# High Rise Building Deformation Monitoring With GPS

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## Abstract

The timely identification of deformation associated with geologic hazards or ground settlement can save lives, avert large financial liabilities and avoid severe environmental damage. Nowadays, it is tempting to consider whether the GPS technology has an important role to play for monitoring the tall buildings still under normal behavior. The advantage of using GPS technology is that it can detect if the structure has drifted until a few centimeters. Besides that, GPS provides cost effective and 3D information that will useful for engineering geologists. A discussion is presents the study on the suitability of using GPS technology for detecting the displacement of the tall buildings and GPS based methods for the monitoring and modeling of the dynamic structures likes high-rise buildings.

**Keywords : GPS, Deformation monitoring, High Rise Building.**

## 1.0 Introduction

Deformation refers to the changes a deformable body undergoes in its shapes, dimension and position. Large engineering structures are subject to deformation due to factors such as changes of ground water level, tidal phenomena, tectonic phenomena, land movements, or any other natural disasters. The large engineering structures may include dams, long span bridges, high rise buildings, reservoirs, sport domes, planetariums, Olympic stadium etc. Therefore it is important to measure this movement for the purpose of safety assessment as well as preventing any disaster in the future.

High-rise building is a multistory building tall enough to require the use of a system of mechanical vertical transportation such as elevators. Although originally designed for commercial purposes, many high-rise buildings are now planned for multiple uses.

The foundation of high-rise buildings must support very heavy gravity loads and they usually consist of concrete piers, piles or caissons that are sunk into the ground. The most important factor in the design of high-rise buildings is the building's need to withstand the lateral forces imposed by winds and potential and ground movements. Most high-rise buildings have frames made of high strength steel and concrete. So, monitoring the tall buildings is very important works to ensure the buildings still under normal behavior.

## 2.0 GPS And Its Application In Monitoring Studies

The Global Positioning System (GPS), sometimes also called NAVSTAR (NAVigation System using Time And Ranging) is a space-based navigation system created and developed by the US Department of Defense (DoD) for real time navigation since the end of the 70's. For the past ten years, the GPS has made a strong impact on the geodetic world. The main goal of the GPS is to provide worldwide, all weather, continuous radio navigation support to users to determine position, velocity and time throughout the world (Hofmann-Wellenhof, 1986).

With recent full constellation of GPS satellites, processing software of satellite signals available, the differential measurement of the satellite signals using geodetic type of GPS receivers will provide any baseline vector with high precision at millimeter level (Leick 1998).

Based on the realistic mathematical model, the most probable value of parameters (coordinates of points) and their covariance matrix can be computed. Also, any quantity used in deformation (or may be slope stability) modeling such network sensitivity and its reliability can also be determined (Caspary, 1987; Halim & Ranjit, 2001).

In basic approaches to geometrical analysis the displacements at discrete points are directly compared with specified tolerances. In more advanced analyses, the point displacements are assessed for spatial trend, and a displacement field is determined by the fitting of a suitable spatial function. The displacement field may then be transformed into a strain field, which provides a unique description of the overall change in geometric status, by the selection of a suitable deformation model (Chrzanowski et al., 1986).

At present, instead of static deformation monitoring approaches, continuous dynamic deformation monitoring methods have been increasingly used to understand natural events such as landslides and to monitor the stability of manmade structures such as building, bridges and dam (Leick., 1998; Bock and Bevis, 1999).

Structural monitoring serves several purposes. For example, it can provide structural response data allowing for the as-built performance to be checked against design criteria, which will be an increasingly useful exercise given the move towards 'performance based design' of structures. Over a long period monitoring can also provide the opportunity to identify 'anomalies' or 'novelties' that may signal unusual loading conditions or modified structural behaviour, which can in the extreme case include damage of failure. A final use is to provide data for calibrating design codes. For the first application, the performance of the building has already been checked against the design and a complete understanding of the way the structure behaves has been obtained (Brownjohn & Pan, 2001). For the second case, procedures are being developed to detect anomalies, but in this case a major value is for the calibration of local design codes.

Recent reports by investigators describe how high precision GPS sensors deployed on large engineering structures (such as dams, bridges, towers and tall (buildings) can provide continuous real-time measurements, which can, in turn, be used to indicate displacements and vibrations caused by temperature changes, wind loading, distant earthquakes, landslides, etc. This information can be made available to the system manager, or interested parties, on a continuous basis, or whenever a preset displacement threshold is exceeded. The response of the structure can then be assessed according to the displacement thresholds reached or the changed dynamic characteristics. In the case of an alarm, the system manager can make a decision to, for example, close the structure for further inspection. This creates an opportunity for real-time structural health monitoring, and therefore leads to enhance public safety (Ogaja, 2001).

High precision dynamic Real Time Kinematic (RTK-GPS) system has been installed to complement existing structural monitoring instrumentation at the Republic Plaza Building, Singapore. The purpose of the GPS system is to provide, to a subcentimetre accuracy, and at a rate of up to 10 samples per second, position vectors with respect to a fixed base station, of two antennas installed on the building parapet. The system will be operated in parallel with, and linked to, an existing logging system that records signals from accelerometers and anemometers. The system is intended to be 'open' to future software-based improvements in positional accuracy determination (Ogaja et. al, 2001).

Real-time GPS technology is an important development to aid continuous deformation monitoring, where the timely detection of any deformation is critical. The kinematic/dynamic parameters of deformation are computed in order to the predict failure events. Hence the use of the Kalman Filter for the estimation of the state vector of a deformation object is very convenient (Grewal and Andrews, 1993).

The Kalman Filter was designed to estimate the linear dynamic systems (Kalman, 1960; Kalman and Bucy, 1961). According to Grewal and Andrews (1993), the Kalman Filter is an estimator for what is called the linear-quadratic Gaussian, while Maybeck (1979) claims that the Kalman Filter is simply an optimal recursive data processing algorithm.

The Kalman Filter provides a method for combining in an optimum fashion all the information available up to and including the time of the latest measurement to provide an estimate at that time. In addition to the measurements, information about the dynamic of the process, statistics of the disturbances involved, and a priori knowledge of the quantities of interest are included in the problem formulation. If the dynamics can be described by linear differential of difference equations and if the disturbances have Gaussian distributions, the resulting estimate is both a maximum likehood and minimum variance estimate (Jansson, 1998).

There are three estimation problems can be solved using Kalman Filter algorithms (Cross, 1983):

i. Filtering – the estimate of the state vector at time $t_k$ using the measurements at all epochs up to and including time $t_k$.
ii. Prediction – the estimation of the state vector at time $t_j$ after the last set of measurements at epoch $t_k$ ($t_j > t_k$).
iii. Smoothing – the estimate of the state vector at time $t_i$ using all the available sets of measurements from the first to last epochs at times $t_1$ and $t_n$ respectively ($t_1 \leq t_i \leq t_n$).

## 3.0 Simulation Test And Tesing of The Program

During the time periods for this study, researches that will carried out includes the literature review towards the concept of GPS and deformation surveying, understanding of the usage of the GPS instrumentation and also data observation. In this research, the GPS instrumentation that been used is Leica 500 System. The observed data will be processed using certain software or developed program. Analysis is made on the results of the data. Lastly, a conclusion of this research is made.

The program have been developed by using Matlab version 6.1 and based on the kalman filter technique during the preliminary study. The developed program will be read input data from GPS receiver for post-processing and performs deformation analyses with the help of kalman filter. The program still needs be improved in order to perform better deformation analysis.

In this study, deformations are detected according to the results calculation of the developed program. There are two type of the output results will be created for deformation analysis, i.e the report (Figure 1.0) and a graph (refer Figure 2.0). For RTK point positioning, there will be a lot of positioning data over the whole observation period. The positioning data will be analyzed in the developed program. Every set of positioning data will be analyzed before moving onto the next set of positioning data for the same point. Figure 1.0 shows the Global Test and the Single Point Test for a set of positioning data. If the Global test passed, then the Single-Point test will be carried out. If the Global test failed, the data processing will skip Single-Point test and analyze the next set of positioning data and so forth. Single-point test comprised of six-analysis components, which is X, Y, Z, Vx (velocity of X-axis), Vy (velocity of Y-axis) and Vz. (velocity of Z-axis) If all statistical test of all six components are smaller than t-table, then it can be considered as no deformation. If any of the six components has values larger than t-table, there are some displacements about the point.

Figure 2.0 shows the graphs of deformation detection. If the waveforms in the graph are steady and consistent, then it can be assumed that the point is stable. However, if the waveforms in the graphs jump from its original consistent path and become consistent in the new path, then there is some detectable deformation.

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------------Global Test ( 11:18:55 ) -------------
  0.13 (Tcalculate) < 1.000 (Table-F)
  Global Test Passess!

--------------Single Point Test-------------------
Difference     t-calculate     t-table      Result
     0.003            0.16      1.96        Stable
    -0.008            0.49      1.96        Stable
     0.004            0.14      1.96        Stable
     0.005            1.77      1.96        Stable
     0.001            0.33      1.96        Stable
     0.007            1.56      1.96        Stable
```

Figure 1.0 : Report Of The Calculation

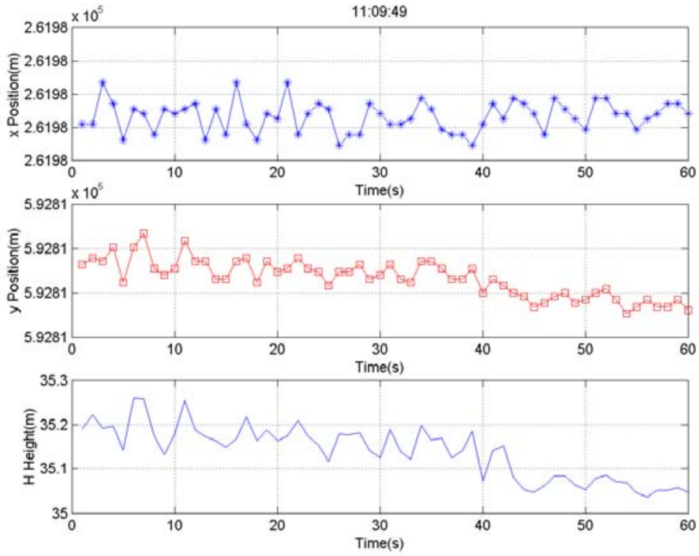


Figure 2.0 : Graph of Deformation Detection

## 4.0 Summary And Conclusion

Deformation is defined as the changes in shapes, dimension and position in geometrical or physical aspect. It is important to measure these movements for the purpose of safety assessment and validation of design assumption. A high accuracy survey is carried out in deformation measurement because the magnitude of deformation is usually very small. A continuous survey is required to determine the magnitude of deformation. In this study, the RTK-GPS has been carried out to accomplish the deformation monitoring at high-rise building and the Kalman Filter technique is used for data analysis.

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