Research on positioning signal acquisition at the cross-correlation interference conditions

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Abstract. In a positioning system based on a base station, it may occur that the signal strength of someone base station is much larger than that of other stations, which is not conducive to signal acquisition. A new way of capturing judgment is proposed for this phenomenon. The original decision method is to judge whether the positioning signal is captured by the ratio between the maximum value and the second largest value of the correlation value. The improved decision mode judges the capture by the variance of the maximum and the next largest value. Compared with the simulation results, the performance of the improved capture decision mode has been greatly improved.

1. Introduction

GNSS provides reliable location services for people's outdoor activities. With the development of urbanization, the proportion of people’s indoor activities is gradually increasing[1]. It is of great significance to study reliable indoor positioning systems. The TC-OFDM system discussed in this paper was developed for the precise positioning of the indoor environment and can provide wide-area high-precision indoor and outdoor location services. Code Division Multiple Access (CDMA) technology has a good positioning advantage[2].The TC-OFDM system also uses this technology to superimpose the positioning signal on the mobile broadcast signal without affecting the user's reception of the mobile broadcast signal[3].

Compared with the satellite system, when the receiver approaches a base station node, the strong signal node will generate strong cross-correlation interference to the weak signal nodes, making the weak signal difficult to detect or causing the ranging error of the weak signal to increase, so that the positioning accuracy is reduced or even unable to be located. The acquisition of signals in a strong cross-correlation interference environment is an important part of the TC-OFDM positioning system.

2. Construction and Geometrical Dimensions of Specimens

2.1. Receive signal model
For discuss easily, it is assumed that the receiver only receives single base station signal, and the signal is processed by the RF front-end filter. The signal expression is as shown in equation 1.

\[ r(t) = aD(t-\tau)S(t-\tau) \cos\{2\pi(f_{IF} + f_d)(t-\tau) + \theta_{IF}\} + n(t) \]  

In the formula (1), \( a, D, S, \tau, f_{IF}, f_d, \theta_{IF}, n \) represent the amplitude, data code, PRN code, propagation delay, IF carrier frequency, Doppler frequency offset, Carrier initial phase, noise, respectively. The signal is sampled by ADC and I/Q separated to obtain a discrete IF signal. The expressions are of formula (2) and formula (3).
In the equations (2) and (3), \( n_i \) and \( n_q \) are the noise signals of the I and Q channels, respectively, obeying the Gaussian white noise distribution.

\[
i(n) = aD(n - \tau)S(n - \tau)\cos[2\pi(f_{IF} + f_d)t(n) + \theta_{IF}] + n_i(n) \tag{2}
\]

\[
q(n) = aD(n - \tau)S(n - \tau)\sin[2\pi(f_{IF} + f_d)t(n) + \theta_{IF}] + n_q(n) \tag{3}
\]

After obtaining the discrete IF signal, the system moves to the capture segment. There are many capture algorithms available, and there are two main classes: serial search capture algorithms and parallel capture algorithms.

### 2.2. Serial capture

The serial capture algorithm is one of the most basic search capture algorithms. The method is simple and easy to operate. The basic principle is serial searching of the PRN code phase and the Doppler frequency offset. Since the signal is sampled, the search step size is usually less than one PRN chip. Besides, in order to obtain higher spreading gain, the general spreading code period is longer, so the number of search for the code phase in the serial acquisition algorithm is large and the efficiency is very low[4-5]. The process of the serial search algorithm is shown in Fig.1.

![serial search processing](image)

The correlation calculation results \( I(n), Q(n) \) expressions in the figure are Equations 4 and 5.

\[
I(n) = aDR(\tau)\text{sinc}(f_cT_{coh})\cos(\phi_e) + n_i \tag{4}
\]

\[
Q(n) = aDR(\tau)\text{sinc}(f_cT_{coh})\sin(\phi_e) + n_q \tag{5}
\]

\( R(\tau), f_c, T_{coh}, \phi_e, n_i, n_q \) are the corresponding autocorrelation function, frequency error, integration time, phase error, I channel noise, and Q channel noise.

### 2.3. Parallel code phase search

Since the serial search algorithm can only search one code phase at a time, in order to improve the search speed of the code phase, a parallel fast algorithm has emerged. This algorithm can obtain all the code phase correlation values at one carrier frequency in one calculation process. So this is a parallel search algorithm [6-7].

The correlation calculation and convolution operation expressions are as shown in Equations 6. In the formula (6), \( R(m) \) represents value between the received signal and the local PRN code, and the calculation amount is very large when directly calculated, which is why the previously described serial capture algorithm is inefficient.

\[
R(m) = \sum_{n=0}^{N-1} x(n)c(n + m) \tag{6}
\]

It can be seen from the form of (6), the process of calculating the correlation value is similar to the convolution calculation process of the time domain signal. Therefore, the correlation calculation can be converted to the frequency domain calculation. The expression is as shown in equation (7).

\[
R(m) = \sum_{n=0}^{N-1} x(n)c(n + m) = x(n) \ast c(-n) = \text{IFFT}[X(K) \cdot C'(K)] \tag{7}
\]

In equation (7), \( \ast \) represents a convolution operation, and \( C'(K) \) is a conjugate of \( C(K) \).
The parallel capture is mainly composed of carrier generator, spread code generator and FFT operation module. The block diagram of the FFT-IFFT often used in the positioning navigation system receiver is shown in Fig.2.

![Diagram of FFT and IFFT](image)

**Fig. 2 Code phase parallel searching**

### 2.4. Capturing judgment

After the correlation value of the signal is obtained, the next step is sending the value to the decision unit to decide whether to capture the PRN chip. Some commonly used decision algorithms include: the ratio of the maximum value to the next largest value, the ratio of the maximum value to the mean value, and the ratio of the maximum value to the fixed threshold. Among them, the judgment method using the ratio of the maximum value to the next largest value is the most. Assume that the maximum value of the correlation values calculated by the previous capture is $V_{\text{max}}$, and the second largest value is $V_{\text{sec}}$. Setting a threshold $R_{\text{th}}$, when $V_{\text{max}} / V_{\text{sec}} > R_{\text{th}}$, it is determined that the signal is captured. The code phase and carrier frequency at which $V_{\text{max}}$ is located are captured phase and carrier information.

### 3. Decision with Strong cross-correlation interference

#### 3.1. Analysis the interference of cross-correlation

Based on base station signal positioning system, one of the biggest challenges is that the receiver must receive multiple base station signals stably. Due to the nature of the PRN sequence, when calculating the correlation value, the result of the correlation contains autocorrelation and cross-correlation. The cross-correlation value affects the decision result. This phenomenon is called multiple access interference. In addition, the terminal may be close to a base station, resulting in a received base station signal strength much greater than other base stations. This high-intensity signal can affect other base station signal acquisition. Combined with the above two points, in the positioning system of the base station, strong cross-correlation interference occurs.

#### 3.2. Simulation of traditional decision

The ratio-based capture decision performance is simulated here. The simulation compares the capture rate and false alarm rate of each different threshold under each SNR condition. Each threshold capture performance is measured by these two parameters. The capture rate indicates the probability that the correlation peak obtained by the decision is the correct code phase; the false alarm rate indicates the probability that the correlation peak obtained by the capture decision is not the true code phase. Therefore, the ideal decision algorithm hopes to obtain a higher capture rate, while the low false alarm rate.

When the threshold is 1.1, 1.3, 1.5, 1.7, the capture rate and false alarm rate are shown in Fig.3 and Fig.4. The abscissa in the figure represents the signal-to-noise ratio of the received signal and Gaussian white noise.

In Figure 3, under the condition of higher signal-to-noise ratio, each threshold has a higher capture rate. After the signal-to-noise ratio is reduced, the capture rate of each threshold decreases. In Fig.4, as the threshold increases, the probability of false capture decreasing. When the threshold is greater than 1.3, the probability of false capture is close to zero.
3.3. Decision with variance

When the local PRN code phase and the carrier frequency are aligned to the code phase of the received signal and the carrier frequency, the difference between the largest and the next largest correlation value is maximized. From this maximum difference, the correct correlation peak in the correlation value can be more accurately resolved. The specific process is as following:

Step 1: Calculate the correlation value at each frequency, get the value $V_{di} = V_{maxi} - V_{seci}$

Step 2: Calculate the ratio of $V_{di}$ to $V_{maxi}$, marked as $V_{ratioi}$

Step 3: Calculate the variance $V_{vari}$ according to $V_{ratio1}, V_{ratio2} \ldots V_{raton}$

Step 4: Select the most value from all $V_{di}$, marked as $V_{dmax}$

Step 5: Remove $V_{dmax}$ and calculate the remaining $V_{di}$ variance $V_{var2}$

Step 6: Determine whether to capture the signal according to $V_{var1}$ and $V_{var2}$

The variance-based decision mode capture performance is shown in Fig.5 and Fig.6, where the abscissa represents the ratio of signal strength between base stations.

Fig. 3 capture rate with ratio-based

Fig. 4 false alarm rate with ratio-based

![Fig. 3 capture rate with ratio-based](image1)

![Fig. 4 false alarm rate with ratio-based](image2)

![Fig. 5 capture rate, cross correlation](image3)

![Fig. 6 false alarm rate, cross correlation](image4)

The variance-based capture performance is much better than the previous one based on the ratio decision method. In Fig.5, when the signal strengths differ greatly, the capture rate can still be maintained above 50% according to the decision mode of the variance, which is 30% higher than the traditional ratio judgment method.

In Fig.6, when the local threshold is 1.1, the false alarm rate is about 20%, and the improved judgment mode has a false alarm rate below 5%. Therefore, the improved decision mode not only improves the capture rate but also has a significant drop in the false alarm rate. It is an ideal decision method for positioning signals under strong signal interference conditions.
In order to measure the performance of the variance-based decision mode in a normal environment, the performance of the improved decision mode under Gaussian white noise conditions is also shown in Figure 7 and Figure 8. Compared with the ratio judgment mode capture performance, when the threshold is 1.1, the capture rate is similar, but the false alarm rate is significantly declining.

Therefore, the variance decision method can not only have better performance in high cross-correlation interference, but also provide good acquisition performance under normal conditions. It is a more general acquisition method.

4. Conclusion

This paper introduces the model of the positioning signal and the commonly used method of capturing judgment firstly. For the signal acquisition under the interference of strong signals to weak signals, this paper proposes a capture decision algorithm based on variance. Through simulation, the improved judgment method has promoted the capture rate of strong cross-correlation interference by 30%, and the error capture situation has also declined significantly. Besides, the capture performance is better than the ratio-based capture performance without cross-correlation interference, so it is a universal capture method.

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