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Rail inspection in track maintenance: A benchmark between the wavelet approach and the more conventional Fourier analysis

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Abstract

Nowadays the power of data analysis tools like the wavelet decomposition of signals is well known and spread. On the other hand the theoretical advantages of such methods often fight with reality, when real field signals are collected and analysed: it sometimes comes out that this time–frequency approach somehow fails, demanding for a deeper insight into the kind of physical problem to be considered, and requiring a sort of "benchmark" between the traditional Fourier approach and the more recent time–frequency one. In this paper, sharply application-oriented, the possibilities offered by the wavelet techniques have been analysed: both the DSP specialist and the field engineer points of view have been joined to exploit the new approach of its best. A real problem has been considered, in which acceleration signals from a train bogie are collected and real-time analysed, to get a diagnostic tool to know the track condition of a subway line. This paper would like to look for a compromise point between complex mathematics based techniques, such as wavelet packet, sometimes hard to comprehend to the application engineer, and the physical meaning of these tools helping in fixing the real method limits.

Therefore the aim is not just trying this analysis on an almost random process, like the accelerations measured on a running bogie, to locate defects, but rather a discussion on the development of the continuous and discrete wavelet transform, in comparison with the classical Fourier analysis or filter banks. Only the minimum mathematical background is provided in the text, with the needed references, to give tools fit for comprehending the physical meaning of the new tools, capable of sparing computing effort, while preserving or even improving the system effectiveness.
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1. Introduction

Non-stationary signals are quite common in everyday life. Moreover it is well known that the conventional Fourier analysis is not capable of describing the evolution of the spectral features of a signal as this evolves in time. A well known paper from Gurley and Kareem [1], (concerning the application of wavelets to earthquake, wind and ocean engineering) recalls an almost educational example in which it is remembered that the same

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spectral shape may derive from a linear system response to an impulse input, as well as to a white-noise input, being these two signals quite different in the time domain. The first step towards the attempt to provide a time frequency localisation of signals, the short time Fourier transform (STFT), suffers from the well known problem of insufficient flexibility to fit to the ''local'' needs for time and frequency resolution. In fact, the initial choice of the observation window length is rigidly maintained all through the analysis, independently from its varying features. The next step consists in a multiresolution approach, in which the signal analysis tool is able to change the window length, narrowing or widening, as a function of the frequency content to be put into evidence. In this way some short duration signal, interested by high frequency contents, may be put into evidence, whereas the Fourier methods would bury them in the background averaged spectral content. Due to this short discussion, acceleration signals collected for track diagnosis from a train bogie are well inserted in the category, for which this time–frequency approach seems to be promising. Therefore, the main interest is to understand which real improvements these new techniques can offer if applied to mechanical vibration measurements, exploiting all the possibilities, thanks to the joint work of DSP specialists and application engineer.

The aim of the paper is to offer an overview of the topic of wavelet applied to a mechanical problem. Even if many papers are being written on the topic of wavelet, a common problem appears: when a mathematical approach is adopted it is hard to grasp the physical meaning of these tool. On the other hand, when the authors are from the application field, they stop to the continuous wavelet, easiest than the most powerful wavelet packet. This justifies the effort to recall some basic concepts, together with their physical meaning, offering a start background review before going to the real world application. The final result is a half way between a benchmark on some new technique (with a deep review of the technique prior to applying it), and a critical review of results in a real case. Perhaps in some way it could be even considered a tutorial.

The paper is organised as follows: first the diagnostic fact will be discussed, to clarify some points driving the adopted strategy. A wavelet survey will be then offered, not just focussing on the well known mathematical aspects, but rather developing those aspects regarding the operational point of view, offering a physical interpretation of the mathematical aspects. The continuous wavelet transform as well as the wavelet packets will be applied to the acquired signals pointing out advantages and drawbacks in terms of data management, filtering capabilities and speed of calculation, discussing and comparing results and assuming as a reference test bench the usual Fourier approach or the application of a filter bank. An interesting merge comes out, in which all the problem aspects are deeply investigated.

2. A new diagnostic tool for quick and easy track inspection

Track maintenance is one of the main problems for public transportation companies: important related aspects are passengers security and vibro-acoustic impact.

Especially for urban railways or subways, the track is severely and continuously loaded, due to the heavy traffic. Moreover, especially along small radius curves, often corrugation grows at very high rates, even in few weeks [2–4,21], requiring proper grinding. Service stops must be avoided due to the huge related costs, so every intervention must be as quick as possible. As a consequence, also track inspections must be performed frequently and quickly.

At present special cars are available, capable to get a rich description of the track conditions, but these cars are very expensive and must operate when the daily service is stopped. The proposal of this paper is for an easier measurement technique, looking for a trade-off between a simpler measurement system, poorer in information (for instance no track gauge is measured), but capable of being mounted on a standard operating vehicle [4], on every bogie, therefore encountering the above mentioned need for a quick diagnostic tool. Data management is an important part of the system development: in a previous paper [4] attention has been focused on the measurement set-up, the present one is devoted to data analysis. All the same, to clarify the operating scenario, some details about the measurement system will be given here too, to make it possible to understand the reasons of some data management strategies.

At this first stage it is remembered that the developed system mainly works to identify rail defects and short pitch corrugation, a big problem in urban railways, being one of the major sources of noise, vibrations, wear and damage, and constituting a big expense in maintenance programs.

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