



GPS DEFORMATION MONITORING AND ANALYSIS FOR LOCAL CORS NETWORK: ISKANDARNET

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ABSTRACT

Monitoring of deformation in urban areas is of great importance, providing useful information to assess seismic hazards and risks. Thus, this study concerns the feasibility using Continuously Operating Reference Stations (CORS) in Iskandar metro-area (termed ISKANDARnet) for deformation monitoring and analysis. A strategy is developed that using three GPS CORS from ISKANDARnet as the object monitoring stations along with nearby International GNSS Services (IGS) stations (e.g. NTUS, XMIS, COCO and PIMO) as the reference monitoring stations. GPS data is streamed and processed by the high precision scientific GPS data processing software module, called Bernese Processing Engine (BPE) in persistent processing strategic. A software package in Matrix Laboratory (MATLAB) language has been developed to conduct a continuous two-epoch analysis by implementing the Iteratively Weighted Similarity Transformation (IWST) method and Similarity Transformation (S-Transformation) to analyse the GPS results in the deformation perspective. With the performance of IWST and S-Transformation, the unstable point able to be identified within the monitoring network as well as compute the deformation displacement vectors. The fluctuation of deformation displacement is visualised on-screen proportional to the associated time series results. Several preliminary works and analysis are stated in this paper. This study will bring the invaluable contribution to the current studies of deformation analysis in Malaysia.

Key words: Deformation monitoring, IWST, ISKANDARnet

1.0 INTRODUCTION

Deformation monitoring is no longer a singularly issue in GPS surveying aspect (Kutoglu, 2010; Kaloop and Li, 2009; Rutledge et al., 2001; Chen et al., 2000). Many experts around the world are trying to detect the natural disasters event in advance by using GPS technique in order to mitigate the collateral damage. In Malaysia, a new rise of GPS CORS network termed ISKANDARnet with its high-precision observation data provides a technically-advanced and cost-effective geoscientific infrastructure for deformation monitoring analysis. Methodologies for GPS data processing and deformation analysis are investigated. The absolute displacement of ISKANDARnet stations are calculated using chronological GPS data, Bernese scientific data-processing engine and in-house deformation analysis software – ConDAS (Lim et al., 2010). The feasibility and effectiveness of the methodologies put forward are discussed and some useful conclusions are given.

2.0 ISKANDARnet

Presently, several regional networks are operational around the world in such locations as in the Australia: states of Victoria (GPSnet), New South Wales (CORsnet) and Queensland (SunPOZ), in the other countries: Germany (SAPOS), Denmark (REFDK), Hong Kong (SatRef), Japan (GEONET), Singapore (SiReNT), and MyRTKnet in Malaysia. Nevertheless, there are only a few systems developed by universities and receiver manufacturers (e.g. Rizos et al., 2003). Hence, the GNSS and Geodynamics (G&G) Research Group, Faculty of Geoinformation Science and Engineering, Universiti Teknologi Malaysia (UTM) has initiated to develop a research-based GPS reference station network infrastructure. The infrastructure so-called Iskandar Malaysia CORS network (ISKANDARnet) has been established in collaboration with Satellite Navigation & Positioning (SNAP) Laboratory of the University of New South Wales, Australia. Figure 1 below shows the network geometry of ISKANDARnet.



Figure 1: Network geometry of ISKANDARnet

The three CORS stations have been established in Iskandar Malaysia namely, ISKANDARnet1 (ISK1) at Universiti Teknologi Malaysia (UTM); ISKANDARnet2 (ISK2) at Port of Tanjung Pelepas (PTP); and ISKANDARnet3 (ISK3) at Community College of Pasir Gudang, with inter-station distance about 24km and up to 43km located at southern part of Malaysia (Shariff et al., 2009) as shown in **Figure 1**. The length of inter-station has been designed to keep the distance between station is long enough in order to assist network ambiguity resolution. ISKANDARnet uses consistent receivers that are Trimble 4700 dual-frequency receivers. The receivers use micro-centered L_1/L_2 antennas with ground-planes TRM33429.00+GP (Iskandarnet, 2010). All antennas are permanently mounted to provide an uninterrupted view of the surrounding sky. GPS antennas are sited on rooftops of buildings and at other stable locations free of multipath. Apart from geodetic applications, the ISKANDARnet is widely used since its inception. It is a regional infrastructure established in the metro-area of Iskandar Malaysia to support various positioning applications using GPS.

3.0 METHOD OF DEFORMATION ANALYSIS

ISKANDARnet is a new GPS CORS station that has been established since 2009. It is capable to provide reliable and high-precision GPS data. **Figure 2** outlines a detailed process of deformation analysis using ISKANDARnet measurements with four International GNSS Service (IGS) stations. The estimation of each epoch employs Bernese GPS software, followed by

deformation analysis using in-house software. Major steps for data processing, deformation analysis and some vital contributing factors are illustrated.

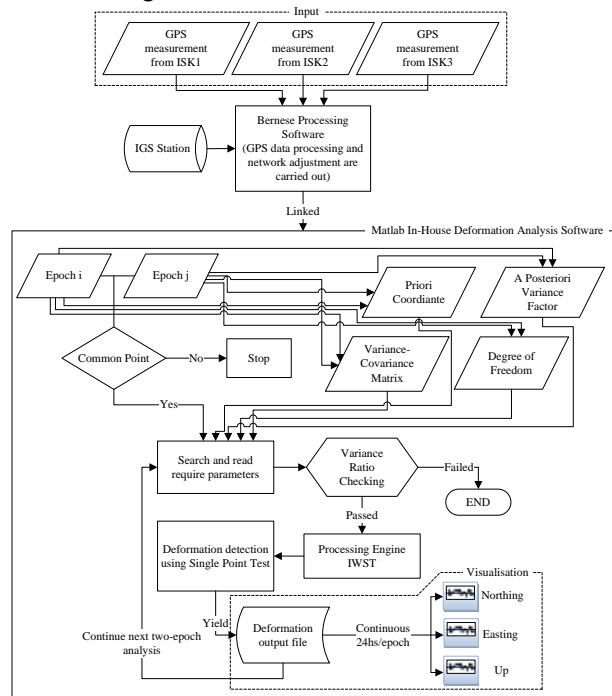


Figure 2: Flow chart of ISKANDARnet data processing and stability analysis

3.1 Stations Selection of Deformation Analysis

The ISKANDARnet consist of three CORS stations currently and there are selected as object monitoring stations respectively. To obtain the absolute displacement from deformation analysis, it is desirable that utilize the stable and precise IGS reference stations close to the ISKANDARnet as stable datum. The selection of IGS stations need to consider the network geometry and orientation of ISKANDARnet so as to fully cover the object points within the baseline of IGS stations. According to the criterion above, the selected IGS reference monitoring stations are: COCO, NTUS, PIMO and XMIS. There are situated respectively at: Keeling Island, Australia; Singapore; Quezon City, Philippines and Christmas Island Indian Ocean, Australia (International GNSS Service, 2010a). Hence, total of 7 stations are used to perform deformation analysis.

3.2 Data Processing Strategy of ISKANDARnet

The selected monitoring stations are obtained via real-time data streaming. These GPS data is streamed continuously by using BKG Ntrip Client (BNC) Version 1.8, a GPS data streaming software developed by Federal Agency for Cartography and Geodesy (BNC, 2009). The data are from ISKANDARnet (ISK1, ISK2, and ISK3 – iskandarnet.fksg.utm.my / 161. 139.104.101), IGS stations (COCO, NTUS, PIMO and XMIS – www.igs-ip.net / 81.3.62.36) that provided real-time data streaming services. These stations are streamed with 24 hours data as one epoch. **Figure 3** illustrates 7 stations of deformation monitoring network.

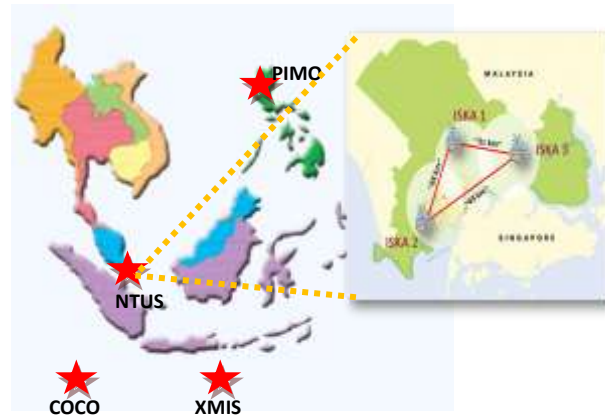


Figure 3: 7 CORS stations of deformation monitoring network

Since the baselines are thousands of kilometers in length, therefore it requires sophisticated data processing software to achieve high accuracy results. In this stage, high capable scientific software – Bernese v. 5.0 is employed for GPS data processing. This software is suitable for scientific studies in surveying fields that require high precision such as first order GPS network. This software can eliminate certain errors and able to rectify any ambiguity in the processing of baselines of high precision which enable to achieve high accuracy GPS results and analysis (Setan and Othman, 2006). There are numbers of GPS deformation monitoring study employed Bernese to process GPS data (Hu et al., 2005; Jia, 2005; Janssen, 2002; Vermeer, 2002). By implementing the Bernese software, data cleaning, cycle slip detection, ambiguity resolution and network adjustment of GPS data all can be achieved to meet the desired criteria. Subsequently, approximate coordinate, estimated coordinate, a posteriori variance factor and variance-covariance matrices can be yield from the GPS data processing step by using Bernese. These parameters are required in order to perform the two-epoch deformation analysis. In other words, these parameters are the inputs of deformation analysis. **Figure 4** shows the main work flow of GPS data processing using Bernese. Table 1 presents the sequence of tasks and its function for GPS data processing using Bernese.

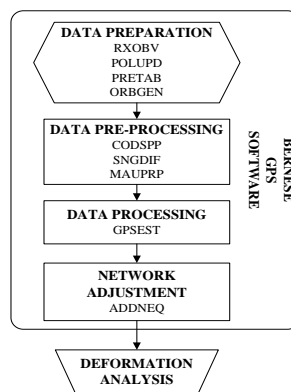


Figure 4: Main work flow of GPS data processing using Bernese

Table 1: The sequence of tasks and its function for GPS data processing

PROGRAM	FUNCTION	STAGE
RXOBV	Import the observations from the RINEX into the Bernese format	Data Preparation
POLUPD	Generate the pole information file in Bernese format	Data Preparation
PRETAB	Generate tabular orbit files from IGS precise files	Data Preparation
ORBGEN	Generate Bernese standard orbit files	Data Preparation
CODSPP	Receiver clock synchronization (correction)	Data Pre-processing
SNGDIF	Baseline generation	Data Pre-processing
MAUPRP	Preprocess Baselines	Data Pre-processing
GPSEST	Create Residual files, store normal equation files, compute ambiguity fixed solution	Data Processing
HELMR1	Fiducial Station Verification, Outlier Rejection	Transformation
ADDNEQ	Final Network Adjustment	Network Adjustment

In fact, there are some specified principles that need to be concerned during data processing:

- i. Use of IGS ultra-rapid orbit that are released four times each day at 0300, 0900, 1500 and 2100 UT (International GNSS Service, 2010b).
- ii. For the pre-processing and processing step 24 hours of 30-second-interval data were employed.
- iii. Minimum elevation angle of 3 degrees is used for continuous monitoring purposes (according to default suggested by BPE Process Control Files [.PFC], RNX2SNX.PCF).
- iv. The (dry and wet) Niell model is applied (recommended for GNSS data analysis with low elevation cutoff angle).
- v. Processing of the double-difference measurements based on the ionosphere-free carrier phase linear combination L3.
- vi. Free solution of each session (normal equations, estimated station coordinates and troposphere parameters are saved).

Once the Bernese software complete the network adjustment step (last step of GPS data processing), it will generate the parameters in separate file or united file such as approximate coordinate, estimated coordinate and a posteriori variance factor are included in the same file (e.g. F1_101630.OUT) and variance-covariance matrix files (e.g. F1_101630.COV). These parameters are extracted and saved into a new notepad file that considered as input file for deformation analysis. Thus, the interconnection between Bernese software and MATLAB software need to be set up. It is apparent that the linkage between software is important in the context of continuous deformation detection.

4.0 IN-HOUSE DEFORMATION ANALYSIS SOFTWARE

In order to carry out the deformation analysis continuously a software prototype named ConDAS was developed using MATLAB. This software is tentatively developed to detect the unstable station in the deformation monitoring network. Some of the details of software are presented as following. **Figure 5** illustrates the block diagram of ConDAS. Future work will be devoted to making the software fully automated.

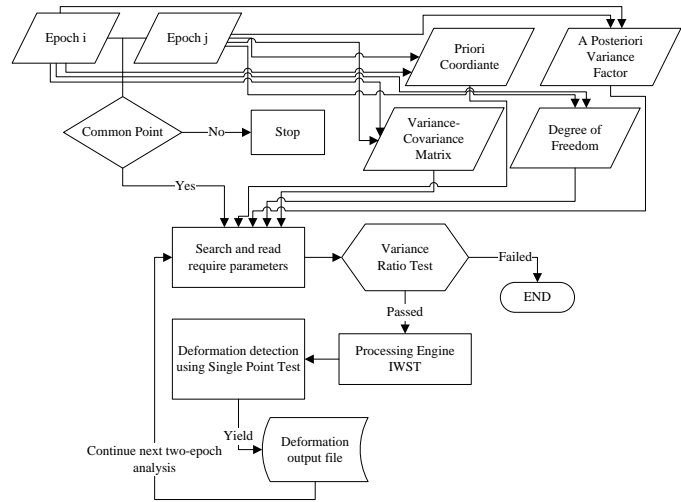


Figure 5: Block diagram of in-house deformation analysis software

4.1 Choice of Parameter

As aforementioned techniques, deformation analysis requires parameters such as provisional coordinate, estimated coordinate and variance covariance matrix. All these parameter will be provided by using GPS processing software – Bernese. ConDAS will search and read this required parameter from Bernese output file and apply them as the input parameters of deformation analysis. **Figure 6** demonstrates the example coding to find and read the required parameters.

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Figure 6: Example coding to find and reading the required parameters

Regarding the **Figure 6**, program is enforced to search the specified parameter according to the string name by using command *findstr*. Repeated command will be applied to search other parameters mentioned above.

4.2 IWST Processing Engine

The core of deformation analysis program is the implementation of IWST algorithm. However, initial checking of data and test on variance ratio are important to ensure that common points, same approximate coordinates and same points names are used in two epochs [15]. Thus, there is a statistic test termed variance ratio test that need to be conducted in order to determine the compatible weighting between two epochs, and any further analysis should be stopped at this stage if test is rejected. The test statistic is referred to as Eq. (1) (Lim et al., 2010; Setan and Singh, 2001).

$$T = \frac{\hat{\sigma}_{oj}^2}{\hat{\sigma}_{oi}^2} \sim F(\alpha, df_j, df_i) \tag{1}$$

with *j* and *i* represent the larger and smaller variance factors, *F* is the Fisher's distribution, α is the chosen significance level (typically $\alpha = 0.05$) and *df_i* and *df_j* are the degrees of freedom for epochs *i* and *j* respectively.

Due to the IWST method requires iteratively changing the weight matrix, *W*, so some of looping command is adopted to form the iterative procedure continues until some certain condition is fulfilled. Some of the MATLAB command such as *for*, *while* are adopted to build up the loop. This is a conditional loop. Program also define the condition for looping stop by using command *if* and *elseif*. After the looping stop, it will proceed to the next calculation without any delay. **Figure 7** illustrated the IWST looping commands.



Figure 7: The looping commands for IWST approach

4.3 Displacement Detection

The ConDAS currently utilises a single point test in detecting displacement that reject any point with its displacement extends beyond the confidence region (Chrzanowski et al., 1994). It is flagged as unstable if a given point fails the test at the specified confidence level. Thus, a *for* loop is established in order to test the stability point by point. At the final stage of program, a summarised deformation output file could be generated. It contains the summary of file used,

statistical summary and station information whether the station is flagged as moved or stable. The output file of deformation analysis is demonstrated in Figure 8



Figure 8: Output file of deformation analysis

At the end of in-house deformation analysis software, there is a command to make the program reiteration constantly. The repeatability of in-house deformation analysis software make the program run in continuously as well as search and read the required parameters for the upcoming two-epoch deformation analysis.

5.0 PRELIMINARY RESULTS

There were seven stations in the deformation monitoring network, four from the IGS stations were used as reference (i.e. COCO, NTUS, PIMO, XMIS) and three stations from local ISKANDARnet (ISK1, ISK2 and ISK3) were used as test points. GPS data processing and two-epoch deformation analysis were performed using two epochs of data (12th and 13th Jun 2010). After the GPS data processing was carried out with Bernese software, two epoch deformation analysis (at 5% significance level) were performed in two stages: i) stability analysis of reference stations using IWST; and ii) deformation analysis of all stations. The stability of reference stations was vital in order to select a set of stable reference stations to conduct the analysis for all stations in the monitoring network. The results of stability analysis in Table 2 confirmed that all four reference stations were stable.

Table 2: Stability analysis of the four reference stations using IWST

Station	Dx [m]	Dy [m]	Dz [m]	Disp.Vect [m]	Test statistic vs critical value	Status
COCO	0.0070	0.0031	-0.0047	0.0090	0.0093 < 2.605535	stable
NTUS	-0.0030	0.0105	0.0000	0.0109	0.0037 < 2.605535	stable
XMIS	0.0076	-0.0077	0.0009	0.0108	0.0124 < 2.605535	stable
PIMO	-0.0116	-0.0059	0.0012	0.0131	0.0043 < 2.605535	stable

Subsequently, deformation analysis of all seven stations was carried out via final S-transformations based on the stable reference points (Table 2). All seven stations were verified as stable (Table 3). Consequently, the results obtained illustrate that the movement experienced by the GPS CORS stations at mm level can be detected. However, there was no significant movement shown as the deformation displacements that exceed the threshold.

Table 3: Stability of all monitoring stations using final S-Transformation based on four stable reference points

Station	Dx [m]	Dy [m]	Dz [m]	Disp.Vect [m]	Test statistic vs critical value	Status
COCO	0.0044	0.0023	-0.0041	0.0065	0.0015 < 2.605209	stable
NTUS	-0.0041	0.0094	0.0011	0.0103	0.005 < 2.605209	stable
XMIS	0.0051	-0.0060	0.0010	0.0080	0.0048 < 2.605209	stable
ISK3	0.0029	-0.0003	0.0009	0.0031	0.0015 < 2.605209	stable
ISK2	-0.0041	0.0039	0.0011	0.0057	0.0024 < 2.605209	stable
ISK1	0.0021	-0.0156	-0.0005	0.0157	0.0067 < 2.605209	stable
PIMO	-0.0055	-0.0057	0.0020	0.0082	0.0022 < 2.605209	stable

Nevertheless the visualisation of ISKANDARnet was carried out by using the computed results. Figure 9 illustrate the trend analysis of ISKANDARnet with two epochs of data (12th and 13th Jun 2010).

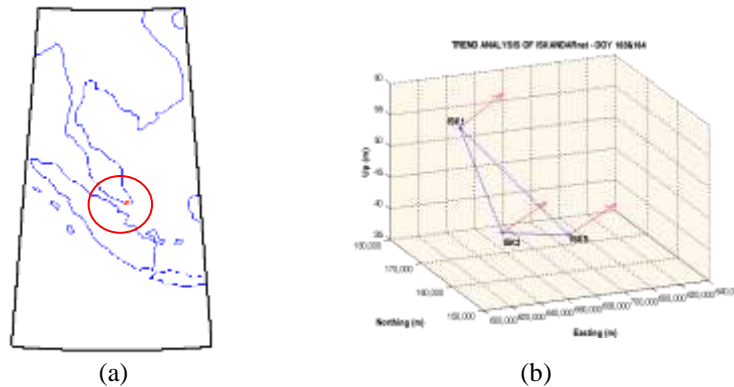


Figure 9: Trend analysis of ISKANDARnet at 12th and 13th Jun 2010.

Figure 9(a) showed the displacement vectors on map. With the intention of distinctly look at the direction of displacement vectors, **Figure 9(b)** was created. There were no significant movements detected and all stations' displacements are under threshold at 12th and 13th Jun 2010.

Next, 30 days of GPS data (1st – 30th Jun 2010) have been processed and analysed continually using the identical aforementioned method. The results of stability analysis show all the stations are stable. The fluctuation of CORS stations: ISK1, ISK2 and ISK3 can be revealed through plotting in Northing, Easting and Up. **Figure 10, 11, 12** shows the variation of ISK1, ISK2 and ISK3 in Northing, Easting and Up.

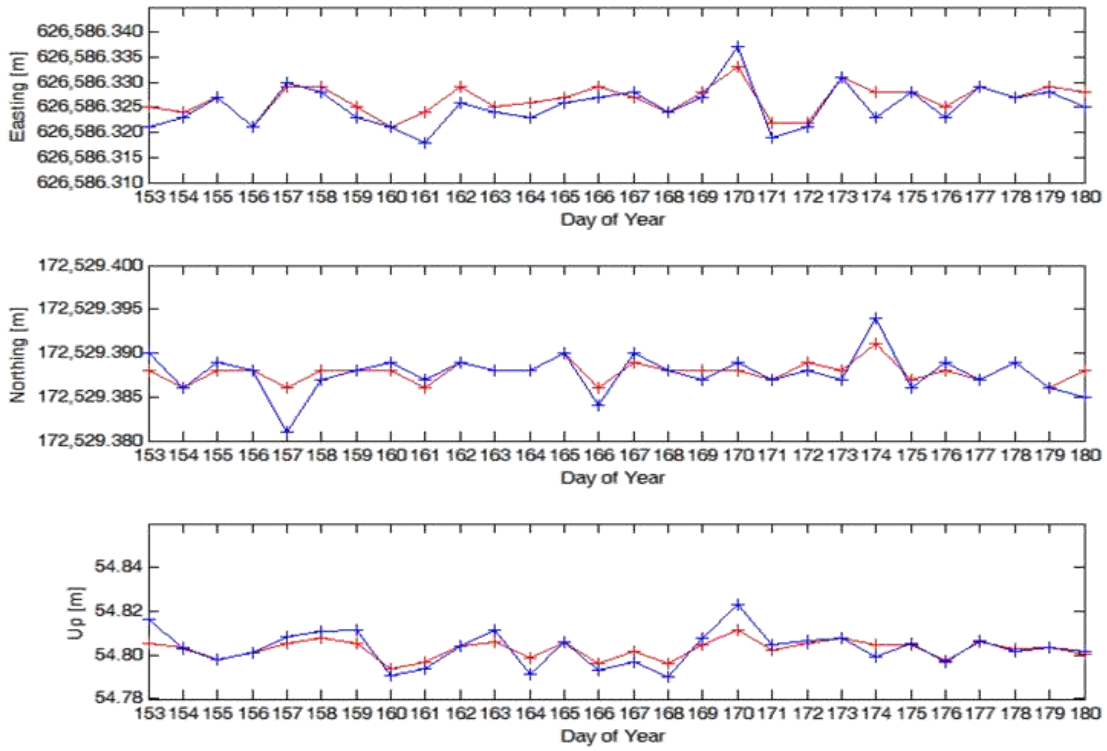


Figure10: Variation of ISK1 in Northing, Easting and Up within 30 days (1st – 30th Jun 2010)

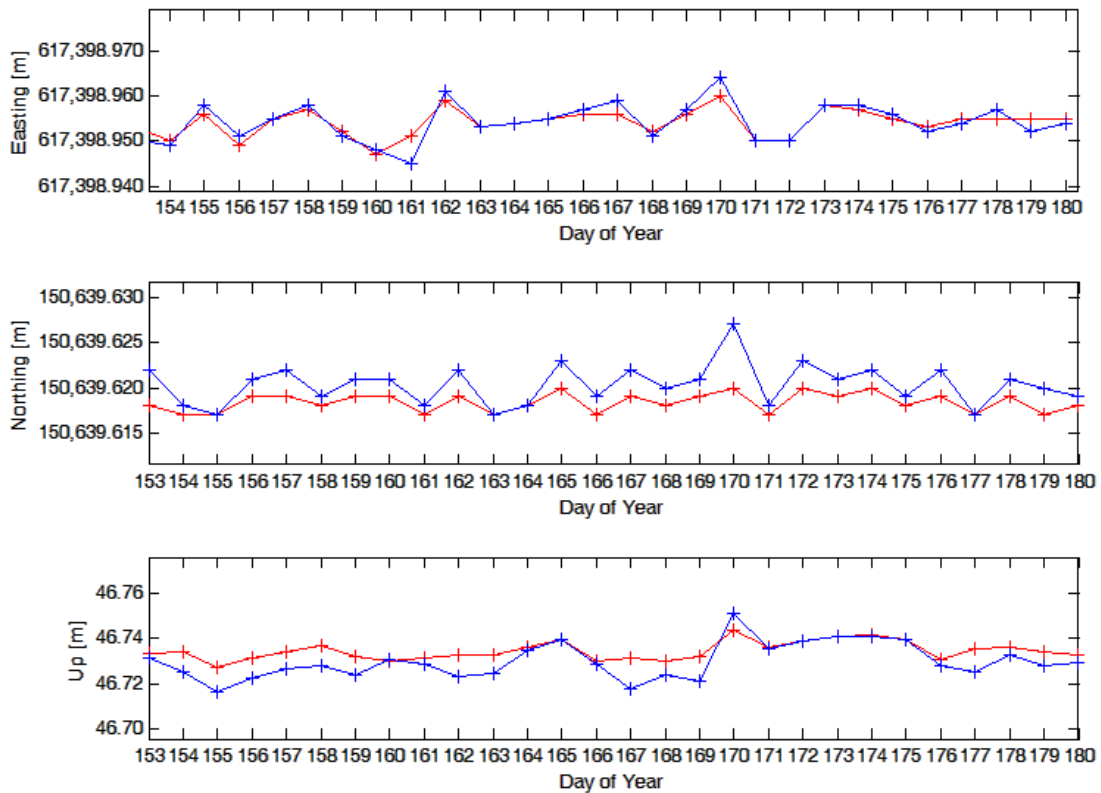


Figure11: Variation of ISK2 in Northing, Easting and Up within 30 days (1st – 30th Jun 2010)

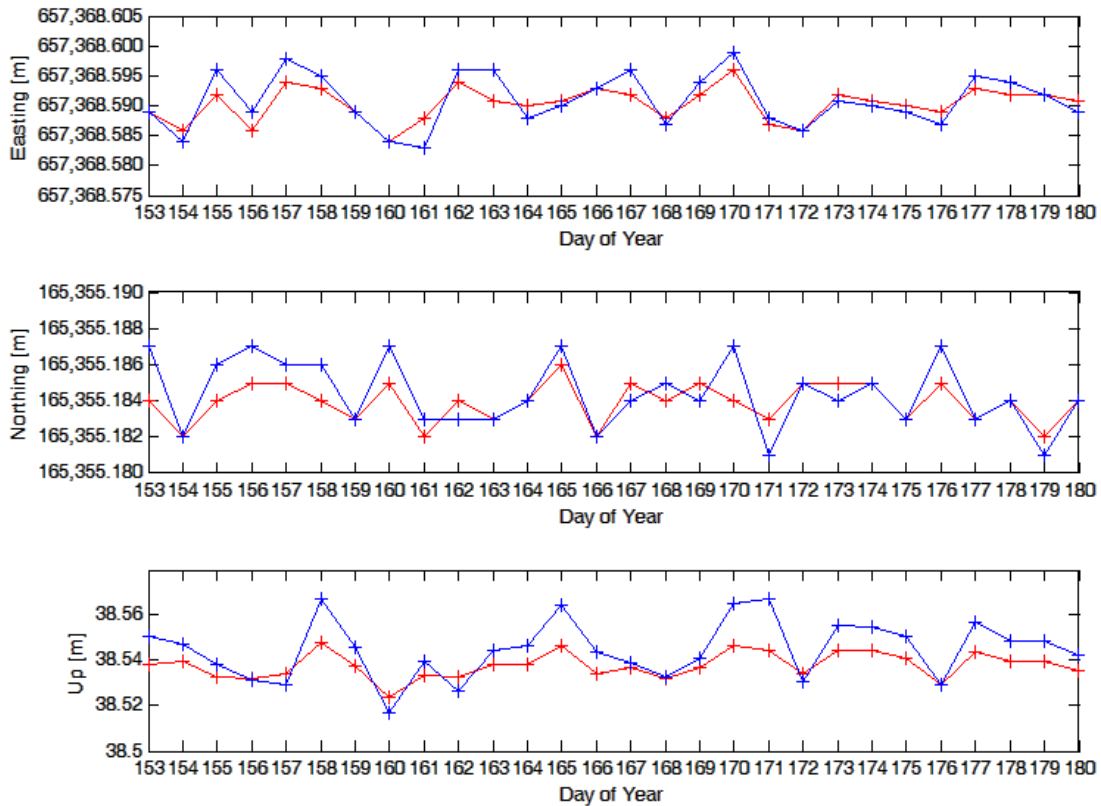


Figure12: Variation of ISK3 in Northing, Easting and Up within 30 days (1st – 30th Jun 2010)

The red lines correspond to the estimated coordinates before the two-epoch deformation analysis executed. Blue lines represent the position after analysis finished. Based on the **Figure 10, 11 and 12**, it can be drawn out that the fluctuations are in millimetre level and no significant movement detected.

6.0 CONCLUDING REMARKS

From this study, the implementation of CORS station is considered suitable for deformation monitoring. In addition, Bernese GPS software and ConDAS are able to produce high accuracy results, which are considered important and vital in deformation monitoring. Nonetheless, preliminary results indicate that the methodology of data processing is feasible and effective. More advanced data analysis techniques will continue to be developed so that more reliable results can be obtained. Future works will involve making the software fully automated.

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