GPS AOA Estimation Technique Based on a Null Despreader

Suk-seung Hwang
Department of Electronic Engineering,
Chosun University,
Gwangju 501-759, Republic of Korea
email: hwangss@chosun.ac.kr

***Abstract*—The Global Positioning System (GPS), which has various military and civilian applications, is designed to estimate the locations of objects including the user. In order to enhance the desired GPS signal and to efficiently suppress the interference signals, the Angle of Arrival (AOA) information for the GPS signal is required on the environment of high-power interferers. After despreading based on a conventional despreader, the GPS AOA can be estimated using the conventional AOA estimation algorithm such as Multiple Signal Classification (MUSIC). However, we must select the GPS AOA from all estimated AOAs, because the result of MUSIC includes AOAs of GPS and interference signals. In order to overcome this problem, in this paper, we propose the GPS AOA estimation algorithm based on a null despreader. In this technique, we compare the estimated AOAs based on the conventional despreader and based on the null despreader. The proposed technique efficiently estimates and selects the desired GPS AOA when existing high-power interference signals. We demonstrate the performance of the proposed technique via a representative computer simulation example.**

***Keywords-Global Positioning System; Angle-of-Arrival; null despreader; Multiple Signal Classification; beamforming* .**

I. INTRODUCTION

The Location Detection Technology (LDT) is utilized in a variety of industrial areas and GPS is one of the representative LDTs for estimating the location of users or objects [1]-[3]. Since GPS employs the low-power Direct-Sequence Spread-Spectrum (DSSS) signal, its Signal-to-Noise Ratio (SNR) is very low (typically as low as -30 dB) and it suffers from the high-power jamming (interference) signals, which Jammer-to-Signal Ratio (JSR) can exceed 40 dB [4]. Also, interference signals have various different forms, such as Continuous Waveform (CW) and Frequency Modulated (FM) signals as the Constant Modulus (CM) signal, a Wide-Band (WB) noise jammer, and a pulsed jammer which has periodic on/off characteristics [5][6]. Although the low SNR problem can be solved by the large spreading gain (≈ 43 dB) of GPS, the high JSR problem might cause the serious location estimation error for the conventional GPS receiver. In order to solve this problem, we employ the adaptive beamforming techniques based on the GPS AOA information, such as the Minimum-Variance-Distortionless-Response (MVDR) [7][8] and the adaptive Generalized Sidelobe Canceler (GSC) [9][10].

Since the GPS signal power before despreading is lower than the noise power level, it is not possible to estimate the GPS AOA using the conventional AOA estimator such as MUSIC. After despreading, the GPS AOA can be estimated using the MUSIC algorithm because it is higher than the noise level, but we must select the GPS AOA from all estimated results because they include AOAs of the high-power interference signals. In this paper, we propose the GPS AOA estimation technique based on a null depsreader, which efficiently estimates and selects the GPS AOA information in the high JSR environment. The estimated results based on the null despreader do not include the GPS AOA but include AOAs of interference signals, because it is designed to reject the GPS signal while retaining the other interference signals [11]. On the other hand, the estimated results based on the conventional despreader include AOAs of the GPS signal and interferers. In order to select the GPS AOA, we compare both results based on the conventional and null despreaders, and determine the AOA included in results of the conventional despreader but excluded in results of the null despreader, as the GPS AOA.

The rest of this paper is organized as follows: In section II, we define the received signal model for the GPS signal, interference or jamming signal, and Additive White Gaussian Noise (AWGN). Section III describes the proposed GPS AOA estimation algorithm based on the null despreader. The performance of the proposed technique is discussed by the representative computer simulation results in Section IV. Finally, conclusions are presented in Section V.

II. RECEIVED SIGNAL MODEL

In this paper, we employ an antenna array with M elements at the receiver and focus on estimating the AOA of the GPS Coarse Acquisition (C/A) code. At discrete sample index k , the received signal vector can be modeled as

$$\mathbf{r}(k) = \mathbf{d}_c c_i(k) b_i(k) + \mathbf{D}\mathbf{s}(k) + \mathbf{v}(k), \qquad (1)$$

where $c_i(k)$ is an element of the cyclostationary pseudorandom noise (PRN) code (length $N = 20 \times 1023$), $b_i(k)$ is the GPS data bit which remains constant over the length of one cycle of the PRN code, for the i th satellite, and $\mathbf{v}(k)$ is the AWGN vector (size M) with independent and identically distributed components, each with zero mean and variance σ^2 . The other quantities and sizes of matrices and vectors in (1) are summarized in Table I, where the

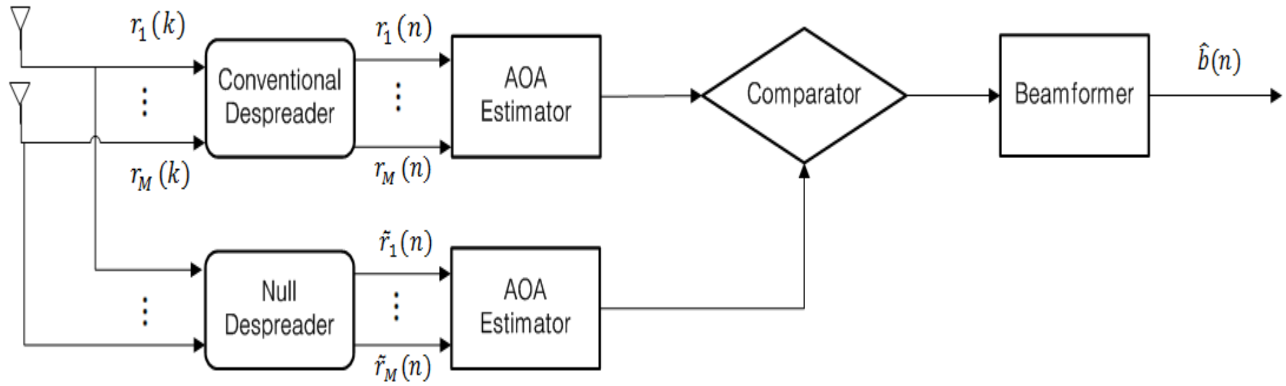

Figure 1. Architecture for the proposed GPS AOA estimation based on the null despreader

column of $\mathbf{D}$ is an AOA array response vector for the interference signal, and L is the number of interference signals. Also, we assume that the receiver utilizes a grid antenna array of size $P \times Q$ ($M = PQ$) as described in [12].

TABLE I. SUMMARY OF RECEIVED SIGNAL MODEL IN (1)

Symbol	Size	Definition
$\mathbf{r}(k)$	$M \times 1$	Received signal vector
$\mathbf{d}_c$	$M \times 1$	Array response vector for the i th satellite
$\mathbf{D}$	$M \times L$	Array response matrix for interference signals
$\mathbf{s}(k)$	$L \times 1$	Vector of interference signals

III. GPS AOA ESTIMATION BASED ON NULL DESPREADER

In this section, we describe the GPS AOA estimation technique based on the null despreader, which efficiently estimates and selects the GPS AOA when high-power interference signals are present. Figure 1 shows the system architecture for AOA estimation of the GPS signal, consisting of a conventional despreader, a null despreader, AOA estimators, and a comparator.

A. AOA Estimation Based on Conventional Despreader Output

Since each satellite employs a unique PRN code with twenty identical C/A codes, the PRN code for the i th satellite is defined as

$$\mathbf{c}_i \triangleq [\mathbf{ca}_i, \dots, \mathbf{ca}_i]^T \tag{2}$$

where $\mathbf{ca}_i$ is a row vector (size 1023) of the C/A code for the i th satellite. The output of a conventional despreader includes the GPS signal, the interference signals, and additive noise, because the power of the GPS signal ($\mathbf{c}_i^T \mathbf{c}_i = N$) is increased above the noise power level. Since $\mathbf{c}_i^T \mathbf{c}_i = N$, it is written as

$$\begin{aligned} \mathbf{r}(n) &\triangleq \mathbf{R}(n)\mathbf{c}_i \\ &= N\mathbf{d}_c b_i(n) + \mathbf{D}\mathbf{s}(n) + \mathbf{v}(n) \end{aligned} \tag{3}$$

where $\mathbf{R}(n) \triangleq [\mathbf{r}(k), \dots, \mathbf{r}(k+N-1)]$, $b_i(n)$ is the GPS data bit for the i th satellite, $\mathbf{s}(n) \triangleq \mathbf{S}(n)\mathbf{c}_i$, $\mathbf{S}(n) \triangleq [\mathbf{s}(k), \dots, \mathbf{s}(k+N-1)]$, $\mathbf{v}(n) \triangleq \mathbf{V}(n)\mathbf{c}_i$, and $\mathbf{V}(n) \triangleq [\mathbf{v}(k), \dots, \mathbf{v}(k+N-1)]$.

For estimating AOAs of GPS and interference signals, in this paper, we consider the MUSIC algorithm which has the excellent performance for high-power signals. An auto-correlation matrix for the output signal of the conventional despreader is defined as

$$\mathbf{R}_r \triangleq E\left[\mathbf{r}(n)\mathbf{r}^H(n)\right] \tag{4}$$

and its eigenstucture is given by

$$\mathbf{R}_r \mathbf{\Gamma} = \mathbf{\Gamma}\mathbf{\Lambda} \tag{5}$$

where $\mathbf{\Lambda} = \mathrm{diag}\{\lambda_1, \dots, \lambda_M\}$ is a diagonal matrix, λ_l is the l th eigenvalue. Using (5), an inverse of MUSIC cost function for estimating AOAs of signals is defined as

$$\Im(\theta,\phi) \triangleq \frac{1}{\mathbf{d}^H(\theta,\phi)\mathbf{\Gamma}_{M-L-1}\mathbf{\Gamma}_{M-L-1}^H \mathbf{d}(\theta,\phi)} \tag{6}$$

where $\mathbf{d}(\theta,\phi)$ is the array response vector corresponding an elevation angle (θ) and an azimuth angle (ϕ), and $\mathbf{\Gamma}_{M-L-1}$ is a matrix (size $M \times (M-L-1)$) whose columns are $M-L-1$ eigenvectors corresponding to the $M-L-1$ smallest eigenvalues of $\mathbf{R}_r$. Signal AOAs are determined

 ISBN: 978-1-61208-624-8

using the $L+1$ largest peaks of $\Im(\theta,\phi)$ in (6). The estimated results based on the conventional despreading output include AOAs of GPS and interference signals.

B. AOA Estimation Based on Null Despreader Output

A null despreader is designed to eliminate the GPS signal and its code consists of ten identical C/A codes and ten identical negative C/A codes. An example of the null despreadering code can be given by

$$\tilde{\mathbf{c}}_i \triangleq [\mathbf{ca}_i, -\mathbf{ca}_i, \ldots, \mathbf{ca}_i, -\mathbf{ca}_i]^T . \tag{7}$$

Since $\mathbf{c}_i^T \tilde{\mathbf{c}}_i = 0$, the output of the null despreader is written as

$$\begin{aligned} \tilde{\mathbf{r}}(n) &\triangleq \mathbf{R}(n)\tilde{\mathbf{c}}_i \\ &= \mathbf{D}\tilde{\mathbf{s}}(n) + \tilde{\mathbf{v}}(n) \end{aligned} \tag{8}$$

where $\tilde{\mathbf{s}}(n) \triangleq \mathbf{S}(n)\tilde{\mathbf{c}}_i$ and $\tilde{\mathbf{v}}(n) \triangleq \mathbf{V}(n)\tilde{\mathbf{c}}_i$. Defining an auto-correlation matrix for the output signal of the null despreader as

$$\mathbf{R}_{\tilde{r}} \triangleq E\left[\tilde{\mathbf{r}}(n)\tilde{\mathbf{r}}^H(n)\right] \tag{9}$$

and using processes of (5) and (6), we estimate AOAs of interference signals from the L largest peaks of $\Im(\theta,\phi)$. Since the GPS signal is removed by the null despreader, $\mathbf{\Gamma}_{M-L-1}$ is changed to $\mathbf{\Gamma}_{M-L}$ in (6). The estimated results based on the null despreading output include AOAs of only interference signals, but it does not include the GPS AOA.

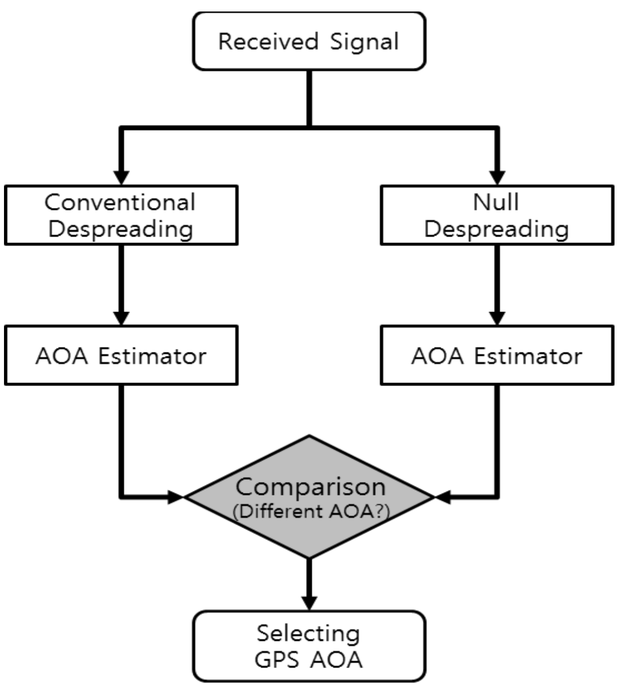

Figure 2. Flow-chart for the proposed GPA AOA estimation technique.

TABLE II. COMPUTER SIMULATION SCENARIO

Signal	Azimuth (°)	Elevation (°)	Center Frequency
GPS	27	78	-
CW	-59,2	78,78	0.16, 0.42
FM	-81	78	0.24
WB	-29,71	78,78	0.08, 0.35
Pulsed	47	78	-

C. Selection of GPS AOA

Although the estimated AOAs based on the conventional despreader consist of AOAs for interference and GPS signals, the estimated AOAs based on the null despreader consist of AOAs for only interference signals. Since the estimated AOAs of interference signals based on both despreaders are identical, we determine the AOA included in the results based on the conventional despreader but not included in the results based on the null despreader, as the GPS AOA. Figure 2 shows a flow-chart of the proposed GPS AOA estimation technique. In order to suppress interference signals, the estimated AOA information of the GPS signal is applied to the adaptive beamformer, such as MVDR or GSC.

IV. COMPUTER SIMULATION

In this section, we provide a computer simulation example to demonstrate the performance of the proposed GPS AOA estimation technique based on the null despeader, when the high-power interference signals exist. Assuming that we employ $M = 8$ antenna elements at the receiver, the received signal consists of two CW interference signals, one FM interference signal, two WB noise interference signals, one pulsed interference signal with the period of 100 samples, and AWGN. The parameters of these signals are summarized in Table II. In addition, SNR of the GPS signal is -30 dB, JSR of each interference signal is 60 dB, and the modulation index and the normalized modulation frequency of the FM interferer are $\beta = 0.05$ and $f_m = 0.001$, respectively.

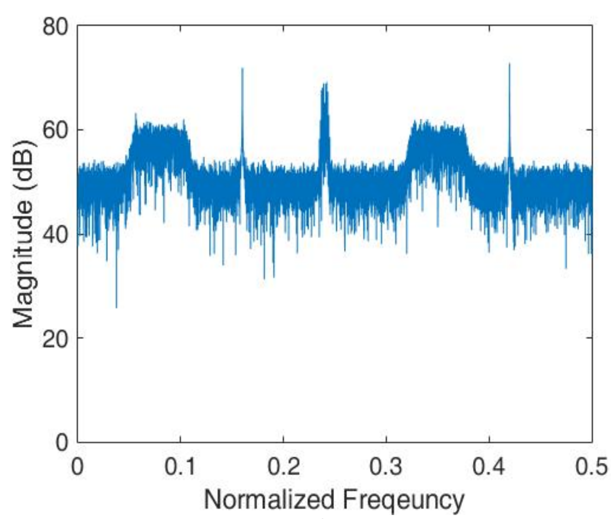

Figure 3. Spectrum of the received signal.

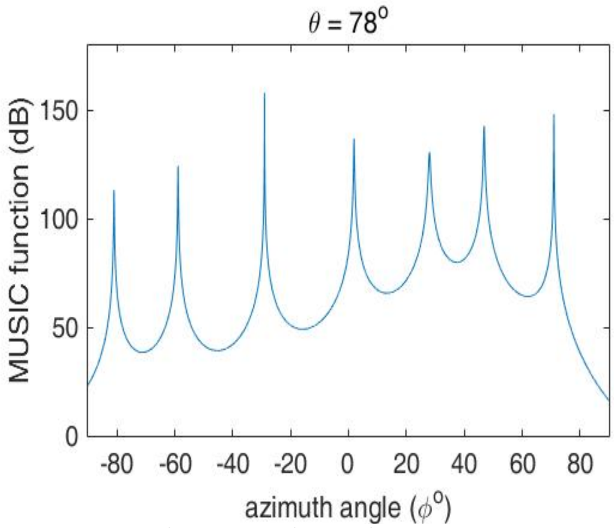

Figure 4. Inverse of MUSIC cost function for the conventional despreading output.

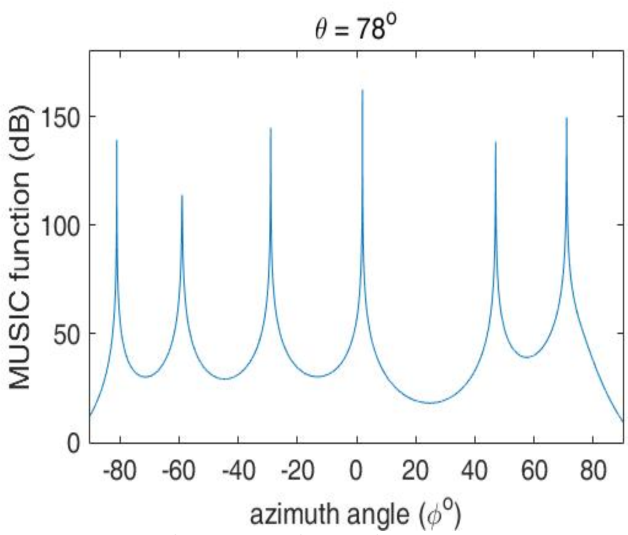

Figure 5. Inverse of MUSIC cost function for the null despreading output.

The spectrum of the received signal, which includes two CW, one FM, two WB noise, and one pulsed interferes, is shown in Figure 3. Figure 4 shows the inverse of MUSIC cost function for the conventional despreading output, at the 78 ° elevation angle, which consists of seven peaks corresponding to AOAs of one GPS signal (azimuth angle (°): 27) and six interference signals (azimuth angles (°): -81, -59, -29, 2, 48, 71). Figure 5 shows the inverse of MUSIC cost function for the null despreading output, at the 78° elevation angle, which consists of six peaks corresponding to AOAs of six interference signals (azimuth angles (°): -81, -59, -29, 2, 48, 71). Comparing peaks in Figure 4 and Figure 5, we select a peak, which is included in peaks of Figure 4 but excluded in peaks of Figure 5, as the GPS AOA.

V. Conclusion

The GPS AOA information is the most important factor for enhancing the quality of the GPS signal and suppressing the high-power interference signals. In this paper, we proposed the efficient GPS AOA estimation technique based on a null despreader, which is designed to remove the GPS signal but retain interference signals. Using the conventional AOA estimator such as MUSIC, the estimated result based on the conventional despreading output includes AOAs of the GPS and interference signals. However, the estimated AOA result based on the null despreading output includes AOAs of only interference signals but excludes the GPS AOA. In the proposed technique, we compare both results and select the AOA which is included in the result of the conventional despreader but is not included in the result of the null despreader, as the GPS signal. The estimated GPS AOA is applied to the adaptive beamformer for rejecting interference signals. The performance of the proposed GPS AOA estimation scheme was illustrated by the computer simulation example. The final version of the paper will include additional computer simulations and more details about algorithm.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. NRF-2015R1D1A1A01058827).

References

[1] S. J. Vaughan-Nichols, “Will mobile computing’s future be location, location, location?,” Computer, vol. 42, pp. 14-17, Feb. 2009.

[2] K. Singh and M. Ismail, “OTDOA location determining technology for Universal Intelligent Positioning System (UIPS) implementation in Malaysia,” Proc. 13th IEEE Int. Conf. on Networks Jointly held with the IEEE 7th Malaysia Int. Conf. on Communication, Kuala Lumpur, Malaysia, Nov. 2005, pp. 1057-1061.

[3] A. Asosheh and H. Khanifar, “A technology selection method: Hospital location detection system,” 2010 5th International Symp. on Telecommunications, Tehran, Iran, Dec. 2010, pp. 992-999.

[4] E. Kaplan, Understanding GPS: Principles and Applications, Artech House, MA, USA, 1996.

[5] S. Hwang and J. J. Shynk, “Multicomponent receiver architectures for GPS inteference suppression,” IEEE Trans. on Aerospace and Electronic Systems, vol. 42, no. 2, pp. 489-502, Apr. 2006.

[6] A. Ndili and P. Enge, “GPS receiver autonomous interference detection,” Proc. IEEE Position Location and Navigation Symp., Palm Springs, CA, USA, Apr. 1998, pp. 123-130.

[7] J. Wang and M. G. Amin, “GPS interference cancellation performance in single and multiple MVDR beamforming methods,” Proc. Fortieth Asilomar Conf. on Signals, Systems, and Computers, Pacific Grove, CA, pp. 2300-2304, Oct. 2006.

[8] D. Li, Q. Yin, P. Mu, and W. Guo, “Robust MVDR beamforming using the DOA matrix decomposition,” Proc. 1st International Symposium on Access Spaces (ISAS ’11), Yokohama, Japan, June 2011, pp. 105- 110.

[9] S. Hwang and J. J. Shynk, “Blind GPS receiver with a modified despreader for interference suppression,” IEEE

Trans. on Aerospace and Electronic Systems, vol. 42, no. 2, pp. 503-513, Apr. 2006.

[10] W. Shao and W.-C. Wang, "A new GSC based MVDR beamformer with CSLMS algorithm for adaptive weights optimization," Proc. 4th International Congress on Image and Signal Processing (CISP '11), Shanghai, China, Oct. 2011, pp. 2299-2302.

[11] S. Hwang and J. J. Shynk, "A null despreader for interference suppression in GPS," Int. J. of Satellite Communications and Networking, vol. 29, issue 4, pp. 315-332, 2011.

[12] H. L. V. Trees, Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory, ed., John Wiley & Sons, New York, 2002.