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An Experimental Identification of Multipath Effect in GPS Positioning Error

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ABSTRACT: The analysis of the GPS multipath effects in maritime environment is constrained with the practice of traditional GPS receiver design, that prevents access to GPS signals in Base-band Processing Domain. Here we propose and validate a simple method for experimental identification of multipath effect in Navigation Processing Domain, based on spectral characterisation of time series of GPS positioning errors.

1 INTRODUCTION

GPS position estimation process is a set of signal processing and estimation methods aimed at providing the user's position estimate based on signals and data broadcast by a GPS satellite and received by the user's GPS equipment. During the process (depicted in Fig 1), the user's GPS receiver measures the pseudo-ranges of all the satellites in radio-vicinity of its aerial, using the Pseudo Random Noise (PRN) signal (code) sequences and the wave-form structure of Navigation Message binary data. Then, a dedicated set of estimation methods is applied on a set of the pseudoranges measured, in order to estimate the solution of navigation problem and yield the values of the variables unknown: three components of the spatial (3D) user position estimate and the user clock error.

The GPS position estimation process is spread over three spectrum signal processing domains, as depicted in Fig 2. In *Radio Frequency Processing Domain (RFPD)*, a GPS receiver processes a received weak modulated satellite signal, marked by in information (contextual) sense with its carrier wave frequency (L1 = 1575.42 MHz, for conventional commercial GPS receiver). The Radio Frequency Processing Domain signal is transformed into *Base-band Processing Domain (BPD)* signal through double-conversion process of demodulation, yielding the BDP signal marked with its base-band spectrum (i. e. the spectrum of PRN signals and the navigation message after the removal of the carrier).

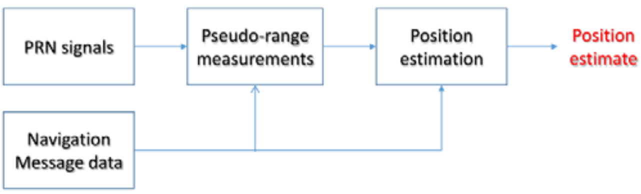

Figure 1. GPS position estimation process

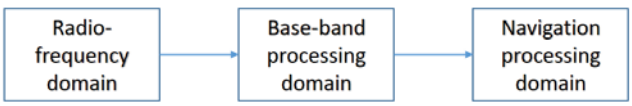

Figure 2. The essential processing domains of an GPS position estimation process

Pseudo-range measurement process is applied on the BPD signal that still comprises all the error effects inherited from the RFPD signal. The range errors induced during the satellite signal transmission and propagation encompasses the results of the ionospheric and multipath effects. Finally, the measured pseudo-ranges and information distilled from the Navigation Message (including the satellite ephemeris and the parameters of standard error correction models, such as Klobuchar's one, for mitigation of ionospheric effects) enters the purely numerical (non-signal) *Navigation Processing Domain (NPD)*, where the statistical estimation methods are applied in order to solve the navigation problem numerically. The results of the NPD processing include the estimation of position determination errors, as inferred from partial statistical processing results in the Base-band and Navigation Processing Domains.

Here we present the results of a recent research, aimed at identification of the effects of one of the GPS positioning error sources (multipath) in maritime environment, using the available dat in Navigation Processing Domain.

2 MULTIPATH-INDUCED GPS POSITIONING ERRORS IN MARITIME ENVIRONMENT

The GPS positioning error budget encompasses all the effects that deteriorate the quality of the GPS position estimate. Two major single contributors to the GPS ranging (pseudo-range measurement) error are the ionospheric delay and multipath. Both error causes extend their stochastic character, that prevents the successful removal of their effects on the GPS position estimation quality.

The multipath effects on the GPS position estimation quality arise from the super-position process in the multipath-prone environments (urban and maritime environments, in particular), as shown in Fig 3. Multiple reflections of the original satellite signal, that travels in the straight line, cause the reception of a number of signals with the same carrier frequency and different travel paths in the receiver's aerial. As the result, the received signal appears as travelled the farther distance than it actually did, causing the pseudo-range measurement error, and thus deteriorating the accuracy of the GPS position estimate.

The sea waves increase the probability of satellite signal reflection, thus rendering the maritime environment a multipath-prone.

The effects of multipath become visible in Base-band Processing Domain, where various advanced statistical signal processing approaches may be applied for identification and mitigation purposes. However, the design of traditional GPS receivers keeps the base-band processing activity manufacture-proprietary and thus depriving third-parties (researchers) from an opportunity for assessment and potential improvement (statistical signal processing methods are the common core-business assets in the GPS receiver manufacturing industry).

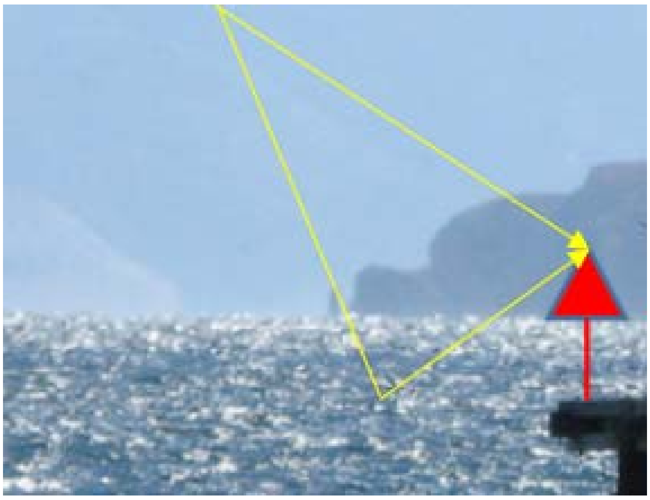

Figure 3. GPS multipath on the sea

A so-called *code–phase combination method* was developed to estimate the multipath error in Navigation Processing Domain providing both the single-frequency GPS code and phase observables are available. The method is founded on the assumed models of the GPS ranging (*R*) and phase (*Φ*) observables, as presented in (1) and (2), respectively.

$$R_p = \rho + c(dt_r - dt^s + T + \alpha_j * STEC + K_{p,r} - K_p^s + M_p + \varepsilon_p \quad (1)$$

$$\Phi_L = \rho + c(dt_r - dt^s + T - \alpha_j * STEC + k_{L,r} - k_L^s + \lambda_L N_L + \lambda_L \omega + m_L + \varepsilon_L \quad (2)$$

The range – phase difference yields (3), as follows:

$$R_1 - \Phi_1 = 2\alpha_1 I + Bias + M + \varepsilon \quad (3)$$

The code-phase combination methods yields a mathematical model (3) that can be utilised for multipath error estimation, after calibration (removing Bias) and the appropriate compensation for the ionospheric effects (I).

3 AN EXPERIMENTAL ASSESSMENT OF MULTIPATH EFFECT ON GPS POSITIONING IN NAVIGATIO PROCESSING DOMAIN

Thus paper presents the results of a research study that focused on identification of multipath effects in GPS position estimation errors times series, based on the post-processing analysis conducted on the set of experimental pseudoranges taken at a buoy and utilising the contextual domain expertise. The information processing procedure revealed patterns of maritime activity and the effects of various GPS positioning error sources in operation. The appropriate information filtering through the assessment of the positioning errors spectrum signatures extracted the effects related to multipath.

The research was conducted using two characteristic scenarios with the GPS pseudo-ranges collected during calm sea, and moderately windy conditions, respectively.

3.1 *Data source*

Raw pseudo-range observations in RINEX format from the GPS reference station buoy situated in Port Garibaldi, Italy were used (Sonel, 2017). Two use-case scenarios were assessed, base on assumption of sea waves created by the wind conditions:

– *Case 1*: calm wind condition, with pseudoranges taken during quiet conditions (wind's velocity mostly under 4 mph) throughout 7th May, 2016, every 30 s, and
– *Case 2*: moderate wind condition, with pseudoranges taken during moderate wind conditions (wind's velocity in range of 10 mph - 20 mph, and gusts of up to 26 mph) throughout 13th May, 2016, every 30 s.

The content of the Navigation Message was obtained in RINEX format for both days in question. Case 1 was used as a reference (benchmark), under presumption of the insignificant multipath effects.

3.2 *Methodology*

A post-processing (simulation) approach based on experimental data was taken in the research presented. the RTKLIB, an open-source GPS pseudo-ranges processing tool, was utilised for GPS positioning error estimation, based on the RINEX files of actual pseudo-range observations. The mask-angle parameter, commonly used for suppressing the multipath effects, was set to 10°, thus allowing for performance assessment of a commercial-grade receiver. RTKLIB returns time series of the GPS northing-, easting-, and height-errors. Time series were analysed in time- (descriptive time series analysis) and frequency- (spectrum determination) domains with the dedicated software developed by our team in R, an open-source framework for statistical computing, analysis and simulation. A detailed methodology of utilisation of RTKLIB for GPS post-processing for research may be found elsewhere (Takasu,, 2013, Filic, Filjar, Ruotsalainen, 2016).

3.3 *Assessment results*

Time series of GPS northing-, easting-, and height-errors (depicted in Figs 4 and 5, for Cases 1 and 2, respectively) were produced and analysed. All the time series for both scenarios express seasonal effects due to partially compensated ionospheric effects (daily pattern of the GPS ionospheric delay dynamics is clearly visible), despite the application of the Klobuchar GPS ionospheric correction model. In addition, the time series extend very regular patterns local peaks in GPS positioning error time series, probably due to the scheduled maritime activities in port.

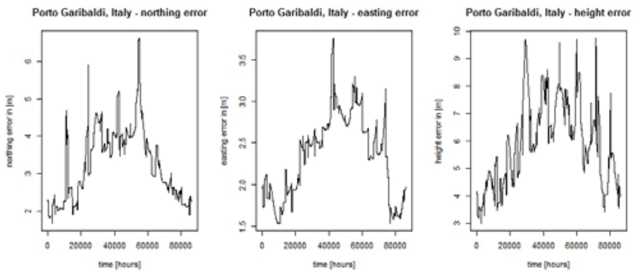

Figure 4. Case 1, mask angle set at 10°

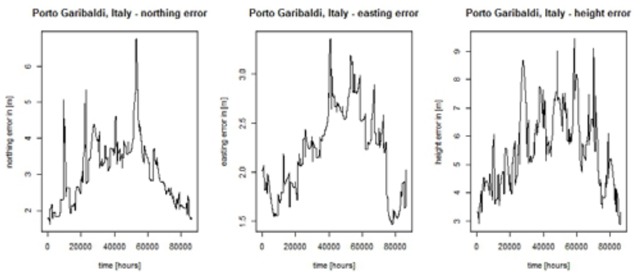

Figure 5. Case 2, mask angle set at 10°

The spectral characteristics of the GPS positioning error time series for Case 2 are presented in Fig 6.

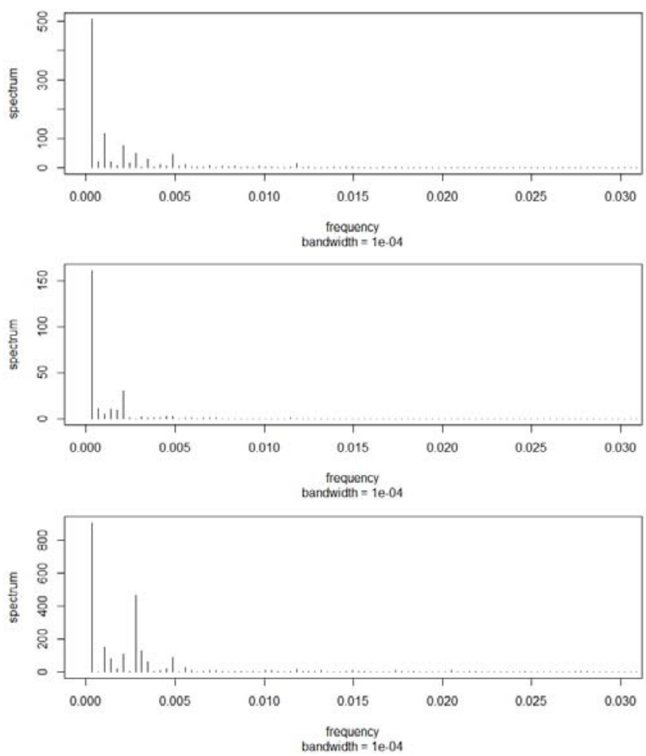

Figure 6. Spectral characterisation of the GPS northing- , easting-, and height- error time series, respectively, for Case 2

4 DISCUSSION

The comparison with the spectral characteristics of the Case 1 time series reveals two remarkable findings, as follows.

First, the common spectral components are either of the same intensity, or even more pronounced in

Case 1. We find this a consequence of the other positioning error sources (such as an uncompensated local ionospheric disturbance) in operation, that overcome the multipath effects when the time-domain is considered.

Second, the Case 2 spectral characterisation reveals more spectral components than in Case 1, rendering them a signature of the multipath effect. The intensity of the new Case 2 spectral components are generally lower than the intensity of the components common to both cases, thus suppressing their visibility in the inspection of time series in the time domain.

Despite the presence of the intensive influence of the other GPS positioning error sources, the spectral characterisation reveals the effect of multipath through correspondence between the encounter of the expanded GPS positioning error spectral and sea waves activity.

5 CONCLUSION

A study is presented here, that addresses the identification of multipath effect in time series of GPS positioning error data taken in maritime environment. An information- (contextual-based) approach was taken based on domain expertise in interpretation of the analysis of the GPS positioning errors time series in time- and frequency- domains. In that way, the GPS positioning performance was assessed in the Navigation processing, rather than in the GPS receiver design-constrained Base-band Processing Domain. The spectral characterisation of the GPS positioning errors time series reveals multipath spectral signature in time series of possible multipath-prone (moderately windy) maritime conditions, despite the masking from the other GPS positioning error sources in operation.

We intend to continue related research in cataloguing the spectral signatures of characteristics maritime GPS positioning conditions, following the path of development of a general maritime GPS multipath model.

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