An UWB Synchronization Algorithm based on Two-stage Enveloping

Yan Xiao[1]* and Zhong-Yong Wang*
Institute of Information Engineering,
Zhengzhou University,
Zhengzhou, China
E-mail: Brad_xiao@163.com[1]*, iezywang@zzu.edu.cn*

Ji Li and Hui-jun ZHANG
Department of Wireless Communication,
Zhengzhou Locaris Technology Co., Ltd.
Zhengzhou, China
E-mail: Jijalica2010@gmail.com, hui-jun@live.cn

***Abstract*—The study of the paper concerns with the timing and synchronization problems in the impulse radio-ultra wideband (IR-UWB) positioning system. A novel synchronization algorithm based on two-stage enveloping method to improve the conventional sliding correlation performance is proposed. The correlator output is processed by two-stage enveloping firstly, then the fine synchronization interval is determined by centering the highest point in the second stage envelope. Time delay estimation (TDE) is completed by peak-picking of the absolute value at the correlator output in fine synchronization interval. The simulation results show that the proposed algorithm has a significantly better synchronization performance when the number of integrators is reduced, which make it very practical to use.**

Index Terms—ultra wideband, sliding correlation, two-stage enveloping, synchronization.

I. INTRODUCTION

This range resolution of a wireless location system depends on the bandwidth of the transmitted signals. It increases with the signal bandwidth [1-3]. The transmitted signals used in impulse radio-ultra wideband (IR-UWB) positioning systems are nanosecond pulses or sub-nanosecond pulses, so the transmission bandwidth is usually more than 500MHz. With such large bandwidth used, the IR-UWB radio signal has a high range resolution, and so an IR-UWB positioning system theoretically can achieve a high positioning accuracy.

Compared with the Global Positioning System (GPS) and Wireless Local Area Network (WLAN) technology, the IR-UWB positioning technology has lower consumption and higher accuracy positioning and so is more suitable for indoor location-based applications [4]. Time delay estimation (TDE) is very important in the IR-UWB positioning technology [5]. A UWB signal is basically a baseband signal without phase and carrier information, hence TDE is the main task for location through synchronization [6]. Peak selecting of sliding correlation is a conventional synchronization method in wireless commutation system [7], but the method needs a long acquisition time and an excessive complexity [8] [9].

This study of the paper concerns with synchronization for the IR-UWB positioning system. We improve the conventional sliding correlation algorithms and propose a novel synchronization algorithm based on two-stage enveloping. This synchronization algorithm uses coarse synchronization and fine synchronization. In the coarse synchronization process, a long step is accepted to reduce the complexity of receiver. The correlator output is processed by two-stage enveloping to obtain a rough region. In the fine synchronization, the interval is determined by centering the highest point of a two-stage envelope. In fine synchronization, the TDE is implemented by peak-picking of the absolute value of the correlator output.

II. THE UWB SIGNAL AND CHANNEL MODEL

The second derivative of Gaussian pulse is used as an UWB signal. Pulse Position Modulation (PPM) is adopted and the data symbols are encoded using a pseudo-noise (PN) code. The second derivative of Gaussian pulse is described by follow equation [10]

$$\frac{d^2 p(t)}{dt^2} = \left(1 - 4\pi \frac{t^2}{\alpha^2}\right) e^{-\frac{2\pi t^2}{\alpha^2}} \tag{1}$$

where $p(t)$ denotes Gaussian pulse and α^2 denotes the shape factor that determines the energy and the width of the pulse.

The transmitted signal modulated by PPM and time-hopping (TH) is described by :

$$s(t) = \sum_j w\left(t - jT_s - c_j T_c - \alpha_j \varepsilon\right) \tag{2}$$

where $s(t)$ denotes the pulse sequence composed of a string of single-cycle pulse $w(t)$, j denotes the sequence number of transmitted pulses, T_s denotes the pulse repetition period, T_c denotes the chip time, c_j denotes the TH sequence and $\alpha_j \varepsilon$ denotes the shift introduced by PPM.

The additive white gauss noise (AWGN) model and CM1 in the IEEE 802.15.3a standard [11] are used to demonstrate the performance of the proposed synchronization algorithm. After the UWB signal is transmitted through AWGN channel, the received signal is described by

$$r(t) = s(t - \tau) + n(t) \tag{3}$$

where τ denotes the channel delay, which is depending on distance of propagation between transmitter and receiver.

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The impulse response of IEEE 802.15.3a standard model is described by

$$h(t)=\sum_{l=0}^{L}\sum_{k=0}^{K}\alpha_{k,l}\delta\left(t-T_l-\tau_{k,l}\right) \tag{4}$$

where $\alpha_{k,l}$ represents the multipath gain coefficients, T_l represents the delay of the l-th cluster, and $\tau_{k,l}$ represents the delay of the k multipath component related to the l-th cluster arrival time T_l.

III. SYNCHRONIZATION ALGORITHM

UWB signal detection and synchronization are completed by received signals acquisition and TDE. The basic method of TDE is a correlation algorithm. The conventional correlation algorithm achieves TDE through peak-picking of a sliding correlation output between the received signals and the template signals. A TDE algorithm based on two-stage enveloping is proposed in this paper. The receiver structure is as shown in Figure 1.

The number of the location searching in coarse synchronization is described by

$$N=T_{\max}/T_{coarse} \tag{5}$$

where T_{coarse} is slide step in coarse synchronization.

The local template waveform is described by

$$v(t)=\sum_{j}v\left(t-jT_s-C_jT_c-\alpha_j\varepsilon-\varphi(n)\right) \tag{6}$$

where $\varphi(n)$ is the search locations in a search cycle, n = 0, 1, 2...N. $\varphi(n)=n\times T_{coarse}$.

The correlator output can be expressed as

$$c(n)=\int_0^{T_{\max}}r(t)v(t)dt \tag{7}$$

where $c(n)$ is the output of a sliding correlator between the received signals and the template signals at the search locations $\varphi(n)$.

After a search cycle, the decision statistics is calculated by $F=P/W_{mean}$, where P is the peak of correlator output and W_{mean} denotes Gaussian white noise. F is compared with the given threshold Th which is selected for signal detection. If $F>Th$, signal acquisition is successful. Otherwise, signal acquisition is failed.

When signal acquisition is completed, the two-stage enveloping is utilized to make smooth processing. In each stage, the moving average filters, which choose the group of points from the input signals around the output points, are used to fit the absolute value of the correlator output. Then the envelope is obtained.

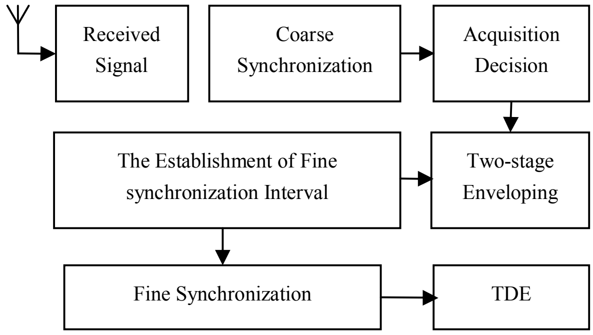

Figure 1. Receiver Structure of UWB Synchronization Algorithm Based on two-stage Enveloping.

The moving average filters can be written as the following form [12]

$$y[i]=\frac{1}{M}\sum_{j=(M-1)/2}^{(M+1)/2}x[i+j] \tag{8}$$

where x[ ] denotes the input signals, y[ ] denotes the output signals and M denotes the number of points in filters.

The output of the first stage enveloping can be represented as

$$c_1(n)=\frac{1}{M_1}\sum_{m=-(M_1-1)/2}^{(M_1+1)/2}c[n+m]. \tag{9}$$

Then the output of the second stage enveloping can be represented as

$$c_2(n)=\frac{1}{M_2}\sum_{m=-(M_2-1)/2}^{(M_2+1)/2}c[n+m]. \tag{10}$$

The method described above, to a great extent, minimizes noise interference, making the envelope curve smoother and the peak of envelope more legible. After choosing the envelope peak point to be the center point, the synchronization interval l_{fine} is determined. Sliding correlation works with fine slide step T_{fine} on the range of fine synchronization intervals. TDE is completed by peak-picking of the absolute value from the correlator output. The UWB synchronization algorithm is based on two-stage enveloping as shown in Figure 2.

IV. SIMULATION AND ANALYSIS

In simulation, the system parameters are set as follow: sampling frequency f_c =5e10Hz, pulse repetition interval T_s =10e-9s, chip duration T_c =1e-9s, bit repetition times N_s is 10, number of chips per frame N_h = 10, period of TH code T_p =10, pulse width T_m =0.5e-9s, shape factor α^2 = 0.2e-9, time shift caused by PPM d_{PPM} =0.5e-9s and search cycle T_{max}=300e-9s. In order to compare the performance of the improved algorithm with the conventional sliding correlation algorithms, two types of simulation are implemented. The simulation parameters are listed in Table 1. The numbers of integrators needed in simulation 1 and simulation 2 are 1000 and 500, respectively.

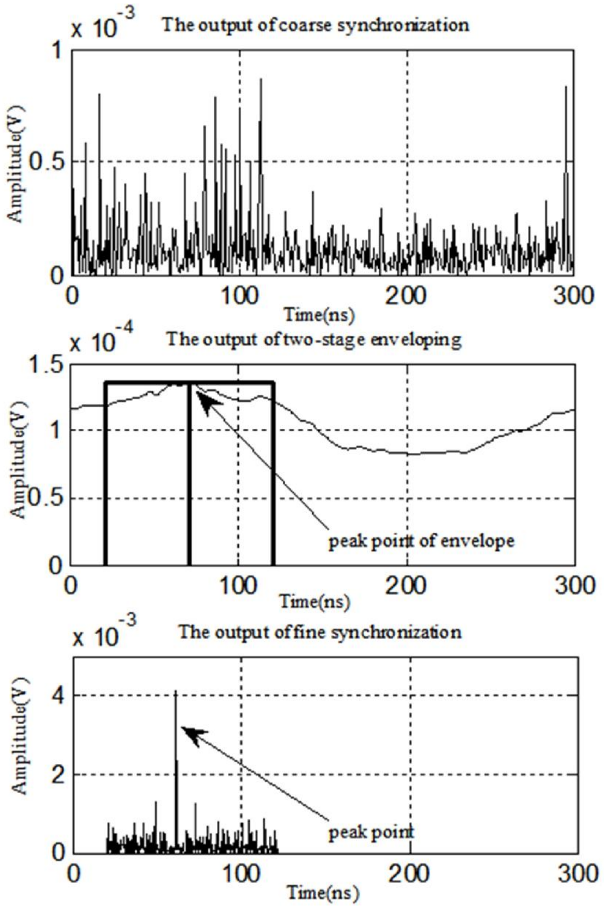

Figure 2. Realization of UWB synchronization algorithm based on two-stage enveloping

TABLE I. SIMULATION PARAMETERS

parameters	Definition	Simulation 1	Simulation 2
T_{coarse}	Silding step of coarse syn (s)	3e-10	6e-10
T_{fine}	Silding step of fine syn (s)	1e-10	2e-10
l_{fine}	The length of fine syn interval (s)	100e-9	100e-9

In the AWGN channel, the simulation results are shown in Figure 3, while in the CM1 channel, the simulation results are shown in Figure 4. SNR denotes the signal-to-noise ratio.

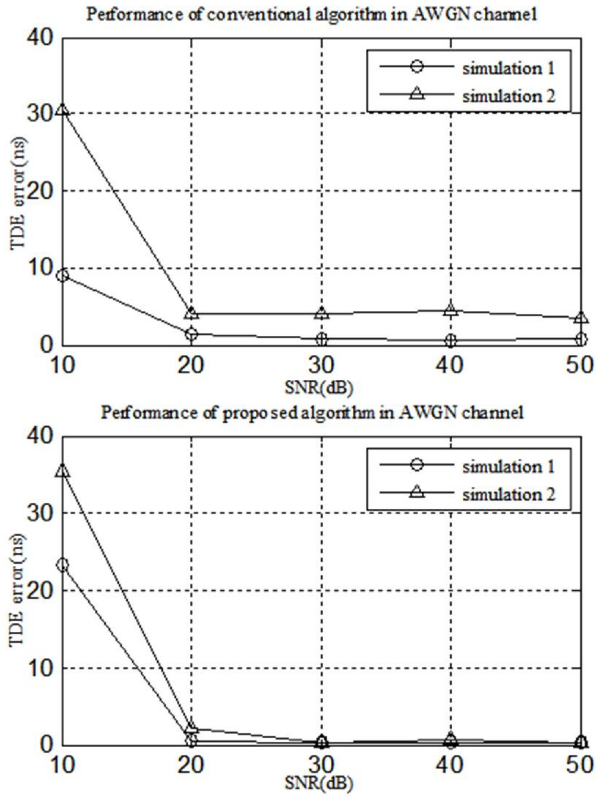

Figure 3. Comparison of TDE error in AWGN channel

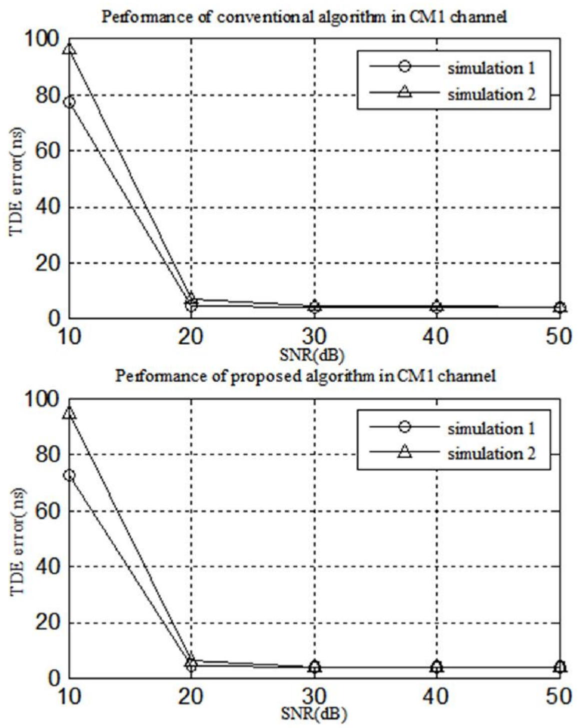

Figure 4. Comparison of TDE error in CM1 channel

In the AWGN channel, from the simulation results, it is found that when the number of the integrators reduces from 1000 to 500, the TDE error increases, yet the two-stage enveloping algorithm still has a better synchronization performance. On the contrary, when the TDE error increases markedly, the synchronization performance of conventional correlation algorithm significantly deteriorates. However, in the CM1 channel, when the number of integrators reduces, the synchronization performances of both algorithms are maintained steady. In brief, comparing with the conventional sliding correlation algorithm, the performance of the proposed algorithm is preferable in the AWGN channel and maintains steady in the CM1 channel.

V. Conclusion

An IR-UWB synchronization algorithm based on two-stage enveloping has been proposed. The simulation results show that this algorithm has significantly better synchronization performance when the number of receiver integrators reduces, which means reducing the complexity and cost of the IR-UWB receiver, thus it is very practical in the IR-UWB position system.

Acknowledgment

The authors would like to acknowledge National Natural Science Foundation of China (61172086) for providing financial support for this work.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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