Phase 2: Innovation & Problem Solving

Title: Structural Health Monitoring System Using IoT and Sensor Networks

Innovation in Problem Solving

Traditional structural inspections are time-consuming, costly, and sometimes miss early signs of damage. A continuous and automated SHM system is required to enhance safety and reduce maintenance costs

Core Problems to Solve

1. Data Acquisition & Sensor Challenges

- **Optimal Sensor Placement**: Determining the best locations and types of sensors (e.g., accelerometers, strain gauges, fibre optics) for effective damage detection.

2. Feature Extraction & Signal Processing

- **Damage-Sensitive Feature Selection**: Identifying key parameters (e.g., natural frequencies, mode shapes, damping ratios) that reliably indicate damage.

3. Damage Detection & Localization

- **False Alarms & Missed Detections**: Reducing Type I (false positive) and Type II (false negative) errors.
- **Localization Accuracy**: Pinpointing damage location precisely, especially in complex structures.

4. Damage Quantification & Prognostics

- **Severity Assessment**: Estimating the extent of damage (e.g., crack length, stiffness reduction).

Innovative Solutions Proposed

1. **Distributed Fiber Optic Sensing (DFOS) + IoT Mesh**

    - Deploy **optical fibres along critical load paths** to measure strain/temperature at **millimetre-scale resolution**. Use **Brillouin Optical Time-Domain Analysis (BOTDA)** for distributed sensing

2. **Edge-AI for Real-Time Anomaly Detection**

- **Tiny ML models** (e.g., quantized CNNs, autoencoders) running on **edge devices** (e.g., NVIDIA Jetson, Raspberry Pi + AI accelerators).
- **Federated Learning** to improve models across multiple structures without centralized data.
- **Adaptive Thresholding** to reduce false alarms under varying environmental conditions.

3. **Blockchain for Tamper-Proof Data Logging**

- Store critical SHM metrics (e.g., strain peaks, crack propagation) on a private blockchain. Use smart contracts to trigger automated inspections when thresholds are breached.
- Advantage**:** Ensures auditability and compliance for high-stakes infrastructure.

4. **Digital Twin Integration for Predictive Maintenance**

- Sync real-time sensor data with a **physics-informed digital twin** (FEM + ML hybrid).**Prognostic algorithms** predict remaining useful life (RUL) based on fatigue models.
- **Advantage:** Enables condition-based maintenance, reducing downtime.

Implementation Strategy

1. **Sensor Deployment:** Installing sensors such as accelerometers, Strain gauges, and Fibre Optic sensors to continuously monitor the Structural conditions
2. **Data Acquisition &processing:** detecting anomalies and predicting failures by using real-time data collection and AI-driven data analytics
3. **Maintenance:** to determine the infrastructure health and optimize maintenance Scheduling using AI-based predictive models
4. **Damage detecting algorithms:** structural weakness can be identified before critical failure can be prevented by using change Tracking AI

Challenges and Solutions

- **Sensor reliability and placements:** making sure that the sensor functions are accurate and positioned optimally
- **Data overload and processing:** Managing a large amount of real-time Data and using it efficiently
- **Cost & Maintenance:** high initial Investment and ongoing Maintenance expenses
- **Advanced Sensor Technology:** Using durable, self-powered sensors to improve reliability.
- **Cost-Effective Monitoring Systems:** Developing wireless and low-maintenance sensor networks.

Expected Outcomes

- **Early damage detection:** identifying structural weakness before it becomes critical
- **Extended Lifespan:** Regular monitoring of the Structure helps in prolonging the life of the infrastructure
- **Safety Assurance:** preventing sudden failures in the Structure and safeguarding human lives
- **Cost Saving:** Reducing maintenance costs by enabling predictive maintenance

Next Steps

1. **Prototype Testing**: Deploy the prototype among a small test group to collect feedback to improve the system's ease of use, accuracy, and reliability.

2. **Continuous Improvement**: Based on feedback, iterate on the design, improve AI accuracy, enhance user interfaces, and expand language support.

3. **Full-Scale Deployment**: After successful testing, plan the deployment of the full-scale solution, focusing on Structural healthcare providers or clients in need.