Local Regularity Analysis at Glottal Opening and Closure Instants in Electroglottogram Signal Using Wavelet Transform Modulus Maxima

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Abstract

This paper deals with singularities characterisation and detection in Electroglottogram (EGG) signal using wavelet transform modulus maxima. These singularities correspond to glottal opening and closure instants (GOIs and GCIs),
Wavelets with one and two vanishing moments are applied to EGG signal. We show that wavelet with one vanishing moment is sufficient to detect singularities of EGG signal and to measure their regularities.

The Lipschitz regularity at any point is the maxima slope of $\log_2$ of wavelet transform modulus maxima as a function of $\log_2 s$ along the maxima lines converging to this point.
Local regularity measures allow us to conclude that EGG signal is more regular at glottal opening instant than at glottal closure instant.

1. Introduction

Voice quality is mainly due to voice source properties. Thus, a better understanding of these properties would help to voice quality analysis characterisation. The source has often been described in terms of voiced source parameters, such as the fundamental period, the speed quotient, the open quotient. These parameters depend essentially on the glottal closure and glottal opening instants (GCI and GOI).

Referring to Childers, at the derivative of the EGG signal, we can observe a strong peak that can be linked to glottal closure and a weak peak that can be linked to glottal opening [12]. In this study, we shall focus on the behaviour of the EGG signal at GCI and GOI as detection of these instants.

A wavelet transform can focus on localized signal structures with a zooming procedure that progressively reduces the scale parameter. Singularities and irregular structures often carry essential information in signal; for example, discontinuities in the intensity of an image indicate the presence of edges in the scene, interesting information also lies in sharp transitions in electrocardiograms and radar signals [2]. Local signal regularity is characterised by the decay of the wavelet transform amplitude across scales. Singularities and edges are detected by following the wavelet transform local maxima at fine scales [7].

As it is very efficient in detecting singularities in signals, wavelet transform approach is very promise in detecting singularities in electroglottography wave [6]. The aim of this paper is to measure the local regularity of the EGG signal at GCI and GOI using wavelet transform modulus maxima WTMM.

The paper is organised as follows. Section 2 concerns characterisation of local regularity of a signal with wavelet transform having specific number of vanishing moments.
Section 3 presents a brief analysis of the wavelet transform modulus maxima properties. It is shown that modulus maxima detect all singularities of the signal. Section 4 gives illustration of Electroglottogram signal wavelet transform with one and two vanishing moments. Section 5 is an application of wavelet transform modulus maxima method to measure EGG signal local regularity at GOI and GCI. Section 6 concludes this work.

2. Characterisation of local regularity with wavelets

As mentioned in the introduction, a remarkable property of the wavelet transform is its ability to characterise the local regularity of functions by decomposing signals into elementary building blocks that are well localised both in time and frequency. This was a major motivation for studying the wavelet transform in mathematics and in applied domains [10]. In mathematics, this local regularity is often measured with Lipschitz exponents [4]. It is shown that the local signal regularity is characterized by the decay of the wavelet transform amplitude across scales. Singularities and edges are detected by following the wavelet transform local maxima at fine scales.

This section shows that wavelet transform with n vanishing moments can be interpreted as a multiscale differential operator of order *n,* and provides a relation between the differentiability of *f* and its wavelet transform decay at fine scales that allows a measure of Lipschitz exponent.

2.1. Local Lipschitz regularity

To characterise singular structures, it is necessary to precisely quantify the local regularity of a signal. Lipschitz exponents provide uniform regularity measurements over time intervals but also at any point.

A function *f* is pointwise Lipschitz $\alpha \geq 0$ at v, if there exist $K > 0$ and a polynomial p_v of degree $m = \lfloor \alpha \rfloor$ such that

$$\forall t \in \Re \,, \ \left| f(t) - p_v(t) \right| \leq K \left| t - v \right|^{\alpha} \tag{1}$$

where p_v is the Taylor polynomial in the neighbourhood of v

$$p_v(t) = \sum_{k=0}^{m-1} \frac{f^{(k)}(v)}{k!}(t-v)^{\alpha} \quad (2)$$

Intuitively, the Lipschitz exponents measure the "smoothness" of *f*; the larger *α*, the more regular the function is at point *v*.

It is proved that the local regularity of *f* at *v* depends on the decay at fine scales of $|Wf(u,s)|$ in the neighbourhood of this point [8], [9]. Measuring this decay directly in the time–scale plane (u,s) provides a measure of Lipschitz exponent. The decay of $|Wf(u,s)|$ can be controlled from its local maxima values.

2.2. Wavelet vanishing moments

To measure the local regularity of a signal, vanishing moments characterising the wavelet are crucial.
A wavelet $\psi(t)$ is said to have *n* vanishing moments if and only if for all positive integer $k < n$, it satisfies [3]

$$\int_{-\infty}^{+\infty} t^k \psi(t)\, dt = 0 \quad (3)$$

2.3. Multiscale differential operator

A wavelet with fast decay has *n* vanishing moments if and only if it exists a function θ with a fast decay such that

$$\psi(t) = (-1)^n \frac{d^n\theta}{dt^n} \quad (4)$$

This theorem proves that when wavelet has *n* vanishing moments, wavelet transform can be interpreted as a multiscale differential operator of order *n* [1]. As

$$wf(u,s) = f * \overline{\psi}_s(u) \quad (5)$$

with

$$\overline{\psi}_s(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{-t}{s}\right) \quad (6)$$

Then wavelet transform can be written as

$$wf(u,s) = s^n \frac{d^n}{du^n}(f * \overline{\theta}_s)(u) \quad (7)$$

with

$$\overline{\theta}_s = \frac{1}{\sqrt{s}}\theta\left(\frac{-t}{s}\right) \quad (8)$$

2.4. Regularity measurements with wavelets

As wavelet has a compact support, the wavelet transform *Wf*(*u,s*) depends upon the values of *f*(*u*) in a neighbourhood of *u* of size proportional to the scale *s* [11]. At fine scales, it provides a localized information on *f*(*u*).

The decay of the wavelet transform amplitude across scales is related to the uniform and pointwise Lipschitz regularity of the signal. Measuring this asymptotic decay is equivalent to zooming into signal structures with a scale that goes to zero.

Referring to Jaffard, if $f \in \mathbf{L}^2(\Re)$ is Lipschitz $\alpha \le n$ at *v*, then there exits *A* such that

$$\forall (u,s) \in \Re \, x \, \Re^+ \ , \ |wf(u,s)| \le A\, s^{\alpha+1/2}\left(1 + \left|\frac{u-v}{s}\right|^{\alpha}\right) \quad (9)$$

To interpret more easily equation 9, we shall suppose that ψ has a compact support equal to [-C, C]. The cone of influence of *v* in the time-scale plane is the set of points (*u*, *s*) such that

$$|u - v| \le C s \quad (10)$$

As a result equation 9 can be written

$$|wf(u,s)| \le A' s^{\alpha+1/2} \quad (11)$$

which is equivalent to

$$\log_2 |wf(u,s)| \le \log_2 A' + \left(\alpha + \frac{1}{2}\right)\log_2 s \quad (12)$$

3. Wavelet transform modulus maxima

Equation 12 proves that the local Lipschitz regularity of *f* at *v* depends on the decay at fine scales of $|Wf(u,s)|$ in the neighbourhood of *v*. Measuring this decay directly in the time-scale plane (*u*,s) is not necessary. The decay of $|Wf(u,s)|$ can indeed be controlled from its local maxima values.

Modulus maxima describe any point (u_0, s_0) such that $|Wf(u,s)|$ is locally maximum at $u = u_0$. This implies that

$$\frac{\partial wf(u_0, s_0)}{\partial u} = 0 \quad (13)$$

This equation defines in the time-scale plane, lines converging to u_0 [7]. In equation 7, wavelet transform is written as a multiscale differential operator:

$$wf(u,s) = s^n \frac{d^n}{du^n}(f * \overline{\theta}_s)(u) \quad (14)$$

When the wavelet has only one vanishing moment, modulus maxima are the maxima of the first derivative of a smoothed function corresponding to discontinuities on the signal. For wavelet having two vanishing moments, the modulus maxima correspond to discontinuities on signal derivative [1]. If the wavelet transform of *f* has no modulus maxima at fine scales then *f* is locally regular.

Hence singularities are detected by finding abscissa, where the wavelet modulus maxima converge at fine scales, and in this case, wavelet vanishing moments characterise the type of singularity.

4. Wavelet transform of EGG signal

In this section we compute wavelet transform of EGG signal using wavelets which are the first and the second derivative of a Gaussian of variance σ^2 with $\sigma = 32.10^{-5}$s. Derivatives of

Gaussian are most often used to guarantee that all maxima lines propagate up to the finest scale.

The EGG signal is extracted from the Keele University database. This one includes two kinds of signals: acoustic speech signals and laryngograph signals. Five adult female speakers and five adult male speakers were recorded in low ambient noise conditions using a sound proof room. Each utterance consisted of the same phonetically balanced English text. In each case, the acoustic and laryngograph signals are time-synchronised and share the same sampling rate value of 20 kHz [12]. Examples taken in this paper are a frame of vowel /o/ uttered by a female speaker. Figure 1 shows the EGG signal at the top followed by its wavelets transform (wavelet with only one vanishing moment) at scales 2^{-4}, 2^{-3}, 2^{-2}, $2^{-1}$and 2^{0}.The wavelet transform of EGG signal shows 2 kinds of peak across scales. The greater one corresponds to glottal closure instant; it's about sharp variations in the signal. However, the second peak seems to be linked to the glottal opening instant, it's about slow variations.

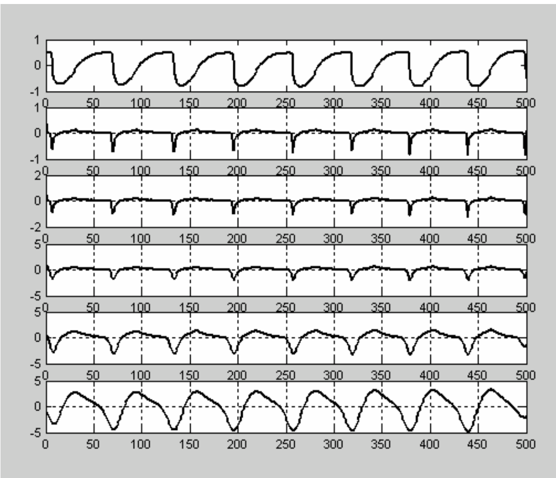

Figure 1: Wavelet transform of EGG signal (wavelet with one vanishing moment) for different values of scale varying from 2^{-4} to 2^{0}. at the top of the figure, we find the EGG signal followed by its wavelet transforms.

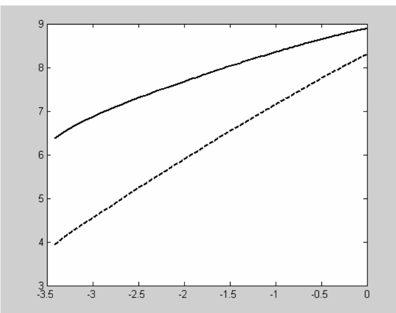

Figure 3: Decay of log2│*Wf*(*u,s*)│ along maxima curves as a function of $\log_2$ s. The solid and dotted lines correspond to maxima curves converging to 8th GCI and its

Figure 2 illustrates the wavelet transform (wavelet with 2 vanishing moments) of the same EGG signal.
Wavelet modulus exhibits perceptible local zero-crossing corresponding to GCI across scales and a moderately clear zero-crossing at GOI. Thus, we conclude that EGG signal in voicing phase, exhibits at GCI and GOI two different types of signal discontinuity.

5. Local regularity measure of EGG signal at GCI and GOI

In section 4, we illustrate that to characterise the EGG signal singularities, wavelet with one vanishing moment is sufficient. As shown previously, the Lipschitz regularity at *v* is the maximum slope of log2│*Wf*(*u,s*)│ as a function of $\log_2$s along the maxima lines converging to *v*.

In figure 3, the solid and dotted lines correspond respectively to the decay of log2│*Wf*(*u,s*)│ calculated with wavelet having one vanishing moment, along maxima lines converging to the eighth GCI and its corresponding GOI shown in figure 1. At GCI, the solid line has a slope of $\alpha+1/2 \approx 0.6$, which indicates that the singularity is Lipschitz 0.1, besides the singularity at GOI is Lipschitz 0.8 referring to the dotted line.

Figure 2: Wavelet transform of EGG signal (wavelet with 2 vanishing moments) for different values of scale varying from 2^{-3} to 2^{0}. at the top of the figure, we find the EGG signal followed by its wavelet transforms.

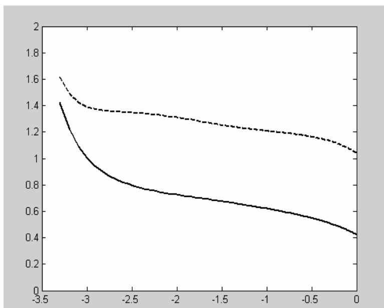

Figure 4: Slope $\alpha+1/2$ as a function of $\log_2$s in solid and dotted lines for respectively the 8th GCI and its corresponding GOI.

Figure 4 represents the evolution of the slope α+1/2 for the two types of singularities studied in figure 3, as a function of log2 s.

Consequently, measures of Lpischitz exponents characterise with accuracy discontinuities of EGG signal detected at GCIs and GOIs.

6. Conclusion

In this paper, we characterise the local regularity of the EGG signal using wavelet transform modulus maxima method. The localized singularities correspond to the glottal closure and opening instants.

Wavelet transform of EGG signal across scales, presents local maxima when using a wavelet that is a first derivative of a smoothing function. Wavelet transform calculated with two vanishing moment wavelet, exhibits local zero-crossing. Consequently the GCI and GOI are indicated by the location of the local modulus maxima obtained by one vanishing moment wavelet.

The analysis of the behaviour of wavelet transform modulus maxima across scales permits detection of singularities and estimation of Lipschitz exponents

For the GCI, the local regularity is given by α=0.1, and for GOI α=0.8.

As a conclusion singularities detected at glottal closure and opening instants are characterised as signal discontinuities and EGG signal is more regular at glottal opening instant than at one of glottal closure.

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