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SIMPLIFIED ANALYSIS OF RAILWAY TRACK DEGRADATION BY MOBILE APPLICATIONS

Rohit Raj Goswami[1], Roberto Sañudo Ortega[2], Stefano Ricci[3]
[1] *IIT Comillas Pontifica Universidad in Madrid, Spain*
[2] *SUM+LAB Cantabria University, Spain*
[3] *Sapienza University of Rome, Italy*

Abstract

This analysis deals with the problem of track degradation and monitoring methods. The main aim is to discuss benefits, drawbacks, and shortages of most of them. There are several monitoring failures approach available today, but no one can predict when or where a failure will occur. This study examines several types of track failures found in railway tracks. Among the many procedures and measures used to deal with these types of track degradation, the authors propose simplified mobile application for investigating the condition of the track. The major goal of the research is to review and provide approaches for track life prediction based on the previous methodologies. The failure prediction can be determined by looking at the degradation of various railway track components. The paper initially addresses railway tracks and their components. Then, it will go over the most usual types of failures that can occur on a railway track and discussion of monitoring techniques. Starting from the methods used when a component fails, it proposes a new prediction method for failures and track life based on the simplified approach to track monitoring using a mobile by a systematic collection of data plots obtained with smartphones in a real track section in India.

Keywords: track maintenance, railways, track monitoring, smart phone monitoring technique, Indian Railway

1 Introduction

The motivation of the paper is to provide an easy and low-cost benchmark for dealing with different failures. Devices for mobile track inspection, easily mountable on passengers and freight commercial trains, are a novel technique for track inspection at high frequency and low cost. It creates a transparent representation of railway corridors in relation to track geometry, enabling resource managers to make fully informed decisions concerning track infrastructure [2]. Using standard smartphone apps, accelerations are measurable in the train in a straightforward and accessible manner. The results demonstrated that measuring ride comfort, studying track quality, and locating individual places along the track were all possible. The average settlement in ballasted railway tracks is very common and caused by vibrational or mechanical movements of trains on the railway tracks [1]. The paper presents a case study based on a phone-monitored track section of approximately 7 km long, located in the West Central zone of Indian railway network.
The present state of such an activity is in the research, and it can be seen in reference [1] that how smart phone can be employed as a method for evaluating track condition and describing the real facts work. A mobile device can be utilized for track monitoring because of this

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real-world experience, resulting in a satisfactory outcome for the track's current state. Some [1, 2, 3] references are used as motivation for work in specific areas of the track in India. One of the most recent ways to assess the status of a track is by using a mobile device. The survey can be completed by any track worker to provide basic guidance on how to utilize the accelerometer application. This kind of surveying is one of the most cost-effective ways to assess the condition of the track. However, it is important to realize that the use of this methodology involves some problems and difficulties. Though this method is a convenient and simple way to assess the state of the track, a tiny shift in the device's location or misalignment in its orientation would skew the data. This means that everybody can make it, but they need to be aware of these requisites when making measurements. For short survey periods, this method is insufficient to check the track's evolution. Differences between measurements during short periods do not show good results (enough differences to compare). To see the actual evolution of the railway tracks, it must be taken across several years. However, for merely checking the track's current state this method is beneficial.

2 Case study

To determine the estimated track settlements, authors intend to use a mobile application to monitor train movement where the acceleration is in the longitudinal, lateral and vertical direction. This is a cost-effective way to determinetrack settlements and related periods. It will inform about the need to clean the ballast, fix any joint parts or improve the track sections. Inspection costs will be lower while inspection frequency will be higher because they do not require a track possession or additional locomotives. The experimental implementation of this approach was on the route between Katni Murwara and Manjhgawan in India (Figure 1).

Figure 1 The survey area from Katni Murwara to Majhgawan.

While monitoring track geometry, the technology creates a digital duplicate of railway corridors, allowing asset managers to make fully informed decisions regarding all track assets. Other applications demonstrate the utility of large-scale surveys in assessing the efficiency of transportation networks, such as studying mobility trends and evaluating the ride quality of transportation systems. Given the importance of frequent track monitoring, especially at critical locations, as well as the cost and difficulty of conducting track geometry inspections across rail networks, there is a need to develop alternative methods for timely collection of information on performances and condition of the track. The present work shows advantages and disadvantages of this methodology and presents an example in a real track. India's category D of railway tracks was chosen. The case study section is about 7 km long with passenger's trains speed of 110 km/h. The surveys cover a period of 65 days of track mobile measurements.

Table 1 Resume of a sequence of measured track data

Measurement Nº	Days	Accelerations (fps-m/s²)	Train speed (110 km/h)	Date
1 (initial)	0	Ax0, Ay0, Az0	V0	4-May-21
2	30	Ax30, Ay30, Az30	V30	3-Jun-21
3	45	Ax45, Ay45, Az45	V45	17-Jun-21
4 (final)	65	Ax65, Ay65, Az65	V65	16-Jul-21

Note: fps - Frames per Second (1/s = fps)

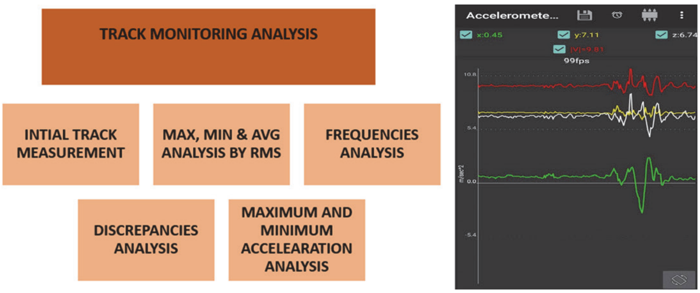

Figure 2 Schematic representation of the methodology and accelerometer measurements displayed by the mobile application

Figure 3 Direction of measurements taken by the mobile phone in relation to train movements

There are important assumptions to consider:

- The position of the mobile device inside the coach should be unchanged. It is important to keep the same position for each measure
- The measurements speed should be the same.
- The initial approach does not divide the signal (wheel-rail and dumping systems of the train) in the different components. It is necessary to use the same vehicle for further measurements (after the initial).

3 Track measurements

The collection of this datasets come from the measurements in the period May-August 2021 on a track section of Indian railway network. The analysis of the resulting graphs, based on maximum and minimum peaks helped to clarify the nature of the detected movements of wheels on rail and the possible effects on passenger's comfort. Figure 4 illustrates the initial track measurement graph, in which the acceleration vs. time graphs were created using Python software for data analysis. Maximum, minimum, and average markings are visible on the plots, indicating the discontinuities in the railway track due to the presence of crossings, switches, river brides and stations, among others. They generate fluctuations of the acceleration and asymmetries, to consider as references for future measurements and analyses. The acceleration in Z direction starts at 10 m/s^2 as application setup, meanwhile X and Y started at 0 m/s^2, except for specific circumstances when the location of the device was at a different level.

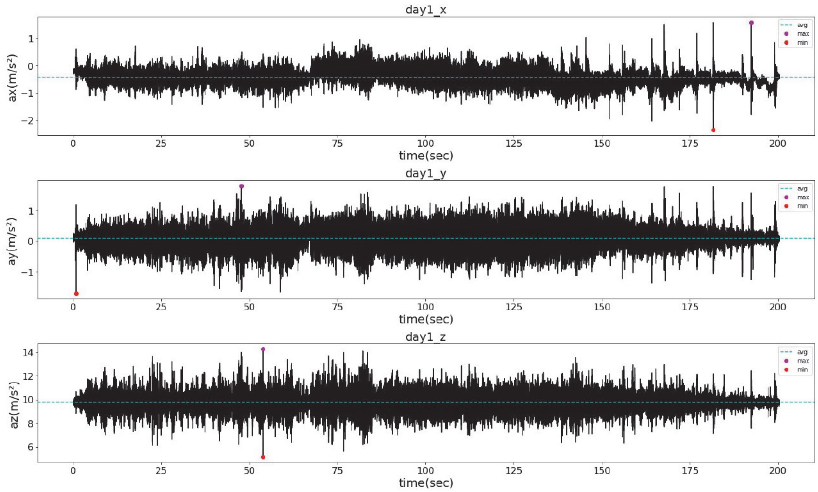

Figure 4 Acceleration measured in X, Y and Z directions during the initial track measurements

The analysis of maximum and minimum data values was by Root Mean Square (RMS) approach. For a set of n values $x_1, x_2, \ldots, x_n$, the RMS value is given by:

$$Xrms = \sqrt{\frac{X_1^2 + X_2^2 + \cdots + X_n^2}{n}} \tag{1}$$

RMS is calculated using the values obtained by the author in the initial measurement analysis by collecting the minimum and maximum values in the acceleration by time graph in the X, Y, and Z directions. The obtained values are then computed in the RMS equation, obtaining some specific results that show different types of problems in different situations shown in table 2. The presence of discontinuities in the railway track caused the hampering of movements resulting in positive and negative peaks in the acceleration versus time graphs. The graph along the Z-axis, however, will not change in evolution, as we will observe in the next step. It took 4 minutes to complete the one-way journey; however, the accelerometer records the values in Frames per Second (FPS), thus 1/s = 1 FPS.

Table 2 The calculation of RMS values is shown in different directions

Days	x_min	x_max	y_min	y_max	z_min	z_max	RMS_x	RMS_y	RMS_z
0	-2.36	1.60	-1.70	1.81	5.14	14.28	0.15	0.14	0.18
30	-2.96	2.36	-2.39	2.52	7.17	12.69	0.20	0.18	0.23
45	-2.98	3.00	-1.45	2.59	3.36	18.33	0.28	0.25	0.12
65	-1.53	2.00	-1.21	1.19	5.34	14.57	0.14	0.26	0.17

As shown in Table 2, minimum, maximum and average values produced by the RMS approach are nearly variable in the case of X and Y, meanwhile it is not the case for Z, because the track's progression was minimal.
The evolution in the values of the railway track plotted in Figure 7 show an asymmetry in the data acquired from separate surveys due to lack of maintenance work caused by COVID-19 lockdown restrictions and variability of train's speed during the measurements.

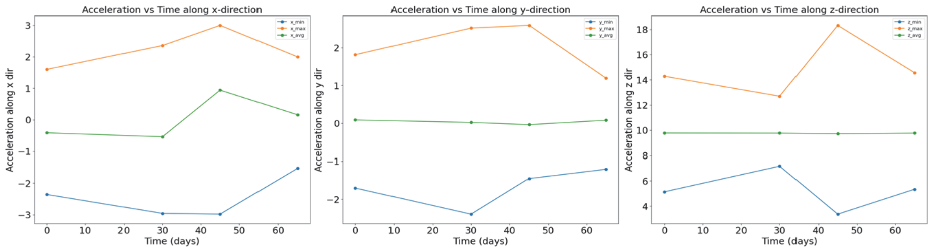

Figure 5 Evolution of the track from day 0 to 65: Z variation is little but X and Y variations are significant

The acceleration vs. time graph becomes non-periodic as a result of this. Finally, the track's discontinuities produced high positive and negative peaks at areas of discontinuity, with the majority of them occurring at railway crossings. Various maintenance works were made during the period of the measurements, therefore X and Y value changes are due to these, meanwhile Z vaues had a minimum variation anyway.
The Frequency Analysis (FA) of the railway tracks measurements focused on the frequency response of the acceleration of the train on track. This isimportant to qualify the wheel movement in different directions and to correlatethem with the other graphs as time progresses. The measurement values are significantly lopsided, in plot 4 as shown in the Figure 6. The values of thefrequency over acceleration in all directions made let us analyses the evolutionof the track over time. If maintenance is not completed or is in progress, it will reflect a sudden fluctuation in frequency graph.
The acceleration was not fluctuating much on the first 3 surveys. But on the survey 4 significant fluctuations appear in the acceleration with respect to the frequency.
Among the first 3 surveys, a little fluctuation could be seen on day 1 over the three directions. These fluctuations are due to the switches near Katni and Murwara stations.

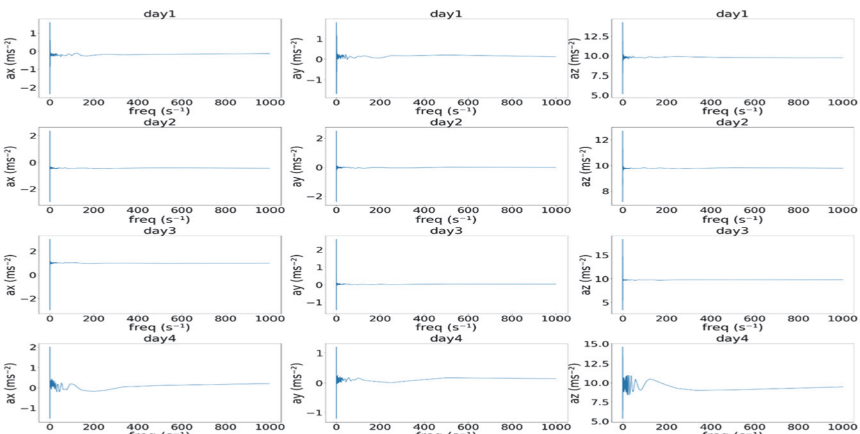

Figure 6 Frequency analysis of the measured accelerations (Our frequency does not have the same axis value in the x direction since the data is asymmetric, that had obtained while survey.)

The radical changes on the plot in the 4th survey on the 65th day are primarily due to the long gap time survey, as it demonstrates the possibility of speed fluctuation, lack of maintenance, poor maintenance, or the section being in the way of maintenance at the time this survey was done. The railway crossing before the final station is to blame for the day 4 random excessive fluctuation in acceleration along the all direction. The fluctuations are more relevant in survey 1, fewer in surveys 2 and 3 and finally higher in survey 4, due to the better maintenance not everywhere and the speed and journey time variability.
In the literature, the discrepancy analysis was mainly developed in X and Y directions, here it is now focused on signals in Z direction, because vertical acceleration is the most important to study track irregularities and wear [4]. The detection of the true condition of the track come from the variations in vehicle movements: if they remain within reasonable values, no severe maintenance is required, meanwhile, they are excessive, it is necessary to investigate the cause and plan extensive repair. The plots in Figure 7, demonstrate the movements of the vehicle in direction Z discussed in the discrepancies between plots. The comparison between the corresponding days, throughout the stretch and in the early days.
Throughout the observation period, there are clear signals of track degradation. The greater degree of disparity is in correspondence of the first river bridge (plot the highest fluctuation is more than 1.4 m/s^2, which is beyond the acceleration guideline on railway bridges. It is possible that vibrations on the bridge, amplifying the fluctuation in the accelerometers.
There are several noticeable discontinuities in the vertical acceleration signals, correlated to various track structures and discontinuities. Changes in the track structure (track transition zones) coincide with entrance and exit to Katni and Kohai rivers. Because our data is asymmetrical, we use the average cut-off, which varies in different graphs. Figure 8 illustrates the maximum and minimum accelerations with a certain cut-off, which is the train wheel movement norms, on rails [5] assessed and shown in blue and red. All the red/blue peaks are caused by changes in train speed, sporadic maintenance along the segment and discontinuities, responsible for the highest peaks in the plots.

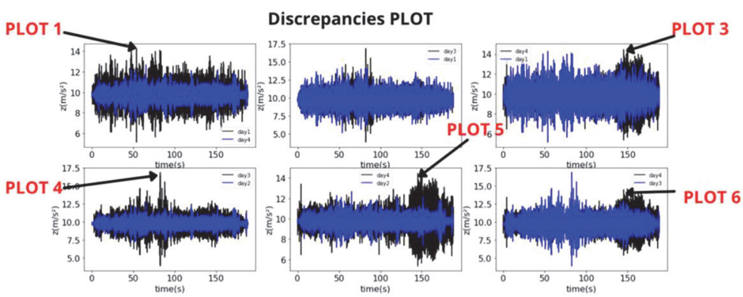

Figure 7 Discrepancies plots in Z direction

There were minor issues with comparison of some plots, caused by the position of the mobile device during the survey, and at the starting graphs, mainly but not only, along the Z-axis, with the graph not started from zero. The cut off is essentially a guideline on Indian railway track where train acceleration and deceleration have been limited for sections of railway track for safety reasons [5]. The plots from figure 8 show peak positions observed acceleration along X and Y in different surveys and at different sections, due to the different in the maintenance work performed between the surveys and the discontinuities in the railway tracks. The peaks arise at these points of discontinuity, as can be seen from the plots. According to the Indian railway guidelines, there is a cut-off for maximum and minimum acceleration.

These points will be part of a benchmark to check what the peaks are mentioned in the guideline [5]. Cut-off Value- The value depicted in blue and red on the plot is based on a cut-off, which is based on IRC standards for passenger comfort.

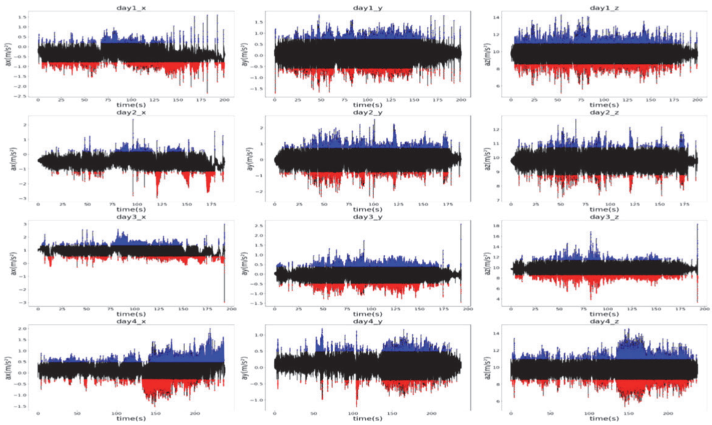

Figure 8 Comparison of maximum and minimum values of acceleration, primarily due to discontinuity (Blue and red indicate that the passenger's comfort level has been exceeded

The wheel movement on the rail is measured in millimeters. Because the data acquired is quite asymmetric, this work cannot be said to be a 100 percent effective computation.The main fluctuations are along Z axis. Particularly at Z3, close to the final station because of the maintenance work during the survey. The cut-off values are determined by the observation of all peaks along the track in all directions, as well as to justify the observation of peaks and to determine whether these fluctuations are compatible with the railway guideline. The asymmetries along X and Y directions are more relevant due to maintenance and track discontinuities, but the inequalities along Z are extremely small.

4 Conclusions

The achieved results demonstrated that mobile applications on cell phones could be helpful to determine the evolution of the state of the track. Nevertheless, it is crucial to discuss the arising critical concerns. It is crucial to take the measurements in the same train and at the same time and with the mobile device in the same position. It is necessary to observe the discrepancies in measurements along different periods of at least 30 days. The comparison of measured vertical acceleration in different surveys were basing on the Discrepancies analysis method. The plots with the highest discrepancies over time are those with the most discontinuities in the tracking. The Frequency Analysis method looks at acceleration variations in all directions over time, resulting in a small fluctuation at the switch points in all directions. The highest Z-direction fluctuations are on day 4, due to a lapse in periodic maintenance prior to the survey. The highest positive acceleration and minimum deceleration were finally under evaluation respect to the parameters from the Indian Railways (IR) rules. The points of maxima and minima accelerations are analysed with a changed cut-off following the rules due to the detected data asymmetry: accelerations and decelerations have overpassed the thresholds provided by the IR standards in a few locations. It can be said that these conventional tools can help to monitor track performance.

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