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Structural Health Monitoring System for Large Structures Using Wireless Sensor Networks: A Machine-Learning Enabled Edge Computing Approach

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Abstract

Structural Health Monitoring (SHM) is critical for the safety, durability, and longevity of critical infrastructures ranging from buildings to very big structures such as wind turbines, and bridges. In traditional cloud-based SHM systems, high latency, energy consumption, and low scalability are the challenges. By integrating Machine Learning (ML) with edge computing via Wireless Sensor Networks (WSNs) leveraging device learning, we propose a new approach to address these issues. Deep Neural Networks (DNNs) are directly deployed on edge devices for real-time data analysis and anomaly detection at sensor nodes using the framework. Thus, it reduces the need for continuous data transmission to the centralized servers, reduces energy consumption, and improves system efficiency. Real-time data are collected from key sensors, such as accelerometers and strain gauges, and processed locally by DNNs. Adaptive retraining is enabled by drift detection algorithms, which allow response to changing structural conditions. The findings show that DNNs on the device provide both latency and scalability benefits and are unable to accurately classify clean as well as noisy sensor data. On-device learning in combination with adaptive retraining to keep the system accurate and reactive to changing structural conditions. This proposed system also finds a quantized model using TensorflowLite, for optimizing DNN deployment on resource-constrained devices, to reduce computational overhead and memory footprint, while maintaining acceptable inference accuracy for real-time processing and data transmission. This research also provides a scalable, adaptive solution for real-time infrastructure monitoring, as well as new avenues for adaptive re-training, predictive maintenance, and energy harvesting for Structural Health Monitoring.

Keywords: *Structural Health Monitoring, Wireless Sensor Network, Edge Computing, On-Device Learning, Adaptive Retraining*