Application of BeiDou Satellite in Frontier Monitoring and Defense System

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Abstract. Aiming at the problem of illegal border crossings on plateaus and mountainous borders, this paper proposes a frontier monitoring and defense system built with BeiDou satellite positioning, timing, navigation, short message communication and other functions to scan and monitor the border in real time. The rapid target positioning method of BeiDou static and dynamic monitoring point fusion of forward intersection and trigonometric leveling technique is presented. Meanwhile, crossing alarm and defense system are connected. For those who enter or cross the boundary illegally, we adopt measures such as warnings, shouting to drive away and positioning and arresting. So as to improve the informatization level of control of frontier and ensure the safety of frontier management personnel.

Keywords: Frontier Monitoring, Beidou Satellite Positioning, Forward Intersection, Short Message Communication

Introduction
China has a vast territory, with a total boundary of 55,200 km, of which the land boundary is about 28,000 km [1], which is crisscrossed or crossed dozens of mountains, plateaus and rivers and borders more than a dozen countries and regions. On this long boundary, in order to safeguard the security of the country and maintain peace and stability in the frontier areas, the border guards never dare to relax. Especially in many areas with harsh environment, such as the Karakoram Mountains, where the altitude is 5,380 m and the average annual temperature is below zero. The wind speed exceeds 17 m/s for half of the year. The natural conditions are so bad that it is not suitable for human habitation, making border patrols very difficult.

At present, the remote monitoring system commonly used in our country can remotely monitor the state of the Zhoushankou and important places in real time, which greatly reduces the workload [2]. However, this kind of remote monitoring system with only video monitoring function has many blind spots, so it is impossible to accurately determine whether the other side has crossed the boundary and meet the actual needs.

Based on the application background of plateaus and mountainous borders, this paper proposes a frontier monitoring and defense system based on BeiDou satellites. The system has functions such as target positioning, monitoring, early warning and command, so as to improve the accuracy and
timeliness of border control. It can realize unmanned patrol, alarm warning, shouting to drive away and positioning arrest in high-risk frontier areas in a remote, all-weather, and automated manner. It can not only guard the country, prevent illegal cross-border behaviors, prevent terrorist attacks and reduce human and material costs. More importantly, it can reduce the workload and effectively protect the safety of frontier control personnel, and greatly improve frontier management and control capabilities.

1. Introduction of BeiDou Satellite Navigation System
On July 31, 2020, Chinese President Xi Jinping announced the official opening of the BeiDou-3 global satellite navigation system. This marks the BeiDou system has entered a new era of global service.

BeiDou Satellite Navigation System is a global satellite navigation system developed and operated independently by China [3]. At present, the BeiDou system has a total of 45 satellites that can provide services. It can provide all kinds of users with all-weather, all-day high-precision and high-reliability positioning, navigation, timing and short message communication services on a global scale [4].

Since its opening, the BeiDou satellite navigation system has been widely used in the fields of transportation, agriculture, forestry and fishery, hydrological monitoring, weather forecasting, communication timing, power dispatch, disaster relief and mitigation, and public safety. It has gradually formed a development path with Chinese characteristics that provides services to the world. From a functional point of view, the BeiDou satellite navigation system can be fully applied to the frontier monitoring and defense system to assist in improving functions, thereby improving border control capabilities and efficiency, saving manpower and financial resources, reducing labor risks and improving safety.

2. The Development Status of Remote Monitoring System
For plateau and mountainous areas with an altitude higher than 5000m and harsh climatic conditions, the geographical situation is extremely difficult and complex. Therefore, many sections of the plateau no-man's land can only maintain periodic and limited patrol, lacking adequate mechanized and automatic control ability. Therefore, for illegal cross-border persons or terrorist organizations, there may be a fluke that they can cross the border illegally through this place.

At present, in view of the difficult situation of manual patrols in harsh natural conditions, the existing remote video monitoring system includes hand-held high-power telescope and photoelectric detection equipment. Hand-held high-power telescope is easy to navigate the valley in the day. The photoelectric detection equipment has two windows. The white light detection window is used in the daytime and the infrared detection window at night. Scanned images can be saved, which is convenient for later retrieval and analysis. However, this remote monitoring system cannot achieve automated border scanning, that is, frontier patrol still need to rely on manual observation. For some important and peripheral areas, it is still necessary to go out and patrol.

Therefore, this remote monitoring system is still not perfect. It does not have the functions of target positioning, monitoring, early warning and defense command. It is not fully applicable to the plateau and mountain border areas, and needs to be improved.

3. The Key Technology of Frontier Monitoring and Defense System Based on BeiDou Satellite

3.1 Design of Monitoring and Defense System for Frontier
Since the natural conditions in the plateau and mountain areas are harsh, manual patrols are difficult and dangerous, modern technology should be used to conduct border patrols to prevent illegal immigrants and terrorist organizations. The area can learn from the basic functions of the installed monitoring system, and on this basis, determine whether it has crossed the boundary by obtaining the opponent's location information, thereby deciding whether to initiate early warning and defense command procedures. This series of monitoring, positioning, early warning and driving away can all be controlled remotely to achieve non-contact frontier control.
The key technology of the frontier monitoring and defense system is how to obtain effective data on the opponent's target location in real time and realize the monitoring and early warning function. The BeiDou Satellite Navigation System independently developed and constructed by China has been completed and opened for service on July 31, 2020. BeiDou satellites have multiple functions such as positioning, timing, navigation, speed measurement, and short message communication. Based on BeiDou, it first completes the high-precision positioning of the reference station of the fixed monitoring point and the dynamic monitoring point. Combined with forward intersection measurement technology, the position data of the opponent's target can be obtained in real time without blind spots. So as to achieve the purpose of monitoring, early warning and defense command of the frontier monitoring and defense system.

3.2 Technical Realization of Frontier Monitoring and Defense System

The frontier monitoring and defense system consists of four parts: the main control room, fixed monitoring points, dynamic monitoring points and warning and defense system. Figure 1 shows the layout of the frontier monitoring and defense system.

![Fig.1 Point Distribution Map of Frontier Monitoring and Defense System](image)

3.2.1 The Main Control Room. Select a relatively open point of view in the plateau and mountain area to establish the main control room. The main control room is equipped with BeiDou command receiver, ultra-long focal high-power telescope, large-aperture photoelectric detection equipment and alarm. The main control room should be selected in a relatively flat position on the mountainside with good visibility to the valley entrance. It is constructed with a reinforced structure, and the control cabinet should be protected as a key point. The diameter of the photoelectric detection equipment is not less than 600 mm, and the main function is to continuously monitor the effective area of the valley entrance. The main control system can receive all the information sent by photoelectric detectors, fixed monitoring points, dynamic monitoring points, and warning and defense systems. Through a series of data analysis, the main control system issues corresponding instructions, and the commander finally determines whether to execute it.

3.2.2 Monitoring Points

1) Set Fixed Monitoring Points and Get Coordinates

The monitoring point is selected in a relatively unobstructed area within a pitch angle of 15°. This area is based on rocks, so stainless steel piles can be used. BeiDou receivers, radar detectors, alarms
and power generation devices are integrated on the piles. The radar detector can be rotated for detection, which is convenient for monitoring at any time. At least two monitoring points are arranged within 3 km from the actual control line, and multiple monitoring points are staggered at 3 km intervals in the longitudinal valley. There is no need for mutual visibility between the monitoring points, as shown in figure 2.

After the monitoring point is completed, the BeiDou data collection can be performed on several monitoring points at the same time according to the layout accuracy requirements of the national second-class earth control network [5]. Through baseline processing, network adjustment calculation and closure error calculation, the geocentric coordinate data of the monitoring point can be obtained.

![Monitoring point network diagram](image)

**Fig.2** Monitoring point network diagram

The monitoring point coordinates obtained by this method have reliable accuracy and can be used as known values.

2) Get the Coordinates of the Target Point

When the target appears within the set threshold near the actual control line, the photoelectric detector in the main control room and the radar detector at the nearby monitoring point within 3 km will trigger the alarm at the same time. The radar detector at the monitoring point is aimed at the target, and the position coordinates of the target point are calculated by the forward intersection positioning principle [6], as shown in figure 3.
Fixed monitoring point 1 \((x_A, y_A)\)

Fixed monitoring point 2 \((x_B, y_B)\)

Target \((x, y)\)

\[
\begin{aligned}
x_p &= \frac{x_A \cdot \cot \beta + x_B \cdot \cot \alpha - y_A + y_B}{\cot \alpha + \cot \beta} \\
y_p &= \frac{y_A \cdot \cot \beta + y_B \cdot \cot \alpha + x_A - x_B}{\cot \alpha + \cot \beta}
\end{aligned}
\]

Fig.3 Schematic diagram of forward intersection measurement

Fig.4 Principle Diagram of Triangular Elevation Measurement

At the same time, the radar detector also needs to measure the vertical angle between the fixed monitoring point and the target point. Using the principle of triangular elevation [8], the height difference between the fixed monitoring point and the target point is calculated, and then the target point elevation is calculated by the known height, as shown in figure 4.
\[ \begin{align*}
S_{AP} & \text{ is the distance between the fixed monitoring point and the target point, } \delta \text{ is the vertical angle between the fixed monitoring point and the target point, both of which are measured values. } z_A \text{ is the vertical coordinate value of the fixed monitoring point, which is a known value. By formula (2), the vertical coordinate value } z_P \text{ of the target point } P \text{ can be obtained.}
\end{align*} \]

At this point, the three-dimensional coordinates \((x_P, y_P, z_P)\) of the target point can be obtained by the combination of forward intersection measurement and trigonometric elevation measurement.

3) Independent Power Supply

The equipment at the monitoring point is basically low-power equipment. Plateaus and mountainous borders are usually windy and unobstructed, so solar or wind power can be used to meet the power supply needs. Each monitoring point is independently powered and does not interfere with each other, which effectively improves safety performance.

3.2.3 Dynamic Monitoring Point. Although only two monitoring points are visible to the target point, the intersection measurement and elevation measurement can be performed to obtain the target point coordinate value, the target point may have a blind zone. It means that the position of the target point cannot be in sight with two monitoring points at the same time, that is, the coordinates of the target point cannot be measured by intersection. Taking into account the special natural conditions of high mountains, steep slopes, deep valleys, narrow gullies, it is possible to use a combination of dynamic and fixed monitoring points for target positioning. Monitoring points include drones and floating balls.

The dynamic monitoring point is equipped with BeiDou receivers, radar detectors, cameras, megaphones and self-destruct devices, which can be operated by remote control. When the wind speed is low, drones are preferred, and floating balls are used on the contrary. The functions of dynamic monitoring points include: 1. Assist the intersection of fixed monitoring points to measure the coordinates of the target point; 2. Taking pictures of the scene and returning the picture in real time; 3. Early warning and warning to drive away.

For special terrain, on the one hand, when the dynamic monitoring point can receive enough BeiDou satellite signals, RTK technology can be used for real-time high-precision positioning, as shown in figure 5. Each fixed monitoring point can become a reference station, and each dynamic monitoring point can become a mobile station. The fixed monitoring point transmits its observation value and station coordinate information to the dynamic monitoring point through the data link. The dynamic monitoring point not only receives the data from the monitoring point through the data link, but also collects the observation data of the BeiDou satellite at the same time, thereby composing the differential observation value for real-time processing and obtaining high-precision positioning results. On the other hand, when the dynamic monitoring point cannot receive enough BeiDou satellite signals to complete satellite positioning, the fixed monitoring point can be used to intersection and locate the dynamic monitoring point.
3.2.4 Warning Defense System. The coordinate data of the target point measured by the intersection of the fixed monitoring point and the dynamic monitoring point will be sent to the main control system in real time. By comparing with the boundary data in the main control system database, it can be judged whether the target has entered our territory. Since targets are often moving, the main control system must predict the target trajectory while obtaining target location information. Based on the speed measurement function of the BeiDou Satellite Navigation System and radar detectors, the main control system can automatically predict the action trajectory route map of the target point through the received data, and then activate the warning defense system to help the commander further complete the alarm warning, call to drive away and positioning arrest command.

3.2.5 Data Communication. The various components of the frontier monitoring and defense system must interact with each other. Users can choose to combine BeiDou short message and radio for data communication, as shown in figure 6.

Fig.5 BeiDou RTK Positioning Principle

The floating ball can be dropped from a long distance, drift down to the effective range, and find a suitable position to fix it through the remote control device. It is also possible to artificially set up a card in a relatively narrow area of the river or in an area with a gentle water flow in advance to facilitate the fixation of the float. The floating ball will always obtain its own position information during the flow of the float. When the floating ball fails to be fixed and flows out of the actual control line, the self-destruction program is automatically started.
Fig.6 Monitoring and Defense System Data Communication

The short message communication is a feature of BeiDou, which is different from the satellite navigation systems of other countries. The BeiDou terminal equipment, the satellite and the ground monitoring station can directly transmit two-way information through satellite signals. It can provide BeiDou authorized users with short message communication services covering the world (the surface and the space above 1000 kilometers) [9]. As a space-based communication method, it has the characteristics of all-weather, wide-area coverage, and high reliability. It is used in frontier monitoring and defense systems with no blind spots, safe and reliable.

4. Conclusion

The primary goal of developing science and technology is to guard the safety of our country. The BeiDou Global Satellite Navigation System is an important tool of our country, and it is now in service. The use of BeiDou Satellite can improve the functions of the frontier monitoring and defense system, thereby improving the informatization level of frontier control. This paper discusses the application of the BeiDou Satellite in the frontier defense monitoring and defense system in plateaus and mountainous borders. The architecture design, key technical solutions and implementation methods of the frontier monitoring and defense system based on the BeiDou Satellite are also proposed. Not only has it solved the problems of steep geographical conditions, harsh natural conditions, and difficulty in manual patrols in the plateau and mountain border areas, but also adopted favorable control measures for illegal border crossings. Although it is still a theoretical assumption, the technical solution is highly maneuverable and can be further studied and promoted in the follow-up.

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