Method for Optimizing Pseudo Code Ranging Accuracy by Carrier Observation

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Abstract. In view of the low precision of the pseudo code ranging, the carrier ranging and the ambiguity of the whole week, the observation is very difficult, a method using carrier smoothing pseudo range measurement is proposed. The method of using carrier phase measurement values to improve carrier ranging pseudo code ranging precision, and at the same time, pseudo code ranging can lock the auxiliary carrier phase, improve the efficiency and accuracy of carrier phase observation, meet the requirement of real-time system. In the end of the paper, the simulation results show the improvement of the carrier smoothing pseudo range to the pseudo range observation.

Introduction

Pseudo code ranging and carrier ranging has become the two most important methods in the field of modern space measurement. Research results show that, the observation noise of the pseudo code ranging is much larger than that of the carrier phase noise. At the same time, it is more serious than the carrier phase observation. So the measurement precision of the pseudo code ranging is lower than the precision of the carrier phase measurement, but its advantage is that it does not have the integer ambiguity. By comparison, the measurement of the carrier phase is usually based on the integer multiple of the carrier wave, so the precision of the measurement is high. But in the measurement process, it is needed to solve the integer ambiguity. Generally speaking, the calculation accuracy of the fuzzy degree is low, and the time of solving process is long, which makes the application of carrier phase ranging in the practical application is limited.

In this paper, the basic method of pseudo code ranging and carrier ranging is introduced. By using the carrier phase measurement of the carrier ranging as an aid to the pseudo code ranging, the phase smoothing is used to improve the precision of the pseudo code ranging. The simulation results of the carrier phase smoothing pseudo range are given.

The Principle of Bi-directional Ranging Based on Pseudo Code

The so-called pseudo code ranging method is measuring the difference between the received and the local pseudo code generator to obtain the propagation delay of PN ranging signal in space, so as to obtain the value of the ranging method[1]. The sketch map of pseudo code ranging is shown in Figure 1:

Figure 1. Schematic diagram of pseudo code ranging.
The pseudo code ranging in the bidirectional time synchronization system can be summarized: Let \( s(t) \) be pseudo code sequence of terminal A emission. The terminal B receive the propagation delay \( \tau \) at the time of \( t \). Meanwhile, terminal B code generator generates a local code \( s(t + \delta t) \) with the same structure of \( s(t) \) under the control of the local clock. \( \delta t \) is the clock difference between two ranging terminals. Then shift the local code through the shift \( \tau' \), then get \( s(t + \delta t - \tau') \). And send it to the correlator associated with the signal operation. Finally, through the integrator, output can be expressed as:

\[
R(\Delta \tau) = \int s(t - \tau)s(t + \delta t - \tau')dt
\]

where, \( \Delta \tau = (t + \delta t - \tau') - (t - \tau) \).

Using the basic equation of pseudo code ranging:

\[
\rho = R + c\delta t
\]

Get the distance between nodes.

There are many errors in the phase delay in the pseudo code ranging, which leads to the low precision of the pseudo code.

**The Principle of Two-Way Ranging Based on Carrier Phase**

Carrier phase observation and measurement is method for determining the pseudo range by measuring the phase change of the carrier signal in the propagation path. Usually the frequency of the transmitted carrier ranging signal is very high, then the carrier phase will have a higher resolution. Therefore, in the process of carrier phase measurement by calculating the carrier phase difference, we can get the high accuracy of the range\(^2\).

Figure 2. Schematic diagram of carrier phase.

Pseudo code measurement is the basis of carrier phase measurement, for the realization of carrier phase measurement, should be carried out on the pseudo random code delay lock, so as to achieve the tracking of the pseudo code signal. When the tracking is successful, the PLL phase lock, lock after the success, through the follow-up of carrier phase, the number of the whole cycle of carrier phase change automatic counting, after any observation time \( t \), the difference can be expressed as:

\[
\varphi'(t) = \delta \varphi'(t) + N'_i(t - t_o) + N'_i(t_o)
\]

where, \( N'_i(t_o) \) is the initial epoch ambiguity, after the success of the signal is locked, it becomes a constant of \( N'_i(t - t_o) \); \( N'_i(t - t_o) \) is carrier phase integer between initial observation time \( t_o \) and follow-up observation time \( t \), determined by the automatic counting of the receiver; \( \varphi'(t) \) is actual observed value at the time of observation \( t \).

Because the carrier frequency is higher, the carrier phase ranging method has a high precision, but it also has some defects. Usually we need to measure the distance is far greater than the carrier wavelength, because the carrier is no sign of a sine wave, can produce ambiguity problem, which restricts the application of carrier phase ranging method in practice.
Carrier Phase Smoothing Pseudo Range

Basic Principles

Carrier phase smoothing pseudo range is a kind of high precision ranging method which combines the advantages of pseudo code ranging and carrier phase ranging. In the system of two-way ranging and time synchronization measurement, the pseudo code and carrier phase are used to measure the distance [3].

The receiver of the ranging terminal can simultaneously carry out the pseudo code ranging and the carrier phase ranging, and their measurement equations can be expressed as:

\[ \rho = R + \epsilon_{\rho} \]  
(4)

\[ \lambda(\phi + N) = R + \epsilon_{\phi} \]  
(5)

here, \( \rho \) is the range value of the measurement of the ranging terminal, \( R \) is the real distance between the ranging terminals, \( \epsilon_{\rho} \) is error terms in the pseudo code ranging, \( \lambda \) is carrier wave length, \( \phi \) is carrier phase, \( N \) is integer ambiguity of carrier phase measurement, \( \epsilon_{\phi} \) is the error term in the process of carrier phase measurement. Can be obtained by the above two type:

\[ \rho - \epsilon_{\rho} = \lambda(\phi + N) - \epsilon_{\phi} \]  
(6)

The hypothesis has been observed for \( n \) times. The equation can be expressed by the following formula:

\[ \rho_{11} = \lambda(\phi_{11} + N) \]  
(7)

\[ \rho_{12} = \lambda(\phi_{12} + N) \]  
(8)

\[ \rho_{m} = \lambda(\phi_{m} + N) \]  
(9)

The following relationship can be obtained by adding \( n \) times above the measurement equation and transposition:

\[ \lambda N = \frac{1}{n} \sum_{k=1}^{n} (\rho_{k} - \lambda \phi_{k}) \]  
(10)

The formula (10) is introduced into the formula (9), then the obtained is the carrier phase smoothed pseudo range, can be expressed as:

\[ \bar{\rho}_{m} = \lambda \phi_{m} + \frac{1}{n} \sum_{k=1}^{n} (\rho_{k} - \lambda \phi_{k}) \]  
(11)

For formula (11), consider the relationship between \( \delta_{\rho} \) and \( \epsilon_{\rho} \) and \( \epsilon_{\phi} \). The random error of the carrier phase measurement is much smaller than that of the pseudo code ranging, that is \( \epsilon_{\phi} \ll \epsilon_{\rho} \). According to the error transfer theorem, we can get the following relations because of the error of the pseudo code observation and the phase observation:

\[ \delta_{\rho}^{2} = \epsilon_{\phi}^{2} + \frac{1}{n}(\epsilon_{\rho}^{2} + \epsilon_{\phi}^{2}) \approx \frac{1}{n} \epsilon_{\rho}^{2} \]  
(12)

By the formula (12) can be seen, after smoothing operation was repeated \( n \) times, \( 1/\sqrt{n} \) smoothed ranging error is reduced to approximately the original pseudo-code ranging error of measurement, that
is, the smoothed carrier phase measurements, the random error code phase measurements has been effectively suppressed \[4\]. \(n\) is called smooth length.

**Simulation**

After the above carrier phase smoothing pseudo-range principle analysis, we know that the carrier phase smoothing pseudo-range principle, is the use of highly accurate carrier phase measurements as an auxiliary, multi-point sampling and filtering, the average of the measured values of the pseudo-code most random error, thereby improving the accuracy of the pseudo-range observation \[5\].

**Static Algorithm Simulation Node.** For two static node, the distance between them does not change because of the impact that the delay range accuracy of transmission channel noise, and sending and receiving devices. The simulation conditions are as follows, provided two nodes separated by 100m, access code rate of 5MHz, the pseudo-code ranging error is 5m, distance carrier phase error is 0.4m. According to the above conditions simulation design simulation, set random errors obey a normal distribution with zero mean, simulation results shown in Figure 3, in order to facilitate comparison, as shown in the figure before and after smoothing the measured pseudo-range values and the real value difference.

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![Comparison of pseudo-range error before and after smoothing](image)

Figure 3. Pseudo-values before and after smoothing away.

Figure 3 shows the smoothed pseudo-distance measurement has been significantly improved, very close to the true value.

Two-way time synchronization system to improve the accuracy of the system also need to meet real-time requirements, therefore need to analyze the relationship between precision and smooth frequency. Simulation experiments were carried out smoothly number \(M \leq 5\), \(M = 10\), \(M = 50\), \(M = 100\), \(M = 150\), \(M = 200\), \(M = 250\) and \(M = 300\) pseudo before and after smoothing the distance value comparison, smooth and draw the corresponding number of times the standard deviation, the comparative analysis of the results shown in Table 1.

<table>
<thead>
<tr>
<th>Smoothing times</th>
<th>Pseudo Range Real Value</th>
<th>Carrier-smoothed Pseudo Range Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Value</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>M=5</td>
<td>1.2874</td>
<td>1.2169</td>
</tr>
<tr>
<td>M=10</td>
<td>1.2169</td>
<td>1.1382</td>
</tr>
<tr>
<td>M=50</td>
<td>1.1382</td>
<td>1.0608</td>
</tr>
<tr>
<td>M=100</td>
<td>1.0608</td>
<td>0.9937</td>
</tr>
<tr>
<td>M=150</td>
<td>0.9937</td>
<td>0.9628</td>
</tr>
<tr>
<td>M=200</td>
<td>0.9628</td>
<td>0.9479</td>
</tr>
<tr>
<td>M=250</td>
<td>0.9479</td>
<td></td>
</tr>
<tr>
<td>M=300</td>
<td>0.9389</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Relationship between smoothing times and ranging accuracy.

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From the data in Figure 1, we can know that the pseudo range error of the carrier phase smoothing is decreasing with the increase of the smoothing times M. After smoothing, the value of the pseudo range error has been reduced from the original 1.3652 to 0.9389, which has been reduced to Figure 3 shows the results of the M=250 to select the pseudo range for smoothing.

**Dynamic Algorithm Simulation Node.** For dynamic node, the error not only from the transmission channel and device latency. Doppler shift his influence cannot be ignored. Given simulation conditions, assuming two synchronization nodes spaced 100m, and to a certain relative velocity separation system selected code rate of 5MHz, the pseudo-code ranging error is 5m, distance carrier phase error is 0.4m. Obtained in Figures 4 and 5, the carrier phase smoothing pseudo distance before and after comparison chart.

![Comparison chart](image1.png) ![Comparison chart (zoom)](image2.png)

Figures 4 and 5 is shown one example of the use of the data before and after smoothing pseudo-range. In order to more clearly see the effect of smoothed, Figure 5 is taken from Figure 4 piece of data. As can be seen from the figure, the pseudo distance difference between the smoothed pseudo distance difference compared to before smoothing, has been greatly improved. Using the same set of data is repeated 300 times carrier phase smoothing, were calculated for each time simulation of pseudo-range error, and its fitting process, obtained a smooth relationship between the frequency and the pseudo-range error, as Figure 6:

![Pseudo range error of dynamic node](image3.png)

Simulation results show that the carrier smoothed pseud-orange can indeed be more accurate than the pseudo-code ranging pseudo-range value. But in addition to the effect of smoothing frequency carrier phase smoothing pseudo-range determinant or determinants of a smooth time. In other words, M values greater the longer the corresponding smoothing time, the harder it is to meet the system's real-time requirements. Therefore, in practice, we have to be trade-offs between the real-time requirements and the effect of smoothing system, finding the most appropriate carrier phase smoothing smoothing length.
Conclusion

In this paper, the carrier phase smoothing pseudo introduced from this approach, the use of Matlab simulation. The method proved Carrier phase smoothed pseudo-range under the premise of the system to meet the real-time, it did improve ranging accuracy.

This is also to improve the timing accuracy of distributed systems provide a new way of thinking, when the master node for signal transmission from the carrier using the system itself transmit signals to the pseudo-code ranging smoothed to obtain more accurate pseudo-range values by this increase timing accuracy, worthy of further study.

References


