Environmentally Sustainable Wireless Track Recording Vehicle Strategy Towards Improving the Safety Standards

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Research Article

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Abstract

Transportation is an integral part of modern society as it enhances the function of mobility leading to an important measure of a society's success. Different modes of transport are used worldwide such as cars, trucks, airplanes, and trains. As much as the other modes of transport have developed over the centuries, the use of rail transport is growing increasingly as well. Debate wise the International Energy Agency have discussed the advantages and the future of railway to be a promising one. The implementation the green technology is becoming more prominent in the marketplace. In response to the existing need of making green products that can serve the green market demands, NCRA CMS Lab MUET has developed a Track Recording Vehicle (TRV) prototype as a substitution to the prevailing Internal Combustion Engine (ICE) operated Track Recording Vehicles. As the traditional Track Recording Vehicles are just mere trains equipped with the Inertial Measurement Units (IMUs) which consume gallons of fossil fuel to operate. The developed TRV is an initiation of upcoming trend of portable instrumented TRV that operates with the rechargeable battery and is capable enough to determine track faults like squats and turn out frogs more efficiently than the existing ICE based TRVs using accelerometer module ADXL335 and logistic regression. The developed instrument was validated on an actual railway track. The result shows that the developed instrument can be used to determine the serviceability of the railway track, thus this strategy helps in improving the safety Standards.

I. Introduction

In 2019, Pakistan marred over 100 train accidents[1]. Most of those accidents were due to lack of railway condition monitoring [2]. Railway condition monitoring consists of railway infrastructure condition monitoring and railway rolling stock condition monitoring [3]. Condition monitoring as a general, assists engineers to analyze the faults so that predictive maintenance could be performed in a timely manner to avoid any fatal outcomes. Railway infrastructure condition monitoring is conducted for predictive maintenance of railway tracks, railway sleepers, drainage, joints and crossings whereas railway rolling stock condition monitoring includes condition monitoring of engine, wheelsets, gearbox, braking and electrical motor faults [4][5][6][7]. As per 2019 analysis, it was found that most of the railway accidents in Pakistan are due to train derailment[1]. Train derailment occurs due to lack of railway track condition monitoring, which needs to be addressed.

The methodologies performed for the railway track condition monitoring which is a part of railway infrastructure condition monitoring, involve two basic types of techniques known as "drive by inspection" and "walk by inspection"[8][9][1]. In drive by inspection methodology, the smart instrumentations are either mounted on the track or on the vehicle. These instrumentations are Inertial Measurement Units[10], Camera Modules [11], Tilt analyzers [12], Fiber Bragg Grating [13][14], Ultrasonic testing [15] and InfraRed Thermography (IRT) [16].

Whereas, the walk by inspection methodology is simply a visual inspection performed by the railway officials which is not a reliable approach of analyzing the track faults by virtue of a mere naked eye [1].

This methodology is performed in most of the developing countries like Pakistan. In Pakistan, Pakistan Railways rely on visual inspection, which is dangerous for the safety of its passengers. Therefore, for addressing the safety of the train's passengers, this study discusses the development of a wirelessly operated track recording vehicle, which is potential replacement of the motorized track recording vehicle and push trolleys that are implemented by the Pakistan Railways with an efficient methodology of analyzing the track faults like squats and turn out frogs using accelerometer ADXL335. The developed vehicle is electrically operated and has a backup time of 3 hours. The vehicle can optimally analyze the track faults due to its constant speed of 5km/h.

Ii. Available Technologies

When it comes to developing countries, budget is a constraint. Therefore, the developed product must be meeting the needs of its local railway system in real time analyzing the track faults. Whereas, in developed countries, instrumented trains are applied on the rail tracks [9][17] and methodologies like fiber bragg grating and ultrasonic testing are executed for the railway track condition monitoring [15][13]. No doubt, these techniques are precise yet also are equally expensive. Wherefore, for the developing countries like Pakistan the reliable methodologies necessitates the use of Inertial Measurement Units and image processing algorithms for the railway track fault diagnosis.

Image processing algorithms like gradient filters, morphological filters and Wavelet transformation are vastly solicited to address the need of the railway condition monitoring [11][18][19]. These image processing techniques can be advanced when merged with the machine learning based algorithms like binary classifier, anomaly detection and dark field illumination methodologies [6][20]. The single camera module is bound to work in two dimensions because of which, it can capture the track faults like squats and turn out frogs [7]. But it is unable to identify three - dimensional track surface faults like joint angles and drainage issues due to its ability of capturing only the top view of the railway track. For the system to capture 3D view, two camera modules at a certain angle are required to be placed on a single track, which makes the cost of the entire system relatively expensive due to its high processing requirements that includes: high-end digital signal processors and microcontroller units.

For the system to analyze the three-dimensional faults, Inertial Measurement Units (IMUs) are applied [7][10]. These IMUs mainly contain accelerometers and gyroscopes. These are effective in measuring track faults but when mounted on the instrumented Track Recording Vehicle, they are unable to identify the track surface faults like squats and turn out frogs due to its wheelset size. To mitigate this issue, the developed vehicle has a novel wheelset size that can enable IMU to detect track surface faults as well as eradicate the undesirable readings of the joint gaps.

Iii. Design Of The Developed Track Recording Vehicle (Trv)

The developed TRV is designed on a metallic frame having length 1.5 m and width 2 m as shown in the figure 1. Such that the frame can withstand a weight of 5kg or more. The wheels of the TRV are spaced at

1.676m away from one another.

This is the length of the broad gauge that is followed in Pakistan. For the navigation of the train, these tracks are powered using Power Line Communication, which can be short-circuited if a metallic body is hovered over the tracks. To resolve this, insulated wheelsets are to be designed as shown in figure 2.

The width of the wheel was 7cm (which is exactly equal to the width of a rail track) + 2 cm (Flange width as it helps to intact the rail wheel on a track). Although various wheel's diameters were tried during the testing phase. The optimal results were acquired from the wheel of 0.3 m diameter + 0.1m wheel flange size as mentioned in table 1 using ADXL335 and handheld track recording vehicle as shown in the figure 3. The handheld track recording vehicle was moved on a constant speed at a track distance of 100m that was having a single squat.

Table 1: Readings of Various Wheelsets

Readings of Wheelsets with Various Diameters on a Squat – Y axis Data from ADXL335				
Time (Sec)	Flange Diameter = 0.4m G Value (N/Kg)	Flange Diameter = 0.6m G Value (N/Kg)	Flange Diameter = 0.8m G Value (N/Kg)	Flange Diameter = 1m G Value (N/Kg)
0.25	62.429	47.943	31.541	19.892
0.5	61.812	46.449	31.327	19.876
0.75	61.817	46.453	31.326	19.877
1	59.607	46.685	31.326	19.877

The final design as shown in figure 4, had two drive wheels (that were connected with a 120 rpm, 12V and 2A DC motor) and 2 revolving wheels.

Iv. Working Of The Developed Tvr

The working of the developed TRV is mentioned in the flowchart in figure 5.

The working basically is divided into two parts namely: the TRV's circuitry and Online Cloud connectivity (Figure 6).

i. Circuit

The circuit workflow diagram of the developed Track Recording Vehicle is mentioned in figure 7:

The two motors are connected with the relay module. The relay module's control pins are connected with a Node MCU whereas, the power pins are connected with a 12V, 7AH DC battery. An accelerometer ADXL335's Y pin is attached with the A0 pin of the Node MCU and GPS module is connected with the Tx and Rx pins of the node MCU. Later, the node MCU is synchronized with an online cloud platform named "Thingspeak" for the damage diagnosis. Whereas, the directions of the Track Recording Vehicle are operated using the Blynk app.

ii. Online Cloud Connectivity

The Node MCU has an Arduino Sketch IDE and is easy to program just like the Arduino. Therefore, in the code Thingspeak and Blynk app libraries are included. SSID and the password of the local WiFi host are provided along with their respective token keys (as mentioned in figure 8). The workflow of the locomotion of the vehicle is entirely separated from the damage diagnosis working.

The blynk app credentials are applied on the locomotion code of the vehicle. The keys are defined in the code such that the vehicle is allowed to move either in the forward direction or reverse direction. Similar to what is performed by the traditional motorized track recording vehicle. As per railway standards, the rail vehicle is only allowed to shift direction when allowed by the control room using level switches that can turn the direction of the vehicle using rail switches.

Whereas the damage diagnosis is performed when the Y-axis of ADXL335 (as shown in figure 9) crosses a specific threshold, which triggers a signal to the thingspeak, specifying the damage.

The trigger is sent along with the directions computed from the GPS module that is attached to the node MCU and is layered on the google maps using Google Map App Development Platform (figure 10).

V. Validations

The validation is performed is comprised of two parts as mentioned below in detail:

i. Accelerometer ADXL335

The validation of the accelerometer ADXL335 is performed with a digital accelerometer ADXL345. In both the accelerometers, the acquired readings were in G values which can be computed using the mentioned below equation:

$$G = Force / Mass \qquad (1)$$

The accelerometers ADXL335 and ADXL345 were mounted at an exactly same position on a working DC motor as shown in the figure 11, the comparative readings of the both sensors in table 2:

Table 2: Y axis values of ADXL335 and ADXL345 from the Test Rig

Y- Axis Values (N/Kg)		
Time (Secs)	ADXL335	ADXL345
0.25	11.393	11.391
0.5	11.382	11.385
0.75	11.392	11.389
1	11.392	11.391

It was determined using the statistical operations that the difference between the two sensors was less +/- 5 G, thus validating the accelerometer ADXL335.

ii. Axle Box Acceleration (ABA)

ABA methodology is commonly used in drive by inspection methodologies [21][22]. This technique mounts the accelerometer on the wheel axle because the readings acquired from the wheel axle are undamped raw data[23]. That plays a vital role in the identification of the sophisticated minor track surface damages like squats and turn out frogs.

In order to validate the ABA methodology, two ADXL335 are mounted on the developed TRV. One is mounted of the vehicle's axle and other is mounted in the center of the vehicle as shown in figure 12. The vehicle is then moved on an auxiliary track of 126 ft (as shown in the figure 13) consisting of a single squat at a speed of 5km/h.

The readings fetched from the accelerometer are mentioned in the table 3 below:

Table 3: ABA Validation Table

Time (Sec)	Axle – Y axis, N/Kg	Center – Y axis, N/Kg
0.25	12.677	12.6420
0.5	14.751	12.6419
0.75	14.664	12.6421
1	14.551	12.6399

Considering the table 3, the readings obtained from the axle are elaborating track defect more descriptively than the one recorded on the center of the Wirelessly controlled Track Recording Vehicle as shown in the graphical representation in figure 14, validating the effectiveness of the Axle Based Acceleration (ABA methodology)

Vi. Readings

The experimentation was performed on a 2km track of a railway junction in collaboration with the Pakistan Railways to determine the threshold value for the identification of the squat damages so that in future the algorithm could be trained using the logistic regression for determining the railway track surface faults like squats and turn out frogs. The track was put under several inspection using RailScan 125+ that analyzed 3 squats on the track surface.

The vehicle, when operated in the intact railway track acquired the following Y- axis data in G values as shown in table 4.

Table 4: Intact Track

Time (Sec)	Axle – Y axis, N/Kg
0.25	12.665
0.5	12.661
0.75	12.663
1	12.663

Whereas, the readings acquired from the Y axis of ADXL335 in terms of G values are mentioned in the table 5:

Table 5: Readings from the Track Surface Damages

Time (Sec)	Squat 1, N/Kg	Squat 2, N/Kg	Squat 3, N/Kg
0.25	14.722	15.087	14.875
0.5	14.567	14.987	14.452
0.75	14.665	14.973	14.451
1	14.773	14.974	14.311
Mean	**14.68175**	**15.005**	**14.522**

The reason, why the Y axis is considered is due to non-differential readings that are acquired from X and Z axis of the ADXL335. Besides in literature, most of the studies support the readings acquired from the Y-axis for the determination of the track damage. Thus, through table, it can be computed that if the threshold of the Y axis exceeds 14.73625 N/Kg then the track surface damage that is identified is Squat/ Turnout frog.

Therefore, 14.73625 N/Kg is the activation function of the logistic regression which can be computed by taking the average of the means obtained from the squats. Such that, if the activation function reaches to the defined threshold then the neuron turns the output bit into high as implemented in the table 6 from table 5.

Table 6: Logistic Regression Conversion of Table 5

Time (Sec)	Squat 1, N/Kg	Squat 2, N/Kg	Squat 3, N/Kg
0.25	0	1	1
0.5	0	1	0
0.75	0	1	0
1	1	1	0

In the developed code, a conditional statement is incorporated that sends the location co-ordinates from the GPS module if the neuron is activated of the logistic regression, resulting in a proper location tracking of the identified track surface damage as shown in the figure 15:

Vii. Conclusions

The developed Wirelessly Track Recording Vehicle identifies the same number of damages as by RailScan 125+, which is a high end ultrasonic flaw detector and has a speed of 1 km/h. Whereas, the developed prototype works in the speed of 5 km/h. The vehicle performs its damage identification using logistic regression. Which is a fast and precise neural network algorithm due to its high accuracy and low latency.

This vehicle is designed as per Pakistan Railways standards for substituting the motorized track recording vehicle that detects the damages using visual inspection (figure 16).

The comparison of the developed vehicle with the existing motorized TRV is mentioned in the table 7:

Table 7: Existing TRV vs Developed TRV

Existing TRV	Developed TRV
Engine Powered	Electrically Powered
Visual inspection	Accelerometer/ Logistic Regression
Human Operated	Wirelessly Operated
Cost around US$15000	Cost around US$1500
Large wheel diameter 1.5ft	Optimal wheel diameter ideal for detection of surface mount damages
Does not satisfy SDGs	Satisfies SDGs

Moreover, due to novel wheel size, the developed vehicle has an advantage over existing image processing techniques that require high processing power as well as on instrumented trains that due to their gigantic size are not able to accurately identify minor track surface faults like Squats and Turn out frogs.

As the developed vehicle is electrically operated, it satisfies the Sustainable Development Goals unlike fossil fuel operated motorized track recording vehicles. The damage detection algorithm implemented in the developed prototype analyzes the damage instantaneously due to its binary classification as well as marks the co-ordinates of the damage using the Google Map Developer platform.

Declarations

Funding:

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Conflicts of interest/Competing interests

The authors affirm of not having any conflict of interest with other writer. This write-up article does not have any studies or examination with human contributor or animals previously executed by any of the writer.

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Figures

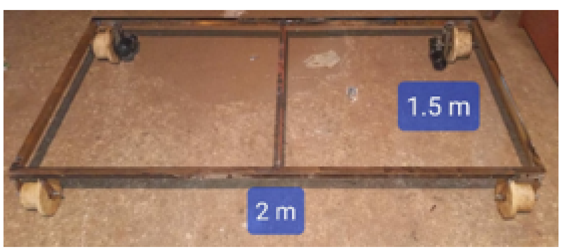

Figure 1

Metallic Frame of TRV

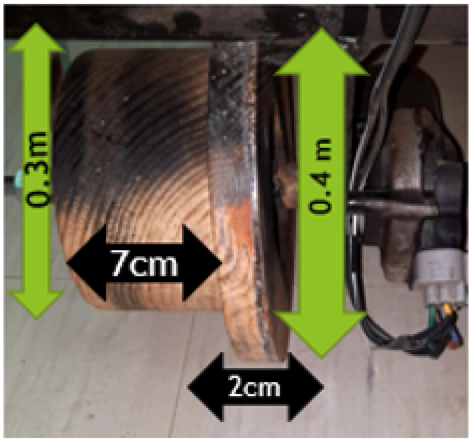

Figure 2

Insulated Rail Wheel

Figure 3

Handheld TRV for testing various wheelsets

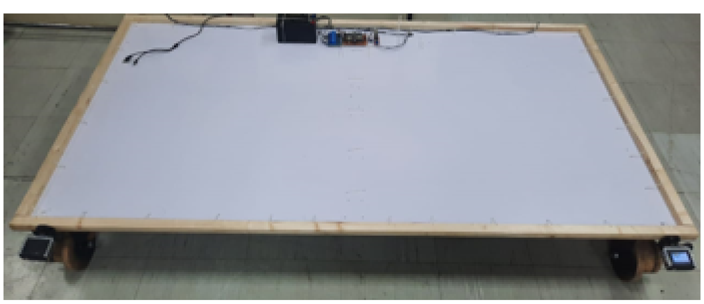

Figure 4

Wirelessly Operated TRV

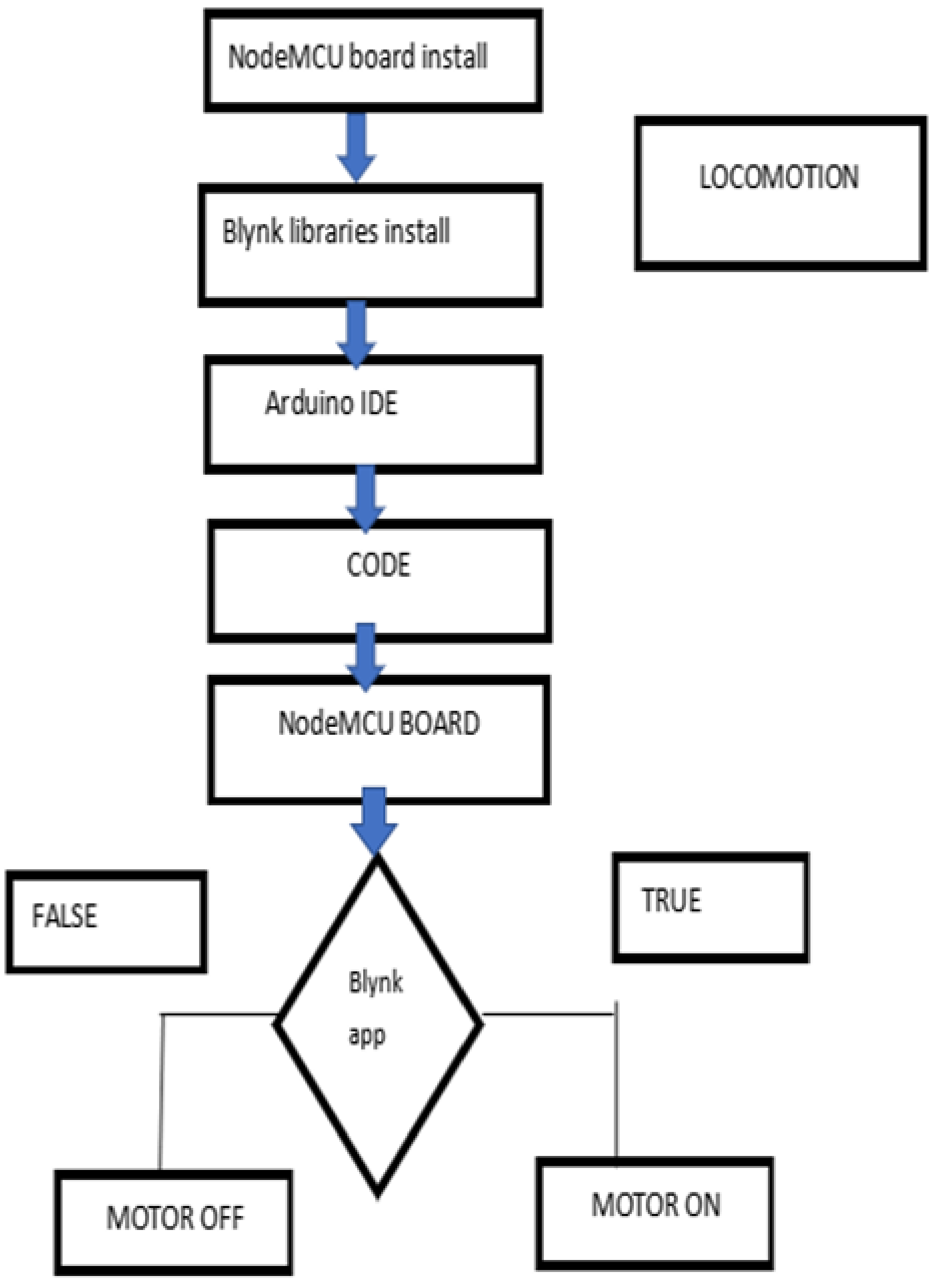

Figure 5

Flow Chart of TRV's locomotion

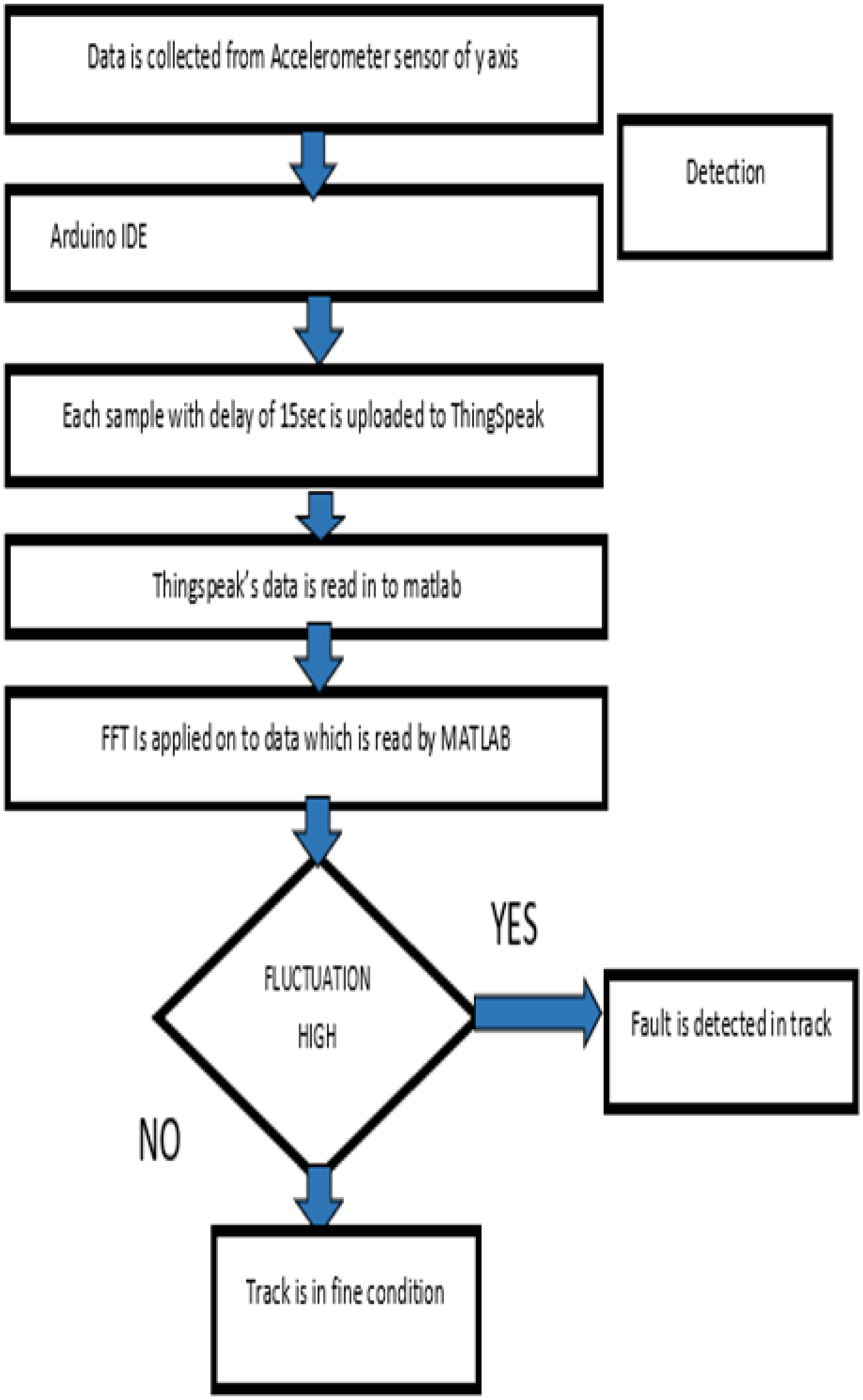

Figure 6

Flow Chart of TRV's Cloud Networking

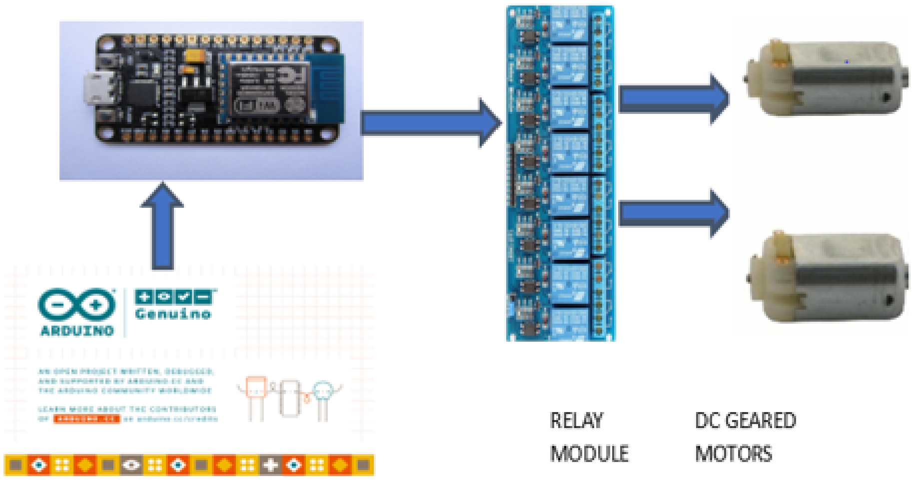

Figure 7

Workflow of TRV's locomotion

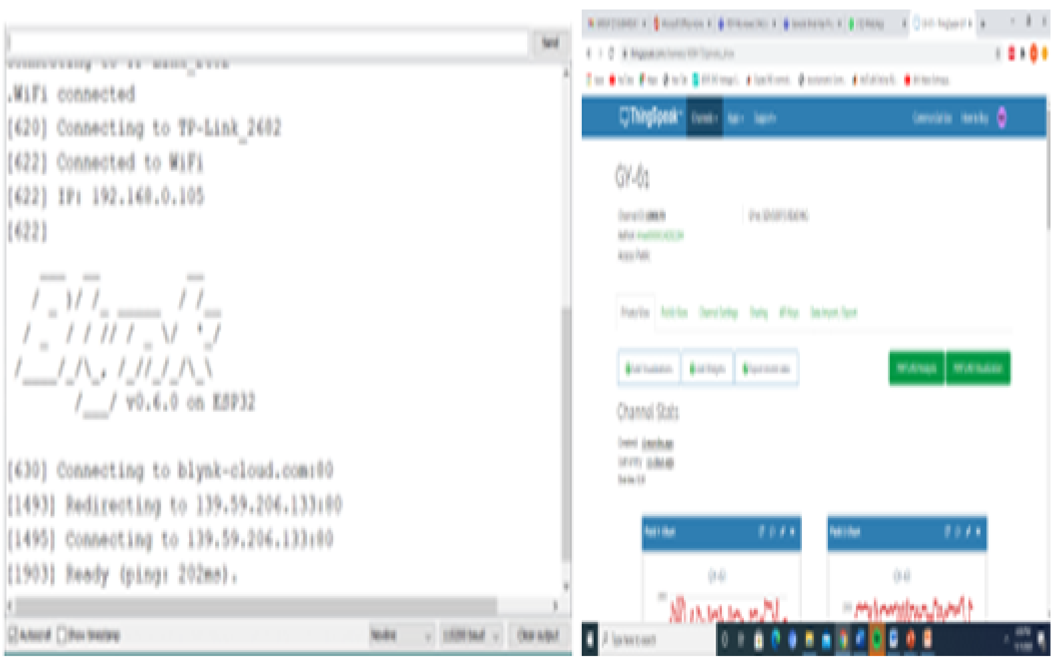

Figure 8

Connectivity with Blynk

Figure 9

ADXL335’s Y Axis data

Figure 10

Google Map App Developer Platform

Figure 11

Accelerometer Validation Rig

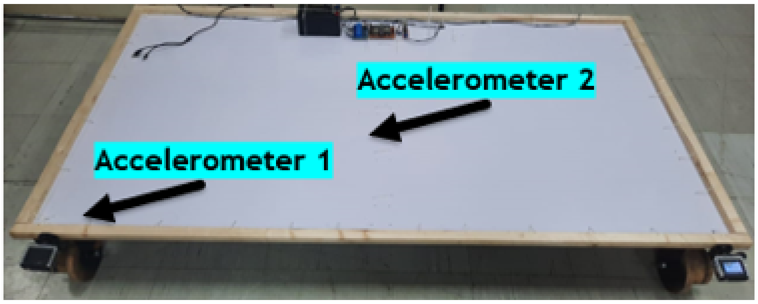

Figure 12

Sensors Placement

Figure 13

TRV running on an Auxiliary Track

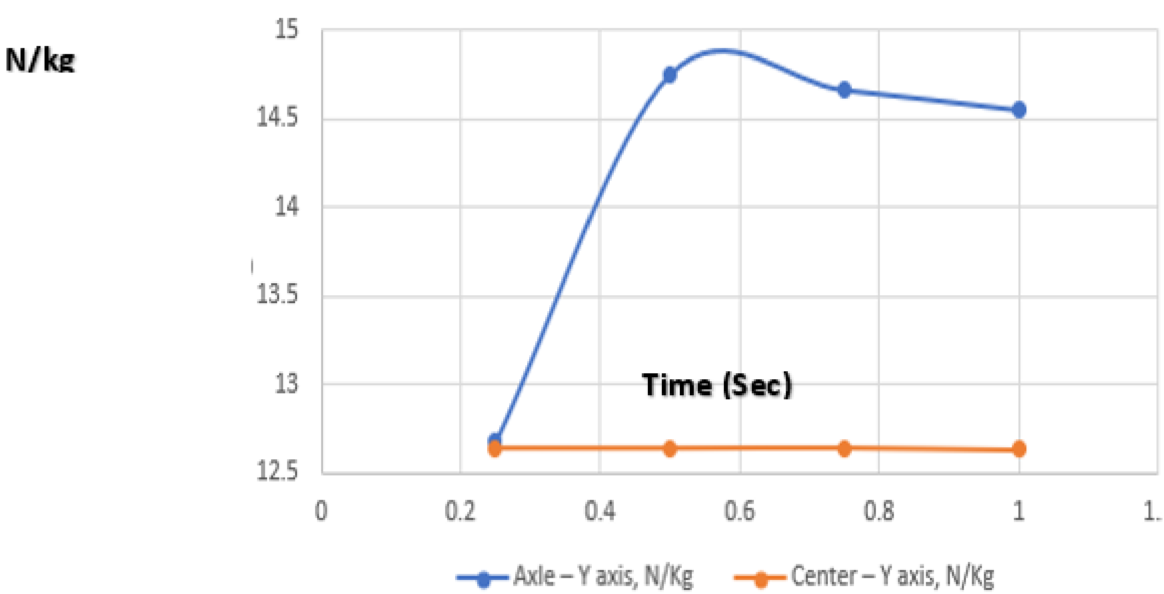

Figure 14

Graphical Validation of ABA.

Figure 15

Marked GPS Co-ordinates.

Figure 16

Motorized TRV