Kalman Filter-Based Real-Time Structural Condition Monitoring

Dr. Radhika M N[1], Akshay Kumar K S[2], Chandana T D[3], Chirag D[4], Dhanush D S[5]

Department of Electronics and Communication Engineering P.E.S College of Engineering, Mandya, Karnataka, India

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Abstract - *This project presents a real-time structural condition monitoring system using a Kalman Filter to enhance the accuracy of sensor data. The system utilizes an ESP32 microcontroller integrated with MPU6050 (accelerometer and gyroscope), strain gauge, and temperature sensor to measure structural parameters. Due to noise and environmental disturbances, sensor readings are filtered using the Kalman Filter for accurate estimation. The ESP32's Wi-Fi capability enables real-time data transmission for monitoring. The proposed system ensures continuous observation, early fault detection, and improved reliability, providing an efficient and cost-effective solution for structural health-monitoring-applications.*

Key Words: Structural Health Monitoring, Kalman Filter, ESP32, IoT, MPU6050, Strain Gauge, Real-Time Monitoring

1.INTRODUCTION

Structural health monitoring is essential for ensuring the safety and durability of structures such as bridges and buildings. Traditional methods are manual and may fail to detect early damage. This project presents a real-time monitoring system using an ESP32 microcontroller integrated with MPU6050, strain gauge, and temperature sensor to measure structural parameters. Sensor data is often affected by noise, which is reduced using a Kalman Filter for accurate estimation. The ESP32 enables wireless data transmission through Wi-Fi. The system provides continuous monitoring, early fault detection, and a cost-effective solution for maintaining structural integrity.

2. PROBLEM STATEMENT

Structural failures in infrastructures such as bridges and buildings occur due to undetected cracks, vibrations, and material degradation. Traditional inspection methods are manual, time consuming, and lack real-time monitoring, leading to delayed detection and increased risks. Existing systems also generate large amounts of raw data without proper analysis.

This project proposes an IoT-based structural health monitoring system using ESP32, MPU6050, strain gauges, and temperature sensors. Sensor data is analyzed to detect anomalies, while a Kalman filter improves accuracy. A web dashboard provides real-time visualization and alert Notifications, enabling early damage detection, efficient maintenance, and improved structural safety.

3.OBJECTIVES

- To develop an IoT-based structural health monitoring system using ESP32, MPU6050, strain gauges, and temperature sensors for continuous real-time data collection.
- To enhance data accuracy using a Kalman filters for reliable monitoring and decision making.
- To design a web-based dashboard that visualizes real-time data and provides instant alerts for abnormal conditions, enabling timely maintenance and improved structural safety.

4.HARDWARE COMPONENTS

4.1 ESP32 Development Board

The ESP32 is a powerful microcontroller with built-in Wi-Fi and Bluetooth capabilities. It acts as the central controller for data acquisition, processing, and wireless communication.

4.2 MPU6050 Sensor

The MPU6050 combines a 3-axis accelerometer and 3-axis gyroscope for measuring vibration, acceleration, and orientation parameters.

4.3 Power Supply

A rechargeable Li-ion battery is used to provide stable power to the monitoring system.

4.4 Jumper Wires and Breadboard

These components are used for establishing circuit connections and prototyping.

5.WORKING MECHANISM

The proposed Structural Health Monitoring (SHM) system operates by continuously collecting structural data using multiple sensors integrated with the ESP32 microcontroller. The collected raw sensor data often contains noise and fluctuations caused by environmental disturbances and sensor inaccuracies. To improve measurement reliability, the ESP32 processes the sensor readings using a Kalman filter algorithm. The Kalman filter estimates accurate values by reducing unwanted noise and smoothing the sensor output.

Fig -1: Kalman SHM Dashboard

The MPU6050 sensor measures vibration and acceleration parameters, the strain gauge detects structural deformation, and the DHT11 sensor monitors environmental conditions such as temperature.

The ESP32 acquires raw sensor readings and processes them using a Kalman Filter algorithm to reduce measurement noise and improve data accuracy. The filtered sensor information is transmitted wirelessly through the ESP32 Wi-Fi module to a cloud platform or web dashboard for real-time monitoring.

When sensor values exceed predefined threshold limits, the system generates warning alerts for early fault detection and preventive maintenance. The entire process operates continuously, ensuring reliable real-time structural condition monitoring and improved infrastructure safety.

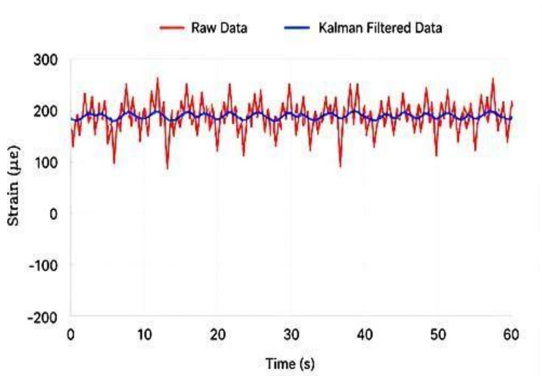

Fig -2: Raw vs Kalman filter

6. RESULTS AND DISCUSSION

The proposed Structural Health Monitoring (SHM) system was successfully implemented using ESP32, MPU6050, strain gauge, and DHT11 sensors. The sensors collected real-time structural data, and the Kalman Filter was applied to reduce noise and improve measurement accuracy. The processed data was transmitted through Wi-Fi and displayed on the SHM dashboard for monitoring.

The comparison between Raw Data and Kalman Filtered Data showed that the Kalman Filter reduced fluctuations and provided smoother and more reliable sensor readings. The system successfully monitored vibration, strain, and temperature values while providing real-time alerts for abnormal conditions. The developed system offers an efficient and low-cost solution for structural safety monitoring.

7. CONCLUSIONS

This project developed a Kalman Filter-Based Real-Time Structural Health Monitoring System using IoT and AI technologies. The system continuously monitored structural parameters and improved sensor accuracy through Kalman Filtering. Real-time monitoring and alert generation helped in early fault detection and preventive maintenance.

The proposed solution is reliable, cost-effective, and suitable for monitoring bridges, buildings, and other infrastructure systems to improve safety and maintenance efficiency.

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