

A BLIND ANTI-JAMMER PRE-PROCESSOR FOR GPS RECEIVERS

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1. Introduction

Global positioning system (GPS) employing satellite-based location techniques has been widely used in providing precision navigational capabilities for aircraft, ships, and ground traffic. Due to a large processing gain with spread spectrum techniques employed, GPS receivers can be effective in extracting the navigational information signals transmitted from satellites at a power level below that of thermal noise [1]-[2]. Nevertheless, performance will significantly degrade if any strong interfering source coexists. Typically, jamming power level less than 40 dB with respect to the signal power level, i.e. jammer-to-signal ratio (JSR) of 40 dB, can be tolerated. This however is so impossible, since, in practice, the existence of strong unintentional radio frequency interference and intentional jammers, which are easily generated due to the weakness of received GPS satellite signal about -160 dBm at earth, will disable the receiver. Consequently, a powerful technique for jammer suppression has gained much attention to guarantee the reliable GPS operations [3]-[4].

In this paper, a novel GPS receiver is proposed for alleviating the performance degradation due to the strong jammer. Specifically, an anti-jammer scheme prior to the correlators is first proposed for assuring the reasonable level of JSR in the inputs of correlators. From the fact that the desired signals are well below the possible jammers, the jammer terms associated with the received data will significantly enlarge the eigenvalue spread of the received data correlation matrix. Based on the received data correlation matrix, a detection algorithm is developed to determine the existence of the strong jammers. An optimal combining is then constructed so as to produce nulls for suppressing the strong jammers as the resultant of the jammer detector is true. Contrarily, a mainbeam is formed for maximum reception of the Signals-of-Interest (SOIs). Moreover, the outputs of the optimal combiner are sent to regular GPS correlators to despread the received data (chip level) into the bit stream. In spite of the success in suppressing the strong jammer, optimal combining performed on the SOIs will introduce phase rotation, which will induce significant degradation in performance. As a remedy, a phase compensator is developed based on the predetermined 8-bit preambles in the first two words (telemetry and TLM) associated with each subframe of GPS data to estimate the phase rotation introduced by the combining scheme. Final, a hard decision detector is used to recover the GPS navigation data bits. Since the strong jammers have been removed preliminarily, the proposed algorithm can effectively extract the SOIs, leading to performance enhancement as compared with conventional methods. Numerical results demonstrate that the proposed scheme exhibits robustness against the strong jammers.

2. Array Model and Proposed Receiver with Blind Anti-Jammer Pre-processor

The scenario considered herein involves a desired signal group composed of J visual satellite vehicles (SVs) and K uncorrelated jammers from directions θ_{di} and θ_{ui} , respectively. These sources are assumed to be narrowband with the same center frequency and in the far field of an array consisting of M elements. Adopting the complex envelop notation, the array data obtained at a certain sampling instant can be put in an $M \times 1$ vector form:

$$\mathbf{x} = \sum_{i=1}^J s_{di} \alpha_i \mathbf{a}(\theta_{di}) + \sum_{i=1}^K s_{ui} \mathbf{a}(\theta_{ui}) + \mathbf{n} = \mathbf{a}_d + \mathbf{A}_u \mathbf{s}_u + \mathbf{n} \tag{1}$$

where $\mathbf{A}_u = [\mathbf{a}(\theta_{u1}), \mathbf{a}(\theta_{u2}), \dots, \mathbf{a}(\theta_{uK})]$, $\mathbf{s}_u = [s_1, s_2, \dots, s_K]^T$, and $\mathbf{a}_d = \sum_{i=1}^J s_{di} \alpha_i \mathbf{a}(\theta_{di})$.

The random scalars s_{di} and s_i represent SOIs from the SVs and jamming signals received at the reference point of the array with signal power σ_{di}^2 and σ_i^2 , respectively, and α_i 's denote the complex amplitudes of the coherent signals. The vectors $\mathbf{a}(\theta_{di})$ and $\mathbf{a}(\theta_{ji})$ are the array steering vectors associated with the desired and jamming sources, respectively. Finally, the vector \mathbf{n} is composed of the complex envelopes of the noise present at the M elements, which are assumed to be spatially white with power σ_n^2 , and uncorrelated with all signals. Note that \mathbf{a}_d is the composite steering vector of the SOIs.

Array processing technique is widely used to alleviate the fading effects for wireless communications systems. To achieve a reliable communication quality, the antenna outputs are weighted and summed to receive the SOIs as much as possible, while the signal-of-not-interest (SONI) suppressed. Specially, in direct sequence spread spectrum (DSSS) systems, the optimal weights associated with the maximum signal-to-interference-plus-noise ratio (MSNR) beamformer are constructed by directly utilizing the input and output signals of correlators. Mathematically speaking, the optimal weights can be obtained by $\mathbf{R}\mathbf{w} = \lambda\tilde{\mathbf{R}}\mathbf{w}$, where \mathbf{R} and $\tilde{\mathbf{R}}$ denote the data correlation matrix associated with the spread and despread data, respectively. The corresponding solution to the eigen-equation is given by the (dominate) eigen-vector associated with the maximum eigen-value. The MSNR beamformer has been shown to effectively deal with strong jammers as the path delays are correctly obtained. However, in presence of strong jammers, the delays of SOI paths are hard to correctly estimate such that the correlators fail to extract the SOIs. This will result in the desired signal cancellation in the MSNR criterion. As a remedy, the strong jammers have to be suppressed before the correlator scheme.

In this paper, a novel GPS receiver, consisting of a blind anti-jammer detector, correlators, and phase compensators, is proposed to alleviate the performance degradation due to the strong jammers.

In DSSS signal environments, if powers of all signals are almost the same power and processing gain (the length of spreading codes) are also identical, statistical properties of interfering signals before despreading are close to those of white Gaussian noise. That is, the eigen-values of the despread data correlation matrix will be almost identical such that the eigen-value spread is small. On the other hand, the eigen-value spread will increase as the signal powers are significantly diverse. In accordance with the above-mentioned, the eigen-value spread can be used to detect the existence of strong signals, which are referred to jammers. The overall procedure of the proposed jammer detector is summarized as below:

1. Compute the received data correlation matrix according to $\hat{\mathbf{R}} = \frac{1}{N} \sum_{n=1}^N \mathbf{x}[n]\mathbf{x}^H[n]$, where $\mathbf{x}[n]$ denotes the n^{th} sample of the received data and N is the number of snapshots (samples).
2. Compute the eigen-values and eigen-value spread η of the received data correlation matrix.
3. Compare the eigen-value spread with a pre-determined threshold γ , which is used to indicate the existence of strong jammers. The strong jammers exist as the value of η is greater than that of γ . Otherwise, only weak jammers exist.

With the jammers detected, the next step is to perform a transformation of the received data to remove the strong jammers. In accordance with the eigen-decomposition technique, the ensemble data correlation matrix \mathbf{R} can be expressed as

$$\mathbf{R} \approx \mathbf{U}_s \mathbf{\Lambda}_s \mathbf{U}_s^H + \mathbf{U}_j \mathbf{\Lambda}_j \mathbf{U}_j^H \quad (2)$$

where \mathbf{U}_s and \mathbf{U}_j denote the signal subspace and the jammer subspace, respectively. The diagonal matrices $\mathbf{\Lambda}_s$ and $\mathbf{\Lambda}_j$ are formed by the eigen-values driven by the SOIs and the strong jammers, respectively. It is noteworthy that the approximation in (2) holds due to the strong jammer assumption. From the fact that power of the strong jammers is well above that of the SOIs, these dominate eigenvectors in \mathbf{U}_j form a subspace for the strong jammers. On the other hand, the other eigenvectors in \mathbf{U}_s span the complementary subspace which is approximately orthogonal to the effective steering vectors of the strong jammers. Hence the general solution of transformation \mathbf{T} for suppressing the strong jammers is suggested by the complementary projection matrix associated with the jammer orthonormal matrix \mathbf{U}_j : $\mathbf{T} = \mathbf{I} - \mathbf{U}_j \mathbf{U}_j^H$.

The weights of the optimal combining are obtained according to the presence/absence of strong

jammers. To ensure an effective suppression of strong jammers, the weights is constructed based on the transformed data $\mathbf{T}\mathbf{x}$. This is done by choosing the weight vector in accordance with the maximum signal-plus-noise-to-noise ratio (MSNNR) criterion:

$$\max_{\mathbf{w}} \frac{E\left\{|\mathbf{w}^H \mathbf{T}\mathbf{x}|^2\right\}}{E\left\{|\mathbf{w}^H \mathbf{T}\mathbf{n}|^2\right\}} \equiv \frac{\mathbf{w}^H \mathbf{T}\mathbf{R}\mathbf{T}\mathbf{w}}{\mathbf{w}^H \mathbf{T}^2 \mathbf{w}} = \frac{\mathbf{w}^H \mathbf{T}\mathbf{R}\mathbf{T}\mathbf{w}}{\mathbf{w}^H \mathbf{T}\mathbf{w}} \quad (3)$$

whose solution is given by the dominant mode of the eigen-equation: $\mathbf{T}\mathbf{R}\mathbf{T}\mathbf{w} = \zeta \mathbf{T}\mathbf{w}$, where ζ denotes the largest eigenvalue of the eigenequation in (3). Note that the fact $\mathbf{T}^2 = \mathbf{T}$ holds since \mathbf{T} is an idempotent matrix. Since the strong jammers have been suppressed, the beam pattern obtained by the weight vector \mathbf{w} can simultaneously form a main-beam for collecting SOIs and nulls for suppressing the strong jammers.

In this case, we can straightforward obtain the weight vector based on the received data. Similarly, the MSNNR criterion can be used again:

$$\max_{\mathbf{w}} \frac{E\left\{|\mathbf{w}^H \mathbf{x}|^2\right\}}{E\left\{|\mathbf{w}^H \mathbf{n}|^2\right\}} \equiv \frac{\mathbf{w}^H \mathbf{R}\mathbf{w}}{\mathbf{w}^H \mathbf{w}} \quad (4)$$

whose solution is given by $\mathbf{R}\mathbf{w} = \tilde{\zeta} \mathbf{w}$, where $\tilde{\zeta}$ denotes the largest eigenvalue. Obviously, the beam pattern obtained by the weight vector \mathbf{w} can perform a main-beam to collect the SOIs.

In spite of the success in suppressing the strong jammers, optimal combining performed on the SOIs will introduce phase rotation, which will induce significant degradation in performance. As a remedy, a phase compensator is developed based on the predetermined 8-bit preambles in the first word associated with each subframe of GPS data, to estimate the phase rotation introduced by the combining scheme.

Specifically, the phase difference among the preamble bits (0,1), hidden in the received data, can be aligned (compensated) by multiplying the despread data together with the pre-determined preamble bits. Since the product of the despread data and the preamble bits will get rid of the effect of phases associated to the preamble bits, the phase-aligned data can be simultaneously processed during many subframes.

Final, a hard decision detector is used to recover the GPS data bits. The overall schematic description of the proposed GPS receiver with jammer remover is illustrated in Figure 1.

3. Computer Simulation

Computer simulations were conducted herein to demonstrate the efficacy of the proposed GPS receiver with the proposed blind anti-jammer pre-processor. A two-element array with half-wavelength inter-element spacing was employed. The antennas were assumed to be identical and omni-directional with unit gain. The scenario involved four SOIs composed of the satellite SVs #7, #15, #27, and #31 of the same power at -10 , 0 , 10 , and 25 degrees, respectively, and a strong CW tone jammer at -45 degree of a power of 60 dB with respect to the satellite signals, i.e. JSR=60 dB. Note that all the parameter settings of the Gold codes associated with the satellites and GPS data format were based on the ICD-GPS-200.

A simulation was performed to examine the effect of input signal-to-noise ratio (SNR) on the proposed algorithm. The corresponding output signal-to-jammer-plus-noise ratio (SJNR) of the combiner and bit-error-rate (BER) were depicted in Figure 2. These plots indicate that all the values of output SJNRs increase as the input SNR increases. This confirms that the proposed anti-jammer pre-processing scheme is quite reliable in suppressing the strong jammer. As compared with the case of single antenna, which fails to suppress the strong jammer leading to low output SJNR, indicates that the proposed scheme achieves an SJNR improvement, meaning that the optimal combiner is not only successful in removing the jammer, but also constructive in receipting the SOIs. In regard to the BER, the proposed algorithm obviously performs well ($\text{BER} < 10^{-4}$) for a moderate input SNR (-20 dB). These simulation results confirm again that the strong jammer is completely suppressed, while the SOIs retained. To gain further insights, the beam pattern of the optimal combiner obtained with SNR= -25 dB was shown in Figure 3. Clearly, the proposed combiner produces a null for suppressing the strong jammer and a mainbeam for constructively collect the SOI power.

4. Conclusion

In this paper, a novel GPS receiver for combating strong jammers is proposed. It is designed with the following procedure. A blind anti-jammer pre-processor is first developed for suppressing the strong jammers. Optimal combining is applied to the transformed data so as to produce nulls for suppressing the strong jammers as the resultant of the jammer detector is true. Contrarily, a mainbeam is formed for maximum reception of the SOIs. Final, the pre-determined 8-bit preambles in the first word associated with each subframe of GPS data are used to compensate the phase rotation introduced by the combiner performed on the SOIs. Numerical results demonstrate that the proposed GPS receiver exhibits a reliable performance as the strong jammers exist.

References

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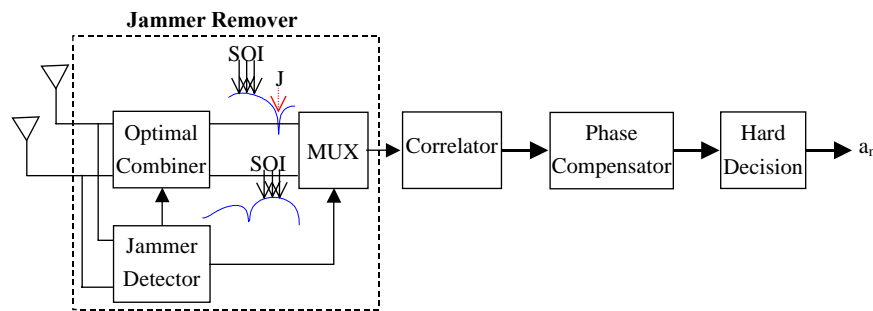


Figure 1: Schematic diagram of proposed GPS receiver with blind anti-jammer detector.

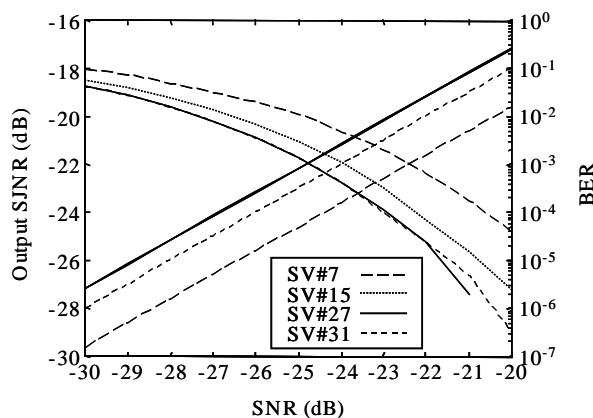


Figure 2: Performance of the proposed receiver with blind anti-jammer pre-processor.

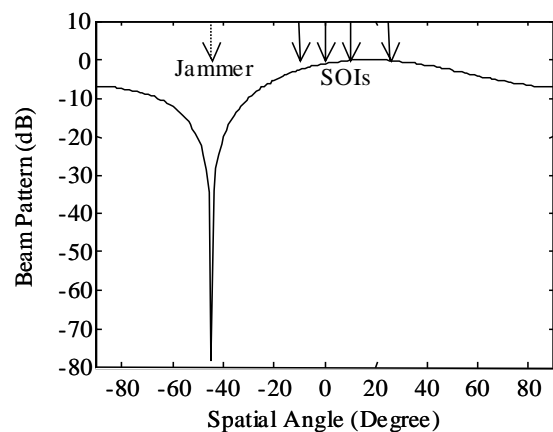


Figure 3: Pattern obtained for SNR=-25 dB. Solid arrows: SOIs. Dashed arrow: Jammer.