Anomaly Detection in Engineering Structures Using WSN and Machine Learning

Nileema Pathak, Suryakant Patil, Preeti Patil

Abstract—Wireless Sensor Networks are widely used for data acquisition in wide areas of applications like Health care, agriculture, surveillance etc. MEMs technology enables development of highly efficient, minute sensors. One of such applications of Wireless Sensor Networks (WSN) is monitoring the engineering structures, for damage detection and characterization. WSN technology is used for detecting the level of damage in huge bridge structures in metros and cities. Various technologies like wi-fi, zigbee, Bluetooth etc are used in the existing system for communication between nodes of the WSN. A novel method using RF technology for WSN is proposed that enables the coverage of a large area and higher data transfer speed.

Novel methods of data analysis using machine learning also needs to be explored, to generate incepts to the huge amount of data generated by sensors. Localization or finding the exact location of the problem area in the sensor network is a tedious task and can be handled well by using machine learning algorithms.

Keywords— WSN, sensor nodes, RF technology, Machine Learning

I. INTRODUCTION

Structural health monitoring (SHM) is at most necessary due to recent incidents of accidents and casualties caused due to negligence in designing and constructing various structures like bridges, buildings, dams, wind turbines and various other forms of infrastructure. IOT and Wireless sensors can be used to monitor various parameters like pressure, level of water, acceleration in relation to the structure that needs to be monitored.

Wireless Sensor Networks are a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location. WSN is a promising technology as they support mobility, are scalable and consume less power.

Wireless sensor network (WSN) is made up of many a thousands of tiny, low power, low cost devices that consist of a processing unit, a sensor and a communication device together called sensor nodes.

These nodes acquire data from their surrounding, and transfer this sensed data to a centrally connected node called coordinator or sinks for aggregating and processing. These nodes work in collaboration with each other. The sensor can be designed to sense various parameters such as temperature, pressure, sound, moisture, weather, and optical sensors. Developing and implementing efficient algorithms that are suitable for many different application scenarios is a challenging task due to various constraints like energy, memory, range etc. WSN designers have to address common problems related to data collection and storage, data reliability, localization, power consumption for routing, fault detection and security.

II. LITERATURE REVIEW

1. Mohammad Abu Alsheikh, Shaowei Lin , Dusit Niyato and Hwee-Pink Tan in their paper “Machine Learning in Wireless Sensor Networks: Algorithms, Strategies, and Applications” have discussed the use of machine learning to solve common issues in wireless sensor networks.[2]

2. Abid, Zeeshan, Raushan & Syed in their paper related to design of Wireless Sensor Network using Arduino and nRF24L01(+) have discussed about using nRF24L01 for RF communicating between nodes of wireless sensor networks.[11]


III. IMPROVING PERFORMANCE

A. Using Machine Learning

Machine learning is all about detection of consistent patterns in performance of any system, training the system to predict future actions and using these predictions to improve the performance of the system.

WSN are deployed in complex environments using mathematical models. Machine learning methods can be used to discover important correlations in the sensor data and propose improved sensor deployment for maximum data coverage.

B. Limitations of using Machine Learning in WSN

Many Machine Learning techniques are computationally expensive. Utilizing them in wireless sensor networks may have negative effects depending upon how often the calculations are done [2]. Limitations of using Machine Learning in WSN are:
Anomaly Detection in Engineering Structures Using WSN and Machine Learning

- Resource Constraint
- Tradeoff between algorithm complexity and the model.
- Dynamic environment
- Data acquisition from remote locations
- Large amount of data

IV. EXISTING SYSTEM

Systems used for structural health monitoring are based on Internet of Things technologies. This system is composed of:

- Bridge Monitoring devices consisting of various sensors
- Communication devices connecting the sensors and the cloud based server used for data analysis
- A dynamic database on the cloud server to analyze data

![Diagram of Existing System](image1)

A. Arduino Board

The Arduino Uno is a microcontroller processing unit based on the ATmega328. It has 14 digital input/output pins, 6 analog inputs.

B. Accelerometer

ADXL335 is a low power, 3 axis accelerometer. ADXL335 IC generates an Analog output. The Accelerometer requires no external devices and works on 5V power supply. It can be directly connected to ADC of a microcontroller. This module can be used to sense motion or angle of tilt in 3 axis. The ADXL335 is a triple axis MEMS accelerometer with extremely low noise and power consumption. The sensor has a full sensing range of +/-3g. By measuring the echo pulse width, the distance to target can easily be calculated.

C. Sensors

- Accelerometer – It is used to measure the vibrations. In the bridge monitoring system it measures the change in frequencies generated due to vibrations occurring in bridge while any heavy vehicle passes over it.
- Ultrasonic Sensor – It is used to measure the level of water. In the bridge monitoring system it measures the water level above the surface of bridge.
- Flex Sensor – It is used for measuring the Angle Displacement, Bends and Flexes within the bridge surface.

D. Communication Module

GPS Module: This Global Positioning System is compatible with UART capable devices including Arduino, Raspberry Pi, MSP430, and MSP432. It is designed to automatically acquire satellite signals and a position fix. Once it has a position fix the on board LED will blink. This LED will continue to blink while the module has a position fix.

GSM Module: This Global System for Mobile Module can work with any GSM network operator SIM card and can be used as a mobile phone with its unique identity number. The IMEI (International Mobile Equipment Identity) number similar to mobile phones can be used for identification purpose. In case of serial connection, the Rx of GSM needs to be connected to Tx of Arduino, and vise versa.

Drawback of Existing System

- Large number of such modules are required to cover the whole area of the bridge.
- Not cost effective
- Finding the exact location of the damaged site is difficult

V. PROPOSED SYSTEM

Proposed system can be designed using Wireless Sensor Networks (WSN). WSN is a wireless network that consists of base stations and numbers of nodes (wireless sensors). These networks are used to monitor physical or environmental conditions like sound, pressure, temperature at various locations spread out at a distance. Data collected from these sensors are passed through the wireless sensor network to a main location. The significant cost reductions of using WSNs for SHM would enable their utilization in important public and private infrastructure and increase the use of applications such as short-term structural monitoring.

Wireless Sensor Network can be used to monitor the condition of engineering infrastructure at real time. WSN is a Wireless ad-hoc network that connects various sensors to the network. Real time sensor data is connected and sent on the network. Networks are formed instantly so that sensor data can be transported wirelessly.

![Diagram of Wireless Sensor Network](image2)

VI. IMPLEMENTATION

Wireless sensor network system is built using many hardware and software components. Each node consists of a processing unit like Arduino Mega, UNO or Nano, Raspberry Pi or Node MCU, a communication module (nRF24L01 module) and a accelerometer. The nodes are labeled as either sink node or source node depending on their functionality in the network. The sink node is the Base node. It works as a coordinator node in the network. The other nodes called source nodes connect to the sink node to send their data for processing.

Nrf24L01 modules are used for communicating between nodes. nRF24L01 is a radio transceiver which is mounted on a single chip. It operates in the 2.4 - 2.5 GHz ISM band. The transceiver consists of a modulator and a demodulator.
A. nRF24L01 Features
- Its Operating Voltage is 3.3V and it requires nominal operating current of 250 mA.
- Operating range is as good as 50 – 200 feet
- Baud Rate is between 250 kbps - 2 Mbps.
- Channel Range: 125
- Maximum 6 Pipelines or simultaneous node connections can be established.
- Communications between the processor and RF module can be done using Maniacbug’s and tmhio RF24 library.

B. Nrf24l01 RF Transceiver
The RF Transceivers can behave as a transmitter as well as a receiver. To make it work as a sensor network, synchronization of the switching between the receiver and transceiver mode of the RF modules is crucial. To make it work seamlessly the nodes need to be properly calibrated. The transmission delay between the sensor sink node and the source node is calculated at the design stage. Then in implementation stage all nodes are calibrated to use this delay time as their time outs setting. The nRF24L01 can receive up to 6 channels of radio communication open in a receiving or read mode simultaneously [1].

VII. RESULTS
1. 'Vibration' is the main parameter in any kind of Bridge fall. "Regular and Irregular Vibrations of the Bridge" are analyzed on a cloud server. Results obtained with three types of accelerometers namely piezoelectric, piezoresistive and capacitive type are compared and analyzed. The Arduino compares those calibrated (subtracted) values with predefined limits. If the values are higher than the predefined values, then an alert message are generated.

<table>
<thead>
<tr>
<th>Accelerometer Reading/Time slot</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Axis</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>3</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>Y Axis</td>
<td>-1</td>
<td>-1</td>
<td>2</td>
<td>-2</td>
<td>-4</td>
<td>-6</td>
<td></td>
</tr>
<tr>
<td>Z Axis</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-2</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1. REGULAR VIBRATIONS

The readings of the 'Device' is sent to the cloud service wherein a graph is included which will plot the readings (values) of the accelerometer sensor in real time. The cloud services used are based on 'Adafruit IO' based on MQTT(Message Queuing Telemetry Transport) protocol which is a messaging protocol for resource constrained devices.
3. Machine learning algorithms are used to efficiently find the areas on the bridge that vibrate abnormally, by forming cluster of normal vibration readings and abnormal vibration readings. Clustering and Classification Techniques can be used for Anomaly detection in Wireless Sensor Networks.

VIII. CONCLUSION

In this paper, a system proposing the use of Wireless sensor Networks for monitoring the bridge structure for possible damages is discussed. WSN constraints and benefits are put forth. The features of nRF24L01 module for communication between nodes of WSN are also put forth. Use of cloud service for data analysis using MQTT messaging protocol has been proved to be very effective for power constrained devices like WSN.

Various possible ways for data analysis is also discussed. Prospects of including machine learning to provide insights to the system and increasing the scope by proving localization of nodes is promising. Neural Networks are found to be effective in finding the location of nodes using time and angle parameters.

REFERENCES


AUTHOR PROFILE

Ms. Nileema S. Pathak Has Completed BE, ME And Is Pursuing Phd In CSE. She is Research Scholar, At Sandip University, Nashik. She Has 16 Research Papers In His Portfolio. Her Research Is Focused On Iot, Machine Learning.

Dr. Suryakant Patil has completed BE, ME, PhD in CSE. He is a Law Scholar with 107 complete patents and 86 Research Papers in his portfolio. He is Editorial Member as well as Reviewer of several International Journals / Conferences. His research focus on interdisciplinary Industrial and Social Innovation.

Dr. Preeti Patil has completed BE, ME, PhD in CSE. She has 9 complete patents and 72 Research Papers in her portfolio. She is active member of ISTE (LM), CSI (LM). Her research is focused on database, machine learning.