A kind of high precision synchronization algorithm for TR - UWB system

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Abstract. The synchronization is the key problem of UWB system, because the non related systems of TR - UWB (Transmitted Reference Ultra - wide - band) evaded the problem of channel estimation, become a kind of hot technology. This paper put forward a kind of high precision synchronization algorithm, made the synchronization error within the set pulse width, greatly improved the ability to resist noise for communication receiver. Analyzed average capture time and capture probability of synchronized for TR - UWB systems, through the simulation experiment confirmed the effectiveness of algorithm.

Introduction

Ultra-wide-band radio uses nanosecond pulse with very low duty cycle to transfer information. Because the energy of pulse is low, each symbol use multiple narrow pulse transmission to obtain processing gain. The signal reception at the receiving end can be divided into coherent reception and non coherent reception. Coherent reception need accurate channel information and the design of receiving template signal, in order to get more signal. Non coherent receiver uses the receiving signal to do templates or do energy detection, which greatly reduces the complexity of the receiver. TR - UWB is a very popular solution which adopts non related auto-correlation receiver.

Coherent receiver must realize the synchronization of pulse level before realizing the symbol synchronization, then extract the symbol synchronization^[6]. Non coherent receiver is the opposite, must go to realize the symbol synchronization, then guide the signal and information alignment. Most of the error of symbol synchronization algorithm in a frame range, it is not enough for demodulating the received signal, because of the low duty cycle and specific location of pulse in the frame is unknown, under the limit condition, can lead to the error rate is 50%. However, due to the receiver with respect to the coherent receiver has good ability to resist synchronization error, synchronization of pulse level is unnecessary, because the cost is too high.

In order to make full use of the performance to resist synchronization error for non coherent receiver, this paper puts forward a kind of synchronization algorithm which precision is much less than the frame time. Making full use of the performance of TR-UWB system, done the precision can be set, can compromise between accuracy and capture time, in order to realize different function of the system^[7]. Although achieved the similar function, but take the maximum delay T_m of system as known parameter, in the real environment, T_m is unable to predict in advance, therefore it doesn't have practicability.

System model

In order to facilitate the research, it is assumed that the signal system is binary, single user, the transmit signal is expressed as:

$$S(t) = \sum_{i=0}^{\infty} \sum_{j=0}^{N_f-1} (\sqrt{E_p} p(t - iN_f T_f - jT_f) + L_i \sqrt{E_p} p(t - iN_f T_f - jT_f - D)) \quad (1)$$

Among them, N_f refers to the number of frame which frame no. is f , T_f refers to the duration

of data frame, $\{L_i = \pm 1\}$ refers to the bit sequence, E_p refers to the signal pulse energy, $p(t)$ refers to the waveform of normalized pulse within the time t , the duration is T_p , the duration of each symbol is $T_s = N_f T_f$, each frame transfers two pulses, the delay time is D , one is guide pulse, the second is the symbol which carried the information. In order to avoid the pulses between the symbols, it is assumed that $T_f \geq 4D$ in the process of research.

Ultra-wide-band channel adopts the model of distinguishable tapped delay: $h(t) = \sum_{l=0}^{N_m-1} \alpha_l \delta(t - T_l)$, N_m is maximum resolution path number, channel amplitude parameter is a log normal distribution, effective multi-path delay is defined as: $T_m = T_{N_m-1} - T_0 + T_p$. Usually, T_f is much bigger than T_m , select $D > T_m + T_p$, in order to avoid the interference between intra-frame and inter-frame, the signal of receiver can be expressed as:

$$r(t) = \sum_{i=0}^{\infty} \sum_{j=0}^{N_f-1} (\sqrt{E_p} g(t - iN_f T_f - jT_f - T_0) + L_i \sqrt{E_p} g(t - iN_f T_f - jT_f - T_0 - D) + n(t)) \quad (2)$$

$g(t) = p(t) * h(t + T_0)$, the effective range of the signal is $[0, T_m]$, the mark of $*$ in above formula refers to convolution. $n(t)$ is additive Gaussian noise, average value is 0, $N_0/2$ refers to bilateral power spectral density. The signal bandwidth of band-pass filter which received source signal passed through is w , center frequency is f_0 , colored Gaussian noise signal is $\hat{n}(t)$, relation function is: $R_{\hat{n}}(T) = wN_0 \frac{\sin(\pi w T)}{\pi w T} \times \cos(2\pi f_0 T)$. Received signal $\gamma(t)$ after passed through band-pass filter expressed as $\hat{r}(t)$.

Algorithm description

(1) Symbol synchronization algorithm

Adopting the algorithm with data-aided $L_i = 1$, the following information symbol $L_{i+1} = 0$, information symbols are alternate, in order to get symbol synchronization information as soon as possible^[3].

It is assumed that receiver captures signal when $n=0$, selects the signal which symbol length is $2N$, operation as below:

$$I_j = \sum_{n=0}^{N_f-1} \int_0^{\frac{T_f}{2}} \hat{r}(t + nT_f + j\frac{T_f}{2}) \hat{r}(t + nT_f + j\frac{T_f}{2} + D) dt, j = 0, \dots, 2N_f - 1. \quad (3)$$

In the absence of noise, formula (3) is equivalent to comparing the energy contained in each symbol of $2N_f$. Because of the adjacent two symbols are interactive, when the complete synchronization, I_j must get the maximum value. When need to realize synchronization between different symbols, the value of I_j is canceled each other. Therefore, at the synchronous moment,

$$\hat{T} = \frac{T_f}{2} \arg \max_j I_j$$

(2) High-precision synchronization

After the symbol synchronized, adopting training sequence of full 1, can according to the precision of the system, adopting the threshold comparison method, to realize the synchronization of high precision. It is assumed that the symbol is T_0 , then to use $[-\frac{T_f}{2}+T_0, \frac{T_f}{2}+T_0]$ to calculate

$$U = \int_{T_v - \frac{T_f}{2}}^{T_v + \frac{T_f}{2}} \hat{r}(t - T_0 - T_v) \hat{r}(t - T_0 - T_v - D) dt \quad (4)$$

If U is less than threshold value T_1 , then enter judgment of the next T_v , in order to facilitate the analysis, adopts the true method of random selection. In order to reduce the discriminant error, in the phase of calibration and verification, can adopt the calculation of multiple frames to improve the signal-to-noise ratio, it is assumed that the times of repetition in the phase of calibration and verification is G_0 and G_1 , then the time spend in the phase of calibration and verification is $G_0 T_f$ and $G_1 T_f$.

Performance analysis

In order to achieve the best performance, analyzing the average capture time of the system, simplifying the process flow diagram, can use an expression to represent the closure of the capture time. The average capture time of symbol synchronization is very simple.

$$E[T_{symbol}] = 2N_f T_f \quad (5)$$

In order to improve the anti-interference ability, adopts method of repeating sampling several times and calculating the average value. It is assumed that the average time is k , then

$$E[T_{symbol}] = 2kN_f T_f \quad (6)$$

High precision synchronization capture the signal flow chart as follows:

Figure1 Signal flow diagram

Figure2 Simplified flow diagram

Figure 1 can calculate state transfer function $H(z)$, through $H(z)$ can calculate the average capture time $\bar{T} = \frac{dH(z)}{dz} \Big|_{z=1}$. In order to get $H(z)$, we need to calculate transfer function of each arrow, the simple channel is constant during the synchronization phase, the output of the integrator in formula (4) only is the function of T_v .

$$U = \sqrt{E_p} R_{\hat{r}(t)\hat{r}(t)} (-T_v) + \hat{n}(t) \quad (7)$$

$\bar{U}$ is Gaussian amplifier variable, average value is $E_u = \sqrt{E_p} R_{\hat{r}(t)\hat{r}(t)} (-T_v)$, variance is $\Delta^2 = \sigma^2 / 2G$. The probability of inspection phase $x = T_1$ and verification phase $x = T_2$ can be obtained easily:

$$P(\bar{U} > x) = \frac{1}{\sqrt{2\pi}} \int_x^{+\infty} \frac{(x - E_u)}{\sigma / \sqrt{G}} e^{-\frac{x^2}{2}} dx \quad (8)$$

G refers to the times of signal repetition in inspection and verification phase.

Define $N = T_f / T_v$. The partition of $U > 0$ is a valid partition, the partition of $U \leq 0$ is a invalid partition, define the valid partition as a collection M , define the invalid partition as a collection K , their number respectively defined as N_{Valid} and N_{Null} . Obviously: $N = N_{Valid} + N_{Null}$. Complex flow diagram can be simplified as a state diagram expressed by the collection, as shown in figure 2.

Above figures simplified the complex signal process. Among them, S is initial state collection, Y is valid partition collection, N is invalid partition collection, E is termination state collection, X is valid partition collection of inspection phase, F is invalid partition collection of inspection phase. Obviously:

$$P_2 = N_{Null} / N \quad (9)$$

Through deduction:

$$P_{YX} = \frac{1}{N_{Valid}} \sum_{i \in M} P_{X_i X_i + N} \quad (10)$$

$$P_{NF} = \frac{1}{N_{Null}} \sum_{i \in K} P_{X_i X_i + N} \quad (11)$$

According to the theory of Markov chain, through deduction:

$$P_{FE} = \frac{\sum_{i \in M} P_{X_i X_i + N} P_{X_i + N X_E}}{\sum_{i \in K} P_{X_i X_i + N}} \quad (12)$$

$$P_{XZ} = \frac{\sum_{i \in M} P_{X_i X_i + N} P_{X_i + N X_E}}{\sum_{i \in K} P_{X_i X_i + N}} \quad (13)$$

$$P_{XY} = P_1(1 - P_{XE}), P_{XN} = P_2(1 - P_{XE}), P_{FY} = P_1(1 - P_{FE}), P_{FN} = P_2(1 - P_{FE}) \quad (14)$$

According to the simplified flow chart of figure 2, the application of Mason formula:

$$H(z) = \frac{P_{FE} P_{NF} (P_1 \beta + P_2 Y) + P_{XE} (P_1 \alpha + P_2 \theta)}{\alpha \gamma - B \theta} \cdot Z^{G_0 + G_1} \quad (15)$$

$$\alpha = 1 - P_{NN} Z^{G_0} - P_{FN} P_{NF} Z^{G_0 + G_1} \quad (16)$$

$$\beta = P_{YN} Z^{G_0} + P_{XN} P_{YX} Z^{G_0 + G_1} \quad (17)$$

$$\gamma = 1 - P_{YY} Z^{G_0} - P_{XY} P_{YX} Z^{G_0 + G_1} \quad (18)$$

$$\theta = P_{NY} Z^{G_0} + P_{FY} P_{NF} Z^{G_0 + G_1} \quad (19)$$

$$\text{The average capture time: } \bar{T} = dH(z) / dz \big|_{z=1} \quad (20)$$

Because the probability of false alarm occurs during the inspection and verification phase, therefore, the average capture time is just one part of parameters for measuring system, and can't completely react the performance of system, the probability of capture is also an important

parameter, most previous papers assume that the calibration system to identify the false alarm with probability 1, it is not possible in the real system, the flow diagram of Markov in figure 2, give full consideration to the probability of false alarm in inspection stage, using the H (Z) and Markov theory obtained by the flow chart, we can obtain the expression of acquisition probability:

$$P_{\text{detection}} = \frac{P_{FE}P_{NF}(PP_{1N} + PP_{1N}P_{1X} + P_2 - PP_{2Y} - PP_{2Y}P_{2X}) + P_{XE}P_{IX}(P - PP_{1N} - PP_{1N}P_{1F} + PP_{2N} + PP_{2N} + PP_{2F}P_{NF})}{(1 - P_{NN} - P_{FN}P_{NF})(1 - P_{YX} - P_{YX}P_{2X}) - (P_{1N} + P_{1N}P_{1X})(P_{2N} + P_{2F}P_{NF})} \quad (21)$$

Simulation and results

In order to verify the validity of the algorithm, the second derivative of the Gaussian pulse is used for simulation. Basic parameters set as follows:

$N_f = 10$, $T_f = 100$ ns, $T_p = 0.7$ ns, $N_m = 15$, $T_v = 3T_p$, $\frac{E_p}{N_0} = 10$ dB, use the fixed value $G_0 = 3$ and $G_1 = 3$.

On the platform of Matlab, the figure of average capture time (unit: T_s) with T_1 and T_2 (unit: E_p) as parameters, as shown in figure 3.

Figure3 average capture time under simulation of Matlab

Figure 4 relationship between average capture time and times of repetition

In the fixed condition of T_1 , T_2 and G , the simulation diagram for the relationship between average capture time and times of repetition, as shown in figure 4.

Can be seen from the simulation results, when $G_0 = 1$, the average capture time is minimal. Simulation results confirmed that the high precision TR-UWB synchronization algorithm makes full use of the energy of multiple channel which designed in this paper, realized the synchronization of high precision. Using the signal flow chart and the theory of Markov, analyzed the different threshold value and times of repetition which influence on average capture time, provided the basis to improve the anti-interference ability of communication system in the set pulse bandwidth.

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