THE UTILIZATION OF RTK-GPS FOR REAL-TIME STRUCTURAL HEALTH DETECTION

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ABSTRACT: As safety precautions, the need for rapid assessment of the state of large engineering structure after extreme events such as earthquake, tsunami, typhoon or related wind effects is highly demanded. Compared to other often used practices such as acceleration integration method, laser distance gauge method and total station method, it is noted that GPS through static surveying technique is capable of providing 0.05 Hz of sampling frequency with location precision of 5~10 mm. Apparently, with the advent of Real-Time Kinematic (RTK-GPS) technique, deformations of various structures such as dams, wide span bridges, highways and high rise buildings can be monitored in real-time mode with 3D positioning accuracy of 10 mm ± 1 to 2 ppm (horizontally) and 15-20 mm ± 2 ppm (vertically). This paper therefore leads to a better understanding on RTK-GPS through simulation test made on a bridge in Universiti Teknologi Malaysia (UTM) campus. For the purpose of real-time structural health detection, well-calibrated GPS Trimble™ 4800 dual-frequency receivers and Pacific Crest™ radio modems were used in this study. By applying static survey mode to determine true coordinates in which will be used latter as "reference", the test was then conducted in real-time using RTK-GPS mode. It is noted that GPS through the utilization of RTK-GPS is potentially capable of being deployed as an effective tool in structural health detection.

KEYWORDS: RTK-GPS, structural health detection

1. INTRODUCTION

Large engineering structure such as dams, wide span bridges, highways and high rise buildings are subject to structural displacements due to deformations generated by the lateral forces imposed by strong winds, temperature variation, load change and earthquakes excitation. Deformation in which refers to the changes of a deformable body (natural or man-made objects) undergoes in its shapes, dimensions and positions, happens in two general conditions i.e. absolute and relative displacement. The physical condition or health of structural engineering can be monitored using several techniques; each with its own advantages and limitations. Apparently, compared to other often used practices such as acceleration integration method, laser distance gauge method and total station method, it is suggested that the NAVSTAR Global Positioning System (GPS) is potentially capable of being deployed as an effective tool in structural health detection. This is due to the worldwide availability of its signal coverage in which has been mainly responsible for rapid developments in various fields of applications. These include not only for engineering, surveying and mapping applications but also for the purpose of highly precise applications such as crustal earth deformation study and structural health detection and monitoring. In parallel to the active development of receiver technology, series of investigations have been conducted to study the performance of GPS for structural health detection. These include Leach & Hyzak, (1994); Lovse et al. (1995); Guochang, (2003), Ashkenazi et al. (1998), Nakamura, (2000), Tamura et al., (2002), Mat Amin et al. (2002), Mat Amin & Wan Akib (2003), Mat Amin et. al. (2007), Breuer et al. (2002), Wan Akib et al. (2001) and Wan Akib et al. (2005). This paper tends to emphasize the concept of GPS measurements and its application in structural health detection. Particular investigations will be concentrated in the utilization of RTK-GPS through simulation test made on a bridge in Universiti Teknologi Malaysia (UTM) campus.

2. GLOBAL POSITIONING SYSTEM (GPS)

GPS is a space-based radio navigation satellite operated by the U.S. Department of Defense (DoD). It consists of nominal constellation of 24 operational satellites inclined at 55° with an orbital radius of 26,560 km (12 sidereal hour period). Users equipped with appropriate receivers on the ground can obtain the antenna position (longitude, latitude, and height, or X, Y, Z coordinates) by tracking signals transmitted from GPS satellites 24 hours per day. Over the past decades, GPS has developed into an efficient yet practical surveying tool capable of quickly collecting vast amount of position information. GPS calculates the user position using a set of values namely observables. These observables consist of logged data derived from the electromagnetic waves received from each simultaneously tracked satellite. In any case, GPS can be divided into two types of observables i.e. pseudo range and carrier phase measurement.

2.1 Pseudo range Measurement

Pseudo range is the measured distance between the antenna phase center of a receiver and the GPS satellite's antenna. As mentioned earlier, it is a requirement to have ranges from the receiver to the satellites in order to compute ones position with precision of about 3 m and 30 cm for C/A and P-code respectively. It is electronically measured by the receiver delay-lock loop and implied by the epochs of emission and reception of the code. As in case of vacuum medium and error free situation, the measured pseudo range is equal to the geometric distance and can be presented as:

$$P_r^s = \rho_r^s = \left(t_r - t^s\right)c \qquad (2.1)$$

where

P_r^s is the measured pseudo range
ρ_r^s is the geometric distance
t_r is the true time at the code reception of the receiver
t^s is the true time at the code emission of the satellite
c is the velocity of light (299729458 ms^{-1})

2.2 Carrier phase Measurement

The second observable which is the carrier phase is generally based on the L1 or L2 carrier signal. Mainly used in high precision applications i.e. structural health detection, this observable is also known as phase pseudo range. In general, phase pseudo range is the ranges to the satellites by measuring phase difference between the received signal and the receiver-generated signal. By shifting the receiver-generated phase to track the received phase from the satellite, the carrier phase with precision better than code measurement (L1 = ±1.9 mm, L2= ±2.4 mm) can be electronically measured. As in case of vacuum medium and error free situation, the measured phase can be expressed as:

$$\Phi_r^s = (\Phi_r - \Phi^s) + N_r^s \qquad (2.2)$$

where

Φ_r^s is the measured phase
Φ_r is the phase of receiver oscillator
Φ^s is the phase of received signal from satellite
N_r^s is the ambiguity related to both receiver and satellite

Further details of the system, its applicability, along with a complete description of the GPS signals, equipment, measurement procedures and basic equations can be found in Kaplan (2006); Hofman-Wellenhof et al. (1997) and Leick (2005).

3. REAL-TIME KINEMATIC GPS (RTK-GPS)

In static observation mode, GPS is capable of providing 0.05 Hz of sampling frequency with location precision of 5~10 mm. Nonetheless, static observation mode can only provide position information in post-processing mode. Apparently, with the advent of Real-Time Kinematic (RTK-GPS) technique, deformations of various structures such as dams, wide span bridges, highways and high rise buildings can be monitored instantaneously with an accuracy of 10 mm ± 1 to 2 ppm (horizontally) and 15-20 mm ± 2 ppm (vertically). RTK-GPS is one of the latest innovations of GPS relative positioning whereby the main concept behind RTK-GPS technique is errors in GPS observables are essentially identical at both receivers (base and rover). Two dual frequencies receivers are linked by radios simultaneously during field observations i.e. base and rover receiver(s). Equipped with radio instrumentation setup (i.e. radio modem and radio antenna), the base receiver is located over a known control point (i.e. benchmark) throughout the duration of the survey. The base receiver transmits correction in a standard format namely Radio Technical Commission for Maritime Service (RTCM) to rover receiver through the use of radio system. Figure 1 illustrates the overview of RTK-GPS technique.

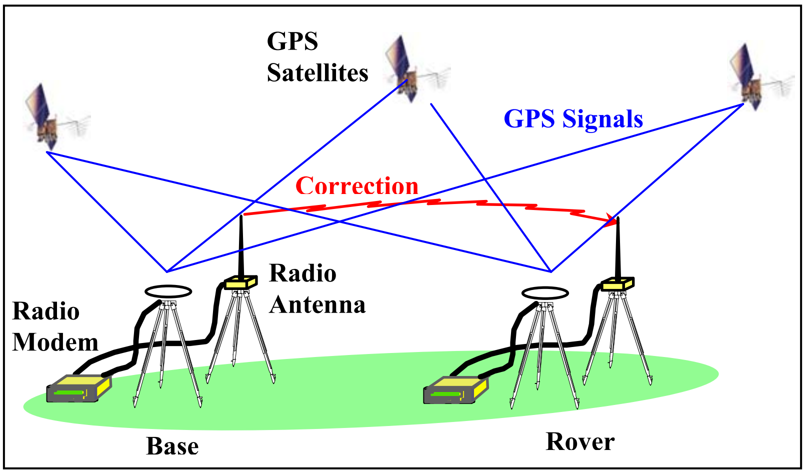

Figure 1. RTK-GPS Overview

The main advantage of RTK-GPS technique is unlike static or any other GPS conventional method, this technique is capable of providing position information instantaneously while in the field in which leads to a higher productivity compared to the post-processing mode. Nonetheless, RTK-GPS requires dual frequencies receivers and radio instrumentation to be set at both reference and roving stations. Even though in term of accuracy, post-processing technique provides better result compared to RTK-GPS, for the purpose of structural health detection, an accuracy of 10 mm ± 1 to 2 ppm (horizontally) and 15-20 mm ± 2 ppm (vertically) provided by RTK-GPS technique are sufficiently enough and still within the acceptable limit.

4. SIMULATION TEST

The aim of this paper is to provide better understanding on RTK-GPS through simulation test made on a bridge in Universiti Teknologi Malaysia (UTM) campus. For the purpose of real-time structural health detection, well-calibrated GPS Trimble™ 4800 dual-frequency receivers and Pacific Crest™ radio modems were used in this study. By applying static survey mode to determine true coordinates in which will be used latter as "reference", the test is then conducted in real-time using RTK-GPS mode.

4.1 Static Surveying

Two epochs of static surveying method is applied to determine the position (true coordinate) of two selected reference points namely P1 and P2 (see Figure 2). Using three GPS Trimble™ 4800 receivers, the field observation was carried out for about one hour per epoch. This survey involved three GPS Trimble™ 4800 receivers. Table 1 entails the parameters used during the static field observation.

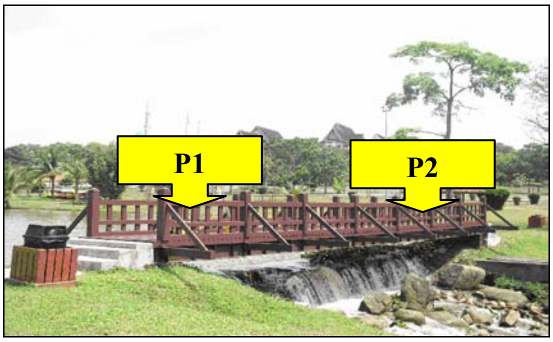

Figure 2. Location of Point P1 and P2

Table 1: Static Surveying Observation Parameters

No	Items	Assigned Parameter
1	Cut-off angle	15 degrees
2	Data interval	15 seconds
3	Coordinate system	WSG 84
4	Datum	MRT 1994

4.2 RTK-GPS Surveying

For the purpose of utilizing RTK-GPS technique, Pacific™ Cress type of radio link has been used in addition to two Trimble™ 4800 dual frequency receivers. For real time data display, real time processing scheme was adopted where positioning data from the rover is recorded directly to an on-site notebook running LabVIEW™ software. Data was collected at 1 Hz for about 15 minutes. Figure 3 illustrates the connection setup between rover receiver and laptop at P1 station.

Figure 3. Overview of Instrumentation Setup

5. ANALYSIS OF RESULT

As mentioned earlier, two epochs of static surveying technique have been conducted to establish the true positions (coordinates) of the monitoring points on the bridge (P1 and P2). The static survey was then processed and adjusted using Trimble™ Geomatic Office v1.6 software. The adjusted geodetic coordinates from the network adjustment is as tabulated in Table 2.

Table 2: True Coordinates of GPS Monitoring Points

Point Name	Latitude (N)	Longitude (E)	Height (m)
BASE	1°33'14.30574"	103°38'17.83999"	21.900
P1	1°33'17.60316"	103°38'17.22900"	19.925
P2	1°33'17.73936"	103°38'17.34540"	19.830

The results for RTK-GPS were illustrated in Table 3 and 4. These tables show the variation of coordinates at the two monitoring points (P1 and P2) compared to the true values listed in Table 2. Table 3 and 4 demonstrate the simple analysis for point P1 and P2, respectively.

Table 3. Analysis for Point P1

Point P1	Northing (m)	Easting (m)	Height (m)
True value (TV)	171946.676	627036.822	12.294
Min value	171946.673	627036.822	12.279
Max value	171946.682	627036.840	12.309
TV-Min	0.003	0.000	0.015
TV-Max	-0.006	-0.018	-0.015
Max-Min	0.009	0.018	0.030
RMS (m)	**0.000**	**0.001**	**0.006**

Table 4. Analysis for Point P2

Point P2	Northing (m)	Easting (m)	Height (m)
True value (TV)	171950.857	627040.422	12.199
Min value	171950.854	627040.422	12.190
Max value	171950.862	627040.440	12.216
TV-Min	0.003	0.000	0.009
TV-Max	-0.005	-0.018	-0.017
Max-Min	0.008	0.018	0.026
RMS (m)	**0.001**	**0.002**	**0.006**

Based on the results, it is noted that the differences between minimum and maximum values are significantly small. The Root Mean Square (RMS) values for P1 are: 0.000 m, 0.001 m and 0.006 m whereas for P2 are: 0.001 m, 0.002 m and 0.006 m for Northing, Easting and Height components respectively. Based on the analyses, conclusion can be made that there is no structural displacement detected at the bridge. It is also suggested that the structural health of the bridge is in a satisfactory condition.

6. CONCLUSION

As safety precautions, the need for rapid assessment of the state of large engineering structure after extreme events such as earthquake, tsunami, typhoon or related wind effects is highly demanded. With recent advances on Global Positioning System (GPS) receiver's technology and data processing software during the past decade, the accuracy of positioning is improving distinctly up to only few millimeters by using a differential GPS carrier-phase approach. Despite of being expensive, in long term aspect, GPS is still an efficient and cost-effective tool in which can be well-integrated into an automated continuously operating system. Compared to other conventional method, it is noted that GPS through the utilization of RTK-GPS is potentially capable of being deployed as an effective tool in structural health detection.

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