An open-source MATLAB package for BDS B2b software defined receiver

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Introduction

Global Navigation Satellite System (GNSS) Software-Defined Receiver (SDR) is a cost-effective and flexible alternative to commercial hardware receiver for a broader range of GNSS research and applications, such as precise positioning, anti-spoofing, and ionospheric sensing. GNSS SDRs are drawing increasing interests among the GNSS communities, and a large number of open-source GNSS SDRs have been made available, such as the GNSS-SDR and CU-GNSS-SDR. While the supported systems and signals vary from different open-source GNSS SDRs, together they contribute significantly to the development of new features and functionalities to meet the evolving user needs.

However, there are still a lack of support for the Chinese BeiDou Navigation Satellite System (BDS), which employs a versatile signal portfolio including the B1I, B1C, B2I, B2a, B2b, and B3I. For example, the GNSS-SDR only support BDS B1I, B2I, and B3I, while CU-GNSS-SDR supports BDS B1I, B1C, B2a, B3I, respectively. Introduced and disseminated by the third generation of BDS (BDS-3) satellites, the B2b signal, with a center frequency of 1207.14 MHz and a bandwidth of 20.46 MHz, provides both Radio Navigation Satellite System (RNSS) service as well as the Precise Point Positioning (PPP-B2b) service to users. Specifically, the RNSS service are provided by the B2b in-phase component (B2b-I) of the BDS-3 Medium Earth Orbit (MEO) and Inclined Geo-Synchronous Orbit (IGSO) satellites, while the PPP service are disseminated by the PPP-B2b in-phase component (PPP-B2b-I) of the BDS-3 Geostationary Earth Orbit (GEO) satellites to support decimeter-level precise positioning and timing. Considering its pivotal role in the whole BDS-3 service portfolio, it is essential to develop an open-source SDR to further promote BDS B2b research and applications.

We aim to bridge the gap by developing a MATLAB-based open-source SDR with comprehensive BDS B2b signal processing functionalities, including display, acquisition, tracking, telemetry decoding, and positioning. In addition, the decoded PPP-B2b corrections are applied to the broadcast navigation ephemeris, and the recovered precise ephemeris could be outputted to standard format for post-processing applications. In the following, we first provide an overview of the developed BDS-B2b SDR package from aspects of primary features and code architecture. Then, experiments are conducted to collected raw BDS B2b signals for performance assessment. Finally, the conclusions are provided.

Overview of BDS B2b SDR

The MATALB-based open-source BDS B2b SDR adopts the framework composed by Li et al. (2019) with new algorithms and modifications to accommodate the specific spreading modulations and navigation massage structures of B2b signals. The primary features of the developed BDS B2b SDR are listed as below:

- Raw signal datasets loading and visualization;
- Acquisition and tracking of B2b signals from BDS MEO/IGSO/GEO satellites;
- Decoding of both BDS B-CNAV3 and PPP-B2b State Space Representation (SSR) messages;
- Implementation of BeiDou Global Ionospheric delay correction Model (BDSGIM);

- Code-based positioning with broadcast navigation ephemeris or with PPP-B2b SSR ephemeris;
- Computation and output of PPP-B2b precise ephemeris to standard SP3 files;
- Supports for BeiDou Coordinate System (BDCS).

The BDS B2b SDR is developed according to the flowchart given in Fig. 1. The users could initialize the BDS B2b SDR package by calling the main interface function, which then reads various processing options and parameters. Several plots are made to visualize the raw signals in the time domain as well as the frequency domain via Power Spectral Density (PSD) plots. After that, the BDS B2b signal processing starts, which including the following major steps:

Step 1: Acquisition. The widely used parallel acquisition strategy is utilized. The correlation of the generated B2b local replica and the received signal is conducted on a satellite-to-satellite basis. The correlation outputs will be compared against the user-configured threshold to detect available satellites, and the obtained coarse estimates of code delay and Doppler frequency will be used in the tracking procedure.

Step 2: Tracking. The tracking loop is mainly composed of the Delay Lock Loop (DLL) and Phase Lock Loop (PLL), which are used to refine the coarse code delay and Doppler frequency estimates following the late-prompt-late structure. Meanwhile, the Carrier-to-Noise Density Ratio (C/N0) is also estimated to indicate the received signal quality. The obtained tracking results will be output for navigation message decoding and pseudorange measurement generation.

Step 3: Navigation. The pseudorange measurements, the satellite ephemeris, and ionospheric model parameters are decoded with the raw navigation bit from tracking, which are then combined to derive navigation solution using the Least-Squares Estimator (LSQ). Note that the user can configure the source of satellite ephemeris either from BCNAV-3 or from PPP-B2b SSR. After that, plots can be generated to show various results as per configuration.

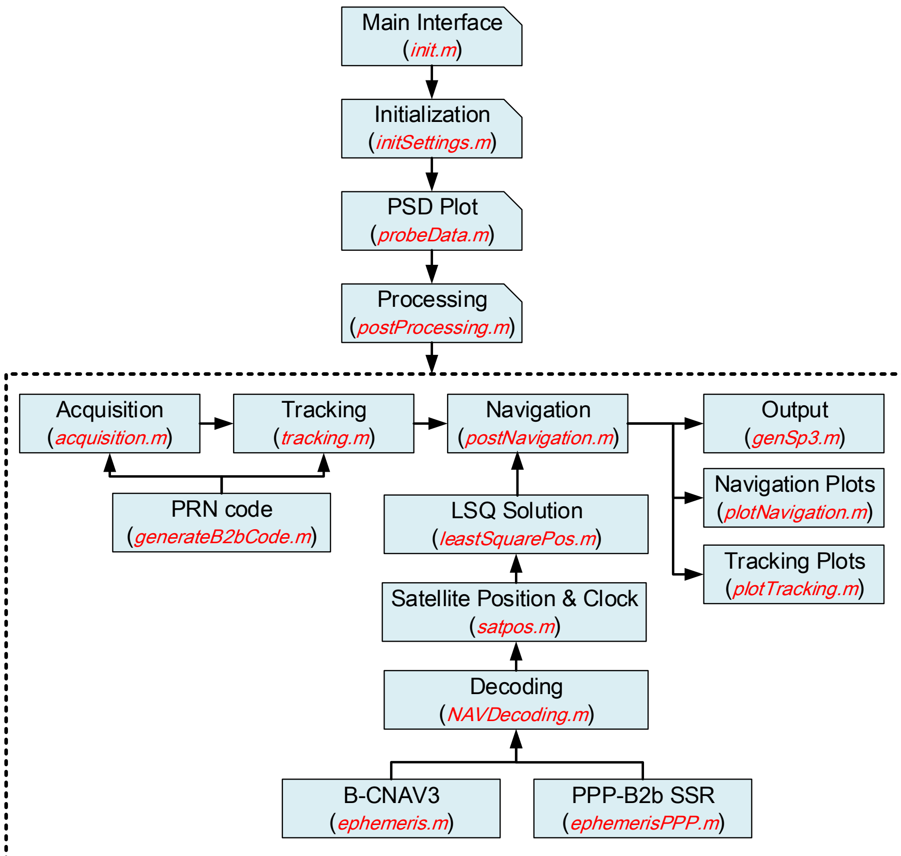

Fig. 1 Flowchart of the BDS B2b SDR

It is noted that the users are required to collect raw BDS B2b signal datasets with appropriate front-ends or alternative data sources before running the software package. Furthermore, the processing options as well as the parameters of the raw signal datasets, including the file location, data format, sampling frequency, intermediate frequency, etc., should be configured accordingly (*initSettings.m*).

Sample datasets, results and discussion

To demonstrate the performance of the developed BDS B2b SDR, sample datasets are collected in Hefei, China, using Commercial-Off-The-Shelf (COTS) Universal Software Radio Peripheral (USRP) B210 device. Figure 2 depicts the hardware setup for the sample dataset collection. Note that the antenna is set up in the rooftop without obvious obstructions, while the USRP B210 runs with sampling frequency of 20 MHz and the obtained baseband raw dataset is saved in the format of Interleaved (I&Q) 32 bits float samples using high-performance personal computer.

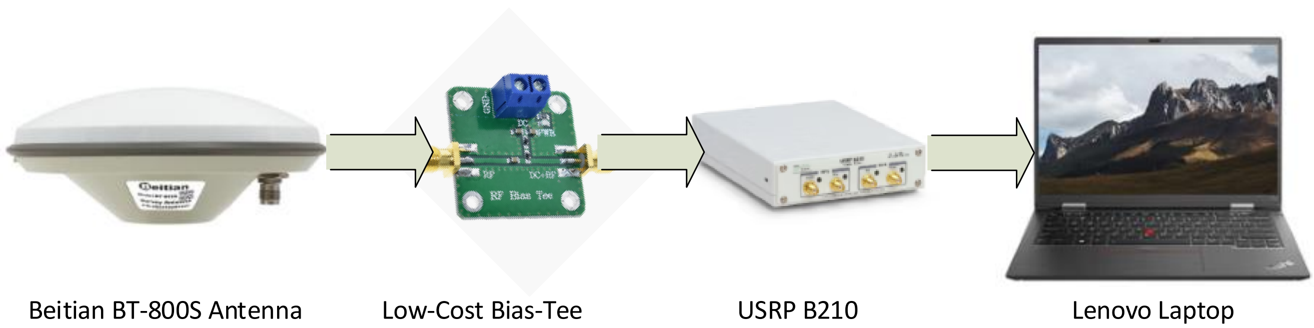

Fig. 2 Hardware setup for sample dataset collection

The quality of the collected dataset is first screened by visualization in the frequency domain using 100-ms data as can be seen in Figures 2.

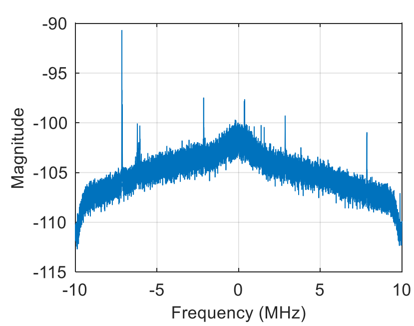

Fig. 2 Frequency domain plots of 100 ms-long interleaved (I&Q) datasets