A Novel Approach to Acquire GPS Signal in the Presence of CWI using DWT

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Abstract

Objectives: Radio frequency interference is major setback for précis estimation of position using GPS receivers in the real time environment. An approach to handle such situations is the implementation of receiver using cutting edge signal processing technologies. Methods/Statistical Analysis: A strong signal from other communication channels and narrow band pulse signal are the major components of interference for GPS signals. Acquisition is primary and important signal processing step in GPS receiver. The performance of a GPS receiver depends on the acquisition process in the presence of interference. In this paper an acquisition method using the Discrete Wavelet Transform is proposed to mitigate the interference and to measure the acquisition parameters. Findings: Conventional GPS receiver uses the Fast Fourier Transform (FFT) to perform convolution in the acquisition process. This method is unable to acquire the GPS signal in the presence of interference. The Discrete Wavelet Transform decomposition and appropriate thresholding method for the convolution in the acquisition process permit the algorithm to demonstrate the successful mitigation of Continuous Wave Interference (CWI). Performance of the conventional and proposed acquisition algorithms are compared based on statistical parameter correlation ratio and maximum peak measured. Results show that the proposed algorithm DWT based acquisition performed well than the conventional method of acquisition.

Keywords: Acquisition, CWI, DWT, GPS, Thresholding

1. Introduction

Reliable positioning and navigation are the thrust areas where a number of applications are growing for the purpose of public services and safety. As a consequence, GNSS is evolving in an accelerating pace and it becomes a most essential technology in a huge number of professional devices. Therefore, parallel to the development of techniques able to improve the positioning accuracy and robustness of the positioning methodologies in order to make sure that the navigation is reliable. As far as GNSS based techniques, the main threats to be considered are intentional or unintentional interference. In general GPS received signals are extremely weak and easily corrupted by interfering signals at receiver antenna. Moreover, the other communication systems which broadcast strong signals on frequencies within or located near the GPS frequency interferes the signal most. In fact, the presence of undesired interference signal can effect in accuracy of positioning or complete loss of receiver tracking. As an example, the terrestrial Digital Video Broadcasting (DVB-T) system may represent a real threat for the GPS receiver operation. In fact, nonlinearity distortion generated in the DVB-T transmitter amplifier may lead to the generation of harmonics in the GPS L1 frequency band. Many other examples of communication systems which may represent a possible in-band unintentional interference sources for the GNSS are described in.

Last but not least, intentional interference is also a threat to be considered for civil GNSS community.

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Portable devices, jamming the GNSS bandwidth, typically broadcast signals frequency modulated where the instantaneous frequency sweeps a range of several MHz in a few microseconds affecting the entire GNSS band targeted by the device. These few examples of interference generated by other communication systems proved that interference is a real issue in GNSS and that proper counter measures have to be designed. In fact, the different interference sources may broadcast signals that are very different in terms of power, modulation, and pulse shape, thus making it difficult to have a universal countermeasure able to cope with all of them. In this paper, this issue is addressed working with a transformed domain approach that is able to deal with a large number of different kinds of interfering sources, thus being effective in a wide range of scenarios.

2. Interference Signal Types

There are two types of interferences sources; namely unintentional and intentional sources. Unintentional sources cover in band Pulse Signal Interference (PSI) e.g. DME/TACAN, UWB, ATC/radar. Continuous Wave Interference (CWI) signals are classified under both type of interference. In terms of unintentional interference sources, CWI is more challenging to mitigate at the receiver compared to PSI signals. Harmonics from Very High Frequency Communications (VHF), amateur radio harmonics and TV sound/video carrier harmonics can be modelled as CWI. Another interference source, Chirp Jammers (CJ) are non-stationary signals and classified under intentional sources. Chirp signals present a change in frequency with time, that is characterized by the slope of the chirp signal (rate of change on the frequency) and its initial frequency. Other than chirp jammers, spoofers are also a threat, however spoofing attacks are rarer. The spoofing waveform might be a replica of the GNSS signal, appearing like a true signal and cause slowly varying time, phase and pseudo-range errors.

2.1 Signal Model

The interfered signal $r_i$ of the $i_{th}$ satellite after front-end can be modeled as

$$r_i = \sqrt{2P_i} c (t_m f_{ci,j} - \tau_i) d (t_m f_{ci,j} - \tau_i) \cos \left( 2\pi (f_{IF} + f_{DI,J}) - \varphi_j \right) + \sqrt{2J_i} \cos \left( 2\pi f_{IF} - \varphi_j \right) + n_{IF,m}$$

where $m$ is the sample index, $d$ is the navigation data message, $P_i$, $\tau_i$, $\varphi_j$ stands for the power, code phase and carrier phase of $i_{th}$ satellite signal and $J_i$, $\varphi_j$ stands for the power and carrier phase of the interference signal. $C(t)$ is the PRN code, $f_{ci,j}$ is the code rate in chips/s, $f_{IF}$ is the IF frequency, $f_i$ is the interference frequency, $f_{DI,j}$ is the Doppler frequency, $t_m$ is the time instant in [s], $n_{IF,m}$ is white Gaussian noise. The worst case interference occurs when the whole power of the interference is located in the coordinates of the GNSS signal, namely the phase and the carrier frequency. Hence, in the worst case the $R_i$ signal becomes

$$r_i = \sqrt{2P_i} c (t_m f_{ci,j} - \tau_i) d (t_m f_{ci,j} - \tau_i) + \sqrt{2J_i} \cos \left( 2\pi (f_{IF} + f_{DI,J}) - \varphi_j \right) + n_{IF,m}$$

In real environments, there are various types of interference signals. It can be narrowband, broadband, wideband depending on the receiver’s bandwidth or it can be pulsed, or having a changing frequency like chirps. Among them three types of interference signals are considered and analyzed which is pulse, continuous wave and AWGN.

![DME pulse pair](image)

Figure 1. DME pulse pair.

2.2 Pulse Interference

Pulse interference occurs only for a short time; however, it may affect GNSS receivers in a large extent if the interference signal is characterized by high power with a large duty cycle. The impact on the GNSS signal can be kept at a minimum by applying proper signal processing techniques such as pulse blanking, clipping or some advanced
techniques like Wavelet transformation based excision. The DME signal interfered into GNSS signal is modelled as

\[ s_{DME}(t) = P \sum_{n=1}^{N} \left( e^{\frac{\pi}{2}(n-\nu)^2} + e^{\frac{\pi}{2}(n-\nu)^2} \right) \cos(2\pi f_{DME}t + \theta_{DME}) \]

**2.3 Continuous Wave Interference**

CWI is another type of interference, appearing in the spectrum as an RF spike. The susceptibility from CW interference sources is much more significant than those originated at pulse interference sources. If CWI exists, it is inevitable that it blocks the process of GNSS receiver. A narrow band CWI can be written as follows:

\[ s_{CWI}(t) = A \cos(2\pi f_c t + \phi) \]

where \( A \) is amplitude of the interference signal, \( f_c \) is the frequency offset from carrier frequency of the desired GNSS signal and \( \phi \) is the initial phase of the interference signal. The potential CWI sources on GNSS L-band are summarized as:

- TV/ Video Harmonics
- Amateur Radio Harmonics
- FM Harmonics
- LDACS

**3. The Wavelet based Acquisition Algorithm**

DWT based signal acquisition algorithms for GPS is proposed. In this method, DWT is used to de-noise the GPS signal and to decrease the number of samples used there by complexity of process is simplified in acquisition. The proposed algorithm is summarized as follows and is depicted in Figure 2. The interference signal is denoised using DWT analysis and the output coefficients are used to compute the correlation with the DWT coefficients of PRN code, instead of original signal. Since major part of the signal is available in detailed coefficients, correlation process uses these coefficients. Then, IDWT and accumulation process is used to detect the peak in acquisition process successfully.

The GPS signal is given to DWT, in this paper Haar wavelet is used as mother wavelet for decomposition, after removing the carrier signal by multiplying with the output of Numerically Controlled Oscillator (NCO) which generates sinusoidal signal. DWT decompose the signal as detailed (cD1) and approximate (cA1) coefficients. Since the major part of the signal contributes in the detailed coefficients, soft thresholding is applied to detailed coefficients using minimax thresholding technique for selecting \( \tau \). Similar procedure is applied to decompose the locally generated PRN code SVPRN6, which results as detailed (cD1) coefficients. Now correlation is performed using soft thresholded detailed coefficients of GPS signal and locally generated PRN code by computing Fourier transform. The highest absolute value of correlation obtained gives the required change in the carrier frequency and delay in PRN code of received GPS signal if it is more than the threshold value. If the acquisition is not completed, then the same process is repeated with change in the frequency in steps of 500Hz of NCO. In the proposed algorithm Donoho’s soft thresholding is used.

\[ S_{\tau}(x) = \begin{cases} x - \tau \text{sgn}(x) & \text{if } |x| > \tau \\ 0 & \text{if } |x| \leq \tau \end{cases} \]

These curtail the coefficients towards zero. The variance of the Gaussian noise to to the wavelet coefficients is used to opt the threshold parameter \( \tau \).

**Figure 2. Acquisition using Discrete Wavelet Transform.**
4. Results and Discussion

Performance of the proposed DWT based acquisition algorithm is verified using GPS IF signal with carrier frequency of 1.25MHz sampled at 5MHz in the presence of CWI.

The proposed DWT and FFT based acquisition algorithms are implemented to acquire the GPS signal in the presence of CWI. The acquisition is carried on simulated GPS signal combined with CWI, over a range of 1.24MHz – 1.26MHz IF frequency with the increment of 500Hz in each step, code delay observed is from 1 to 5000 samples. The search frequency observed and indexed as 1 to 41. The results are plotted as a function of time, frequency and correlation magnitude as shown in Fig. 3 and Fig. 4. From the Figure 3, it found that a maximum peak is detected at 3125th sample and 27th frequency index (i.e. 1.2535MHz) using both the methods at -7db CW I level.

From the Figure 4, it found that the maximum peak is able to detect using proposed method but not using FFT method at -27dB CW interference level. Figure 5(a) and (b) shows plot of autocorrelation maximum magnitude plot at different interference levels using FFT and proposed methods respectively.

Figure 3. Signal acquisition in the presence of -7dB CW interference using a) FFT method b) DWT method.

Figure 4. Signal acquisition in the presence of -27 dB CW interference using a) FFT method b) DWT method.

Figure 5. Correlation peaks obtained in Signal acquisition in the presence of CW interference using (a) FFT method (b) DWT method.
Table 1 shows the performance of FFT and wavelet based acquisition algorithms in the presence of CWI. Performance is evaluated using measuring the statistical parameter correlation ratio. From the table 1 it is observed that the FFT based acquisition is not performed well higher levels of CWI (at -27dB of AWGN the correlation ratio is -0.079). However, the Wavelet based acquisition is able to detect the signal at -27dB (correlation ratio is 0.27).

| CWI Noise level | I peak magnitude | II peak magnitude | Correlation ratio (cr) |
|-----------------|------------------|-------------------|------------------------|
| Using FFT       | Using DWT        | Using FFT          | Using DWT              | Using FFT          | Using DWT              |
| -7dB            | 2475             | 2514              | 0.7733                 | 0.7641              |
| -14dB           | 2402             | 2536              | 0.7057                 | 0.6648              |
| -21dB           | 2320             | 2575              | 0.4250                 | 0.4936              |
| -24dB           | 2248             | 2635              | 0.2171                 | 0.3992              |
| -27dB           | 2340             | 3176              | -0.0799                | 0.2717              |

I peak is magnitude of peak at Doppler frequency
II peak is magnitude of next maximum peak
\[ \text{cr}=1-\frac{\text{II peak}}{\text{I peak}} \]

Correlation magnitudes obtained in acquisition using FFT and proposed methods in the presence CW interferences are compared and plotted as function of frequency index and maximum peak magnitude obtained in Figure 5. From the figure, it is clearly found that the maximum correlation peak firmly obtained using proposed method. However, using FFT method signal is not able detect. Finally, correlation ratio is computed from the correlation magnitude plots for CW I different CNR levels and plotted in Figure 6. From the Figure it is observed that the proposed method able to acquire the GPS signal whereas FFT method not able to detect at higher interference levels.

5. Conclusions

In this paper, an innovative robust GPS acquisition algorithm exploiting the Discrete Wavelet Transform has been presented. A simulated SVPRN 6, IF signal of one second with 1.25MHz carrier frequency, Doppler shift of 3390Hz, 3125 samples of code delay is used for testing the proposed algorithms. The signal is sampled at 5M samples per second. The proposed algorithm is tested in the presence of different levels of simulated CW interference signals. From the results it is found that the proposed method performed well in the presence of higher levels of interferences. Whereas FFT based acquisition is not able to detect the signal in the presence of higher levels of interference. Hence, the proposed method is very useful in implementation of robust acquisition in software GPS receivers.

6. References

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