Performance Improvement Using Wavelet Denoising for UWB-IR System

Joon Key Kim, Sung Jin Park, Seung Man Yang, Sung Sue Hwang, and Suk Chan Kim

***Abstract*—In this paper, we propose the effective way to demodulate the reference signal distorted by the channel in the UWB-IR system, adopting wavelet denoising algorithm, that generates a noise minimized template and DWT algorithm, calculates the variance of the noise to distinguish energy dense band.**

***Index Terms*—Denoising, DWT, UWB-IR, wavelet**

I. Introduction

UWB-IR (ultra wide band impulse radio) system transmits reference signal before sending the data signal [1]. During the transmission, a distortion arises because of the signal affected from AWGN (additive white Gaussian noise). There is a way to minimize such noise using a template, which is from the average of reference signal changed by the channel [2]. In this paper, we propose two steps for demodulating the received signal. Firstly, we adapted wavelet denoising method for reducing the noise in the reference signal to generate a template. In the second step, DWT (discrete wavelet transformation) method, which estimates the variance of the noise to get the MED (mean excess delay) and RMS (root mean square) delay, instead of using every samples of the template.

In section II, we briefly explain the conventional UWB communication system. The wavelet denoising algorithm is going to be presented in section III. In section IV, a way to detect the symbol is introduced. The simulation results and conclusion are in V and VI respectively.

II. UWB Communication System

UWB communication technique is a one way for wireless communication that uses 3.1 GHz ~ 10.6 GHz frequency band. A study in UWB has been accelerated since 2002, when FCC (Federal Communications Commission) accepted for commercialization. UWB communication can use the spectral resource more efficiently, because it can share the frequency spectrum with the existing systems. Moreover, UWB communication system spends only -41.3dBm power per 1MHz, thus it is expected to be more useful way to save energy.

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UWB system transmits the reference signal before sending the data. AWGN is added while the signal is passing through the channel. The average of reference signal is used to reduce the noise of received signal. Noise can be estimated more accurately, if the number of reference signals increase. However, the data rate may decrease inverse proportional to the number of reference signal. In this paper, a way to use less number of reference signal is proposed.

III. Wavelet Denoising

Most of the wavelet based denosing techniques are using multi-resolution analysis to divide the original signal and the noise. For preceding this analysis, the most important thing to do is setting up a threshold, which will decide whether the wavelet coefficient has more noise component or less. In 1994, Donoho and Johnstone presented wavelet shrinkage method [3]-[4] that can estimate desired signal from corrupted signal effectively.

A model of noise mixed signal can be expressed as

$$u(t) = f(t) + w(t) \tag{1}$$

where $w(t)$, $f(t)$ and u are 0 mean σ^2 variance Gaussian white noise, unknown finite energy signal and the signal corrupted by noise respectively. It is hard to recover the exact value of $f(t)$. Therefore, estimated signal $\hat{f}(t)$ would be reasonable to solve the problem. We can get the optimal estimate of $f(t)$ when maximizing signal to noise ratio witch is described on equation (2).

$$SNR = -20\log_{10}\left(\frac{E(\| f(t) - \hat{f}(t) \|)}{E(\| f(t) \|)}\right) \tag{2}$$

Wavelet denoising algorithm that proposed in [3] has three steps. DWT, thresholding and inverse wavelet transformation are those steps.

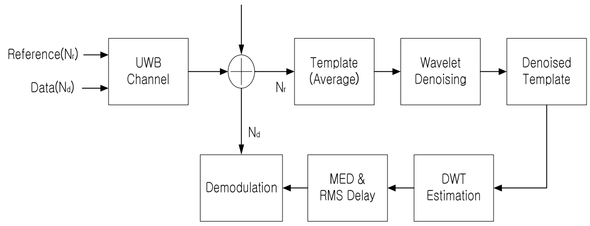


Fig. 1. Block diagram of symbol detection algorithm.

A. Discrete Wavelet Transformation

Wavelet Transformation is expressed as a basis function which consists of constant time-frequency information. As a result, it has an advantage for solving non-stationary signal problem. The unknown signal $f(t)$ can be shown as equation(3). Where $\Psi_{j,k}(t)$ and $a_{j,k}$ are basis function and wavelet coefficient respectively. The basis function is expressed as equation (4).

$$f(t)=\sum_{j,k} a_{j,k}\Psi_{j,k}(t) \quad (3)$$

$$\Psi_{j,k}(t)=2^{j/2}\Psi\left(2^{j}t-k\right) \quad (4)$$

The inverse wavelet transformation works as the opposite of the wavelet transformation.

B. Thresholding

The second step is thresholding that shrinks the coefficients of wavelet. There are two types of thresholding, one is hard thresholding and the other one soft thresholding expressed in equation(5) and (6) respectively.

$$T_{hard}(x,\lambda)=\begin{cases} x, & \text{if } |x|\geq\lambda \\ 0, & \text{if } |x|<\lambda \end{cases} \quad (5)$$

$$T_{soft}(x,\lambda)=\begin{cases} sign(x)(|x|-\lambda), & \text{if } |x|\geq\lambda \\ 0, & \text{if } |x|<\lambda \end{cases} \quad (6)$$

Hard thresholding is the method defining the wavelet coefficient be 0, if the absolute value of coefficients in each bands are smaller than the threshold. Soft thresholding reduces each coefficient with the amount of the threshold value.

IV. Symbol Detection

Fig. 1 is a block diagram of symbol detection algorithm. The reference signal and data signal transmit through the channel are defined as equation (7).

$$r(t)=\sum_{j=0}^{N_r-1}\sqrt{E_g}h(t-jT_f)+\sum_{j=0}^{N_d-1}\sqrt{E_g}h(t-jT_f-NT_f)+n(t) \quad (7)$$

where E_g, $h(t)$, T_f, N_r, N_d and $n(t)$ are transmitted Energy, channel response, frame time, number of reference signal, number data signal which is going to be transferred and AWGN with the power spectral density $N_0/2$ respectively. Equation (8) shows how we can get the denoised template signal.

$$\hat{h}(k)=\frac{1}{N_r}\sum_{n=0}^{N_r-1} r(k+nM) \quad k=0,1\ldots,M-1 \quad (8)$$

To estimate MED and RMS delay, we proceed the DWT and acquire the standard deviation of the template of denoised signal as written in equation (9).

$$\hat{\sigma}=\frac{meadian(|d_j(k)|)}{0.6745} \quad (9)$$

where $d_j(k)$ is detail coefficient of decomposed wavelet. MED and RMS delay can be estimated by using equation(9) as a threshold.

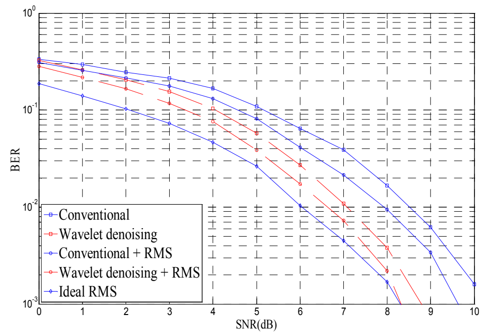
$$MED=\frac{\sum_{k=1}^{M} k\left|\hat{r}(k)\right|^2}{\sum_{k=1}^{M}\left|\hat{r}(k)\right|^2} \quad (10)$$

$$RMS^2=\frac{\sum_{k=1}^{M}(k-MED)^2\left|\hat{r}(k)\right|^2}{\sum_{k=1}^{M}\left|\hat{r}(k)\right|^2} \quad (11)$$

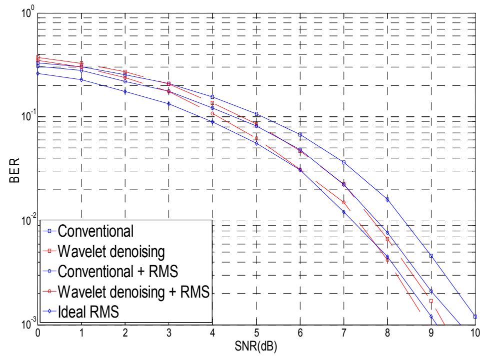
Now we can estimate the optimal numbers of sample which can be expressed as the equation below.

$$N_{opt}=MED+RMS \quad (12)$$

Conventional system had to calculate $\vec{r}_j^{\,T}\vec{\hat{h}}$ in every moment of the sample but the method we propose can improve the performance of the system by only needs to calculate N_{opt} numbers of sample and demodulate the received signal.



(a) CM1



(b) CM3

Fig. 2. Block diagram of symbol detection algorithm

V. Simulation Result

TABLE I. PARAMETERS FOR SIMULATION

Parameter	Value
Number of Reference (N_r)	100
Number of Data (N_d)	100
Pulse Duration	0.5 nsec
Frame Time	100 nsec
Sample Time	0.05 nsec
Number of Channel	100
Channel Model	CM1, CM3
Modulation	PAM

The parameters for the simulation are in Table I. The channel has two type that proposed in IEEE 802.15.3a, CM1 and CM3 model. Wavelet denoising has 4 levels, used Daubechies wavelet function and adapted rigrsure threshold method [5].

The simulation result under CM1 channel is shown in Fig. 2(a). At BER=10e-2, the performance of using wavelet denoising algorithm only improves about 1.5dB comparing to the result, which is not using wavelet denoising. Moreover, close to 0.5dB of SNR improvement is shown, when adapting MED and RMS estimation.

Fig. 2 (b) shows the simulation result when CM3 is used for the channel model. At BER=10e-2, there is about 0.6dB of SNR improvement can be observed by wavelet denosing algorithm, 0.4dB by MED and RMS estimation.

VI. Conclusion

In this paper, the analysis of effective method for symbol detection has conducted. The simulation result shows that using wavelet denoising to generate denoised template is a better way to improve the performance of the system then the conventional one. Moreover, the estimation of MED and RMS to find the section that has less noise component was also a considerable work for improving the performance of UWB-IR system.

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