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An IoT Based Real-time Railway Fishplate Monitoring System for Early Warning

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***Abstract*—Fishplate joint monitoring is of utmost importance in rail communication system to avoid accidents. Rail accidents generally occur due to the derailment of trains from the track. One of the primary reasons of derailment of train is losing alignment of rails due to loosened fishplates. So, monitoring rail alignment and fishplate bolt position is required to ensure railway safety and security. In this paper, an IoT based real-time railway fishplate monitoring system is proposed. The proposed system keeps track of the position of every bolt of each fishplate and alerts a central railway monitoring center as well as nearby stations and approaching train drivers if any bolt gets loosened. This system utilizes GSM communication and is capable of working in areas where cellular network atleast 2G is available. An embedded system detects the fault location with the help of a mechanical gear and raises warning as soon as any bolt rotation is detected. The proposed system is comparatively much cheaper. Besides, in a simulation based warning accuracy test, the results of the system show high accuracy which indicates the effectiveness of the system. Accidents probability and frequency are expected to be reduced significantly by this system.**

***Index Terms*—Railway fishplate, IoT, Electrical Pulse Generator, Arduino, GSM**

I. Introduction

Rail transportation system is one of the primary means of communication. Both the scope of rail transportation and the number of trains is ever increasing with the increasing requirement of transportation for people and goods. With this increment, railway accidents have become a matter of grave concern. Statistics released from the United States Department of Transportation indicates that from 1975-2019 nearly 67572 train accidents happened nationwide due to derailments [1] which resulted in killing 140 and injuring 6172. So it is imperative to ensure safety and security to make rail transportation system more reliable. One of the primary measures for railway safety is the monitoring of fishplates. Rail fishplate, also called rail joint bars, is one of the most common types of rail fasteners. In rail transport modelling, a fishplate is often a small copper or nickel silver plate that slips onto both rails to provide the functions of maintaining alignment and electrical continuity. The top and bottom edges are tapered inwards so the device wedges itself between the top and bottom of the rail when it is bolted into place. Detachment of fishplate in railway can cause severe accident and result in large number of casualties. So, monitoring of railway fishplates is very crucial to ensure track alignment and avoid derailment. But it is very time consuming and costly to manually check the condition of each and every fishplate of the railway system regularly. So, an automated system which can monitor the condition of the fishplates regularly can reduced the number of accidents due to derailment.

There has been an attempt to detect and monitor crack growth in rail steels by acoustic emission (AE) techniques capable of detecting crack growth. But the derived signal might not be precise due to noise and collected signal amplitude similarity [2]. Another group reported the development and testing of two independent techniques: Video monitoring and ground motion detection combined with webcam, telescope and geophones for detecting dynamic displacement of railway track but this proved to be a fairly complex and expensive [3]. One paper showed the development of a portable track condition monitoring system using an in-service vehicle probe consisting of sensors and GPS which uses vibration and noise signals to detect irregular conditions and pinpoint the location. Although it has an easy implementation advantage, it is sensitive to noise and cannot detect faults in advance [4]. A digital image correlation based rail track inspection system using 3D images of the rail road was proposed in another paper. 3D images of the tracks are analyzed to raise a warning about any fault in the track. It provides continuous monitoring but not very precise at high speed [5]. In another paper, fishplate tempering is detected using a low cost and low power consuming system consisting of piezoresistive sensors and microcontrollers. They used RF signal transmitter for wireless communication [6]. A distributed and multiplexed optical fiber and bragg grating sensors based railway track condition monitoring system is suggested which is already in use for high accuracy. Optical fiber line is used for transmission of signal after pca and fourier analysis which makes it fairly expensive [7].

In this paper, an IoT based real time automated system is proposed that can check the condition of the bolts of a fishplate and send information to the concerned authority. A fishplate is generally kept attached to the rails of the rail track with bolts. When these bolts get loosened, they start

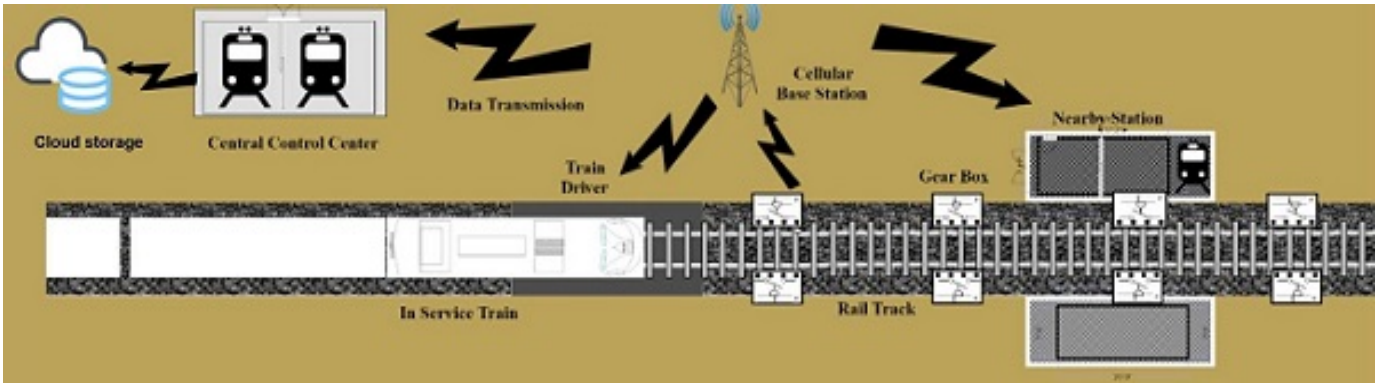

Fig. 1. Schematic diagram of the IoT based real-time fishplate monitoring system.

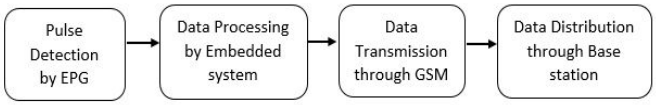

Fig. 2. Block diagram of the complete system.

to rotate and the chances of two rails attached by a fishplate losing alignment increase. Detecting this rotation is a way to predict the increased probability of losing alignment of rails. In this proposed system, an electrical pulse generator (EPG) based fault detection and GSM based wireless communication system has been used for conveying the warning signal. The GSM module is a part of an embedded system, which controls the whole system. The system also sends a dummy signal continuously to ensure system availability. This system functions as a continuous monitoring system by raising warning as soon as significant bolt movement takes place and thus prevents accidents by giving an early warning.

II. Proposed System Model

Fig. 1 shows the schematic diagram of the proposed system where proposed device is attached to railway fishplate. The device collects fishplate condition information and sends it to a cellular base station through GSM module. From base station information is sent to central control room, nearby station and nearby train (if necessary). Working principle of our proposed device is demonstrated in Fig. 2 where total task has been divided into four major tasks.

A. Rotation Detection by EPG

The proposed system detects the rotation of the bolts that connect the fishplates to the rail. There are other systems to monitor railway track that use other sensors like vibration sensors, piezoelectric sensors, load sensors etc. But in the proposed system we particularly wanted to detect if the bolts are in the right place or not. So, a new tool was designed that can account for the rotation of the bolts. That's how we came up with the idea to connect a gear with the bolt and create a switch that closes when the bolt is rotated by significant amount. This device is named Electrical pulse

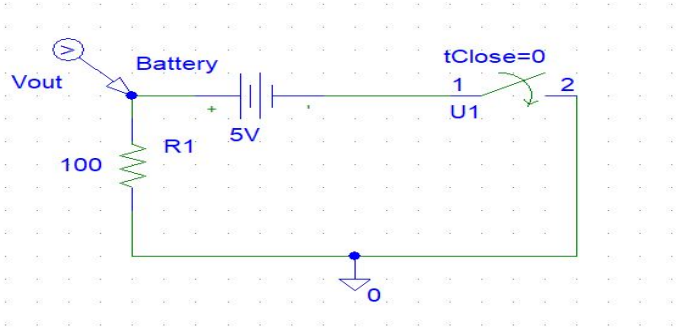

Fig. 3. Equivalent circuit diagram.

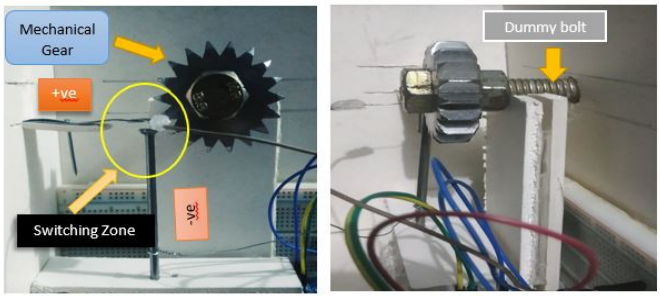

Fig. 4. Experimental setup.

generator (EPG). Fig. 3 shows circuit diagram of EPG. Fig. 4 shows a setup of EPG. When bolt rotates, the mechanical gear also rotates as it's attached to bolt. Its designed in a way so that when a significant amount of rotation is occurred, one end of the switch connected with the gear is shorted with the other end. Now there will be a current flow and a voltage will drop across the resistor shown in Fig. 3 circuit diagram. Thus a pulse is generated, it is named as Vout. This pulse is recorded by embedded system (in propposed system, by Arduino Uno board's digital pin).

B. Data Processing by Embedded System

In this step, the data (pulse due to rotation of the bolt) received from the EPG is analyzed by an embedded system.

Detailed information about rotation of bolt and number of rotation, location of bolt where rotation occurred is stored in embedded system. Necessary calculations regarding condition of fishbolt is also performed by it. Embedded system also managea, controls other equipment connected to it. Arduino Uno [8] is used as embedded system. It is coded to receive pulse from the EPG then analyze the data and finally command the GSM module to send the information to specific target. When the input pulse is received in the digital pin of Arduino Uno, the pin gives a logical output of 1. The code that is used in the system is written in such a way that whenever it finds a logical reading of 1 in the digital pin, it commands GSM module to begin data transmission. In short, embedded system works as the brain of the whole system.

C. Data Transmission through GSM

- After processing the data, embedded system commands GSM module to send out a text message. This task is done by a SIM card set up inside the GSM module and by the command of the code uploaded in the microcontroller. The text message contains information about device number (represents location of the fault), number of rotation, how much loose the bolt is. Beside the data transmission to alert about loosening of bolt, a default message is also sent continuously after a certain period of time just to make sure that the sensor is still there.
- GSM module is used to establish communication between two mobile device. GSM service is quite available. So, system's continuous and uninterrupted performance can be easily ensured. Data transmission is also more reliable and flexible through GSM than other communication device like bluetooth and wifi. GSM module is also cheap which reduces project cost. For this advantage GSM is preferred to other mode of communication. It performs wireless transmission of information. The GSM module is activated by the command of the code uploaded in the Arduino uno board. When the module is commanded, a previously typed text message is sent to target phone number. The text and target phone number can be changed from the code. Thus, for every time bolt rotates and if its amount is risky, system will send a message to the nearby station, central control room and nearby train driver.

D. Calculation for Warning generation

Every response is not necessary to send warning. Warning should be sent when the bolt is loosend by a significant amount. Calculation is done as follows to generate warning:

The gear used in the system has 32 teeth. In order to create a pulse, If one tooth rotates and travels to the same place its next tooth had been before the rotation, then the angular displacement of the tooth is $\frac{360}{32} = 11.25$. The angular displacement of the bolt will also be same, $\theta = (11.25^\circ)$ Now, if we assume a 10.9 grade hex bolt of $14mm$ diameter is used as the fishbolt here, The pitch of the bolt is $p = 2mm$. And as it is a single start bolt, the lead (linear displacement due to one full rotation) of the bolt will also be, $l = p = 2mm$. So, for 11.25° of rotation the linear displacement of the bolt becomes: $d = (\frac{l}{360} \times \theta) = 0.0625mm$. That is a very small displacement and may not be enough to generate a warning. So, we can set a threshold of $0.5mm$ displacement of the bolt to generate a warning. This would take the teeth to be moved $\frac{0.5}{d} = 8$ times or to create 8 pulses to generate the warning that the bolt is loose enough to be considered risky.

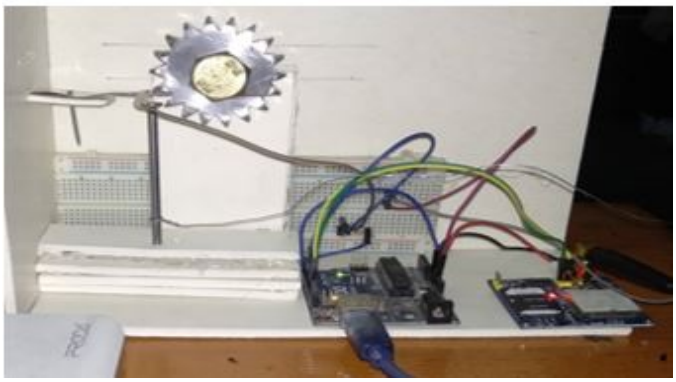

Fig. 5. Complete experimental setup for performance evaluation.

E. Data Distribution through Base Station

GSM module sends data to nearby base station. Base station works as final distributor of data packet. Base station sends information to nearby station, central control room. Central control room uploads the information to cloud via internet. This information is sent to nearby train driver if there is any risk of accident.

III. Experiment and Results

A. Experimental Setup and Description

To evaluate the proposed system Performance an experimental setup was created. Fig. 5 shows the setup. The dummy bolt was manually rotated. Rotation was done by an amount so that 100 gear teeth pass by and for every gear tooth passing by a delay of 15 second was made to record response. This time we set threshold 11.25° as angular displacement threshold. So, for each gear tooth passing by, a pulse should be detected by EPG and system should send text to nearby station. Another 100 responses was recorded giving 15 second interval. This time bolt was not rotated manually. But vibration was created manually which is hypothetically equivalent to vibration due to train moving on the rail. In that case, EPG should not detect any pulse since there was no rotation.

B. Result Analysis

Fig. 6 shows results of the experiments conducted. From the table we can see that, when the gear tooth was rotated

Rotated? / Detected?	Yes	No
Yes	92	3
No	8	97
Total	100	100

Fig. 6. Experimental result.

it detected the rotation 92 times and failed to detect 8 times. From this test, we calculate the following parameters.

$$\%\textit{True Positive} = \frac{\textit{Number of successful detection} \times 100}{\textit{Total number of tooth pass by}} = \frac{92 \times 100}{100} = 92\%$$

$$\%\textit{False Negative} = \frac{\textit{Number of failed detection} \times 100}{\textit{Total number of tooth pass by}} = \frac{8 \times 100}{100} = 8\%$$

We have also done experiment for another 100 times to see if it gives any false alarm due to vibration. The system generates only 3 false alarms out of 100 tests and for the other 97 times, it does not generate any false alarm. Therefore, the proposed system has shown quite good result in preventing false alarm due to vibration. From this test, we calculate the following parameters.

$$\%\textit{True Negative} = \frac{\textit{Number of no detection} \times 100}{\textit{Number of time vibration applied}} = \frac{97 \times 100}{100} = 97\%$$

$$\%\textit{False Positive} = \frac{\textit{Number of false detection} \times 100}{\textit{Number of time vibration applied}} = \frac{3 \times 100}{100} = 3\%$$

The results from our test are very promising although it is not possible to test it with real life conditions. However, the developed system is just a model and it can be expected that when a working prototype will be developed, it will perform according to our observed results.

IV. Future Work

Future improvement of the proposed method suggested in this paper includes making the pulse generator false proof in case of shorting by water. This can be done in two ways. The first way is to make the gear box water proof. This method might be costly or inconvenient as the box might need to be opened after a certain interval for physical checking or repairs in case a bolt rotates and raises warning. Hence a second method can be addition of hydro sensor. This sensor can send signal if the gear box is submerged in water to avoid false warning caused by pulse generation due to short circuit by water. To further improve the system, infrared (IR) or other type optical sensors can be integrated at particular intervals to detect track bending due to excessive heat generation from friction as well as washing away of ballast by water. Millions of nodes will be maintained and the huge amount of data will be analyzed for real time monitoring.

V. Conclusion

This paper has presented an IoT based real time automated system that can monitor the condition of the bolts of the rail fishplates and send warning to the control room so that the concerned authority can make rapid decision to avoid severe accident. The proposed system is a very simple and cost effective one that can be easily implemented. This system has showed about 92% of true positive result and 97% true negative result. This is a fairly high accuracy compared to the existing methods. However, the actual system has not been implemented in any real track and the performance of the whole system has been evaluated by manually simulating bolt rotation and checking the responses. So, this paper has showed a hypothetical result instead of an actual system implementation. The system has showed a very promising performance. This method does not take into account corrugation or wheel flats. But it detects the fishplate bolt rotation and track alignment fault with high accuracy. The paper has introduced a new design of an iron-based metal gear. The use of microcontroller along with GSM communication enables loosened bolt location detection with high precision without the use of GPS, reliable data transmission and overall cost reduction. Implementation of the proposed fault detection system is expected to have a significant effect in respect of safety and reduce the number of accidents by a high margin.

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