ADAPTIVE NULL STEERING METHOD USING A DUAL-POLARIZED ANTENNA TO MITIGATE GPS RHCP INTERFERENCE

Kwansik Park[1,2], **Jiwon Seo**[1,2]

[(1)]*School of Integrated Technology, Yonsei University*
85 Songdogwahak-ro, Yeonsu-gu, Incheon 406-840, Korea
Email: jiwon.seo@yonsei.ac.kr

[(2)]*Yonsei Institute of Convergence Technology, Yonsei University*
85 Songdogwahak-ro, Yeonsu-gu, Incheon 406-840, Korea

ABSTRACT

The Global Navigation Satellite Systems (GNSS) receivers are vulnerable to unintentional and intentional Radio Frequency Interference (RFI), which can degrade navigation accuracy significantly or prevent the acquisition and tracking of GNSS signals, due to the weak received signal power of GNSS. Various methods have been developed to mitigate RFI, and the Controlled Reception Pattern Antenna (CRPA) is known to be one of the most effective GNSS anti-jamming techniques. However, since the antenna array has disadvantages of its high cost, computational complexity, and large size, its applications are very limited.

In this paper, an interference mitigation technique using a single antenna with dual polarization is presented. The dual-polarized antenna can receive Right Hand Circularly Polarized (RHCP) and Left Hand Circularly Polarized (LHCP) components of the incoming signal simultaneously. The impact of RFI can be mitigated by placing a spatial null in the direction of the RFI. The spatial null is formed by assigning properly adjusted complex weights to the RHCP and LHCP components of the received signal. Among various adaptive weight calculation algorithms, the Minimum Variance Distortionless Response (MVDR) algorithm is widely used. The MVDR algorithm maintains a unit gain in the directions of the GNSS signals based on the given steering vectors and places spatial nulls toward the directions of the interferences by minimizing the total output power. The optimal weight vector can be calculated from a constrained minimization problem using the Lagrange multiplier method. A matrix inversion-based approach and an iterative approach can be utilized to obtain the optimal weight vector. This paper adopts an iterative approach which can avoid the matrix inversion for computational efficiency.

Simulations are performed to demonstrate the interference mitigation performance of the proposed Global Positioning System (GPS) anti-jamming technique based on a single-element dual-polarized antenna and an adaptive weight calculation algorithm. In each interference scenario, GPS and interference signals impinge on the dual-polarized antenna from different directions. For simplicity, it is assumed that the dual-polarized antenna has isotropic RHCP and LHCP antenna gains in all directions and the antenna perfectly cancels the signals with opposite polarization.

INTRODUCTION

Despite the usefulness of Global Navigation Satellite Systems (GNSS), one of the main drawback is vulnerability to both intentional and unintentional Radio Frequency Interference (RFI) due to the weak received signal power (typically -20 dB below noise floor). This susceptibility has drawn significant attention because the RFIs can prevent the acquisition and tracking of GNSS signals or cause significant degradation of Positioning, Navigation, Timing (PNT) accuracy.

Various signal processing techniques have been studied in order to mitigate the RFIs [1-3]. It has been known that antenna array processing techniques have greater interference mitigation capability over single-antenna-based methods because an antenna array provides spatial degrees of freedom to separate the GNSS signal from undesired interferences whereas a single antenna does not have the same capability. However, the applications of the antenna array are limited because the antenna array typically has disadvantages of its high cost, computational complexity, and large size.

The polarization of Global Positioning System (GPS) signals is Right Hand Circularly Polarized (RHCP). It is known that an N-element RHCP antenna array has N-1 degrees of freedom in the sense that the array can form up to N-1 spatial beams and nulls. If a dual-polarized (i.e., RHCP and Left Hand Circularly Polarized, LHCP) antenna array is used instead of a typical RHCP antenna array, the degrees of freedom of the array increase to 2N-1. Thus, the maximum number of spatial beams and nulls, which can be formed by the dual-polarized antenna array, also increases to 2N-1 [4, 5].

This paper considers an adaptive GPS anti-jamming technique based on a single-element dual-polarized antenna. A single-element dual-polarized antenna provides one degree of freedom and it can place one spatial null in the direction of the interference. The weight vector is obtained using Minimum Variance Distortionless Response (MVDR) algorithm which minimizes the output power subject to a unit gain constraint in the direction of the desired signal. Although the optimal weight can be calculated from a constrained minimization problem using the Lagrange multiplier method, the weight vector is updated iteratively using the constrained Least Mean Square (LMS) algorithm [6] in this paper to avoid the matrix inversion for computational efficiency.

The rest of this paper is organized as follows. Firstly, the received signal model is described as a function of elevation angle. Secondly, the adaptive null steering based on a single-element dual-polarized antenna is discussed. Finally, simulation results is presented to evaluate the performance of the proposed method in several interference scenarios and the conclusion is given.

SIGNAL MODEL

The polarization of the electromagnetic field describes the way that the direction and magnitude of the field vector changes in time. When a GPS signal arrives from a direction, the polarization of the received signal is elliptical, and the elliptical polarization can be represented by a combination of a RHCP and LHCP component as follows:

$$\vec{E} = E_R(\hat{x} - j\hat{y}) + E_L(\hat{x} + j\hat{y}) \tag{1}$$

where $\vec{E}$ is the polarization vector of the elliptically polarized signal received at the dual-polarized antenna, E_R is the magnitude of the RHCP component, and E_L is the magnitude of the LHCP component. If it is assumed that the dual-polarized antenna has isotropic RHCP and LHCP antenna gains in all directions and the antenna perfectly cancels the signals with opposite polarization, the magnitude of RHCP and LHCP components can be expressed as follows when a RHCP signal, whose amplitude is A, is incident upon a dual-polarized antenna with an elevation angle θ:

$$\begin{aligned} E_R &= \left(\frac{1+\sin\theta}{2}\right)A \\ E_L &= \left(\frac{1-\sin\theta}{2}\right)A \end{aligned} \tag{2}$$

The magnitude of each component is equal to the amplitude of the original RHCP signal multiplied by a factor which is dependent on the direction of the incident signal. This difference between the magnitudes of two components makes it possible to separate the GPS signal from other undesired signals by placing a spatial null in the direction of the interference.

ADAPTIVE NULL STEERING METHOD

The block diagram of the proposed GPS anti-jamming technique based on a single-element dual-polarized antenna is shown in Fig. 1. After the down conversion to the Intermediate Frequency (IF) and sampling, the complex IF signal corresponding to each polarization is multiplied by a complex weight and summed to produce an output signal as follows:

$$\begin{aligned} W &= [w_R \quad w_L]^T \\ X(k) &= [x_R(k) \quad x_L(k)]^T \\ y(k) &= W^H X(k) \end{aligned} \tag{3}$$

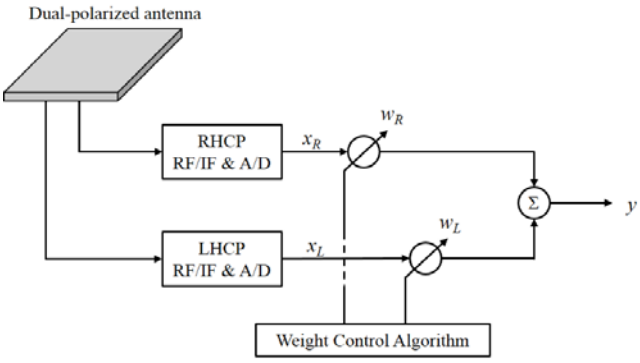

Fig. 1. Block diagram of the null-steering dual-polarized antenna.

where W is the complex weight vector, $X(k)$ is the complex IF signal vector whose elements $x_R(k)$ and $x_L(k)$ are the RHCP and LHCP components of the original IF signal, respectively, and $y(k)$ is the output signal. The complex weight vector is obtained using the MVDR algorithm which minimizes the output power subject to a unit gain constraint in the direction of the GPS signal as follows:

$$\text{minimize } W^H R W \quad \text{subject to } W^H C = 1 \tag{4}$$

where R is the covariance matrix of the received data samples and C is the steering vector given by:

$$\begin{aligned} R &= E[X(k)X^H(k)] \\ C &= \begin{bmatrix} \frac{1+\sin\theta_s}{2} & \frac{1-\sin\theta_s}{2} \end{bmatrix}^T \end{aligned} \tag{5}$$

where $E[\cdot]$ stands for statistical expectation and θ_s is the elevation angle of the GPS signal which can be obtained from the given knowledge of the antenna position and the ephemerides of satellite tracked in the corresponding channel of the receiver. The covariance matrix R can be approximately estimated by averaging over N epochs of the received data samples as follows:

$$R(k) \approx \frac{1}{N} \sum_{i=k-N-1}^{k} X(i) X^H(i) \tag{6}$$

The optimal weight vector for the above constrained minimization problem can be obtained by the Lagrange multiplier approach and can be expressed as:

$$W_{opt} = R^{-1}C(C^T R^{-1} C)^{-1} \tag{7}$$

Although the optimal weight vector can be obtained by (7), it requires estimation and then inversion of the covariance matrix R. For computational simplicity, this paper adopts an iterative approach, which is derived in [6], to avoid the matrix inversion. The weight vector is recursively updated as follows:

$$\begin{aligned} F &= C(C^T C)^{-1} \\ P &= I - C(C^T C)^{-1} C^T \\ W(0) &= F \\ W(k+1) &= P(W(k) - \mu P R(k) W(k)) + F \end{aligned} \tag{8}$$

where I is an identity matrix and μ is the adaptation step size which satisfies $0 < \mu < 2/\{3trace(R)\}$.
After the above processing, the antenna gain in the direction of θ is given by:

$$\begin{aligned} GP(\theta) &= W^H S \\ &= W^H \begin{bmatrix} \frac{1+\sin\theta}{2} & \frac{1-\sin\theta}{2} \end{bmatrix}^T \end{aligned} \tag{9}$$

SIMULATION RESULTS

In this section, simulations for several interference scenarios, summarized in Table 1, are presented in order to demonstrate the interference mitigation performances of the proposed GPS anti-jamming method. In each scenario, the GPS signals and the RHCP interference signals impinge on the dual-polarized antenna from different directions. The number of epochs for the covariance estimation is set to 100.

Figs. 2-4 represent the obtained gain patterns for the interference scenarios. The dotted red lines indicate the elevation angles of the interference signals. It is clear that spatial nulls are formed in the directions of the interference signals, and thus the interferences are mitigated.

Table 1. Interference scenarios for simulations

Scenario	J/S	IF Frequency		Elevation angle	
		GPS	Interference	GPS	Interference
1	50 dB	4.13 MHz	4.28 MHz	80°	20°
2	50 dB	4.13 MHz	3.89 MHz	75°	40°
3	50 dB	4.13 MHz	4.13 MHz	120°	150°

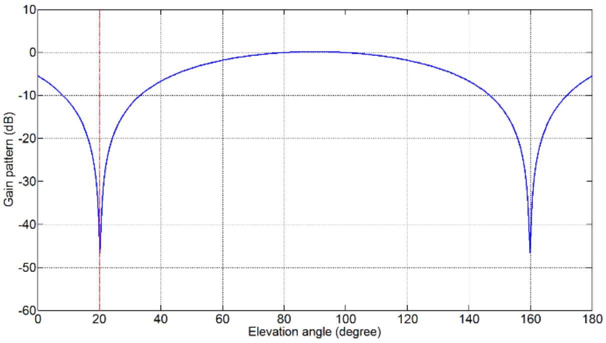

Fig. 2. Gain pattern for the interference scenario 1

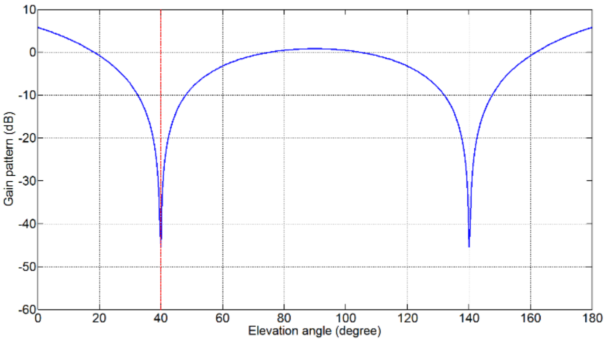

Fig. 3. Gain pattern for the interference scenario 2

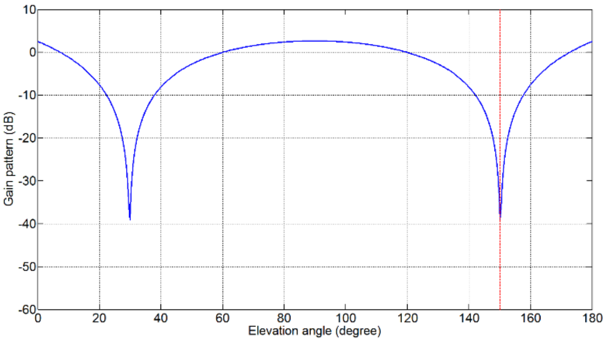

Fig. 4. Gain pattern for the interference scenario 3

CONCLUSION

In this paper, an adaptive null steering method using a dual-polarized antenna to mitigate GPS RHCP interference is proposed. For the calculations of the optimal weights, the MVDR algorithm is utilized, and an iterative approach is adopted to avoid matrix inversion for computational efficiency. The obtained weights place spatial nulls in the directions of interferences while maintaining a unit gain in the directions of GPS signals. Several simulations are performed and the resultant gain pattern for each interference scenario is shown in order to demonstrate the interference mitigation performance of the proposed GPS anti-jamming technique.

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