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), Bernoulli

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.

3. SNR Theory

![Diagram of SNR theory](image)

- Geometry of a multipath signal, antenna height (H), and satellite elevation angle (θ).
- Delays (Δt) represent the difference in time between the direct signal transmitted from the satellite, the GPS signal reflected from the ground, and the return signal transmitted from the reflected signal back to the GPS receiver.
- The ratio of the antenna phase center to the satellite phase center represents the angular distance between the two points.

\[ SNR^2 = A_0^2 + A_0^2 + 2A_0 A_0 \cos\phi \]

\[ \omega = \frac{d\phi}{dt} \]

\[ SNR_{obs} = A_0 \cos(2\pi \frac{H}{H} \sin \theta + \phi) \]

4. Simulation and Analysis

- GPS SNR observations → Bernoulli → \( l_p, A_0, \theta_0, \eta_0 \) → NLS → \( l_p, A_0, \theta_0, \eta_0 \)

The proposed method uses the Bernoulli estimation of parameters as the introduction of the input parameter of NLS (nonlinear least square) algorithm (I) method.

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

![Graph showing GPS tide height variations](image)

- GPS observed tide height variations at the Port of Newcastle are compared with the LSP method and the SNR method.

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 cut-off).
- 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 factors, 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