GNSS Signal Reception System Based on Open-Source SDR Platforms

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Abstract: ***This paper presents a low-cost GPS signal reception system based on open-source SDR (Software-Defined Radio) technology. Using RTL-SDR hardware and the GNURadio software platform, it achieves acquisition, tracking, and positioning of GPS L1-band signals. Through a modular design, the system implements key stages such as signal synchronization, navigation message decoding, and position calculation, delivering civil-grade positioning accuracy in open-sky environments. Experimental results show that the solution is low-cost and highly flexible, making it suitable for scientific research, education, and civil navigation applications.***

Keywords: Software-Defined Radio (SDR); GPS signal reception; RTL-SDR; GNURadio; Low-cost positioning.

1. INTRODUCTION

Traditional GPS reception relies primarily on dedicated hardware architectures to acquire, track, and position signals. The core process involves: receiving L1-band (1575.42 MHz) satellite signals via an antenna, down-converting them to an intermediate frequency by the RF front-end, and then having an ASIC perform C/A code serial-search acquisition and carrier wipe-off. A delay-locked loop (DLL) and phase-locked loop (PLL) then precisely track the pseudo-code phase and Doppler shift, after which the navigation message is demodulated and pseudoranges are computed. Although this fixed-hardware design guarantees positioning functionality, it suffers from poor flexibility and limited multi-system compatibility. Software-Defined Radio (SDR) is a wireless communication system built on computer technology, where signal processing and communication functions are switched mainly through software. SDR implements hardware functions in software, freeing device communication from hardware constraints. Compared with traditional schemes, SDR is highly flexible and open, transforming single-purpose systems into general-purpose ones, because acquisition and tracking algorithms can be programmed on general-purpose processors. Figure 1 illustrates the SDR receiver workflow; its digital signal-processing portion is expanded compared with traditional receivers, performing many analog-circuit functions in software. This paper develops a GPS signal reception system based on the open-source SDR software GNURadio and RTL-SDR hardware, aiming to achieve GPS positioning with low-cost SDR equipment. Yang, Wang, and Chen (2024) proposed a GCN-MF model that integrates graph convolutional networks with matrix factorization to improve recommendation accuracy[1]. Concurrently, for network infrastructure, Zhang et al. (2025) developed MamNet, a hybrid model designed for time-series forecasting and frequency pattern analysis in network traffic[2]. Innovations in robotics and software architecture are demonstrated by Guo (2025), who applied deterministic AI for optimal robotic manipulator trajectory control[3], and Zhou (2025), who researched performance monitoring and optimization strategies within microservices architectures[4]. Advancements in computer vision include the work of Peng, Zheng, and Chen (2024), who introduced a dual-augmentor framework to improve domain generalization in 3D human pose estimation[5]. For specialized industrial applications, Meng (2023) utilized neural networks to develop an evaluation system for green cabling of cables[6]. Significant progress is also evident in AI-driven healthcare, where We et al. (2025) leveraged multimodal physiological data for the intelligent monitoring of anesthesia depth[7]. A substantial research focus remains on augmenting the capabilities of large language models (LLMs). Zhang et al. (2024) enhanced logical reasoning in LLMs using a multi-stage ensemble architecture with adaptive attention[8], while Zhang et al. (2025) employed dynamic cross-attention and multi-level feature fusion for fine-grained image captioning in advertising[9]. Further innovations in LLM applications include Zhang et al. (2025)'s use of LLaMA-based meta-attention networks to maximize scoring divergence in automated essay assessment[10]; Huang et al. (2025)'s improvement of document-level question answering via multi-hop retrieval-augmented generation with LLaMA 3[11]; and Wang and Bi (2025)'s development of a hierarchical adaptive fine-tuning framework to enhance multi-task learning in large-scale models[12].

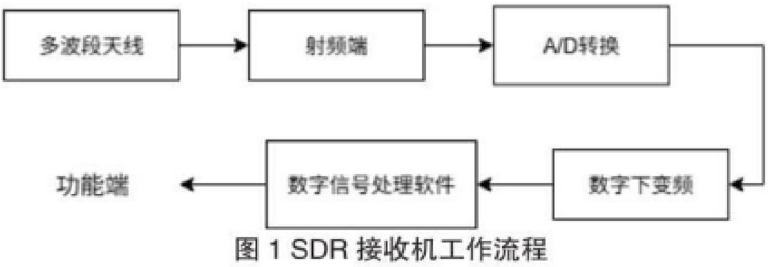

Figure 1: Hardware Platform RTL-SDR

RTL-SDR (Realtek Software Defined Radio) is a low-cost software-defined radio based on the R820T2 tuner and the Realtek RTL2832U chip. The RTL2832U chip in the device can directly output raw I/Q samples, and with open-source drivers it can be turned into a fully functional SDR receiver. Figure 2 shows the internal block diagram of the RTL-SDR; its operating frequency range spans from 25MHz to 1.75GHz, supports a maximum sample rate of 3.2MS/s, and digitizes signals via an 8-bit ADC. As the world's most popular entry-level SDR, the RTL-SDR—priced at under $20 and backed by a rich ecosystem—is widely used for amateur radio monitoring, ADS-B aircraft tracking, weather-satellite image reception, shortwave communications, and more. The RTL-SDR Blog V4 used in this paper further incorporates a TCXO temperature-compensated crystal oscillator, Bias-Tee power injection, and other enhancements to boost performance.

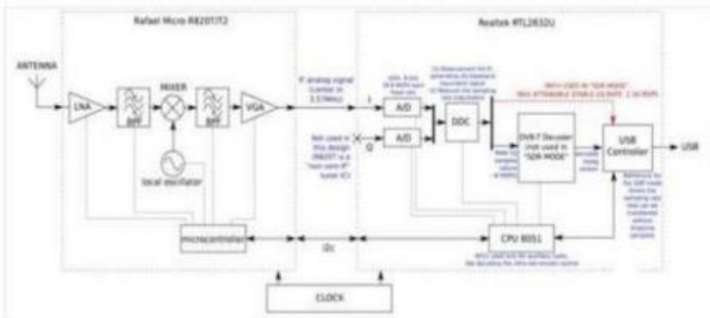

Figure 2: RTL-SDR internal block diagram

2. GNURADIO-BASED GPS SIGNAL RECEPTION PLATFORM DESIGN

GNU Radio is a free and open-source software-defined radio (SDR) platform that has become the core framework for building flexible, modular wireless communication systems. Its key feature is the ability—via the graphical flowgraph design tool (GNU Radio Companion, GRC) or Python/C++ APIs—to connect signal sources, processing blocks, and sinks into a complete signal-processing chain, supporting the full development flow from baseband simulation to real-time RF communication [7]. The built-in library contains more than 300 blocks covering digital signal-processing functions such as modulation/demodulation (e.g., QAM, PSK), filtering (FIR/IIR), and spectrum analysis, and can be extended to 5G, satellite communications, and other advanced applications. Through hardware interfaces like the RTL-SDR, GNU Radio can perform real-time signal transmission and reception with bandwidths up to 16MHz. Its active open-source community continuously contributes third-party modules while providing comprehensive official documentation and tutorials, making it an essential tool for education, research, and commercial communication-system development. The specific implementation of the system is described below.

2.1 Main Software Design of the GPS Signal Reception System

The main software portion of the GPS signal reception system is shown in Figure 3. It consists of the osmocom Source block, Polyphase Channelizer block, sat block, Bit_Sync_PRN block, Subframe_Decoder_PRN block, Position Solver block, and Ephemeris_DB block, forming a complete GPS signal reception and processing system. The osmocom Source block serves as the RF front end, receiving the 1575.42 MHz L1-band signal via an RTL-SDR device at a 2.048 MS/s sampling rate. After channelization by the Polyphase Channelizer, the four outputs are routed to their corresponding sat blocks. Bit_Sync_PRN then performs bit synchronization, using the 1.024kHz bit-rate output window to precisely align the GPS navigation message. The synchronized data stream is passed to the Subframe_Decoder_PRN block to decode the navigation message; a preamble detector identifies the start of each navigation subframe, and the ephemeris parameters are parsed field by field according to the frame structure.

Each Subframe_Decoder_PRN block is configured with a PRN number, and its ephemeris data are exchanged with the Ephemeris_DB block via the ephemeris_out interface. Finally, the Position Solver block combines data from four satellites and computes the position through pseudorange calculations.

In addition, the system supports replacing the online RTL-SDR input of the osmocom Source block with prerecorded GPS baseband signals, or using ephemeris files from NASA data centers or the IGS data center of Wuhan University to generate GPS baseband signals via gps-sdr-sim, as well as pseudolite signal inputs, thereby further expanding the system's applicability.

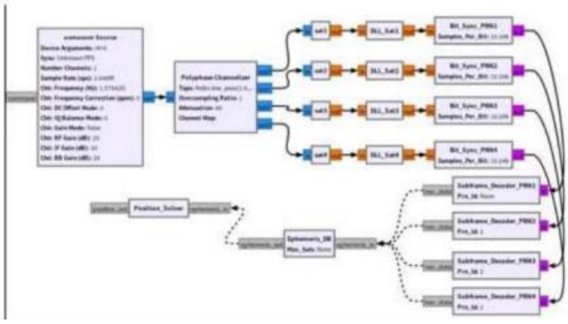

Figure 3: Main Processing Flow of the GPS Receiver System

2.2 Detailed Implementation of the Synchronous Demodulation Block sat

The synchronous demodulation sat module is an integrated unit whose internal structure is shown in Figure 4. The sat module specifically comprises a Frequency Xlating FIR Filter, Rational Resampler, Polyphase Clock Sync, Costas Loop, AGC, and Correlate Access Code Tag. Among these, the FIR filter corrects frequency offset through mixing and filtering; the Rational Resampler performs sample-rate conversion to suit subsequent processing; the Polyphase Clock Sync precisely adjusts symbol timing to eliminate inter-symbol interference; the Costas Loop recovers the carrier phase with a second-order PLL whose loop bandwidth is 10Hz; the AGC dynamically adjusts signal amplitude to ensure processing stability; and the Correlate Access Code marks the start of valid data frames via correlation detection. The processed signal is finally delivered to the downstream bit-synchronization module. Overall, this module integrates carrier synchronization, symbol timing recovery, automatic gain control, and data-frame positioning for satellite signals, forming the critical link in the GPS signal-processing chain from physical-layer conditioning to frame extraction.

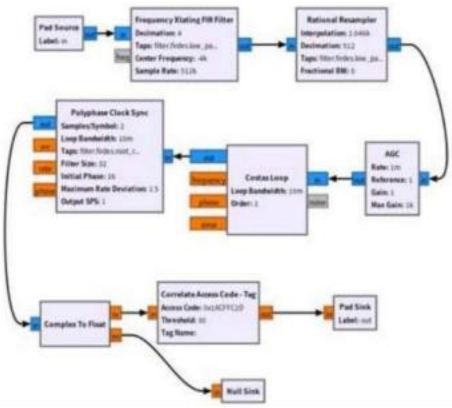

Figure 4: Synchronous demodulation sat module

3. SIGNAL RECEPTION RESULTS AND TESTING

3.1 Positioning Result Output

GPS baseband signal processing is completed inside GNU Radio, and the results are output via a Python script. The output is shown in Figure 5. The coordinates are accurate to 14 decimal places; the actual positioning difference is at the sub-meter level. The small numerical variations among the three sets of coordinates reflect the receiver's position within a 5-meter range. The entire dataset is continuous and meets the requirements of high-precision navigation and positioning applications.

Figure 5: Output results

Positioning accuracy tests were conducted in a residential area and nearby open terrain. Multiple points within a 10-meter range were sampled; the measured coordinates and the actual positions were imported into Google Maps for visualization, as shown in Figure 6, and the error results under different environments are compared in Table 1. The results show that even under interference (e.g., urban multipath), the measurement error in multi-point tests remains within 10 meters, satisfying the needs of civilian navigation and positioning.

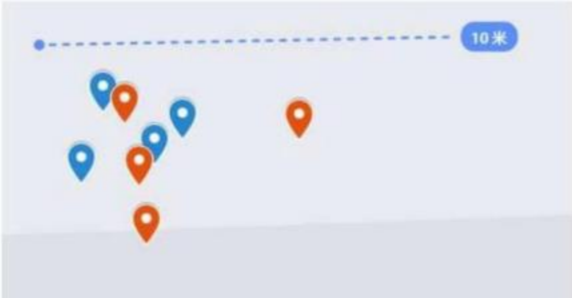

Figure 6: Google Maps test results

Table 1: Test errors at different locations 4 Conclusion

	开阔地带	楼顶	城市道路
定位精度(m)	3.7 ± 1.5	5.5 ± 3	15.3 ± 6.6
漂移误差(m)	2.5 ± 0.9	6 ± 3.7	7 ± 2.5

This paper presents a low-cost GPS signal reception system based on open-source SDR technology. Using RTL-SDR hardware and the GNURadio software platform, it implements basic functions such as satellite signal acquisition, tracking, and positioning. The system fully leverages the low cost and portability of RTL-SDR, and, by combining GNURadio's modular design and programmability, constructs a complete GPS signal-processing chain. Test results show that the system can achieve civil-navigation-level accuracy in open areas and meet positioning requirements. The solution not only reduces the hardware cost of traditional GPS receivers but also offers excellent scalability, making it adaptable to multiple satellite navigation signals in the future. By optimizing algorithms and enhancing hardware performance, the system is expected to play a greater role in low-cost high-precision positioning, scientific research and education, and multi-mode navigation fusion.

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