Implementation of BeiDou-Based Pseudolite Monitoring System for Cross-Border Logistics along the Belt and Road Initiative: A Student Innovation Project

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Abstract: Driven by the "Belt and Road" initiative and the globalization service of Beidou, real-time dynamic monitoring of cross-border supply chains has become a key demand for reducing logistics costs and increasing efficiency. In response to the practical pain points such as satellite signal blockage and insufficient positioning accuracy in cross-border transportation, our student team, relying on the school-enterprise cooperation platform, developed the "Without a Trace - Cross-border Supply Chain Dynamic Monitoring Device Based on Pseudo-Satellite Enhanced Beidou". This device integrates ground pseudo-satellite enhancement technology and Beidou positioning system, and through "star-ground integrated" collaborative positioning, it achieves high-precision monitoring and visual management of the entire cross-border logistics chain, and effectively reduces operational carbon emissions. This article starts from the real participation experience of vocational college students, systematically reviews the complete scientific research process of the project from topic selection, technical breakthroughs to competition awards, shares the practical experiences of the team in scheme design, software and hardware debugging, and scene verification, and reflects on the enabling role of the industry-academia integration platform in enhancing students' innovation ability and professional quality. The article aims to provide a reference case for vocational college students to participate in cutting-edge technology research and development, and also contributes a youth perspective to the implementation and promotion of Beidou technology in cross-border logistics.

Keywords: Beidou Satellite Navigation System; Pseudo-satellite Enhancement; Cross-border Supply Chain; Dynamic Monitoring

1. Why Do a Student Team Focus on Beidou and Cross-border Logistics

As students of a vocational college, we first came into contact with the Beidou Satellite Navigation System in class. When the teacher talked about the successful global networking of Beidou-3, we realized that this Chinese autonomous navigation system not only serves national strategies but is also penetrating into civilian fields such as logistics, transportation, and agriculture. Just at this time, the school released an announcement for recruitment of research projects in cooperation with enterprises, planning to establish a "Beidou Cross-border Application Research Center" and soliciting innovative solutions from student teams. Several of us immediately agreed and decided to take "Beidou + Cross-border Supply Chain Monitoring" as the direction, attempting to use the knowledge we have learned to solve problems in real scenarios.

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The starting point of the topic was derived from the research on the pain points of cross-border logistics. We learned that for goods transported by rail and road from Guangzhou to South Asia, they often have to pass through mountainous areas, long tunnels, and densely packed container areas at ports. The satellite signals in these places are intermittent, causing the consignors to be unable to know the location of the goods in real time and even experiencing situations where the goods were stranded at the border for several days without being discovered. Although the Beidou system covers the entire globe, its positioning accuracy and availability are greatly reduced in these "non-exposed spaces". After reviewing the literature, we found that the Pseudolite technology can set up ground signal transmitters in local areas and jointly calculate with space satellites to significantly improve positioning accuracy. This inspired us: Can we design a small-scale pseudo-satellite enhancement device that can be deployed at key nodes and cooperate with the cargo terminal to achieve uninterrupted monitoring of the entire cross-border chain?

With this idea, we formed a cross-disciplinary student team and officially embarked on the research and competition journey of the project.

2. Technical Principles and System Design: From Theory to Practice

The Beidou satellite navigation system can provide high-precision positioning, navigation, and timing services globally. However, its signals significantly attenuate when penetrating obstacles. In cross-border logistics scenarios, when container trucks pass through mountain tunnels, park beneath port bridge cranes, or travel along the urban periphery with numerous buildings, the terminal often receives only 2 to 3 satellite signals, failing to reach the minimum measurement requirements for calculation, resulting in positioning interruption or drift.

The essence of a pseudo-satellite is "moving the satellite to the ground". It is installed at known coordinates on the ground and emits navigation signals compatible with the Beidou format. The mobile terminal simultaneously receives signals from both the real Beidou satellites and the ground pseudo-satellites, and performs unified calculation. Due to the proximity and strong signal of the pseudo-satellite to the user and its geometric distribution that can be artificially optimized, the positioning accuracy within the area can be improved from the pure Beidou's 10-meter level to the meter level or even sub-meter level. Literature indicates that when 4 pseudo-satellites are deployed, the PDOP value can be better than 1.3, and the positioning accuracy can reach around 1.3 meters, which fully meets the requirements of logistics monitoring.

Based on the positioning principles learned in class and the engineering cases investigated outside the classroom, we designed a four-layer architecture: perception layer - transmission layer - enhancement layer - application layer.

The core innovation of the entire system lies in the lightweight implementation of the "pseudo-satellite and Beidou joint calculation algorithm". We optimized the traditional least squares calculation process and transplanted it to the embedded platform, enabling the terminal to complete mixed positioning calculations within 1 second, with power consumption only increasing by 5%.

3. The research participation journey of the student team: Challenges, Breakthroughs and Growth

At the beginning of the project, our understanding of the pseudo-satellite was limited to the conceptual level. To master the signal generation and synchronization technology, the team divided into groups to read nearly 50 Chinese and English papers and used the open-source software-defined radio platform (USRP) to conduct signal simulation experiments. The most challenging part was solving the time synchronization problem between the pseudo-satellite and the real Beidou satellite - if the clock of the pseudo-satellite had a deviation from the Beidou system time, the joint calculation would introduce even greater errors. We spent three consecutive weeks in the laboratory, repeatedly adjusting and training the algorithm, and finally, using the NTP + PPS (second pulse) combination solution, we achieved microsecond-level synchronization, with the error controlled within an acceptable range.

Hardware design was also full of challenges. We lacked experience in RF circuit design, and the power output of the first version of the pseudo-satellite transmission module was unstable, resulting in an effective coverage range of only 20 meters. Later, under the guidance of the teacher, we switched to an integrated RF front-end chip and optimized the antenna matching network, ultimately increasing the coverage radius to 150 meters, meeting the reinforcement needs of key areas in the park and the port.

After theoretical simulation and laboratory verification, we had to go to the real scene. With the support of the research center and the cooperative logistics enterprises, we selected a simulated transportation route of about 200 kilometers, including urban roads, highways, mountain tunnels and port storage yards. The team was divided into two groups, one collecting terminal data while the other debugging the pseudo-satellite base station. The test results were exciting: In the pure Beidou mode, the failure rate of positioning in the tunnel was as high as 73%, while enabling the pseudo-satellite enhancement increased the positioning availability rate to 98.5%, and the horizontal positioning error was reduced from an average of 8.7 meters to 1.2 meters. The environmental sensor data was also completely transmitted without packet loss.

However, we also discovered new problems: The pseudo-satellite signal and the Beidou signal would have cross-correlation interference at the receiver front end, causing the capture sensitivity to drop in some scenarios. We adjusted the transmission power of the pseudo-satellite and the code phase offset to reduce the interference impact and wrote this experience into the operation specifications of the device.

After the project was formed, we registered for the Youth Carbon Neutrality Innovation Competition. During the preparation period, the team not only had to improve the technology but also had to closely combine the project with the theme of low-carbon development. We calculated the carbon emission reduction brought by the full-chain monitoring for reducing vehicle idling and optimizing routes, estimating that each 10,000 TEU (standard container) could save about 120 tons of fuel and 380 tons of carbon dioxide. These data made the green value of the project more intuitive. During the presentation rehearsal, the judges questioned the deployment cost of the pseudo-satellite base station. We answered candidly: The base station adopts a modular design and is powered by solar energy, with a single station cost controlled at the ten-thousand-yuan level, and it is reusable and migratable. Compared with increasing the cost of human patrol and cargo

insurance, the overall economic benefit is significant. Eventually, our solution was recognized by the experts and stood out in the innovation group of the South China region.

4. Integration of Industry and Education and the Reshaping of Vocational College Students' Research Abilities

Our success is inseparable from the support of the industry-academia integration community. This platform combines enterprises, undergraduate institutions, and vocational colleges. Enterprises provide real demands and application scenarios, undergraduate institutions provide basic theoretical guidance, while our vocational college students leverage their strong hands-on skills and close proximity to the front line to undertake core tasks such as hardware integration, on-site debugging, and data analysis. The research center not only opened experimental venues and equipment but also coordinated logistics to provide test vehicles and routes, enabling our research to iterate in a real environment.

This "real-world practice" model makes us realize that research is not isolated work but a demand-driven, problem-oriented engineering practice. From the very beginning, we designed the reliability, maintainability, and cost controllability of the device according to product-level requirements, rather than just creating a demonstration prototype.

Looking back on the entire process, our greatest growth was not in mastering technical details, but in learning how to face unknown problems. When the positioning algorithm diverged, we no longer panickedly sought help from teachers but first independently investigated the data flow and verified the coordinate conversion parameters; when communication was interrupted, we would actively try to switch to the backup channel. This problem-solving methodology is something that classroom teaching cannot provide. At the same time, we deeply realized that vocational college students can play an important role in the Beidou industry chain - we are good at rapid prototyping, on-site deployment, and user training, and these precisely are the human resources support needed in the most extensive application of Beidou.

We observed that many vocational college students have excellent ideas and innovative desires, but often lack platforms and mentors to guide them. The industry-academia integration project precisely bridges this gap. It is suggested that more special research funds for vocational colleges should be established, with simplified participation thresholds and encouragement for cross-disciplinary team formation. Schools should also link competition achievements with course credits to stimulate more students to engage in applied research.

Although the program has completed prototype verification and received recognition in the competition, there is still a long way to go before it can be widely commercialized. As young students, we are extremely proud to be involved in the national Beidou strategy and the "Belt and Road" initiative. We believe that vocational college students not only have the spirit of craftsmanship but also have the potential for scientific research innovation. As long as we provide the right soil and opportunities, we can also find our place in the application of cutting-edge technologies and contribute our youthful strength to intelligent logistics and green development.

5. References

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