Communication and ranging composite system based on parallel combinatory spread spectrum technology

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Abstract: The communication and ranging composite system can realise information transmission and distance measurement at the same time, which reduces the complexity of the system and expands the application scope. In order to improve the communication rate and the time delay estimation accuracy in low Signal-to-Noise Ratio (SNR) of the composite system, the Parallel Combinatory Spread Spectrum (PCSS) technology is applied, and the mW composite sequence is used as the spread spectrum sequence, and the improved generalised cross-correlation algorithm is adopted. The algorithm performs exponential calculation on the correlation function, then the correlation function obtained by inverse Fourier transform is performed as a high power operation, and finally performs the time delay estimation. The simulation results show that the improved communication and ranging composite system improves the information transmission rate and has better time delay estimation performance. The proposed system can accomplish ranging and communication tasks more effectively.

Keywords: communication and ranging composite system; parallel combinatory spread spectrum; mW sequence; time delay estimation; generalised cross-correlation.

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1 Introduction

The communication and ranging composite system (abbreviated as the composite system) can accomplish communication and ranging at the same time, which reduces the complexity and power consumption of the equipment. In the fields of satellite communication and navigation, deep space exploration, and inter-satellite link communication, the integrated communication and ranging technology has been widely used, and it is also the key development direction in the field of communication (Bai et al., 2020). Because of its strong anti-interference ability and low probability of interception, spread spectrum system is widely used in the transmission of communication information (Malygin et al., 2020; Kim et al., 2020). In addition, the pseudo-random code ranging can achieve high precision measurement, which is a commonly used ranging method at present. Therefore, spread spectrum technology is usually used to implement the composite system.

Wang (2015) used Direct Sequence Spread Spectrum (DSSS) technology to design the composite system, but there are some problems such as the technical parameters contradiction. Yi (2007) proposed a composite system based on Tamed Spread Spectrum (TSS) technology, which can solve the contradiction between ranging range and communication rate, but cannot meet the demands of high efficiency information transmission. Professor Zhu proposed a new spread spectrum mode – PSCC technology (Chen et al., 2019a), which improved the data transmission ability and frequency band utilisation, and has been widely used. Dou et al. (2011) applied the PCSS to the ultra-wideband model, which improved the security performance and communication efficiency of the communication system. Shi (2018) applied the PCSS to through-the-earth communication, which improved the anti-interference ability and information transmission ability, and provided support for underground military communication. Zhou et al. (2019) applied the PCSS technology to underwater acoustic communication, which improved the communication rate while maintaining the communication stability. In Zhang et al. (2015), the PCSS technology was applied to audio data hiding system, which improved the hiding efficiency. In this paper, in order to further improve the communication efficiency, the PCSS is applied to the composite system.

The Time Difference of Arrival (TDOA) (Laas and Xu, 2021) estimation is key to ensure the composite system to complete the communication and ranging tasks, and the used correlation algorithm affects the performance of TDOA estimation in the composite system. Wang (2018) completed the integrated task of communication and relative positioning between aircrafts by using TDOA detection technology based on ordinary correlation function, but the anti-noise ability of the composite system is poor. Teng (2005) used the Generalised Cross-Correlation (GCC) algorithm to complete the ranging task of the composite system, but the time delay estimation had some limitations in low SNR. Song (2012) put forward the time delay estimation of composite system by using generalised cyclic correlation function, which had large calculation amount. Stock et al. (2014) used the cross-correlation algorithm of energy spectrum estimation to estimate the time delay of the composite system, and the complexity of the algorithm is relatively high. In order to improve the time delay estimation performance of the composite system in low SNR, an improved generalised cross-correlation time delay estimation method is proposed in this paper. The algorithm is applied to the composite system, which weakens the influence of noise effectively, increases the relative value of main peak and secondary peak.

2 Composite system model

The work flow chart of the composite system is shown in Figure 1. First, the baseband signal is transmitted by the transmitting part, modulated and sent into the channel; then received by the receiving part of the object under test, the received signal is demodulated and despread, communication information is restored and TDOA estimation is completed. The composite system based on the DSSS technology cannot achieve high precision, large range ranging and high speed communication at the same time. The application of the link sequence solves the problem of the contradiction between the requirements of the pseudo-random sequence parameters in the communication and ranging tasks, which makes the composite system have the ability of double range ranging. Therefore, in order to ensure the composite system can complete the communication task and the ranging task much more effectively, the link sequence and the PCSS technology are applied to the composite system (Wang, 2019). The data sequence mapping algorithm is the core part of the PCSS technology, and the specific working principle of the PCSS system is shown in Sub-section 3.1. Link sequence is composed of internal sequence (internal code) and external sequence (external code), and its specific working principle is shown in Sub-section 3.2.

The structure model of the composite system based on PCSS is shown in Figure 2. Firstly, internal sequence generator generates M alternative PN sequences, k bits communication data is transformed into parallel data through serial/parallel conversion, and r sequences are selected from the M alternative sequences according to the 'data-sequence mapping rules'. Secondly, the selected sequences are superimposed on the adder to generate the internal code of the link sequence. Then the external code is generated by the external sequence generator, the internal code and the external code are combined to generate the multi-ary link sequence. Finally, the multi-ary link sequence is modulated and transmitted.

Figure 1 Composite system work flow chat

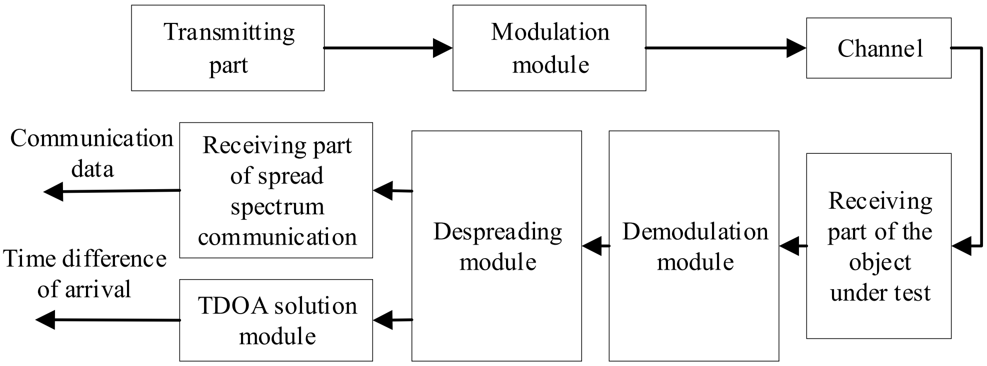
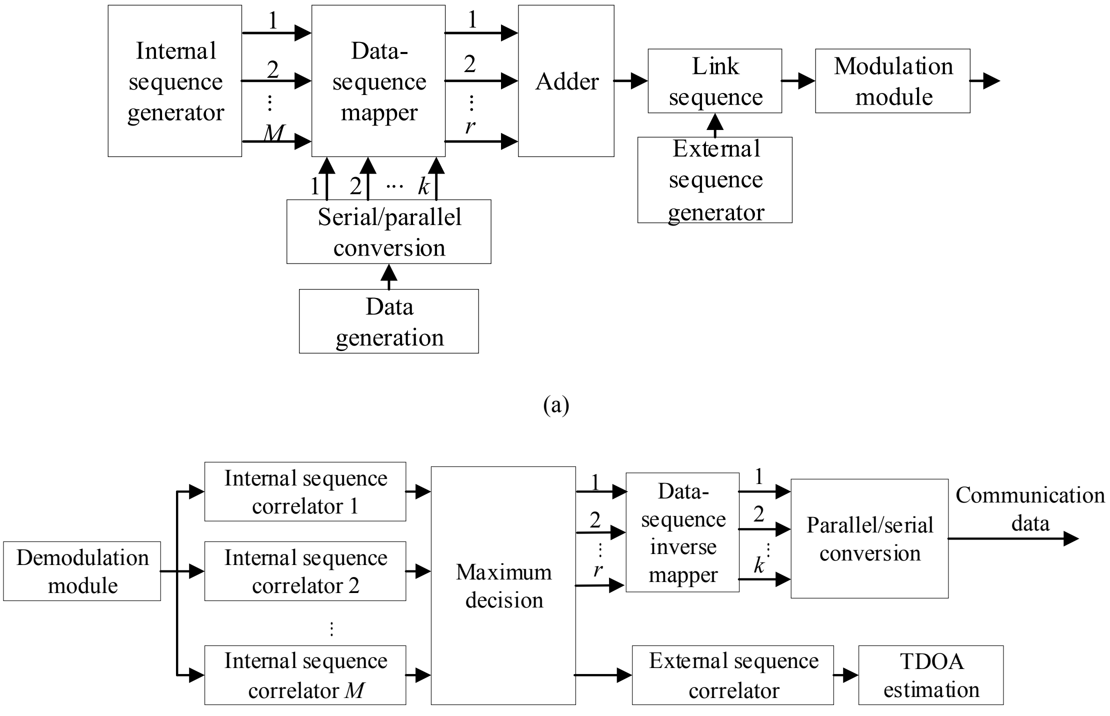


Figure 2 Structure model of composite system based on PCSS. (a) Transmitting terminal (b) Receiving terminal



(a)

(b)

The receiver of the system first carries out the demodulation and recovers the multi-ary link sequence. The link sequence and the local sequences are correlated to obtain the TDOA and derive the distance value. At the same time, the communication data is obtained according to the 'data-sequence inverse mapping rules'.

3 Key technologies of the composite system based on PCSS

3.1 PCSS communication technology

PCSS is an efficient spread spectrum technology on the basis of DSSS and TSS (Liu et al., 2016). Selecting r sequences from M spread spectrum sequences as combined sequences that will be sent. There are C_M^r possible selection states in total, the information amount that can be transmitted is $\log_2 C_M^r$ bits, and r sequences have 2^r polar states, and the information amount that can be transmitted is r bits. The maximum information amount transmitted by the PCSS system is:

$$k = r + \left[\log_2\left(C_M^r\right)\right] \tag{1}$$

where M is the total number of spreading sequences, r is the number of selected spread spectrum sequences and $[x]$ represents the largest integer not exceeding the x.

At the transmitting end of the system, send k bits data into the data-sequence mapper simultaneously, according to the data sequence mapping algorithm, r sequences are selected from the M alternative PN sequences, and the polarity of each sequence is given, then the PCSS sequence is obtained (Gao et al., 2020):

$$PN = \left(q_{i_1}PN_{i_1}, q_{i2}PN_{i2}, \ldots, q_{ir}PN_{ir}\right) \tag{2}$$

where q_{i_j} is the polarity control factor selected by the sequences r and sequences are superimposed in time domain to generate PCSS sequence:

$$D(t) = \sum_{j=1}^{r} q_{i_j} PN_{i_j}(t) \tag{3}$$

After the combined spread spectrum sequence is modulated, the transmitted signal is obtained:

$$S(t) = \sqrt{2p}D(t)\cos\left(\omega \cdot t + \phi\right) \tag{4}$$

where p is the power of the sequence, ω is the carrier angular frequency, φ is the carrier phase.

The data sequence mapping algorithm is an important part of the system, which directly affects the correctness of the recovered communication data at the receiving end (Chen et al., 2019b). In this paper, a data sequence mapping algorithm based on r-combination is used to define a sequence number for the spreading sequence, and the mapping of information data to spreading sequence can be transformed into the mapping of information data to spreading sequence number. According to Du (2016), the r-combination problem based on size ordering has the following theorems.

Theorem 1: *Take any r elements from n different elements. When known that the combination sequence number of r-combination based on size ordering is N, the element*

$a_i\left(1 \le i \le r\right)$ *of the combination is determined by the following formula.*

$$\min_{\{a_i\}} C_{n-a_i}^{r-i+1} \le C_n^r - N - \sum_{t=1}^{i-1} C_{n-a_i}^{r-t+1} \tag{5}$$

Theorem 2: *Take any r elements combination from n different elements. When the elements of the r combination are* $(a_1, a_2, a_3, ..., a_r)$, *the combination sequence number N based on the permutation is determined by the following formula, where* $a_0 = 0$.

$$N = a_r - a_{r-1} + \sum_{t=0}^{r-2}\left(C_{n-a_t}^{r-t} - C_{n+1-a_{t+1}}^{r-t}\right) \tag{6}$$

The input *k* bits data is divided into two parts: d_c and d_s, where d_c is *k*–*r* bits, $\left\{d_1, d_2, ..., d_{k-r}\right\}$ and d_s is *r* bits, $\left\{d_{k-r+1}, d_{k-r+2}, ..., d_k\right\}$. Converting the information data d_c into a decimal number *N* according to equation (7).

$$N = d_1 \cdot 2^0 + d_2 \cdot 2^1 + ... + d_{k-r} \cdot 2^{k-r-1} \tag{7}$$

Taking *N* as the combination sequence number, according to Theorem 1, the *r* sequences in the spread spectrum set can be uniquely determined correspondingly. Then, determine the polarity of the combined sequence according to d_s and equation (8), and finally get the transmit sequence.

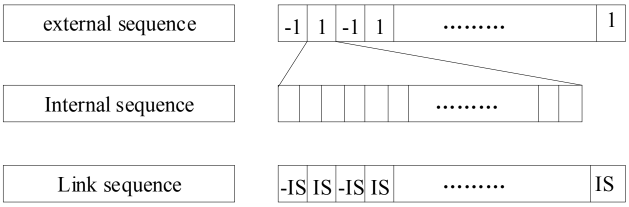
$$q_{ij} = (-1)^{d_{k-r+j}}, j = 1, 2, ..., r \tag{8}$$

At the PCSS receiver, the received information is demodulated and the PCSS signal is recovered; the spread spectrum sequence is correlated with the local *M* alternative sequences. In a good channel environment, due to the linearity and correlation characteristics of the selected sequences, *r* peaks will appear in the *M* correlation values. According to the *PN* sequences corresponding to the peak values to determine its *PN* sequence numbers, and then according to Theorem 2 and the polarity of the correlation peaks, the *k* bits data can be recovered finally, and the entire communication process can be completed.

3.2 Link sequence technology

The schematic diagram of the link sequence is shown in Figure 3. Among them, the internal sequences are composed of *M* pseudo-random sequences with good correlation characteristics, and the external sequence is a pseudo-random sequence, which is simple and easy to generate. Parallel communication data is used as a control signal to select the internal sequences, and the external sequence and the selected internal sequences by the data are combined to generate a link sequence. The link sequence is used as the spread spectrum sequence of the composite system to realise the functions of dual range ranging and efficient communication.

Figure 3 Link sequence schematic diagram

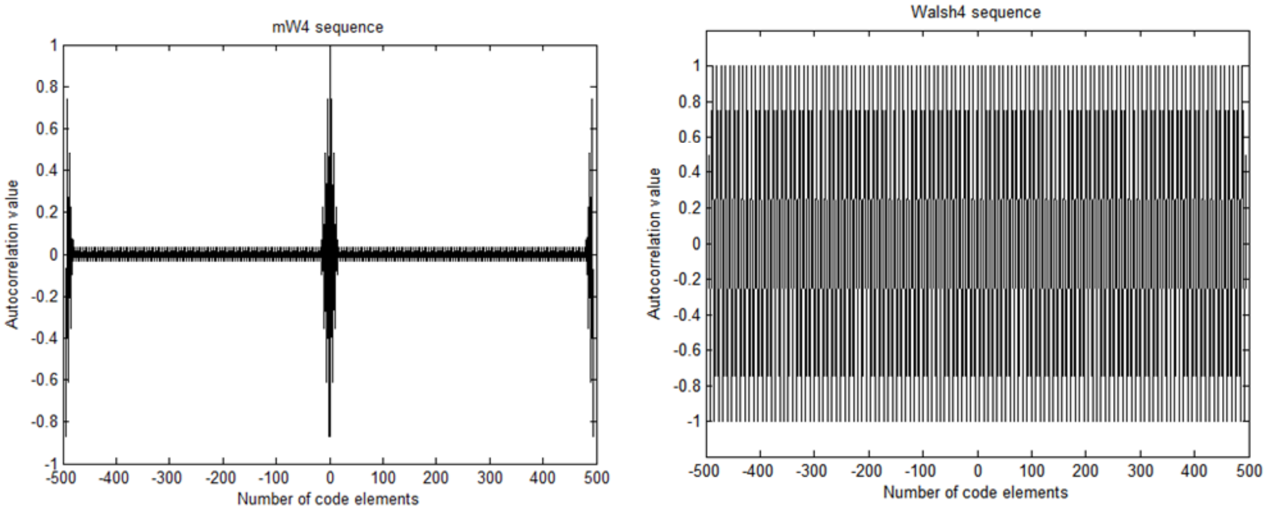


3.3 Selection of PN sequences

The *PN* sequence performs spread spectrum processing on the communication signal, and can measure the distance, especially when the target distance is far away, the long *PN* sequence can achieve unambiguous ranging (Wang et al., 2020). In the composite system, *PN* sequences should have good auto-correlation and cross-correlation characteristics, and have long period and large independent address number (Sihvo et al., 2020). The ideal auto-correlation characteristic means that the pseudo-random sequences should have a sharp auto-correlation function value, and the ideal cross-correlation characteristic means that the cross-correlation function between a sequence and any other sequence is approximately zero, that is, it has orthogonal characteristics, which is also the standard for composite system to select spread spectrum sequences (Zhao et al., 2021; Shu, 2020). The m sequences have good auto-correlation characteristics, but m sequences with the same period and different feedback coefficients have poor cross-correlation (Zeng et al., 2021). Walsh sequences have poor auto-correlation characteristics, but Walsh sequences with different order rates have better cross-correlation characteristics. mW sequences are composite sequence generated by m sequences and Walsh sequences, which has good auto-correlation and cross-correlation characteristics at the same time.

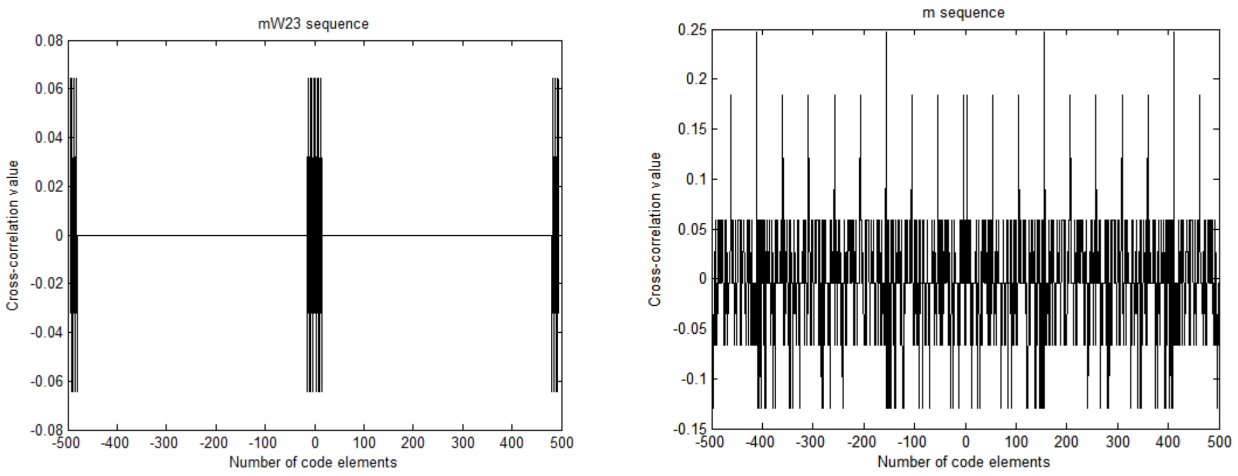
In order to ensure the reliable performance of the composite system and reduce the BER of the system, this paper chooses the mW sequences (*mW*1, *mW*2,..., *mW*16) composed of 5th order m sequence and 16th order Walsh sequences (*mW*1, *mW*2,..., *mW*16). The auto-correlation function of mW sequence and Walsh sequence is shown in Figure 4. It can be seen that the auto-correlation function of the Walsh sequence has multiple correlation peaks, while the mW sequence has a sharp auto-correlation value. Therefore, mW sequence has better auto-correlation than Walsh sequence with similar period. The cross-correlation function of mW sequence and the cross-correlation function of m sequence are shown in Figure 5. It can be seen that the cross-correlation function value of the m sequence is larger, while the cross-correlation function value of the mW sequence is closer to zero. Therefore, mW sequence has better cross-correlation than the m sequence with similar period.

Figure 4 Auto-correlation function graphs: (a) mW4 sequence auto-correlation function (b) Walsh4 sequence auto-correlation function



(a) (b)

Figure 5 Cross-correlation function graphs: (a) mW23 sequence cross-correlation function, (b) *m* sequence cross-correlation function



(a) (b)

3.4 *Time delay estimation algorithm*

Assuming that $x(t)$ is the local signal of a known node and $y(t)$ is the received signal, the mathematical expressions are:

$$x(t) = s(t) + m(t) \tag{9}$$

$$y(t) = s\left(t - \tau_0\right) + n(t) \tag{10}$$

where $s(t)$ is the signal to be transmitted, $s\left(t - \tau_0\right)$ is the signal received by a known node, and $m(t)$ and $n(t)$ represent the noises in the local environment and channel environment respectively.

The ranging task of the composite system is to use correlation operations to obtain the propagation delay of the local sequences and the received sequence, then calculate the TDOA according to (11), and finally obtain the distance between the node to be measured and the known node (Zhang et al., 2019). The mathematical relationship between the distance L and the propagation delay τ_0 is expressed by (12).

The cross-correlation function describes the degree of correlation between two random signals $x(t)$ and $y(t)$ at any two different moments t_1 and t_2, which is defined as $R\left(t_1, t_2\right) = E\left[x\left(t_1\right) \cdot y\left(t_2\right)\right]$ (Heydari, 2021; Zhang et al., 2021). In this experiment, according to the cross-correlation function between the received signal and the local signal, the time delay estimation of the local sequences and the received sequence can be obtained. Therefore, the performance of correlation operation has an important influence on the ranging performance of the composite system.

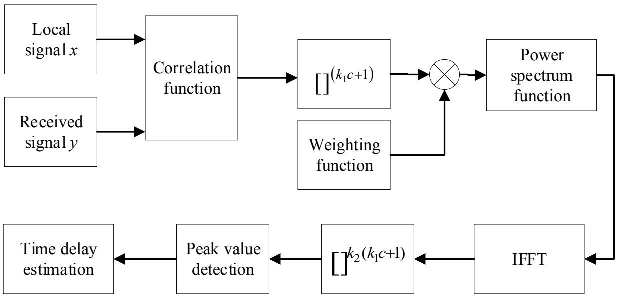
$$\text{TDOA} = \tau_0 \cdot T_c - T_z - T_j \tag{11}$$

$$L = \text{TDOA} \cdot \frac{C}{2} = \left(\tau_0 \cdot T_c - T_z - T_j\right) \cdot \frac{C}{2} \tag{12}$$

where L represents the distance between the node to be tested and the known node; TDOA represents the time difference of arrival; τ_0 is the time delay between local signal and received signal; T_c represents the symbol width, C is the speed of light, $C = 3.0\times10^8$m/s; T_z is the time of the frequency conversion forwarding; T_j is the processing time of TDOA solution.

There are many time delay estimation algorithms based on correlation function. The existing composite systems mainly use common cross-correlation algorithms, generalised cross-correlation algorithms and cyclic correlation algorithms. In addition, the secondary correlation algorithm and the generalised secondary correlation algorithm are widely used in sound source localisation (Jian et al., 2021). Considering the performance and complexity of the algorithm, this paper proposes an improved generalised cross-correlation time delay estimation algorithm, which weakens the influence of noise and increases the relative values of the main peak and the secondary peak. The algorithm's working principle is shown in Figure 6.

Figure 6 Improved generalised cross-correlation algorithm flow chart



Firstly, the local signal $x(t)$ of the known node and the signal $y(t)$ received by the known node are correlated:

$$\begin{aligned} R_{xy}(\tau) &= E\left[y(t+\tau)\cdot x(t)\right] \\ &= E\left[(s(t+\tau-\tau_0)+n(t+\tau))\cdot(s(t)+m(t))\right] \\ &= E\left[s(t+\tau-\tau_0)\cdot s(t)\right] + E\left[s(t+\tau-\tau_0)\cdot m(t)\right] \\ &\quad + E\left[s(t)\cdot n(t+\tau)\right] + E\left[n(t+\tau)\cdot m(t)\right] \\ &= R_s(\tau-\tau_0) + R_{ms}(\tau-\tau_0) + R_{sn}(\tau) + R_{mn}(\tau) \end{aligned} \tag{13}$$

where $R_s\left(\tau-\tau_0\right)$ is the correlation function between the local signal and the received signal, $R_{ms}\left(\tau-\tau_0\right)$ is the correlation function between the received signal and the local noise, $R_{sn}\left(\tau\right)$ is the correlation function between the received signal and the noise in the channel environment, and $R_{mn}\left(\tau\right)$ is the correlation function between the local noise and the noise in the channel environment.

Assuming that there is no correlation between the interference or noise and the signal, the correlation function of the arrival sequence and the local sequences is simplified to:

$$R_{xy}(\tau) = R_s\left(\tau-\tau_0\right) \tag{14}$$

According to the property of correlation function, $R_s\left(\tau-\tau_0\right)$ has a maximum value when $\tau = \tau_0$.

According to the Wiener-Khinchin Theorem (Miao et al., 2019; Jia et al., 2020), the generalised cross-correlation function is:

$$R_{xy}(\tau) = \frac{1}{\pi}\int_0^{\pi} \phi_{xy}(\omega) G_{xy}(\omega) e^{j\omega\tau} d\omega \tag{15}$$

where $\phi_{xy}(\omega)$ is the generalised weighted function, and $G_{xy}(\omega)$ is the cross power spectral density function of $x(t)$ and $y(t)$ (Hu et al., 2018).

The smooth coherent (SCOT) weighted function was used:

$$\phi_{xy}(\omega) = \frac{1}{\sqrt{G_x(\omega) * G_y(\omega)}} \tag{16}$$

where $G_x(\omega)$ and $G_y(\omega)$ are the auto-power spectral density functions of $x(t)$ and $y(t)$, respectively. When the SNR is large, the smooth coherent method has a strong ability to suppress noise and can reduce the influence of signal fluctuations on TDOA estimation (Yan et al., 2018).

The exponential calculation formulas of the improved algorithm are as follows:

$$p = \left[R_{xy}(\tau)\right]^{(k_1c+1)} \tag{17}$$

$$q = \left[l\right]^{k_2(k_1c+1)} \tag{18}$$

where P is the result of the correlation function exponential operation, and c is the SNR in dB. l is the correlation function after the inverse Fourier transform, and q is the result of the inverse Fourier transform exponential operation. k_1 and k_2 are the parameters to be determined, k_1 determines the multiple of signal and noise compression; k_2 determines the peak value of the correlation function and the algorithm complexity. Since the parameters directly affect the performance of the algorithm and the accuracy of the system delay estimation, they are analysed and tested many times in this paper.

In order to weaken the influence of noise to the signal in low SNR, k_1 could be any decimal. In equation (17), when SNR = 0, the exponential part is equal to 1, and the result is the correlation function itself; when SNR < 0, the amplitude of signal and noise can be compressed in the same proportion; when SNR > 0, the correlation function can be regarded as a square operation. Therefore, in order to make the composite system work in lower SNR, and reducing the influence of noise on the signal, $k_1 = 0.001$ is taken in this experiment.

Equation (18) carries on the high power operation to the correlation function after the inverse Fourier transform to increase the relative value of the main peak and the secondary peak, and k_2 should be a positive integer. When k_2 is an even number, the cross-correlation peak value is a positive number, and in order to ensure that the delay estimation results can reflect the positive and negative polarities of the external sequence, k_2 should be odd number, and larger the value of k_2, higher the complexity of the algorithm. Through many experimental analysis of k_2, when k_2 is set to 3, 5, 7 and 9, the delay estimation performance of the composite system is better. Therefore, in order to increase the operation speed and judge the composition of the external sequence at the same time, $k_2 = 3$ is selected in this experiment.

4 Simulation results and analyses

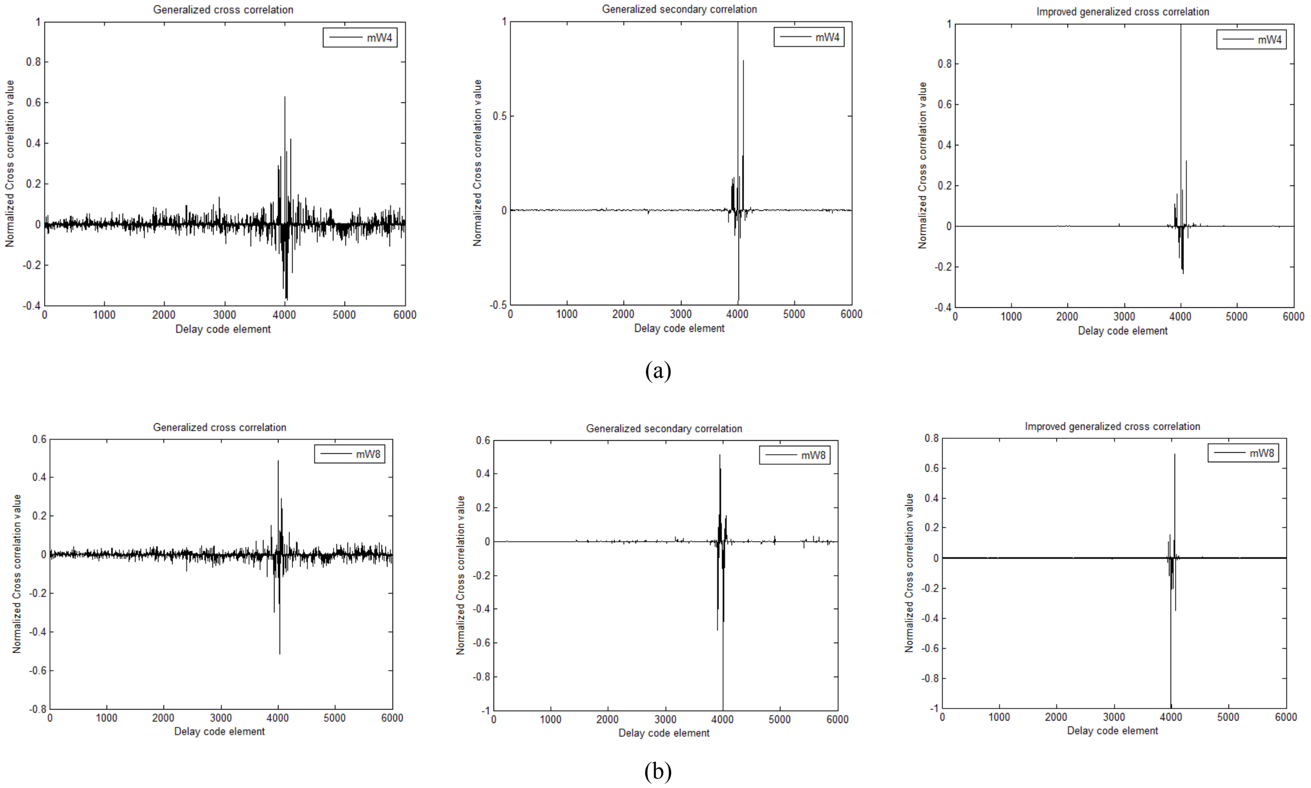
4.1 Simulation parameters setting

The arrival time difference estimation model of the composite system is established on the Matlab platform. It is assumed that the channel is a Gaussian white noise channel, the SNR ranges from –15 to 10 dB. Because the PCSS sequence is a multi-value sequence, a multi-ary digital modulation method such as Multiple Phase Shift Keying (MPSK), Multiple Amplitude Shift Keying (MASK) and Multiple Quadrature Amplitude Modulation (MQAM) can be used. Among them, MQAM has higher anti-noise performance and can get better BER performance. In this paper, 16QAM modulation is adopted. The pseudo-random code rate is 15 Mchip/s. The signal frequency is 15 MHz, and the carrier frequency is 150 MHz. The composite system adopts link sequence and PCSS, the data transmission ability of the system is determined by equation (1). Increasing *M* and *r* will increase the amount of information transmitted by the composite system, but the computational complexity of the system will increase, and the BER of the system will also increase. Therefore, in order to ensure the reliability of the composite system and reduce the BER, this paper chooses the *PN* sequences $M = 16$, the selected transmission sequences $r = 3$, the information code length $k = 12$, internal codes are composed of mW sequences with good correlation properties (the combination of 5th order *m* sequences and 16th order Walsh sequences), and the external sequence is the 5th order *m* sequence. Assuming that the composite system samples 8 points per chip period and the received signal delays 4000 sampling symbols.

4.2 System ranging performance analysis

For the TDOA estimation of the composite system, it can be judged according to the time when the peak value of cross-correlation function appears. Under the condition of low SNR, the improved time delay estimation algorithm is simulated and compared with the generalised cross-correlation algorithm and the generalised secondary correlation algorithm. When SNR = –10 dB, the simulation results are shown in Figure 7.

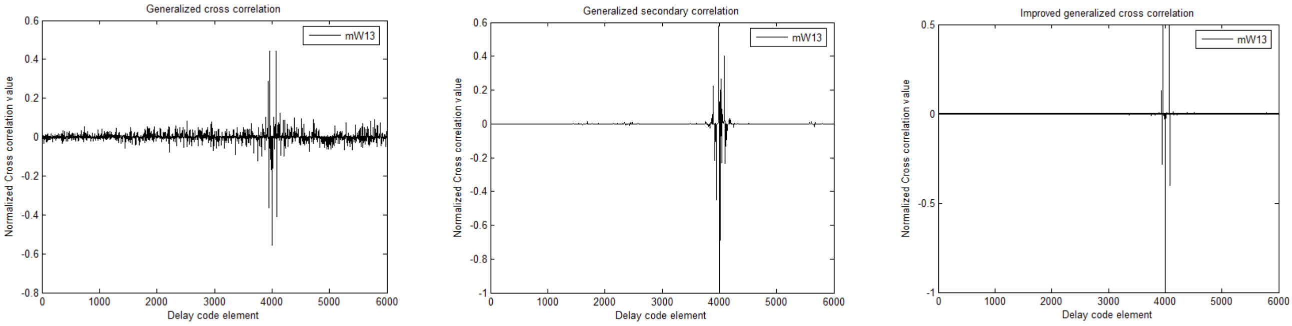
Figure 7 The time delay estimation results graph of the three algorithms for SNR= –10 dB. (a) The received sequence passes through the internal sequence correlator 4 (b) The received sequence passes through the internal sequence correlator 8 (c) The received sequence passes through the internal sequence correlator 13



(a)

(b)

Figure 7 The time delay estimation results of the three algorithms for SNR = –10 dB. (a) The received sequence passes through the internal sequence correlator 4 (b) The received sequence passes through the internal sequence correlator 8 (c) The received sequence passes through the internal sequence correlator 13 (continued)



(c)

It can be seen from Figure 7 that the receiver obtains the three values with the largest absolute value of correlation value, and the composite system based on PCSS can complete the ranging task. However, the anti-noise performance of the generalised cross-correlation algorithm is limited, and it is easily affected by noise or interference, and the time delay estimation performance is poor; the generalised secondary correlation algorithm has good anti-noise performance, but the secondary peak value is large, which is not conducive to improve the ranging accuracy; while the improved generalised cross-correlation algorithm has better anti-noise performance, and the peak value of correlation function is more prominent, and has obvious advantages.

In order to further verify the time delay estimation performance of the improved algorithm, simulation experiments are carried out on the Root Mean Square Error (RMSE) of the generalised cross-correlation algorithm, generalised secondary correlation algorithm and the improved generalised cross-correlation algorithm. The RMSE (Qian et al., 2020) is defined as:

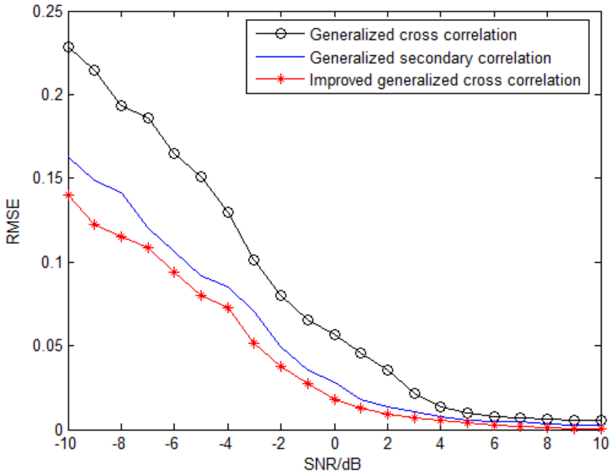
$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\tau_i - \tau_0\right)^2} \tag{19}$$

where N is the total number of time delay estimates, τ_i is the i-th time delay estimation value and τ_0 is the real time delay value.

Under the condition of SNR= –10~10 dB for 30 experiments, the RMSE obtained is shown in Figure 8.

It can be seen from Figure 8 that with the increasing of SNR, the RMSE decreases. Compared with the generalised cross-correlation algorithm and the generalised secondary correlation algorithm, the improved generalised cross-correlation algorithm has lower RMSE at different SNR, so the improved algorithm has good performance advantages under both low SNR and high SNR. Especially with the decreasing of SNR, the RMSE difference values between the improved algorithm and the generalised cross-correlation algorithm are larger, and it has better time delay estimation performance.

Figure 8 Performance comparison of three time delay estimation algorithms



4.3 System communication performance analysis

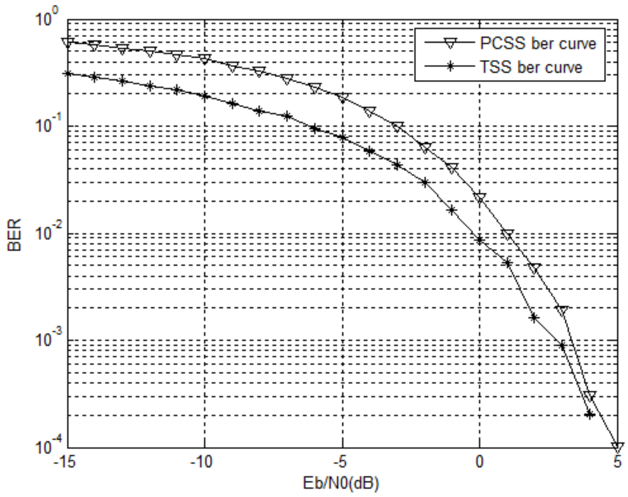
The internal sequences of the composite system is composed of 16 alternative *PN* sequences with good correlation characteristics, and the receiver needs 16 internal sequence correlators for correlation processing. The system randomly generates 12 bits binary communication data of 100110101011. In order to verify the communication performance of the improved composite system, the received multi-ary link sequence is passed through the internal sequence correlators, according to the serial numbers of the three correlators with the largest output absolute value and the polarity of the correlation value, the composition of the internal sequences and the external sequence can be judged and the communication data can be recovered.

According to the simulation results in Figure 7, the internal sequence numbers transmitted by the composite system are mW4, mW8, mW13, and the corresponding sequence numbers are {4, 8, 13}. According to Theorem 2, the combined serial number N = 309 can be obtained, and the binary data d_c = 100110101 can be recovered. According to the polarity of the peak values of correlator 4, 8 and 13, the information data d_s = 011 is recovered, then the corresponding binary communication data is 100110101011, which is consistent with the result of the communication data generated by the transmitter, indicating that the communication data is recovered correctly.

The BER comparison between a composite system based on PCSS technology and a composite system based on TSS technology is illustrated in Figure 9, where the abscissa represents the bit SNR, and the ordinate represents the BER. According to the BER simulation diagram, it can be seen that the composite system based on the PCSS technology can meet the performance requirements of practical applications. Compared with the composite system based on the TSS technology, its performance is slightly worse, which is the cost of improving the effectiveness of the system.

Specifically, under the simulation conditions of Sub-section 4.1, the composite system based on DSSS can only transmit 1 bit at a time, and its communication rate is $R_b = 6\times10^4$ (bit/s); The composite system based on TSS can transmit $\log_2 C_{M_1}^1 = 2$ bits at a time ($M_1 = 4$, M_1 is the total number of spreading sequences), and its communication rate is $R_b = 12\times10^4$ (bit/s); The composite system based on PCSS can transmit $r+\left[\log_2 C_M^r\right] = 12$ bits at the same time, and its communication rate is $R_b = 72\times10^4$ (bit/s). Through comparison, it can be seen that the composite system based on PCSS improves the communication efficiency of the system under the premise of ensuring reliability.

Figure 9 BER comparison graph



Based on the above analysis, it is concluded that compared with the composite system based on TSS, the composite system based on PCSS introduces more complex mapping algorithm, realises more bit mapping, improves the information transmission efficiency, and at the same time, the reliability of the composite system is reduced, but it can still meet the needs of practical applications.

5 Conclusion

In this paper, an improved communication and ranging composite system is proposed, which applies PCSS technology to increase the information transmission rate, uses the improved generalised cross-correlation algorithm to estimate TDOA, and performs exponential operation on the correlation function, gives a certain weight in the frequency domain. Then the correlation function obtained by inverse Fourier transform is performed as a high power operation, and finally the time delay is estimated, which reduces the influence of noise effectively and increases the relative value of the main peak and the secondary peak. Through the Matlab simulation results, it can be seen that the proposed composite system can correctly recover the communication data, complete the ranging task at the same time and has a better time delay estimation performance in low SNR.

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