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An Evaluation of the Potential Use of Ballast Tampers for Dynamic Track Monitoring

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Abstract

This paper focuses on analysing the potential use of ballast tampers for dynamic track monitoring. Ballast tampers are ubiquitous in modern railway networks as essential maintenance devices for ballasted tracks, and expanding their utility would help dispensing with dedicated monitoring trains, which are complex and expensive. In order to test this possibility, a conventional tamper has been equipped with accelerometers and vibration data has been registered while the tamper travelled along lines 3 and 7 of the Valencia metro network.

Data thus acquired has been then processed and analysed, and accelerograms and vibration spectra have been obtained. From this data it is possible to locate potential track defects that could be then identify through visual inspection, hence showing that conventional dynamic monitoring could be carried out by ballast tampers. Moreover, vibration spectrograms have been also obtained, which represent a more advanced approach towards dynamic monitoring that could help directly identifying defects from vibration signals, without subsequent visual inspection. Although this would require further research, it also proves that vibration data from ballast tampers may also be used in ongoing investigation into improved dynamic monitoring.

Keywords: Maintenance, Dynamic monitoring, Ballast tamper, Acceleration, Vibration spectrum, Track defects.

1 Introduction

Ballasted tracks are still the most common track typology across the world. However, despite its overall reliability and good performance, it requires continuous maintenance to ensure that track geometry remains stable enough for a safe train operation. This maintenance takes the form, among other operations, of frequent ballast tamping, which requires costly and specialised equipment (i.e. tampers) as well as a dedicated crew. As a reference, the main Spanish rail administrator, ADIF, spends more than 92,000 €/km annually to maintain high-speed ballasted tracks [1].

Another crucial aspect of maintenance is track monitoring, which means gathering accurate data regarding the track status (and, particularly, its geometry) in order to assess its condition and plan maintenance operations accordingly. Track monitoring usually combines different operations such as visual inspections, direct geometric measurements and dynamic monitoring [2]. The latter is particularly useful, as it allows monitoring long track sections relatively quickly. On the other hand, it requires highly specialised (and expensive) monitoring trains such as the SENECA used by ADIF.

As an alternative to such specialised vehicles, many studies have been carried out over the last years to analyse whether reliable and accurate dynamic monitoring could be done with conventional passenger trains during their daily operation, by means of equipping such trains with accelerometers and other sensors. This kind of research has been applied to high-speed trains [3] and metro trains [4] with promising results, but it is yet to become a standard monitoring procedure and rail managers still rely on dedicated monitoring vehicles.

In this context, our research proposes to use ballast tampers to carry out dynamic track monitoring. Ballast tampers are, as explained before, a crucial maintenance tool for ballasted tracks and, as such, are used by every track maintenance company and routinely travel along rail networks. These highly specialised machines are usually equipped with geometric sensors to measure track gauge and other geometric parameters, but they are not capable of dynamic monitoring.

Installing accelerometers on ballast tampers to turn them into dynamic monitoring vehicles was first proposed by Offenbacher et al. [5] as a mean to dispense with dedicated monitoring trains. However, as tampers have completely different damping systems than those of passenger trains, it is necessary to analyse in detail the correlation between on-board accelerations and track defects to adapt monitoring procedures to this particular kind of rail vehicle.

Moreover, conventional dynamic monitoring neither identifies a specific track defect nor assess its severity. Instead, registered on-board accelerations are compared to previously defined thresholds so that any excess pinpoints the location of a potential track imperfection, but visual inspection is still needed to assess the situation and determine whether a maintenance operation is required [6]. There is abundant research aiming at a more precise correlation between on-board accelerations and track defects [3, 4, 6, 7, 8], but there is still ample room for further investigation.

Within this framework, the main objective of this study is to evaluate the use of ballast tampers as dynamic monitoring devices by installing accelerometers on-board and registering accelerations while the tamper travels along a railway line. Furthermore, the study also aims to contribute to ongoing research regarding acceleration data analysis to achieve a more useful dynamic monitoring.

2 Methods

In order to assess the potential use of ballast tampers for dynamic track monitoring, a conventional tamper was equipped with accelerometers so as to register on-board accelerations while the vehicle travels along a railway line. The tamper chosen is a metric gauge PLASSER & TEURER 07-16, as shown in Figure 1.

Figure 1: Monitored tamper machine.

The main characteristics of the tamper are shown in Table 1.

Parameter	Value
Tare	33,000 kg
Maximum speed	80 km/h
Tamping ratio	600 m/h

Table 1: Tamper features.

The sensors installed on the tamper are accelerometers, both piezoelectric and capacitive, with varying ranges and sensitivities. This kind of sensors have been used in previous studies related to train and track monitoring [6, 9], and thus have been proved reliable and useful. Their main characteristics are shown in Table 2.

Sensor	Manufacturer	Model	Sensitivity (mV/g)	Range (m/s^2)
Piezoelectric	MMF	KS76C-100	100	550
Piezoelectric	MMF	KS776C-10	10	5500
Capacitive	MEAS-SPEC	4610-002-060	1000	20

Table 2: Accelerometers features.

Additionally, the tamper is also equipped with a GPS (model GPT BT-Q818 manufactured by QSTARZ) to measure position and speed during the monitoring process. This is essential to accurately locate any noticeable acceleration peak along the monitored track. All sensors are connected to a portable device with three Data Acquisition Cards (DAC) and 12 channels. This device is placed in the tamper cabin and stores all the data registered by the sensors and the GPS. Accelerometers' signal is recorded with a sampling frequency of 8 kHz, in line with previous studies related to dynamic monitoring [4, 6].

A total of four accelerometers were installed in the tamper. Three were placed on the right side of the vehicle and one on the left side, all of them in the bogie structure as shown in Figures 2 and 3. The one on the left, as well as one on the right, register vertical accelerations. The other two on the right register transversal accelerations. Sensors were fixed using magnetic attachments and duct tape. The GPS was placed on the tamper cabin.

Figure 2: Vertical piezoelectric accelerometer placed on the tamper's first bogie.

Figure 3: Lateral capacitive accelerometer placed on the tamper's first bogie.

Finally, two cameras were installed below the tamper to record the rail-wheel contact during the monitoring procedure (Figure 4). This was done to help identifying track defects by comparing each acceleration peak with the corresponding camera footage.

Figure 4: Camera installed below the tamper to record rail-wheel contact.

The tamper thus equipped with sensors travelled during one night along sections of line 3 of the Valencia metropolitan network between the stations of Av. del Cid and Rafelbunyol. Parts of line 7 were also monitored between Machado and València Sud stations (see Figure 5).

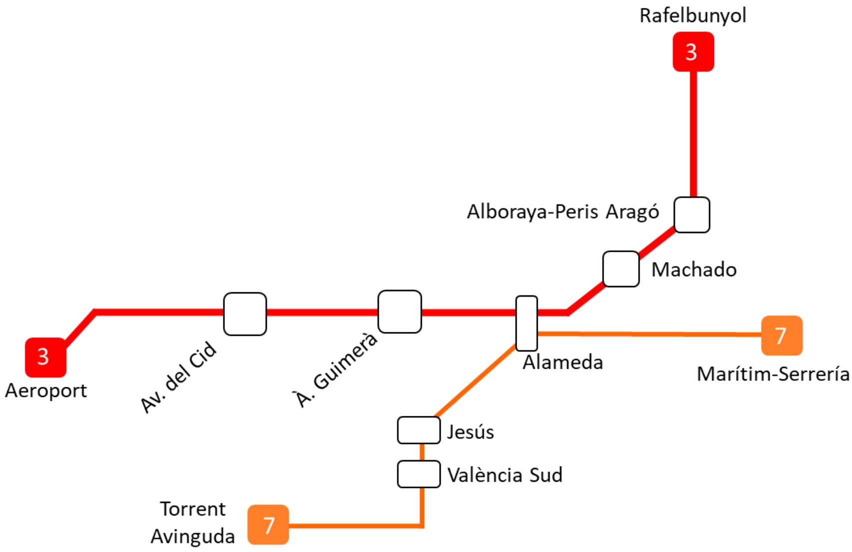

Figure 5: Monitored track sections within the Valencia metro network.

Accelerations were recorded in both directions, gathering up four datasets with a combined length of 1650 seconds, as shown in Table 3.

Dataset ID	Length (s)	Number of data points	Track section
UP-230208_005025	250	2,949,600	Av. Cid – Alboraya P. Aragó
UP-230208_011305	500	4,725,600	Alboraya P. Aragó – Rafelbunyol
UP-230208_020219	400	4,082,400	Rafelbunyol – Machado
UP-230208_030007	500	4,692,000	Machado – València Sud

Table 3: Obtained datasets.

The acceleration data thus gathered was then filtered using a low-pass filter to remove noise, and vibration spectra were calculated for further analysis. The results obtained are discussed in the next section.

3 Results

Figure 6 shows the filtered accelerogram and corresponding vibration spectrum measured for vertical accelerations in the right-side axle-box. This data corresponds to the fourth dataset described in Table 3. From this kind of data, it is possible to identify remarkable acceleration peaks that may be due to track defects that induce a dynamic load in the tamper. On the other hand, the vibration spectrum allows assessing which frequencies are excited in the tamper.

For this particular dataset, which corresponds to the trip between Machado and València Sud stations, there are several vertical acceleration peaks that reach in excess of 20 m/s^2, located at 264, 330, 517, 522, 542 and 575 seconds. This only indicates a potential track defect at those locations, as is the case with the conventional approach to dynamic monitoring. In order to better analyse this data, spectrograms are calculated to assess how different vibration components evolve along the journey. This is done by dividing the whole dataset into partially overlapping windows of equal duration (20 seconds) and obtaining the vibration spectrum for each window. These are then joined to form a single graphic, following the methodology presented by Salvador [10]. Figure 8 shows an excerpt of the spectrogram corresponding to the vertical accelerations of figure 6, focused on the time window between 260 and 280 seconds. Please note that pairing accelerograms in figures 8 and 9 are filtered differently than those shown in figures 6 and 7.

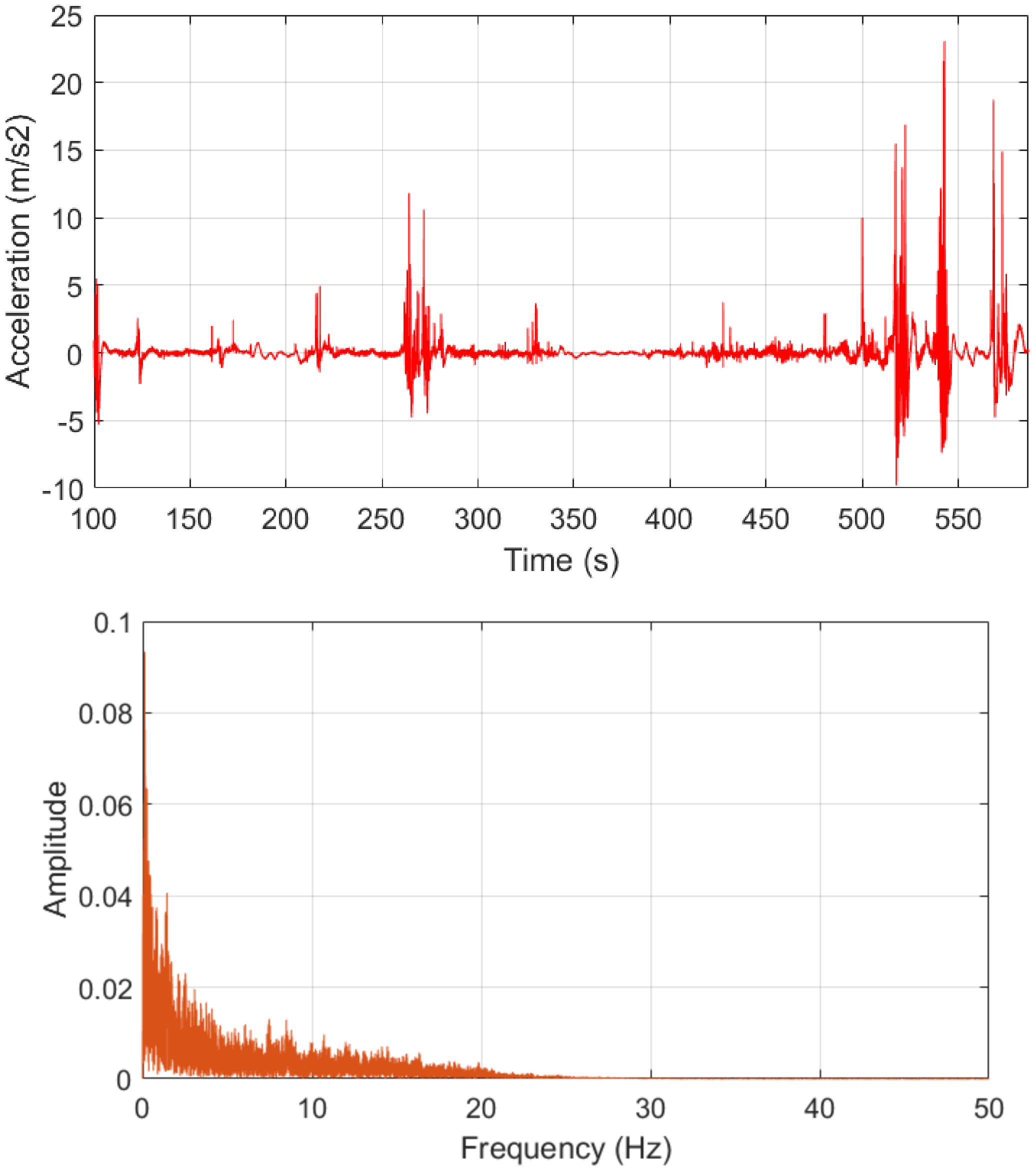

Figure 6: Filtered accelerogram (up) and vibration spectrum (down) recorded for vertical accelerations in the right-side axle-box between Machado and València Sud.

Conversely, Figure 7 shows the filtered accelerogram and corresponding vibration spectrum measured for lateral accelerations in the same location and for the same dataset. In this case, main acceleration peaks, reaching over 600 m/s^2 in a few cases, are located at 123, 167, 216, 261, 330, 419, 518 and 540 seconds. Figure 9 shows the corresponding spectrogram, in this case focused on the time window between 160 and 180 seconds.

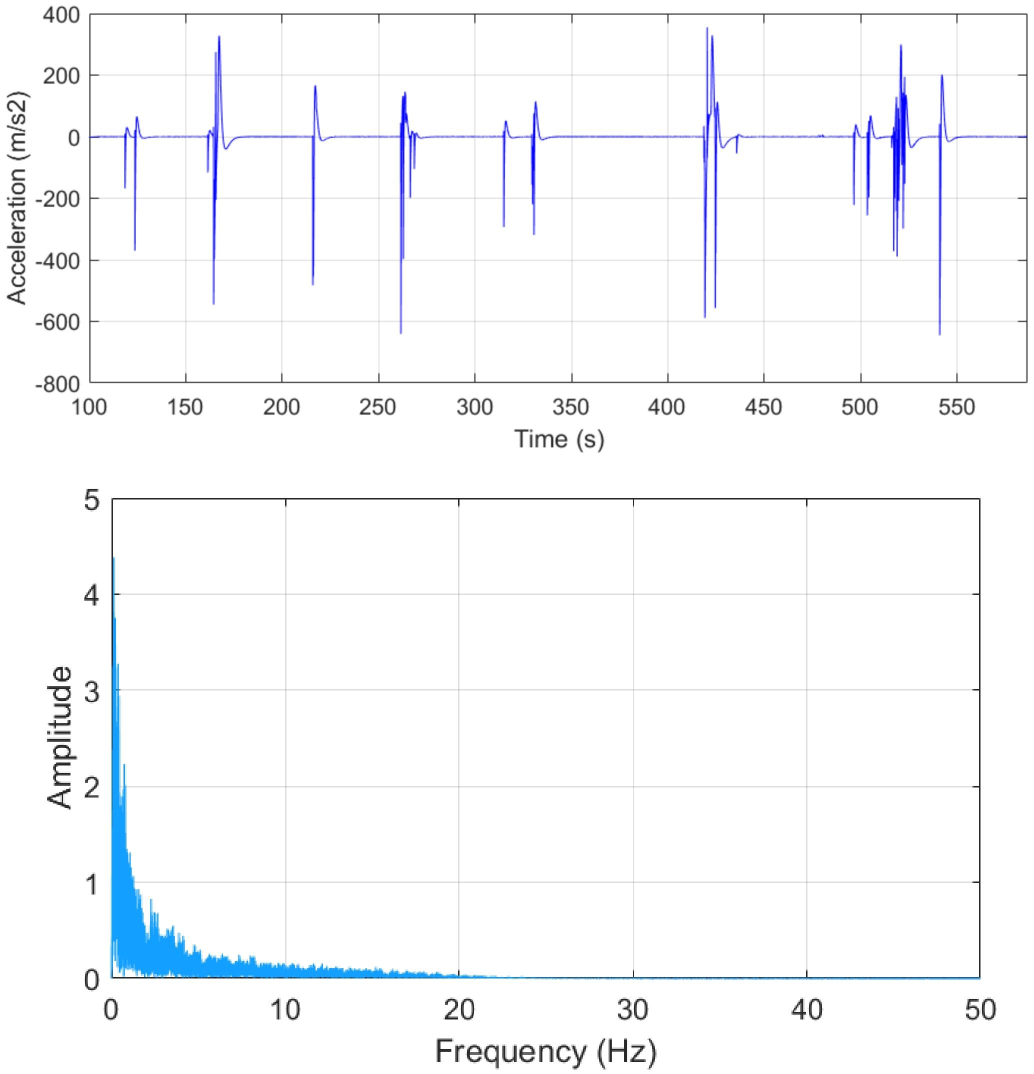

Figure 7: Filtered accelerogram (up) and vibration spectrum (down) recorded for lateral accelerations in the right-side axle-box between Machado and València Sud.

Spectrograms allow identifying both isolated irregularities (such as rail joints) that take the form of vertical lines, and continuous irregularities (such as rail corrugation) that take the form of horizontal ones. Examples of these are marked in figure 8 with blue and black boxes, respectively. However, in order to properly correlate those spectrogram signals with specific defects, a detailed survey of the track would be required, but as the figures show, it is possible to carry out such analysis from data provided by an instrumented tamper.

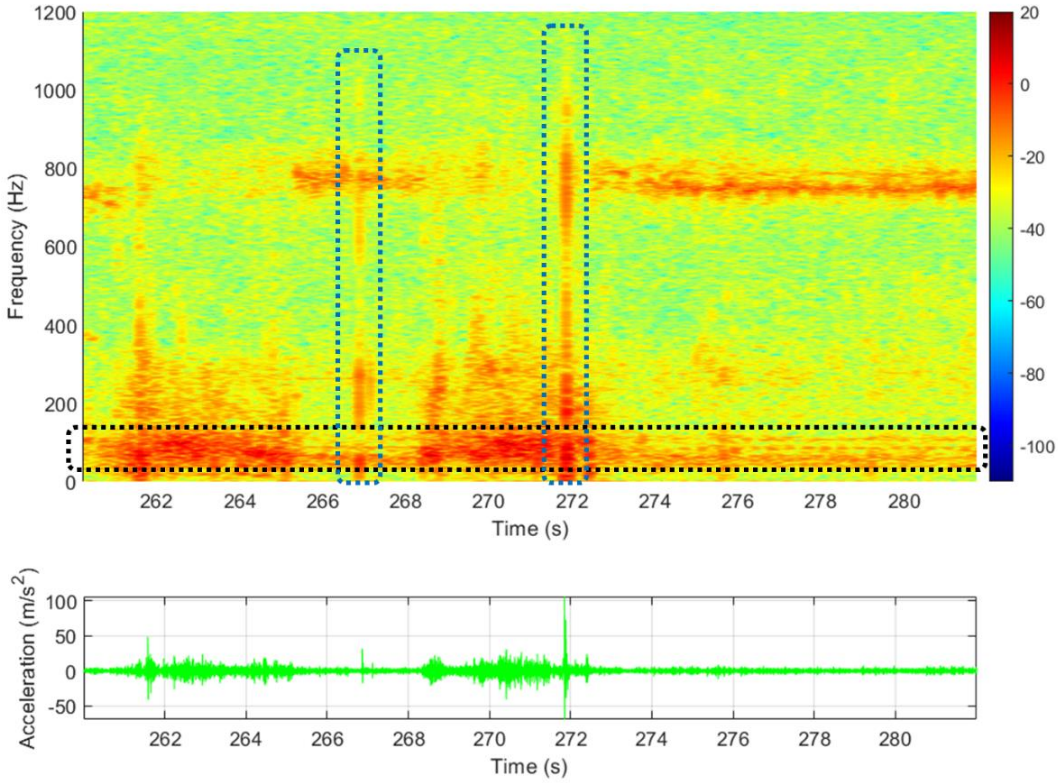

Figure 8: Spectrogram and matching accelerogram for vertical accelerations in the right-side axle-box within the 260-280 seconds window. Horizontal black box marks a continuous irregularity, vertical blue boxes mark isolated irregularities.

The same approach may be applied to lateral accelerations: in figure 9, vertical lines like the one marked by a blue box are caused by isolated irregularities. On the other hand, the spectrograms may show signals that are not due to defects or any track-train interaction, but caused by vehicle elements such as the engines or the braking system. For instance, the continuous signal with increasing frequency marked by a horizontal black box in figure 9 is caused by the release of the tamper brake shoes. This must be considered when analysing spectrograms to avoid erroneous detection of track defects.

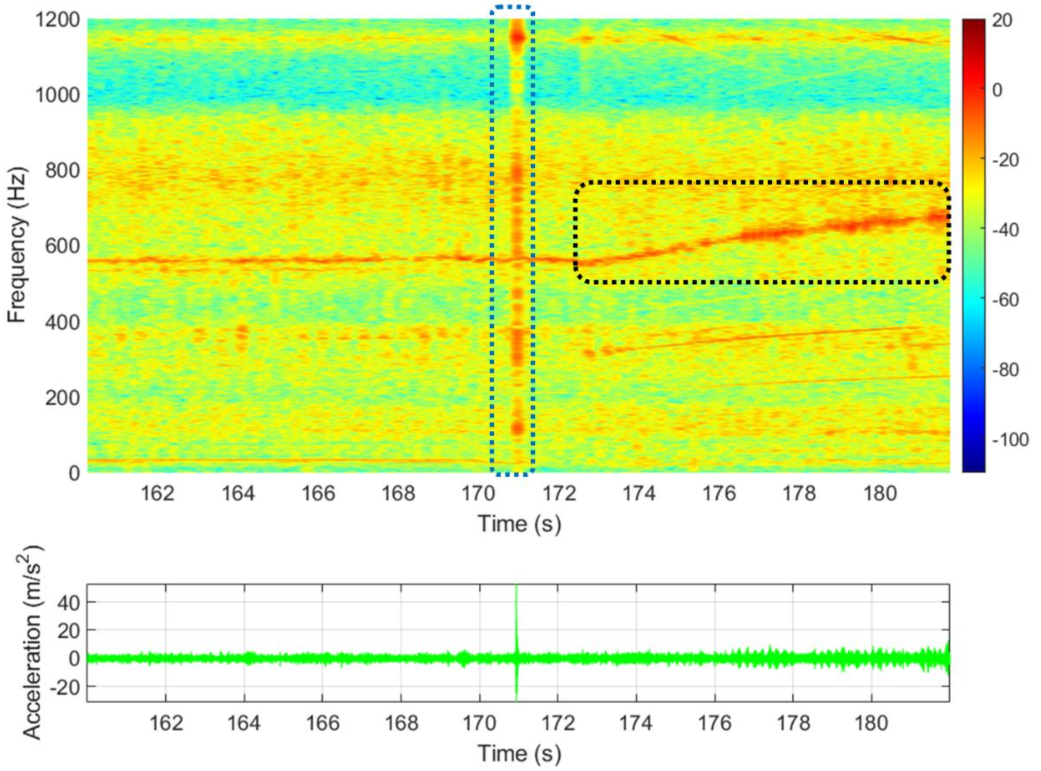

Figure 9: Spectrogram and matching accelerogram for lateral accelerations in the right-side axle-box within the 160-180 seconds window. Horizontal black box marks the release of the tamper brake shoes, vertical blue box marks an isolated irregularity

Overall, we can see that it is possible to use an instrumented tamper machine to carry out dynamic track monitoring, following traditional monitoring schemes to locate potential track defects (which can then be assessed through visual inspections). This would allow expanding the usefulness of ballast tampers (which are already widely used maintenance machines), as they could be used to monitor the track status while traveling along the network, thus dispensing with expensive, dedicated monitoring vehicles. Moreover, this approach could be useful to further expand the ongoing research aiming at a more accurate dynamic monitoring that directly identifies and assesses track defects, as tampers may become an additional source of data that can be then analysed through spectrograms.

4 Conclusions and Contributions

A research project has been carried out to assess whether ballast tamping machines could be used for reliable dynamic track monitoring which is usually carried out by dedicated and costly monitoring vehicles. In order to do so, a ballast tamper was equipped with accelerometers, cameras and GPS, and data was recorded while the tamper travelled along the Valencia metropolitan network in Spain. Acceleration data was then filtered and analysed, together with the camera footage showing wheel-rail contact.

The results obtained show that it is perfectly feasible to use a tamper machine for dynamic monitoring purposes within a conventional approach, where acceleration data helps locating potential track defects along a rail line which are then evaluated through visual inspection. Moreover, installing accelerometers on-board ballast tampers, which are very common maintenance machines, could provide extensive data which could be used on ongoing research to improve dynamic monitoring and achieve a more accurate methodology that correctly identifies track defects and assess their severity without later visual inspections.

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