PROJECT ABSTRACT

Bridge Vibration Structural Health Monitor

A classroom-scale structural health monitoring loop: an MPU6050 accelerometer on an ESP32 samples a model bridge girder at 100 Hz, streams to a cloud dashboard, and the pipeline extracts modal frequencies via FFT, compares them against design estimates, and tracks long-term drift as a damage indicator — built-to-order with hardware, firmware, dashboard, report, PPT and viva kit.

01. Title

Bridge Vibration Structural Health Monitor

02. Introduction / Background

Bridges are inspected visually on schedules, but structural damage — a cracked girder, a loosened bearing — changes how a bridge vibrates long before it is visible. Structural health monitoring (SHM) is the engineering answer: measure the vibration signature, and watch the modal frequencies drift as stiffness is lost. Full SHM installations cost lakhs, so students study the theory without ever touching it. This project is a working, classroom-scale SHM loop: an accelerometer node on a model bridge girder samples at 100 Hz and streams to the cloud; the pipeline computes RMS acceleration, runs an FFT, picks the modal peaks, and compares each mode against the design estimate. A 30-day drift chart makes the core SHM principle tangible: healthy structure, flat line; stiffness loss, downward drift past the alert band. The dashboard also logs events — heavy-vehicle passes, wind gusts — so the student learns to separate normal excitation from structural change, which is the actual skill in vibration monitoring.

03. Problem Statement

Vibration-based health monitoring is taught as theory (modes, FFT, damping) while the sensing pipeline — sampling, streaming, spectral analysis, baseline comparison, drift tracking — stays abstract. Students need a hands-on loop where they can watch a bridge's “notes” in the spectrum, see a heavy vehicle pass as an RMS spike, and understand why a slow downward drift of the first mode is the damage signature inspectors look for.

04. Objectives

- Sample 3-axis acceleration at 100 Hz from an MPU6050 on an ESP32 and stream it to the cloud.
- Display the live time-domain waveform with RMS over 10-minute windows against a 0.15 g alert threshold.
- Compute the FFT spectrum with automatically marked modal peaks (1st/2nd bending, 1st torsion, 3rd bending).
- Compare measured modes against design estimates (1st bending design 4.9 Hz) with per-mode drift percentages.
- Track 30-day 1st-mode drift inside a ±2% healthy band; sustained drift beyond ±5% raises an inspection alert.

- Log excitation events (vehicle passes, wind gusts) alongside vibration data.
- Provide a baseline calibration procedure for the student's own model bridge.

05. Proposed Methodology

The MPU6050 (±2 g range) samples at 100 Hz — resolving modes up to the 50 Hz Nyquist limit, adequate for the model bridge; the report states this bound explicitly. The ESP32 batches and streams over Wi-Fi. The cloud pipeline computes rolling 10-minute RMS and runs an FFT per window; peak detection identifies the modal frequencies, which are compared against the documented design estimates from the model bridge's calculation (measured 4.82 Hz vs design 4.90 Hz for the 1st bending mode, Δ –1.6%, in the demo). Daily baseline FFTs feed the 30-day drift chart. Temperature-induced stiffness changes are discussed as a confounding factor. Drift-as-damage is demonstrated as a principle; the demo structure is not actually damaged — deliberately damaging the model is an optional, documented student experiment.

06. System Architecture / Working

Accelerometer node (ESP32 + MPU6050 bolted to the model girder, battery) → Wi-Fi → cloud ingestion (MQTT/HTTP) → pipeline (RMS, FFT, peak detection, baseline comparison, drift tracking, time-series storage) → dashboard (dominant frequency, RMS, status pill, live time-domain chart, modal comparison table, FFT spectrum with marked peaks, event log, 30-day drift chart). The working flow is: mount the node on the model bridge → establish the healthy baseline → watch live modes and events → track drift over weeks → document findings for the report.

07. Hardware / Software Requirements

- ESP32 development board; MPU6050 accelerometer module; battery pack
- Model bridge girder (documented design with modal estimates); rigid accelerometer mount
- Wi-Fi network at the installation point
- Cloud ingestion endpoint + time-series storage (documented setup)
- Dashboard web app with canvas charts (included)

08. Expected Outcomes

A live dashboard showing the model's signature (1st bending 4.82 Hz, RMS 0.031 g, NORMAL status with drift inside the ±2% band), the FFT spectrum with four marked modes, and an event log distinguishing a heavy-vehicle pass (0.118 g peak, within limit) from a mode-3 drift watch — the student learns to separate excitation from structural change.

09. Applications

- Structural-health-monitoring and vibrations coursework
- Demonstrating FFT and modal analysis on real data
- Civil-instrumentation teaching with a model structure
- Template for machine-vibration monitoring projects

10. Future Scope

- Multi-node arrays for mode-shape estimation

- Wireless time-synchronised sampling across nodes
- Temperature compensation of drift
- On-device FFT to reduce transmitted data