

## Degradation in the detection of millimetric dynamic movements due to metallic objects close to the GPS antenna

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**Resumo:** Este trabalho apresenta os resultados de alguns experimentos com o GPS, realizados em ambientes diferentes. Em um dos ambientes, as antenas GPS foram colocadas próximas de objetos metálicos; no outro ambiente não havia objetos metálicos. Os experimentos foram realizados com um par de receptores GPS. Na antena considerada móvel foi aplicado movimento periódico por um dispositivo eletro-mecânico; a outra antena foi mantida estática. A análise dos dados mostrou que a detecção de movimentos dinâmicos milimétricos foi totalmente degradada pela presença dos objetos metálicos ao redor da antena. Por outro lado, a análise dos dados obtidos dos testes de campo realizados no ambiente sem a presença de objetos metálicos, mostra claramente um pico no espectro que representa os deslocamentos periódicos milimétricos. Os deslocamentos realizados com a antena móvel foram de 4.5 mm e 3 mm, ambos realizados nas direções vertical e horizontal. Para extrair os deslocamentos dos resíduos, obtidos do processamento da dupla diferença de fase, é necessário realizar tratamento nos dados aplicando FFT e filtro.

**Palavras chave:** GPS, monitoramento, deslocamentos milimétricos, movimentos dinâmicos

**Abstract:** It work presents results of experiments, with GPS, carried out in different environments. In one environment, the GPS antennas were close to metallic objects and not in the other. Experiments were carried out with one pair of GPS receivers. The rover antenna had periodic millimeter displacements applied by a device, and the other was static. The data analysis showed that the detection of millimetric dynamic movements was degraded totally by the presence of metallic objects. On the other hand, the data analysis of field tests carried out in the environment without metallic objects show clearly, the peak of the power spectrum which represents the millimetric displacements. The displacement measurements for the rover antenna were 4.5 mm and 3 mm, both vertically and horizontally. To extract the displacement from the residuals it is necessary to proceed by cleaning the data applying the FFT band pass filtering.

**Keywords:** GPS, monitoring, millimetric displacements, dynamic movements

### 1 Introduction

Small quasi-periodic movements can appear in a wide range of situations, it is the case in large concrete or steel structures under a dynamic load. The amplitude and frequency depend respectively, on the stiffness and natural frequency oscillation. Usually the time behavior can be represented by a quasi sine or quasi-damped sine functions.

The frequency ranges from sub hertz to hertz and the amplitude from a few millimeters to centimeters (LACHAPELLE et al., 1995). Traditionally the movements are measured with conventional surveying instruments, strength meters and displacement gauges. Many efforts have been made to use the GPS as a measuring tool (ROBERTS et al., 1999; ROBERTS et al., 2000; ZHANG et al., 2000 and RADOVANOVIC et al., 2000).

To evaluate the detectable threshold, field simulation experiments were carried out. One series with the GPS antennas installed over an aluminum roof at the Transport Department and close by the sustaining tower of the GPS permanent station, as shown in Figure 1, and another series with the antennas at an open clear field, Figure 2.



**Figura 1 :**  
Aluminum roof at the  
Transport Department

**Figura 2 :**  
Antennas at a clear field

The detection of the movement is made by the Fourier analyses of the phase residuals method proposed by SCHAAL (2001a,b).

As the 6 mm movement results showed a good signal to noise relation, smaller amplitude experiments were developed.

## 2 Field Tests



**Figura 3 :** Two GPS antennas over the aluminum  
roof and the rover antenna over the device

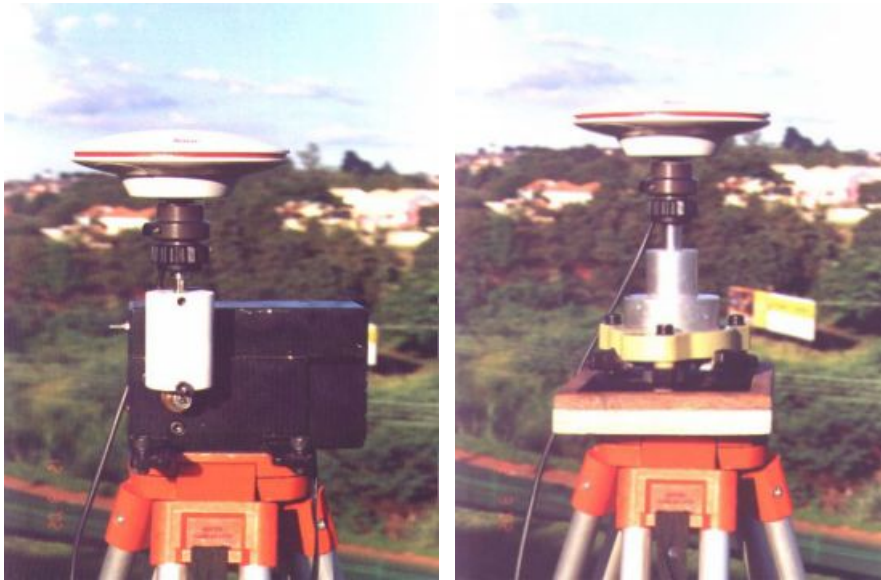
The instruments used for this field test consisted of a pair of Leica SR530 receivers with Leica AT 502 antennas, and a pair of Novatel Propak 3151 RE receivers with Garmin GA29 antennas.

Data was collected over a six minutes period at 0.2 s intervals. In the first minute both antennas remained static. During the remaining five minutes remained were applied vertical or horizontal displacements to the rover antenna.

The hypothesis that aluminum roof and the metallic tower can cause multipath that degrade the detection of displacements of 3 mm and 4.5 mm were confirmed. The Figure 3 illustrates a pair of GPS antennas over an aluminum roof.

Figure 4 illustrates an electro-mechanical device that applied vertical displacements on the antenna. The device moves the antenna up and down in a sinusoidal movement exactly 4.5 or 3 millimeters with the period ranging from 3 seconds, controlled by the voltage applied to the motor.

Figure 5 illustrates the device that allowed horizontal displacements to be applied to the antenna. It is possible to move exactly 4.5 mm with the period ranging from 2 seconds.



**Figura 4 :**  
Electro-mechanical device that applies vertical displacement on the GPS antenna

**Figura 5 :**  
Device that allowed apply horizontal displacement on the GPS antenna by hands

Two processing software programs were used, Leica Ski Pro v2.2 and OMNI (from NGS) because they generate an ASCII file for the phase residual data. Ski Pro can process 0.1 seconds data however does not allow selecting the reference satellite. OMNI can handle 0.2 second interval. Table 1 presents the observation conditions of six selected experiments and the last column gives the non-orthogonal correction to be applied on the measurement.

Following the table a brief analyses of each experiment and the respective results.

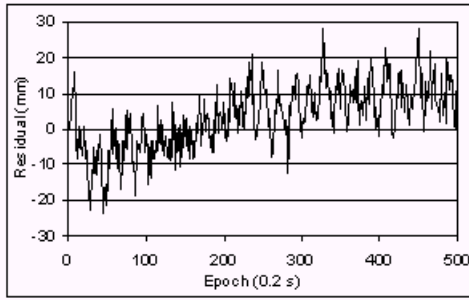
**Tabela 1 :** Description of experiments conditions

Experiment	Receiver	Epoch Interval sec.	Displacement Direction	Displacement Amplitude mm	Displacement Period sec.	Reference Satellite Elevation	Measuring Satellite Elevation	Angle correction
1	Leica 530	0.2	Vertical	6	2	07	72	1.10
2	Leica 530	0.2	Vertical	4.5	3	13°	76°	1.20
3	Leica 530	0.2	Vertical	3,0	3	13°	76°	1.20
4	Leica 530	0.2	Vertical	4.5	3	07°	76°	1.10
5	Leica 530	0.2	Vertical	3,0	3	08°	75°	1.15
6	Leica 530	0.2	Horizontal	4.5	2	73°	09°	1.40

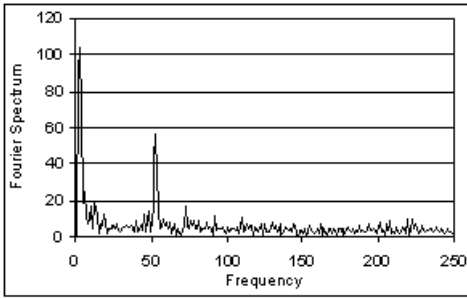
**3 Field Tests carried out over the aluminum roof and results**

Figures 6, 7 and 8 present the results of the experiment where 6 mm vertical displacement was applied on the rover antenna the. It was carried out over the aluminum roof. Figure 6 shows the raw residuals, Figure 7 shows the power spectrum which is presented

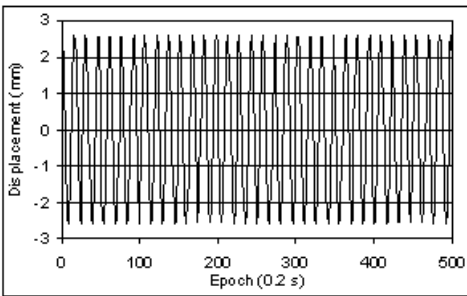
with a peak due to 6 mm vertical displacement and Figure 8 shows filtered results with a span of 5 mm. Results in 5.5 mm, very close to the real displacement, were obtained by applying the angular correction.



**Figure 6** : Raw residuals – 6 mm vertical displacement (LEICA GPS 530 receiver)

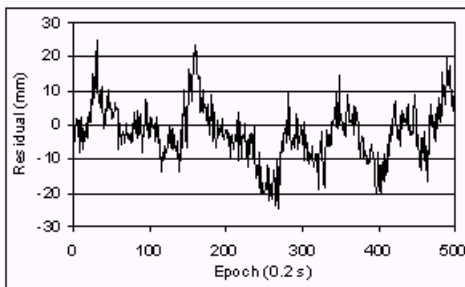


**Figure 7** : Power spectrum of the 6 mm displacement

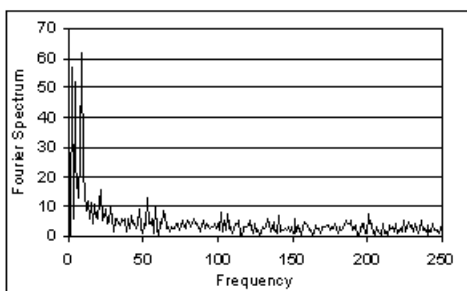


**Figure 8** : Filtered residuals of 6 mm displacement

Experiment 2 applied the 4.5 mm vertical displacement on the rover antenna. During the experiment, the measuring and reference satellites were, respectively, close to  $76^\circ$  and  $13^\circ$ . Figures 9 and 10 present the raw residuals and power spectrum without any peak at higher frequencies that would overlap any antenna movement of 4.5 mm.



**Figure 9** : Raw residuals – 4.5 mm vertical displacement (LEICA GPS 530 receiver)



**Figure 10** : Power spectrum of the 4.5 mm vertical displacement

Experiment 3 applied the 3 mm vertical displacement on the rover antenna. During the experiment the measuring and reference satellites were, respectively, close to  $76^\circ$  and  $13^\circ$ . Figures 11 and 12 illustrate the raw residuals and power spectrum without any peak

at higher frequencies that would overlap any antenna movement of 3 mm.

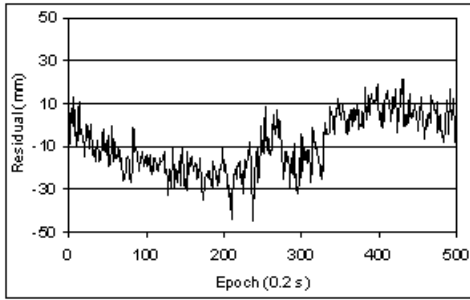


Figure 11 : Raw residuals – vertical displacement

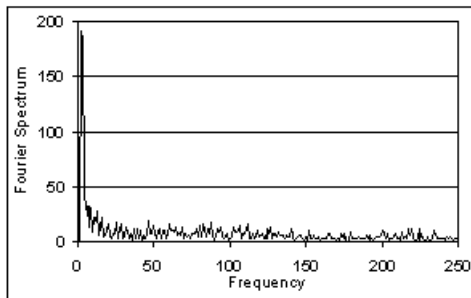


Figure 12 : Power spectrum of the 3 mm vertical displacement

#### 4 Field Tests carried out in a clear environment

Experiment 4 applied the 4.5 mm vertical displacement on the rover antenna. During the experiment the measuring and reference satellites were, respectively, close to  $76^\circ$  and  $07^\circ$ . Figures 13 and 14 illustrate respectively, the raw residuals and power spectrum with a peak of higher frequencies that would overlap an antenna movement of 4.5 mm. Applying the FFT, the frequency of the periodic component is very clear. Figure 15 presents the detail of peak due to the movement. Figure 16 presents the filtered results with a span of 4 mm. Results in 4.3 mm, very close to the real displacement, were obtained by applying the angular correction.

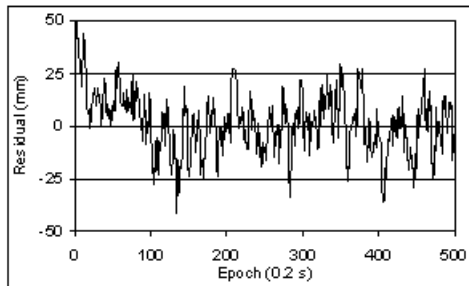


Figure 13 : Raw residuals – 4.5 mm vertical displacement (LEICA GPS 530 receiver)

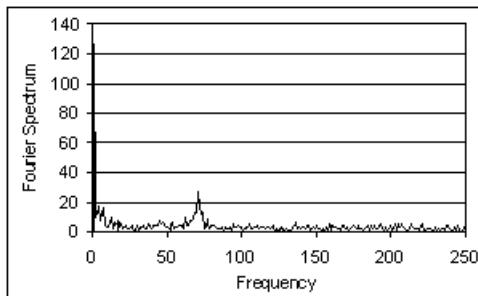
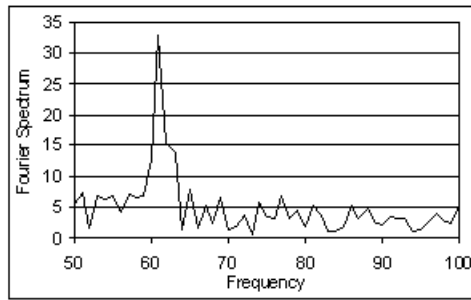
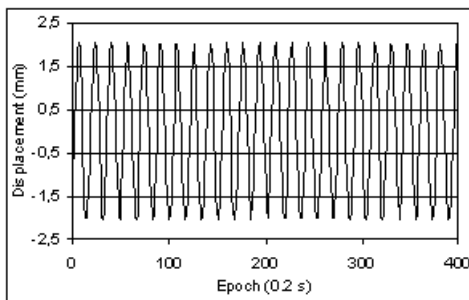


Figure 14 : Power spectrum of 4.5 mm vertical displacement

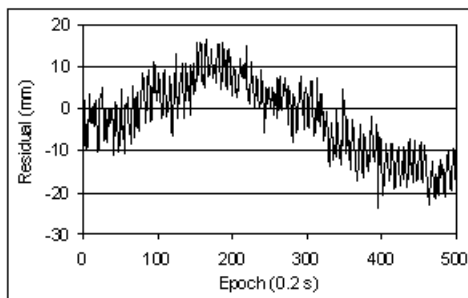


**Figure 15** : Detail of power spectrum which represents the 4.5 mm vertical displacement

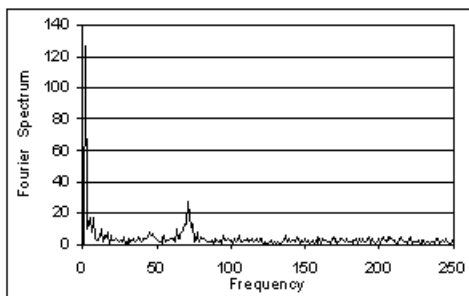


**Figure 16** : Filtered residuals of 4.5 mm vertical displacement

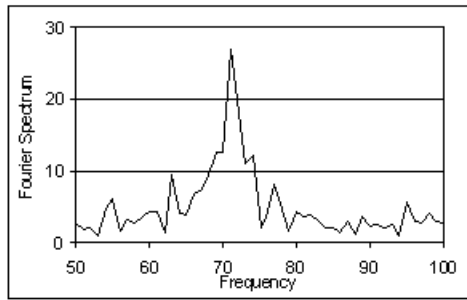
Experiment 5 applied the 4.5 mm horizontal displacement on the rover antenna. During the experiment, the measuring and reference satellites were, respectively, close to  $73^\circ$  and  $09^\circ$ . Figures 17 and 18 present, respectively, the raw residuals and power spectrum with a peak at higher frequencies that would overlap an antenna movement of 4.5 mm. Applying the FFT, the frequency of the periodic component is very clear. Figure 19 presents the detail of peak due to the movement. Figure 20 presents the filtered results with a span of 4 mm. Results in 4.5 mm were obtained by applying the angular correction.



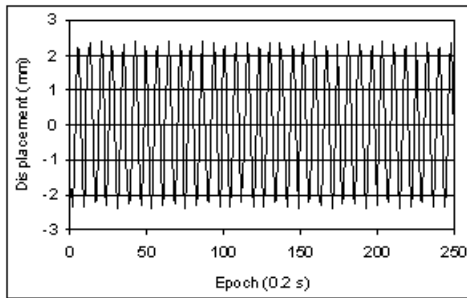
**Figure 17** : Raw residuals – 4.5 mm horizontal displacement (LEICA GPS 530 receiver)



**Figure 18** : Power spectrum of 4.5 mm horizontal displacement

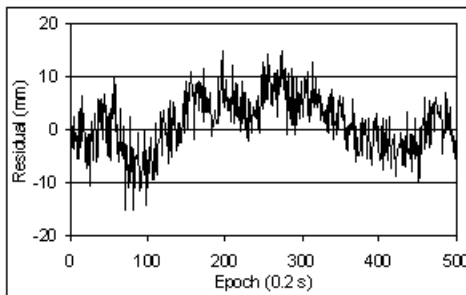


**Figure 19** : Detail of power spectrum which represents the 4.5 mm horizontal displacement

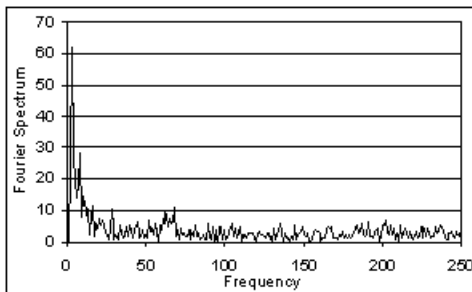


**Figure 20** : Filtered residuals of 4.5 mm horizontal displacement

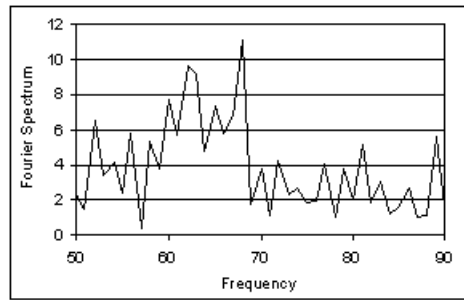
Finally, experiment 6 was carried out applying the 3 mm vertical displacement on the rover antenna. During the experiment the measuring and reference satellites were, respectively, close to  $75^\circ$  and  $08^\circ$ . Figures 21 and 22 presents, respectively, the raw residuals and power spectrum which is presented with a peak at higher frequencies that would overlap an antenna movement of 3 mm. Figure 23 presents the detail of peak due to the movement. Figure 24 presents the filtered results with a span of 1.6 mm. Results in 2,2 mm were obtained by applying the angular correction.



**Figure 21** : Raw residuals – 3 mm vertical displacement (LEICA GPS 530 receiver)

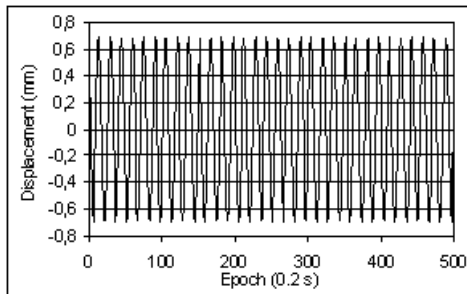


**Figure 22** : Power spectrum of 3 mm vertical displacement



**Figura 23** : Detail of power spectrum which represents the 3 mm vertical displacement

It is possible to note, in the Figure 23, that the multipath presents in urban environments can amount to an error of almost two millimeters.



**Figura 24** : Filtered residuals of 3 mm vertical displacement

## 5 Conclusion

This method has shown that it is possible to detect small periodic antenna displacements with millimetric precision. Experiments and results show that the degradation in the detection of millimetric dynamic movements due to metallic objects, close to GPS antennas, occurs and should be more investigated, as well as the FFT filtering technique. Multipath is very often present in construction and urban environments and can amount to an error of a few millimeters. Principles of reducing the effect of multipath caused by metallic objects need to be investigated. The results of the last field test indicated that the limit of the detection the millimetric dynamic movement by GPS is around 2 mm. The noise due to multipath present in urban environments t can amount to an error of almost two millimeters. It is important to use equipment that has the least amount of internal electronic noise as possible.

## 6 Acknowledgments

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