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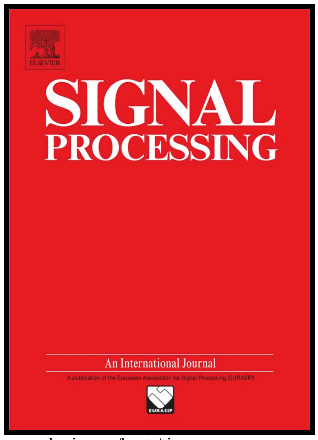

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Cubic Phase Function: A Simple Solution to Polynomial Phase Signal Analysis

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Abstract

This article provides an overview of the cubic phase function (CPF) as a tool proposed for both parametric and nonparametric estimation of the frequency modulated (FM) and in particular polynomial phase signals (PPS). This simple tool motivated small revolution in this field with numerous extensions and applications. We are describing the CPF and compare some of its extensions for both one-dimensional and two-dimensional signals. The comparisons are performed in terms of accuracy (measured with signal-to-noise (SNR) threshold and mean-squared error (MSE)) and computational complexity. Also, we review the CPF and related transforms applications.

Keywords: Frequency modulated signals, Time-frequency analysis, Polynomial phase signals, Parameter estimation, Cubic phase function, Chirp-rate, Instantaneous frequency.

I. Introduction

Engineers in many fields often encounter non-stationary signals including biological, speech and music signals, radio signals in wireless communications and radars, and dispersive seismic signals [1]- [57]. The conventional Fourier transform (FT), a popular tool to bridge between time and frequency, is considered to be inadequate to analyze such real-life signals [1], [2], [4]. In contrast, joint time-frequency (TF) analysis is an efficient way to reveal frequency contents of signals evolving over time, alternatively known as the instantaneous frequency (IF).

One particularly interesting model of non-stationary signals is the polynomial phase signal (PPS) model. The last 25 years have witnessed tremendous developments in the area of PPS parameter estimation, driven by applications originated in radars, sonars, biomedicine, machine engine testing, etc. [58]- [95]. The maximum likelihood (ML) estimator has limited application due to a required multi-dimensional search over the parameter space. Early developments for the PPS parameter estimation are based on high-order ambiguity function (HAF) and its product form (PHAF) [91], [96]. The HAF-based estimation procedure consists of phase order decrementing by the process known as the phase differentiation (PD) until obtained signal is a sinusoid (the PPS of the first order). Then, the highest-order phase parameter is estimated using the fast algorithm, i.e., by an one-dimensional (1-D) search over the parameter space. This strategy is efficient but with numerous shortcomings. Firstly, in each stage of the procedure, the PD (performed by the auto-correlation function) reduces signal length and increases the number of noise-related terms in the resulted signal. These effects increase the signal-to-noise-ratio (SNR) threshold and estimation mean