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ANALYSIS OF VIBRATIONS USING WAVELET TRANSFORM AND STFT TO CHARACTERIZE DEFECTS IN WHEEL-RAIL CONTACT

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ABSTRACT
Characterization of the defects in wheel-rail contact, in railway transport, using vibration signals has been, in the last years, an important factor in the maintenance of the railroads in order to limit the impact of the vibrations both in the own installations and in its surroundings.
This work is a contribution to the study and the characterization of possible present defects in movable material of the subway of Barcelona (FCMB). For it, the use of time-frequency techniques for signal analysis is proposed. In the work, signals coming from the vibration of the foot of the rail to the passage of a train are analyzed using STFT (Short Time Fourier Transform) and CWT (Continue Wavelet Transform).
The vibration signals, generated by the passage of a train on the railway line, are non-stationary. So, techniques based on FT (Fourier Transform) and used for stationary signals are not suitable for the analysis and the characterization of this type of signals. When applying FT to a signal, the temporary information is lost. Therefore, it does not allow establishing the exact moment in which significant alterations of the signal, coming from the defects in the wheel-rail contact, takes place.
In order to solve this problem, the STFT and the CWT are used to analyze the obtained in situ non-stationary vibrations.
Keywords: Signal analysis, Continue Wavelet Transform, STFT, fault, Rail-wheel contact

1. INTRODUCTION
Irregularities in the wheels, presence of wheelflats in them, and longitudinal and transverse defects on the rail are some problems that are daily present on railway operation. They are the cause of vibrations that affect both to the installations, the mobile material and the surroundings. One of the tasks of the maintenance departments of the metropolitan railways is the examination of the rail and the wheels in order to detect faults in both elements. These faults have been studied theoretically and experimentally, but separately by some authors; for the rail: Caprioli et al [1], Toyilat et al [3], Mandriota et al [4], Cannon et al [5], and others; for the wheels: Yang and Letourneau [6], Jianhai, et al [9], Skarlatos, et al [7], Branghin, et al [11], and others. There are, also, several works [2, 10, and 12] that involve the wheel-rail contact as one system. They do not go deeply into the subject of signal analysis applied to the predictive maintenance. The Vibration Laboratory of the Department of Mechanical Engineering of the Technical University of Catalonia has made in last years measurements of the vibration signals generated by the passage of the trains of the Metropolitan Railroad of Barcelona (FCMB). These signals have been processed in the laboratory for their analysis in order to predict possible failures. The present work is an application of time-frequency analysis

using the STFT and CWT simultaneously to improve detection and characterization of faults in the wheel-rail contact of the present train lines of FCMB.

In order to analyze and to process of vibration signals applied to mechanical system maintenance, Fourier Transform (FT) has been widely used with satisfactory results when the stationary signals are stationary. However, this is not the case when the spectrum of the signal changes in time (non stationary signals). FT detects the presence of a certain frequency but it does not offer information about the evolution in the time of the spectral characteristics of the signal. Many temporary aspects of the signal, such as the beginning and the end of a finite signal and the moment that a singularity occurs in a transitory signal, cannot be analyzed appropriately by the FT. So, it appears the need of using simultaneously analysis in the temporary domain and in the frequency domain. In this work, the possibility of using the STFT and the CWT, that are hardware and software available, for the obtained signals is explored

2. APPLICATION OF THE STFT AND THE CWT TO THE VIBRATION SIGNALS REGISTERED BY THE PASSAGE OF THE TRAIN

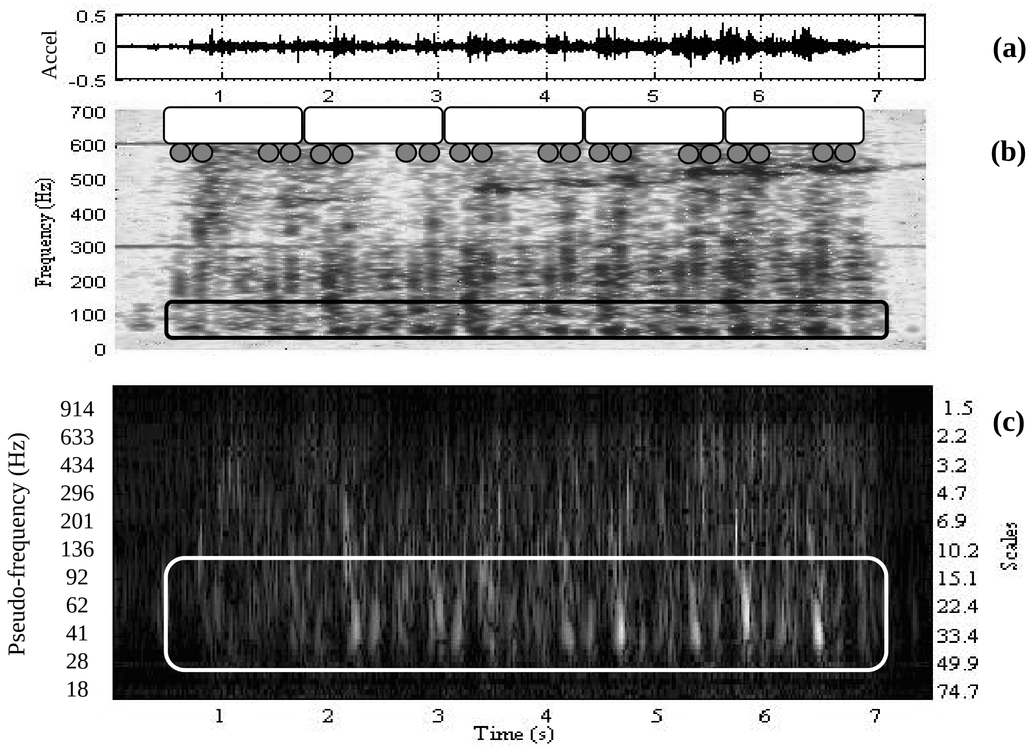

Figure 1. Registered vibration signal, (a) original, (b) STFT, (c) CWT

Vibrations in the trains are generally produced in the contact between the wheel and the rail, and they are transmitted across the fixing of the rail, the ballast, the structure of the tunnel, the foundations of the buildings and, in general, the whole structure [13]. In the present study, 19 registers corresponding to the vibration produced by the passages of the trains from line 3 of FCMB are analyzed; they are taken on the foot of the rail by a piezoelectric accelerometer [8]. The vertical component of vibration is measured; the signals have been sampled to 2 kHz and after they are passed through a low-pass antialiasing filter with a cut frequency of 600 Hz, which is considered significant to characterize the frequency content of the possible irregularities. For the implementation of the STFT in the registered signals, a window Hanning is used with 512 samples (aprox. 0,25 s), overlapping the 75% of the successive windows. For the CWT, a Meyer wavelet is used with scales generated by an exponential model. Figure 1a shows a vibration register (acceleration) corresponding to the passage of a train of the network of FCMB. Figure 1b shows the STFT, where the mark that every wheel leaves when it passes by the point of measure is observed. Figure 1c shows the CWT for the same signal using an interval of frequencies in logarithmic scale. The significant events that are present in the STFT also are reflected by the CWT; the main ones about 60 Hz (framed on graphs) and others of less intensity between 400 Hz and 600 Hz. The STFT shows a clearer vision of the events so, for this reason, is used as a general identifier of possible faults of the wheel-rail contact; the CWT shows a good application in the same frequency interval but allowing doing a wider frequencial sweep.

3. RESULTS

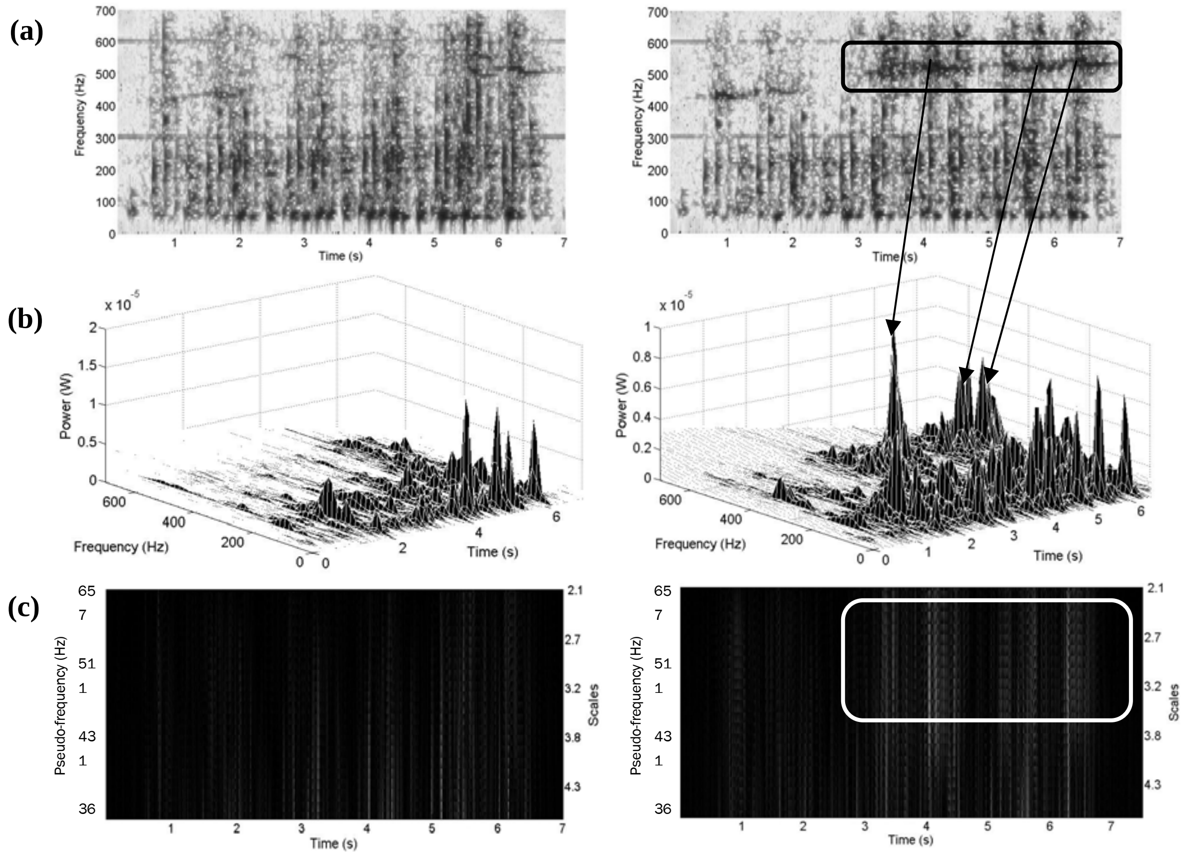

Figure 2.Vibration analysis of two trains, (a) STFT, (b) PED, (c) CWT of chosen interval

The available vibration registers are analyzed in order to show the obtained results using STFT and CWT. Two registers are profoundly studied. The first comes from a train without special characteristics and the second one comes from a train with some irregularities (framed in figure 2). The implementation of CWT requires the selection of the wavelet that will be used. For doing it, it has been taken into account both the characteristics of the signal and the own characteristics of each wavelet. Meyer's wavelet is chosen because it is defined in the frequency domain like its weighting function.

Using STFT, the frequency ranges where significant events appear are characterized. Furthermore, it is detected the appearance instant that identifies the wheel number which is passing by the point of measure (figure 2a). These events are also shown in the power spectral density (figure 2b). By knowing, through STFT, the frequency interval where these irregularities appear (400 Hz-600 Hz) in the wheel-rail contact, the CWT is used (figure 2c) in order to look for a best temporary and frequency identification of the irregularities.

4. CONCLUSIONS

In this work, an application to analyze vibration signals, coming from the trains of FCMB, is developed using STFT and CWT techniques as tools to determine which wheel and which type of irregularity is present at it. This is done in order to diminish the generated vibration.

The analyzed vibration signals have a non stationary behaviour. So, FT is not a good tool to fix in which wheel or in which instant a fault occurs. STFT and CWT application have shown as two efficient tools to improve the analysis of this type of signals. They are useful to characterize and to predict faults in the wheel-rail contact.

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