GPS for Monitoring the Dynamic Response of Tall Buildings

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Introduction

Previously, the approximate global displacements of large Civil Engineering structures could only be ascertained using the integration of measured accelerometer data. As the sampling rates of Global Positioning Systems (GPS) have reached levels of 10 Hz, they are now suitable for monitoring longer period structures to within millimeters. The current effort is dedicated toward long-term monitoring of a host of tall buildings in Chicago as part of a larger NSF study (Abdelrazaq et al. 2000). In developing the GPS for this project, a series of static and dynamic calibration tests, utilizing a small shake table, were performed outdoors to quantify the system performance. The objectives included quantifying the influence of background noise, baseline distance, antenna mount dynamics, and lighting protection. Tests were also conducted to investigate the significance of geometric dilution of precision (GDOP). The kinematic performance of the system was verified for signals of varying amplitude, frequency and complexity. This paper will more focus on the application of these systems for long-term monitoring of tall buildings in urban environments and overview important errors and considerations affecting the feasibility of these applications.

Inherent GPS Errors

Global Positioning Systems (Enge and Misra 1999) utilize the triangulation of satellites overhead to determine a position on the earth's surface marked by a GPS antenna. As the distance between each satellite and the antenna is calculated based on the GPS signal travel time, this time must be quantified with great precision. Unfortunately, interferences in the earth's lower (troposphere) and upper (ionosphere) atmospheres can modify the travel time of the GPS signal. Ionospheric errors can be corrected by using both L-band frequencies in the GPS transmission signal, or so called dual-frequency techniques. Appropriate models for this error will consider the level of solar activity, which will peak in 2002. Tropospheric errors are associated with changes in temperature, pressure and humidity. The notion of differential GPS (DGPS) has been developed to remedy a number of these lower atmospheric error sources by using a stationary receiver as a base station. Any motions of this stationary receiver are assumed to be the result of local troposheric errors, and resulting error corrections are transmitted to the rover station, or GPS station monitored for motion. Through the use of DGPS with a dual-frequency approach, the position of the rover can be determined within millimeters. The Leica MC-500 system featured in this project utilizes the aforementioned strategies to achieve kinematic error accuracy of *5 mm + 2 ppm* (RMS) and static accuracy of *3 mm + 0.5 ppm* (RMS). Note that with the accuracy is a function of the baseline distance between the reference and rover.

Understandably, both the availability and position of satellites will limit the accuracy of GPS results. In general, as three coordinates of position as well as a time bias correction must be determined, a minimum of four satellites with elevations greater than 15° are required. This mask angle limit is imposed since the quality of signals transmitted at low elevations may be

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compromised. The suitability of satellites positioned above the mask angle is quantified by the Geometric Dilution of Precision (GDOP), which considers their orientation. Ideally, GDOP errors should range between 2 and 4, though the measure will fluctuate throughout the observation period as satellites orbit the earth. Typically, in order to resolve the ambiguities, up to seven satellites may be required, depending on the DGOP associated with their positions. When this condition is achievable, RMS static errors can be held to less than 2 mm.

Multi-path Errors Challenges for GPS in Urban Environments

Figure 1: Choke ring antenna used in study.

As dual frequency and DGPS have minimized errors considerably, multi-path errors become the most considerable challenge in urban environments where reflective surfaces are most prominent. Reflected signals, having a longer path, create interference and prevent accurate satellite tracking. Fortunately, multi-path contamination can be rejected as the signal is acquired through the use of choke ring antennas, as advocated in this study. The flush-mount antenna, shown in Figure 1, features concentric choke rings of various radius and depths (Tranquilla et al. 1994).

Summary: Important Issues for GPS Monitoring in Urban Environments

When using GPS to monitor large Civil Engineering structures in an urban environment, a number of important considerations are relevant:

- The performance of the GPS is highly dependent on its ability to view the sky without obstructions. For optimal results, a 15° mask angle should be maintained in all quadrants to avoid noise induced by low-elevation satellite signals.
- Reflective surfaces will contribute multi-path errors and thus must be avoided both beneath and in the immediate vicinity of the antenna. The use of choke-ring antennas can further prevent the interferences caused by multi-path errors.
- The antenna mount should be completely rigid and firmly affixed to a structural member in order to accurately track structural displacements.
- The reference station must be as rigid as possible. In urban environments, this requirement is increasingly difficult to meet, as shorter buildings are often shielded by taller buildings, violating the mask angle requirements.
- GDOP becomes an important concern in achieving accurate results, as poor satellite orientation is an additional error source. Thus, the accuracy of the GPS measurements will vary throughout the day, even when an optimal number of satellites are in view.

References

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