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Frequency Based Approach for Railway Track Faults Monitoring in Pakistan

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***Abstract*— When it comes to mass travel or transportation of heavy cargo and shipment, trains are widely used in Pakistan. Since the Pakistan Railway (PR) network is established over thousands of kilometers, 'Manual or Visual Inspection' is not viable for such a huge network. An automated track monitoring system is required to replace the current inspection method so that technicians can carry out the maintenance at the right time, and the frequency of accidents can be lowered. This paper discusses an automated system that can automatically determine the upcoming damages or flaws in the rail tracks without the need for visual inspection. An electronic device comprising of Accelerometer ADXL345, Raspberry Pi, and a GPS module is designed to build such a system. The main working principle of this prototype device will be comparing the live recorded values of a track with a pre-calibrated data set of an undamaged track, which in our case was recorded on the Kotri Railway Station of Pakistan using the same device. In our experiment, the device was attached to an in-service track-monitoring vehicle on Kotri Railway Station. The inspection vehicle periodically traveled over the rail network, and the ADXL sensor recorded the values. After value acquisition, some processing took place using different techniques like FFT and comparison to identify whether the rail was safe or not. The fault location was also recorded using the GPS connected to the device. All results were displayed on an HTTP server so that any device could access it. Despite the successful development of the aforementioned system, expected results were not attained when the device was tested in a real-time environment due to built-in communication delays of Raspberry pi.**

***Keywords*—Railway Monitoring System for Pakistan, Fast Fourier Transform, ADXL345 , Accelerometer, Frequency Based**

I. Introduction

Trains are the most well-known mode of transportation not just in Pakistan but all over the world, due to its low cost and ability to go a long distance in a short amount of time. Trains are not only used as a mean of travel, but also for delivering large shipments across the country and all over the world; the quality and technology may differ, but the essential concept and transportation principle stays the same. With considering low cost of traveling and transportation, however a huge amount of investment is required initially to set up the rail tracks leading out to each destination and routing back. These rail tracks are responsible for all transportation, smoothness, and hauling various sized engines worldwide. Considering that the rail tracks and train wheels are both forms of metal, this is enough to create wear and tear on the rail tracks on its own, but we also have an extraordinarily massive mass of transport, cargos, and other shipments coupled to the heavy rail engine. This merely assures that the rail tracks responsible for train movement will wear off after a set period and require maintenance, repair, or replacement in the worst-case scenario.

In most countries, railways make up a significant portion of the transportation infrastructure. For instance, the Pakistan Railways (PR) has a network of 7,791 route kilometers, with 7,346 kilometers of broad gauge and 445 kilometers of meter gauge. The network has 633 stations, 1,043 km double-track portions, and 285 kilometers of electrified sections. The Karachi-Lodhran part of the network (843 kilometers) and 193 kilometers of other short sections are double-tracked, while 286 kilometers from Lahore to Khanewal are electrified. The PR network also connects to three neighboring countries: Taftan in Iran, Wagha in India, and Chaman and Landi Kotal in Afghanistan. To avoid service disruptions and preserve the system's safety, it is critical to use good monitoring and maintenance procedures for railway networks. In 2019, BBC published a report stating, "historical data from Pakistan Railways shows there were 757 train accidents between 2012 and 2017. That is an average of about 125 incidents a year." According to Dawn's official website statistics, several severe rail accidents have occurred in Pakistan because of train derailments in the last 8 years. Some major incidents among these are; The Karakoram Express derailment at Bandhi Railway Station on May 07, 2014, as a result of which 2 people died, and 15 others got injured [1]. Another disaster took place on November 17, 2015, when The Jaffar Express was derailed on its route from Quetta to Rawalpindi, killing 19 people [1]. In December 2018, one passenger died, and six others sustained injuries when the last three coaches of Shalimar Express derailed and hit Millat Express, which was stationed at an adjacent track [1]. The frequency of accidents remained the same or continued to grow throughout these years, instead of decreasing. Last year, on March 07, several carriages of Lahore-bound Karachi Express derailed between Mando Dero and Sanghi Railway Stations in Rohri, which resulted in the death of 1, and serious injuries of 30 others [1].

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The concept of this research is simple. Each station has a track inspection vehicle, which is used for manual inspection. To perform the experiment properly, one station will be considered and the survey vehicle of that station will be implanted with a prototype device. The device will feature sensor capabilities and record location of defaulted track. The sensor's function is simple and robust; the sensor device will most likely be an accelerometer or gyroscopic device capable of detecting physical movement, jerk, vibration, or rotation. This will allow us to track the vehicle movement on the rails easily. If the track is as smooth as it should be, the values recorded by the accelerometer will be smooth and consistent. If the survey train passes over a spot on the track that has undergone a lot of wear and tear, a significant change would be seen in the values of the sensor. Based on the changing value of the sensor, the program stored in raspberry pi, which is responsible for detecting changes and applying thresholding to the returned values, will identify whether the track is defaulted or not. These values or data, which will be compared with the sensor's values in real-time, will be collected first at previously known perfectly smooth spots on a track, some worn off tracks, and some completely damaged tracks to calibrate all three possible outcomes, such as safe, require maintenance, and caution/danger.

The research findings are intended to be utilized in Pakistan to implement automated railway track monitoring systems to ensure the early detection of track faults and the avoidance of railway accidents. The final model is planned to be put on a regular Pakistan railway inspection vehicle, which travels around the rail network and measures the frequency periodically. The location on the track where the real-time (recorded) frequency differs from the typical (dataset) frequency indicates a likely track fault. A GPS Tracking System will be utilized to capture the fault's real-time location so that the survey and technical team can carry out maintenance of the track at proper time.

II. LITERATURE REVIEW

The junction of wheels and railway is typically strengthened as the train's speed increases, leading to the strengthening of the steel, fatigue of the fragmented structure, crushing and aging of the railway line. Damaged closures will also intensify the junction of tires and rails, hasten vehicle degradation and tracking and pose threats for running safety training. Furthermore, fastener failure has a cascading impact on the performance of nearby connections, showing that it can be integrated into a sequence of track structural disorders. As a result, early identification of reinforcing system degradation and rapid repairs are essential assuring the train system's safety. In standard test methods, the train status is monitored visually and by hand. Train engineers devised several acquisition methods that differed significantly from vision-based results and vibration-based acquisitions to overcome the constraints of visual inspections and enhance safety conditions.

A. Vibration Based Damage Detection of Railways

Scholars established the train speed vibration-based visual modes after discovering damage to a building that supported vibration. Many of the quickest tests are based on vibration techniques. The acceleration of the train is often regarded as a matter of research. Liu et al. [2] proposed a method based on the formation of an orthogonal empirical model that includes time-frequency entropy to obtain stabilizing conditions, in which the acceleration of the train vibrates with the power hammer was researched. Valikhani et al. [3] developed a validation test method with which they used a large wavelet change to analyze train speeds. However, these methods of detecting installers using train acceleration could only detect congestion in limited locations.

In practice, the rare symptoms of ABA caused by fastener damage are very different from those caused by track irregularities or wheel/train defects. Therefore, technology with a strong discharge feature is inevitably needed to identify the insignificant difference between ABA symptoms caused by injury and non-injury conjunctions et al. [4] The convolutional neural network (CNN) had received increasing attention in detecting structural damage. CNN could study mapping between input and output without direct statistical expression and used for detection operations. Other scriptural studies [5 - 8] proved this strong vehicle tracking system responses could be affected by fastener damage, so it is promising to detect fastener damage by looking at power differences answers.

Monitoring the conditions of railway tracks is essential for ensuring railway safety. Acceleration of the inspection vehicle may be used to detect various track faults. Equipping the inspection vehicle with simple sensors and GPS may dramatically change the current style of rail maintenance and thus contribute to establishing safe transport systems. To make the monitoring process efficient, there are several different techniques used around the globe, that are reflected in various articles in the field of railway track condition monitoring systems.

Abdollah Malekjafarian, et al. [9] carried out an experimental case study to investigate the use of drive-by train measurements for railway track monitoring. The experiment was performed on an Irish in-service train equipped with accelerometer sensors and a global positioning system. The focus was on a 6-kilometer portion of the line where maintenance readings from a Track Recording Vehicle (TRV) were available. The Hilbert transform was used to obtain the real-time amplitudes of acceleration signals. A two-step speed correction technique was applied to the data, i.e., first, data below a threshold limit was removed from the data set, and then the remaining signals were scaled using a scaling factor. The scaled amplitudes were then compared with the TRV data, and the result depicted a tremendous amount of resemblance between both data.

Velmurugan K and Rajesh T [10] described a new rail crack detection approach based on the change in infrared emission of the rail surface when a train wheel passes over it. The study revolved around applying wireless sensor networks for identifying fractures in railway tracks. Ultrasonic sensors were embedded in the rail's interior wall at 1.75 kilometers apart. At specified intervals, this high-energy pulse was transmitted in two directions. The signal was sent through the rail and received by receivers. Adjacent transmitters send ultrasonic waves with the same frequency but different periods. The receivers then told which way the signal was coming from (left or right). The amplitude of the waves received by receivers were lowered if there was a break in the rail, and an alert signal was produced.

B. Damage Detection of Railways by the Method of Transformed Acceleration

Rail infrastructure testing is expensive and difficult due to the extensive network. Furthermore, the powerful engagement of architectures in ordinary and sudden traffic makes locating and

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fixing a major difficulty. Predicted cautions of some percentage say reducing network interference is attractive and helpful Several investigators were researching this indirect train track test ten years ago, a technique in which the structural reaction can be read directly on it although the feedback of a moving mobile object is utilized as a replacement.

Based on the acquired data and comparison between the ideal rail track and the damaged track, own assumptions could be made and create simple thresholding to determine whether the track is flawed or working fine based on the acquired values of velocity and speed frequencies. Pablo Salvador, et al. [11] conducted an experimental study on the Metropolitan Rail Network of Valencia (Spain). The study found that introducing simple Digital Signal Processing techniques into the railway industry can improve the track surveying process. A variety of axle-box acceleration techniques were gathered and examined. Various abnormalities, such as track singularities and vibration modes, may be recognized using spectrum analysis techniques and time-frequency representations. The article concluded that a wide range of track faults might be discovered without supplementary studies using a Hamming time frame of 0.5 s and overlapping of 95%.

III. APPROACH

The proposed methodology's implementation begins with installing the Raspbian Operating System on the Raspberry pi controller. The model used in this project is Raspberry Pi 4, with a RAM of 4GB. The board offers four universal serial bus interfaces for connecting the peripherals, all of which are operated simultaneously, providing the standard 5-volt output supply to the components connected to it. It also provides several other features such as GPIO, mini HDMI, Wi-Fi, Bluetooth, HDD, and USB Microphone. Once the OS is installed, an attachable LCD Display with a GPIO and an HDMI interface compatible with raspberry pi's hardware and software is connected to the hardware, and desktop mode is set up from the OS settings. This makes the prototype portable and allows it to fit anywhere on the inspection vehicle. Next, an inertial sensor such as an accelerometer is connected to the system to detect the precise movement of the inspection vehicle. The ADXL345 is a tri-axis accelerometer that measures the speed in X, Y, and Z-axis with a powerful range of +/- 16g with 13bit resolution capable of transmitting data at a rate of 3200 times per second, an operating frequency of 3200Hz, the maximum bandwidth of the accelerometer, which makes it output digital values on each axis, output formatted as 16-bit, uninterrupted by SPI or I2C processes. Another advantage of this low-power sensor is that it uses only 23 micro-amperes while measuring or operating in standby using 0.1 micro-amperes. Finally, a GPS module is connected to the system to capture the exact location of the damaged track. Communication between the GPS module and the Pi occurs via a simple serial connection. Therefore, the GPS module must be connected to the TX and RX pins of the Raspberry Pi. The GPS starts working as soon as the raspberry pi is powered up since it is connected to the power pins of the pi.

After setting up all components in one place, the device was programmed. A python script was coded and tested on the computer first and integrated into the device after successful testing. The code comprised of several Python libraries, which were responsible for various tasks, such as plotting the values on the graph, applying the Fast Fourier Transform (FFT) algorithm on a given set of data, using micro artificial algorithms to run the script, and sending requests to the HTTP server to transfer and output the final results on a webpage.

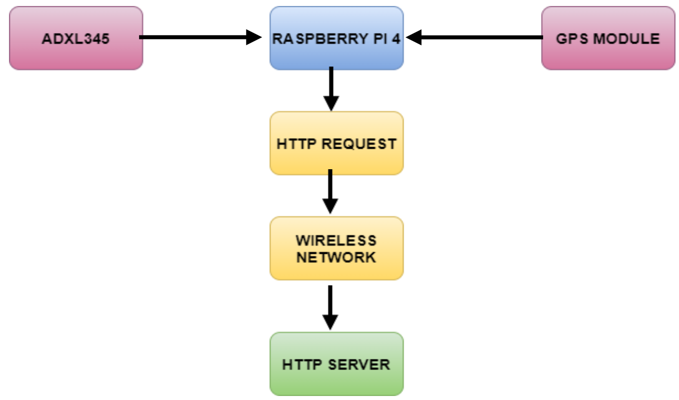

Fig. 1 Building Blocks of the system

The working principle can be elucidated in three stages on the data collected from the same device on the Kotri railway junction.

First, the ADXL345 sensor communicates with the raspberry pi via a Serial Peripheral Interface (SPI). The sensor has an internal inertial sensor called MEMS, abbreviated for Micro Electrical Mechanical Switches or Sensors. These sensors are triggered by the actual physical movement, which can be either moving in a particular direction or orientation at a certain angle in the case of a gyroscope. These values are unique and given in the 3-6 axis of rotation. In the case of ADXL345, we receive 3 axes of rotation X, Y, and Z. When the inspection vehicle moves on the track, it experiences some vibrations and movements along the rail track, depending solely on the smoothness and roughness of the rail track itself, the sensor detects all these movement-based values and sends it to the raspberry pi computer board. As the data is received, the raspberry pi starts functioning according to the python script, first saving the incoming values into an array of a particular number (1500 or 2000 values). The collected data is in the time domain and needs to be converted into the frequency domain for easy manipulation and understanding. After successfully collecting one batch of values, the values of the y-axis are converted into the frequency domain by applying the Fast Fourier Transform (FFT) algorithm. The other two axes values are ignored since, in the case of jerk toleration on a broken track, the maximum change occurs in the y-axis. Once the data is converted into the frequency domain, a graph is plotted, which can be visualized on the connected LCD. From this outcome, maximum peak values are filtered out, and their mean is calculated, stored as a threshold point for the testing data. The magnitude of the threshold is considered in positive and negative forms (+100 and -100, for instance). A small part of the same data set is tested against this code. The testing data points are converted into FFT

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and compared with the calculated threshold point. If the incoming value surpasses the positive threshold, it is stored as “High.” If it exceeds the negative threshold, it is stored as “Low.” And the point where both magnitudes are similar is ignored since it indicates an undamaged area.

Secondly, the raspberry pi records the localization of the vehicle or itself, to be more precise, via the attached GPS module. The GPS module uses a universal asynchronous transfer receive protocol to communicate with the raspberry pi, also known as the two wire interface. This module provides raspberry pi with a few values like date, time, latitude, longitude, etc. But since we need to capture the localization only, we store the latitude and longitude values and neglect the other data.

Once the values from the sensor are saved, FFT is applied, and the Location is acquired from the GPS module, we finally send all of this data to an HTTP server in the form of an HTTP request. This data is divided into 3 different columns of displaying values; High (for values that exceed the positive threshold), Low (for lowest values that exceed the negative threshold), and Location (which shows the GPS coordinates of each point). Along with the coordinates, the location is also displayed in the form of a map, which is obtained by the latitude and longitude coordinates.

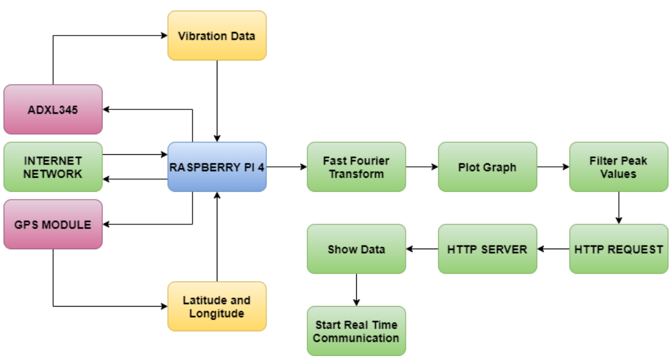

Fig. 2 Infrastructure of the working system

IV. RESULTS

A. Testing on pre-acquired values

We separated a few values for testing from the pre-acquired dataset and tested the device against these values. The accelerometer values array was passed to the program in the time domain. As soon as the program receives the values, it applies Fast Fourier transform(FFT) on the values and converts them into the frequency domain to make further processing easier. After FFT is applied, a graph of values is plotted as shown.

Fig. 3 Plotted graph after converting values in frequency domain

The resulting graph plotted by the python script is accurate in graphical format but not in numerical format. This means that the numbers shown in the graph are not true or even near the true values, but the variations are exact. What happens is that the matplotlib library plots the graph over a fixed scale of numbers. This means that the data is correct but just rescaled to be shown on the graph correctly. Once the graph is plotted, we get our threshold values and send an HTTP request to the server using the command request.post(). Once the request hits the server, the values can be seen on the server along with the localization of the latitude and longitude.

Hight	Low	Lat Long
327	-382	
327	-355	
336	-355	
336	-348	
369	-348	
369	-321	
384	-321	
384		
449		
449		
498		
498		
525		
525		

Fig. 4 Output on the Server for pre acquired testing values

B. Testing on real-time recorded values

Since we also tested the program in real-time transmission. As soon as the device starts moving, the accelerometer collects values and sends them to the raspberry pi. The raspberry pi accepts these values with a delay of 3 values per second, which may seem minute but is a huge delay when monitoring hundreds of kilometers of railway lines. Another problem in real-time transmission is converting real-time data into the frequency domain. Since the Python FFT library applies the algorithm to only a group of values, values in real-time are recorded one by one with a delay. In order to deal with this problem, we have to wait for 1500 values to be recorded to apply FFT, which increased the delay even further and made the processing even slower.

However, to still test the system, instead of converting values into the frequency domain, we considered the values in the time domain, just for testing of the device. The testing was performed in the premises of Mehran UET Jamshoro on an artificially designed train model. The ADXL sensor records real values as the device moves, and Raspberry Pi receives the recorded values with a small delay of 3 values per second. In the case of real-

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time recorded values, the graph starts plotting as soon as the first value is recorded. The recorded values are then compared one by one with the threshold point (which is +-100 in this case). The values that surpass the threshold point are shown in listed on the right-hand side under the heading of "Spikes," as shown in the figure. The real-time location of these points is also displayed on a map.

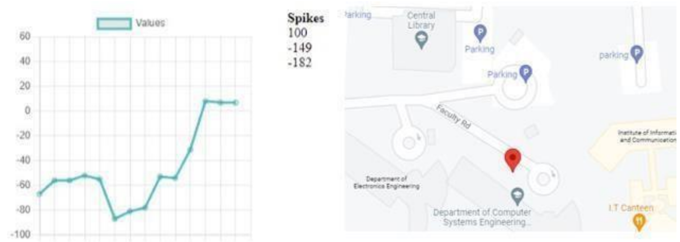

Fig. 5 Output on the Server for real-time recorded values (university premises)

V. CONCLUSION

After completion of the project and a lot of research on the results we acquired, we concluded that the device prototype does work, but there is a flaw of slow communication between the Raspberry Pi computer board and the ADXL345 sensor module. This flaw may seem small at this stage; however, when it comes to monitoring real-time data of the vast area of railway networks of Pakistan that cannot afford any miscalculation, we cannot risk anything, not even as small as a delay of a few seconds. Getting a delay in values from the sensor is not the only problem; a delay in communication means that we are missing out on many values that the sensor is taking in but not received by the raspberry pi board. For instance, if the sensor outputs 100 values in a second interval and the raspberry pi can only take 4-5 values, we are missing out on 95% of real-time input. Keep in mind that these 4 to 5 values also need a small delay to be uploaded on the HTTP server. If the same processoris being used, it will result in missing out on some faults, which has a result can cause accidents, resulting in loss of lives and precious cargos and shipments and a lot more resources and time in recovering from the damage.

To conclude, the overall program and algorithm work fine; however, there is a need to shift from raspberry pi and adxl345 to a much faster and robust hardware system so that the delay in communication is balanced.

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