

# **A Study On A Simple and All-Round GPS-Based Structure Monitoring System**

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## **Abstract**

Numerous accidents and disasters in the past have called for the need of structure to serve as an alarm or early-warning system. The monitoring could be categorised into normal (or non-urgent) and urgent monitoring schemes, depending on the case of monitoring, such as, the age and integrity of the monitored objects as well as the external load sustained by the monitored objects. This paper describes a GPS-based structure monitoring system, which is currently being developed at UTM, to undertake both normal and urgent monitoring survey. The normal monitoring scheme is performed as a regular check up when the monitored object is considered as healthy (or stable). In this case, the observations are preferentially carried out periodically and the results are obtained via post-processing (by using GPSAD2000). However, urgent monitoring scheme is performed when the stability status or integrity of the structure is questionable. Consequently, the online and continuous observation will be performed to provide the near real-time results. On the other hand, to serve the purpose of the study of structural dynamic response, other than providing the time-domain analysis, by using Fast Fourier Transform (FFT), the analysis could also be done in frequency domain. The research is the pilot study on the all-round GPS-based monitoring system.

## **1.0 Introduction**

According to a study from the Ministry of Science, Technology and Innovation, Malaysia, the use of non-destructive testing (NDT) in inspecting concrete is not as common as in the metallic construction. This may be due to lack of demand or no specific requirement by code or standard from the related sectors as compared to metallic construction. Nevertheless, the accidents and disasters such as Highland Towers, tsunami, landslides, Singapore Hotel New World, Thailand Royal Plaza Hotel and Singapore Nicoll Highway in the past have showed how crucial and important the alarm system is.

Structural health monitoring (SHM) is a more modern version of NDT (Thomas Hay, 2004). In practice, NDT will be launch onto the concrete structure when their integrity are found to be questionable to have a detail diagnosis of the structure. Nevertheless, the essence of SHM technology is to develop autonomous built-in systems for the continuous real-time monitoring, inspection, and damage detection of structures with minimum labor involvement (Chang, 1997, Summary Report on the first International Workshop on Structural Health Monitoring)<sup>1</sup>. For the safety measure, the alarm system should have to be installed in the area or on the structure as the embedded early-warning system.

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<sup>1</sup> Quoted in "A Probabilistic Approach to Damage Localization in Structural", Hussein Said Harb, 2005, North Carolina State University.

This paper describes how GPS can be employed to serve as an all-round structure monitoring system. A prototype, Sparrow, which is particularly designed based on the concept of SHM, have been developed in UTM. Sparrow provides the automated (for urgent monitoring), online, continuous and real-time (for urgent monitoring) solution.

Basically, Sparrow consists of two major segments: field segment and system segment. The field segment comprises four discrete components: Slave, Master, Checker and Control Centre; the system segment comprises two distinct components: Conveyor and Compiler. Figure 1 shows the structure of Sparrow.

Sparrow is developed in Visual Basic environment. For the pilot study, this research doesn't focus on developing raw GPS data processing algorithm. Sparrow uses the output computed by the commercial GPS firmware and software. In this study, Trimble GPS is the commercial equipment employed. The software are inclusive of Trimble Geomatics Office (TGO), GPS Configurator and Trimble Reference Station.

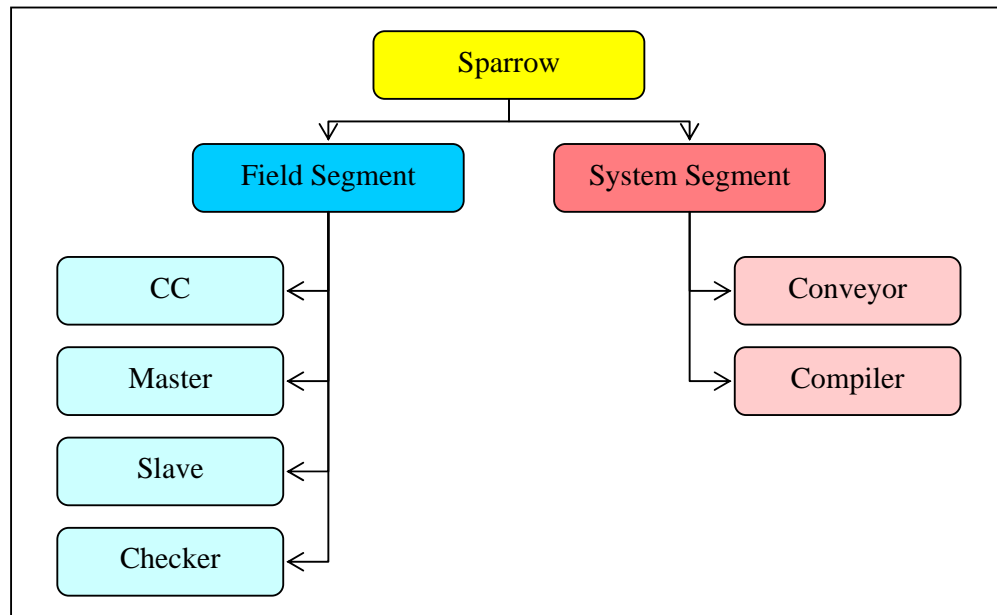


Figure 1: Structure of Sparrow

## 2.0 The Structure of Sparrow

### Field Segment

Slave station is the station set on the monitored object. Master station is the reference station to the entire Slave station. Checker station is the station used to check the stability of Master station. Control centre is the platform where all analyses and results are presented. Figure 2 below illustrates the layout or distribution example of the field segment components.

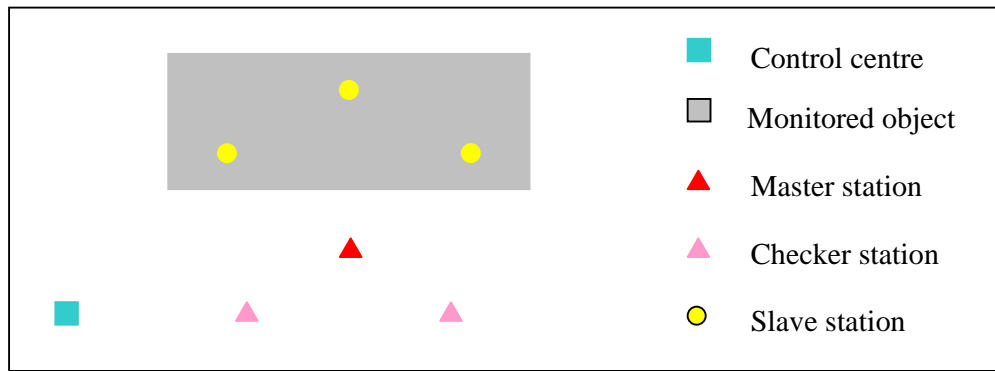


Figure 2: Example of the field segment components layout.

### System Segment

Conveyor is the component to collect the data (RINEX file or NMEA message) from the GPS receivers, archive the collected data, to convert the collected data into Compiler readable (for urgent monitoring) and transfer the collected data to Compiler.

In the cases of urgent monitoring, the receiver will be configured into output mode and NMEA message will be collected. Before the data are transferred to Compiler, Conveyor will filter off the useless information and transform coordinate from global datum (GDM2000) to local datum (RSO) which is more understandable in Malaysia. On the other hand, in the cases of normal monitoring, Conveyor will directly archive the collected RINEX files to Compiler and the RINEX files will only be transferred to control centre manually and remotely when the user is to study the displacement trend.

The data transfer from Conveyor to Compiler is done via the input and output (I/O) port by using standard Transmission Control Protocol/Internet Protocol (TCP/IP). In addition the whole system is installed with the remote computer control. All the stations are well connected with each others. Therefore user at the control centre is able to remotely collect the RINEX files manually.

Compiler is the component installed at the Control Centre. Compiler is responsible to process the data received from Conveyor and present the analyses and results. For the cases of urgent monitoring and dynamic response study, the processing will be performed automatically by the Compiler. However, for the cases of normal monitoring, user will have to process the data manually using GPSAD2000 which is embedded in the Compiler.

GPSAD2000 (Halim and Bong, 2000) is the software formerly developed in UTM. The main features of GPSAD2000 are least squares estimation (LSE) of GPS baseline vectors, 3-D deformation detection (via congruency testing) and graphical visualization.

### 3.0 3 + 1 Suited Cases

The pilot study focuses on the all-round structure monitoring system where the aim is to serve 3 (normal, urgent and normal-turned-urgent) + 1 (structural dynamic response study) cases of monitoring as follow.

## Normal monitoring

Sparrow is though not able to perform the automated analysis and result presentation by using static GPS method. Nevertheless, normal monitoring allows the post-processing to obtain the off-line results. The analysis could be done by using GPSAD2000.

## Urgent monitoring

Sparrow is predominantly designed to provide online and continuous observation as well as the instant result (near real-time solution). Sparrow is thus able to perform the urgent monitoring scheme.

## Normal-turned-urgent monitoring

The main strength of Sparrow is its capability to be employed in the normal-turned-urgent monitoring. Normal-turned-urgent monitoring is the case where the integrity or stability of the monitored object is found to be doubtful and for the sake of precaution the normal monitoring needs to be turned to urgent monitoring. In this case, Sparrow is able to cope without any extra effort to put in. This is because all the GPS receivers have been well set up at the monitored object and well connected as well as controlled by the control centre. Users can switch the survey mode at the control centre without going to the field.

## Structure dynamic response study

Dynamic response of the structure (e.g. tower and tall building) today may have interest a lot of relevant agencies. Traditionally accelerometers have been widely used for the dynamic response of structure. Nevertheless, an integration process is normally required to arrive at the relative static displacements, and thus accelerometers cannot offer online solutions (Li, X. et al, 2003). Preliminary studies have proved the technical feasibility of using GPS to monitor dynamic structural response due to winds, traffic, earthquakes and similar loading events (Ashkenazi & Roberts, 1997; Tamura et al., 2002)<sup>2</sup>. Therefore it is an advantage of GPS, although it may not be as good as other devices in other terms.

## 4.0 Functionality

### Stability Checking of Single Reference Station

When come to the urgent monitoring, stability of the reference stations are always questionable. The worries are there because sometimes mistakes can happen when the only reference station is being disturbed or deformed while the Slave stations are in good condition. To prevent this mistake, the reference station can be checked from time to time with the Checker stations (at least two). The checking can be done manually by using the embedded GPSAD2000. If the existing reference station is found to be disturbed or deformed or displaced, one of the checker stations can be used to replace the existing reference station while preparing for another new station (either Master or Checker). The replacement can be done on the spot because all the stations are well controlled by control centre.

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<sup>2</sup> Quoted in "Integration of GPS, Accelerometer and Optical Fibre Sensors for Structural Deformation Monitoring", Li, X. et al, 2003.

## Flexible and Scaleable

When come to the larger area of monitoring where the baseline length may exceed 5km, the accuracy and the precision of the data are even less promising with single reference station. In this case, the matter may be resolved by converting the Master and Checkers into multi-tasking reference stations. They will be functioned as the Master stations (to their Slaves) as well as the Checker stations (among themselves). Figure 3 below illustrates the multi-tasking reference stations.

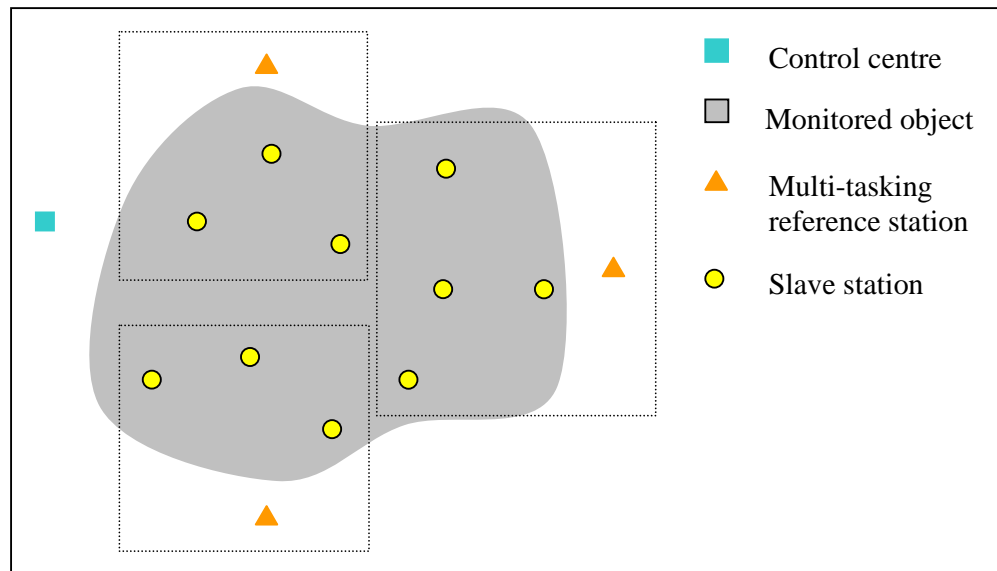


Figure 3: Multi-tasking reference station.

## The local and global threshold

Sparrow provides two thresholds, local threshold and global threshold, as the observer of the safety measure. Continuous RTK data keep on varying. Local threshold is adaptable to the variation of RTK data as it is based on the mean (average) of every incoming datasets. Global threshold is rigid. It is used to detect the deformation which occurs very gradually. In some circumstances, local threshold may not be able to detect the slow deformation as it may be adaptable to the changes.

## Versatile analysis

Although the outcome of GPS method doesn't diagnose the health of the monitored structure as directly as do other methods (e.g. ultrasonic, acoustic emission, radiography, magnetic, etc.), it, with lower cost, helps analyse the movement or displacement of the monitored structure by providing the complementary feedback of its response. Over a certain period of observation, the displacement trend (magnitude, direction and velocity) analysis could be obtained. Other than providing the time-domain analysis, by using Fast Fourier Transform (FFT), it could also be done in frequency domain.

## Total result presentation

In monitoring survey, the end users are more often than not familiar with the geodetic method. The user-friendliness of the analysis as well as result presentation is important.

Sparrow presents the analyses and results in both numerical and graphical formats. In addition, Sparrow also offers the latest (updating) and history (past) options. The updating option shows the last 20 outputs; the history option holds the entire hourly-grouped outputs.

## 5.0 Conclusion

This research is the kick-start of the study on all-round GPS-based monitoring system and Sparrow is the prototyping project. As the result, there is still room for improvement. The GPS receiver configuration could be performed by using the Trimble Standard Interface Protocol (TSIP) and the algorithm of baseline processing, least square estimation as well as deformation detection could be developed in a single module so that the normal monitoring scheme will be performed in automated mode in preference to manual mode. In addition, the schedule of performing the normal monitoring scheme will also be better organised as it is the online and automated solution. In short, the normal monitoring as the regular check up will be done in accordance to the preset timer automatically, such as daily check up. As the result, once the regular check up indicates that the integrity of the monitored object is doubtful, the relevant agencies will be informed instantly so that the users can have the option whether to turn to urgent monitoring at the first moment (or even automatically) or not. On the other hand, the algorithm should be developed in C++ environment which will give the faster and more stable performance.

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