Railway Track Condition Monitoring with ABA Methodology By using Smart IMU Sensors

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Abstract: Most of the railway tracks in Pakistan have surpassed their service lives and are unable to carry rail traffic load. To avoid any unwanted incidence, railway condition monitoring serves as a vital part in the fault detection. One of those crucial faults that is invisible to the image processing algorithms is railway track drainage issue, whose main causes can be residual of rainwater on the track surface, dew, moisture, snow, and seepage of water from adjacent areas. As a result, the level of moisture increases causing the partial erosion in the track's embarkment, which consequently leads to the corrugation. This paper demonstrates how the early detection of railway track faults is possible via enhanced instrumentation based on axle box acceleration (ABA) and adequate postprocessing. Therefore, in this study an IoT enabled device is developed using Microcontroller Unit (Node MCU Esp-32), an accelerometer (ADXL345) and a 5V, 10000mAH battery which recognizes the track faults from the accelerometer, and a binary classifier shows the faulty and unfaulty conditions. The proposed system has been tested on Realtime environment whose response can be continuously monitored from anywhere.

Keywords: *Railway track monitoring, Esp-32, Accelerometer, Axle Box Acceleration, Binary Classifier.*

1. Introduction

Rail transport infrastructure contributes to the country's economy and development because of its extensive use and rising mobility demands [1]. Besides, the rail transport is not always intended and produces unintended or unexpected consequences such as rail corrugation, human error, unprotected railroad crossings, derailments, mechanical failure, speedy trains etc. which reduces track and wheel's service life often result in fatalities and serious injury. The severity of this problem can be best understood by reported railway accidents happened in recent years. On July 3, 2020, incident near Sheikhupura took lives of 20 people due to collision of train with a coach[2]. On June 3, 2020, a passenger train, the Jinnah Express hit a loaded car near Hyderabad, killing 20 people whereas train collision with bus near Rohri killed 19 people [3].

The report published in Dawn newspaper mentions that 2019 is regarded as the tough year for Pakistan railways as 100 accidents are reported in that year, also horrible derailment is reported as a main cause of minor and major accidents [4]. The mentioned severe incidents require a proper concern to fix the issue immediately so that the country and public could be saved from greater losses. Great research is required in this era to sort out and implement efficient techniques for maintaining railroad network and prevent them from disturbances as conventional methods i.e., visual assessment of railway track is not an effective inspection. The traditional method is prone to human error, labor, and time-consuming hence, for a reliable automatic system which inspect the railway track with maximum accuracy is required. Therefore, an automatic prototype is proposed to monitor the railway track squats using Inertial Measurement Units (IMU) aided with Axle Based Acceleration (ABA) methodology.

The prototype comprised of ADXL345, a triple axes digital accelerometer, Node MCU Esp-32 with built-in Wi-Fi module and Global Positioning System (GPS) module and mounted on Track Recording Vehicle (TRV) to record the track faults and location coordinates. The information is recorded on an online database i.e., Thingspeak, and that data is further processed using binary classifier. The developed system is a time and cost-effective solution for railway track inspection with satisfactory results hence reducing the minor and severe accidents.

1.1. System Block Diagram:

The working mechanism of proposed system is shown in Fig.1.

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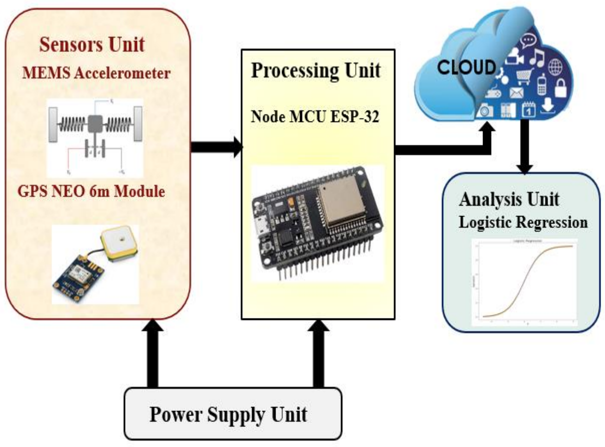

Figure.1. Proposed system Block Diagram

The Sensors Unit comprises of MEMS accelerometer ADXL345 and GPS NEO 6m module. The Processing unit includes Esp32 through which sensors' data is sent to IOT Cloud (Thingspeak). The collected data is analyzed by using logistic regression for defects detection. The power supply unit is connected to Sensors and processing units.

2. Related Work

The condition monitoring of railway framework is being carried out for a century when inspections were performed manually without any automated system[5]. Several condition-monitoring systems have been introduced within the railway industry to facilitate the manual inspection techniques. Researchers have been taking advantage of computer aided inspection to improve efficiency, and accuracy in the condition monitoring systems[6] . Manual Inspection was aided with the development of wireless cloud platform, but it produced large uploading delays[7]. Some other techniques, including visual inspection (image recognition camera-based systems) in which cameras were mounted on the roof of a train for image capturing and image processing techniques were applied to determine the railway faults, but it produced large processing delays, also pollutants and roughness reduce the accuracy of ordinary cameras)[1], [6], [7].

The broadly utilized technique for railway tracks condition monitoring is ultrasonic testing. But this method is not reliable in determining the defects deeper than 5 mm and provides inefficient results where the railway tracks are extremely damaged or fatigued[2] [8]Another well-known technique is Eddy current method, Lift-off and grinding marks can limit performance, unable to determine the depth of defect directly[2][9]. Laser technology (laser sensors are expensive due to their high maintenance cost, and they are sensitive to environmental dirt [2][10], acoustic detection provides limited performance at high levels of external noise also provides delays while interfacing with real-time applications[2]. Each of the techniques discussed has different advantages in terms of accuracy, robustness and cost but acquiring

fully automated railroad inspection analysis is still a challenging task. Hence, railway track condition monitoring using ABA methodology using logistic regression is studied. Accelerometers are widely used for modeling, tracking, and control in various frameworks [11]. Taking advantage of MEMS accelerometers, ABA has appeared in the diagnosis of serious corrugation, welds, and low-standard insulated joints[11][12].Inertial Measurement Units are highly focused in the literature due to their accuracy and reasonable cost. They can be mounted on the train axle box, bogie, or inside the carriage, to measure continuous real-time responses at commercial speeds[11][12][13].

3. Methodology

In this paper, railway track fault detection system with ABA methodology is proposed. The hardware setup consists of a microcontroller (Esp32), a digital accelerometer and a GPS module which is low cost and best alternate of existing systems. It reduces the risk of accidents occurred due to train derailment by detecting railway track faults, and uploading the tracks recorded data to Thingspeak (an online database platform) using IoT. Data from multiple sensors was acquired from railway junctions with various situations (healthy and unhealthy) to extricate the oscillations associated with track's degradation. whilst a vehicle moves over normal track, the ABA signal alters due to the natural vibrations of the Track Recording Vehicle.

The existence of unwanted deterioration (e.g., terrible welds and fatigued rail pads) can badly affect the vehicle-track interaction, this degradation can be recorded within the ABA signal. At the crossing and welds, simply a minor change arises in the amplitudes and periods of the ABA indicators; consequently, it is difficult to analyze them and extract sufficient records in the time domain. Therefore, frequency analysis technique is used for fault's detection, as it can offer vital statistics which were challenging to discover within the time domain[14]. Finally, recorded data will be processed using logistic regressions resulting the final output as faulty and non-faulty conditions. The Figure.2 below shows the overall system methodology.

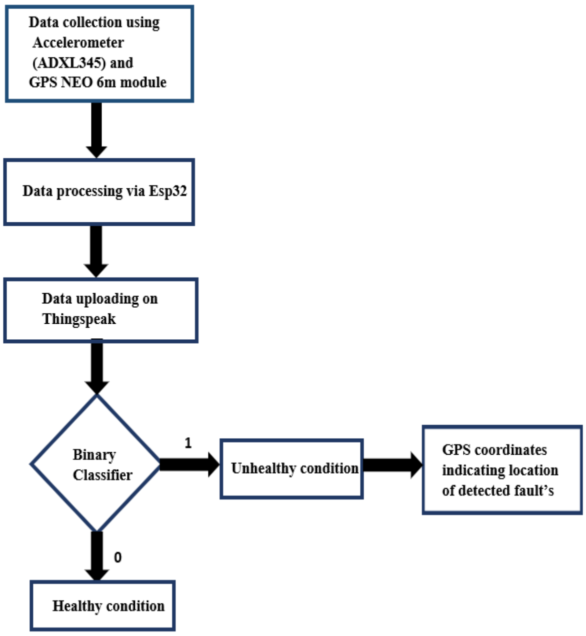

Figure.2. Flow chart of proposed methodology

3.1 Hardware Setup:

ABA Methodology:

In this paper, the axle box acceleration (ABA) system has been used for the railway track fault's detection due to its the feasibility in many aspects. It extricates fluctuations in dynamic responses using vibration-based analysis technique. The ABA system has been widely used on ordinary as well as railway tracks to detect various types of defects[11], [12], [15], such as terrible corrugation, fatigued track, and low-standard insulated joints. The primary preferences of the ABA contrasted with other railroad condition checking frameworks are its reasonable cost, simplicity of upkeep, and smooth execution at commercial speeds. It detects low frequency vibration faults with higher accuracy[16]. In different nations like Japan, Poland, Italy, and Korea, ABA framework has been traditionally executed for the inspection of railway road absconds[17].

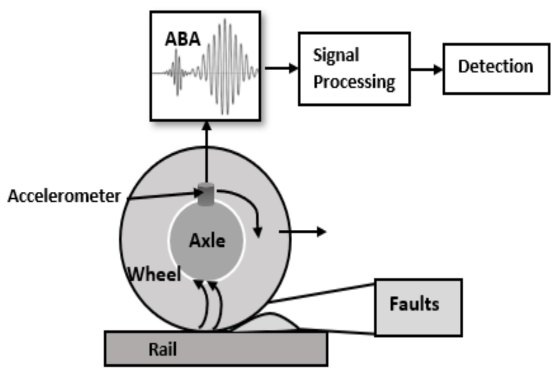

Figure.3. Schematic view of instrumentation setup for ABA

Selection of ADXL345

The selection of optimal device was an important parameter as whole research depended upon the selection of accelerometer. The ADXL345, a general-purpose accelerometer, ideal for use in a wide range of applications. It has been frequently used in literature due to its ideal performance and the robustness to errors[18]. Hence, ADXL345 is used in this prototype.

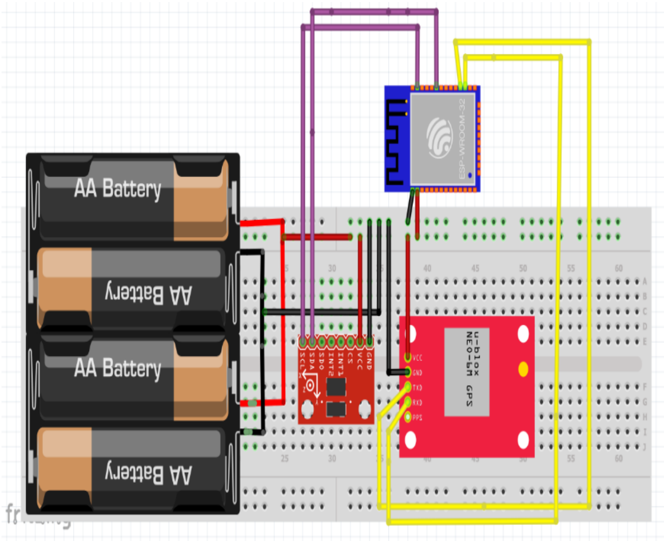

Figure.4. Circuit Diagram of developed system

Furthermore, the proposed prototype is made flexible so that accelerometer can be replaced by any other industrial or commercial grade sensor as per system specifications (Figure.4)

Connecting with Esp-32 and GPS NEO6m:

In this research, Esp-32 module is used to establish connection between sensor module and the internet. Due to its huge operational characteristics, compatibility with Wi-Fi standards and protocols[19]. In literature studies, majority of the faults have been determined by using Y-axis values of accelerometer because the structure gives high fluctuations in Y dimension [7], [11]. Hence, the Y-axis values from ADXL345 accelerometer has been considered for defects detection. For the fault's location coordinates, GPS Neo6m is used, which can track nearly 22 satellites so that location coordinates can be easily identified [14]. The GPS module is connected with Esp-32 via Tx and Rx pin, as shown in Fig.5. The location coordinates are sent to cloud along with accelerometer's data. Arduino IDE software is used for the programming of Esp-32. The internet connectivity was provided by entering Wi-Fi credentials to the module. In order to upload data on cloud network, an API key serves as the intermediator between the module and cloud network. For data visualization, Thing speak was used.

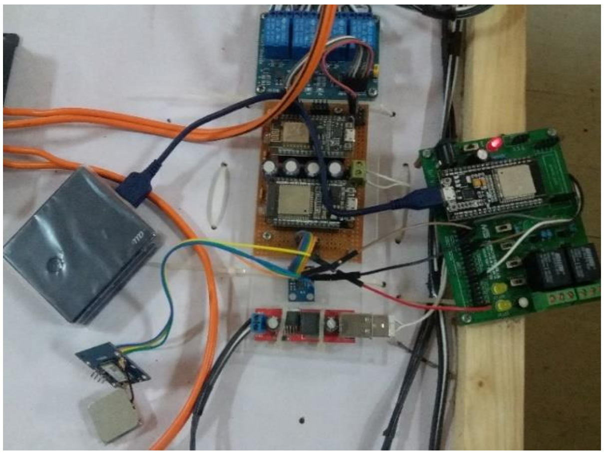

Figure.5. Realtime Testing with developed prototype

Communication with the Cloud:

The main purpose of the research is to develop the smart instrumentation linking with the cloud community so that response of the whole system can be monitored remotely. The communications take place via API, which is reliable and secure medium of communication[7], [21] .

Thingspeak (an IoT cloud platform) is used to send and record data in CSV format. The gathered data can be easily utilized for further analysis like FFT, correlation, covariance, regression, etc. [7].

Data Analysis:

Firstly, the data taken from Thingspeak is processed in Python using Fast Fourier Transform for the frequency analysis, following equation (1). The peak values (spikes) in FFT graph show the faulty conditions [22]– [24]. After, the data is analyzed using logistic regression using equation (2).

$$x[k] = \sum_{n=0}^{N-1} x[n]\, e^{\frac{-j2\pi kn}{N}} \quad (1)$$

The equation for linear regression is

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n \quad (2)$$

Where Y is the approximated outcome; β_0 is the point touching Y-Axis, $\beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n$ is the figure of independent variable (X_n) valued by its respective beta coefficient (β) [23].

4. Results and Discussion

Figure.6. shows the acceleration data obtained on thingspeak from the implemented prototype on TRV, at the speed of 40km/h.

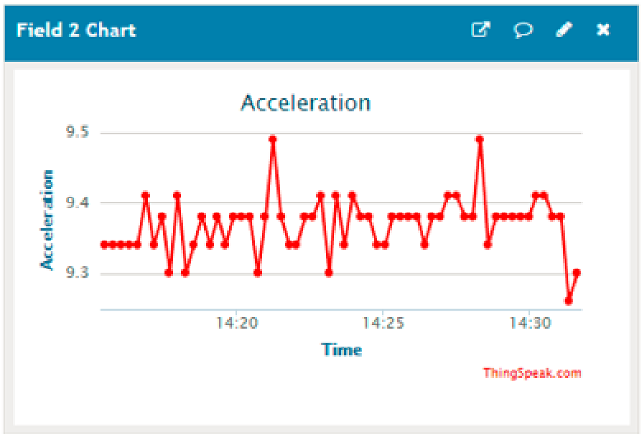

Figure.6. Collected data on thingspeak.

The processing of data is performed by applying FFT in order to capture the spikes of faults as shown in Figure.7.

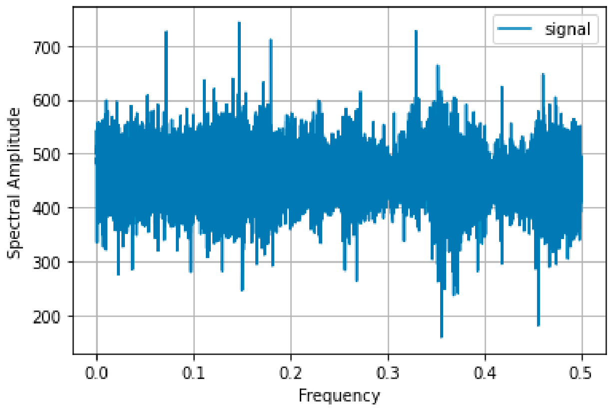

Figure.7. Processing of data using FFT

Faulty and non-faulty conditions are acquired by using logistic regression algorithm, the faulty locations can be clearly noticed from the Figure.8.

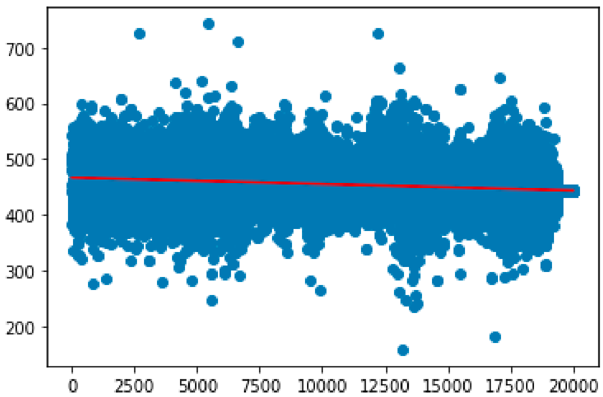

Figure 8: Logistic Regression analysis for Faults Recognition.

4. Conclusion

In this research, railway track condition monitoring has been done by developing an IOT based Smart Instrumentation system. IMU sensors were mounted on the TRV's axle box running at the speed of 40km/h, location coordinates were obtained using GPS. The nonlinear variations in the structure were carried out by ABA methodology, data measured by the y-axis of accelerometer was used to estimate the abnormalities. It is concluded that scaled amplitudes give repetition for multiple measurements. The scaled amplitudes for a 2 km dataset are compared with TRV measurements. This confirms that the locations with peak frequency levels correspond to the unhealthy conditions of track.

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