Proceedings, 11th FIG Symposium on Deformation Measurements, Santorini, Greece, 2003.

EXPERIMENTAL ASSESSMENT OF THE ACCURACY OF RTK - GPS FOR MONITORING MOVEMENTS / OSCILLATIONS OF FLEXIBLE ENGINEERING STRUCTURES

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Abstract

In order to provide an independent and unbiased assessment of the accuracy of the RTK-GPS technique we simulated the assumed quasi-periodic movement of real structures excited by dynamic loads with circular horizontal movements of known parameters (radius and period of rotation). Our experiments were based on the analysis of recordings of two 10Hz, dual-band radio-linked receivers, one fixed on rotating platform (rover) and another one (reference) fixed in a nearby position. The standard error of the horizontal and vertical coordinates of the rotating receiver (Rover) was found to range for the RTK technique between 6-25mm and 9-43 mm, for the whole range of the movement during experiments (period 3-19sec, radius 20-50cm). This accuracy is totally operational and can be obtained at a minimum cost; it is also adequate for real-time monitoring kinematics and deformation of most flexible engineering structures (bridges, masts, etc.).

1. Introduction

Engineers commonly use accelerometers to detect deflections or drift of structures such as tall buildings excited by dynamic loads, for example wind. However accelerometers measure acceleration and a double integration is necessary to obtain displacements. The precision of such displacement is limited mainly by errors due to the double integration.

GPS has recently appeared as an alternative in the monitoring deformations and oscillations of large flexible structures such as bridges (for instance due to wind loading) and tall masts. The first examples come from experiments in the 2200m-long suspended Humber Bridge, England (Ashkenazi et al., 1997) and the Great Belt Bridge, Denmark (Lennartz-Johansen, 1999). Lateral deflections of the order of 2-15cm of simple harmonic nature at the bridge midspan, as well as vertical displacements of the deck of the order of up to 40, or even >100cm, assigned to wind and heavy traffic loads, have been identified through these experiments. Furthermore, even in absence of wind loads, experiments in several hundred meters high TV mast revealed relative pseudo-periodic movements of control points with an amplitude of about 10cm (Wasilewski et al., 1999, Fig. 1).

The success of such experiments has encouraged the application of the real-time kinematic GPS (RTK-GPS) in many large bridges (for instance the new Hong-Kong Bridges, Kai-yuen et al., 2001) as an integral part of their structural health monitoring, in combination with conventional monitoring techniques (accelerometers, pressure gauges, etc.); the latter cannot detect lateral shifts of the structures, or slow deformations (for instance temperature - induced ones), while geodetic techniques can provide direct and precise estimates of displacements.

In all these cases, however, either post-processing techniques for GPS data were used, or the accuracy of real time RTK-GPS results is not assessed through independent data.

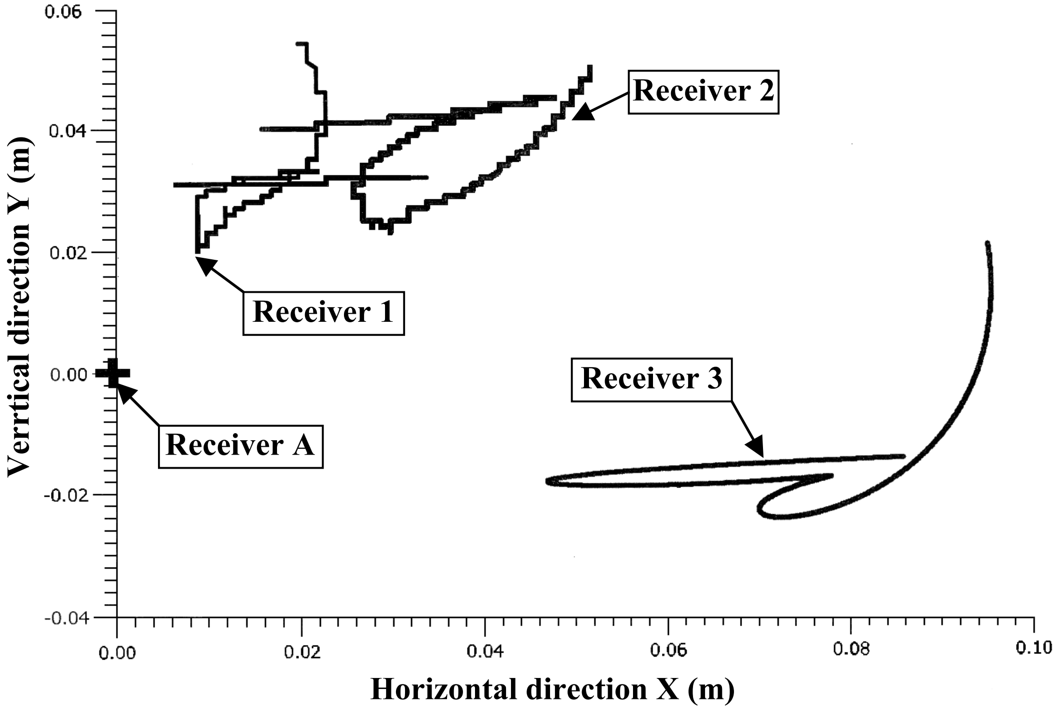


Figure 1: Vertical view of the estimated tracking of the three receivers (Receiver 1, 2 & 3) relative to Receiver A that were established on the TV-mast in different heights. (Wasilewski et al., 1999).

In order to provide an independent and unbiased assessment of the accuracy of the RTK-GPS technique we simulated the assumed quasi-periodic movement of real civil engineering structures (cable stayed bridges, tall buildings, antennas, etc) with radial circulal movements of known parameters (radius and period of rotation).

2. The Experiment

A GPS receiver (Rover) was forced to move in known circular orbits fixed on a rod rotating thanks to an electric motor and close to a base receiver (Fig. 2). Angular velocity, radius and vertical level of rotation were kept fixed during each experiment. The period of rotation was ranging between T=3-19sec, at 1sec interval and the radius between 20-50cm, at 10cm interval, while rover and base receivers were connected with 1Hz radiolink (Fig. 3).
The experiments were made with two Javad Legacy-H receivers, two external antennas Javad JPS-LEGANT-E and two radiolinks SATEL (frequency 468.6 MHz), on the roof of the building of Department of Civil Engineering, University of Patras, from January 2002 till April 2002.
Experiments were made in different times of the day, different conditions and different satellite constellations. Each experiment lasted between 5 and 15 minutes, and the coordinates of the rotating receiver were recorded at a frequency of 1 Hz.

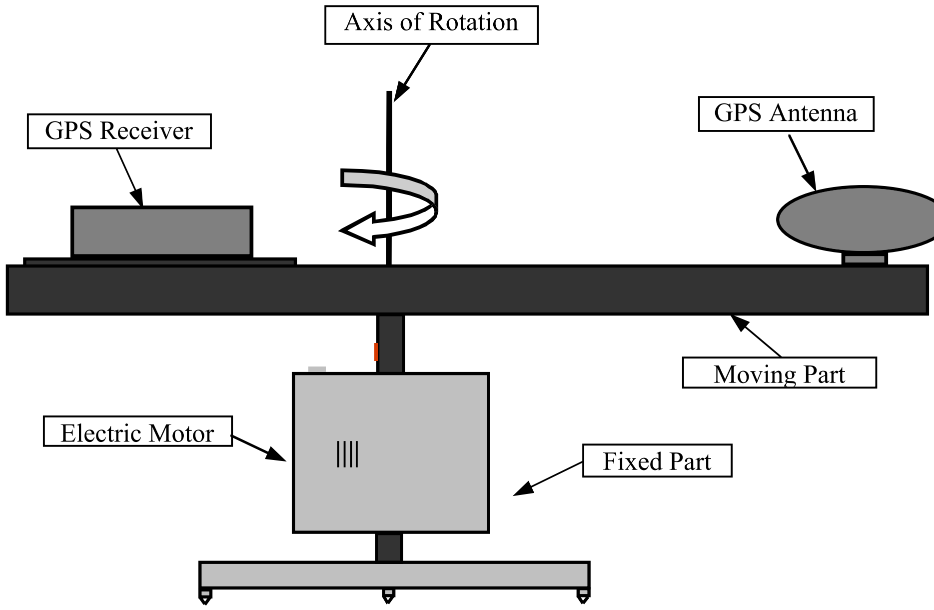


Figure 2: Sketch of the experimental device used during the experiments. It consists of two parts: the moving and the fixed part. On the moving rod the GPS antenna was attached, at 20-50cm distance from the axis of rotation. The period of rotation ranged between 3-19sec.

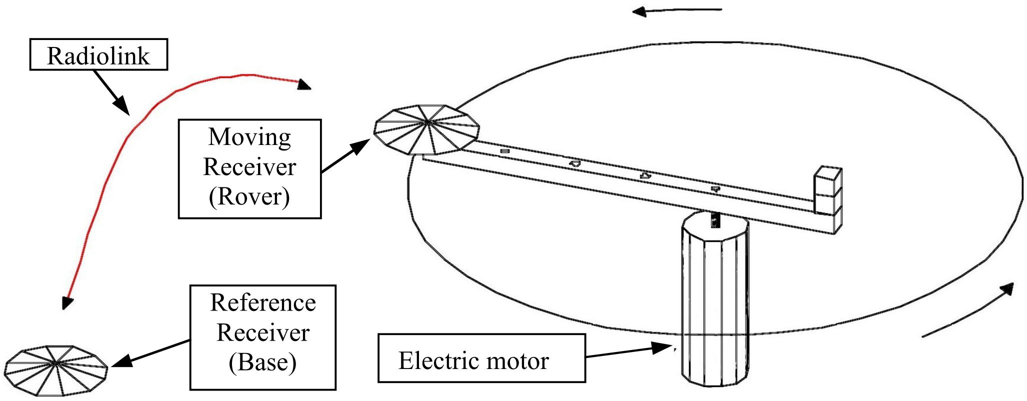


Figure 3: Sketch of the receiver positions. The moving receiver was fixed on a rotating rod and the reference receiver was installed in a nearby position.

3. Data Processing and analysis

After a period of tests and preparation, forty four final experiments in total, in different combinations of period and radius of rotation were made. Each session includes almost 800 coordinates recorded every 1 sec. The recorded coordinates of the moving receiver (Rover) were subsequently analysed, processed and compared with their real value.
At a first step, we computed the coordinates of the center of rotation of the Rover as a mean value of coordinates of recorded Rover position in all experiments.
Ideally, the distance between the center of Rover rotation and of the recorded coordinates of the Rover at any moment would be equal to the radius of rotation, fixed at each session (experiment).

However, due to various errors this distance differs from the real value of the radius R by a small amount ΔRi (Fig. 4). The statistical analysis of ΔRi can therefore provide an estimate of the accuracy in recorded horizontal coordinates.
Similarly, since the Rover was forced to move on a horizontal plane, the deviation Δhi of computed Rover height h at a moment i from the average value of the Rover height h (Δhi=hi-h) in all experiments statistically describes the accuracy of the computed vertical coordinates.

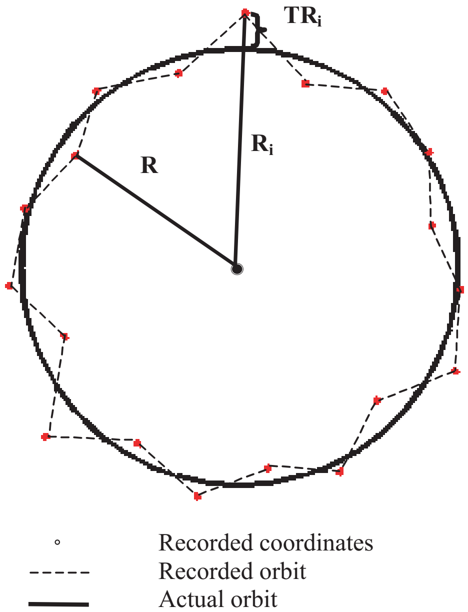
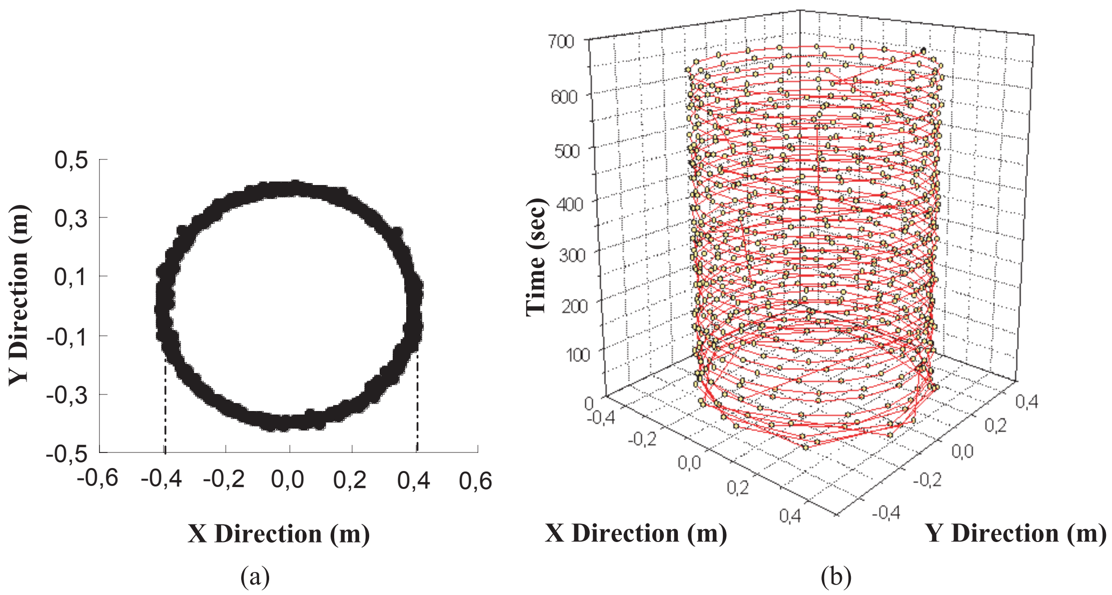


Figure 4: Recorded and real circular orbit (horizontal)



We have subsequently computed the mean deviation ΔRi and Δhi in all experiments, and the corresponding estimates of X and Y coordinates, assumed of equal accuracy; a result confirmed by the nearly circular plot of recorded coordinates (Fig. 5). The results of all experiments were plotted in Figure 6.

The analysis of our data indicate that for each session (experiment with a specific radius and period of rotation), recorded coordinates were very close to the real values (Fig. 5), while outliers were found not to exceed 1.5% of the observations. X and Y coordinates proved to be of the same accuracy.

4. Results and conclusions

The standard error of the horizontal coordinates of the rotating receiver (Rover) was found to range between 6-25mm (Fig. 6a), for the whole range of the movement during experiments (period 3-19sec, radius 20-50cm). The corresponding standard error of the vertical coordinates of the rotating receiver (Rover) was found to range between 9-43mm (Fig. 6b).
This is one of the very first experiments ever made to assess the accuracy of GPS, which proved to be better than 25mm for the RTK technique, in the horizontal plane.
This accuracy is totally operational and can be obtained at a minimum cost; it is also adequate for real-time monitoring kinematics and deformations of most flexible engineering structures (bridges, masts, etc.).

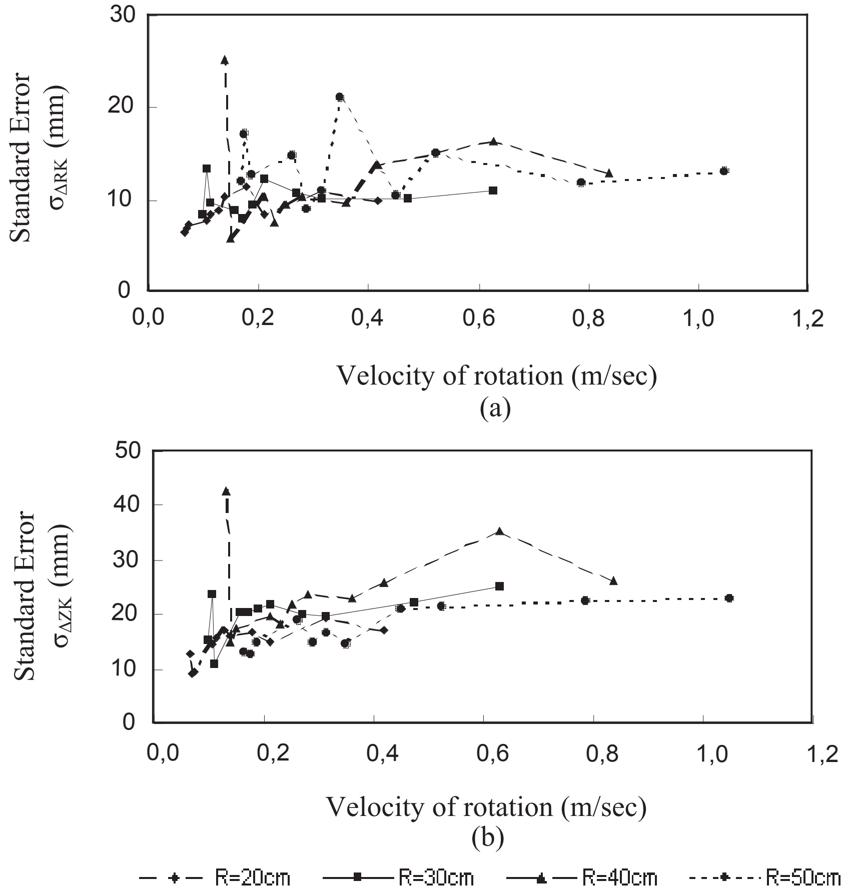


Figure 6: Estimated standard error of the horizontal (a) and vertical (b) computed coordinates of the ROVER receiver for the RTK technique as a function of the velocity of rotation.

Aknowledgements

This research is a contribution to the K. Karatheodori, University of Patras and the PENED Greek secreteriat of Research and Technology research programmes.

References

Ashkenazi V., and Roberts G. (1997). Experimental monitoring of the Humber bridge using GPS. *Civil Engineering,* 120, 177-182.

Kai-yuen W., King-leung M. and Wai-yee C. (2001). Monitoring Hong Kong' s Bridges, Real-Time Kinematic Spans the Gap. *GPS World*, 12(7), 10 – 18.

Lennartz-Johansen H. (1999). Analyzing Europe's largest suspension bridge. *Proccedings of the 9th FIG International Symposium on Deformation Measurements,* Poland, 320-324.

Wasilewski A., Rzepecka Z. and Kapcia J. (1999). Application of GPS RTK technique to study of deformation of Aerial Radio – TV masts. *Proceedings of the 9th FIG International Symposium on Deformation Measurements,* Poland, 168-180.