Advancing Bridge Safety Through Affordable GNSS-Based Continuous Monitoring

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Key words: Bridge surveying; Deformation measurement; Engineering survey; GNSS monitoring; · Structural health monitoring (SHM); · Bridge engineering; · Low-cost sensors; · Raspberry Pi; · Displacement analysis

SUMMARY

This research project investigates the potential of low-cost, continuous monitoring of bridges and other civil engineering structures using Global Navigation Satellite Systems (GNSS). The objective is to develop and validate a cost-efficient methodology capable of providing reliable and precise information on structural displacements and deformations, thereby enabling early damage detection and improving structural safety and maintenance strategies.

Conventional monitoring techniques—such as periodic levelling or complex sensor-based systems—require significant financial and human resources, which limits their application to a small number of high-priority or already damaged structures. Continuous monitoring, although methodologically advantageous, has therefore remained largely impractical for broad implementation. Yet, permanent observation is essential for detecting gradual or cyclic changes at an early stage, facilitating preventive maintenance and avoiding critical failures or traffic disruptions.

Building upon long-term research at the Berlin University of Applied Sciences (Berliner Hochschule für Technik), a modular GNSS-based monitoring system has been developed using cost-effective, freely programmable Raspberry Pi units. The system combines GNSS receivers with auxiliary sensors—such as temperature, humidity, inclination, and acceleration sensors—enabling versatile adaptation to various structural types and site conditions. The cost per measurement point is approximately 30–40% of conventional commercial systems, offering a scalable approach for large-scale deployment.

Continuous acquisition of positional data allows the detection of structural displacements on the order of 5 mm, which can be correlated with environmental data to distinguish temperature- and

moisture-induced deformations from load- or damage-related movements. This integration of structural and environmental information provides a more comprehensive understanding of the behaviour of bridge structures than periodic measurements, typically conducted on weekly or monthly intervals.

Despite the slightly lower point accuracy compared to classical terrestrial surveying, continuous data series provide higher analytical value, as cyclical and environmental influences can be statistically filtered and compensated. The results demonstrate that low-cost GNSS monitoring can achieve sufficient precision for the early detection of structural anomalies while significantly reducing system costs and maintenance demands.

The proposed system thus represents a viable step toward cost-efficient, digitalized structural health monitoring. Its scalability and affordability open new perspectives for preventive infrastructure management, extending the service life of bridges and mitigating the economic and societal impacts of unexpected structural failures.