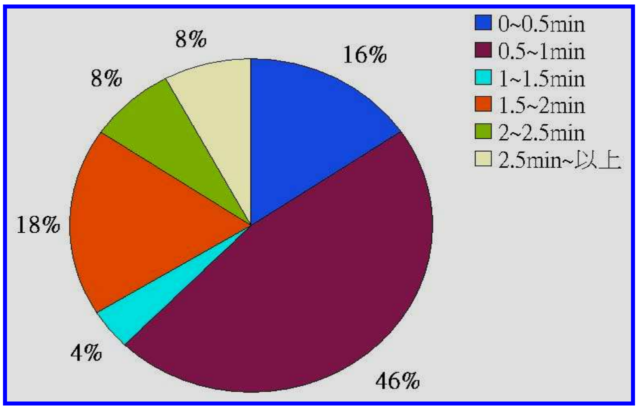

Fig. 4-9 Statistics of northern area VBS-RTK network initialization time

5、Conclusions and Suggestions

5.1 Conclusions:

(A) From April 1994 to December 1995, four VBS-RTK test items conducted in the North, Middle, and East-Middle service networks have reached the following preliminary conclusions:

1. The static VBS-RTK positioning interpolation test:

（1）System initialization time is generally less than 1 minute.

（2）Average success rate is as high as 98.38%.

（3）Average positioning accuracy (RMS) is 1.44 cm in the north-south direction, 1.48 cm in east-west, and 3.87 cm in height.

（4）The precision of VBS-RTK (expressed in standard deviations) is highly consistent with its accuracy (expressed in RMS values). In practice, proper requirements for horizontal and vertical accuracies are needed, in order to preserve the reliability of positioning results.

2. The static VBS-RTK positioning extrapolation test:

The extrapolation positioning accuracy decreases with the distance between the rover station and the master base station, especially in the height direction. For instance, when the distance between the rover station and the master base station was 18 km, the average horizontal positioning accuracy could reach 2 cm, but when the distance was increased to 32 km, the positioning accuracy notably diminished as the distance became larger.

3. The kinematic VBS-RTK field positioning test:

（1）Totally 411 control points of different orders were field tested to compute the differences between the VBS-RTK coordinates and the known TWD97 coordinates. These coordinate differences are obviously regionally distributed. In northern areas north of Hsinchu, horizontal differences were smaller than 5 cm. In middle areas (Miaoli, Taichung, and Nantao), the differences in the East direction were ranged from 6 to 30 cm, mainly caused by the 1999 Chi-Chi earthquake. In east areas (I-Lan and Hwa-lien), the horizontal differences were above 10 cm.

（2）Initialization time is an important factor for measuring system efficiency. Based on the VBS-RTK initialization time analysis conducted in the North service network on 71 control points, 62% of system initialization time was completed within 1 minute, 82% within 2 minutes, and only 8% exceeded 2.5 minutes.

(B) Because the accuracy requirement for relative base station coordinates is merely 1 cm, the station coordinates used by the e-GPS system is regionally different from the officially announced TWD97 coordinates by MOI. There is a systematic shift between the two systems. As a result, the user cannot directly apply VRS-RTK positioning results to current cadastral surveys.

5.2 Suggestions:

（1）Based on the field experience collected from the VBS-RTK experiment, the data communication quality for transmitting rover station position information and virtual base station observations is a major factor affecting the success rate of VBS-RTK kinematic positioning. It is suggested to develop other data communication techniques such as radio network or active base stations, to assist the current GSM/GPRS modem communication structure, and to increase VBS-RTK positioning efficiency.

（2）It was discovered in the experiment that occasionally in some cases the initialization of VBS-RTK failed or took a very long time to complete, and the positioning results were also inaccurate. It is believed that the above incidents were caused by wrongly composed ionospheric-error correction model in the GPSNet software. Therefore, it is suggested in the paper to develop a more appropriate ionospheric-correction model for the Taiwan area, to improve the accuracy and reliability of VBS-RTK positioning.

（3）As mentioned above, the positioning results of e-GPS VBS-RTK system is different from the official TWD97 coordinates, as there is a systematic shift between the two systems. Currently in post-processing mode, we adopted a 4- or 6-parameter Helmert plane transformation with least-squares collocation to transform the e-GPS coordinates to the official TWD97 coordinates and temporally solved the problem. But for future practical applications, it is suggested to study the feasibility of introducing the velocity information of base stations, i.e., a dynamic datum.

(4) Taiwan is located in the collision zone of the Eurasian plate and Philippine Sea plate, and the resulting tectonic activities will cause severe relative motions between the base stations in different e-GPS service networks. To correctly update and maintain the base station coordinates, it is suggested to incorporate the e-GPS base stations into national geodetic coordinate system for efficient and proper maintenance and management. With their long-term continuous GPS observations, precise velocity field information of the base stations can be estimated for keeping up acceptable operation of the e-GPS system and to obtain official coordinate results.

6. References:

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