# ANALYSIS ON LANDSLIDE MONITORING USING E-GPS SYSTEM AND MULTI-ANTENNA GPS TECHNOLOGY

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**KEY WORDS:** **e**-GPS; multi-antenna GPS; landslide; Taiwan

**ABSTRACT:**

Based on GPS technology, this study monitored the movement of the landslide that impacted Taiwan’s Formosa Freeway. Two monitoring systems and two data-processing software programs were employed. Auxiliary data were obtained from the GPS, rain gauges, inclinometers, and water table meters for landslide analysis. The goal of multi-sensor monitoring was to construct an automatic early warning system for driver safety. Analytical results indicate that the landslide moved on average 1 cm/month in the southeast direction; that is, it moved slowly toward the Formosa Freeway, thereby posing a potential safety hazard for drivers. The positioning precision of the multi-antenna GPS (0.18, 0.25, and 0.57 cm in the north, east and vertical directions, respectively) was better than that of static relative positioning (0.29, 0.44 and 1.01 cm) and that of e-GPS technology (1.69, 1.35 and 2.45 cm).

## 1. PREFACE

In Taiwan, landslides on mountains are widespread and over-exploitation has increased the frequency of natural disasters such as landslides, rockslides, and debris flows. For instance, a large landslide occurred on the Kuanhsi section of the Formosa Freeway in the summer of 2004. This landslide ruptured the concrete slope protection, and compressed and deformed the drainage system. At the same time, a large soil and rock landslide damaged the road surface. Although no casualties occurred, it was a serious threat to driver safety.

Although some engineering reinforcement techniques, such as concrete piles, the anchor construction method, and drainage ditches, were applied to prevent further damage, the movement of the landslide warrants attention. This study adopted the landslide area as its study area and used a multi-antenna GPS system to automatically monitor landslide movement in real time under all weather conditions. Other measuring equipment, such as a ground-based LIDAR, rain gauges, inclinometers, and water table meters, assisted in the analysis of GPS data. This study also used the e-GPS system (virtual reference station) to measure landslide displacement regularly. The multi-antenna GPS and e-GPS systems were compared to determine the benefits and drawbacks of different GPS techniques and determine the feasibility using GPS for landslide monitoring.

## 2. E-GPS SYSTEM OF TAIWAN

Traditional real-time kinematic (RTK) GPS positioning adopts single reference stations, and was often adversely affected by systematic errors such as ionospheric and tropospheric delay. As a result the rover station must be located within ~10 km of the reference station to achieve centimeter-level accuracy. Medium-range (~50 km) RTK GPS positioning has been proven to be feasible for highly precise applications. Upon the availability of fast and stable Internet access and the mature virtual reference station (VRS) technique, the network-based RTK-GPS has become an important tool of survey engineering. Take the National Land Surveying and Mapping Center, Ministry of the Interior of Taiwan, which started setting up real-time GPS reference stations in 2004. With the distance between reference stations in the GPS tracking network not exceeding 50 km, 86 reference stations were implemented on Taiwan Island and the offshore islands of Penghu, Kinmen, Matzu, Lanyu and Green Island by the end of 2006. Figure 1 shows the distribution of these RTK-GPS stations.

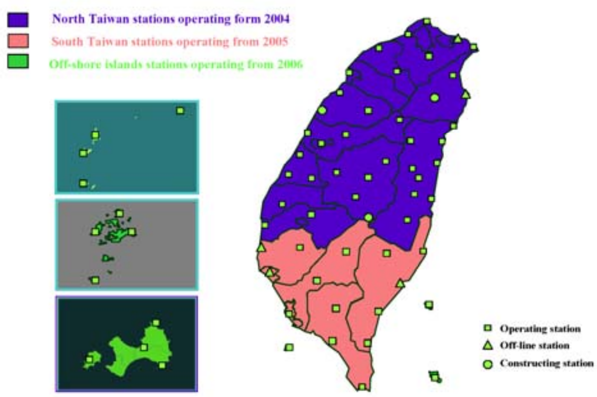


Figure 1. The distribution of the RTK-GPS network in Taiwan

The Trimble GPSNet algorithm version 2.5 with VRS technique was utilized in Taiwan previously for real-time data processing. The horizontal precision of the network-based RTK-GPS is

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about 2 cm, the vertical precision is around 5 cm. Given such positioning precision this technique has been found useful in wide applications (Yeh *et al.*, 2006). However, for applications where longer baseline distances are desirable, the time required for resolving the integer ambiguities increases. In some cases, determining the integer ambiguities become difficult, especially in the afternoon because systematic errors, such as the ionospheric effect, cannot be eliminated effectively using double-difference technique (Karunanayake *et al.*, 2007).

In terms of positioning method, VRS and the Area Correction Parameters (ACP) can improve RTK efficiency when baseline distance exceeds 10 km. ACP generates different corrected parameters for different areas and thus improves positioning precision of the rover stations. However, a rover station must be located between three reference stations such that the control center can identify the corrected parameter for the rover station via interpolation. The advantage of ACP is that only a connection with one of the three reference stations is required. The corrected parameters can be obtained by the rover station without connecting to the control center (Landau *et al.*, 2007). In Germany, the two methods of VRS and ACP have been widely utilized where real-time positioning efficiency of cm-level precision could be attained even when baseline distance is as long as 30–50 km (Seeber, 2000).

Via wireless radio communication, the global system for mobile (GSM) communications can also transmit VRS or ACPs data to users, allowing users to achieve real-time cm-level positioning precision. The advantages of using GSM communications are increased distance and reliability of data communication, and decreased initialization time (Vollath *et al.*, 2001). Furthermore, the effective distance between a reference station and rover station for conventional RTK positioning (single reference station) is limited to less than 10 km. In some countries GPS reference station networks exist, and provide data to individual users. For RTK, due to the need for short distances between reference and rover, the networks need to be very dense. However, it is difficult to setup a lot of GPS reference stations because the budget is limited. After using the VRS technology, the distance between each reference station can be about 50 km. Therefore, reference stations with VRS can provide the RTK service to all areas and obtain highly precise positioning in real-time (Sejas et al., 2007; Yeh et al., 2009).

The principle of the VRS positioning is to collect and calculate regional error parameters from real-time data received by many GPS tracking stations with the Internet connection. These are used to create a Virtual Reference Station, situated only a few meters from where any rover is situated, together with the raw data, which would have come from it. The rover interprets and uses the data just as if it has come from real reference station. The resulting performance improvement of RTK is dramatic (Landau *et al.*, 2002). To produce VRS data for each rover station, an RTK user only needs to set up one GPS receiver on the rover station and transmit approximate coordinates in the NMEA (National Marine Electronics Association) format via GSM/GPRS to the control center. After the control center combines VRS data, these data are transmitted in the RTCM (Radio Technical Commission for Maritime) format back to the rover station. After calculating RTK positioning with a typically very short baseline distance, the cm-level precision coordinates can be obtained. Figure 2 presents the principle of VRS positioning.

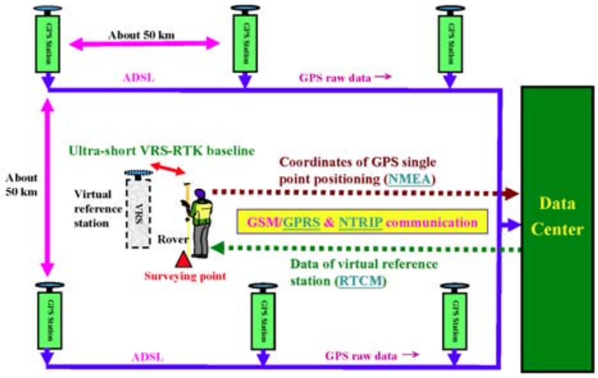



Figure 2. The principle of VRS positioning

The procedure of VRS positioning is.

(1) Pre-processing tracking network observations: Establishing the tracking network database and completing coordinate adjustments for each reference station.
(2) Calculating the data of regional stations: Collecting and calculating continuous observations from each GPS reference station, obtaining accurate coordinates and establishing the ACP database.
(3) Generating VRS data for the rover station: Rover station reports approximate coordinates in the NMEA format to the control center via wireless communication. The control center then calculates systematic error around the rover station and combines GPS observations with nearby reference stations to produce VRS data. Finally, the control center transmits VRS data in the RTCM format back to the rover station.
(4) Coordinate calculation of the rover station: After receiving VRS data, the rover station starts processing the very short baseline length using RTK positioning.

## 3. DATA COLLECT AND ANALYSIS

Eight multi-antenna GPS (labelled P1–P8) were installed in the study area. The monitoring points and GPS antennas were uniformly distributed to monitor landslide movement. Furthermore, this study assessed the efficiency and functionality of the antennas and monitoring points under various topographical restrictions. Other automatic monitoring equipment assisted in GPS data analysis.

Figure 3. Experimental area and multi-antenna GPS system

Figure 4 and 5 show the average coordinates and standard deviation in the northern (N), eastern (E), and vertical (h) directions at point P3 and P6, respectively. The slope of the trend in the N direction was −0.0008 and displacement per month was −0.56 cm. Experimental results show that the landslide is moving southward, toward the Formosa Freeway. Conversely, the E direction has a positive trend slope. In this case, the slope value at P3 was 0.0003 and its monthly displacement was 0.21 cm. This analytical result shows that the landslide is sliding eastward, toward a low-lying area. In the h direction, the slope value was 0.004 and its monthly displacement was 2.8 cm. According to experimental data, the study area may be receiving pressure from the area at its top, causing the study area to rise in height.

The data collected by the multi-antenna GPS system were processed using MAGMS software version 2.32 and TGO software version 1.5. Table 1 shows the standard deviations measured by different methods, including the e-GPS and multi-antenna GPS systems; the data were processed by MAGMS and TGO. The precision of the multi-antenna GPS processed by MAGMS was best among three measurement methods. Conversely, the e-GPS system had poor precision.

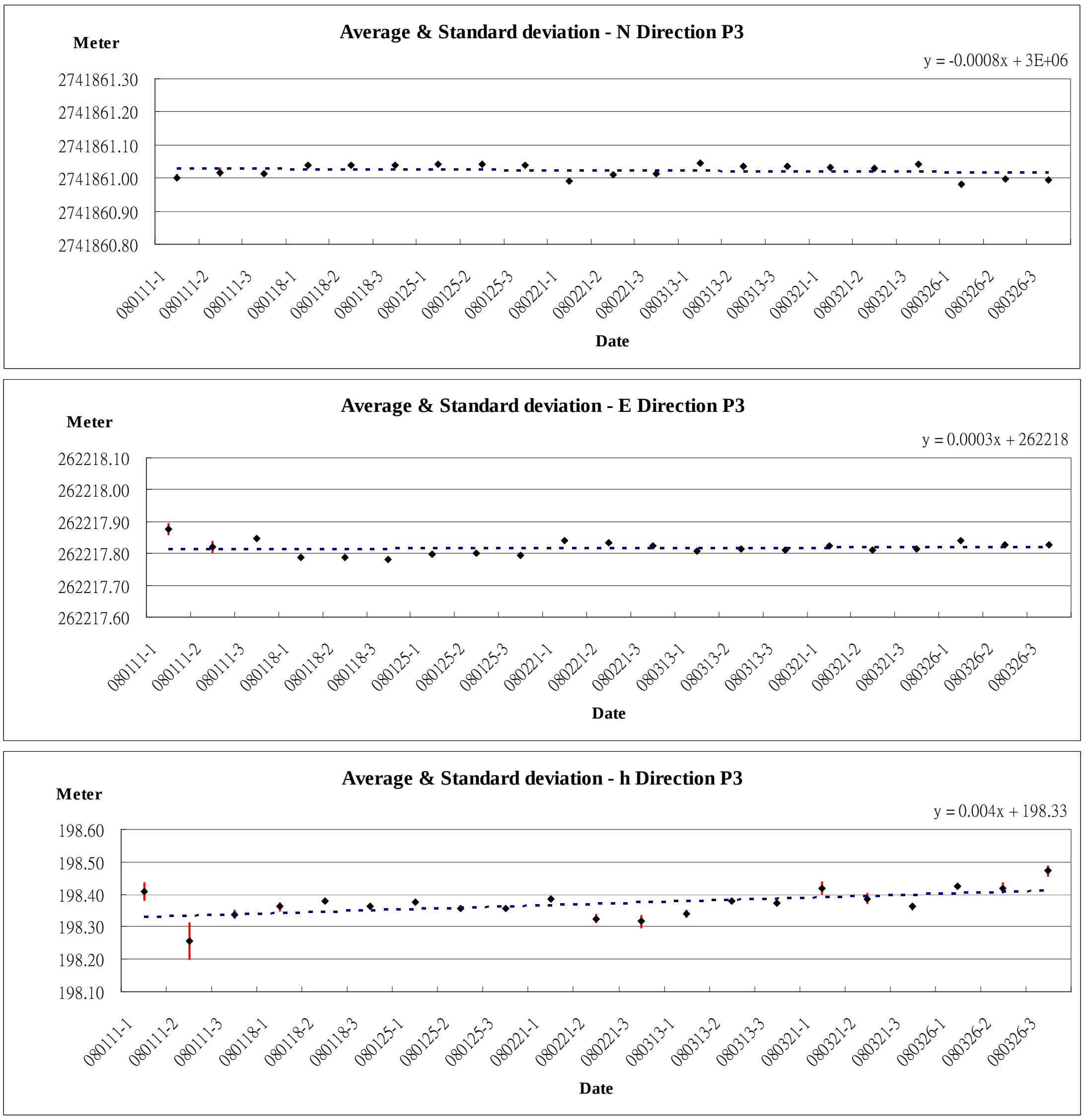



Figure 4. Trends and standard deviations in the northern, eastern and vertical directions

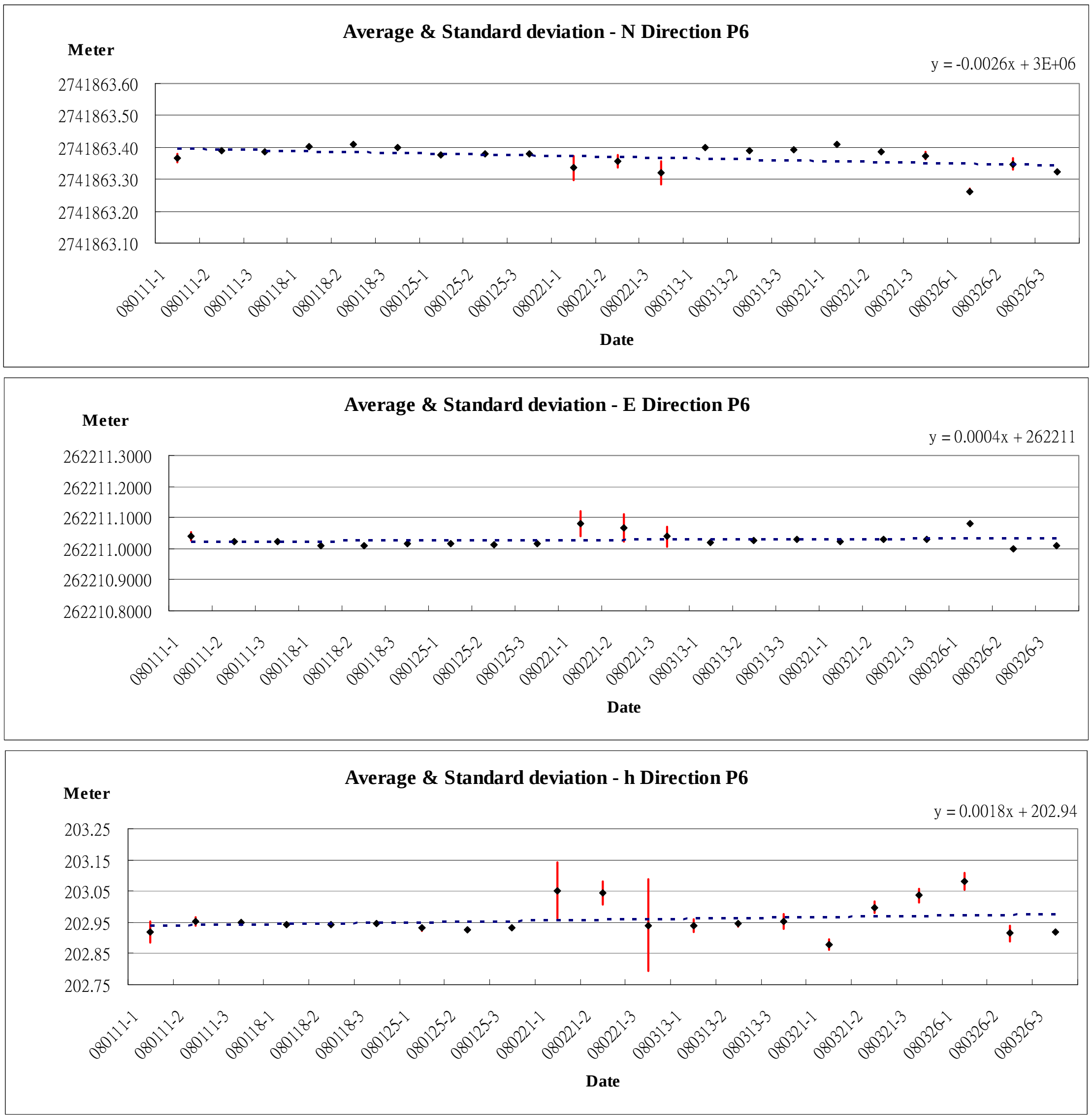



Figure 5. Trends and standard deviations in the northern, eastern and vertical directions

Table 1. Standard deviation in centimeter obtained by e-GPS and multi-antenna GPS

| | e-GPS | | | TGO | | | MaGMS | | |
|---|---|---|---|---|---|---|---|---|---|
| Point | N | E | h | N | E | h | N | E | h |
| P2 | 2.03 | 1.17 | 3.32 | 0.10 | 0.15 | 0.13 | 0.05 | 0.14 | 0.30 |
| P3 | 2.05 | 1.91 | 2.12 | 0.36 | 0.29 | 0.75 | 0.28 | 0.27 | 0.87 |
| P5 | 0.99 | 1.44 | 2.35 | 0.20 | 0.50 | 1.13 | 0.19 | 0.38 | 0.45 |
| P6 | 1.69 | 0.86 | 2.02 | 0.16 | 0.06 | 0.69 | 0.19 | 0.16 | 0.34 |
| P7 | N/A | N/A | N/A | 0.64 | 1.20 | 2.34 | 0.22 | 0.27 | 0.87 |
| Average | 1.69 | 1.35 | 2.45 | 0.29 | 0.44 | 1.01 | 0.18 | 0.25 | 0.57 |

The data collecting from the multi-antenna GPS systems are processed by MAGMS v2.32, a multi-antenna GPS system Software, and TGO v1.5 software. We used the label “gm01” for No.1 GPS antenna, gm02 for No.2 GPS antenna and so on. Due to the limited space, only the gm03 point results are shown in this paper. Figure 6 and Figure 7 show the coordinates of gm03 and its standard deviations obtained from TGOv1.5 and MaGMS v2.32, respectively. The difference of the two calculated coordinates is the order of cm. It is believed that the different results are caused by different algorithms of the two GPS processing software. While a slight difference occurs, the two calculated coordinates show the same fluctuation trend in the N, E, h directions. This shows that two GPS processing programs can obtain the same trend.

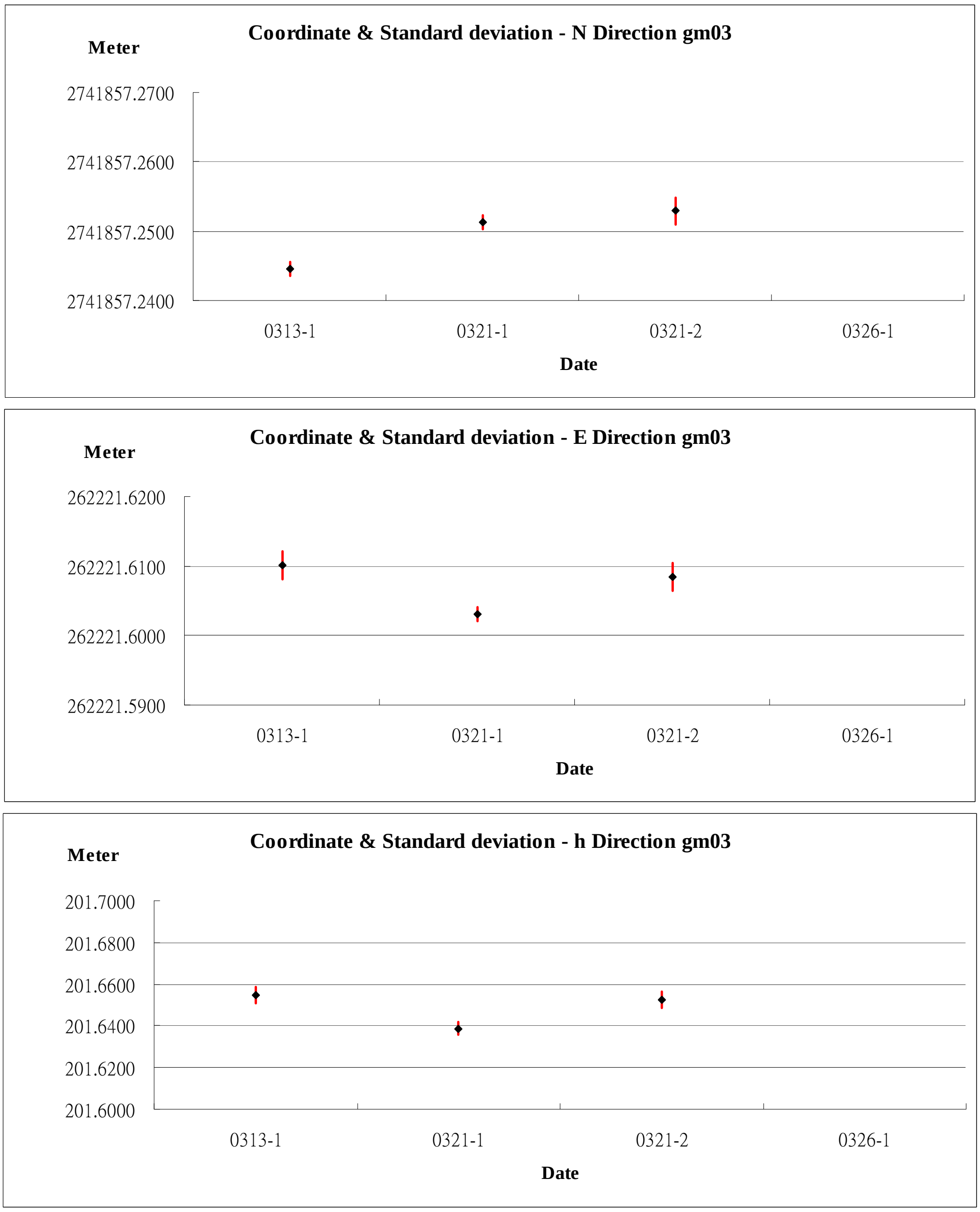
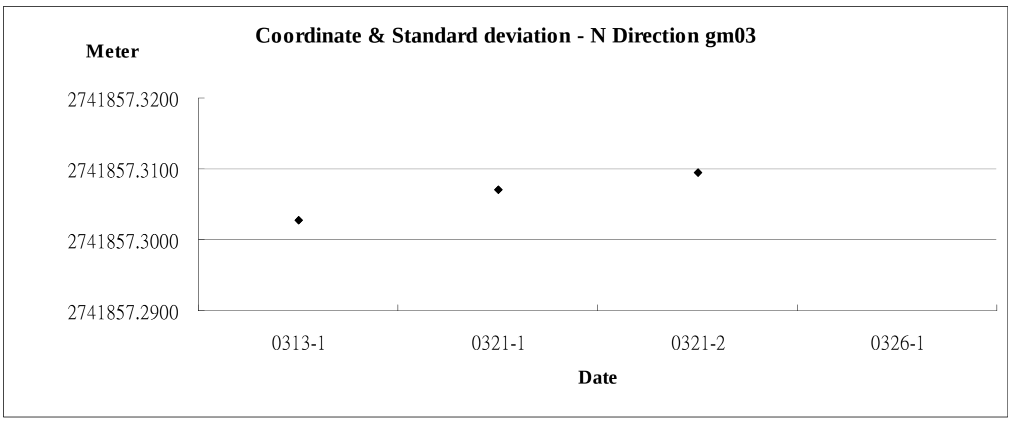



Figure 6. Results calculated by TGO software



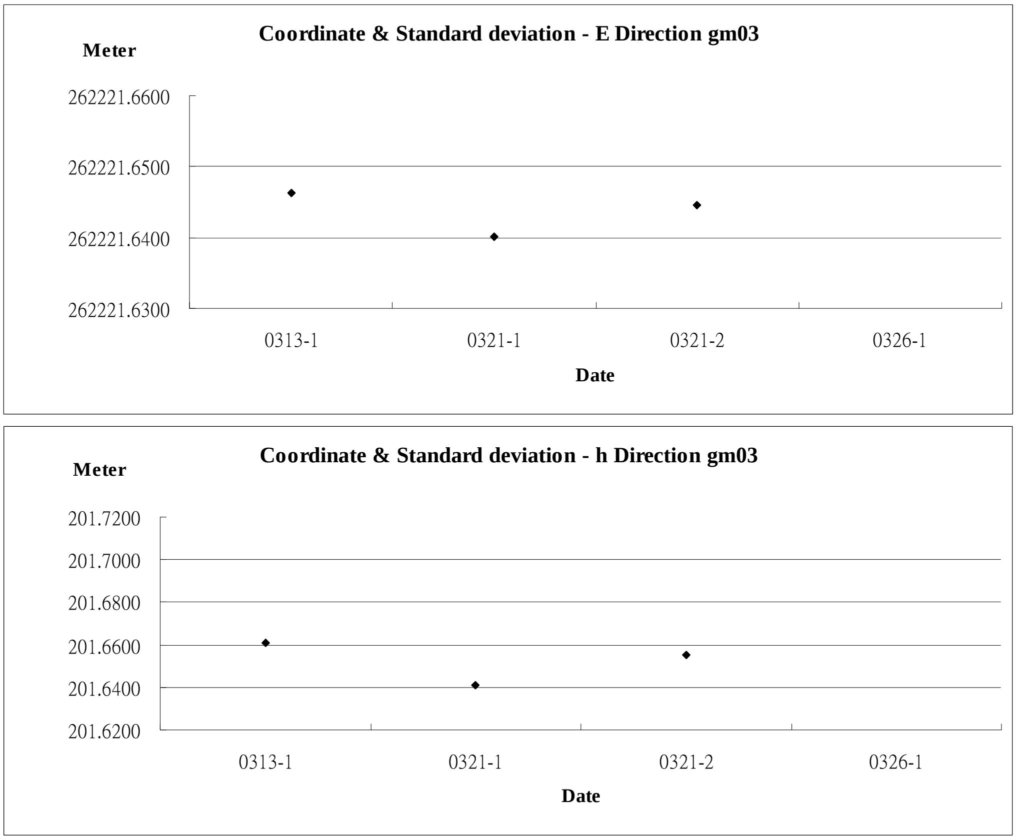



Figure 7. Results calculated by MaGMS software

## 4. CONCLUSIONS

Experimental results indicate that the landslide is moving in a south-eastern direction. The monthly rate of movement was about 1 cm, directly toward the Formosa Freeway. The threat of this landslide hitting the Formosa Freeway must be monitored continuously. Although the e-GPS technology was faster and more economical than the traditional GPS system, it is only suitable for monitoring large movements.

## 5. ACKNOWLEDGMENTS

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## 6. REFERENCES

Ding, X. L., W. J. Dai, W. T. Yang, X. W. Zhou, J. Lam, Q. Zhang, L. Wang, 2007. Application of multi-antenna GPS technology in monitoring stability of slopes, Strategic Integration of Surveying Services, FIG Working Week 2007.

Karunanayake, M. D., M. E. Cannon, G. Lachapelle, 2007. Analysis of assistance data on AGPS performance, *Measurement Science and Technology*, 18(7), pp. 1908-1916.

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

Landau, H., Chen, X., Kipka, A., Vollath, U., 2007. Network RTK: Getting ready for GNSS modernization, *GPS World*, 18(4), pp. 50-55.

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, *Proceedings of the IUGG XXIV General Assembly*, 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), pp. 451-460.

Yeh, T. K., Y. S. Hu, X. L. Ding, C. S. Chen, 2007. Landslide monitoring using multi-antenna GPS deformation monitoring system, AGU Fall Meeting, December 10 ~ December 14, San Francisco, California, USA, G13B-1239.

Yeh, T. K., C. Hwang, G. Xu, C. S. Wang, C. C. Lee, 2009. Determination of global positioning system (GPS) receiver clock errors: impact on positioning accuracy, *Measurement Science and Technology*, 20, 075105, 10.1088/0957-0233/20/7/075105.