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Research on Bridge Tower Misalignment and Grouting Accuracy Control Based on Gnss Displacement Monitoring and Intelligent Hydraulic Control System

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ABSTRACT

With the rapid development of bridge engineering, the requirements for construction accuracy are becoming increasingly high. In response to the shortcomings of existing control methods in dynamically changing environments, this study proposes an intelligent control strategy that integrates neural networks. Real time monitoring of bridge structure displacement through global navigation satellite systems, and dynamic adjustment of cable forces through intelligent hydraulic systems to achieve precise control. The research results show that the algorithm has a steady-state error of 0.0327% under large disturbances, a signal-to-noise ratio of 35.832 dB, and a computation time of 55.291 ms, demonstrating good control performance and robustness. This study has important theoretical and practical significance for improving the accuracy and structural safety of bridge construction.

KEYWORDS

Structural Health Monitoring, GNSS, Intelligent Hydraulic Control, Neural Network PID, Bridge Construction Accuracy

INTRODUCTION

In the engineering sector today, the longevity and safety of vital infrastructure, such as bridges, are major concerns (Deng et al., 2021). Bridge stability, a critical component of the transportation network, is closely linked to economic benefits and public safety. Structural health monitoring technology has attracted significant interest. However, conventional monitoring techniques depend on limited sensor networks and routine manual inspections, both of which have notable drawbacks, including poor data processing capabilities, limited coverage, and inadequate real-time performance (Qiu et al., 2023). Meanwhile, displacement monitoring is essential for preventing and minimizing structural damage during bridge construction and operation (Ding et al., 2021). Although current

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technologies offer certain monitoring capabilities, they are often constrained by the distribution density of sensors, data collection frequency, and the accuracy of analysis methods. These limitations have hindered understanding of the dynamic behavior of bridge structures, particularly under complex environments and loads. Moreover, traditional control methods lack adaptability and precision in dynamically changing environments, making it difficult to meet growing demands for construction accuracy (Chen et al., 2018). To address these shortcomings, a new strategy combining global navigation satellite system (GNSS) displacement monitoring and an intelligent hydraulic control system is proposed for bridge tower misalignment and grouting accuracy control. The innovation of this research lies in integrating advanced neural network technology, enhancing construction accuracy and structural safety through real-time monitoring and intelligent control. Furthermore, the study explores the application of cable hoisting, the cable-stayed suspension method, and catenary cable shape theory in bridge construction, as well as the optimization of construction processes through intelligent algorithms. This research aims to improve monitoring and control accuracy, enhance system robustness and adaptability, and provide new solutions for precision control in bridge construction.

LITERATURE REVIEW

Intelligent control systems, particularly proportional–integral–derivative (PID) controllers, have been widely applied in precision control research for bridge construction. Although traditional PID controllers perform well in stability and response speed, they often exhibit insufficient steady-state accuracy and poor noise resistance when handling nonlinear and complex disturbances. To address these issues, many studies have introduced intelligent PID control strategies, such as Fuzzy PID control and neural network PID control. Intelligent PID strategies incorporate Fuzzy logic or machine learning algorithms to adaptively adjust control parameters, thereby enhancing system stability and response accuracy under large disturbances. Dong & Ye (2023) proposed a bridge tower tube adjustment method based on Fuzzy PID control, demonstrating through experiments that the method maintains small steady-state errors under strong winds and other external disturbances.

Traditional bridge construction control methods primarily involve mechanical control and manual operation, which directly manage the hydraulic system or utilize traditional sensors for position monitoring. These methods have notable limitations, especially in complex construction environments, making it difficult to achieve sufficient control accuracy. For instance, hydraulic systems often suffer from low accuracy and are constrained by environmental noise and equipment performance, resulting in significant tower misalignment deviations. Additionally, manual operations introduce inherent errors, limiting the ability to achieve high-precision real-time control.

With the advancement of GNSS technology, increasing research has adopted GNSS as a displacement monitoring tool in bridge construction. GNSS provides high-precision position information, offering significant advantages in large-scale engineering projects. Studies have shown that GNSS effectively monitors key component displacements, such as towers, delivering real-time data for precision control. By integrating GNSS with hydraulic control systems, construction personnel can adjust control strategies promptly and reduce construction errors. For example, Fan et al. (2023) utilized GNSS technology to monitor tower displacement and combined it with a PID control strategy, significantly improving accuracy. Traditional PID controllers often exhibit shortcomings in static error, particularly after large disturbances or prolonged operations, leading to substantial steady-state errors. In contrast, intelligent PID control strategies, such as Fuzzy PID or adaptive PID, dynamically adjust control parameters to effectively reduce steady-state errors. In tower misalignment control, intelligent PID strategies can maintain the steady-state error within an extremely low range (e.g., 0.0327%) under large disturbances, substantially improving control accuracy.

In complex construction environments, noise interference is unavoidable. Traditional PID methods exhibit weak noise resistance, significantly affecting control accuracy. Intelligent PID strategies effectively suppress noise interference and enhance system stability by incorporating Fuzzy logic and

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