Continuous Deformation Monitoring Using GPS and Robust Method: ISKANDARNET

Lim Meng Chan *, Halim Setan and Rusli Othman
Department of Geomatic Engineering, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia
E-mail: mengchanlim@yahoo.com, halim@utm.my, rusliothman@utm.my

KEY WORDS: Deformation analysis, continuous, robust, ConDAS, Bernese

ABSTRACT:

With the well-accepted use of Global Positioning System (GPS) in the surveying field today, GPS is widely used for monitoring some natural phenomena and man-made structures for providing useful information to assess seismic hazards and risks. This paper describes a software system for continuous GPS deformation detection and analysis via robust method, named ConDAS that currently being developed at Universiti Teknologi Malaysia. It is a software system that designed to cooperate with high precision GPS processing software - Bernese. The main components of ConDAS are: parameter extraction (from Bernese output), deformation detection (via IWST and S-transformation) and graphical visualisation. All these components are integrated in one environment using MATLAB. ConDAS runs under Windows operating system, is accessible for presenting the results of deformation detection, both numerically and visually. A GPS deformation monitoring network (three stations from ISKANDARnet and four nearby IGS stations) was designed to detect the displacement by implementing ConDAS. This paper highlights the architecture, the design of the software system and the results. Test results show that the system performed satisfactorily, and ISKANDARnet is stable.

1. INTRODUCTION

Deformation monitoring is a kind of continuous recording positions (horizontal and vertical coordinates) precisely regardless the deformation pattern and instrument used. However, GPS has revolutionised the science of positioning and earth measurement, because of high-efficient, high precision, no distance limitation, all weather operation and highly automated. Thus the technology of GPS positioning is greatly recommended by many experts to detect the natural disaster event in advance (Kutoglu, 2010; Kaloop and Li, 2009; Rutledge et al., 2001; Chen et al., 2000).

A window-based software system for GPS deformation detection and analysis via robust method, called ConDAS, is currently being developed at Universiti Teknologi Malaysia. It is a software system that designed to cooperate with high precision GPS processing software - Bernese. The main components of ConDAS are: parameter extraction (from Bernese output), deformation detection and graphical visualisation. All these components are integrated in one environment using MATLAB.

This paper describes the design and architecture of ConDAS and highlights the test results of ConDAS with a collected dataset using several nearby IGS stations as control points with the three ISKANDARnet station as object point.

2. 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 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 and Real Estate, 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.

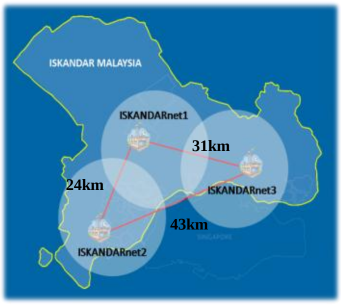


Figure 1: Network geometry of ISKANDARnet

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 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. METHODS

This research is devoted to develop a software system that adapts to GPS deformation detection and analysis for local CORS network: ISKANDARnet. Due to the extraordinary demands for displacement detection accuracy, a high precision GPS processing software, namely Bernese 5.0 is employed. Figure 2 outlines detailed process of the entire study.

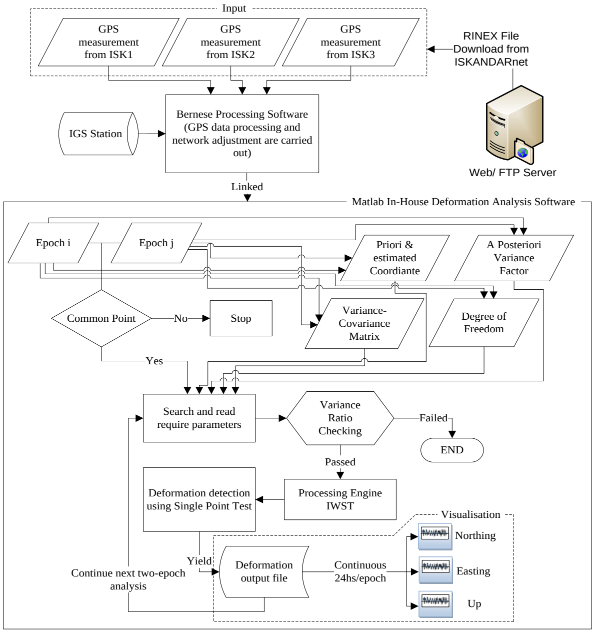


Figure 2: The outline of data processing and analysis for deformation detection system.

As fore-mentioned ConDAS is designed to cooperate with Bernese software for deformation detection and analysis, thus this study can be clarified by two parts: GPS data processing strategy and data analysis strategy for deformation detection system.

3.1 GPS Data Processing Strategy

Initially, four nearby International GPS Service (IGS) stations, where COCO, NTUS, PIMO and XMIS have been chosen as the control point for investigating the stability of every ISKANDARnet's station. Since the baselines are thousands of kilometres in length, therefore it requires sophisticated data processing software to achieve high accuracy results. In this stage, Bernese 5.0 is employed for GPS data processing. This software is suitable for scientific studies in surveying fields that require high precision especially tuned for long baselines and small movements. 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 (Haasdyk et al., 2010; 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. Figure 3 shows the main work flow of GPS data processing using Bernese. There are some specified principles and criteria that need to be concerned, especially for this study where can be found in Lim et al (2010b).

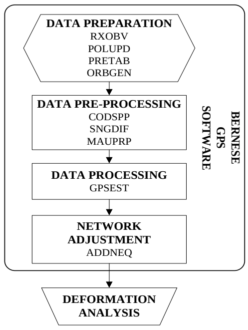


Figure 3: Main work flow of GPS data processing using Bernese

3.2 Deformation Analysis Technique

The determination of deformations is mainly formed from two parts. The first is the measurement of deformation and the second is the analysis of these measurements (Aguilera et al., 2007). However, deformation analysis using the geodetic method mainly consists of a two-step analysis via independent adjustment of the network of each epoch, followed by deformation detection between the two epochs (Setan and Singh, 2001). In this case, network adjustment is covered by Bernese 5.0 software and ConDAS carry out the two-epoch deformation analysis.

Generally, classical deformation analysis applied in geodesy (Caspary, 1988) is extracting the deformation vectors and the variance-covariance matrix. In this classification, Iteratively Weighted Similarity Transformation (IWST) tends to compute the displacement vector and its variance-covariance matrix by iteratively changing weight matrix, W. In fact, IWST method belongs to the family of "robust" methods. It enables us to find the best datum, in a sense that such datum will have the minimal distorting influence on the vector of displacement (Chrzanowski et al., 1994). However, for the deformation analysis here is strongly recommended that execute the final S-transformation after the IWST is applied. A flow chart of IWST with final S-Transformation method is illustrated in Figure 4. For further computation of IWST and S-Transformation, please refer to Lim et al. (2010a), Chen et al. (1990).

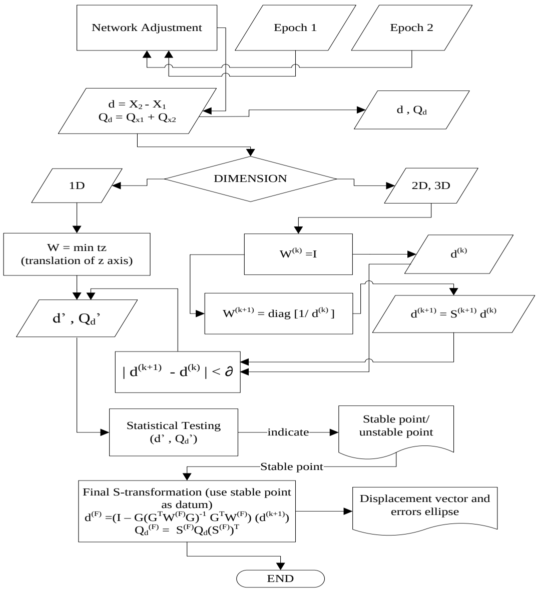


Figure 4: Flow chart of IWST with final S-Transformation

4. SYSTEM DEVELOPMENT APPROACH

In principle, ConDAS is being developed using Matrix Laboratory (MATLAB). This software system is tentatively developed to detect the unstable stations in a deformation monitoring network by IWST method and S-Transformation to analyse the GPS results in the deformation perspective. Figure 5 illustrates the overall workflow of ConDAS.

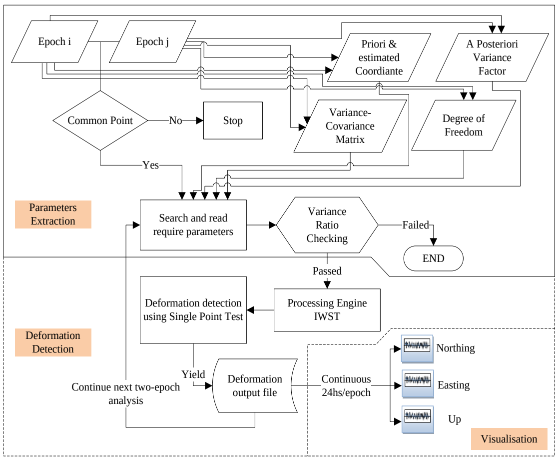


Figure 5: Block diagram of ConDAS

As an overall, ConDAS consists of three modules: parameters extraction module, deformation detection module and visualisation module. The architecture and function of modules are described respectively as following.

4.1 Parameters Extraction Module

After high accuracy coordinates computation from Bernese GPS software, a posteriori variance factor, degree of freedom and variance-covariance matrices can be obtained from the result files. These parameters are required in order to perform the two-epoch deformation analysis. In other words, these parameters are the inputs of deformation analysis. For this study, a Bernese parameter extraction module has been created using Matlab. It was designed to suit with Bernese in order to extract the required parameters according to the format of Bernese results files. Three types of result files were used for extraction, for instance: a priori coordinate file and adjusted coordinate file in STA folder (e.g.: APR110010.CRD & R1_110010.CRD), along with covariance file in OUT folder (e.g.: R1_11001.COV). Figure 6(a) illustrates GUI of parameters extraction module and Figure 6(b) illustrates a deformation input file after parameters extraction was performed.

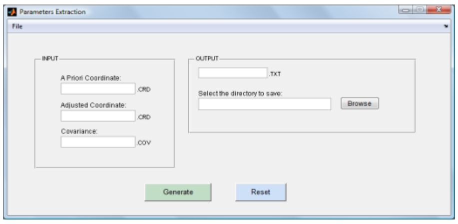


Figure 6(a): GUI of parameters extraction

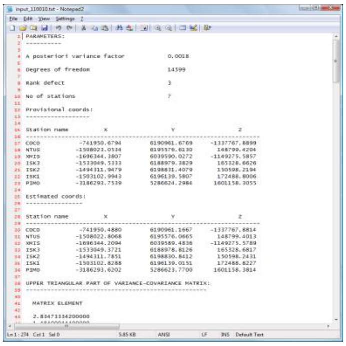


Figure 6(b): Example format of deformation input file.

A deformation input file in text file (.txt) was generated as Figure 6(b) after parameters extraction from Bernese. Subsequently, ConDAS read the deformation input file and enforced to search the particular parameters according to the string name using command *findstr*. Repeated command will be applied to search other parameters that mentioned previously until those particular parameters were found. A warning message will pop out if the specify parameters are deemed to be not exist.

4.2 Deformation Detection Module

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, similar approximate coordinates and same points names are used in two epochs. 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 Equation 1 (Lim et al., 2010a; Setan and Singh, 2001).

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

with j and i represent the larger and smaller variance factors, F is the Fisher's distribution, α is the chosen significance level (typically α = 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. In the last iteration of computation, a final S-transformation is performed to get the actual value of the displacement vector using stable points as datum that verified by the previous IWST analysis. Figure 7(a) demonstrates the GUI of deformation detection module.

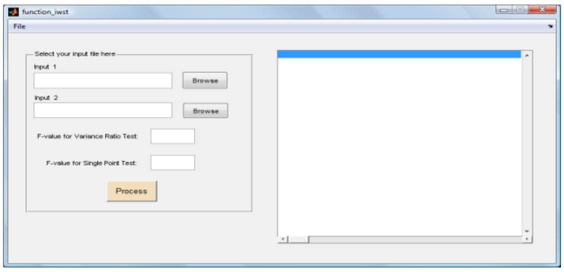
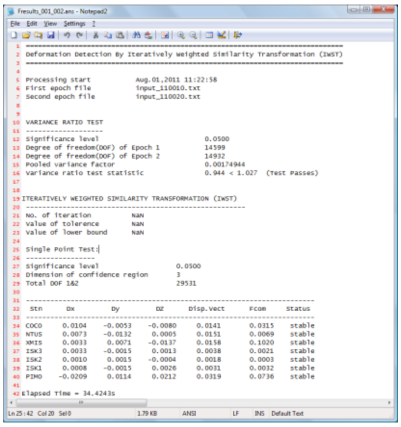


Figure 7(a): GUI of deformation detection module



```
Fresults_001_002.ans - Notepad2
=====================================================================
Deformation Detection By Iteratively Weighted Similarity Transformation (IWST)
=====================================================================

Processing start         Aug.01,2011 11:22:58
First epoch file         input_110010.txt
Second epoch file        input_110020.txt


VARIANCE RATIO TEST
-------------------
Significance level                         0.0500
Degree of freedom(DOF) of Epoch 1          14599
Degree of freedom(DOF) of Epoch 2          14932
Pooled variance factor                     0.00174944
Variance ratio test statistic              0.944 < 1.027  (Test Passes)


ITERATIVELY WEIGHTED SIMILARITY TRANSFORMATION (IWST)
-----------------------------------------------------
No. of iteration         NaN
Value of tolerence       NaN
Value of lower bound     NaN

Single Point Test:
-----------------
Significance level                  0.0500
Dimension of confidence region      3
Total DOF 1&2                       29531

---------------------------------------------------------------------
 Stn      DX        Dy        DZ       Disp.Vect     Fcom    Status
---------------------------------------------------------------------
COCO     0.0104   -0.0053   -0.0080    0.0141      0.0315   stable
NTUS     0.0073   -0.0132    0.0005    0.0151      0.0069   stable
XMIS     0.0033    0.0071   -0.0137    0.0158      0.1020   stable
ISK3     0.0033   -0.0015    0.0013    0.0038      0.0021   stable
ISK2     0.0010    0.0015   -0.0004    0.0018      0.0003   stable
ISK1     0.0008   -0.0015    0.0026    0.0031      0.0032   stable
PIMO    -0.0209    0.0114    0.0212    0.0319      0.0736   stable

Elapsed Time = 34.4243s
Ln 25:42  Col 20  Sel 0    1.79 KB   ANSI   LF   INS   Default Text
```

Figure 7(b): Output file of deformation detection module

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

4.3 Visualisation Module

The visualisation module still under modification hence no GUI is available currently. However, this module is specially designed to plot the displacement vector in Northing, Easting and Up respectively. The end user can have a glance of view on the fluctuation in displacements via this module.

5. TESTING RESULTS

5.1 Validation of ConDAS

Lately, the validation of ConDAS software system was conducted by using the existing GPS data set from Malaysia Real-Time Kinematic GNSS Network (MyRTKnet). The processed data set start from 4th Dec 2004 until 31th Dec 2004 was before and after the Aceh earthquake incident happens. Total six of IGS stations (ALIC, DARW, DGAR, HYDE, KARR and KUNM) have been chosen as the control points and two stations from MyRTKnet: JHJY and LGKW were selected as object points. However, only the stable control point (among the selected IGS station) that being verified by ConDAS can be used as datum to compute the displacement vectors of object points. Throughout the analysis, all stations were stable before the earthquake happen. However, the results show the LGKW station was moved start from 26th Dec 2004 and onwards. The computed displacement was varied from 11.67cm-13.35cm. This result was mostly identical with Jhonny (2010).

5.2 Deformation Trend of ISKANDARnet

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 three months data (1st Jan 2011 – 31th Mar 2011). However, ISKANDARnet was undergone some rigorous on-site maintenance during mid of Mar until May. Thus, only two months over data (1st Jan 2011 – 16th Mar 2011) are available in this paper. 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 of two epoch's data (1st and 2nd Jan 2011) in Table 1 confirmed that all four reference stations were stable.

Table 1: 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	-0.0035	-0.0046	0.0028	0.0064	0.0018 < 2.60547	stable
NTUS	0.0037	-0.0217	-0.0009	0.0220	0.0113 < 2.60547	stable
XMIS	-0.0023	0.0132	-0.0052	0.0144	0.0068 < 2.60547	stable
PIMO	0.0022	0.0131	0.0032	0.0137	0.0022 < 2.60547	stable

Subsequently, deformation analysis of all seven stations was carried out via final S-transformations based on the stable reference points (Table 1). All seven stations were verified as stable (Table 2). Consequently, the results obtained illustrate that the movement experienced by the GPS CORS stations at cm level can be detected. However, there was no significant movement shown as the deformation displacements that exceed the threshold.

Table 2: 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	-0.0014	-0.0035	0.0025	0.0046	0.0004 < 2.60521	stable
NTUS	0.0024	-0.0132	-0.0018	0.0135	0.0069 < 2.60521	stable
XMIS	-0.0001	0.0095	-0.0048	0.0106	0.0048 < 2.60521	stable
ISK3	-0.0012	-0.0012	-0.0011	0.0020	0.0006 < 2.60521	stable
ISK2	-0.0040	0.0016	-0.0027	0.0050	0.0027 < 2.60521	stable
ISK1	-0.0040	-0.0010	0.0001	0.0042	0.0019 < 2.60521	stable
PIMO	-0.0009	0.0073	0.0041	0.0084	0.0012 < 2.60521	stable

Next, two months over of GPS data (1st Jan – 16th Mar 2011) have been processed and analysed continually using the identical aforementioned method. The epoch on 1st Jan 2011 was selected as reference epoch for any epochs against it. 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 8, 9, 10 shows the variation of ISK1, ISK2 and ISK3 in Northing, Easting and Up.

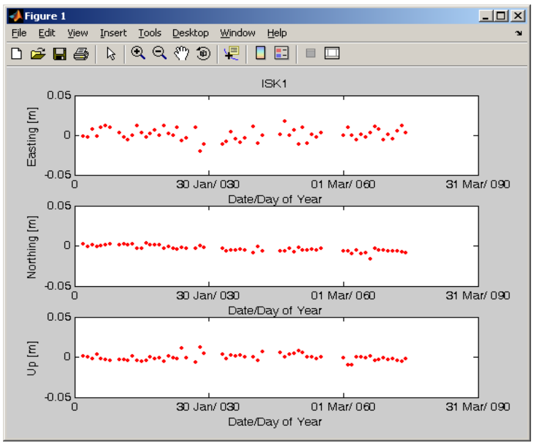


Figure 8: Fluctuations of ISK1 in Northing, Easting and Up within 3 months (1st Jan 2011 – 16th Mar 2011)

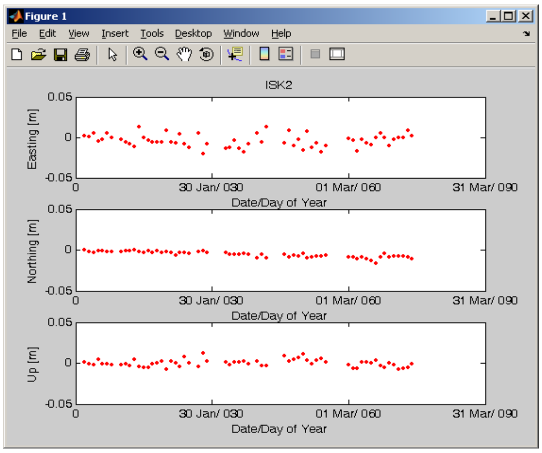


Figure 9: Fluctuations of ISK2 in Northing, Easting and Up within 3 months (1st Jan 2011 – 16th Mar 2011)

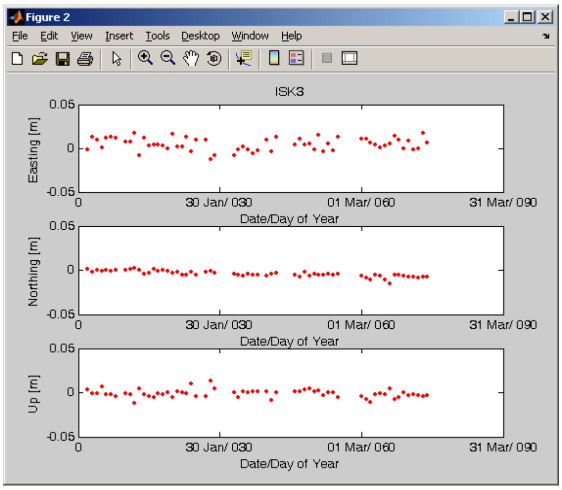


Figure 10: Fluctuations of ISK3 in Northing, Easting and Up within 3 months (1st Jan 2011 – 16th Mar 2011)

Based on the Figure 8, 9 and 10, it can be drawn out that the fluctuations are in centimetre level and no significant movement detected.

6. CONCLUSION

In this paper, a windows-based software system for GPS deformation detection via IWST methods, called ConDAS, has been described. It has been proved to have potential for providing high-quality stability information of the ISKANDARnet. The test results show the suitability of this software system for practical applications. The future works are tend to improve the flexibility of this software system in data searching, loading and code embedding.

REFERENCES

Aguilera, D.G., Lahoz, J.G. and Serrano, J.A.S., 2007. First Experiences with The Deformation Analysis of A Large Dam Combining Laser Scanning and High-accuracy Surveying. *XXI International CIPA Symposium*. 01-06 October. Athens, Greece.

Caspary, W.F., 1988. *Concept of Network and Deformation Analysis*. Monograph 11, School of Surveying, University of New South Wales, Kensington, 183pp.

Chen, Y. Q., Chrzanowski, A. and Secord, J. M., 1990. A Strategy for the Analysis of the Stability of Reference Points in Deformation Surveys. *CISM Journal ACSGC*, 44(2): 141-149.

Chen, Y., Ding, X., Huang, D. and Zhu, J., 2000. A Multi-antenna GPS System for Local Area Deformation Monitoring. *Earth Planets Space*, 52, 873-876.

Chrzanowski, A., Caissy, M., Grodecki, J. and Secord, J., 1994. Software Development and Training for Geometrical Deformation Analysis. *UNB Final Report*. Contract No. 23244-2-4333/01-SQ.

Haasdyk, J., Roberts, C. and Janssen, V., 2010. Automated Monitoring of CORSnet-NSW using the Bernese Software. *FIG Congress 2010*, Sydney, Australia, April 11-16.

Hu, Y.J., Zhang, K.F. and Liu, G.J., 2005. Deformation Monitoring and Analysis using Regional GPS Permanent Tracking Station Networks. *FIG Working Week.* Cairo, Egypt, April 16-21.

Iskandarnet, 2010. *Iskandarnet status*. Retrieved May 26, 2010, from http://www.fksg.utm.my/ISKANDARnet/status.html

Janssen, V., 2002. GPS Volcano Deformation Monitoring. *GPS Solutions*. 6: 128-130, DOI 10.1007/s 10291-002-0020-8.

Jia, M.B., 2005. Crustal Deformation from the Sumatra-Andaman Earthquake. *AUSGEO news*, issue 80.

Jhonny, 2010. Post-Seismic Earthquake Deformation Monitoring in Peninsular Malaysia using Global Positioning System. Master Degree Thesis, pp. 58. Universiti Teknologi Malaysia, Johor Bahru.

Kaloop, M.R. and H. Li, 2009. Tower bridge movement analysis with GPS and accelerometer techniques: Case study yonghe tower bridge. *Inform. Technol. J.*, 8: 1213-1220.

Kutoglu, H. S., 2010. Datum Issue in Deformation Monitoring using GPS. *Proceedings of FIG Congress 2010 on Deformation Measurement using GNSS Commission: 5 and 6*, Sydney, Australia, April 11-16.

Lim, M.C., Setan, H. and Othman, R., 2010a. A Strategy for Continuous Deformation Analysis using IWST and S-Transformation. *Word Engineering Congress 2010*, Kuching, Sarawak, Malaysia, 2-5 August.

Lim, M.C., Halim setan and Rusli Othman, 2010b. GPS Deformation Monitoring and Analysis for Local CORS Network: ISKANDARnet. Geoinformation Scienc Journal (GSJ), Vol.10, No.2, pp: 1-14.ISSN 1511-9491© 2009 FKSG.

Rizos, C., Kinlyside, D.A., Yan, T.S., Omar, S. and Musa, T.A., 2003. Implementing network RTK: The SydNET CORS infrastructure. *6th Int. Symp. on Satellite Navigation Technology Including Mobile Positioning & Location Services*, Melbourne, Australia, 22-25 July.

Rutledge, D., Gnipp, J. and Kramer, J., 2001. Advances in Real-Time GPS Deformation Monitoring for Landslides, Volcanoes and Structures. *Proceedings of 10th International (FIG) Symposium on Deformation Measurements*, Orange, CA, 110-121.

Setan, H. and Othman, R., 2006. Monitoring of Offshore Platform Subsidence using Permanent GPS Stations. *Journal of Global Positioning Systems.* Vol. 5, No. 1-2:17-21. ISSN 1446-3156.

Setan, H. and R. Singh., 2001. Deformation Analysis of a Geodetic Monitoring Network. *Geomatica*. 55(3), 333-346.

Shariff, N.S.M., Musa, T.A., Ses, S., Omar, K., Rizos, C. and Lim, S., 2009. ISKANDARnet: A Network-Based Real-Time Kinematic Positioning System in ISKANDAR Malaysia for Research Platform. *10th South East Asian Survey Congress (SEASC)*, Bali, Indonesia, August 4-7.

Vermeer, M., 2002. Review of The GPS Deformation Monitoring Studies Commissioned by Posiva Oy on the Olkiluoto, Kivetty and Romuvaara sites, 1994-2000. *STUK-YTO-TR* 186. Helsinki.

ACKNOWLEDGEMENTS

The authors would like to thank Department of Survey and Mapping Malaysia (DSMM) for providing valuable MyRTKnet GPS data. Authors are grateful to Ministry of Science, Technology and Innovation (MOSTI) for providing the Science Fund (Vot. 79350) and Ministry of Higher Education (MOHE) for providing the and RUG (Vot. Q.J130000.7127.02J69) on research funding purpose. The authors also grateful to GNSS & Geodynamics Research Group (FKSG, Universiti Teknologi Malaysia) which provide the research facility for data processing purposes.