A DOR Signal Correlation Processing Method

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Abstract We research a correlation processing method suitable for the DOR signals. First, we preprocess the raw data to achieve the Doppler dynamic information of the received signal. Then we generate a signal, which has a similar frequency on board locally, and utilize the signal to do correlation processing with the raw data. The local generated signal phase model is adjusted continuously by using the Doppler dynamic information from preprocessing; it eliminates the frequency dynamic changes caused by the relative motion of the spacecraft and the earth. Finally, we processes the different channel DOR signal differential phase with Bandwidth Synthesis and calculate the final DOR delay. This method was utilized in CE3 interferometry test data correlation processing; the residual delay is relatively stable and verifies the correctness of this method.

Keywords DOR Signal, local correlation, Doppler dynamic

1 Introduction

The conventional interferometry data processing algorithm for each observation station makes integer bit delay compensation, fringe stop, Fourier transform, fraction bit delay compensation, multiply accumulation, and so on [1, 2, 3]. This method is quite practical for broadband continuous spectrum signal. The spacecraft DOR signals are point-frequency signals, which have a few MHz interval with each other. Processing the DOR signals with the conventional FX correlation method requires a very high spectral resolution to achieve a sufficient SNR and accuracy, and most of the output data are noise data, so the accuracy is relatively low [4].

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2 DOR Signal Processing Algorithm

2.1 Local Correlation Algorithm

References [4] and [5] provide a complete description of the DOR signal local correlation algorithm.

Assume that the one-way light time signal from the spacecraft to Station 1 is p_1 and to Station 2 is p_2. Then the relation of the transmission times t_1 and t_2 with the reception time t is:

$$t_1 = t - p_1 \tag{1}$$

$$t_2 = t - p_2 \tag{2}$$

Assume the spacecraft DOR signal expression at transmission time to be:

$$s_i(t) = e^{j(2\pi f_i t + \Phi_{oi})}$$

,

where f_i is the DOR signal frequency, Φ_{oi} is the original phase of the DOR signals, so that the received signals to the two stations are expressed respectively:

$$s_{rec1}(t) = e^{j(2\pi f_i (t-p_1) + \Phi_{o1})} \tag{3}$$

$$s_{rec2}(t) = e^{j(2\pi f_i (t-p_2) + \Phi_{o2})} \tag{4}$$

The spacecraft transmits a radio-frequency signal, but the stations receive a baseband signal after down-

conversion, and add the equipment phase delay and the clock delay. The two stations record actual signals that may be expressed as:

$$s_{rec1-f_i}(t) = e^{j(2\pi(f_i-f_{0i})t-2\pi f_i p_1+\Phi_{o1}+\Phi_{1i})} \quad (5)$$

$$s_{rec2-f_i}(t) = e^{j(2\pi(f_i-f_{0i})(t-\Delta\tau_c)-2\pi f_i p_2+\Phi_{o2}+\Phi_{2i})} \quad (6)$$

f_{0i} is the sky-frequency. $\Delta\tau_c$ is the clock error of two stations. Φ_{1i} and Φ_{2i} are the signal phase delays through the two stations.

The noiseless local model signals of the two stations are expressed as:

$$s_{mod1-f_i}(t) = e^{j(2\pi(f_i^m-f_{0i})t-2\pi f_i^m p_1^m)} \quad (7)$$

$$s_{mod2-f_i}(t) = e^{j(2\pi(f_i^m-f_{0i})(t-\Delta\tau_c)-2\pi f_i^m p_2^m)} \quad (8)$$

f_i^m is the estimated transmitting frequency of the spacecraft signal. p_1^m and p_2^m are the delay models of the received signal.

The DOR signal real frequency of Station 1 can be obtained from test data. Then the transmitting frequency of the spacecraft signal can be estimated.

The playback data of the station can be cross-correlated with the local noiseless model signal giving the two point-frequency signal correlation phase of Station 1 expressed as:

$$\varphi_{cor1}^i = 2\pi(f_i - f_i^m)t - 2\pi f_i(p_1 - p_1^m) + \varphi_{o1} + \varphi_{1i}$$

Without considering the impact of the initial phase noise introduced by phase noise and instrument, so:

$$\varphi_{cor1}^i = 2\pi(f_i - f_i^m)t - 2\pi f_i(p_1 - p_1^m)$$

Similarly, the correlation phase of the two point-frequency of the two stations can be expressed as:

$$\varphi_{cor2}^i = 2\pi(f_i - f_i^m)t - 2\pi f_i(p_2 - p_2^m)$$

The difference phase of the two stations corresponds to the transmitting frequencies f_1 and f_2 and can be expressed as:

$$\varphi_{dif}^{f_1} = 2\pi f_1(p_2 - p_1) + 2\pi f_1(p_1^m - p_2^m) \quad (9)$$

$$\varphi_{dif}^{f_2} = 2\pi f_2(p_2 - p_1) + 2\pi f_2(p_1^m - p_2^m) \quad (10)$$

Differencing Equations 9 and 10 gives the DOR delay:

$$p_2 - p_1 = \frac{\varphi_{dif}^{f_1} - \varphi_{dif}^{f_2}}{2\pi(f_1 - f_2)} - (p_1^m - p_2^m)$$

2.2 Frequency and Phase Correction Based on Polynomial Fitting

During the data processing, the residual frequency has much Doppler influence because of the error between the delay model and the real propagation delay and the error between the estimated transmitting frequency and the real transmitting frequency. To obtain the final DOR delay we have to correct the frequency and phase of the dynamic variation.

The correlation residual frequency of the actual signal and the local signal is $f_{res}(t)$ and the residual phase is $\phi_{res}(t)$. Then $f_{res}(t)$ can be expressed through an N-order polynomial fitting :

$$f_{res}(t) = \sum_{i=0}^{N} a_i \cdot t^i$$

Then the residual phase is:

$$\phi_{res}(t) = 2\pi \cdot \int f_{res}(t)dt = 2\pi \cdot \sum_{i=0}^{N} (\frac{a_i \cdot t^{i+1}}{i+1} + \phi_0)$$

,

where ϕ_0 is a constant. There are two steps to correct the local model signal based on the polynomial fitting of the residual phase:

(1) Obtain the single station residual phase correction term by fitting a polynomial to the residual frequency, and correct the phase of the local signal to let the residual frequency in several Hz after the correlation of the raw signal and the corrected local model signal.

(2) Based on Step 1, cross-correlate the results of the two raw data and local signal, extract the phase of the tone, fit a polynomial to the phase variation, and correct it in the phase model of Station 2 to make the residual frequency equal for the two stations.

3 Measured Data Processing and Analysis

We processed the Station A and B data of the CE3 mission. The measured data is in six channels, quantized

in 8-bit with a bandwidth of 200 kHz. The duration is 300 s. The third channel is the main carrier signal; the first, second, fifth, and sixth channels are the DOR signal. The fourth channel is the ranging tone. The frequency spectrogram is shown in Figure 1 and Figure 2.

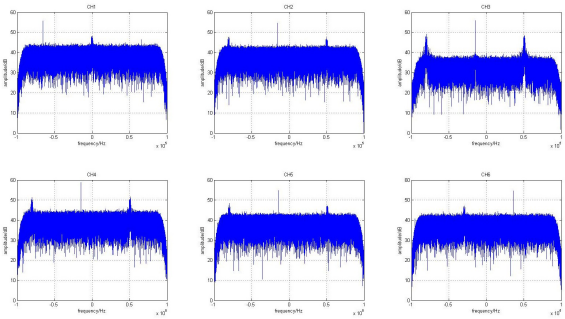

Fig. 1 Frequency spectrogram for Station A.

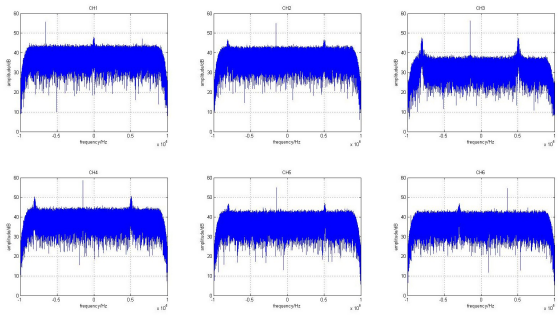

Fig. 2 Frequency spectrogram for Station B.

Cross-correlating the recorded raw data and the local model signal resulted in the DOR signal residual frequency variation shown in Figure 3. Then we fit a polynomial to the residual frequency and corrected the residual phase to the local model signal. The corrected residual frequency of each channel is shown in Figure 4.

The residual frequency variation decreases in 300 s, the maximum variation is about 1.5 Hz. The tiny fluctuation is caused by the instability of the oscillator on board. The variations of Station A and B are similar; this is consistent with the expected result. The difference residual phase of corresponding channel is shown in Figure 5. The difference residual phase variation tendency of each channel is steady and similar, the difference residual phase of 20-s accumulation is shown in Figure 6.

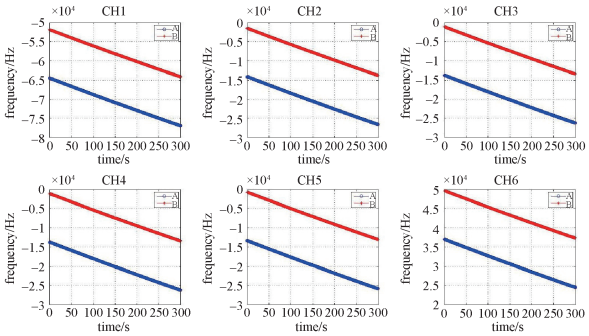

Fig. 3 Residual frequency dynamic variation of Station A and B.

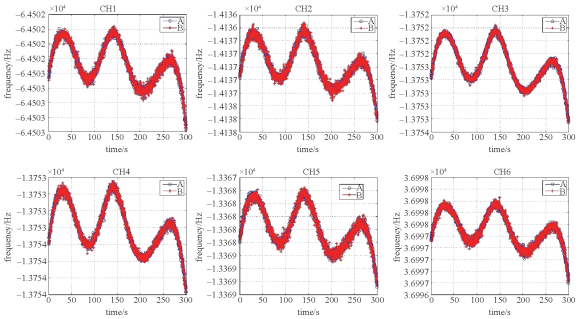

Fig. 4 Residual frequency dynamic variation of Station A and B after polynomial fitting correction.

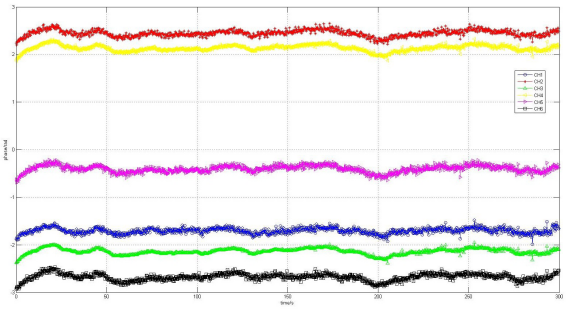

Fig. 5 Difference residual phase.

The variation tendency of difference residual phase decreases via accumulation. The average residual delay is 1090.625 ns, the mean square error is 0.127 ns. The big residual delay (about $1\mu s$) is due to the inaccuracy of the initial delay model. However, the stability of the residual delay verifies the correctness of the algorithm.

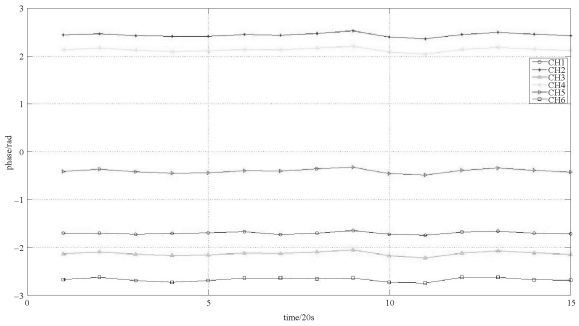

Fig. 6 Difference residual phase via accumulation.

4 Conclusions

The polynomial fitting method is utilized to correct the local signal model and eliminate the residual frequency dynamic variation and the frequency error of corresponding channels. We can compare the results with the spacecraft precise orbit subsequent for further comparative analysis.

References

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