Available online at www.sciencedirect.com
ScienceDirect
Signal Processing 87 (2007) 1234–1250
SIGNAL PROCESSING
www.elsevier.com/locate/sigpro

# IF estimation for multicomponent signals using image processing techniques in the time–frequency domain ☆

L. Rankine[a,*], M. Mesbah[a], B. Boashash[a,b]

[a]Perinatal Research Centre, University of Queensland, Royal Brisbane and Women's Hospital, Brisbane, Qld. 4029, Australia
[b]College of Engineering, University of Sharjah, Sharjah, UAE

Received 16 March 2006; received in revised form 12 October 2006; accepted 27 October 2006
Available online 8 December 2006

**Abstract**

This paper presents a method for estimating the instantaneous frequency (IF) of multicomponent signals. The technique involves, firstly, the transformation of the one-dimensional signal to the two-dimensional time–frequency (TF) domain using a reduced interference quadratic TF distribution. IF estimation of signal components is then achieved by implementing two image processing steps: local peak detection of the TF representation followed by an image processing technique called component linking. The proposed IF estimator is tested on noisy synthetic monocomponent and multicomponent signals exhibiting linear and nonlinear laws. For low signal-to-noise ratio (SNR) environments, a TF peak filtering preprocessing step is used for signal enhancement. Application of the IF estimation scheme to real signals is illustrated with newborn EEG signals. Finally, to illustrate the potential use of the proposed IF estimation method in classifying signals based on their TF components' IFs, a classification method using least squares data-fitting is proposed and illustrated on synthetic and real signals.


*Keywords:* Instantaneous frequency; Multicomponent signals; Time–frequency representation; Image processing; EEG

## 1. Introduction

The instantaneous frequency (IF) is a signal parameter which is of significant importance in many real applications, such as radar, sonar, telecommunications and biomedicine [1]. For an analytic [2], monocomponent signal,

$$z(t) = a(t)e^{j\phi(t)} \quad (1)$$

the IF is defined as

$$f_i(t) = \frac{1}{2\pi}\frac{d\phi(t)}{dt}, \quad (2)$$

where $a(t)$ and $\phi(t)$ are two real functions that are referred to as the instantaneous amplitude and instantaneous phase, respectively.

A review of techniques for estimating the IF, such as phase difference estimators, zero crossing-based IF estimation, adaptive parameterization methods and time–frequency (TF)-based techniques, can be found in [3]. Among those, TF-based IF estimation

☆This work was supported through grants from the NHMRC and ARC.
*Corresponding author. Tel.: +61 7 3346 4948; fax: +61 3636 2123.
*E-mail address:* lrankine@somc.uq.edu.au (L. Rankine).
*URL:* http://www.som.uq.edu.au/research/sprcg.

0165-1684/$ - see front matter 
doi:10.1016/j.sigpro.2006.10.013

techniques have received considerable attention recently, as illustrated by the papers [4–10].

As discussed in [1], an ideal TF representation of a monocomponent signal of the form (1) would exhibit a peak about the IF, with an amplitude related to the signal envelope. It has been shown that some quadratic time–frequency distributions (QTFDs), such as the Wigner–Ville distribution (WVD) and modified B-distribution (MBD) [11,12], provide a peak centered at the IF for linear frequency modulated (LFM) signals. Therefore, an intuitive method for estimating the IF is to take the peak of these QTFDs, as described in [3]. However, care must be taken with nonlinear frequency modulated signal components as the peak estimate is biased (see [5,6,12] for further details).

Consider now a multicomponent signal, $z(t)$, composed of a sum of monocomponent signals corrupted with complex-valued additive white Gaussian noise, $r(t)$, with independently and identically distributed (i.i.d) real and imaginary parts, such that

$$z(t) = \sum_{i=1}^{M} a_i(t)\mathrm{e}^{\mathrm{j}\phi_i(t)} + r(t), \tag{3}$$

where $a_i(t)$ and $\phi_i(t)$ are the amplitude envelope and instantaneous phase of the $i$th signal component, respectively, and $M$ is the number of signal components. In this paper, we classify a multicomponent signal as being either TF separable or TF nonseparable. A TF nonseparable signal is defined as a signal whose TF components are either too close to separate in the TF domain or with components that actually intersect. A TF separable multicomponent signal is, however, a signal whose TF components are clearly separated in the TF domain and hence possess a unique TF decomposition. We restrict our present study to the case of TF separable multicomponent (referred to from this point on as just multicomponent) signals whose TF components are characterized by continuous IFs. This characteristic is shared by most physiological signals such as newborn EEG [13] and heart rate variability [14].

The idea of a single IF for a multicomponent signal, as defined by (3), becomes meaningless [1]. Instead, estimation of the IF of each individual component is the desired information to be extracted from multicomponent signals.

Component IF estimation for multicomponent signals using the local peaks of QTFDs has previously been proposed. In [12], an adaptive QTFD was presented and local peaks were used to estimate the IF of components. However, this method requires a priori information about the ratio between signal component amplitudes, assuming the component amplitudes are constant, so that local maxima caused by crossterms and noise can be ignored by setting an appropriate threshold level [12]. For this reason, the method was not assessed with low signal-to-noise ratio (SNR) signals or real signals with time-varying amplitudes.

The two-dimensional representation of a signal in the joint TF domain has led to the use of pattern recognition techniques to extract the individual IFs of multicomponent signals. In [7], the authors developed a method for estimating the parameters associated with LFM signals using a Wigner–Hough transform. This technique was extended in [8] to be applicable to nonlinear frequency modulated signals. In [9], the authors proposed a combined Hough–Radon transform of a positive TF distribution to estimate multicomponent IFs. The authors in [10] developed a technique for multicomponent IF estimation based on the randomized Hough transform (RHT) of the TF representation, using edge information obtained from matched filtering-based edge detection to eliminate spurious votes in the RHT.

The Hough transform, used in each of the methods presented in [7–10], is a well-known method for finding curves in images [15]. However, the Hough transform requires a priori information about the class of IF law (e.g. *linear*, *quadratic*, *cubic*, *hyperbolic*, *sinusoidal*, etc.) contained in the signal so that the TF representation can be transformed to the appropriate Hough parameter space. This means that the component IF laws of a signal which contains, for example, a component with a linear IF law and a component with a sinusoidal IF law, cannot both be accurately estimated simultaneously. The IF estimation methods incorporating the Hough transform also provide poor results if the IF of a signal component is not easily represented by a parametric function [9].

This paper proposes a new technique for multicomponent IF estimation without requiring a threshold to be set for local peaks in the TF domain or a priori knowledge of the class of IF law. The technique involves a TF transformation of the signal using a high resolution, reduced interference QTFD. Component IFs are then extracted by a two-step process: detection of local peaks in the TF