DATUM PROBLEM OF NETWORK-BASED RTK-GPS POSITIONING IN TAIWAN

Ta-Kang Yeh[1] Yu-Sheng Hu[1] Ming-Han Chang[1] Zu-Yu Lee[1] Yuei-An Liou[2]

1. Institute of Geomatics and Disaster Prevention Technology, Ching Yun University, bigsteel@cyu.edu.tw
2. Center for Space and Remote Sensing Research, National Central University

ABSTRACT:

The conventional single-reference station positioning is affected by systematic errors such as ionospheric and tropospheric delay, so that the rover must be located within 10 km from the reference station in order to acquire centimeter-level accuracy. The medium-range real-time kinematic has been proven feasible and can be used for high precision applications. However, the longer of the baseline, the more of the time for resolving the integral ambiguity is required. This is due to the fact that systematic errors can not be eliminated effectively by double-differencing. Recently, network approaches have been proposed to overcome the limitation of the single-reference station positioning. The real-time systematic error modeling can be achieved with the use of GPS network.

For expanding the effective range and decreasing the density of the reference stations, Land Survey Bureau, Ministry of the Interior in Taiwan set up a national GPS network. In order to obtain the high precision positioning and provide the multi-goals services, a GPS network including 66 stations already been constructed in Taiwan. The users can download the corrections from the data center via the wireless internet and obtain the centimeter-level accuracy positioning. The service is very useful for surveyors and the high precision coordinates can be obtained real time.

KEY WORDS: GPS, RTK, network-based

1. INTRODUCTION

The RTK (Real-Time Kinematic) has become the most important technology of surveying engineering due to the faster wireless and internet communication. Land Survey Bureau, Ministry of the Interior in Taiwan started to set up the real-time GPS reference stations since year 2004. The GPS tracking network in accordance with the principle that the distance between reference stations should not be more than 50 km. Until 2006, 66 reference stations have been launched in Taiwan Island, Penghu, Kingman, Matzu, Lanyu and Green Island. Figure 1 shows the distribution of RTK-GPS network in Taiwan. So far, the VRS (Virtual Reference Station) technology was utilized for surveying. The horizontal precision of RTK-GPS in Taiwan is about 2 cm, height precision is around 5 cm and its positioning precision has been widely applied to various fields (Yeh et al., 2006).

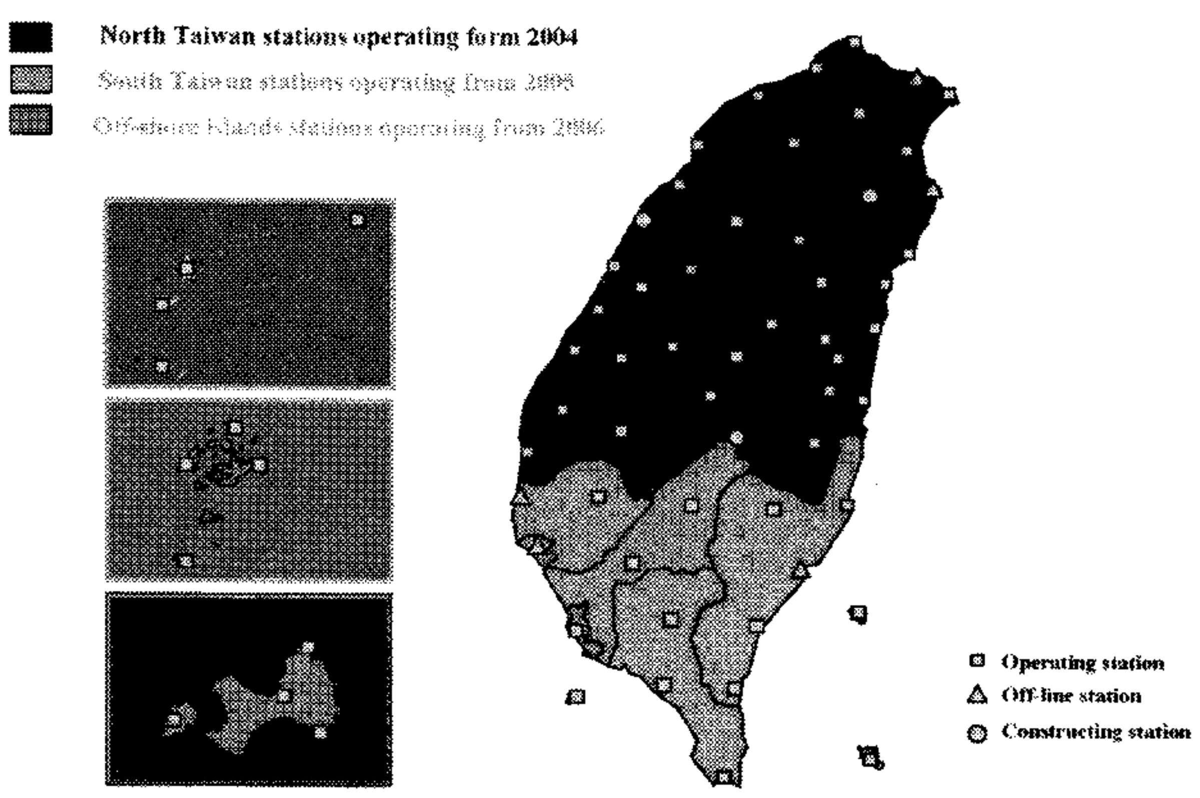

Figure 1. The distribution of RTK-GPS network in Taiwan

In terms of positioning technology, the more applicable projects are VRS and ACP (Area Correction Parameters), to improve the efficiency of real-time kinematics positioning among the medium and the long range baseline. In Germany, these two methods, VRS and ACP, have been adapted in a practical way. Even if the distance of baseline is between 30 and 50 km, the efficiency of cm-level real-time positioning could be reached (Seeber, 2000). The basic concept of ACP is to offer different corrected parameters among various areas and to improve the coordinates of the rover station. But the measuring point must be located in three reference stations and find out the corrected parameter of the rover station. The advantage of this concept is that only need to make a connection with either one of these three reference stations. The corrected parameters can be obtained by the rover station without connecting with the control center.

As far as the communication is concerned, replaced with wireless radio communication, the GSM/GPRS could also supply cm-level positioning precision to the users. Apart from increasing the working distance of RTK, increase the reliability of the system and decrease the time of the initialization are the important advantage (Vollath et al., 2001). Moreover, in order to high precision positioning, the working distance of traditional single station RTK is very limited about 10 km baseline. More reference stations with VRS positioning can supply the RTK to full area (Landau et al., 2002; Sejas et al., 2007).

However, network-based RTK-GPS requires the strict coordinate precision of the reference stations. Once if the coordinate error of the reference station is larger than 2 cm, it will lead to the false resolution. Due to the active plate boundary, it is a very serious problem in Taiwan. According to the decade statistics from Academia Sinica, western Taiwan moves averagely 2 cm every year while eastern Taiwan can even move 7 cm (Yu et al., 2003). Thus, the coordinates measured by RTK-GPS contracts with the current TWD97 (Taiwan Datum 1997) with an error of few centimeters. Such an error is still acceptable in northern Taiwan. Once when it comes to central and eastern Taiwan, the average error has reached 10-30 cm. The positioning result must go through the coordinate transformation and then can apply to the surveying engineering (Chen and Yeh, 2002). Therefore, through the actual coordinates of satellite control points from northern and eastern Taiwan and plus the assistance of 7, 4 and 6 parameter methods for the coordinate transformation, this research is to improve the accuracy of RTK-GPS positioning.

As far as the coordinate transformation is concerned, the different scale means the deformation of point but not the deformation of coordinate system. Since the coordinate transformation does not need to consider the scale parameter, the transformation can be conducted by three rotation parameters and three shift parameters (Vanicek and Steeves, 1996). Besides, using an adjustment model applied to two regional transformations, apart from considering the feature of point coordinate, could calculate all the regional coordinates to obtain the transformation parameters. The method is first to transform from geodetic coordinate to geocentric coordinate. Then the transformation conducts with the 7 parameter model. After the adjustment, the residual vector on three components of each point can be obtained (Reit, 1998). Another method is to use the linear least square collocation and joint the unlinear Gauss-Jacobi algorithms. First, use polynomial to calculate the scale parameter and then put it into the rotation parameter equation to calculate three rotation parameters. Finally, follow the 7 parameter transformation to find out three shift parameters (Awange and Grafarend, 2003). This algorithm has some advantages including the known values adopted for the calculation, no need for linearization and iteration, and the automatic composition of variance-covariance matrix.

2. THEORIES OF VRS POSITIONING

The principle of VRS positioning is collecting and calculating the database of regional error parameters from the real-time data received by many GPS tracking stations with the internet connection. To produce VRS data of each rover station, the RTK user only need to set up a GPS receiver on the rover station and to transmit approximate coordinates in the format of NMEA (National Marine Electronics Association) via GSM/GPRS to the control center. After processing the VRS data, transmit in a format of RTCM (Radio Technical Commission for Maritime) back to the GPS rover station. After calculating the RTK positioning with ultra short distance baseline, the cm-level precision coordinates can be obtained. Figure 2 presents the principle of VRS positioning.

Furthermore, the government in Taiwan issued the coordinate system has been through ten years and some of the issued values have been moved. Although the RTK-GPS obtains the real coordinates, they are not suitable for cadastral survey and engineering. Some problems of coordinate transformation occur in these applications. This research uses coordinate transformation with 4, 6, and 7 parameter in comparison with the difference between before and after transformation, and evaluates their advantages and disadvantages to improve the precision of VRS positioning.

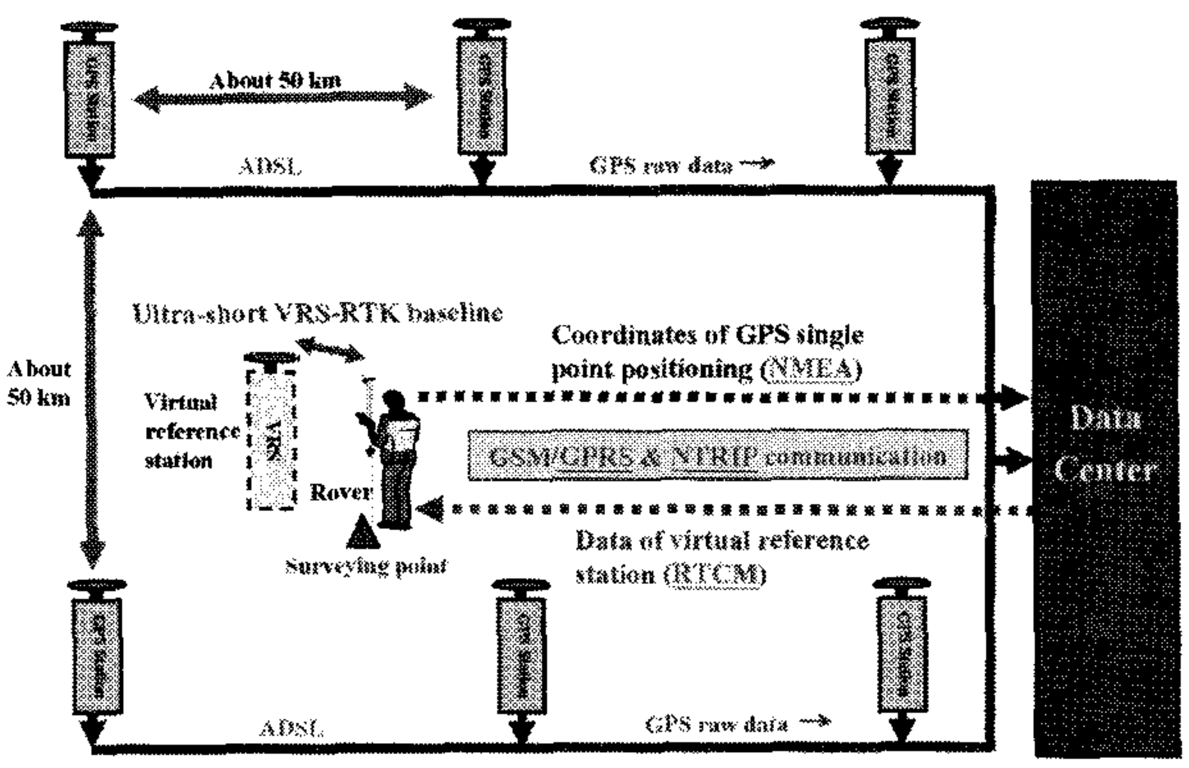

Figure 2. The principle of VRS positioning

3. THE PRECISION CERTIFICATION OF VRS POSITIONING IN TAIWAN

When it comes to the precision certification, 20 satellite control points and leveling points were randomly chosen in North Taiwan to survey the VRS positioning during August, 2006. After finishing the calculation of ambiguity, it started the initialization immediately and calculated the new ambiguity. Fifteen measurements tested repeatedly at the same point and location coordinates ware saved. In order to avoid the error from the instrument, Leica ATX1230 and Trimble 5800 were used at the same time to measure the coordinates. The software that control center used was Trimble GPSNet version 2.5. The data analysis was to obtain the average and standard deviation of fifteen coordinates from each point measured by two machines. Then, in comparison with the TWD97 coordinate and the differences are obtained. When the average error and standard deviation are calculated, absolute value must be obtained in priority and to avoid the reduction of the positive and negative values.

When it comes to the performance of average standard deviation on two types of instruments, the horizontal direction of Leica is about 0.5 cm, Trimble is about 0.8cm. The height direction of Leica is around 1.6 cm and Trimble is around 1.8 cm. The performance of these machines is quite similar. Figure 3 shows the standard deviation of positioning coordinates using Leica and Trimble. The performance of Leica averagely is better than that of Trimble. However, under some certain special circumstances, such as the less number of satellites, Leica is easier to produce some larger errors.

This part should result from the different method of ambiguity calculation by each factory.

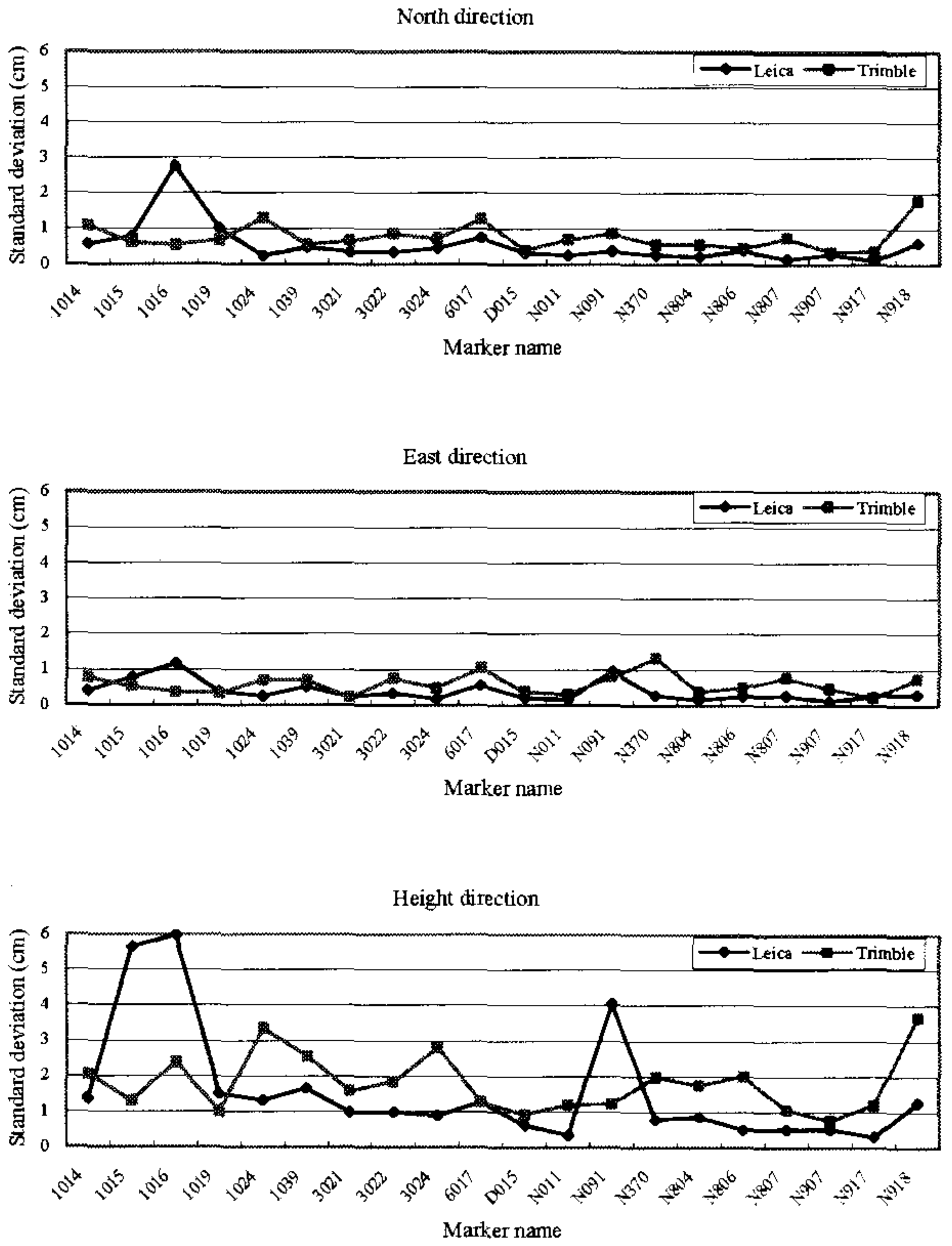

Figure 3. The standard deviation of positioning coordinates using Leica and Trimble

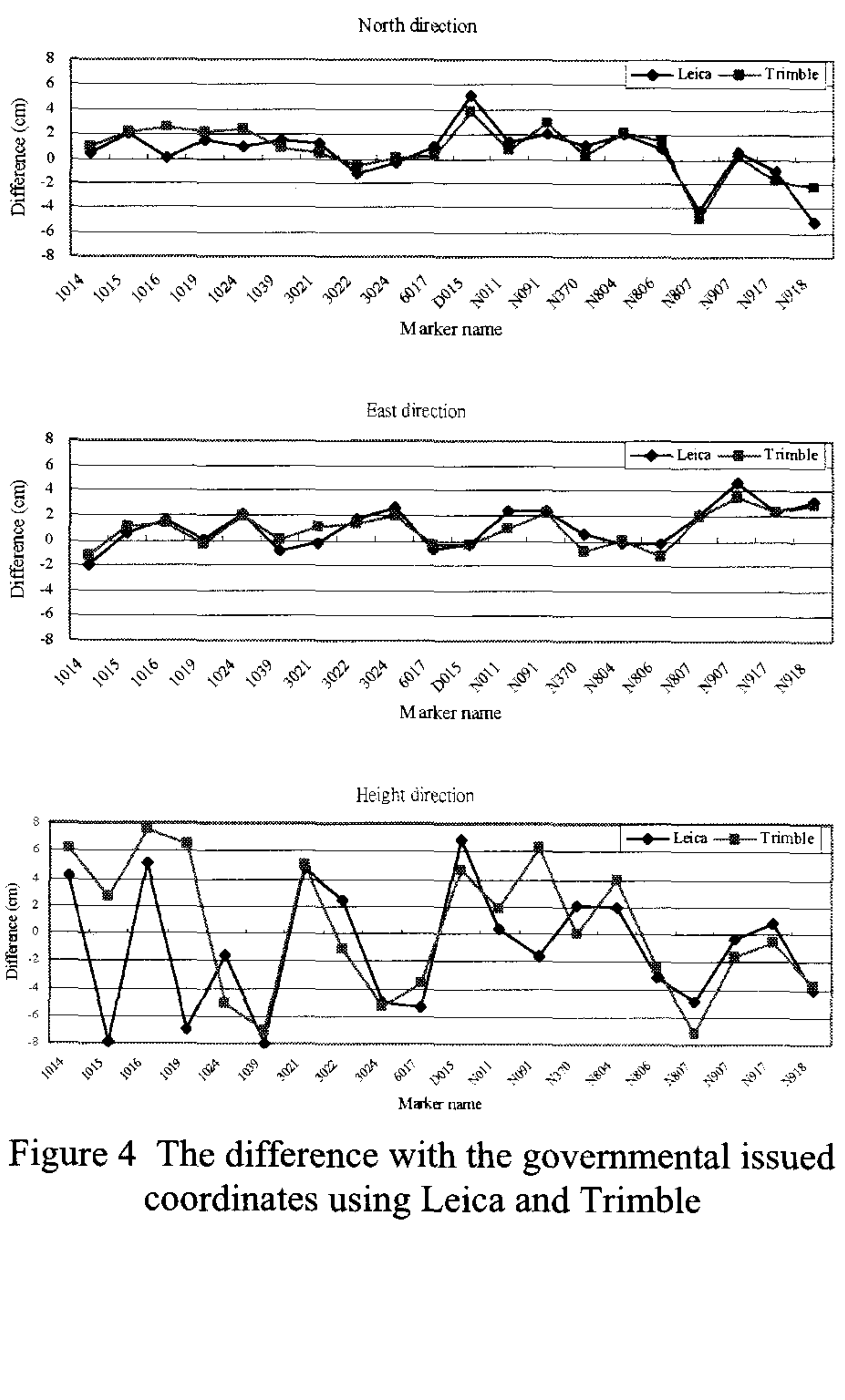

Figure 4 The difference with the governmental issued coordinates using Leica and Trimble

When it comes to the average difference of these two types of instruments, the horizontal direction of Leica is about 1.7 cm and Trimble is about 1.6 cm. The height direction of Leica is around 3.9 cm and Trimble is around 4.1 cm. Two machines have similar performance. Figure 4 presents the difference with the governmental issued coordinates using Leica and Trimble. The N and E direction of these two machines are generally the same. Certain similar difference exists between that one and the TWD97 coordinate. It is supposed to result from the influence of plate movement and the coordinates of satellite control points moved. On the horizontal direction, 1-2 cm movement has appeared. As for the height coordinates measured by two machines are generally relevant. Larger errors in height direction occur on the measuring results on the leveling points. It might result from the worse sky view to make the insufficiency satellite number of VRS positioning.

4. ENHANCING THE PRECISION OF VRS POSITIONING USING THE COORDINATE TRANSFORMATION

In terms of coordinate transformation, the data measured by Trimble in Chapter 3 were adapted to test. The procedure of coordinate transformation with 7 parameters is that the measured values before and after coordinate transformation minus the TWD97 coordinate, respectively, to obtain the differences. When it comes to calculate the average error, maximum error and standard deviation, those above-mentioned differences should get the absolute value and then to calculate in order to avoid the reduction of the positive and negative values. Table 1 shows the differences before and after coordinate transformation with 7 parameters in North Taiwan. After the correction of 7 parameters transformation, in the average difference, north direction slightly upgrades from 1.6 cm to 1.2 cm with the improvement of 25%. East direction slightly upgrades from 1.3 cm to 1.0 cm with the improvement of 23% and height direction slightly upgrades from 4.1 cm to 2.3 cm with the improvement of 44%.

Table 1. The differences before and after coordinate transformation with 7 parameters in North Taiwan

	Difference before coordinate transformation			Difference after coordinate transformation with 7 parameters		
Direction	North	East	Height	North	East	Height
Average error (cm)	1.6	1.3	4.1	1.2	1.0	2.3
Maximum error (cm)	4.9	3.5	7.5	3.7	2.9	5.3
Standard deviation (cm)	1.3	1.0	2.3	0.9	0.8	1.7

Then, the same data is used to execute the coordinate transformation with 4 parameters and 6 parameters, respectively. Table 2 and 3 present the differences before and after coordinate transformation with 4 parameters and 6 parameters in North Taiwan. In table 2, 4 parameters and 7 parameters are generally the same. Only

4 parameters can deal with 2-dimensional horizontal coordinate but can not deal with the height coordinate transformation. In table 3, after the correction of 6 parameters transformation, in the average difference, north direction upgrades from 1.6 cm to 1.0 cm with the improvement of 38%. East direction upgrades from 1.3 cm to 0.9 cm with the improvement of 31%.

Table 2. The differences before and after coordinate transformation with 4 parameters in North Taiwan

	Difference before coordinate transformation		Difference after coordinate transformation with 4 parameters	
Direction	North	East	North	East
Average error (cm)	1.6	1.3	1.2	1.0
Maximum error (cm)	4.9	3.5	3.7	2.9
Standard deviation (cm)	1.3	1.0	0.9	0.8

Table 3. The differences before and after coordinate transformation with 6 parameters in North Taiwan

	Difference before coordinate transformation		Difference after coordinate transformation with 6 parameters	
Direction	North	East	North	East
Average error (cm)	1.6	1.3	1.0	0.9
Maximum error (cm)	4.9	3.5	2.7	2.8
Standard deviation (cm)	1.3	1.0	0.7	0.8

To sum up, when VRS positioning is executed in north Taiwan, if 4 parameters and 6 parameters transformation are used, they can only improve the precision of horizontal coordinates. 7 parameters transformation can upgrade the accuracy of 3-dimensional coordinate. Horizontal direction can improve 23-25% while height direction can improve 44%. If the precision of horizontal coordinate is the only thing to be considered, the best choice is to use 6 parameters transformation with the improvement of 31-38%.

5. CONCLUSIONS

In Taiwan, after the proper parameter transformation, the coordinate measured by RTK positioning does not restrict in the change of reference frame. In the area of transformation, mean and high accurate coordinates can be obtained. The average errors in 3-dimensional directions are within 2.5 cm.

As for the result of precision certification, in the average standard deviation of interior precision, the horizontal direction of Leica is about 0.5 cm, and Trimble is about 0.8 cm while the height direction of Leica is around 1.6 cm and Trimble is around 1.8 cm. As for the average difference of exterior precision, the horizontal direction of Leica is about 1.7 cm and Trimble is about 1.6 cm while the height direction of Leica is around 3.9 cm and Trimble is around 4.1 cm. Two kinds of instructions have similar performances. As for the machine manual, Leica is more convenient. During the test, more difficult to calculate the ambiguity from 12:00 to 14:00. At this time, less number of GPS satellites was received.

As for the result of coordinate transformation, when VRS positioning is executed in North Taiwan, 7 parameters transformation can improve the accuracy of 3-dimensional coordinate. Horizontal direction improves 23-25% while height direction improves 44%. However, if the accuracy of horizontal coordinate is the only concern, using 6 parameters transformation will be the best choice with the improvement of 31-38%. In more active plant movement area, such as East Taiwan, using 7 parameters transformation can improve 81-93% of the horizontal precision and 33% of the height precision. Using 6 parameters transformation can improve 89-95% of horizontal precision.

Further researches in future can focus on the evaluation on the changing amount of all the control points in the whole island, continue to modify the coordinate transformation model and design the most appropriate model in Taiwan. Furthermore, the ionospheric delay data storage by control center can also be used to evaluate the change of ionosphere nearby Taiwan, and to apply to the ambiguity calculation in order to improve the success rate and positioning precision of RTK-GPS surveying.

6. REFERENCES

Awange, J. L., E. W. Grafarend, 2003. Explicit solution of the overdetermined three-dimensional resection problem, Journal of Geodesy, 76, 605-616.

Chen, C. S., T. K. Yeh, 2002. Enhancing precision of global positioning system using short-range distance baseline field, Journal of Surveying Engineering-ASCE, 128(1), 21-38.

Landau, H., U. Vollath, X. Chen, 2002. Virtual reference station systems, Journal of Global Positioning Systems, 1(2), 137-143.

Reit, B. G., 1998. The 7-parameter transformation to horizontal geodetic datum, Survey Review, 34, 400-412.

Seeber, G., 2000. Real-time satellite positioning on the centimeter level in the 21st century using permanent reference stations, Proceedings of the ION GPS2000, Salt Lake City, Utah.

Sejas, M. I., C. P. Krueger, B. Heck, 2007. Post-processing of GPS data with one minute of observations using virtual reference stations, IUGG XXIV General Assembly, July 2 ~ July 13, Perugia, Italy.

Vollath, U., A. Decking, H. Landau, C. Pagels, 2001. Long-range RTK positioning using virtual reference stations, Proceedings of the International Symposium on Kinematic System in Geodesy, Geomatics and Navigation, Banff, Canada.

Yeh, T. K., C. S. Wang, C. W. Lee, Y. A. Liou, 2006. Construction and uncertainty evaluation of a calibration system for GPS receivers, Metrologia, 43(5), 451-460.