文章编号:2095-6134(2015)06-0803-04

An algorithm for CAPS signal acquisition and synthesis with dual-linear polarized antennas*

GAN Tong[1], WANG Xiaolan[2,3], MA Guanyi[2]

(1 *Research Institute for Sustainable Humanosphere*, *Kyoto University*, *Kyoto* 606 - 8501, *Japan*; 2 *National Astronomical Observatories*, *Chinese Academy of Sciences*, *Beijing* 100012, *China*; 3 *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*)

(Received 27 November 2014; Revised 13 May 2015)

Gan T, Wang X L, Ma G Y. An algorithm for CAPS signal acquisition and synthesis with dual - linear polarized antennas[J]. Journal of University of Chinese Academy of Sciences, 2015,32(6):803-806.

Abstract A polarization loss of 3 dB is caused by circular polarized antenna when receiving the linear polarized signal in China area positioning system (CAPS). This work proposes to use dual-linear polarized antenna to receive CAPS signal and accordingly develops a signal acquisition and synthesis algorithm. The algorithm first performs signal acquisition with the dual-linear polarization antenna channels. According to the acquisition results the algorithm then synchronizes the signals. After the synchronization, it sums the signals from the two channels using the maximal-SNR (signal-to-noise ratio) combination. The algorithm is verified by its application to an experimental receiver. By analyzing the CAPS data acquired by the experimental receiver, it is found that the SNR of the synthesized signal increases by about 1.5 dB over the one-channel signals.

Key words CAPS system; dual-linear polarized antennas; signal acquisition; signal synthesis; SNR

CLC number: TN967.1 **Document code**: A **doi**: 10.7523/j.issn.2095-6134.2015.06.012

双线性极化天线的 CAPS 信号合成捕获算法

甘 彤[1], 王晓岚[2,3], 马冠一[2]

(1 京都大学生存圈研究所, 京都 606 - 8501; 2 中国科学院国家天文台, 北京 100012; 3 中国科学院大学, 北京 100049)

摘 要 针对中国区域定位系统(China area positioning system,CAPS)接收机采用圆极化天线接收极化信号时会引入 3 dB 的极化损失问题,提出一种基于双线性极化天线的信号合成捕获算法.该算法先对双线性极化天线接收的两路 CAPS 导航信号进行捕获,并根据捕获结果进行信号同步;进而利用最大信噪比合并来合成两路信号,从而提高接收信号的信噪比.通过实测数据分析表明,该算法得到的合成信号的信噪比比单路信号得到的信噪比增加 1.5dB,提高了信号接收的灵敏度.

关键词 CAPS 系统; 双极性极化天线; 信号捕获; 信号合成; 信噪比

* Supported by the Key Research Programs of Chinese Academy of Sciences (KGFZD-125-14-005-2, KJCX2-EW-J01) and the Knowledge Innovation Program of Chinese Academy of Sciences (KGCX2-EW-407-1)

CAPS is a regional satellite navigation system. Its space segment consists of commercial geostationary (GEO) communication satellites and inclined geosynchronous orbit (IGSO) communication satellites. It is different from the general global navigation satellite system (GNSS) in that its navigation message are generated on the ground and uploaded to the communication satellites with the satellites transferring the message to the ground[1-2].

Because communication satellites are used as navigation satellites in CAPS, the polarization of the navigation signal is the same as that of the satellite transponders, which include horizontally polarized antennas and vertically polarized antennas. So with circular polarization antennas CAPS receivers can receive both horizontally polarized and vertically polarized signals. However, this will introduce a polarization loss of 3 dB[3]. This paper proposes to use dual-linear polarization antennas to receive signals individually and develops a signal synthesis and acquisition algorithm to reduce the polarization loss. The algorithm uses the maximal-SNR combining to improve the signal to noise ratio of the synthesized signal.

1 Algorithm

1.1 Polarization angle

Using E to express the signal field strength, the component of signal coupled to the horizontally polarized antenna S1 is

$$E_{\parallel} = E\cos\alpha \boldsymbol{x}, \tag{1}$$

where α is the polarization angle which is the angle between the antenna polarization and the electric field of the signal. $\boldsymbol{x}$ is the unit vector in horizontal direction.

The component of signal coupled to the vertically polarized antenna S2 is

$$E_{\perp} = E\sin\alpha \boldsymbol{y}, \tag{2}$$

where $\boldsymbol{y}$ is the unit vector in vertical direction.

With dual-linear polarized antenna, a polarization loss will be introduced because of the polarization angle α. The maximal-SNR combining of synthesized signal can be used to reduce the polarization loss[4].

1.2 Maximal-SNR combination of synthesized signals

For the two signals received with the dual-linear polarized antenna, we have

$$x_i(k) = A_i\cos(2\pi f + \phi_i) + n_i(k),\ i = 1,2, \tag{3}$$

where $x_i(k)$, related to the signal of i channel, $i = 1$ for horizontal polarized antenna, $i = 2$ for vertical polarized antenna. A_i is the amplitude of signal i channel, $A_1 = A\cos\alpha$, $A_2 = A\sin\alpha$, A is the signal amplitude. f is carrier frequency. φ_i is the phase of i channel. $n_i(k)$ is white Gaussian noise of received, the variance of it is σ_i^2, and the white Gaussian noise of any channel is uncorrelated[5]. Define $\boldsymbol{W} = [\omega_1, \omega_2]^{\mathrm{T}}$ to be the maximal ratio combining weight, the synthesized signal[6] can be expressed as the following

$$z(k) = \boldsymbol{W}^{\mathrm{T}}\boldsymbol{x} = \omega_1 A_1\cos(2\pi f + \phi_1) + \omega_2 A_2\cos(2\pi f + \phi_2) + \omega_1 n_1(k) + \omega_2 n_2(k) = s_c(k) + n_c(k), \tag{4}$$

where $s_c(k)$, related to signal of weighted. $n_c(k)$ is the noise of weighted.

According to Cauchy-Schwarz inequality[5], the maximal-SNR combining of synthesized signal is

$$\mathrm{SNR}_{c\max} = \frac{A_1^2}{\sigma_1^2} + \frac{A_2^2}{\sigma_2^2}. \tag{5}$$

The increase SNR of the synthesized signal is $10\lg\left[\frac{\sigma_1^2 A_2^2 + \sigma_2^2 A_1^2}{A_1^2\sigma_2^2}\right]$ dB and $10\lg\left[\frac{\sigma_1^2 A_2^2 + \sigma_2^2 A_1^2}{A_2^2\sigma_1^2}\right]$ dB corresponding to the two antenna channels, respectively.

1.3 Implementation steps

Figure 1 shows the dual-linear polarization antenna system of CAPS[7-9], the acquisition algorithm of implementation steps as the following

a) Acquire signals of two channels using the acquisition algorithm of parallel code phase search.

b) Calculate the best weights of maximal-SNR combining of synthesized signal when both signals are acquired, and multiply by a synchronization signal which generated by the code phase delay, then put into the adding device to complete the maximal-SNR combining of synthesized signal.

c) Export the result of acquisition, using the acquisition algorithm of parallel code phase search.

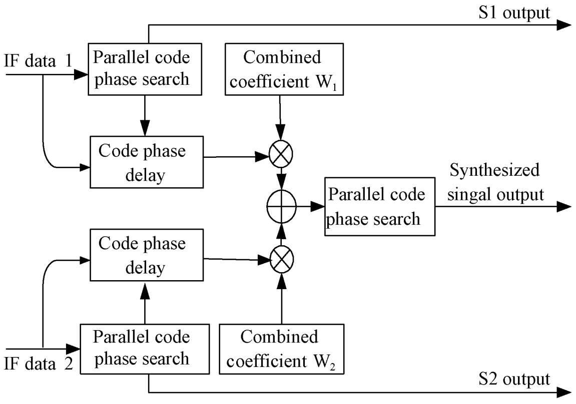

Fig. 1　Algorithm for signal synthesis and acquisition of CAPS

2　Results of the application to CAPS receiver

In order to demonstrate the performance of the algorithm, dual-linear polarized antenna and two down-converters are implemented to a CAPS receiver. An Adlink acquisition card PCI-9820 is used to collect the data. The navigation messages adopts transmission rate of 50 bps, code rate of 10.23 MHz, the code length of 10 230, the code period of 1 ms, and carrier frequency is 3 826.15 MHz. Both down-converters use the same clock reference which is provided by a temperature-compensation Crystal Oscillator (TCXO). The intermediate frequency (IF) signal is 20.46 MHz. The sampling rate of acquisition card PCI-9820 is 60 MHz and continuous sampling time is 20 ms. So for the code period of 1 ms there are 60 000 sampling points. The acquisition use a length of 9 ms data to carry out 1 ms coherent integration and nine incoherent integration, the frequency step and search frequency range are 500 Hz and ±7 KHz, respectively. The algorithm is realized in MATLAB.

Figure 2 shows individual acquisition results from S1 and S2 channel signals. The SNR from the horizontal polarized antenna is 18.425 2 dB, the correlation peak is located at frequency offset of 0 Hz and sampling point of 28 636 (corresponding to 4 882 code phase). The SNR from the vertical polarized antenna is 18.993 2 dB, the correlation peak is located at frequency offset of 0 Hz and sampling point of 28 637 (corresponding to 4 883 code phase).

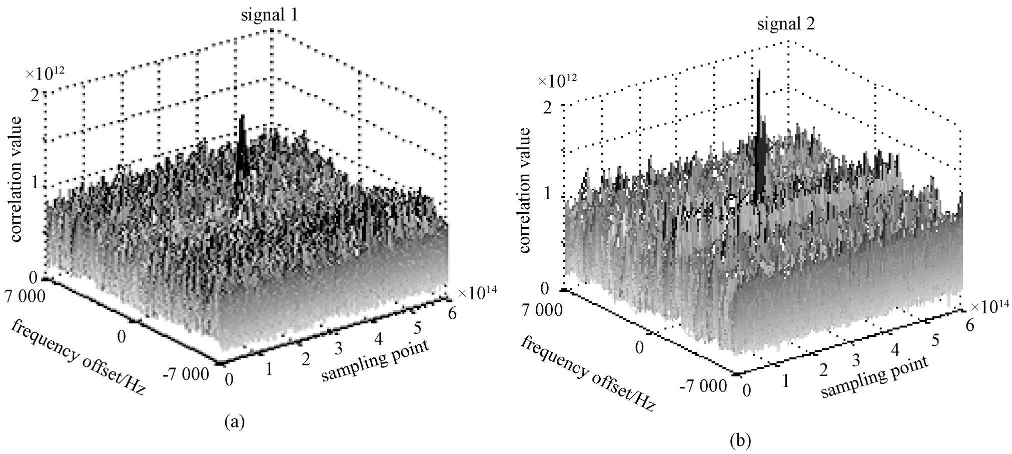

Fig. 2　Certain acquisition results of one-channel signal

Figure 3 shows the acquisition result of synthesized signal. The SNR from the vertical polarized antenna is 20.525 3 dB, the correlation peak is located at frequency offset of 0 Hz and sampling point of 28 636 (corresponding to 4 882 code phase). Compared to the result from the single antenna, we can find that correlation peak value is larger and its noise is smaller. The SNR of synthesized signal is improved and the noise is restrained by using maximal-SNR combining of synthesized signal.

Figure 4 shows the SNR of 11 groups of

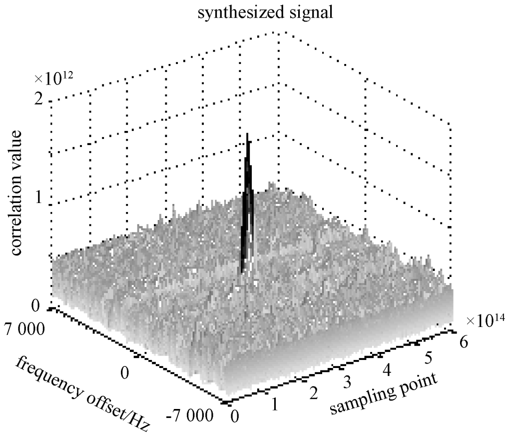

Fig. 3 Certain acquisition results of synthesized signal

different data with the same polarization angle. The SNR of S2 signal is always greater than channel 1 signal. Therefore the synthesized weights ω_2 is bigger than ω_1, which means channel 2 signal contributes more to the synthesized signal. Meanwhile, the SNR of synthesized signal is obviously larger than that from single channel signal, and the difference between them is from 1.458 8 dB to 1.630 0 dB, its average is about 1.5 dB. By analyzing the measured

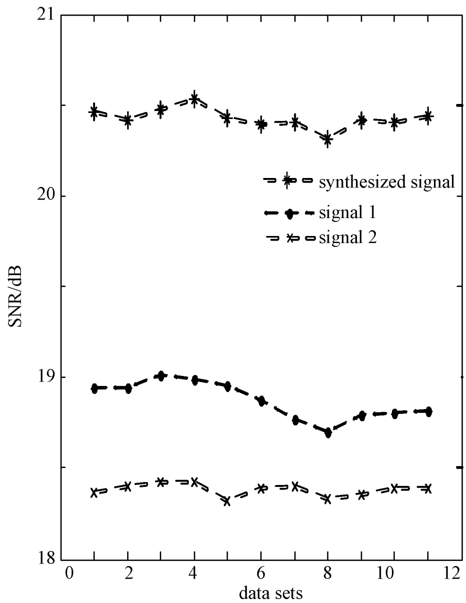

Fig. 4 SNRs of one-channel signal and the synthesized signal

data show that the measured results accord with theoretical analysis.

3 Summary

The proposed acquisition and synthesize algorithm uses two linear polarization antennas to receive signals individually and synthesize the signals by maximal-SNR combining to reduce the polarization loss. The algorithm improves the SNR of the synthesized signal effectively. By analyzing the data acquired by the experimental receiver, the SNR of the synthesized signal increases about 1.5 dB over the one-channel signals.

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