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Polyspectral technique for the analysis of stress-waves characteristics and species recognition in wood veneers

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ABSTRACT

In this work a simple technique to obtain information about the species of wood samples using stress-wave sounds in the audible range is presented. However, spectra of wood sounds generated by pendulum impact are very complex and feature extraction for classification purposes is very difficult. Polyspectral techniques have been successfully applied to several problems from radar pattern recognition to medical signal processing. Following this approach, convolution of four different sound impacts has been done. This permits to extract clear polyspectral features suitable for wood species recognition with possible applications to both human assisted and automatic wood identification systems with minimal intersample variability. Results indicate that using this technique only the two most intense polyspectral peaks are enough for species recognition.

1. Introduction

There is considerable interest in the automatic species recognition and grading of wood, but this is a very difficult problem due to the notorious wood variability, both inter and intra species.

Most techniques for the acoustic study of wood species are based on ultrasounds. The main reference is the Bucur book [1], but many works also use this approach, for example [2–5].

However, stress-waves produced by surface impact with a suitable pendulum allow for simple and powerful techniques for wood characterization. In a previous work [6], a number of wood species were identified by means of a spectral analysis of the sound produced by pendulum impact of veneer samples. Spectral variability of the sound produced in veneers from different areas of the same tree may be large, difficulting so the task of species identification by stress-wave techniques. Stress induced waveforms in wood are indeed very complex, so advanced mathematical methods are needed to improve feature extraction in the frequency domain. Polyspectra may be used to extract such features from these kind of sound signals.

Acoustic spectra of stress-waves in wood are complex and nearly flat in the audible range, so the isolation of spectral features suitable for species identification is difficult. It can be done, as it was shown in [6], when combined with time domain properties of the pulse, but the variability of sounds from different samples of the same species can mask the main spectral lines used for wood classification.

A wood species recognition system based solely on spectral properties would be desirable. Isolation of the most important spectral bands can be progressively enhanced by means of polyspectral approaches. Polyspectra, or higher-order spectra, can be calculated from the Fourier transform of the higher order cumulants of the temporal series, sound in this case. Generally, polyspectral techniques are used to search for non-linear interactions of continuous spectra of waves in one dimension [7–9].

2. Materials and methods

The experimental setup is similar to the one described in [6], but it has been improved. The main difference is the use of a small steel hammer periodically moved by a motor instead of a plastic pendulum.

Microphones used in this study had a frequency response from 20 Hz to 20 kHz. A standard sound card able to 192 kHz sampling, was used for the recordings. The Praat program [10] was used for all the sound processing operations. The sound recordings were made in quiet, but not anechoic, conditions.

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Around 20 impacts for each wood sample were recorded. The use of a motor controlled small steel hammer allowed for more uniform impact recordings and better statistics.

In order to minimize the variability of wood properties under different ambiental conditions, moisture content was regularly measured and temperature was kept to a constant value of 22 Celsius. All wood veneer moisture ratios were in the range of $13 \pm 2\%$.

The samples had identical dimensions to the previously used in [6]. They were cleanly cut veneers, 10×10 cm squares, with 0.3 mm thickness. The number of studied species were increased to 19, due to the greatly enhanced classification potential of the polyspectral features. The samples from the same species had similar grain patterns.

The studied wood species were: *Antiaris africana* Engl., *Guibourtia demeusei* J. Leonard, *Castanea sativa* Mill., *Cedrus libani* A. Rich., *Prunus cerasus* L., *Lovoa trichilioides* Harms, *Acer campestre*, *Copaifera salikounda* Heckel, *Fraxinus excelsior* L., *Milicia excelsa* (Welw.) C.C. Berg, *Acer pseudoplatanus*, *Guibourtia ehie* J. Leonard, *Aningeria robusta* Aubr. and Pellegr., *Pyrus communis* L., *Pinus palustris*, *Pinus sylvestris* L., *Quercus robur* L., *Entandrophragma cylindricum* Sprague and *Tieghemella heckelii* Pierre.

Clear spectral features of many systems are difficult to obtain due to noise or complexity of the excited material. Wood sounds produced by impact share these problems. In order to overcome the limitations of frequency domain analyses, polyspectral techniques have been developed. The idea is very simple, it consists on using higher-order cumulants, so bispectrum, trispectrum and, in general, polyspectra, can be calculated.

We want to keep calculations as simple and fast and possible in order to find solutions to real-time wood species classification problems. With this constraint in mind, we have explored a similar approach using only direct and inverse FFT algorithms to keep the computational cost of the technique to a minimum. In this sense, only convolutions of impact sounds and the spectrum of the final result are necessary, so the computational time required in any reasonable modern computer is under 1 s.

In essence, the spectral information of several impact sounds is combined and expanded in power convolution series. From a mathematical point of view, power convolution series can be applied to one signal only, but we have found that convolving several pulses from different samples reduce the problem of intersample variability to a negligible value, less than 5% in all cases. Following this approach, the main spectral features used for species identification are not affected.

Our polyspectral approach is simpler than the standard one, because the convolution of several sound pulses are enough for wood classification purposes. A fully polyspectral treatment is not necessary in general. So, actually, our technique is reduced to the calculation of formal convolution series of different pulses from the same species. This is not completely equivalent to a standard convolution series, because mathematically speaking, a convolution power series is formed from the iterated convolution of the same pulse, not different ones.

It is shown in this work that only four different pulses need to be convolved in order to minimize the spectral variability of different samples of the same wood species, while producing very clear features for recognition. This results in a very cost effective technique, because the four convolutions and the Fourier transform of the resulting sound can be calculated very fast, almost in real time, for such short pulses.

This result is not based on any strong mathematical analysis, but by numerical experiments, comparing the different obtained spectra in successive powers of convolution. Spectra derived from convolution powers less than 4 were not detailed enough to assure an unambiguous species classification of the wood samples, while powers greater than 4 involved more computational resources without adding new information. So 4 iterated convolutions represent a kind of optimal compromise between computational speed and wood characterization by means of stress-waves.

Using only direct and inverse FFT (Fast Fourier Transform) calculations, wood species can be clearly and quickly identified selecting at a minimum of four pulses from different samples of the same species. The only prerequisites are identical geometrical parameters and wood free from defects for all studied samples.

3. Results and discussion

The suitability of stress-wave analysis by impact to identify wood species was confirmed in [6], but several difficulties were encountered in the frequency domain. These difficulties were mainly associated with the poor separation of clear spectral lines for species identification and variability from one sample to another. So, it was necessary to include information from the pulse shape in the time domain to resolve ambiguities in the species identification.

An identification method based solely in spectral features is simpler and more useful. Although frequency bands are difficult to isolate and analize in the first spectrum of each impact pulse, the power convolution operation is able to compress and intensify these frequency bands, making them clearly visible.

A comparison between the first spectrum of one impact sound and the spectrum of 4-convolved impacts is shown in Fig. 1. A duration of 20 ms was selected for all impact sounds before convolving them.

It can be seen that the spectrum of the 4-convolved sounds presents far clearer frequency bands than the first spectrum. These frequency bands are enough for species identification in all the studied cases, as Fig. 2.

Visual inspection of 4-convolved spectra reveals that enough information for species identification is found in the 0–10,000 Hz range. Thus, audible acoustical techniques are very useful for wood analysis without the complexities of ultrasound based measures.

Spectral features can be grouped in roughly three different frequency ranges. The first one extends from 0 to 1000 Hz approximately. The second range is more complex and can be seen in the 1000–2000 Hz interval. The third range, from 2000 to 10,000 Hz is the more variable. Some woods, like *M. excelsa*, present very clearly separated and smooth frequency bands, while others, like *Q. robur*,

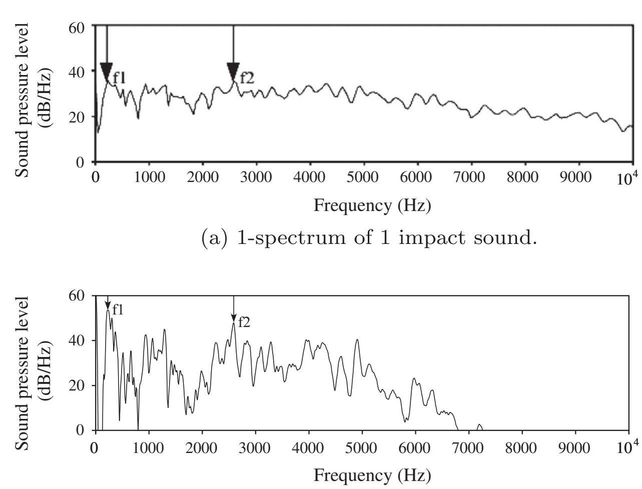

Fig. 1. Comparison between the spectrum of 1 impact sound and 4-convolved impacts for wood veneers of *Antiaris africana* wood.