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TOA estimation based on ICA for UWB multipath

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ABSTRACT

Time of Arrival (TOA) estimation used with impulse-radio ultra-wideband transmission is currently the most popular technique for accurate localization. TOA estimation based energy-detection (ED) is a very feasible technology for sub-Nyquist sampling rate and no requirements on the knowledge of the signal shape,Nevertheless,this method is vulnerable to the interference of noise and other wireless systems. This paper presents a method based independent component analysis (ICA) to mitigate the interference. ICA can separate various kinds of source signals,according to the principle of these source signals statistical independence,then we estimate TOA from the extracted UWB signals.

Compared with other two traditional ED estimators:Multiscale Energy Products and ED-adaptive estimator via simulation,we demonstrate that the proposed TOA estimation has superior performance,and it is a very good method for interference suppression in IR-UWB systems.

KEYWORDS

Ultra-wideband (UWB); Time of arrival (TOA); First path (FP); Energy-detection (ED); Independent component analysis(ICA).

INTRODUCTION

Impulse-radio ultra-wideband (IR-UWB) technology with extremely wide bandwidth, short pulse duration, high time resolution, low complexity, can provide accurate positioning accuracy, is very suitable for accurate ranging and localization. However,there are potential interferences between UWB and other communication systems due to its great frequency occupancies[1]. A common way to perform positioning is based on TOA (Time of Arrival) estimation. From the signal travel time,the distance between transmitter and receiver can be calculated. The aim of TOA estimation is to determine the first path (FP) which represent the line-of-sight path in a multipath environment[2]. However,the FP is often not the strongest,and sometimes considerably weaker than the other,thus making its identification challenging. Different techniques have been proposed for estimating TOA. Matched filtering (MF) is the optimum technique. However,it requires a high Nyquist sampling rate and a priori knowledge of the received pulse shapes, which may change from an environment to another. Therefore, it is difficult to implement. the energy-detection (ED) receiver is widely used for its low-complexity and feasibility of realization. The main advantages of the ED are possibility for sub-Nyquist sampling rate,and no requirements on the knowledge of the fignal shape. But the performance of the ED method can suffer considerably in the presence of strong other wireless systems (narrowband) interference[3].

In this paper,we propose a method to estimate the TOA. This method includes two parts:interference rejection and estimation the TOA of FP. First, this method use a technique called independent component analysis (ICA) to separate UWB signals from a mixture of original source received signals without mixing coefficients. Through the analysis of mixed signal features,UWB signal is seperated from other signals,when the received signals are a mixture of UWB signal,tone, multition, the additive white Gaussian noise and partial-band interferences. Secondly,we estimate the TOA using the threshold-based ED.

The ED detects the signal by comparing the received signal energy to a threshold. Proper system model of IR-UWB is established,For the case of tone,multition and partial-band interferences,we will compare the performance of proposed method with other two typical ED methods. Simulation results demonstrate the improvements in the mean absolute error (MAE) of TOA estimation when the proposed method is employed,and it can effectively suppress interference.

The rest of the paper is organized as follows:The system model is presented in Section II. Section III describes the proposed TOA estimation scheme. Simulation results and discussions are presented in Section IV, and Section V concludes the paper.

SYSTEM DESCRIPTION

IR-UWB system model

We consider an IR-UWB system where the transmitted pulse modulated by TH-PAM arrives at the receiver. The transmitted signal can be writtern as

$$r(t) = \sum_j e_{[j/N_S]} w(t - jT_f - c_j T_c) \tag{1}$$

Where w(t) is the pulse waveform, T_f is the frame time,c_j is a pseudoradom code which selects one of the N_c slots,having a duration of T_c, $T_c = T_f / N_c \geq T_p$. The transmission of one information symbol takes N_S pulses, e_j is the jth pulse. $e_j \in \{-1,+1\}$ is random-polarity code of the jth transmitted symbol. $w(t)$ is the second order derivatives of the Gaussian pulse in the following manner $w(t) = (1 - 4\pi(\frac{t}{\gamma_m})^2)\exp(-2\pi(\frac{t}{\gamma_m})^2)$. γ_m determines the chip time T_p nanoseconds. We also assume that the maximum channel delay is much smaller than the symbol duration so that the inter-symbol interference(ISI) is negligible.

Perfect synchronization between the transmitter and the receiver is assumed here. The received signal through the multipath channel h(t) can be expressed as

$$y(t) = \sum_{l=1}^{L} \alpha_l r(t - \tau_l) + n(t) + J(t) \tag{2}$$

Where α_l and τ_l are the fading coefficient and the delay of the l-th path,respectively. The desired TOA τ_{TOA} is τ_1 and L is the number of multipath components. Equation (2) is a simple model to describe the IEEE 802.15.4a channel,which will be used in the simulation. n(t) is the additive white Gaussian noise (AWGN) with mean zero and spectral density $N_0/2$ where N_0 is the noise power density. J(t) is the interferences.

Interference model

The bandwidrh of interference signal J(t) include multiton interferences $J_m(t)$ and partial-band interference $J_p(t)$.

$$J(t) = J_m(t) + J_p(t) \quad (3)$$

When the bandwidth of interference signal is far smaller than the UWB's, $W_j << W_{UWB}$. it can be seen as tone interference. tone interference has the form: $J(t) = a\cos(2\pi f_j t)$. Where f_j is carrier frequency. Multiton interferences using N_t equal power tones can be described by

$$J_m(t) = \sum_{l=1}^{N_i} \sqrt{2/N_i}\cos(2\pi f_l t) \quad (4)$$

When N_i>>1,according to the central limit theorem, the distribution of J(t) tends to a Gaussian one.

partial-band interference $J_p(t)$ spreads noise of total power evenly over some frequency range of bandwith W_j. This reaults in an equivalent sigle-sided noise power spectral density:

$$S_J(f) = \begin{cases} \frac{J}{W_j}, & \left|f - f_J\right| \le W_j \\ 0, & other \end{cases} \quad (5)$$

TIME-OF-ARRIVAL ESTIMATION BASED ON ICA

In the proposed technique, the received mixed signals is separated by ICA to extract the UWB signals, and then we employ the energy derection (ED) to estimate TOA using threshold-crossing.

Extraction UWB signals by ICA

As a statistical processing technique for multidimensional signals recently developing from blind source separation (BSS), independent component analysis (ICA) can separate independent signals from measured mixed data according to the basic statistical features of the sources,without an explicit knowledge of mixing coeffients and waveform structure. By the central limit theorem, random variables such as composed of many independent random variables, as long as the independent with finite mean and variance of each independent random variables, regardless of what kind of distribution, the random distribution will be close to Gauss. Therefore in the separation process, the separation of the independent non Gauss metrics to estimate the separation results. The process has completed the separation of the independent components, when Gauss reached the maximum.

In most ICA methods,there are some condition assumed:

(1)the number of the received signals is larger than the sources signals's

(2)the components of sources signals's is statistically independent.

(3)A is a matrix of full column rank.

ICA generally pre-whiten the receive data spatially, in order to separate easily. there are two steps in whitening:uncorrelation and having unit variance.

The goal of ICA is to transform sources signals linearly into independence between source signals. Introducing the data vector X and the source vector S,the linear ICA mixture model is given by

$$X = A \bullet s \quad (6)$$

Where, $s=[s_1,s_2,\circ\ \circ\ \circ, s_m]^T$ is m-dimension vector of the sources signals whose components is independent and the mean-value of s is zero. $x=[x_1,x_2,\circ\ \circ\ \circ,x_n]^T$ is n-dimension vector of the observed signals. A is a $n\times m$ mixing matrix,and that m<=n,meaning that there are at most as many sources signals s as mixtures x. Because of the components of sources signals is statistically independent, ICA estimate an $m\times n$ unmixing matrix W such that the m-vector WX(t) recovers the original sources as well as possible.

$$y = W \bullet X$$

Where y_i(i = 1, 2, …, m) is the estimation of sources s.

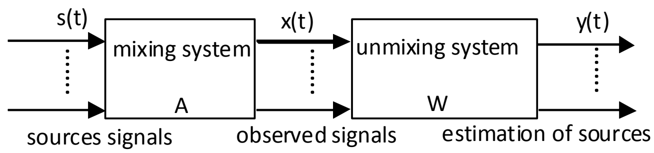

Figure 1: Block diagram of ICA

The starting point of ICA theory and its separation algorithms is how to measure the separation between the independence components,the criterion of independence mainly include:kurtosis、differential entropy、negentropy and mutual information. We applied the so-called FastICA algorithm to separate the sources. The FastICA scheme is then as follows:

(1)Choose an initial vector W and ||W||=1.

(2)Let $W(n+1)=E\{Xg(W^T(n)X)\}-E\{g'(W^T(n)X)\}W(n)$,where the nonquadratic function g is g(y)=-exp(-y2/2).

(3)Normalization: $W(n+1)=\frac{W(n+1)}{\|W(n+1)\|}$.

(4)If W converged,finished,otherwise go back to (2)

TOA Estimate based on ED(energy detector)

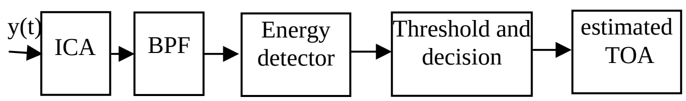

Figure 2 : Block diagram of the energy detection TOA estimator structure

A typical structure of the ED receiver is shown in Figure 2,the received signal is passed through a bandpass filter to eliminate the remaining out-of-band interference,then a square-law device and an integrator to collect energy,and a threshold block and a decision make device.

The samples at the output of the square-law device are given by

$$z[j,n]=\sum_{j=1}^{N_s}\int_{(j-1)T_f+(c_j+n-1)T_b}^{(j-1)T_f+(c_j+n)T_b}|\,r(t)\,|^2\,dt \quad \textbf{(7)}$$

Where the signal is input to a square-law device with an integration interval of T_b. z[j,n] is the nth sample in the jth(j=1,2,…,N_s) frame. Assume the FP completely falls within its corresponding time slot after integration. Many of these samples contain UWB signal only,for Signals after ICA separation. The next step is to select a method to set the threshold optimization. The threshold is selected between maximum and minimum energy samples. In [],a novel method is proposed to detect the FP and to improve TOA estimation. The method determines which sample contains the FP by calculating the frequencies of different samples crossing the threshold over several frames.

PERFORMANCE SIMULATION

We used computer simulations to show the performance of the proposed TOA estimator. In order to compare our results, the performance on mean absolute error (MAE) is compared with two other typical ED methods: Multiscale Energy Products (MEP) and ED-adaptive[4][5]. MEP estimate TOA based on a bank of cascaded multi-scale energy collection filters which enhance and shift the peak sample closer to the leading edge. ED-adaptive chooses TOA using a normalized threshold[6]. In the simulation,we choose the appropriate threshold based on the distribution to minimize the false detection probability in[6]. Simulations are carried out on each of the 50 channel realizations of the IEEE 802.15.4a channel model 1 (CM1) for residential line-of-sight environments and the channel model 2 (CM2) for residential non-line-of-sight environments. The channel realizations are sampled at 8GHz and path resolution is 4ns, and each realization has a TOA uniformly distributed within (0,T_f). The other simulation parameters are $T_p=1ns$, $\tau_m=0.25ns$, $T_f=200ns$, $T_b=1ns$. In interference suppression algorithm,we consider the number of mixed signals received is as much as the signal sources. The signal to interference ratio is defined as SIR=Eb/Nj.

In the presence of tone interference, we set the number of interference signals and receiver antennas is 5 and 7 respectively and the channel model is CM1,assuming SNR=-4dB and SIR=-28dB. we get the separation result employing

ICA,showed in figure 3. We can find the signal is separated very well from the interference signal and noise,bit error rate is 0.

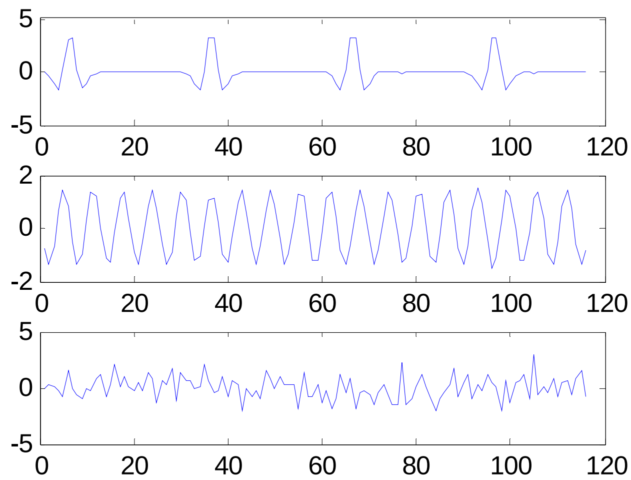

Figure 3 : The separation results in the noise and tone interference

The performance comparison among our method,MEP and ED-adaptive is depicted in Figure 4. Simulation results report that our method provides significant performance improvement when SIR=-28dB and SNR from -5dB to 25dB,in CM1 and CM2.

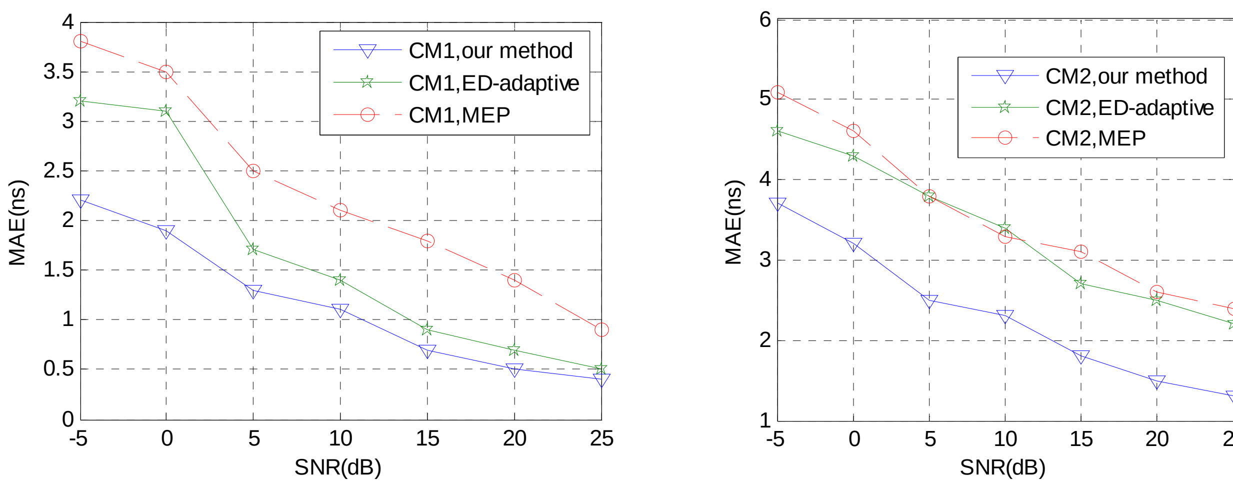

Figure 4 : Performance comparision between proposed method and conventional methods

CONCLUSION

In this paper,a TOA estimation based on ICA for IR-UWB has been propposed. This method can mitigate interferences of tone,multition and partial-band in ED-receiver,at very low signal to interference ratio and signal to noise ratio. Moreover,it does not need the knowledge of the pulse shape and other statisitics. Simulation results demonstrate that our estimator gives more accurate results than the other two ED-based methods.

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