ALGORITHM FOR THE DETECTION AND
PARAMETER ESTIMATION
OF MULTICOMPONENT LFM SIGNALS

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Abstract A novel algorithm based on Radon-Ambiguity Transform (RAT) and Adaptive Signal Decomposition (ASD) is presented for the detection and parameter estimation of multicomponent Linear Frequency Modulated (LFM) signals. The key problem lies in the chirplet estimation. Genetic algorithm is employed to search for the optimization parameter of chirplet. High estimation accuracy can be obtained even at low Signal-to-Noise Ratio (SNR). Finally simulation results are provided to demonstrate the performance of the proposed algorithm.

Key words Multicomponent Linear Frequency Modulated (LFM) signals; Parameter estimation; Radon-Ambiguity Transform (RAT); Adaptive Signal Decomposition (ASD); Genetic algorithm

I. Introduction

Linear Frequency Modulated (LFM or chirp) signals are widely used in many fields such as radar, communication, sonar, and biology. The detection and parameter estimation of LFM signals has been focused in the field of signal processing. Cohen-based\textsuperscript{[1]} time frequency analysis is an effective tool for analyzing and detecting the nonstationary signals. But for multicomponent LFM signal at low Signal-to-Noise Ratio (SNR), cross terms and noise will seriously affect the time frequency characteristics. Many techniques such as Radon Wigner-Ville transform\textsuperscript{[2]}, Radon-Ambiguity Transform (RAT)\textsuperscript{[3,4]}, Radon-Gabor transform\textsuperscript{[5]}, and so on, have been proposed to solve this problem. However, the above methods can only obtain a part of parameter estimation for multicomponent LFM signals without time delay.

In this letter, we focus on the problem of detection and parameter estimation of multicomponent LFM signals corrupted by additive white Gaussian noise. The multicomponent LFM signals analyzed in this letter have different parameters, e.g., amplitude, time delay, chirp rate and duration. The dechirp technique used in Refs.\textsuperscript{[4,5]} is unsuitable for the signals discussed in this letter, because it can only be used to estimate the initial frequency of LFM signal without time delay. A novel method based on RAT and Adaptive Signal Decomposition (ASD) for detection and parameter estimation of multicomponent LFM signals is presented. First, RAT is used to detect and estimate the chirp rate of the strongest signal component. Adaptive Signal Decomposition (ASD) based on chirplet is performed via genetic algorithm, which is suitable for low SNR condition. Then a recursive algorithm based on RAT and ASD is given. This method also gives the estimation of amplitude, time delay and duration of multicomponent LFM signals besides other parameters. Simulation results

\textsuperscript{1}Manuscript received date: June 28, 2004; revised date: August 14, 2004. Supported by Key Lab. for Radar Signal Processing Foundation (No. 51431050103ZS0106) Communication author: Yuan Weiming, born in 1976, male, Doctoral candidate. Key Lab. for Radar Signal Processing, Xidian University, Xi'an 710071, China.
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indicate that it is effective for detection and parameter estimation of multicomponent LFM signals even at low SNR.

II. Radon-Ambiguity Transform and Adaptive Signal Decomposition

1. Radon-Ambiguity Transform (RAT)

The model of the received noisy multicomponent LFM signals is

$$x(t) = \sum_{i=1}^{M} s_i(t) + n(t)$$

$$s_i(t) = A_i \exp(j2\pi f_i(t - t_i) + \pi \mu_i (t - t_i)^2), \quad t_i \leq t \leq t_i + \Delta T_i$$

where $n(t)$ represents white Gaussian noise, and $s_i(t)$ is LFM signal. $A_i, f_i, t_i, \mu_i$ and $\Delta T_i$ are the amplitude, initial frequency, time delay, chirp rate and duration of the LFM signals, respectively.

The Ambiguity Function (AF) of $x(t)$ is defined as

$$A\text{F}(\tau, \xi) = \int_{-\infty}^{\infty} x(t)x^*(t + \tau)e^{j2\pi \xi t}dt$$

where $\tau$ denotes the time delay and $\xi$ the Doppler shift. A contour plot of the AF modulus for a typical LFM signal is shown in Fig.1, with a line passing through the origin of $\tau-\xi$ plane. In Fig.1, $\mu$ represents the chirp rate, $\mu = \tan \alpha$.

Radon transform is performed on the time-frequency plane of the ambiguity function modulus by computing a series of line integrals, which pass through the origin. The angle of each line integral corresponds to a hypothesized chirp rate of the LFM. Hence, LFM signals may be detected by performing a one-dimensional search for peaks in the line integral values versus angle (chirp rate).

Two detectors in RAT domain are given in Ref.[3], and it was proved that the envelope detector was superior in detecting weak LFM signals[3]. Envelope detector is defined as

$$\eta(\mu) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} |A\text{F}(\tau, \xi)|\delta(\xi - \mu \tau)d\tau d\xi = \int_{-\infty}^{\infty} |A\text{F}(\tau, \mu \tau)|d\tau$$

A series of such line integrals are computed to search for the maxima $\eta(\mu)$, and a peak appeared corresponding to the chirp rate. For multicomponent LFM signals with different chirp rate, multi-local maximum values will be obtained. In fact, the strongest