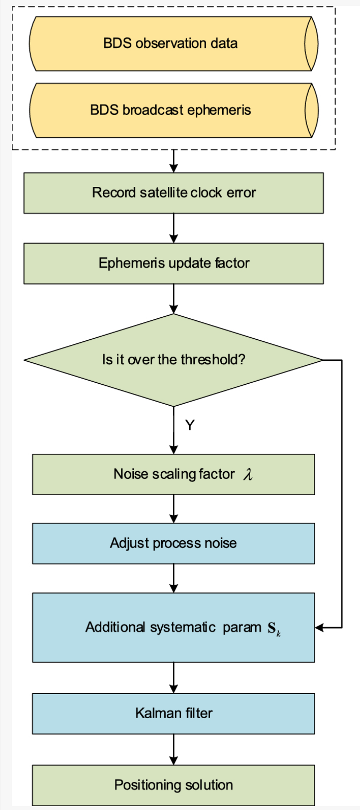
Adaptive Kalman filter boosts BDS-3 navigation accuracy in challenging environments

GA, UNITED STATES, December 10, 2025 /EINPresswire.com/ -- Precise Point Positioning (PPP) is widely used for high-accuracy navigation, but broadcast ephemeris from the BDS-3 system still suffers from hourly discontinuities that degrade real-time performance. This study introduces a new PPP strategy that integrates a covariance-adaptive Kalman filter to compensate for sudden orbit and clock jumps during each ephemeris update. By incorporating systematic parameters and dynamically scaling process noise, the algorithm better captures unexpected changes in satellite signals. Tests using one week of static global data and a 10-hour marine kinematic dataset show significant gains in accuracy, demonstrating that the proposed method effectively stabilizes PPP solutions and delivers robust, sub-meter real-time positioning.



The flow of the proposed algorithm.

Real-time Precise Point Positioning (PPP) is central to navigation applications where centimeter- or decimeter-level accuracy is required, including autonomous driving, Unmanned Aerial Vehicle (UAV) flight control, and offshore operations. While BeiDou Navigation Satellite System (BDS)-3 broadcast ephemeris is increasingly recognized for providing comparable orbit precision to real-time precise products, its hourly updates introduce discontinuities that lead to unexpected jumps in satellite clock and orbit parameters. These inconsistencies reduce accuracy and reliability, especially in environments where internet-based correction services are unavailable. Current compensation models rely heavily on preset parameters and fixed noise settings, which fail to adapt to sudden clock bias variations. Due to these challenges, a more adaptive, discontinuity-aware PPP strategy needs to be developed for BDS-3 applications.

Researchers from the China University of Geosciences (Beijing) have developed a real-time PPP algorithm that compensates for hourly discontinuities in BDS-3 broadcast ephemeris, according to a study published in Satellite Navigation on November 27, 2025. The team introduced a covariance-adaptive Kalman filter capable of detecting clock jumps and adjusting stochastic models in real time. Static and kinematic experiments revealed notable improvements in horizontal, vertical, and 3D accuracy, demonstrating the algorithm's ability to deliver stable and precise positioning even in network-limited environments.

The new algorithm addresses two major limitations of BDS-3 broadcast ephemeris: hourly signal discontinuities and the resulting inaccuracies in satellite clock and orbit information. To overcome these issues, the researchers enhanced the PPP observation model with additional systematic parameters to compensate for abrupt broadcast-ephemeris changes. They also designed a novel discontinuity detection factor that quantifies the magnitude of satellite clock jumps by comparing broadcasted and predicted clock biases. When a jump is detected, an adaptive scaling factor dynamically increases the Kalman filter's process noise, allowing the model to rapidly accommodate sudden variations.

Static tests using one week of data from seven globally distributed IGS stations showed the algorithm (PPP_MAKF) reduced 3D RMS positioning error from 35.62 cm (standard PPP) to 24.64 cm—a 30.82% improvement. Hourly jump patterns, clearly visible in inter-epoch differences (Fig. 10 on p. 8), were effectively absorbed by the adaptive systematic parameters.

A 10-hour kinematic test conducted in the South China Sea further demonstrated robustness in dynamic conditions. Compared with conventional broadcast-based PPP, the new algorithm improved horizontal accuracy by 7.32%, vertical by 45.32%, and overall 3D accuracy by 39.07% (Table 6 on p. 9). Carrier-phase residuals were also significantly reduced, indicating smoother and more reliable real-time performance.

"The key challenge with BDS-3 broadcast ephemeris lies in its hourly updates, which introduce abrupt clock and orbit variations," said the study's corresponding author. "Our adaptive Kalman filtering strategy allows the positioning model to recognize and respond to these jumps instantly, rather than relying on static compensation rules. This is particularly important for users operating in remote or marine environments where correction services are limited. We believe this approach sets a foundation for more resilient real-time positioning across next-generation GNSS applications."

The proposed algorithm offers a pathway toward reliable sub-meter real-time positioning in regions with limited access to internet-based correction services, such as offshore platforms, remote rural areas, polar regions, and emergency-response settings. Its robustness against broadcast-ephemeris discontinuities also makes it suitable for GNSS-based orbit determination of low-Earth-orbit satellites and for enhancing the stability of autonomous vehicles and drones relying on BDS-3 signals. Looking forward, integrating the method into multi-GNSS systems—such as GPS, Galileo, and QZSS—could further enhance accuracy and availability, contributing to more resilient global navigation solutions.

References

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