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Direction-of-arrival (DOA) tracking using improved direction lock loop with real-time bias correction for antenna array based GNSS receivers

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Abstract

For the antenna array based Global Navigation Satellite Systems (GNSS) receivers on a moving platform, the direction lock loop is a simple and effective method to achieve direction-of-arrival (DOA) tracking of GNSS signals. However, the discriminators used in the direction lock loop will introduce a noticeable DOA tracking bias when the true DOA is not zero. To solve this problem, an improved direction lock loop with real-time bias correction, which is independent of antenna array parameters, is proposed to achieve an unbiased DOA tracking in this paper. Then, three discriminators including coherent real part method, non-coherent amplitude method and non-coherent power method, are theoretically discussed, and further compared in terms of the output curve, convergence range, gain, mean square error (MSE). Finally, several typical simulation scenarios are designed for verifying the proposed method in accordance with the effects of DOA tracking with and without bias correction. Simulation results show that the proposed method can effectively track the signal DOA and significantly decrease the DOA tracking bias under different scenarios.

Keywords: DOA tracking; Direction lock loop; Antenna array; GNSS

1. Introduction

GNSS has been widely applied in positioning, navigation and timing on various platforms (e.g., Jin et al., 2011, 2013, 2016a, 2016b). For antenna array based GNSS receivers on a moving platform, the steering vectors of incident signals are closely related to the attitude of the platform. It is necessary to keep adjusting the main beam to track the signal DOA while the attitude of the antenna array is changing. However, how to track the DOA of GNSS signals stably and effectively is a key problem in the practical engineering application.

DOA tracking can be achieved by solving the steering vector in real time when the attitude parameters of the platform are accurately obtained through external sensors (e.g., Wang et al., 2015; Daneshmand et al., 2014). Although this method can be easily implemented, the high precision attitude sensors are costly and susceptible to the environment parameters such as temperature, vibration, etc. Meanwhile, the measurement error of the sensors will accumulate during long time running, which will finally degrade the DOA tacking performance (e.g., Kozlov et al., 2015; Matič et al., 2015). In order to realize low cost and high reliability of DOA tracking, many methods based on array signal processing technology have been widely

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studied in recent years. These methods do not need any additional sensors and can be easily integrated and expanded. In (Chan and Litva, 1995; Reddy et al., 2015; Choi and Yoo, 2015), spatial spectrum estimation algorithms are developed to obtain the signal DOA in different scenarios. However, all these methods are computationally intensive, and it is difficult to balance the complexity and tracking accuracy in practical applications. In (Yang, 1995a, 1995b; Badeau et al., 2005; Doukopoulos and Moustakides, 2008), subspace tracking algorithms are proposed and improved for tracking the moving targets, but the convergence capability and numerical stability should be reviewed carefully. So far, fast and stable subspace tracking is still under improvement. Referring to the delay lock loop (DLL) for code tracking and phase lock loop (PLL) for carrier tracking which have been widely used in the baseband signal processing module for traditional GNSS receivers, direction lock loop was proposed for DOA tracking in (Min et al., 2002, 2004; Seo et al., 2002; Diab et al., 2007). Moreover, this method was further studied in (Nateghi and Komjani, 2007; Denic et al., 2007; Wang et al., 2011). However, all these above direction lock loop implements will introduce a noticeable DOA tracking bias when the true signal DOA is not zero. The biased discriminator leads to an inaccurate DOA tracking result and greatly decreases the practical value of this method. Therefore, an unbiased and robust method is desired for DOA tracking in practical applications.

Based on and beyond the existing work, we present an unbiased DOA tracking implementation using direction lock loop with real-time bias correction in this paper. The main advantages of this method can be summarized as follows. Firstly, the bias correction value is calculated in real time. Secondly, it is independent of the array platform parameter. Finally, it does not need any pre-calibration or initialization. Performance analysis and computer simulation are then carried out to verify the proposed method in detail. The rest of this paper is organized as follows. We first present the improved direction lock loop scheme with real-time bias correction in Section 2. Then, different discriminators for the proposed method are analyzed from the point of view of the effect of bias correction, discriminator gain, convergence range, and MSE in Section 3. Section 4 reports the simulation results, followed by conclusions in Section 5. Throughout this paper, we use $\boldsymbol{I}$, $Re[\cdot]$, $\mathrm{var}[\cdot]$, $\mathrm{j}=\sqrt{-1}$, $(\cdot)^*$, $(\cdot)^{\mathrm{T}}$, $(\cdot)^{\mathrm{H}}$ to denote identity matrix, real part operator, statistical variance operator, imaginary unit, complex conjugate, transpose, and Hermitian operator respectively.

2. Direction lock loop with bias correction

2.1. Signal model

In the traditional direction lock loop, the received data after dispreading by the local PRN code in each antenna element is spatially correlated with a right-shifted and a left-shifted array response, where the shift angle space is set to a constant value. Then the outputs of the spatial correlators are passed to the discriminator to calculate the current DOA tracking error. After smoothed by the loop filter, the DOA tracking value is updated and regarded as a new DOA estimation at next time, thereby forming a closed loop to realize DOA tracking.

When the signal DOA is not zero, the discriminator in the direction lock loop will have a biased output, which can induce a significant error in the DOA tracking result (e.g., Min et al., 2002, 2004). So it is essential to introduce the bias correction processing to the DOA tracking loop. As shown in Fig. 1, an improved direction lock loop for DOA tracking with real-time error correction is presented. Based on the original direction lock loop, a new pair of spatial correlators, which uses the steering vector of the current DOA estimation as the input data vector, is employed to calculate and compensate the DOA tracking bias, thus eventually reducing the DOA tracking bias.

Considering the pseudorandom noise (PRN) code adopted in GNSS signal has a good cross-correlation characteristic, the signal components of other satellites after dispreading in each antenna element can be ignored. When using a uniform linear array with N half-wavelength spaced

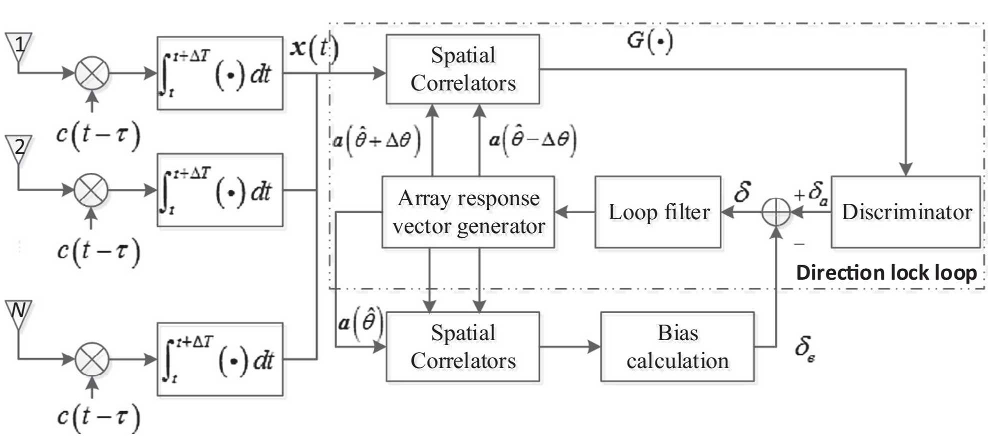

Fig. 1. Block diagram of DOA tracking using improved direction lock loop.

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