Bionic Wavelet Transform: A New Time-Frequency Method Based on an Auditory Model

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Artigo

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Autores: Jun Yao e Yuan-Ting Zhang. Fonte: IEEE Transactions no Biomedical Engineering, Vol. 48, No. 8, Agosto 2001.

Introdução I

1. BWT (Bionic Wavelet Transform).
2. Ajustable resolution along time and frequency axis.
3. BWT has properties that are appropriate for speech signal processing, especially for cochelar implants.
4. D.L. Jones and T.W. Parks has proven that the choice of mother wavelet function dramatically affects the appearance and quality of the resultant time-frequency representation. [1]
5. Many attemps have been made to apply different mother functions at different times and frequencies: adaptive Wavelet Transform (AWT) and Wavelet Packets (WP), both of which select mother functions. Some papers have shown that AWT or WP achieves good tradeoff between resolutions and, thus, has good applications in data compression and representation.

Introdução II

6. Gabor Transform, a well-defined STFT (Short-Time Fourier Transform), gives a mathematical abstract of the signal processing mechanism of the human vision field both in the function itself and in the bandpass filter (BPF) bank property.
7. Usually, the filters in human auditory and visual systems are viewed as constant-Q filters. These facts explain why WT, which has a constant Q, is viewed to work in a mechanism more similar to bio-systems than STFT.
8. Early experiments on the cochlear partition in human and animal cadavers found that the basilar membrane in the cochlea had frequency selectivity, which showed that a passive cochlea analyzes the signal in the time-frequency domain.

Introdução III

9. The findings of otoacoustics emissions (OAEs) provided evidences that the cochlea in an active nonlinear system.
10. One important role of outer hair cells (OHCs) is that they provide time-frequency adjustable resolution and signal amplification, which is necessary to keep the high sensitivity and frequency selectivity of the cochlea in vivo.

[1] D.L. Jones and T.W. Parks, A high resoltution data-adaptive time-frequency representation, IEEE Trans. Acoust. Speech, Signal Processing, vol. 38, pp. 2127-2135, Dec 1990.

Basilar Membrane (BM) I

The basilar membrane (BM) is modeled by the following equation

$$d''(x,t) + R_{eq}(x,d)d'(x,t)/L(x) + \omega_0^2(x)d(x,t) = P \qquad (1)$$

- x distance along BM from basal end,
- t time,
- d displacement of the BM,
- d' and d'' first- and second-order differentials of d in terms of t,
- P pressure difference across the BM,
- ω_0 character frequency of the point and equals $1/\sqrt{L(x)C(x)}$, where $L(x)$ and $C(x)$ represent the acoustic mass and compliance, respectively.

Equivalent Resistence I

The equivalent resistence, R_{eq}, in (1) is given by

$$R_{eq} = R(x) - G_1(x)\frac{d_{1/2}}{d_{1/2} + |d(x,t)|}R(x) \tag{2}$$

- $R(x)$ passive resistence correponding to the acoustic resistence,
- $d_{1/2}$ saturation factor,
- $G_1(x)$ active gain factor whose value is related to the activity of the correspondeing OHC-group.

The second term in (2) represents the active resistence function of the OHC control.

Modified Model I

Nonlinear damping alone is not enought to describe the active mechanism of the cochlea, and that nonlinear compliance is also necessary We further modified this model by including the nonlinear capacitance

$$C_{eq}(x) = (1 + G_2(x)|\frac{\partial[d(x,t)]}{\partial t}|)^2 C(x) \quad (3)$$

where $G_2(x)$ is the active fator that associates with the effect of the active mechanism on the compliance on a point of BM. The modified model has the same formula as (1), but ω_0 equals $1/\sqrt{L(x)C_{eq}(x)}$.

Definition of Bionic Wavelet Transform I

The mother function, $h(t)$, is an envelop function, $\tilde{h}(t)$, modulated by the sinusoidal signal at frequency f_0

$$h(t) = \frac{1}{\sqrt{a}}\tilde{h}(t)e^{j\omega_0 t} \tag{4}$$

where $\omega_0 = 2\pi f_0$. If the signal to be analysed is $f(t)$, the WT is defined as

$$(WTf)(\tau, a) = \frac{1}{\sqrt{a}}\int f(t)\tilde{h}^*(\frac{t-\tau}{a})e^{-j\omega_0(\frac{t-\tau}{a})}dt. \tag{5}$$

Introducing the OHC-like Control I

A new parameter T, where $T > 0$, is introduced into the WT mother function resulting in BWT mother function

$$h_T(t) = \frac{1}{T\sqrt{a}}\tilde{h}(\frac{t}{T})e^{j\omega_0 t}. \quad (6)$$

With this new mother funtion, the BWT is defined as

$$(BWT_T f)(\tau, a) = \frac{1}{T\sqrt{a}}\int f(t)\tilde{h}^*(\frac{t-\tau}{aT})e^{-j\omega_0(\frac{t-\tau}{a})}dt. \quad (7)$$

The envelop of the BWT mother function can be adjusted by the parameter T.

Comparing... I

The Fourier Transform of $h(t)$ and $h_T(t)$ are

$$H(\omega) = \frac{1}{\sqrt{a}} \tilde{H}(\omega - \omega_0) \tag{8}$$

$$H_T(\omega) = \frac{1}{\sqrt{a}} \tilde{H}[T(\omega - \omega_0)] \tag{9}$$

respectively. Follows then the quality factor relation

$$Q_T = TQ_0. \tag{10}$$