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Design and Implementation of GNSS Monitoring System on a Domestic Platform

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Abstract: In response to the urgent need of the country and the military for independent and controllable information industry technology, as well as the future development trend of information and creative products, a GNSS monitoring system based on a domestically produced platform has been designed to ensure information security and enhance the level of independent and controllable capabilities. This system relies on domestic processor chips and the Galaxy Kirin operating system to achieve GPS GLONASS 、 The main functions of the Beidou Navigation System are real-time monitoring and ionospheric scintillation monitoring.

Key words:GNSS；Domestic；Autonomous Control；Ionospheric scintillation；

1 Introduction

At present, in the world, the United States GPS, Russia's GLONASS, Europe's Galileo, China's Beidou satellite navigation system together constitute the Global Navigation Satellite System [1] (Global Navigation Satellite System, GNSS).

With the rapid advancement of information technology, China's cyberspace development has achieved remarkable progress while revealing critical vulnerabilities in cybersecurity: Over 80% of information systems remain overly reliant on foreign technological products, with weak core R&D capabilities and dependence on foreign technologies, creating growing tensions with national security requirements[2]. To address this, developing domestically controlled GNSS monitoring systems not only enhances self-reliance but also eliminates information security risks stemming from foreign component dependencies, meeting the high-security demands for autonomous services in critical sectors[3].

The ionosphere, as a crucial component of Earth's space environment, exerts significant impacts on various radio information systems. Accurate measurement of ionospheric parameters is essential for effectively mitigating and eliminating these effects. [4] When GNSS satellite signals traverse the ionosphere, irregular structures within it cause rapid random fluctuations in both amplitude and phase of the signals—a phenomenon known as ionospheric flutter. This flutter phenomenon can induce bit errors and signal distortion in navigation receivers, thereby compromising the accuracy of positioning results.

In order to improve the level of autonomy and controllability, this paper proposes a GNSS monitoring system under a domestic platform. The system uses multiple GNSS monitoring devices to form a network for monitoring, which can realize the monitoring of ionospheric changes in local areas and obtain real-time status change information of ionospheric flicker, so as to realize the prediction and early warning of ionospheric environmental impact effects.

2 System composition and main functions

2.1 Basic composition

The GNSS monitoring system based on localized platform is divided into three parts: GNSS monitoring device end, client and server.

The GNSS monitoring device end mainly includes GNSS monitoring device end software and GNSS monitoring device; the server includes background service and central database.

Table 1 System monitoring frequency information

Number	Name	Point	（MHz）
1	GPS	L1/L2/L5	L1：1575.42 L2：1227.60 L5：1176.45
2	GLONASS	G1	G1：1598.0625–1605.375
3	Beidou	B1/B2/B3	B1：1561.098 B2：1207.14 B3：1268.52

The GNSS monitoring system collects navigation satellite monitoring data through distributed devices across specific geographic areas. After processing the collected data, it transmits the information via wired networks to the server software. The server continuously receives real-time updates from device endpoints, including satellite monitoring data and equipment status information. This data is stored in a centralized database before being distributed to client devices. Simultaneously, the server processes control commands received from clients and relays these instructions back to the GNSS monitoring devices.

The service server is deployed on the cloud computing platform, which adopts the mechanism of "microservice + container (Docker)", uses the underlying Feiteng processor and the operating system Kylin, and has the advantages of rapid development, efficient deployment, safe operation and easy portability.

As shown in Figure 1, GNSS monitoring center forecasters utilize the computer at their workstation to access real-time data through client software. This system allows them to view GNSS monitoring data from relevant equipment, track device status, and integrate data from multiple monitoring devices to reflect comprehensive GNSS monitoring information and ionospheric flicker detection across specific regions. Forecasters can also issue control commands via the client software to each GNSS monitoring device, such as remotely upgrading firmware, performing remote power on/off operations, or accessing historical monitoring records.

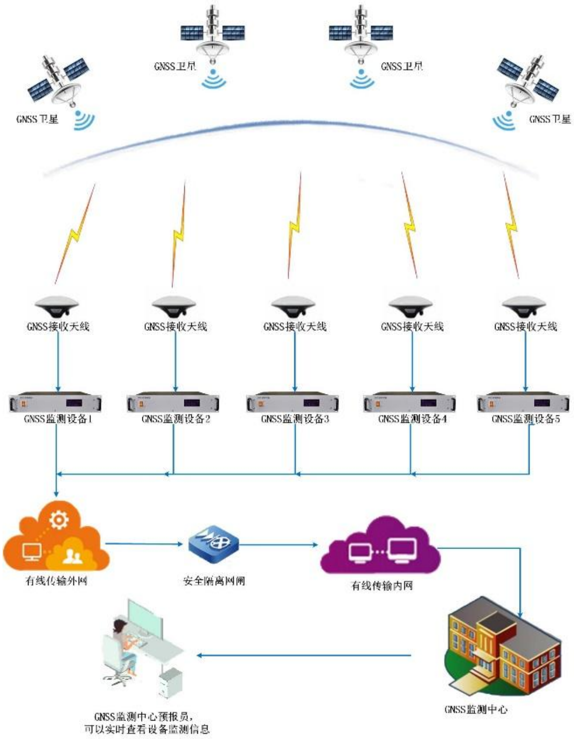

Figure 1 Working principle diagram of GNSS monitoring system

2.2 major function

The GNSS monitoring system has the following two functional advantages in key monitoring areas, such as military areas and key protection areas:

① Real-time monitoring, safe and efficient. Through the efficient and safe cloud platform, the system can continuously obtain the GNSS monitoring status information in the area for a long time, report the real-time information to the center and store it in the database of the center at the same time, and users can view the real-time or historical monitoring information as needed.

② The system is self-controlled, stable, and reliable. Designed with domestic key hardware and software, it leverages independent innovation advantages to continuously enhance stability and reliability. The hardware infrastructure utilizes the domestically produced Phytium 2000+ processor as the monitoring center's foundation, while the software adopts the domestically developed Kylin operating system. Using QT development tools, both the hardware and software effectively avoid a series of "chokepoint" issues that could hinder technological advancement.

The domestically developed GNSS monitoring system breaks away from the traditional "hardware X86 + software Windows" design and implementation model. By leveraging China's self-developed and controllable platform, it not only elevates the domestication level of GNSS monitoring but also significantly reduces cybersecurity risks. This innovation provides timely and efficient GNSS data support for critical regional monitoring operations.

3 Algorithmic applications

3.1 Satellite signal-to-noise ratio calculation

The Carrier-to-Noise Density Ratio (C/N0) of satellite signals serves as the core parameter for evaluating navigation satellite signal quality. The C/N0 calculation model integrates signal propagation theory, noise analysis, and receiver processing technologies, functioning as a fundamental tool for assessing Global Navigation Satellite System (GNSS) performance. In practical applications, it requires comprehensive consideration of environmental interference, hardware characteristics, and algorithm implementation to accurately reflect signal quality and support high-precision navigation and monitoring. The unit is measured in decibels per hertz (dB-Hz).

$$\frac{C}{N_0} = 10 \cdot \log_{10}(C) - 10 \cdot \log_{10} \quad (k \cdot Tsys \quad)$$

Here, C is the signal power, N0 is the noise power density, k: Boltzmann constant (1.38×10-23 J/K), and Tsys is the system noise temperature (unit: K, including antenna noise and receiver noise).

Table 2 shows the typical values of signal-to-noise ratio

Number	**signal condition**	**C/N_0Value range （dB-Hz）**	**remarks**
1	Good	$C/N_0 \geqslant 40$	Open environment
2	medium	$30 \leqslant C/N_0 < 40$	urban environment
3	weak	$C/N0 < 30$	Indoor / strong interference

3.2 Ionospheric flicker index calculation

Ionospheric flicker refers to the random fluctuations in signal amplitude and phase caused by the irregular structure of electron density when GNSS signals pass through the ionosphere. Its calculation model requires a comprehensive integration of physical mechanisms and statistical characteristics. The following is the process and related algorithms for systematically calculating the ionospheric flicker index, as shown in Figure .

3.2.1 Amplitude flicker index (S4) calculation

The S_4 index reflects the normalized standard deviation of signal power, and the calculation formula is:

$$S_4 = \sqrt{\frac{\langle P^2 \rangle - \langle P \rangle^2}{\langle P \rangle^2}}$$

P: Received signal power (unit: dB-Hz or linear value); ⟨ ·⟩ : Average value within the time window (usually 30 seconds to 5 minutes).

Table 3 Physical definition of S4

Number	**Flashing**	**S_4Value range**	**remarks**
1	Little	$S_4 < 0.3$	The impact on navigation is negligible

2	Middle	$0.3 \leqslant S_4 < 0.6$	It may cause positioning error
3	Strong	$0.6 \leqslant S_4$	Easy to cause receiver lock loss

3.2.2 Phase shift index (S4) calculation

Phase shift index is the time standard deviation of carrier phase, and the calculation formula is:

$$\sigma_{\emptyset} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\emptyset_i - \overline{\emptyset})^2}$$

$\emptyset_i$： Carrier phase of the i-th sampling point (unit: arc degrees);

$\overline{\emptyset}$ ： Phase mean within the time window;

N： Number of sampling points (usually 1 minute window, N=60 when the sampling rate is 1Hz);

Correction methods: ① To eliminate clock difference and hardware delay, the dual-difference method (difference between satellite and receiver) is used to suppress systematic errors; ② High-pass filter is used to filter out low-frequency phase changes (such as ionospheric TEC gradient) and retain high-frequency flicker components.

4 system design and realization,system design and implementation

The localized GNSS monitoring system is developed using the MVC architecture, with business logic, data processing, and interface display developed separately. By leveraging message service (MQ) and Redis middleware for cross-component communication, the system achieves streamlined operations that feature low coupling, high reusability, rapid deployment, cost-effective lifecycle management, and superior maintainability.

Secondly, the GNSS monitoring system relies on "cloud computing platform" + "container" + "load balancing", which improves the stability of the system, high concurrent processing capacity, rapid deployment ability and information security protection ability.

4.1 hardware design

The hardware composition of GNS monitoring equipment is mainly: receiver board, industrial control computer, power adapter, network relay and network switch, as shown in Figure.

The GNSS monitoring device receives navigation satellite signals through an external GNSS antenna. After demodulation, it captures real-time data and transmits it to the industrial control computer. The embedded GNSS monitoring software on the industrial control computer processes this data by calculating positioning information, satellite identification numbers, satellite status, carrier-to-noise ratio (CNR), and time synchronization data. These satellite monitoring parameters are then uploaded to the central hub via a network switch.

The power adapter provides regulated voltage to network relays, switches, navigation receivers, and industrial control computers. When users activate external switches locally, the GNSS monitoring system is fully powered on. Through client-side commands, the network relay receives remote power control instructions to manage power supply for navigation receivers and industrial computers, enabling real-time remote operation of devices. This mechanism ensures rapid restoration of monitoring functions in case of equipment downtime.

Table 4 Design of GPS system positioning information table

Number	definition	Unit	data type	Remark
1	Frame header			0xEB 0x90 0x01 0x01
2	Date longth		u2	2*8+2*4+1+1 （Remove the frame header, data length and frame tail）
3	latitude	Degree	f8	

4	longitude	Degree	f8	
5	The ellipses are tall	Meter	f4	
6	High elevation anomaly	Meter	f4	
7	Positioning signs		u1	1 ： Effective positioning 0：The positioning is invalid
8	check sum		u1	
9	Frame end			0xFC 0x05

Table 5 Design of available satellite numbers for BDS system

Number	definition	Unit	Data type	Remark
1	Frame header			0xEB 0x90 0x02 0x02
2	Data longh		u2	n+1 （Remove the frame header，data length and frame tail）
3	Visible satellite number		u1	Satellite1
			u1	Satellite2
				…
			u1	Satelliten
4	check sum		u1	
5	Frame end			0xFC 0x05

4.2 Software Design

This paper adopts a bottom-up hierarchical design strategy based on software engineering development standards, with functional modules divided according to business logic types. The architecture is illustrated in Figure 4. The system software is primarily composed of four interconnected layers: the Support Layer, Data Layer, Function Layer, and Presentation Layer. These layers work in close coordination to collectively fulfill the monitoring tasks of the Global Navigation Satellite System (GNSS).

4.2.1 Support layer

Operation environment support: This layer is based on "Domestic Feiteng processor + Kirin operating system" [6]. It is the necessary system environment for the operation of the system server, and provides computing, network, data management, resource scheduling, application development, application release and other functional services.

High concurrency processing: This function mainly relies on "NGINX" software load balancing , which improves data throughput and enhances real-time high concurrency processing capability of data by using limited network bandwidth, ensuring the availability of a large number of GNSS monitoring devices when they are connected.

Cybersecurity Assurance: All GNSS monitoring devices are connected to wired external networks. GNSS monitoring data is centrally aggregated through external networks and then transmitted via a secure network exchange system into the internal wired network. This configuration ensures stable and smooth data access while providing robust cybersecurity barriers for both servers and clients through boundary protection, access control, and intrusion prevention mechanisms.

Map tool: This function mainly provides the map API interface based on CGCS2000 standard to support the drawing of relevant geographic information.

4.2.2 Date layer

The system primarily fulfills three core functions: data storage, data management, and interface services. Data Storage: The system stores navigation device information, ionospheric scintillation data, and star calendar data in their respective databases. Data Management: By executing database queries, it enables operations including adding, deleting, modifying, and retrieving data, ensuring the timeliness of GNSS monitoring data. Interface Services: Through database interface calls, the system achieves stable and interactive connectivity between the front-end and backend systems.

4.2.3 functional layer

The system primarily implements functions including data parsing, flicker index calculation, positioning and timing synchronization, data forwarding, comprehensive evaluation, and map loading. Data parsing: Processes data packets uploaded by GNSS monitoring devices, then pushes them to relevant API interfaces based on packet content such as satellite ID, carrier-to-noise ratio (CNR), elevation azimuth information, and satellite health status. Flicker index calculation: Utilizes ionospheric flicker calculation models based on acquired CNR data to generate ionospheric amplitude and phase flicker indices. Positioning and timing synchronization: Extracts time information from ephemeris records and publishes it through message services for third-party applications. Data forwarding: Transmits client commands received to the device-side software. Comprehensive evaluation: Integrates ephemeris data from multiple GNSS monitoring devices and ionospheric flicker index information into charts for user presentation. Map loading: Calls map API interfaces to load map data.

4.2.4 Performance layer

Parameter Settings: Users can select monitoring information from satellite navigation systems they care about, such as star maps, signal-to-noise ratio (SNR) bar charts, and ionospheric scintillation index diagrams. Output Display: The graphical interface displays key parameters including elevation angles, azimuth angles, SNR values at navigation frequency points, and satellite IDs for selected satellites. Command Execution: Supports remote activation or upgrade of one or multiple GNSS monitoring devices based on user requirements. Historical Data Playback: Enables users to review satellite monitoring data within specified time periods.

4.3 System deployment and implementation

A domestically developed GNSS monitoring system has been successfully developed and installed with five sets of localized GNSS monitoring devices in the test area. The client software enables real-time tracking of equipment status, including online/offline status, geographic coordinates, and operational parameters. Additionally, users can remotely control device operations (power on/off) and adjust configuration settings for specific units.

As shown in Figure 5, users can select relevant GNSS monitoring equipment as needed to view real-time navigation satellite monitoring data of the current equipment. For example: star map, visible satellite chronology information, satellite coordinate information, and visible satellite signal-to-noise ratio bar chart for each frequency point.

As shown in Figure 6, users can view the ionospheric flicker monitoring information and ionospheric flicker alarm information of relevant GNSS monitoring equipment as needed.

As shown in Figure 7, the user can view the real-time latitude and longitude coordinates, positioning error, number of visible satellites, and current ionospheric flicker index of all GNSS monitoring devices in the usability display interface.

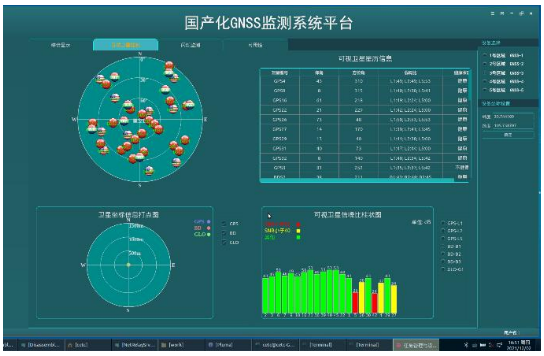

Figure 5. Navigation satellite monitoring interface of domestic GNSS system platform

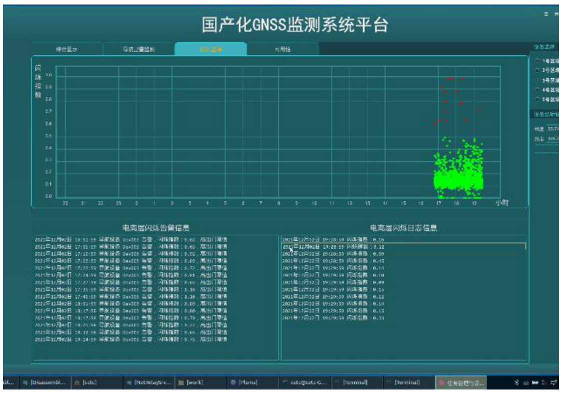

Figure 6 Ionospheric flicker monitoring interface of domestic GNSS system platform

Figure 7. Availability display interface of domestic GNSS system platform

5 conclusion

This paper addresses the growing demand for domestically controllable services in China's information security sector by developing a "GNSS Monitoring System Built on Domestic Platforms". The study provides a comprehensive analysis of the system's application model, operational principles, hardware architecture, software design, functional modules, system composition, and implementation approaches. Through coordinated testing and debugging in designated experimental zones, the system has demonstrated measurable effectiveness, showcasing both technological advancement and practical applicability for broader adoption.

With the continuous advancement of China's indigenous innovation products, a comprehensive system has been established. The domestically developed GNSS monitoring system, utilizing homegrown processors and operating systems, provides innovative solutions for addressing security challenges in GNSS applications while ensuring fundamental autonomy, controllability, and secure trustworthiness in this critical field.

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