KINEMATIC MEASUREMENT AND PROCESSING STRATEGY FOR DYNAMIC MONITORING OF ENGINEERING STRUCTURES USING GLOBAL POSITIONING SYSTEM

ZULKARNAINI BIN MAT AMIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Geomatic Engineering)

Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

JULY 2013

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to my supervisor, Prof. Dr. Wan Abd. Aziz Wan Akib and Prof. Dr. Halim Setan for their guidance, suggestion and advice throughout the course of this research.

I also would like to express my appreciation to the following for their contribution and assistance towards the successful completion of this thesis.

- Academic staff of the Department of Civil and Building Engineering, Loughborough University, UK for providing the data for this study.
- Mr. Keith Boucher of the Department of Geography, Loughborough University, UK for providing wind information.
- The Management of the Penang Bridge Sdn Bhd (PBSB) which is the concessionaire of the Penang Bridge for providing access to the bridge.
- Mr Shu Kian Kok for collaboration in program development of Kalman filtering.

Finally, I would like to express my deep gratitude and appreciation to my wife and family for unstinting love and patience, continuous support and encouragement throughout the years of my study.

ABSTRACT

Demands in engineering structures protection against destructive stimulations have lead to a significant research in this area. In particular, the non-destructive evaluation sensor such as the Global Positioning System (GPS) is valuable to assess the serviceability, safety and integrity of these structures such as tall buildings and bridges. Nevertheless, the attainable accuracy of the GPS measurements is dependent upon the presence of errors or noises in the measurements. These include satellite and receiver clock errors, satellite geometry, satellite orbit, multipath and atmospheric errors. Some of the errors can be eliminated or minimised by applying differencing techniques, but others require particular attention if a high accuracy result is sought. This thesis explores the development of an integrated methodology and systematic processing for kinematic GPS method in continuous structural monitoring applications. The research presented here reinforced the theory of spectral representation of the signal, which was used to recover the signature of the disturbed signature from the priori signature. This method works when there were at least two sets of measurements from the so-called fixed and moving stations. It has been justified in this research that as these stations are closed together, they are strongly correlated with respect to GPS error sources and thus cancel some of the errors. A correlation coefficient between stations of up to 0.831 has been obtained in this study. By deriving their signatures using the Fast Fourier Transform, a method of minimising these spatial correlated errors by signatures differences and displacement detection with the aid of Kalman filter method has been developed. The developed technique is validated through a simulation test and real applications on a tower block and cable-stayed bridge. The test has demonstrated the potential of this technique for the improvement of observed values. Results have shown that an increase of almost 50% to 60% in position estimates was achieved by applying this technique. This can be interpreted by the Root Mean Square Error (RMSE) of simulated displacement in longitudinal direction with respect to true displacement has decreased from $\pm$0.004 m to $\pm$0.002 m by processing through the developed technique. Similarly, for vertical direction, the RMSE has decreased from $\pm$0.009 m to $\pm$0.006 m. The test conducted on the special designed simulation device shows that the responses with tip displacement of 1cm can be detected by kinematic GPS when compared with the actual displacement. A tower and cable-stayed bridge trials indicate the ability of the developed technique to detect displacement of more than 3 cm. The comparative results in the case of simulation study and real trials on structures proved that the proposed technique can enhance displacement measurement accuracy and capable of assessing the allowable safety tolerance of the engineering structures.

ABSTRAK

Tuntutan dalam penjagaan struktur kejuruteraan akibat daripada perangsangan kemusnahan telah memberi laluan kepada penyelidikan yang signifikan dalam bidang ini. Secara khusus, penderia penilaian tanpa musnah seperti *Global Positioning System* (GPS) berguna untuk menilai kebolehkhidmatan, keselamatan dan integriti struktur seperti bangunan tinggi dan jambatan. Walau bagaimanapun, ketepatan yang diperolehi daripada pengukuran GPS bergantung kepada kewujudan selisih atau hingar dalam pengukuran. Ini termasuklah selisih-selisih satelit, jam alat penerima, geometri satelit, berbilang-alur dan atmosfera. Sebahagian daripada selisih tersebut boleh dihapuskan atau dikurangkan dengan melaksanakan teknik pembezaan, tetapi sebahagian yang lain memerlukan perhatian khusus jika keputusan yang berketepatan tinggi diperlukan. Tesis ini mengkaji pembangunan integrasi metodologi dan pemprosesan yang sistematik dengan menggunakan kaedah GPS kinematik dalam aplikasi pemantauan struktur secara berterusan. Kajian yang dibincangkan ini menguatkan teori perwakilan spektrum isyarat yang digunakan untuk memulihkan kembali pengenalan asal isyarat daripada isyarat terganggu. Kaedah ini berfungsi apabila terdapat sekurang-kurangnya dua set cerapan daripada stesen-stesen yang dikenali sebagai stesen tetap dan bergerak. Ianya telah diwajarkan dalam kajian ini, iaitu apabila kedua-dua stesen adalah berdekatan antara satu sama lain, sekaitannya daripada segi sumber selisih GPS adalah tinggi dan oleh itu sebahagian daripada selisih-selisih ini akan terhapus. Pekali sekaitan sehingga 0.831 antara stesen telah diperolehi dalam kajian ini. Dengan menerbitkan pengenalan isyarat menggunakan *Fast Fourier Transform*, kaedah untuk meminimumkan selisih-selisih *spatial* yang sekait melalui pembezaan spektrum dan pengesanan anjakan dengan bantuan penuras *Kalman* telah dibangunkan. Teknik yang dibangunkan ini telah sahkan melalui ujian simulasi dan aplikasi sebenar ke atas blok menara dan jambatan kabel tambat. Ujian telah membuktikan keupayaan teknik ini untuk meningkatkan hasil cerapan. Keputusan menunjukkan peningkatan sehingga 50% hingga 60% dalam anggaran kedudukan dapat dicapai menggunakan teknik ini. Ianya boleh diterjemahkan oleh nilai *Root Mean Square Error* (RMSE) bagi anjakan simulasi dalam arah membujur yang merujuk kepada anjakan sebenar telah menurun daripada ±0.004 m kepada ±0.002 m melalui pemprosesan dengan teknik yang dibangunkan. Begitu juga bagi arah tegak, nilai RMSE telah menurun dari ±0.009 m kepada ±0.006 m. Ujian yang dijalankan terhadap peranti simulasi menunjukkan tindakbalas dengan anjakan hujung sebanyak 1cm boleh dikesan oleh teknik GPS kinematik apabila dibandingkan dengan anjakan sebenar. Ujian ke atas blok menara dan jambatan kabel tambat pula menunjukkan kemampuan teknik yang dibangunkan untuk mengesan anjakan lebih dari 3 cm. Keputusan perbandingan dalam kes ujian simulasi dan ujian sebenar ke atas struktur membuktikan teknik yang dicadangkan boleh meningkatkan ketepatan pengukuran anjakan dan mampu untuk menilai had terima keselamatan bagi struktur kejuruteraan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Monitoring the integrity of engineered structures such as bridges and tall buildings is critical to understanding the health of structures and their safety aspects. Such structures have allowance or tolerance for deformation under the action of load. Topic on structural responses due to load is elaborated in great length in Chapter 2. The standard approach to detect the geometrical and physical status of the structures is through deformation monitoring. For this reason, deformation monitoring is one of the tasks of structural engineers to ensure the safety of the structures.

Monitoring of engineered structures using geodetic methods has become a prime concern due to its precision, portability and most importantly non-destructive or non-disturbance nature of the technique. The application of this technique was initiated by Teskey and Porter (1988) using integrated geodetic measurement and finite element model to monitor large concrete structures. From their work, new approach was successfully demonstrated and proved that it is possible to determine the structural deformation behaviour when loading are applied. Furthermore, advancement in geodetic instrumentation such as motorised theodolite makes it possible to evaluate structures such as bridges (Katowski, 1995). Until recently, the Global Navigation Satellite Systems (GNSS) technology, specifically the Global Positioning System (GPS) developed by the United States is becoming a leading technology used in structural monitoring (Ogaja, et al., 2007).

The technique used for deformation monitoring should provide quality and reliable results. Moreover, the capability of the technique to produce three-dimensional data is an added advantage especially for structural monitoring. Compared to other geodetic techniques such as precise levelling, GPS can fulfil these requirements by providing three-dimensional data for used in the interpretation of horizontal and vertical displacements. In relation to Electronic Distance Measurement (EDM), GPS also can yield results in real or near real-time.

As will be discussed in Chapter 2, GPS is satellite-based navigation systems, which permit users to determine their position in three-dimensional space with high precision output. The precision of a few millimetres within a relatively short period of time can be guaranteed to all users through the use of developed techniques in GPS positioning. Relative positioning, either static or kinematic is now well established and is used extensively in deformation monitoring. It has been demonstrated that GPS is feasible alternative to costly conventional geodetic techniques with no significant loss of accuracy when used for deformation monitoring. This has been proven by the abundant reports on the utilisation of GPS as a monitoring tool or sensor in many conferences and in published articles.

GPS has been utilised in the repeated monitoring of crustal and earth deformation for many years but it has only been recently investigated in the context of continuous monitoring for civil engineering structures. Few reasons on why GPS has gain wide acceptance in continuous monitoring are listed as follows:

- the requirement to measure deformation or assessment of magnitude of structural damage where sudden failure may follow;
- the performance improvement and system capabilities of GPS;
- the capabilities of GPS to provide data on demand and detect any short term variation such as measurement due to wind or traffic loadings.

Numerous researches have been made toward the application of GPS in continuous monitoring at global, regional and local scales. At the regional scale, several permanent continuous array systems have been established especially for crustal deformation applications ((Bock, *et al.*, 1993; Jaldehag, *et al.*, 1996) and (Chen, 1998)). Likewise, at local scale, GPS has been tested as a deformation sensor for civil engineering ((Lovse, *et al.*, 1995); (Leach and Hyzak, 1994); (Guo and Ge, 1997); (Ashkenazi and Roberts, 1997); (Brown, *et al.*, 1999); (M. Celebi, 2000; Mehmet Celebi, *et al.*, 1999), (Ogaja, et al., 2001), (M. Celebi and Sanli, 2002), (Tamura, *et al.*, 2002), (Breuer, *et al.*, 2002), (Roberts, *et al.*, 2004)), (Aziz, *et al.*, 2005), (Hu and Xu, 2009; Seco, *et al.*, 2007) and (Hu, *et al.*, 2009; Seco, *et al.*, 2007; Stiros and Moschas, 2011), to list a few. Further discussion on these applications can be found in Chapter 2.

The high accuracy required for continuous monitoring applications are fully dependent on the GPS errors introduced in measurements as discussed in Section 2.1.3. It is very important to identify features that are clearly not due to displacement and to separate between noise and true movement. Consequently, this is an important issue in continuous monitoring applications. Nevertheless, for most regional scale applications where daily GPS solution were resolved, few errors are not critical since they are averaged out and tend to reduce (e.g. King, *et.al.*, (1995)). But for short or urgent observation monitoring campaigns, such as health assessment of engineering structures, the influence of GPS errors is very significant. To obtain reliable and consistent GPS results, there is a need to reduce these errors either through measurement procedures or data processing or both. As most past investigations on these ad hoc applications have not taken into account or addressed this issue, thus, areas requiring further research include:

- a methodology on the use of GPS in structural monitoring;
- a system for reducing the effect of GPS errors.

Consequently, this study attempts to fill the gap in this important research area. In addition, there is growing interest on the use of GPS for health monitoring of engineered structures, which requires work to be done in this area in order to improve the performance of the technique up to acceptable level.

1.1 Problem Statement

Recently, the GPS has been increasingly used to monitor the static and quasi-static deformations of large structures, such as long suspension bridges and tall buildings. Conventional approaches such as using total station has limitation as it is not able to provide the necessary displacement detection accuracy with sufficient update frequency and precision compare to GPS which provide sampling rates sufficient to track the displacement of dynamically excited objects with an accuracy of the order of millimeters (Casciati and Fuggini, 2008). Similarly with accelerometer instrument which measure acceleration and requires double integration in order to derive displacement.

The kinematic versions of the post-processing kinematic and real time kinematic (RTK) modes of the GPS have been used to monitor dynamic deformations of those engineering structures. As these techniques provide the trajectory of positions, their performance should be assessed. This is one of the issues which are addressed in this study to assess the measurement accuracy of GPS in dynamic status. To be used in structural monitoring, this sensor should be thoroughly validated before its application in full scale. Ultimately, a special device where harmonic movements can be simulated has been devised. These movements were recorded by the rotating GPS antenna and their coordinates were compared with the true value.

As indicated earlier, the research gap in this kinematic monitoring of engineering structures are the methodology on the application of GPS and treatment of GPS errors. The implementation of kinematic GPS techniques in structural monitoring have been reported and published in many publications as discussed in Chapter 2. Most of the tests found in the literature were conducted in controlled and real environments, usually consisting of only two GPS receivers installed at the reference point and structure. Summarizing previous research, the outcome of this study is that by complying with an appropriate procedure for kinematic GPS observation and processing can solved common GPS errors for short baseline and provide reliable results in structural monitoring.

1.2 Aim and Objectives

The aim of this research is to investigate the feasibility of kinematic GPS positioning in structural monitoring through systematic processing. In order to meet this aim, the following objectives were established:

1. To investigate the accuracy of kinematic GPS method.
2. To develop an efficient and systematic processing for continuous monitoring applications.
3. To testify and validate the developed kinematic GPS processing technique in structural monitoring.

1.3 Scope of Study

The research is involved with a study and utilisation of kinematic GPS to accomplish structural monitoring application. This research covers the accuracy assessment of the kinematic GPS and identifying on the most ideal observation and processing strategies to determine the structure displacement based on kinematic GPS Specifically, three objectives of the study have been addressed. In order to facilitate the objectives of the study, the following scopes have been embarked:

i. Validation on the accuracy of kinematic GPS has been performed through an experiment. The basic idea of an experiment was to determine the trajectory of positions in dynamic mode. This was by forcing receiver to rotate in known horizontal circular orbits and to compare its changing coordinates with the real ones. For the purpose of this experiment, a special rotating bar device has been devised.

ii. Determination of spatial correlation between two GPS receivers simultaneously tracking satellites was accomplished through short and long baselines observations. This experiment was vital to identify and develop a methodology for implementing kinematic GPS in structural monitoring. For this purpose, the statistical between these two receivers was deduced.

iii. Developing a model for observation and processing strategies of kinematic GPS data. The Savitsky-Golay filter which is a low pass filter has been used to remove high frequency noise in measurement and the spectral representation based on the Fast Fourier Transform has been applied to the GPS data. Error removal method has been introduced to eliminate common GPS errors to the measurements, hence structural deformations can be extracted. With the aid of Kalman filter, statistical tests on deformation can be performed. For all processing purposes, the MATLAB routines have been used.

iv. The feasibility and testing of the proposed methodology was conducted using a special fabricated simulation device which able to move in horizontal and vertical directions.

v. Full scale monitoring observations have been performed on tower and cable-stayed bridge. At each structure, the study was conducted during the time there was wind and traffic loadings, respectively.

1.4 Research Methodology

In completing this study, a detail and systematic planning is needed to achieve all the stated objectives. This is important so that each step taken will be noteworthy towards the completion of the study. Figure 3.5 and Chapter 4 to 6 can be referred for a detailed and clear explanation of the research methodology.

To achieve the aforementioned objectives, the following methodology is to be applied:

1. Performing kinematic GPS surveys for the following purposes:
    - to analyse the variability of epoch by epoch solution resulting from the measurement;
    - validating the accuracy and position of the kinematic GPS surveys;
    - investigating observation and processing procedures, for example the utilisation of different data collection rates and the use of satellite orbit in data processing;
    - investigating the effect of station separation (between roving receivers):
    - deriving spatial correlation between time series of positions of roving receivers;
2. Data filtering to filter high frequency noises.
3. Developing a systematic processing approach for data analysis based on the spectral representation of the data using the Fast Fourier Transform method.
4. Performing kinematic GPS surveys on a simulated object.
5. Performing kinematic GPS surveys on two engineering structures i.e. tower and cable-stayed bridge.

The overall methodology of this research can be summarized as depicted in Figure 1.1.

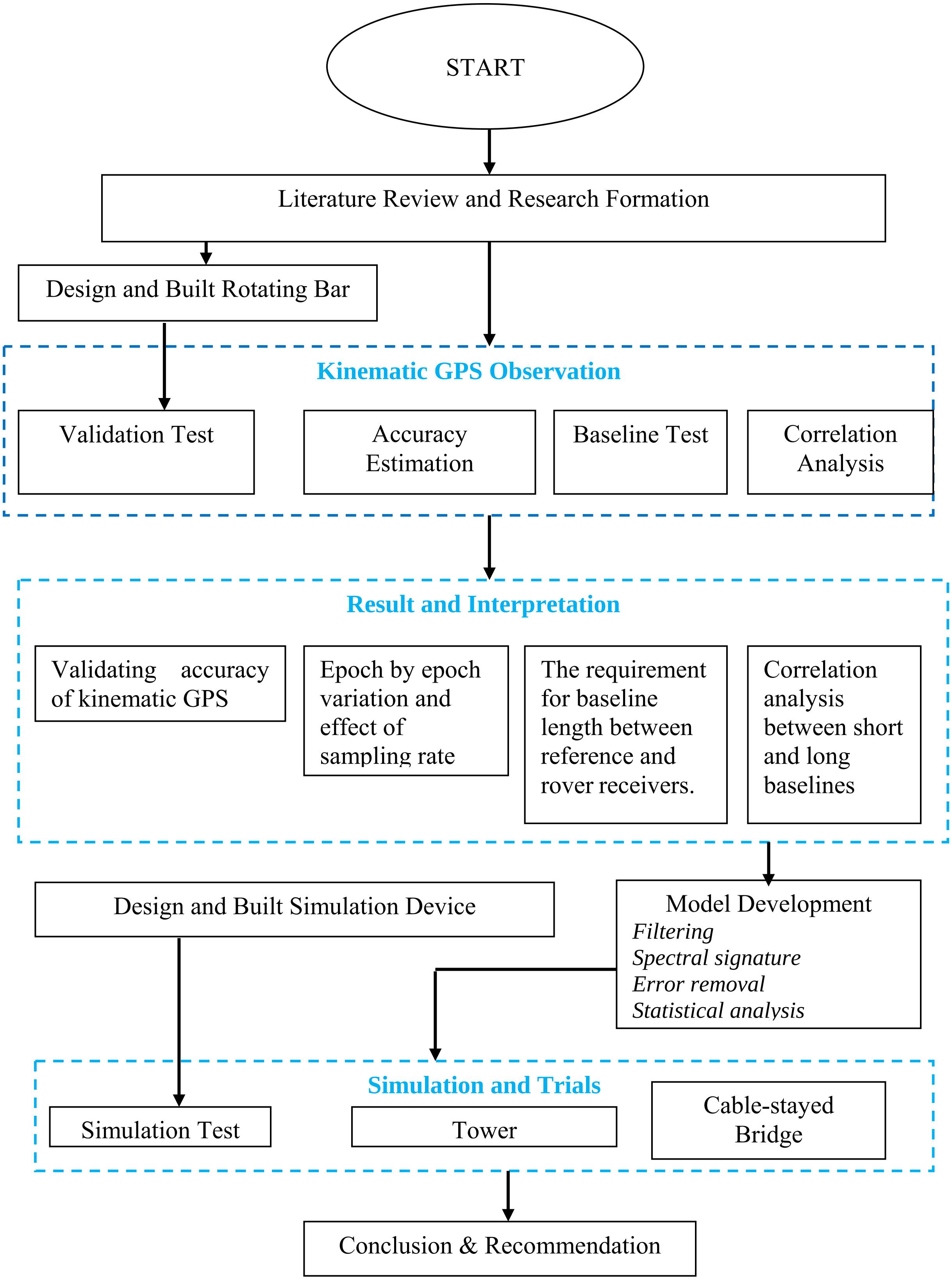

Figure 1.1: Research Methodology

1.5 Contribution of the Study

Dynamic monitoring of structures or structural health monitoring provides critical data for rapid condition assessment and damage detection in structures due to forces such as winds and traffic load and also catastrophic event such as earthquake. Consequently, many structural monitoring studies using geodetic and non-geodetic sensors, for determining and analysing different kinds of engineering structures such as high-rise buildings and bridges are implemented. Currently, GPS is a valuable geodetic sensor to track the changes in the dynamic characteristics of the structure and to detect damage after an extreme event. Research on GPS as a geodetic sensor for the above applications have been mentioned in many published articles such as to tall buildings ((Bashor, *et al.*, 2012; Yi, *et al.*, 2010a, 2010b) and bridges (Erdoğan and Gülal, 2009; Kaloop and Li, 2011). In this study, a few issues related to the use of GPS for structural monitoring have been dealt with and resulted to the contribution of the following:

Assessment on the GPS performance of dynamic mode has been performed in order to validate before its application in full scale. The harmonic movement were simulated by a rotating GPS receiver antenna and the recorded coordinates were compared with the real ones. The results satisfy the precision requirements expected for dynamic monitoring study.

The variations in the position of the receiver (rover) located on the monitored structure during the observation period have been established. These variations are not similar to the ones obtained from the receiver located on the free and clear sky nearby (base). This concludes that during the characterization of the accuracy, that structure distortions and any GPS errors are masked in the results obtained. Because the rover and base GPS receivers were close to each other, signals recorded by each one of them were affected by identical atmospheric effects, and hence the comparison of the recordings of the stable (base) receiver with those of the rover (moving) receiver permits to record the displacement history of the rover receiver. In any case it is proven that by eliminating these errors, the displacements suffered by this structure can be determined.

The spectral information gathered from the time series of the base receiver has been used to estimate the true variation of positions with respect to error free GPS solutions. A Fourier transform is performed on time series in order to obtain spectra. Using these spectra, a signal reconstruction was performed to the rover's time series. The signal reconstruction method used in this study is the inverse Fourier transform. Consequently a method based on a local regularity analysis for detecting and removing artefact signatures in noisy GPS signals being developed.

1.6 Outline of the Thesis

The thesis is divided into seven chapters and brief description of each chapter is given as follows.

Chapter 1 introduces the aim of the research by describing an overview of GPS applications in deformation monitoring. The aim and objectives of the research are then described with a particular methodology to fulfil the stated objectives.

Chapter 2 reviews the literature on the use GPS in deformation monitoring. A brief introduction to basic principles of GPS and its error sources is also presented. Two practical aspects of deformation monitoring, i.e. repeated and continuous are examined. Special attention was paid to continuous monitoring or specifically structural monitoring since this approach is of growing interest to date and form the basis of this research. Until recently, the efficiency of GPS to structural monitoring has been established, nevertheless the loading effect to the large engineering structures cannot be neglected and for this reason a special topic on this issue was elaborated in this chapter.

Chapter 3 introduces a theory on random processes. Description on random processes includes (1) types of random processes, (2) statistical properties, and (3) analysis. In addition, data filtering is also summarised. Finally the proposed processing strategy on the use of GPS for structural monitoring was presented. The goal is to acknowledge their suitability and adaptability for data analysis discussed in subsequent chapters.

Chapter 4 describes various tests using kinematic GPS positioning technique in order to satisfy the aforementioned objectives. The practical and processing procedures are presented in detail. At the end, a new approach for GPS error reduction is proposed based on synthesis of the above tests and information reviewed in the previous chapter.

Chapter 5 presents the application of the methodology described in Chapter 4 to simulation experiment using a constructed device, which allows displacement along horizontal and vertical axes. Considering the spectral nature of data sets, a new data analysis strategy for continuous monitoring is developed, which embodies the findings from Chapter 4. Then the efficiency of the newly developed approach is demonstrated.

Building upon the materials presented in previous chapters, Chapter 6 presents the application of the technique to two examples of engineering structures subjected to wind and traffic loadings. The results confirm the efficiency of the technique for use in structural monitoring.

Finally, Chapter 7 summarises this thesis with conclusions drawn from the results and gives few recommendations for future developments.

Figure 1.2 summarized the organisation of this thesis.

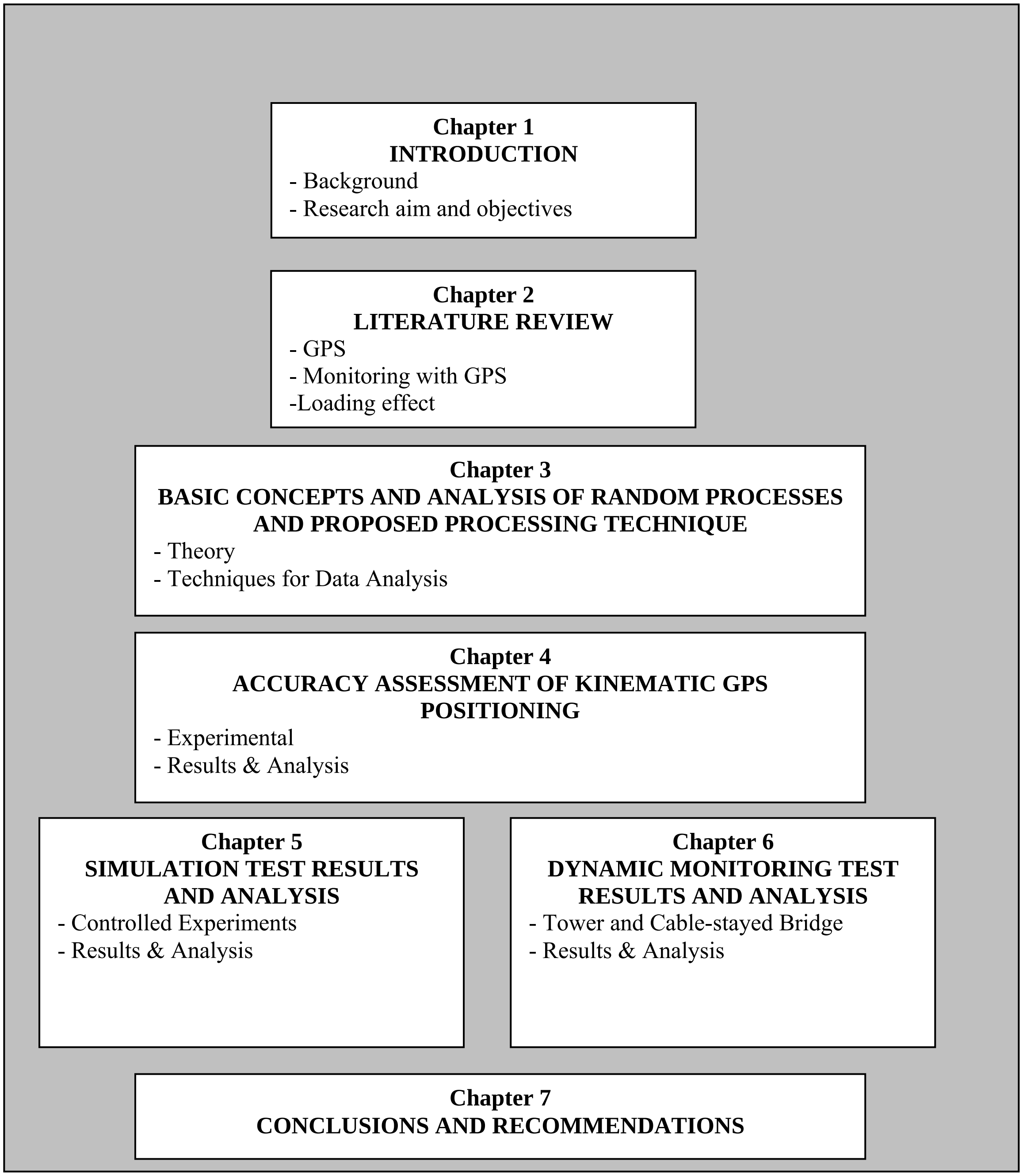

Figure 1.2: Outline of Thesis

REFERENCES

Abidin, H. Z., Meilano, I., Suganda, O. K., Kusuma, M. A., Muhardi, D., Yolanda, O., Setyadi, B., & Sukhyar. (1998). *Monitoring the Deformation of Guntur Volcano Using Repeated GPS Survey Method.* Paper presented at the FIG XXI International Congress, Brighton, England.

Agnew, D., Bock, Y., Dong, D., Donellan, A., Feigl, K., Hager, B., Herring, T., Jackson, D., King, R., et al. (1997). Space-Geodetic Measurements of Crustal Motion in Central and Southern California. from http://www.unavco.ucar.edu/

Ambrose, J., & Vergun, D. (1995). *Simplified Building Design for Wind and Eathquake Forces*. New York, Chichester, Brisbane, Toronto, Singapore: John Wiley & Sons, Inc.

Ananga, N., Sakurai, S., & Kawashima, I. (1997). Cut Slope Deformation Determination with GPS. *Survey Review, 34*(265), 144-150.

Anom. (2011). Current GPS Constellation.

Ashkenazi, V., Dodson, A. H., & Roberts, G. W. (1998). *Real-Time Monitoring of Bridges by GPS.* Paper presented at the FIG XXI International Congress, Brighton, England.

Ashkenazi, V., Moore, T., Roberts, G. W., & Simonds, S. (1998). *Construction Plant Control by Kinematic GPS and GLONASS.* Paper presented at the The 11th International Technical Meeting of the Satellite Division of the Institute of Navigation 1998, Nashville, USA.

Ashkenazi, V., & Roberts, G. W. (1997). Experimental monitoring of the Humber bridge using GPS. *Proceedings of the Institution of Civil Engineers-Civil Engineering, 120*(4), 177-182.

Aunon, J., & Chandrasekar, V. (1997). *Introduction to Probability and Random Processes*. New York: The McGraw-Hill Companies, Inc.

Aziz, W. A. W., Zulkarnaini, M. A., & Kok, S. K. (2005, 16-21 April, 2005). *The Deformation Study of High Building Using RTK-GPS: A First Experience in Malaysia*. Paper presented at the FIG Working Week 2005 and GSDI-8, Egypt.

Barbarella, M., Bitell, G., Folloni, G., Russo, R., Gubellini, A., & Tomassini, L. (1988). *Deformation Surveys of Landslide Using Terrestial Measurements and Space Techniques*. Paper presented at the The 5th International FIG Symposium on Deformation Measurements, New Brunswick, Canada.

Barnes, J. B., Ackroyd, N., & Cross, P. A. (1998). *Stochastic Modelling for Very High Precision Real-Time Kinematic GPS in an Engineering Environment*. Paper presented at the FIG XXI International Congress, Brighton, England.

Bashor, R., Bobby, S., Kijewski-Correa, T., & Kareem, A. (2012). Full-scale performance evaluation of tall buildings under wind. *Journal of Wind Engineering and Industrial Aerodynamics, 104–106*(0), 88-97.

Basseville, M. (1988). Detecting Changes in Signals and Systems- A Survey. *Automatica, 24*(3), 309-326.

Bendat, J. S., & Piersol, A. G. (1986). *Random Data: Analysis and Measurement Procedures* (2 ed.). Chichester: Wiley.

Betti., Biagi, L., Crespi, M., & Riguzzi, F. (1999). GPS Sensitivity Analysis in Applied to Non-Permanent Deformation Control Networks. *Journal of Geodesy, 73*, 158-167.

Blewitt, G., Heflin, M. B., Hurst, K. J., Jefferson, D. C., Webb, F. H., & Zumberge, J. (1993). Absolute Far -Field Displacements from the 28 June 1992 Landers Earthquake Sequence. *Nature, 361*, 340-342.

Blodgett, J., & Ikehara, M. E. (1989). Monitoring of Land Subsidence in Sacramento Valley, California Using GPS. *Journal of Surveying Engineering, 116*(2), 112-130.

Bock, Y., Agnew, D. C., Fang, P., Genrich, J. F., Hager, B. H., Herring, T. A., Hudnut, K. W., King, R. W., Larsen, S., et al. (1993). Detection of Crustal Deformation from the Landers Earthquake Sequence Using Continuous Geodetic Measurements. *Nature, 361*, 337-340.

Boucher, C., & Altamimi, Z. (1996). ITRF and its Relationship to GPS. from http://schubert.ign.fr:8000/CIAG/WITRF/ITRF-GPS.html

Boucher, K. (1980). *The Wind Environment Around A Tall Building* (No. 3). Loughborough: Department of Geography, Loughborough University.

Breuer, P., Chmielewski, T., Gorski, P., & Konopka, E. (2002). Application of GPS technology to measurements of displacements of high-rise structures due to weak winds. *Journal of Wind Engineering and Industrial Aerodynamics, 90*(3), 223-230.

Brigham, E. O. (1974). *The Fast Fourier Transform*. Englewoods, Cliffs, N.J.: Prentice-Hall, Inc.

Brown, R. G., & Hwang, P. Y. C. (1997). *Introduction to Random Signals and Applied Kalman Filtering* (Third ed.). New York: John Wiley & Sons. Inc.

Brown, C. J., Karuna, R., Ashkenazi, V., Roberts, G. W., & Evans, R. A. (1999). Monitoring of Structures Using GPS. *Proc. Instn. Civ. Engrs Structs & Bldgs, 134*, 97-105.

BS 6399. (1997). Loading for Buildings Part 2. Code of Practice for Wind Loads. London, England: British Standards Institution.

Cannon, M. E., Lachapelle, G., & Szarmes, M. C. (1997). DGPS Kinematic Carrier Phase Signal Simulation Analysis for Precise Velocity and Position Determination. *Navigation: Journal of the Institute of Navigation, 44*(231-245).

Casciati, F., & Fuggini, C. (2008a). Measuring the displacements of a steel structure by GPS units. *Life-Cycle Civil Engineering*, 501-506.

Casciati, F., & Fuggini, C. (2008b). Monitoring an Industrial Steel Building by GPS Receivers. *Proceedings of the Fourth European Workshop on Structural Health Monitoring 2008*, 219-226.

Casciati, F., & Fuggini, C. (2011). Monitoring a steel building using GPS sensors. *Smart Structures and Systems, 7*(5), 349-363.

Caspary, W. F. (1987). *Concepts of Network and Deformation Analysis*. Sydney, Australia: School of Surveying, The University of New South Wales.

Celebi, M. (2000). GPS in dynamic monitoring of long-period structures. *Soil Dynamics and Earthquake Engineering, 20*(5-8), 477-483.

Celebi, M. (2005). *Recent Advances to Obtain Real-Time Displacements for Engineering Applications*. Paper presented at the Structures 2005, New York, New York.

Celebi, M. (2007). Health monitoring of buildings using threshold drift ratios - Now an established method. *Structural Health Monitoring 2007: Quantification, Validation, and Implementation, Vols 1 and 2*, 467-475.

Celebi, M. (2008). Seismic monitoring to assess performance of structures in near-real time: Recent progress. *2008 Seismic Engineering Conference Commemorating the 1908 Messina and Reggio Calabria Earthquake, Parts 1 and 2, 1020*, 848-855.

Celebi, M. (2009). Seismic Monitoring to Assess Performance of Structures in Near-Real Time: Recent Progress. *Seismic Risk Assessment and Retrofitting: With Special Emphasis on Existing Low-Rise Structures, 10*, 1-24.

Celebi, M., Prescott, W., Stein, R., Hudnut, K., Behr, J., & Wilson, S. (1999). GPS Monitoring of Dynamic Behavior of Long-Period Structures. *Earthquake Spectra, 15*(1), 55-66.

Celebi, M., & Sanli, A. (2002a). GPS in pioneering dynamic monitoring of long-period structures. *Earthquake Spectra, 18*(1), 47-61.

Celebi, M., & Sanli, A. (2002b). GPS in Pioneering Dynamic Monitoring of Long Period Structures. *Earthquake Spectra, 18*(1), 47-61.

Chan, W.-S., Xu, Y.-L., Ding, X.-L., Xiong, Y.-L., & Dai, W.-J. (2006). Assessment of Dynamic Measurement Accuracy of GPS in Three Directions. *Journal of Surveying Engineering, 132*(3), 108-117.

Chatfield, C. (1996). *The Analysis of Time Series: An Introduction* (5 ed.): Chapman & Hall, London.

Chen, B., Ng, C. L., Xu, Y. L., Wong, K. Y., & Chan, K. W. Y. (2007). Temperature loading effects on a long span suspension bridge. *Proceedings of International Conference on Health Monitoring of Structure, Materials and Environment, Vols 1 and 2*, 650-656.

Chen, X. (1998). *Continuous GPS Monitoring of Crustal Deformation with the Western Canada Deformation Array: 1992-1995*. New Brunswick: Department of Geodesy and Geomatics Engineering, University of New Brunswick.

Chow, E., & Willsky, A. (1984). Analytical redundancy and the design of robust failure detection systems. *Automatic Control, IEEE Transactions on, 29*(7), 603-614.

Chrzanowski, A. (1985). *Selected Topics in Engeneering Surveys*: Department of Surveying Engeneering, University of New Brunswick, Canada.

Chrzanowski, A., Chen, Y., Leeman, R. W., & Leal, J. (1989). Integration of the Global Positioning System with Geodetic Leveling Surveys in Ground Subsidence Studies. *CISM Journal, 43*(4), 377-386.

Chrzanowski, A., & Chen, Y. Q. (1994). Modeling of GPS Systematic Errors in Monotoring and Control Surveys. *Journal of Surveying Engineering, 120*(4), 145-155.

Cooper, G. R., & McGillem, C. D. (1999). *Probabilistic Methods of Signal and System Analysis* (3 ed.). New York: Oxford Univ. Press.

Cooper, M. A. R. (1987). *Control Survey in Engineering*. London: Collins.

Cooper, M. A. R., & Cross, P. A. (1988). Statistical Concepts and their Application in Photogrammetry and Surveying. *Photogrammetric Record, 12*(71), 637-663.

Cross, P. A. (1983). *Advanced Least Square Applied to Position-Fixing*. London, U.K.: North East London Polytechnic.

Cross, P. A. (1987). Kalman Filtering and its Application to Offshore Position-Fixing. *The Hydrographic Journal, 44*, 19-25.

Cruddace, P. R., Cross, P. A., Veis, G., Billiris, H., Paradissis, D., Galanis, J., Lyon-Caen, H., Briole, P., Ambrosius, B. A. C., et al. (2000). An Interdisciplinary Approach to Studying Seismic Hazard Throughout Greece. 2000

Czompo, J. (1991). Use of Spectral Methods in Strapdown ISS Data Processing. *Bulletin Geodesique*(65), 122-129.

Davenport, A. G. (1998). What Makes a Structure Wind Sensitive. In J. D. Riera & A. G. Davenport (Eds.), *Wind Effects on Buildings and Structures* (pp. 1-13). Rotterdam: A.A. Balkema.

Department of Survey & Mapping. (1999). GPS Cadastral Survey Guidelines, *Circular 6/1999*. Kuala Lumpur: Department of Survey & Mapping.

Duff, K., & Hyzak, M. (1997). Structural Monitoring with GPS. *Public Roads*(Spring 1997).

Dyrbye, C., & Hansen, S. O. (1996). *Wind Loads on Structures*. Chichester, New York, Brisbane, Toronto, Singapore: John Wiley & Sons.

Edwards, S. J., Cross, P. A., Barnes, J. B., & Betaille, D. (1999). A Methodology for Benchmarking Real Time Kinematic GPS. *Survey Review, 35*(273), 163-174.

Egger, K. (1988). *Dam Monitoring and Geodetic Deformation Measurements.* Paper presented at the The 5th Internation FIG Symposium on Deformation Measurements, New Brunswick, Canada.

Elkaim, G., O'Connor, M., Bell, T., & Parkinson, B. W. (1996). *System Identification of a Farm Vehicle Using Carrier-Phase Differential GPS.* Paper presented at the The 9th International Technical Meeting of the Satellite Division of the Institute of Navigation 1996, Kansas City, USA.

El-Rabbany, A. E. (1994). *The Effect of Physical Correlations on the Ambiguity Resolution and Accuracy Estimation in GPS Differential Positioning*. New Brunswick: Department of Geodesy and Geomatics Engineering.

Erdoğan, H., & Gülal, E. (2009). The application of time series analysis to describe the dynamic movements of suspension bridges. *Nonlinear Analysis: Real World Applications, 10*(2), 910-927.

Euler, S. J., & Muller, U. (1996). *Real-time Precise GPS for Railroad Mapping.* Paper presented at the IEEE Position Location and Navigation Symposium (IEEE PLANS 1996).

Eurocode 1. (1991). Eurocode 1: Basis of Design and Actions on StructuresPart 3: Traffic loads on Bridges: British Standards Institution.

Fraser, C. (1996). *Design Aspects of Utilizing Photogrammetry for Deformation Measurements.* Paper presented at the The 8th International Symposium on Deformation Measurement, Hong Kong.

Frei, E., Ryf, A., & Scherrer, R. (1992). *Use of Global Positioning System in Dam Deformation and Engineering Surveys*. Switzerland: Leica.

Fugate, M. L., Sohn, H., & Farrar, C. R. (2001). Vibration-Based Damage Detection Using Statistical Process Control. [doi: 10.1006/mssp.2000.1323]. *Mechanical Systems and Signal Processing, 15*(4), 707-721.

Georgiadou, Y., & Kleusberg, A. (1988). On Carrier Signal Multipath Effects in Relative GPS Positioning. *Manuscripta Geodaetica, 13*, 172-179.

Ghassemi, K., & Fisher, S. C. (1997). *Performance Projection of GPS IIF*. Paper presented at the The 10th International Technical Meeting of the Satellite Division of the Institute of Navigation, Kansas City.

Gili, J. A., Corominas, J., & Rius, J. (2000). Using Global Positioning System Technique in Landslide Monitoring. *Journal of Engineering Geology, 55*, 167-192.

Gobiani, H. (2001). Personal Communication: Leicester City Council.

GPSWorld. (2011). 2010 GPS Receiver Survey. Retrieved November, 2011, from http://www.gpsworld.com/professional-oem/2010-receiver-survey-gps-world-9360

Guo, J., & Ge, S. (1997). *Research of Displacement and Frequency of Tall Building under Wind Load Using GPS.* Paper presented at the The 10th International Technical Meeting of the Satellite Division of the Institute of Navigation, Kansas City.

Guo, J., Xu, L., Dai, L., McDonald, M., Wu, J., & Li, Y. (2005). Application of the Real-Time Kinematic Global Positioning System in Bridge Safety Monitoring. *Journal of Bridge Engineering, 10*(2), 163-168.

Han, S., & Rizos, C. (1995). Standardization of the Variance-Covariance Matrix for GPS Rapid Static Positioning. *Geomatic Research Australasia, 62*, 37-54.

Han, S., & Rizos, C. (2000). GPS Multipath Mitigation Using FIR Filters. *Survey Review, 35*(277), 487-498.

Hartinger, H., & Brunner, F. K. (1998, April 20-22). *Experimental Detection of Deformations using GPS.* Paper presented at the Symposium on Geodesy for Geotechnical & Structural Engineering, Eisenstadt.

Haryono. (1985). *Penubuhan garis dasar untuk pengkalibrasian alat ukur jarak elektronik* Unpublished manuscript, Skudai.

Hasan, J., Azhari, M., & Chang, D. (2010, 11-16 April, 2010). *The Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) in 2010 and Beyond.* Paper presented at the FIG Congress 2010, Sydney, Australia.

Hill, C., & Moore, T. (2000). A Free Receiver Upgrade? - GPS Surveying without Selective Availability. *Surveying World, 8*(5), 21-22.

Hoffmann-Wellenhof, Lichtenegger, H., & Wasle, E. (2008). *GNSS-Global Navigation Satellite Systems*. New York: SpringerWien.

Hofmann-Wellenhof, B., & Lichtenegger, H. (1997). *GPS Theory and Practice* (4 ed.). Wien Austria: Springer-Verlag.

Hsu, P. H. (1996). *The Use of GPS for Monotoring Crustal Deformation.* Unpublished Ph.D., The University of Nottingham, U.K.

Hu, Q. G., & Xu, C. (2009). Application of RTK-GPS Technology in Vibration Characteristics Test of High Pylon. *2009 International Conference on Information Technology and Computer Science, Vol 1, Proceedings*, 79-82.

Hudnut, K. W., Shen, Z., Murray, M., McClusky, S., King, R., Herring, T., Hager, B., Feng, Y., Fang, P., et al. (1996). Co-Seismic Displacements of the 1994 Northridge, California, Earthquake. *Bulletin of the Seismological Society of America, 86*(1B), S19-S36.

Ince, C. D., & Sahin, M. (2000). Real-time Deformation Monitoring with GPS and Kalman Filter. *Earth Planets and Space, 52*, 837-840.

Isermann, R. (1984). Process Fault Detection Based on Modeling and Estimation Methods- A Survey. *Automatica, 20*(4), 387-404.

Jaldehag, R. T. K., Johansson, J. M., & Ronnang, B. O. (1996). Geodesy Using the Swedish Permanent GPS Network: Effect of Signal Scaterring on Estimates of Relative Side Positions. *Journal of Geophysical Research, 101*(B8), 17841-17860.

James, J. F. (1995). *A Student's Guide to Fourier Transforms: with Application in Physics and Engineering*. New York: Cambridge University Press.

Jia, M., Montgomery, B., & Ding, X. (1998). On Realiability Measures for Kinematic Surveys. *Geomatica, 52*, 37-44.

Kahmen, H. (1996, 1996). *New Developments in Instrumentation for Precise Engineering and Deformation Surveys.* Paper presented at the The 8th International FIG Symposium on Deformation Measurements, Hong Kong.

Kaloop, M. R., & Li, H. (2011). Sensitivity and analysis GPS signals based bridge damage using GPS observations and wavelet transform. *Measurement, 44*(5), 927-937.

Kaplan, E. D., & Hegarty, C. J. (Eds.). (2006). *Understanding GPS: Principles and Applications, 2nd Edition* (2nd ed.). Boston, USA: Artech House.

Katowski, O. (1995). *Precision Deformation Measurement with Automatic Monitoring Systems.* Paper presented at the The 5th South East Asia & 36th Australian Surveyors Congress, Singapore.

Kelley, C. W., & Fisher, S. C. (1997). *Orbital Optimization of the GPS Constellation and its Effect on Accuracy and Availability.* Paper presented at the The 10th

International Technical Meeting of the Satellite Division of the Institute of Navigation 1997, Kansas City, USA.

Key, K. W., Born, G. H., Leaman, K. D., & Vertes, P. (1999). A New GPS Data Processing Algorithm for the Positioning of Oceanographic Experiments. [doi: 10.1175/1520-0426(1999)016<1127:ANGDPA>2.0.CO;2]. *Journal of Atmospheric and Oceanic Technology, 16*(8), 1127-1137.

Kijewski-Correa, T., Kareem, A., & Kochly, M. (2006). Experimental Verification and Full-Scale Deployment of Global Positioning Systems to Monitor the Dynamic Response of Tall Buildings. *Journal of Structural Engineering, 132*(8), 1242-1253.

King, N. E., Svarc, J. L., Fogleman, E. B., Gross, W. K., Clark, K. W., Hamilton, G. D., Stiffler, C. H., & Sutton, J. M. (1995). Continous GPS Observations Across the Hayward Fault, California, 1991-1994. *Journal of Geophysical Research, 100*(B10), 20271-20283.

Kleusberg, A., Georgiadou, Y., & Draget, H. (1988). Establishment of Crustal Deformation Networks using GPS: A Case Study. *CISM Journal, 42*(4), 341-351.

Kochly, M., & Kijewski-Correa, T. (2006). Experimental verification of a GPS network: Characterization and removal of multipath effects. *Smart Structures and Materials 2006: Sensors and Smart Structures Technologies for Civil, Mechanical , and Aerospace Systems, Pts 1 and 2, 6174*.

Kondo, H., & Cannon, M. E. (1995). *Real-time Landslide Detection System using Precise Carrier Phase GPS.* Paper presented at the The 8th International Technical Meeting of the Satellite Division of the Institute of Navigation 1995.

Langley, R. B. (1991). The GPS Receiver: An Introduction. *GPS World,* 50-53.

Langley, R. B. (1998). GPS Recievers and the Observables. In J. G. Teunissen & A. Kleusberg (Eds.), *GPS for Geodesy* (pp. 151-185). Berlin, Heidelberg, New York, Barcelona, Budapest, Hong Kong, London, Milan, Paris, Singapore, Tokyo: Springer.

Larocca, A. P. C., R.E., S., & Santos, M. C. (2005, July). Dynamic Behaviour Monitoring of Hawkshaw Bridge Using High-rate GPS Data. *Professional Surveyor, 25*.

Leach, M. P., & Hyzak, M. D. (1994). *GPS Structural Monitoring as Applied to a Cable-Stayed Suspension Bridge*. Paper presented at the FIG XX-International Congress, Melbourne,Australia.

Leick, A. (1995). *GPS Satellite Surveying* (2 ed.). New York , Chichester,Brisbane, Toronto and Singapore: Wiley.

Leick, A. (2004). *GPS Satellite Surveying*. Hoboken, New Jersey, USA: John Wiley & Sons.

Li, X. J., Ge, L. L., Ambikairajah, E., Rizos, C., Tamura, Y., & Yoshida, A. (2006). Full-scale structural monitoring using an integrated GPS and accelerometer system. *Gps Solutions, 10*(4), 233-247.

Liu, C., Meng, X., & Yao, L. (2007). A real-time kinematic GPS positioning based structural health monitoring system for the 32 km donghai bridge in china. *Structural Health Monitoring 2007: Quantification, Validation, and Implementation, Vols 1 and 2*, 1262-1271.

Lovse, J. W., Teskey, W. F., & Lachapelle, G. (1995). Dynamic Deformation Monitoring of Tall Structure Using GPS Technology. *Journal of Surveying Engineering, 121*(1), 35-40.

Martin, W., & Ladd, J. (1997). *GPS+GLONASS Surveying.* Paper presented at the The 10th International Technical Meeting of the Satellite Division of the Institute of Navigation 1997, Kansas City, USA.

Mat Amin, Z. (2003a). *Detection of GPS Multipath Error Using Different Antenna* Paper presented at the Malaysian Science and Technology Congress, MSTC 2003.

Mat Amin, Z. (2003b). *The Effect of GPS Multipath Error on Continuous Monitoring Applications.*: Universiti Teknologi Malaysia.

Mc Donald, K. D. (2002). The Modernization of GPS: Plans, New Capabilities and the Future Relationship to Galileo. *Journal of Global Positioning System, 1*(1), 1-17.

McGown, A., McDonald, H., Milne, P., Duff, K., & Innes, J. (1998). Structural Deformation Monotoring by Land Surveying and GPS. *Surveying World*(Jan/Feb), 32-35.

Mendis, P., Ngo, T., Hariots, N., Hira, A., Samali, B., & Cheung, J. (2007). Wind Loading on Tall Buildings. *EJSE Special Issue: Loading on Structures*, 41-54.

Mertikas, S. P. (2001). Automatic and Online Detection of Small but Persistent Shifts in GPS Station Coordinates by Statistical Process Control. *GPS Solutions, 5*(1), 39-50.

Neilan, R., Heflin, M., Watkins, M., & Zumberg, J. (1996). *The International GPS Service (IGS) as a Continuous Reference System for Precise GPS Positioning*. Paper presented at the ASPRS/ACSM.

Neilan, R. E., Zumberge, J. F., Beutler, G., & Kouba, J. (1997). *The International GPS Service: A Global Resource for GPS Applications and Research*. Paper presented at the he 10th International Technical Meeting of the Satellite Division of the Institute of Navigation 1997, Kansas City.

Neimeier, W. (1981). Statistical Tests for Detecting Movements in Repeatedly Measured Geodetic Networks. *Tectonophysics, 71*, 335-351.

Nichols, M. E. (1996). *Applications for Satellite Positioning Technology in the Construction Industry*. Paper presented at the IEEE Position Location and Navigation Symposium (IEEE PLANS 1996).

Nickitopoulou, A., Protopsalti, K., & Stiros, S. (2006). Monitoring dynamic and quasi-static deformations of large flexible engineering structures with GPS: Accuracy, limitations and promises. *Engineering Structures, 28*(10), 1471-1482.

Nowak, A. S., & Collins, K. R. (2000). *Reliability of Structures*. Boston, Burr Ridge, Duburque,Madison, New York, San Francisco,: Mc-Graw Hill.

O'Brien, E. J., & Keogh, D. L. (1999). *Bridge Deck Analysis*. London, New York: E&FN Spoon.

Ogaja, C. (2001, 11-14 Sept. 2001). *On-line GPS Integrity Monitoring and Deformation Analysis for Structural Monitoring Applications*. Paper presented at the 14th Technical Meeting of the Satellite Division of the US Inst. of Navigation, Salt Lake City, Utah, USA.

Ogaja, C., Chris, R., Jinling, W., & Brownjohn, J. (2001). GPS and Building Monitoring Case Study: Republic Plaza Building, Singapore. *Australian Surveyor*.

Ogaja, C., Wang, J., & Rizos, C. (2003). Detection of Wind-Induced Response by Wavelet Transformed GPS Solutions. *Journal of Surveying Engineering, 129*(3), 99-104.

Omar, K., Jhonny, & Mohamed, A. (2010). *Post Seismic Deformation Monitoring in Peninsular Malaysia Using Global Positioning System*. Paper presented at the International Symposium on GPS/GNSS 2010.

Parkinson, B. W., & Spilker, J. J. (Eds.). (1996). *Global Positioning System: Theory and Applications Volume 1* (Vol. 1). Washington, USA: American Institute of Aeronautics and Astronautics, Inc.

Piechocinski, J., & Jonsson, B. (1993, May, 1993). *Measurement of Deformation by the Use of GPS.* Paper presented at the 7th International FIG Symposium on Deformation Measurements, Banff, Canada.

Press, W. H., Flannery, B. P., Teukolsky, S. A., & Vetterling, W. T. (1986). *Numerical Recipes, The Art of Scientific Computing*. New York: Cambridge Univ. Press.

Protopsalti, K., Nickitopoulou, A., Psimoulis, P. A., Pytharouli, S., Kontogianni, V., Triantafillidis, P., & Stiros, S. (2004, 28 June - 1 July, 2004). *Accuracy of Simple GPS Kinematic Techniques: Evidence from Experiments, and Implications for the Study of Large Flexible Engineering Structures*, 1st FIG International Sympsosium on Engineering Surveys for Construction Works and Structural Engineering.

Psimoulls, P., Pytharouli, S., Karambalis, D., & Stiros, S. (2008). Potential of Global Positioning System (GPS) to measure frequencies of oscillations of engineering structures. *Journal of Sound and Vibration, 318*(3), 606-623.

Psimoulis, P. A., & Stiros, S. C. (2008). Experimental Assessment of the Accuracy of GPS and RTS for the Determination of the Parameters of Oscillation of Major Structures. *Computer-Aided Civil and Infrastructure Engineering, 23*(5), 389-403.

Randall, B. (1997). *Real Time Kinematic Positioning in Hydrographic Surveys Using DGPS-Some Problems.* Paper presented at the First Tran Tasman Surveyors Conference, 38th Australian Surveyors Congress, Newcastle, Australia.

Rayner, J. N. (1971). *An Introduction to Spectral Analysis*. London: Pion.

Riera, J. D., & Davenport, A. G. (Eds.). (1998). *Wind Effects on Buildings and Structures*. Rotterdam: A.A. Balkema.

Rizos, C., Galas, R., & Reigber, C. (1996). *Design Challenges in the Development of a GPS-Based Volcano Monitoring System.* Paper presented at the The 8th Internation FIG Symposium on Deformation Measurements, Hong Kong.

Rizos, C., Han, S., & Roberts, C. (1997). *Permanent Automatic Low-Cost GPS Deformation System: Error Mitigation Strategies and System Architecture.* Paper presented at the The 10th International Technical Meeting of the Satellite Division of the Institute of Navigation, Kansas City, USA.

Roberts, G. W., Meng, X., & Dodson, A. H. (2000, September 2000). *Structural Dynamic and Deflection Monitoring Using Integrated GPS and Triaxial Accelerometers.* Paper presented at the Proc. ION-GPS 2000 The 13th International Technical Meeting of the Satellite Division of the Institute of NAvigation, Salt Lake, USA.

Roberts, G. W., Meng, X., & Dodson, A. H. (2001). *The Use of Kinematic GPS and Triaxial Accelerometers to Monitorr the Deflections of Large Bridges.* Paper presented at the The 10th FIG International Symposium on Deformation Measurements.

Roberts, G. W., Meng, X., & Dodson, A. H. (2004). Integrating a Global Positioning System and Accelerometers to Monitor the Deflection of Bridges. *Journal of Surveying Engineering, 130*(2), 65-72.

Roberts, W. D. S., & Cross, P. A. (1993). The Effect of DGPS Temporal Correlation within the Kalman Filter Applied to Offshore Positioning. *The Hydrographic Journal, 67*, 5-11.

Ryall, M. J. (2000). Loads and Load Distribution. In M. J. Ryall, G. A. R. Parke & J. E. Harding (Eds.), *Manual of Bridge Engineering* (pp. 43-94). London: Thomas Telford Publishing.

Sakurai, S., & Hamada, K. (1996). *Monitoring Slope Stability by Means of GPS.* Paper presented at the 8th Internation FIG Symposium on Deformation Measurements, Hong Kong.

Salas, J. D., Delleur, J. W., Yevjevich, V., & Lane, W. L. (1980). *Applied Modeling of Hydrologic Time Series*. Colorado, USA: Water Resources Publication, LLC.

Salzmann, M. A. (1994). A Real-Time Quality Control Procedure for Use in Integrated Navigation Systems. *The Hydrographic Journal, 72*, 25-30.

Savitsky, A., & Golay, M. J. E. (1964). Smoothing and Differentiation of Data by Simplified Least Squares Procedures. *Analytical Chemistry, 36*(8), 1627-1639.

Savvadis, P., Martinond, J., Katsambalos, K., Hatzfeld, D., Badellas, A., & Tokmakidis, K. (1997). Determination of Ground Displacement in the Seismic Zone of Volvi, Greece. *Survey Review, 34*(266), 229-236.

Schenewerk, M. S., MacKay, J. R., Kass, W., Chin, M., & Mader, G. (1997). Rapid Turnaround GPS Ephemerides from the National Geodetic Survey. 1997, from http://www.ngs.noaa.gov/CORS/ion.html

Scwieger, V. (1996). *An Approach to Determine Correlations between GPS Monitored Deformation Epochs.* Paper presented at the The 8th International Symposium on Deformation Measurement, Hong Kong.

Seco, A., Tirapu, F., Ramirez, F., Garcia, B., & Cabrejas, J. (2007). Assessing building displacement with GPS. *Building and Environment, 42*(1), 393-399.

Shiavi, R. (1999). *Introduction to Applied Statistical Signal Analysis* (2 ed.). San Diego: Academic Press.

Shih, T. Y., Ko, J. B., & Shih, H. Y. (2000). The FFT Based Methods for DEM Analysis of Translations Between Reference Coordinate Systems. *Geomatics Research Australia, 72*(June), 61-70.

Shimizu, N., Mizuta, Y., Condo, H., & Ono, H. (1996). *A New GPS Real-Time Monitoring System for Deformation Measurements and its Application.* Paper presented at the 8th Internation FIG Symposium on Deformation Measurements, Hong Kong.

Sohn, H., Fugate, M. L., & Farrar, C. R. (2000). *Continuous Stuctural Monitoring Using Statistical Process Control*. Paper presented at the IMAC 18.

Steinberg, G., & Papo, H. B. (1988). *Survey of Vertical Deformation by GPS and Precise Levelling.* Paper presented at the 5th Internation FIG Symposium on Deformation Measurements, New Brunswick, Canada.

Stewart, M. P. (1998). The Application of Antenna Phase Centre Models to the West Australian State GPS Network. *Geomatics Research Australasia, 68*, 61-78.

Stiros, S., & Moschas, F. (2011). Measurement of the dynamic displacements and of the modal frequencies of a short-span pedestrian bridge using GPS and an accelerometer. *Engineering Structures, 33*(1), 10-17.

Stiros, S., Nickitopoulou, A., & Protopsalti, K. (2006). Monitoring dynamic and quasi-static deformations of large flexible engineering structures with GPS: Accuracy, limitations and promises. *Engineering Structures, 28*(10), 1471-1482.

Stiros, S., & Psimoulis, P. (2008). Experimental assessment of the accuracy of GPS and RTS for the determination of the parameters of oscillation of major structures. *Computer-Aided Civil and Infrastructure Engineering, 23*(5), 389-403.

Strang, G., & Borre, K. (1997). *Linear Algebra, Geodesy, and GPS*. Wellesley, USA: Wellesley-Cambridge Press.

Tamura, Y., Matsui, M., Pagnini, L.-C., Ishibashi, R., & Yoshida, A. (2002). Measurement of wind-induced response of buildings using RTK-GPS. *Journal of Wind Engineering and Industrial Aerodynamics, 90*(12-15), 1783-1793.

Teskey, W. F., & Porter, T. R. (1988, 1988). *An Integrated Method for Monitoring the Deformation Behavior of Engineering Structures.* Paper presented at the 5th Internation FIG Symposium on Deformation Measurements, New Brunswick, Canada.

Teunissen, P. J. G. (1990). Quality Control in Integrated Navigation Systems. *IEEEE AES Magazine*(July), 35-41.

Teunissen, P. J. G., & Salzmann, M. A. (1989). A Recursive Slippage Test for Use in State-Space Filtering. *Manuscripta Geodaetica, 14*, 383-390.

Tiberius, C. C. J. M. (1998). Quality Control in Positioning. *The Hydrographic Journal, 90*, 3-8.

Ting Hua, Y., Hong Nam, Li & Ming, GU. (2010). Full-scale measurements of dynamic response of suspension bridge subjected to environmental loads using GPS technology. *Sci China Tec Sci, 53*(2), 469-479.

Tsakiri, M., Lekidis, V., Stewart, M., & Karabelas, J. (2003, 2003). *Testing Procedures for the Monitoring of Seismic Induced Vibrations on Cable-*

stayed Highway Bridge. Paper presented at the 11th FIG Symposium on Deformation Measurement, Santorini, Greece.

Van Diggelen, F. (1997). *GPS and GPS+GLONASS RTK*. Paper presented at the The 10th International Technical Meeting of the Satellite Division of the Institute of Navigation 1997, Kansas City, USA.

Ware, R., Alber, C., Rocken, C., & Solheim, F. (1997). GPS Surveying with 1 mm Precision Using Corrections for Atmospheric Slant Path Delay. *, Geophysical Research Letters, 24*(15), 1859-1862.

Wasilewski, A., Oszczak, S., Rzepecka, Z., & Baran, W. (1996). *Application of GPS Technique to Displacement Studies of a Horizontal Control Network of Polish Copper Basin Area*. Paper presented at the The 8th Internation FIG Symposium on Deformation Measurements, Hong Kong.

Watson, C., Watson, T., & Coleman, R. (2007). Structural monitoring of cable-stayed bridge: Analysis of GPS versus modeled deflections. *Journal of Surveying Engineering-Asce, 133*(1), 23-28.

Wells, D. E., Beck, N., Delikaraoglou, D., Kleusberg, A., Krakiwsky, E. J., Lachapelle, G., Langley, R. B., Nakiboglu, M., Schwarz, K. P., et al. (1987). *Guide to GPS Positioning*. New Brunswick, Canada: Canadian GPS Associates.

Wendt, J., & Dietrich, R. (1997). *Geodetic Investigations on Recent Crustal Deformations in the Saxon Part of the Vogtland*. Paper presented at the The 4th International Seminar 'GPS in Central Europe', Penc, Hungary.

Westgard, J. O., Groth, T., Aronsson, T., & Verdler, C. (1977). Combined Shewhart-Cusum Control Chart for Improved Quality Control in Clinical Chemistry. *Clinical Chemistry, 23*(10), 1881-1887.

Wiederholt, L. F., & Kaplan, E. D. (1996). GPS System Segments. In E. D. Kaplan (Ed.), *Understanding GPS: Principles and Applications*. Boston, USA: Artech House Publishers.

Wilson, J. R. (2010). New capabilities for GPS II/III. *Aerospace America, 48*(2), 32-36.

Wiss, J. F., & Curth, O. E. (1970). Wind Deflections of Tall Concrete Frame Buildings. *Journal of the Structural Division, Proc. of the ASCE Society of Civil Engineers, 96*(ST7), 1461-1481.

Xu, Y. L., Chen, B., Ng, C. L., Wong, K. Y., & Chan, W. Y. (2010). Monitoring temperature effect on a long suspension bridge. *Structural Control & Health Monitoring, 17*(6), 632-653.

Yi, T. H., Li, H. N., & Gu, M. (2010a). Full-scale measurements of dynamic response of suspension bridge subjected to environmental loads using GPS technology. *Science China-Technological Sciences, 53*(2), 469-479.

Yi, T. H., Li, H. N., & Gu, M. (2010b). Recent research and applications of GPS based technology for bridge health monitoring. *Science China-Technological Sciences, 53*(10), 2597-2610.