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Potential of estimating track irregularities from in-service vehicles using smartphones

P. Leibner[1], A. von Stillfried[1] and C. Schindler[1]

**[1]Institute for Rail Vehicles and Transport Systems,
RWTH Aachen University, Aachen, Germany**

Abstract

The necessary inspection of railway tracks currently still requires high effort and costs, even though cheap sensors and IoT-capable devices are widely available. Such devices could be installed in regular in-service rail vehicles and potentially monitor and measure track irregularities comparably well. This would enable new possibilities for railway operators as they could provide services that are traditionally executed by network operators. Smartphones are a typical example of these kind of devices. Existing studies already researched upon the usage of smartphones in rail vehicles to potentially measure track irregularities. However, from our knowledge none of the previous studies assessed the quality of smartphone accelerometers. Therefore, we conducted experiments on a shaker test rig with different smartphones to study the frequency response of different devices. This paper presents the results of these experiments and shows that smartphones are in general not suitable to measure track irregularities directly. We show that the quality of the data only allows for monitoring applications with the focus of detecting larger deviations over time. The exact calculation of deviations respectively track irregularities is not viable from our perspective.

Keywords: inspection, railway tracks, smartphones, track irregularities.

1 Introduction

As a result of railway operation track wear occurs over time, which can either result in increasing track irregularities or track geometry errors. Depending on the wavelength, occurring irregularities can decrease the passenger comfort or in the worst case even affect the ride safety if the tracks are not properly maintained. To monitor track conditions, track geometry cars measure the complete railway network on a regular basis. This, however, requires high effort and costs. For example, German railway tracks with a maximum speed greater than 230 km/h must be inspected every two months [1] and the total maintenance costs of the rail superstructure in the German network added up to more than 1.4 million euros in 2019 [2]. To reduce cost and increase efficiency of track monitoring, we therefore study the possibility to estimate track irregularities from in-service vehicles using smartphones.

The use of smartphone accelerometers has already been research upon in various studies for different use-cases. The authors of [3] for example concentrate on detecting damages on vehicles, e.g., wheel flat spots and bearing damages. However, the authors do not make any statements on the quality of the smartphone data. Another paper investigated the long-term degradation of tracks based on smartphone measurements. The authors obtained cross-correlation values above 0.85 between the smartphone measurements and existing track irregularities [4]. Other works developed a standard algorithm for infrastructure supervision [5] or investigated the effects of speed on vibration when measuring with smartphones [6]. Afterall, all these papers consider the smartphones as a black box without studying the quality of the accelerometer data itself. We therefore conducted experiments on a shaker test rig to analyse the properties of several smartphones.

Our results show that typical smartphones can detect a frequency range up to 100 Hz, partly with significant dampening. Higher frequencies can either not be recorded because of low sampling frequencies or internal low-pass filters with a low corner frequency. For the application of measuring track irregularities, a frequency range up to 100 Hz could be considered sufficient, since even when running at high speeds, the corresponding minimum detectable wavelength would be below one meter. Consequently, track geometry errors like rail corrugation can only be detected using smartphones when running with low speeds (30 km/h or lower).

2 Methods

Before carrying out experiments on a shaker rig, we selected six different smartphones both from a lower and an upper price segment. The selected devices are listed in Table 1. In general, we tried to select smartphones with different accelerometers, but to check whether also two devices with the same accelerometer can show different behaviour, we selected two devices with same sensor. The maximum available sampling rates of the devices range between 200 and 800 Hz.

Manufacturer	**Smartphone**	**Price (List Price)**	**Accelerometer**	**Fs [Hz]**
Nokia	XR20	499,00 €	ICM4X6XX[1]	500
Nokia	G10	139,00 €	STK8321	200
Samsung	A52s	449,00 €	LSM6DSO	800
Samsung	A32	279,00 €	LSM6DSL	200
Motorola	One	249,00 €	LSM6DSM	200
Motorola	g 10	149,00 €	ICM4X6XX[1]	500

Table 1: Selection of smartphones.

To study the capability of the devices to record acceleration for scientific or industrial uses, we mounted the smartphones on a shaker test-rig to identify the transfer functions from the outside of the device to the output of the sensors. We employed an internally developed Android App that utilizes the Sensor API of the Android SDK to read the sensor values.

Figure 1 shows our test-setup. The smartphone is mounted on a flat rigid steel plate using multiple slices of double-sided tape. To make sure that the smartphones are in a flat position, the plate has a small cut-out to leave room for any camera bumps that some of the smartphones have. The choice of using double-sided tape was made based on the assumption that a device would most likely be mounted in a similar way on any other structure, e.g., a rail vehicle car body. Furthermore, tape can be very strong but still removed without residue from the smartphone. During our experiments, the smartphones also never loosened due to the excitation of the shaker. On the steel plate we also mounted an industrial grade accelerometer (PCB 3741B1230G) with a measurement range of ± 30 g and frequency range from 0 to 1000 Hz. This sensor was used as reference respectively input signal to determine the transfer functions.

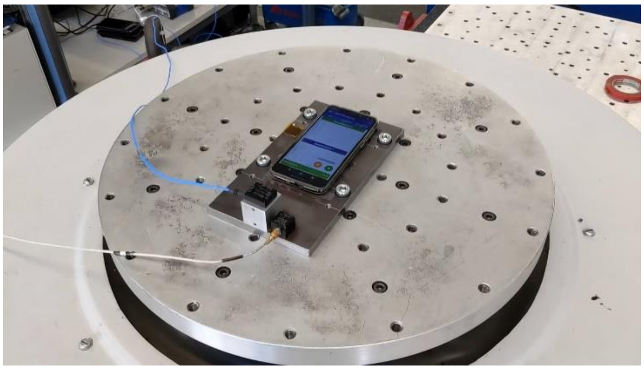

Figure 1: The test setup with a smartphone placed on the shaker.

Within this analysis we only considered the transfer function in vertical direction, but we plan to identify the transfer functions in both horizontal directions in the future. After making sure that our measurement was correctly working, we excited each of the smartphones using sine sweeps generated by the shaker. The sine sweeps had an amplitude of 1 g and frequency range from 5 to 2000 Hz. Each sweep had a sweep velocity of 2 octaves/minute.

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[1] This name represents a family of accelerometers. The exact accelerometer model could not be determined based on the Android Sensor API.

3 Results

To estimate the transfer function for each smartphone, we used the power spectral density estimated from the smartphone sensor readings and divided it by the cross spectral density between the input signal from the industrial sensor and the output signal of the smartphone sensor. Figure 2 shows the magnitude plots of the estimated transfer functions for each device. Instead of an ideally constant gain of 1 within the whole frequency range, all tested smartphones show some deviations. Some of the device's responses display low-pass filter behaviour, which can be seen very clearly for example in the response of the Samsung A52s device. Also, some devices have clearly visible eigenfrequencies (e.g., the Nokia XR 20 or the Motorola g10).

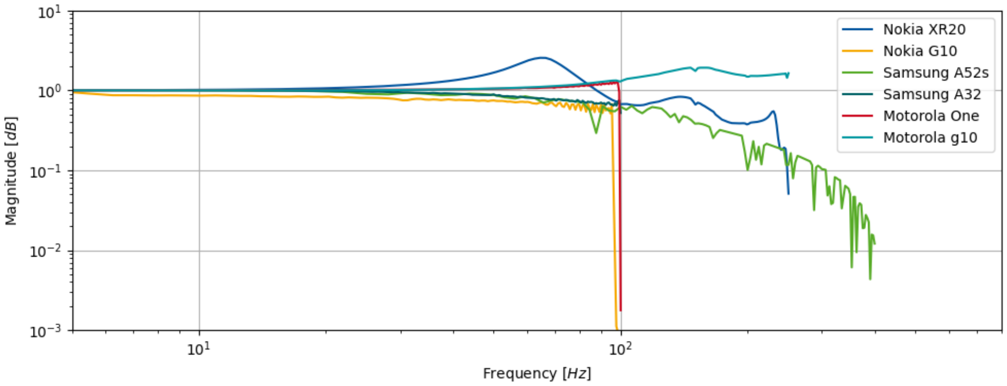

Figure 2: Magnitude plot of estimated transfer functions.

For a quantitative assessment we calculated the mean gain for each smartphone for a frequency range from 5 to 20 Hz and from 5 to 100 Hz. The values can be found in Table 2.

	Nokia XR 20	Nokia G10	Samsung A52s	Samsung A32	Motorola One	Motorola g10
K (5 to 20 Hz)	1.028	0.854	0.997	0.996	1.007	1.000
K (5 to 100 Hz)	1.422	0.700	0.809	0.848	1.075	1.101

Table 2: Calculated gain values for each smartphone and for a frequency range of 5 to 20 Hz and 5 to 100 Hz.

Due to built-in low-pass filters better gain values (i.e., a gain closer to 1) can be observed for the smaller frequency range from 5 to 20 Hz. The best devices appear to be Samsung A52s and the Motorola g10 for both frequency ranges. In contrast, the worst device appears to be the Motorola One with a constant gain of 0.510 and 0.521 respectively. The results show that the maximum sampling rate of each device does not give a reliable indication about the frequencies that can be measured with confidence. The Samsung A52s has a maximum available sampling rate of 800 Hz but significant dampening is already visible at 100 Hz due to the corner frequency of the device's internal low-pass filter. The use of low-pass filters after the sampling circuit to mitigate anti-alias effects is a common design principle. However, for smartphones the internal corner frequencies do not always seem to be matched well with the sampling rate that is being made available for the user.

4 Conclusions and Contributions

Based on our results we conclude that smartphone accelerometers cannot replace industrial sensors by any means. The sensors built into such devices deliver no consistent or reliable results, which is unsurprising due to their much lower production cost. We found that most devices show satisfactory behaviour up to frequencies of 20 Hz, higher frequencies up to 100 Hz already show signs of dampening. Frequencies above 100 Hz can either not be measured due the device's sampling rate or are subject of significant dampening due to internal low-pass filters. Furthermore, even devices with the same type of accelerometer must not necessarily show the same frequency response.

For the means of measuring track irregularities, we conclude that smartphones should only be used for track monitoring but not for exact track measurements. While the frequency range is in general sufficient to detect track irregularities, even in vehicles running at high speeds, the influence of a device's internal transfer function is too significant to trust the measured output accelerations such that track irregularities could be calculated based on the data. Hence, smartphones are likely only sufficient to detect larger deviations occurring over time but not able to output concrete displacements. If an operator decides to use smartphones or devices with similar sensors for track monitoring, we advocate that the operator at least uses the same type of smartphone throughout its fleet since the transfer function and properties of individual smartphones can differ substantially. For the case of scientific uses we also recommend tests on a shaker-rig, similar to our experiments, to identify the quality and properties of the used sensor.

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