Narrowband Interference Mitigation in Angle-Frequency Direct Product Domain in UWB Receivers

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***Abstract* - The high precision ranging using ultra wideband (UWB) requires mitigation of interference from other communication systems, in particular from narrowband interference (NBI). There have been many studies of adaptive notch filters (ANF) to cope with NBI at various frequencies. This paper proposes a novel adaptive NBI mitigation method which uses the direction of arrival as well as frequency selectivity. We use an array antenna and apply the optimal weight which directs nulls to large-power waves. This realizes NBI suppression because of the lower power spectrum of the UWB pulse signal. Our method does not need any iteration such as feedback loop, and thus requires only a small calculation cost. Simulations demonstrate that the proposed method is applicable to variously directional and multiple-frequency NBIs.**

***Index Terms* —Ultra wideband (UWB), Power inversion.**

1. Introduction

High-precision positional information receives increasing attention in recent years. The importance of location sensing systems has become greater in many commercial and public applications. However, Global Positioning System (GPS) is less reliable in congested environments, for example, between or inside buildings.

Ultra-wideband (UWB) is considered as a promising solution for high ranging precision using time-of-arrival (TOA) measurements. In a UWB system, signals spread to a highly wide bandwidth. Even in severe environments, UWB utilizes the characteristics of resolving multipath and penetrating obstacles [1].

Position recognition systems based on UWB is expected to work under narrowband-interference (NBI) presence, which is caused by wireless LAN, Bluetooth and other narrow band communications. This problem can be resolved by using notch filters. Several schemes based on adaptive notch filters (ANF) have been proposed [2][3].

So far, there is no NBI mitigation method utilizing not only frequency but direction of arrival. In this paper, we propose a novel NBI suppression scheme. This method can mitigate NBI using an array antenna. We use simple one-dimensional array with small amount of calculation and accomplish interference mitigation. We report the bit error ratio (BER) performance for various signal-to-interference ratio (SIR) quantitatively.

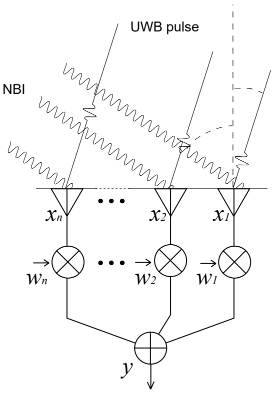

Fig. 1. The structure of n-element linear array.

2. UWB System Model

We consider a packet-based system of impulse-radio UWB (IR-UWB) based on IEEE 802.15.4a specification [4]. One bit data is represented by the position of the pulse burst which exists in either the first half or the second half of a symbol.

A receiver processes the bursts by using the energy detection (ED) scheme. Although coherent ranging is more accurate, the ED receiver has advantages such as simple structure, operability at sub-Nyquist sampling rates and tolerance to pulse-shape distortion [5].

3. Proposal of NBI Mitigation Scheme

In this paper, we propose a technique to mitigate NBI by steering nulls of an array antenna toward the direction of interference adaptively. It is an expansion of the idea of power inversion adaptive array (PIAA) [6] to the use in UWB systems. PIAA points nulls of the array to the direction of large-power signal. When a desired signal is a sequence of UWB pulses while interference is narrowband, the spectrum density of the pulses is much smaller than that of the interference. By taking advantage of this characteristic, turning nulls to the NBI is realized [7]. This NBI mitigation method does not need optimization technique, such as a feedback loop, and thus requires only a small amount of calculation.

We consider an N-element linear array as shown in Fig.1. Suppose K antenna elements forms one-dimentional array with equal interval. We define a complex input vector X(t) and a complex weight vector W as

$$\begin{aligned} \boldsymbol{X}(t) &= [x_1, x_2, \dots, x_K]^T \\ \boldsymbol{W} &= [w_1, w_2, \dots, w_K]^T \end{aligned} \tag{1}$$

when $[\cdot]^T$ means transpose.

The correlation matrix is defined as

$$R_{\mathrm{xx}} = E\left[\boldsymbol{X}(t)\boldsymbol{X}^H(t)\right]. \tag{2}$$

The optimal weight and the steering vector is calculated as

$$\begin{aligned} \boldsymbol{W}_{\mathrm{opt}} &= {R_{\mathrm{xx}}}^{-1}\boldsymbol{S} \\ \boldsymbol{S} &= [1, 0, \dots, 0]^T. \end{aligned} \tag{3}$$

This optimal weight with a fixed first element of the steering vector is regulated to minimize the output power. This minimization is accomplished by turning nulls to the strong input-power direction, which point NBIs. Since the UWB signal has lower power-spectrum density, UWB signal is out of the power suppression.

4. Simulation and Performance Analysis

The simulations presented in this section use UWB symbols based on IEEE 802.15.4a. The weight update makes two types of sampling time slots, that is, one in which a pulse burst exists (t_{sb}) and that includes no burst (t_{sn}). Every t_{sb} slot has more input energy than a t_{sn} slot, which makes the optimal weight suppress its output harder. Therefore, the burst position is identical with the position of a low energy slot in the optimal output.

The incident wave contains one desired UWB signal, two NBIs and additive white Gaussian noise (AWGN). The array has 10 elements. The UWB signal is a sequence of second order derivatives of the Gaussian pulse, and arrives from −30° relative to the broadside direction. The NBIs, having a single 2.4GHz and 5.0GHz, come from 30° and −10°, respectively. The element spacing is half a wavelength of 2.4 GHz, which is 6.25 cm.

Fig.2 shows the power spectrum densities. NBIs have peaks at 2.4GHz and 5GHz in the total incident wave. In the optimized-weight output, the mitigation of NBI is confirmed.

Fig.3 shows the BER as a function of signal-to-noise ratio (SNR) for various SIR values. In the original output $x_1(t)$, the BER goes higher as the SIR gets stronger. In the optimal output $y_{\mathrm{opt}}(t)$, the BER becomes much lower than the original output. In a conventional method [3], SNR is set to 17dB. This means our method achieves lower BER at the same SNR.

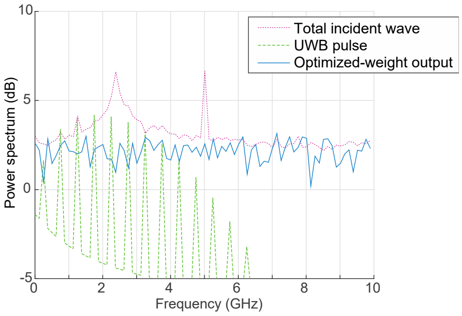

Fig. 2. Power spectra of total incident wave, UWB pulse, and optimized-weight output.

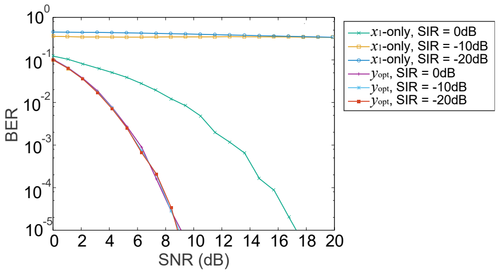

Fig. 3. BER versus SNR of x_1-only and y_{opt} signals.

5. Conclusion

We proposed and demonstrated a novel interference mitigation method utilizing the low power spectrum characteristics of a UWB signal. The simulation results showed that the binary data of the desired signal is restored. This method does not need a priori knowledge about interference waves. It can cope with variously directional and multiple-frequency interference waves without rigorous adjustment of of the element number in the array antenna.

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