High Precision Estimation of the Parameters for Near-Surface GNSS Reflectometry

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1. Objectives

- Introduce a new robust technique to estimate GPS antenna height using the multipath recorded in the signal-to-noise ratio (SNR)
- Evaluate and compare the existing technique based on the **Lomb-Scargle periodogram (LSP)** and the proposed **inversion** method using GPS SNR multipath signal simulation
- Demonstrate the new technique to determine in-situ sea level at the port of Newcastle

Keywords: Signal-to-noise ratio (SNR), Nonlinear Least Square (NLS), Multi-path, Lomb-Scargle periodogram (LSP), Bertocco

2. Introduction

- The interference between direct and reflected signal (i.e., multipath) produces a modulation such as a damped sinusoid that can be observed in the SNR recorded by a GPS receiver [1]
- Changes in the environment of reflecting surface (such as soil moisture, water level, snow cover and vegetation) affect the SNR modulation frequency, amplitude and the phase
- The frequency of the SNR modulation indicates the height of the GPS antenna from the reflecting surface
- The precise estimation of the SNR frequency and its formal error from noisy SNR records is key to successful applications

Fig.1. The satellite image (left) shows the port of Newcastle and the NEWE CORSnet GNSS station (right) is located at the port of Newcastle. Leica GRX 1200+ receiver is used in the station.

3. SNR Theory

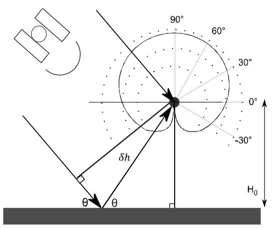


Fig. 2. Geometry of a multipath signal, for antenna height (H_o) and satellite elevation angle (ϑ). Bold black lines represent the direct signal transmitted from the satellite. The gray line is the reflected signal from the ground. The antenna's phase center is shown as the small dot. The solid line represents the gain pattern of the antenna. The radial distance between the antenna phase center and the solid line represents the strength of the antenna gain. Thus, an elevation angle of 90◦ has an antenna gain that is ~40%stronger than that for an elevation angle of 0◦.(Reproduced image) [1]

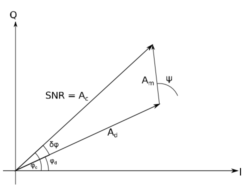


Fig. 3. Phasor diagram for in-phase (I) and quadrature (Q) channels, describing relationship between the amplitudes of the direct (A_d), multipath (A_m), and composite (A_c) signals and their phases – multipath relative phase ψ and carrier phase error dϕ. (Reproduced image) [1]

$$SNR^2 = A_d^2 + A_m^2 + 2A_dA_m\cos\psi$$

$$\delta h = 2H_0 \sin\theta$$

$$\omega = \frac{d\psi}{dt} = \frac{2\pi}{\lambda} 2H_0\cos\theta \frac{d\theta}{dt}$$

$$x = \sin u$$

$$\omega = \frac{d\psi}{dt} = \frac{2\pi}{\lambda} 2H_0\sin\theta$$

$$SNR_{multi} = A\cos(2\pi \frac{2H_0}{\lambda}\sin\theta + \phi)$$

$$f_{SNR(multi)} = \frac{2H_0}{\lambda_L}$$

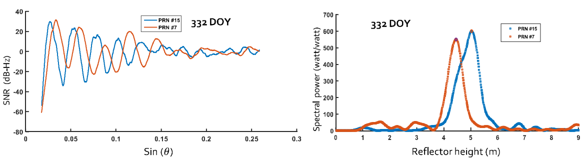
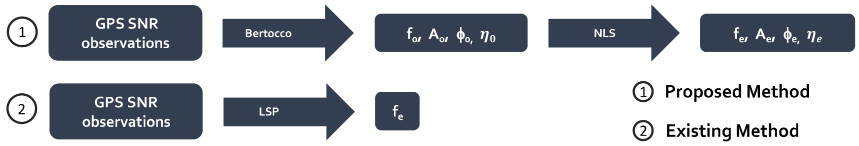


Fig.4. GPS detrended SNR observations (left) and results from LSP analysis of the same data (right). SNR observations of PRN #7 and #15 recorded from NEWE CORSnet GNSS station on 2015 Nov 28 (332 DOY) are presented. Reflector height of PRN #15 is higher (or tide height is lower) than the reflector height of PRN #7 (or tide height is higher) at the times of SNR recordings.

4. Simulation and Analysis



The proposed method uses the Bertocco [4] estimation of parameters as the initial values for the input parameter of NLS (Levenberg-Marquardt algorithm) [7] method.

$$SNR_{multi} = Ae^{-\eta\sin\theta}\cos(\frac{4\pi H_0}{\lambda}\sin\theta + \phi) + n,\ n \sim N(0,\sigma^2)$$ ← SNR observation equation

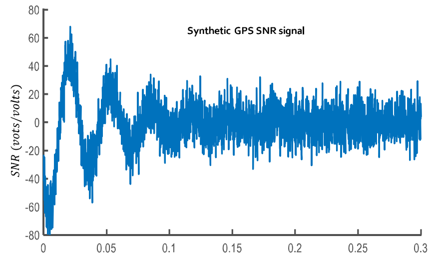


Fig .5.

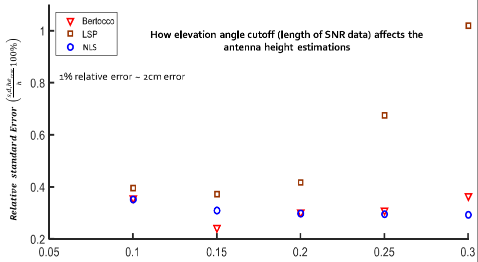


Fig .6.

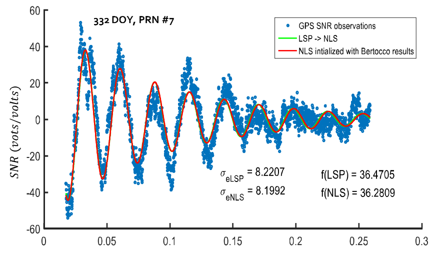


Fig .8.

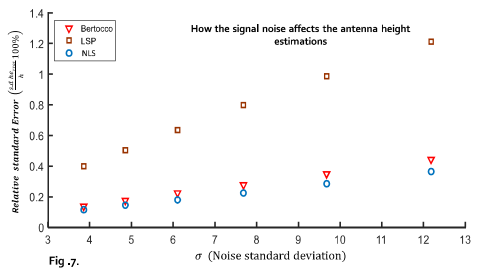


Fig .7.

Fig.5. shows a synthetic GPS SNR signal which was used for the Monte Carlo simulations. **Fig .6. and Fig. 7.** show, respectively, the comparison of relative standard error of height estimations from Monte Carlo simulation of the GPS SNR synthetic signal for varying length of SNR data (Chosen cutoff for elevation angle) and varying Gaussian noise addition. The Bertocco and NLS GPS antenna height estimations show significantly lower relative standard error for higher noise level and lower SNR data lengths.

Fig. 8. shows the real detrended GPS SNR data and it's full waveform estimated from proposed inversion method (red color) for 332 DOY at the port of Newcastle. Also, the posterior s.d. of the proposed inversion method produces a lower value than the LSP method. The difference of height estimations for corresponding frequency estimations is about 2cm.

5. Case Study: GPS Tide Heights at the Port of Newcastle

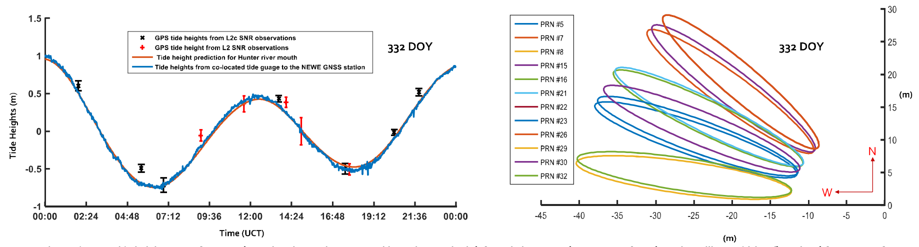


Fig. 9. The GPS tide height (port of Newcastle) estimations using proposed inversion method (left) and First Fresnel Zones(FFZ) for selected satellites (which reflect signal from sea surface) at elevation angle of 10° (right) on 28th Nov 2015. The error bars represent formal error. The tide height estimations from L2c (Black) SNR data show a better accuracy than L2 (Red) SNR data. The origin coordinate of the FFZ graph shows the antenna location of FFZ diagram.

6. Discussion

- LSP does not take the damping nature of a sinusoid into account while our new method does.
- The LSP frequency estimates depend highly on the periodogram estimation parameters such as the amount of zero-padding (i.e. over factor sampling) and the length of SNR data (i.e. choice of the elevation angle cutoff).
- The frequency estimates from our new inversion method are robust and provide the formal error estimates in a straightforward manner.
- The proposed technique determines the full waveform of the SNR modulation including not only frequency but also damping factor, amplitude, and phase shift. This allows us to monitor the reflection surface properties as well as the antenna specific parameters.
- The proposed precision analysis algorithm for GPS multipath is expected to particularly benefit applications in soil moisture and vegetation mapping, which require detection of subtle changes in modulation frequency.

7. Reference

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