Optik 127 (2016) 1607–1614

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A simultaneous multiple BeiDou signal acquisition algorithm for a software-based GNSS receiver

Fei Xie [a,*], Jianye Liu [a], Rongbing Li [a], Shaojun Feng [b]

[a] Navigation Research Center, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
[b] Department of Civil and Environmental Engineering, Imperial College London, London, UK

ARTICLE INFO

Article history:
Received 18 March 2015
Accepted 3 November 2015

Keywords:
Signal processing
Software receiver
BeiDou navigation
Acquisition algorithm
Code generation

ABSTRACT

The time needed for a Global Navigation Satellite System (GNSS) receiver to acquire satellite signals is one of the key parameters to assess the performance of a receiver. This presents a challenge for a software receiver in which more frequency bins and satellite codes are required to search using conventional methods. In order to speed up the acquisition process of the BeiDou software receiver in a cold start, this paper proposes a simultaneous multiple Code Division Multiple Access (CDMA) signal acquisition algorithm. The time for searching satellites is reduced by constructing new local codes to enable the capability of detecting the presence of multiple BeiDou satellites. Besides, the individual phase identification approach for each visible satellite is further presented with multiple satellites acquisition. So a search within the PRNs used for the generation of local combined code is performed. Finally, the test results show that the proposed acquisition algorithm can effectively detect multiple BeiDou satellites simultaneously. In addition, the test results show that signal acquisition time can be reduced by 8.7% to 24.1% depending on different combination numbers and different numbers of visible satellites in the combination list.

1. Introduction

Global Positioning System (GPS) is one of the most successfully technique achievements. It can be found a lot of applications in many areas such as transport, mobile network synchronization and social networking. However, GPS signal is even weaker than thermal noise when it reaches the Earth surface. The other similar navigation systems including GLONASS, regional operational BeiDou and future operational Galileo have brought both opportunities and challenges for navigation system design, including GNSS/INS integrated system. The BeiDou navigation satellite system is independently built and operated by China, which will consist of 30 non-geostationary and 5 geostationary satellites (GEO). According to its overall planning schedule, the system is planned to be established completely and provide global service by 2020. Moreover, it is compatible with other global satellite navigation systems. As the 16th BeiDou satellite was launched on October 25, 2012, the system has provided regional Asia Pacific service since early year 2013, with a constellation of five satellites in geostationary orbit, five in inclined geostationary orbit (IGSO) and four in medium earth orbit (MEO). In the near future, BeiDou navigation satellite system will independently provide open services for global users, and particularly provide high quality services in Asia Pacific region.

BeiDou software receiver provides full access to base band signals processing based on intermediate frequency (IF) signal inside the receiver channels. The first critical stage is the acquisition block that aims to determine visible satellites and phase/frequency of the received signals. The acquisition stage usually needs to perform a correlation operation between the input samples and locally generated replicas of the signals transmitted by the different satellites. In a hardware receiver, the correlation of acquisition algorithm is usually completed in an application-specific integrated circuit (ASIC), and the serial search acquisition (SSA) is an often-used method which scans all the bins in the code phase and carrier frequency [1]. However, all possible values of the code phase and frequency scanning showed that the serial search acquisition method is a very time-consuming procedure in a software receiver. In order to reduce the computational load, the frequency-domain acquisition methods usually exploit a Discrete Fourier Transform (DFT) or a Fast Fourier Transform (FFT) conversion to implement the correlation operation in the frequency domain [2–4].

To improve the sensitivity of acquisition results, several different techniques, such as non-coherent, coherent and the differentially coherent have been proposed for the acquisition of CDMA

* Corresponding author at: 78 Bancang Street, Nanjing, Jiangsu Province 210042, China.
E-mail address: xiefei@njnu.edu.cn (F. Xie).

http://dx.doi.org/10.1016/j.ijleo.2015.11.071
0030-4026/

signals [5–11]. Besides, expressions for the false alarm and detection probabilities of acquisition have been analyzed [12,13]. In particular, coherent combing is the optimal processing strategy that provides the highest acquisition sensitivity at the expenses of an increased computational load since non-coherent combing suffers from squaring loss compared to coherent combing [14]. However, the effect of navigation data bit transitions has to be considered when choosing the length of coherent integration time. To eliminate the impact of Doppler frequency, the GPS signal acquisition aided by SINS was proposed for the acquisition of weak signals [15]. However, these researches mainly focus on one satellite or treat multiple satellites acquisition individually.

In order to reduce the search time of signals acquisition in cold start period of receiver, a fast acquisition algorithm capable of acquiring multiple BeiDou satellites' signals simultaneously has been proposed. The fast acquisition is based on parallel phase acquisition approach which can search all the code phase bins simultaneously. Consequently, the search space is reduced from three domains to two domains (PRN and Doppler frequency). The proposed simultaneous multiple satellites acquisition algorithm is achieved by the construction of new local codes which contain combinations of PRNs from different satellites. The new local codes are therefore used to perform correlation processing with the received signals. Upon the detection of the existence of PRNs, a further correlation with one of the code in each combination is carried out in order to identify the signal to be tracked. If the correlation of a new local code resulting no-existence of signals, all the satellite PRNs in this combination can be excluded at the same time. Therefore, the total searching time for non-visible satellites is reduced compared to the traditional parallel acquisition approach.

The rest of this paper is organized as follows. In Section 2 we briefly analyze the QPSK modulation for BeiDou B1 signal in order to lay the foundation for the generation of combined local codes, and then the simultaneous acquisition algorithm for multiple BeiDou satellites is proposed. In Section 3 the phase and frequency identification method for individual visible satellite is described. The computation complexities of different complexity algorithms are also analyzed theoretically. Section 4 shows the test results to demonstrate the capability and performance of the proposed algorithm before the paper is concluded in Section 5.

2. A simultaneous multiple BeiDou signal acquisition algorithm

2.1. Modulation analysis for BEIDOU signals

For different GNSS, a number of satellites transmit navigation signals in different modulations on a variety of different frequency bands. According to the BeiDou ICD for open service signal B1 and B2, the BeiDou satellites exploit the Quadrature Phase Shift Keying (QPSK) modulation to transit navigation signals on B1 and B2 frequency bands [16]. Unlike BPSK, QPSK sends two bits of digital information at a time, so the data transmitting rate with QPSK is doubled of that with BPSK. Only B1 signal is considered and studied in this paper. The QPSK modulated waveform is shown in Fig. 1.

The BeiDou B1 signal is the sum of component I (open) and Q (authorization) which are in phase quadrature of each other. The ranging code and navigation message are modulated on carrier. The modulation processing of BeiDou B1 signal can be seen in Fig. 2.

For BeiDou B1 navigation message that has a rate 50 bps, a secondary code of Neumann Hoffman (NH) code is modulated on ranging code. As shown in Fig. 3, the period of NH code is selected as long as the duration of a navigation message bit. According to the BeiDou ICD document, the B1 signal adopts the NH code with length of 20 bits, which the bit duration is 1 ms. It is modulated

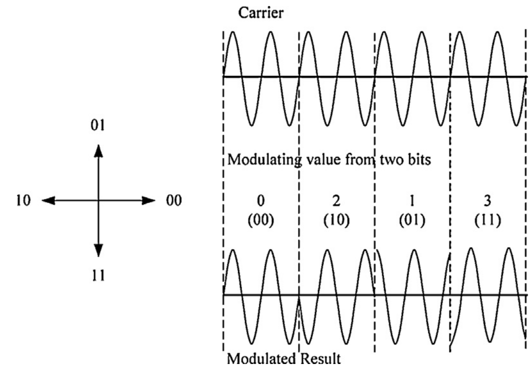

Fig. 1. Modulation waveform of QPSK.

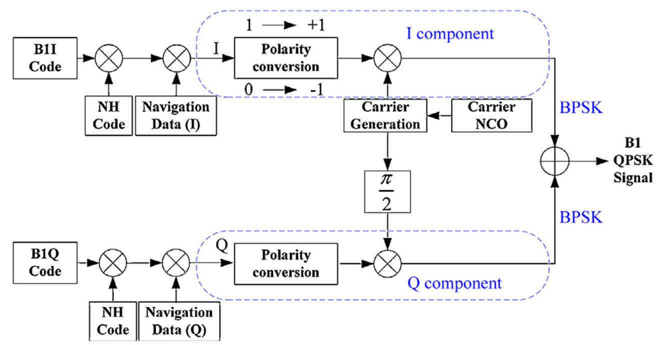

Fig. 2. Modulation processing of BeiDou B1 signal.

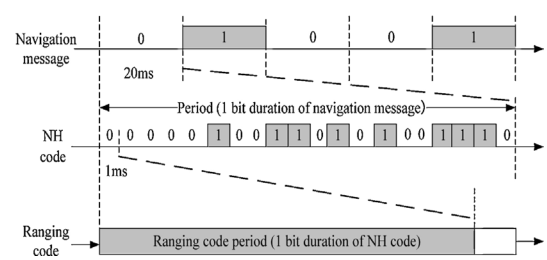

Fig. 3. The NH code period and structure.

on the ranging code synchronously with navigation data. In addition, the Neumann Hoffman (NH) code of BeiDou B1 signal can be removed in period of bit/frame synchronization.

According to the QPSK modulation principle, two navigation data bits are transmitted simultaneously with the BPSK modulation. One data bits produce the In-phase (I) component and the other data bits produce the Quadrature (Q) component. So the mathematical expression of a BeiDou B1 IF signal can be represented by:

$$S_k^j = A_C D_I^j(t) C_I^j(t-\tau_I)\cos[2\pi f_c t + \phi_I^j] + A_C D_Q^j(t) C_Q^j(t-\tau_Q)\sin[2\pi f_c t + \phi_Q^j] + n_{Cj} = S_I^j + S_Q^j + n_{Cj} \quad (1)$$

where A_c is amplitude of BeiDou B1 IF signal; $D_1(t)$ and $D_1(t)$ are the navigation data respectively modulated with the NH code in component I and Q; τ_I and τ_Q denotes the code chips corresponding with time delay of components I and Q respectively; f_c is the carrier frequency of BeiDou IF signals; ϕ_I, ϕ_Q are initial phase of IF carrier in components I and Q; n_{Cj} is received BeiDou IF signal noise.

Comparing with the GPS C/A code has a chipping rate of 1.024 Mbps and a length of 1023 chips, the BeiDou B1 ranging code has a chipping rate of 2.046 Mbps, and the length is 2046 chips. Since QPSK modulation consists of two BPSK modulations