Application of Beidou Technology in Monitoring of Existing Building Deformation

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Abstract: Existing buildings are prone to structural deformation under multiple factors including environmental erosion, material aging, and surrounding engineering activities. Deformation monitoring serves as a critical component in ensuring structural safety. Traditional monitoring methods, however, suffer from inherent limitations such as low accuracy, inefficiency, and difficulties in real-time continuous monitoring, making them inadequate for modern building safety management. The BeiDou Navigation Satellite System (BDS), China's independently developed global satellite navigation system, has emerged as a new core technological support for existing building deformation monitoring. Leveraging its core advantages including high-precision positioning, all-weather operation, and automated data collection, BDS has become a pivotal solution in this field. This paper systematically explains the application principles of BDS technology in building deformation monitoring, analyzes its core technological advantages, introduces practical achievements through typical application scenarios, identifies major challenges in current implementations, proposes targeted development strategies, and ultimately outlines future trends. The study aims to provide theoretical and practical references for the large-scale and standardized application of this technology in existing building deformation monitoring.

Keywords: BeiDou Navigation Satellite System; Existing Buildings; Deformation Monitoring; High-Precision Positioning; Structural Safety Early Warning

1. Introduction

With China's urbanization advancing, the number of super high-rise buildings and large-span structures continues to grow, while older buildings are entering an aging phase. The structural deformation of existing buildings has become a growing safety concern, making real-time and precise deformation monitoring crucial for building safety management. Traditional deformation monitoring relies on manual inspections combined with instruments like total stations and laser plumb bobs. However, this method is prone to environmental interference, leading to cumulative errors. Moreover, its heavy reliance on manual operations not only reduces efficiency but also fails to support round-the-clock continuous monitoring, making it incompatible with modern monitoring requirements.

The BeiDou Navigation Satellite System (BDS) delivers core functionalities including high-precision positioning, navigation, and time synchronization. Since its regional service launch in 2012, the system has achieved rapid industrialization [3]. In 2014, China designated building safety monitoring as a key industry application for BDS [7], with the Ministry of Housing and Urban-Rural Development initiating the development of technical guidelines. This policy framework established robust standards for BDS-based deformation monitoring in construction. Boasting millimeter-level positioning accuracy and fully controllable technology, BDS effectively addresses the limitations of traditional monitoring methods. It has been widely adopted for structural deformation monitoring in high-rise buildings, historic structures, and aging hazardous buildings, serving as a critical technical support for existing building safety management.

2. Application Principles and Core Advantages of Beidou Technology in Deformation Monitoring of Existing Buildings

2.1 Application Principle

The application of BeiDou technology in monitoring deformation of existing buildings centers on establishing a multi-sensor fusion monitoring system based on high-precision positioning. Through an automated architecture covering "data collection, transmission, analysis, and early warning", this system enables precise detection and dynamic management of structural deformations [1]. The system comprises three core subsystems: 1) The real-time measurement subsystem, centered around BeiDou high-precision terminals, integrates fiber Bragg grating strain gauges, temperature sensors, inclinometers, and wind speed sensors. Utilizing wireless networking technology, it synchronizes comprehensive building status indicators (displacement, settlement, acceleration) with localized parameters (stress, strain, crack progression), achieving static positioning accuracy of 3mm±1ppm (RMS) in planar coordinates and 5mm±1ppm (RMS) in elevation – meeting stringent precision requirements for micro-deformation monitoring. 2) The communication network subsystem employs hybrid wireless-wired transmission modes, utilizing edge computing for data preprocessing and compression to overcome transmission bottlenecks, ensuring efficient data flow to control centers. 3) The control center analysis subsystem serves as the system's core hub, featuring four key functions: optimized monitoring point deployment, structural damage identification, model correction, and safety assessment with graded warnings. Through in-depth analysis of real-time data, it enables dynamic structural safety evaluation and risk alerts.

The precision of Beidou-based deformation monitoring can be classified into four tiers (Tier 1 to Tier 4) according to project requirements. The coordinate error of monitoring points is determined by referencing the reference station, considering both the project's allowable deformation limits and the response time of data processing [3]. Furthermore, the comprehensive deployment of the Beidou Ground-Based Enhanced Network (CORS) significantly improves positioning accuracy and stability, effectively addressing urban positioning challenges and providing reliable technical support for monitoring existing building deformations.

2.2 Core Advantages

Beidou technology demonstrates significant advantages over traditional methods in monitoring deformation of existing buildings. Its core features include high precision and objectivity, enabling millimeter-level static positioning and centimeter-level dynamic positioning. The monitoring data is directly collected by satellites and sensors, eliminating the need for manual intervention and preventing human errors. This system accurately captures minute building deformations, meeting the high-precision monitoring requirements of super high-rise buildings and cultural heritage structures. Additionally, the Beidou system overcomes environmental limitations such as weather and time constraints, allowing 24/7 automated monitoring. It resolves the challenges of traditional monitoring methods in adverse weather conditions and nighttime operations. The real-time transmission of monitoring data to control centers provides critical time for early deformation alerts and emergency response [8].

Beidou technology delivers three key advantages: extensive coverage, cost efficiency, and operational excellence. A single base station can monitor vast areas while rapidly deploying monitoring points across multiple buildings. Minimal staffing is required for equipment maintenance, significantly reducing labor costs, while automated data collection and processing accelerate analysis. Through multi-sensor fusion technology, it simultaneously tracks displacement, settlement, stress, and environmental parameters like temperature and humidity, providing a comprehensive picture of structural deformation. The data is stored long-term as safety records, offering robust support for trend analysis and structural reinforcement [9].

Furthermore, as China's independently developed satellite navigation system, the BeiDou system has achieved full domestic production of its core technologies and key equipment, fundamentally eliminating reliance on foreign technologies and effectively ensuring the security and confidentiality of building deformation monitoring data. With the gradual implementation of technical guidelines by the Ministry of Housing and Urban-Rural Development, the application of BeiDou technology in building monitoring has become increasingly standardized and regulated. Technical requirements for critical aspects such as monitoring point deployment, equipment selection, and data accuracy have been clearly defined, laying a solid foundation for large-scale industry adoption. This also ensures comparability and scalability of monitoring results across different projects [10].

3. Typical Application of Beidou Technology in Monitoring of Existing Building Deformation

The core advantages of BeiDou technology enable it to meet deformation monitoring requirements for existing buildings across diverse types and environments. It has been widely adopted in typical scenarios including super high-rise and tall buildings, old hazardous structures, historical cultural heritage buildings, and structures affected by surrounding engineering projects or geological hazards [2,3,4].

Super high-rise and tall buildings, due to their great height and strong flexibility, are prone to dynamic swaying and settlement under the influence of factors such as wind loads and temperature changes, requiring extremely high monitoring accuracy. In super high-rise building projects such as Shenzhen Ping An Finance Center and Beijing China Zun, by scientifically deploying Beidou monitoring points, developing dedicated calculation algorithms, or adopting a composite monitoring mode of "traditional instruments + Beidou verification," technical challenges such as signal obstruction and error accumulation have been effectively resolved. This enables precise capture of building deformation characteristics, providing reliable data support for building verticality correction and structural safety assessment [4,6].

Due to substandard construction standards and severely aged materials, old and dangerous buildings exhibit concealed and sudden deformation characteristics. In the Beidou Construction Safety Monitoring Demonstration Project promoted by the Ministry of Housing and Urban-Rural Development, multi-sensor fusion monitoring systems have been deployed in old and dangerous building areas across multiple regions nationwide. This system can accurately capture millimeter-level micro-deformations and automatically triggers an early warning mechanism when deformation approaches the threshold. It provides sufficient time for reinforcement and renovation of dangerous buildings and safe evacuation of personnel, becoming a crucial technical measure for the safety management of old and dangerous buildings [2,7].

The monitoring of historical and cultural heritage buildings requires a balance between high precision and non-contact technology. In the infrastructure renovation project of the Palace Museum, a comprehensive monitoring and early warning system was established by deploying BeiDou receivers and integrating various supporting sensors. This system enables real-time monitoring of critical indicators such as subsidence, tilt, and vibration in ancient city walls and buildings. It not only ensures the safe and orderly progress of renovation work but also achieves refined protection of cultural heritage structures, fully demonstrating the applicability and effectiveness of BeiDou technology in long-term deformation monitoring of historical and cultural heritage buildings [3].

Buildings affected by adjacent projects such as subway construction or foundation pit excavation are prone to secondary deformation due to ground subsidence. Existing structures in earthquake-prone fault zones or subsidence-prone areas are susceptible to cumulative deformation caused by geological changes. For these scenarios, the Beidou monitoring system captures real-time deformation data to guide construction teams in adjusting parameters promptly, thereby preventing structural damage. In disaster-prone regions, Beidou technology enables full-cycle monitoring of building deformation, allowing rapid post-earthquake damage assessment and providing scientific data for post-disaster relief and urban planning adjustments [2].

4. Existing Problems of Beidou Technology in Monitoring of Existing Building Deformation

Beidou technology has achieved remarkable results in monitoring deformation of existing buildings. However, multiple factors including technological development stages, industry support systems, and market promotion efforts still pose challenges to its large-scale and standardized application [2,3,5].

The persistently high equipment costs and uneven regional adoption of the system pose significant challenges. The substantial initial investment and ongoing maintenance expenses for Beidou high-precision terminals and supporting equipment make them unaffordable for small and medium-sized cities with lower economic development levels, as well as for public welfare projects like urban renewal in aging neighborhoods. As a result, this technology remains concentrated in major projects within first-tier cities, while its application in monitoring existing buildings in third-and fourth-tier cities and rural areas remains limited.

In complex environments, signals are prone to interference, leading to reduced positioning accuracy. Urban core areas with dense buildings often experience satellite signal blockage and loss of lock. Structures like glass curtain walls generate multipath effects that disrupt signal transmission, while enclosed spaces such as building interiors and underground areas suffer from inadequate signal coverage. Although the integrated inertial navigation and Beidou system technology can partially address these issues, its high cost and technical complexity make large-scale engineering implementation challenging.

The system's multi-source data integration capability remains inadequate, requiring enhanced predictive and early-warning capabilities. The monitoring process involves positioning data, sensor readings, and environmental metrics, yet lacks robust fusion algorithms to support these diverse data sources, with data analysis methods remaining relatively simplistic. The application of intelligent algorithms in predicting deformation of existing buildings is still in its exploratory phase, exhibiting insufficient model accuracy and generalization capacity. Additionally, some monitoring systems experience data processing delays, compromising the real-time responsiveness of early-warning systems.

The standard system remains underdeveloped, with a critical shortage of interdisciplinary professionals. Specialized monitoring standards for various types of existing buildings-including wooden heritage structures and dilapidated brick-concrete buildings-have yet to be established. Key parameters such as monitoring point deployment and warning threshold settings lack unified guidelines. Furthermore, the scarcity of cross-disciplinary experts in satellite navigation, civil engineering, and data analysis impedes the optimization of monitoring systems and in-depth data analysis [3,7].

The data sharing mechanism is inadequate, and comprehensive control capabilities are lacking. Monitoring data are scattered across independent databases of local housing and urban-rural development departments and related enterprises, with no unified national big data platform for building safety. The poor interoperability of data prevents the realization of dynamic, nationwide control over the safety of existing buildings and hinders the full utilization of monitoring data [3,7].

5. Development Strategies of Beidou Technology in Existing Building Deformation Monitoring

To address the existing challenges in applying BeiDou technology for deformation monitoring of existing buildings, this study proposes targeted development strategies from multiple dimensions-technology R&D, industry support systems, policy incentives, and talent cultivation-by aligning with technological trends and practical industry needs, thereby advancing BeiDou technology toward large-scale, standardized, and intelligent applications [2,3,7].

1. Accelerate technology commercialization to reduce equipment costs. Boost R&D investment in Beidou core chips and high-precision terminals, supporting domestic innovation and mass production to cut manufacturing expenses. The government provides equipment procurement and maintenance subsidies for public welfare monitoring projects like old neighborhood renovations, lowering implementation barriers at the grassroots level. Encourage enterprises to develop lightweight, tiered monitoring devices and introduce affordable terminals to meet diverse scenario-specific needs.

2. Optimize signal enhancement technologies to improve adaptability in complex environments. Accelerate nationwide coverage of the BeiDou ground-based augmentation network to enhance positioning accuracy in urban complex environments; refine the inertial navigation + BeiDou integrated positioning technology to achieve miniaturization and cost reduction of integrated devices. Eliminate multipath interference through data preprocessing, and develop BeiDou signal relay equipment to achieve full coverage monitoring in enclosed scenarios such as building interiors and underground spaces.

3. Enhance multi-source data integration to improve deformation prediction and early warning capabilities. By leveraging AI and big data technologies, develop multi-source data fusion algorithms and construct integrated

analytical models to uncover data correlations. Tailor intelligent algorithms and establish specialized prediction models based on the structural characteristics and deformation patterns of different building types. Develop efficient real-time data processing software to reduce computational latency, enabling a shift from passive monitoring to proactive early warning systems.

4. Enhance the industry standard system and cultivate interdisciplinary talents. Expedite the development of specialized Beidou monitoring standards for various types of existing buildings, establishing comprehensive monitoring protocols to standardize technical applications. Universities should introduce interdisciplinary courses integrating satellite navigation and civil engineering, while housing and urban-rural development authorities collaborate with industry associations to conduct specialized technical training. Deep industry-academia-research partnerships should be encouraged to drive innovation and commercialization of Beidou monitoring technologies.

5. Establish a unified national big data platform to enable data sharing and comprehensive oversight. By leveraging the national, provincial, and municipal-level Beidou-based building safety monitoring service platforms, we will consolidate regional monitoring data to create a centralized national building safety big data center, while refining cross-departmental data-sharing mechanisms. Utilizing big data and cloud computing technologies, we will conduct in-depth analysis of monitoring data to identify patterns in building deformation, thereby providing data-driven support for formulating building safety policies and disaster prevention measures, ultimately achieving dynamic, nationwide monitoring of existing building safety.

6. Future Outlook

With the comprehensive deployment and optimization upgrade of the BeiDou-3 Global Navigation Satellite System, its application prospects in the field of existing building deformation monitoring are highly promising, steadily advancing toward multi-technology integration, functional diversification, deepened localization, and large-scale application [2,4,7]. BeiDou technology will deeply integrate with cutting-edge technologies such as Building Information Modeling (BIM), the Internet of Things, and digital twins to construct a visualized digital twin monitoring system, further enhancing intelligent monitoring capabilities. Monitoring functions will expand from traditional displacement and settlement monitoring to comprehensive multi-dimensional monitoring including structural stress and material durability, while adding value-added services like environmental monitoring and fire safety status monitoring to achieve integrated lifecycle management of existing buildings. Through continuous innovation in domestic technologies and equipment, a fully autonomous monitoring technology system will be established, promoting international cooperation and achievement export of BeiDou technology. With gradual reduction in equipment costs and continuous improvement of industry standards, BeiDou technology will gradually spread from first-tier cities to urban and rural areas, becoming a routine technical means for existing building safety management and providing strong technical support for safe city construction.

7. Conclusion

The BeiDou Navigation Satellite System (BDS) has effectively addressed the limitations of traditional building deformation monitoring through its core advantages of high-precision positioning, round-the-clock continuous monitoring, and automated data collection. It has been widely implemented in various scenarios including super high-rise buildings, dilapidated structures, and historic cultural heritage sites. These applications have fully validated its technical feasibility and practical value, providing scientific data support for structural safety assessments and disaster prevention in existing buildings. This system plays a crucial role in safeguarding public safety and driving the transformation and upgrading of the construction industry.

Currently, the application of BeiDou technology still faces challenges in cost control, signal anti-interference, data fusion, standardization, talent supply, and data sharing. These bottlenecks need to be addressed through measures such as advancing technological industrialization, optimizing signal enhancement techniques, refining data fusion algorithms, improving standard systems, and establishing a unified data platform. In the future, with the continuous development of the BeiDou-3 system and the deep integration of multidisciplinary technologies, BeiDou technology will achieve large-scale, standardized, and intelligent applications in the field of existing building deformation monitoring. It will become a critical infrastructure for smart cities and building safety management, providing stronger technical support for the structural safety management of existing buildings in China.

References

[1] Liu W. BeiDou high-precision technology in safety monitoring schemes for large-span structures and oversized buildings [J]. Construction Science and Technology, 2016(6):45-47.

[2] Guo Liqiao. Application prospects of Beidou high-precision technology in the field of building safety[J]. Construction Science and Technology, 2016(6):14-15.

[3] Wang Shudong. Application research of Beidou system in building safety monitoring [J]. Surveying and Spatial Geographic Information, 2018,41(2):40-42.

[4] Yue Guohui, Zhang Shengliang, Jiao Junjuan. Application of Beidou in construction surveying [J]. Satellite Applications, 2025(3):48-51.

[5] He Q. Research on Construction Safety Monitoring System Based on BeiDou [J]. BeiDou and Space Information Application Technology, 2024(3):6-11.

[6] Zhao J, Bai C, Shi QJ, et al. A deformation monitoring method for super high-rise buildings based on improved Beidou satellite navigation [J]. Journal of Shenyang University of Technology, 2022,44(4):426-430.

[7] Editorial Department of this journal. Promoting the Application of "Beidou" in Construction Safety [J]. Construction Science and Technology, 2016(6):1.

[8] Ministry of Housing and Urban-Rural Development of the People's Republic of China. JGJ 8-2016 Code for Measurement of Building Deformation [S]. Beijing: China Architecture & Building Press, 2016.

[9] Lin C, Zou J, Huang J. Application of high-precision measurement receiver based on Beidou in displacement monitoring[J]. Surveying and Mapping Bulletin, 2015(2):61-66.

[10] Peng S, Liu JK, Zhang YL, et al. Deformation analysis of highway rock slopes excavated based on the BeiDou-3 remote monitoring system [J]. Science and Technology in Engineering, 2022,22(33):14898-14906.

