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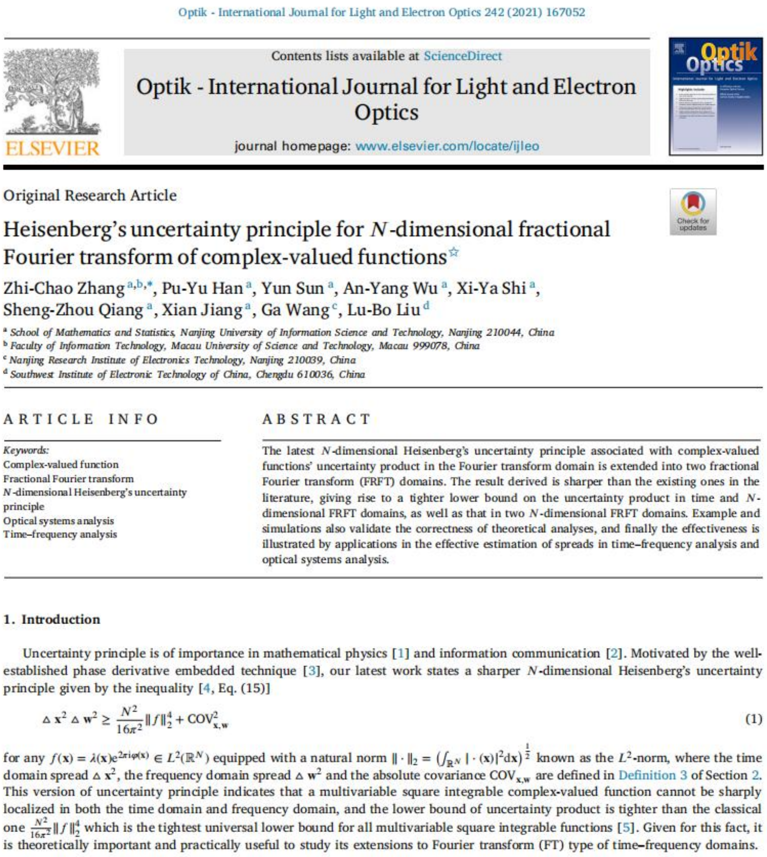
1.2021 年 4 月 发表 SCI 论文：Heisenberg’s uncertainty principle for N-dimensional fractional Fourier transform of complex-valued functions



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Original Research Article

Heisenberg’s uncertainty principle for N-dimensional fractional Fourier transform of complex-valued functions☆

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ABSTRACT

The latest N-dimensional Heisenberg’s uncertainty principle associated with complex-valued functions’ uncertainty product in the Fourier transform domain is extended into two fractional Fourier transform (FRFT) domains. The result derived is sharper than the existing ones in the literature, giving rise to a tighter lower bound on the uncertainty product in time and N-dimensional FRFT domains, as well as that in two N-dimensional FRFT domains. Example and simulations also validate the correctness of theoretical analyses, and finally the effectiveness is illustrated by applications in the effective estimation of spreads in time–frequency analysis and optical systems analysis.

1. Introduction

Uncertainty principle is of importance in mathematical physics [1] and information communication [2]. Motivated by the well-established phase derivative embedded technique [3], our latest work states a sharper N-dimensional Heisenberg’s uncertainty principle given by the inequality [4, Eq. (15)]

$$\triangle \mathbf{x}^2 \triangle \mathbf{w}^2 \geq \frac{N^2}{16\pi^2}\|f\|_2^4 + \mathrm{COV}_{\mathbf{x},\mathbf{w}}^2 \qquad (1)$$

for any $f(\mathbf{x}) = \lambda(\mathbf{x})e^{2\pi i\varphi(\mathbf{x})} \in L^2(\mathbb{R}^N)$ equipped with a natural norm $\|\cdot\|_2 = (\int_{\mathbb{R}^N}|\cdot(\mathbf{x})|^2 d\mathbf{x})^{\frac{1}{2}}$ known as the L^2-norm, where the time domain spread $\triangle \mathbf{x}^2$, the frequency domain spread $\triangle \mathbf{w}^2$ and the absolute covariance $\mathrm{COV}_{\mathbf{x},\mathbf{w}}$ are defined in Definition 3 of Section 2. This version of uncertainty principle indicates that a multivariable square integrable complex-valued function cannot be sharply localized in both the time domain and frequency domain, and the lower bound of uncertainty product is tighter than the classical one $\frac{N^2}{16\pi^2}\|f\|_2^4$ which is the tightest universal lower bound for all multivariable square integrable functions [5]. Given for this fact, it is theoretically important and practically useful to study its extensions to Fourier transform (FT) type of time–frequency domains.

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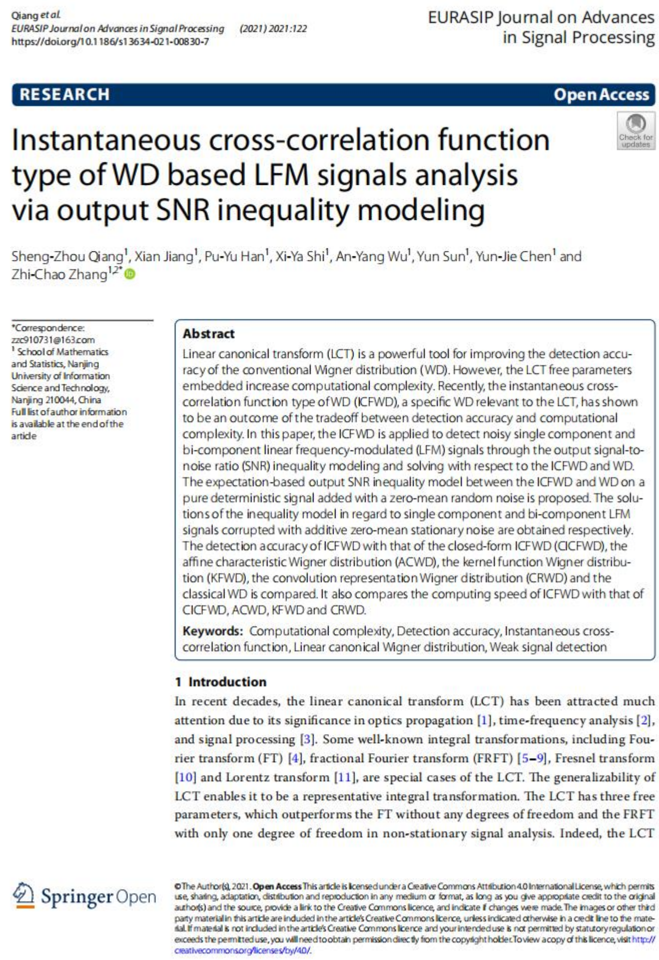

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RESEARCH **Open Access**

Instantaneous cross-correlation function type of WD based LFM signals analysis via output SNR inequality modeling

Sheng-Zhou Qiang[1], Xian Jiang[1], Pu-Yu Han[1], Xi-Ya Shi[1], An-Yang Wu[1], Yun Sun[1], Yun-Jie Chen[1] and Zhi-Chao Zhang[1,2*]

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Abstract
Linear canonical transform (LCT) is a powerful tool for improving the detection accuracy of the conventional Wigner distribution (WD). However, the LCT free parameters embedded increase computational complexity. Recently, the instantaneous cross-correlation function type of WD (ICFWD), a specific WD relevant to the LCT, has shown to be an outcome of the tradeoff between detection accuracy and computational complexity. In this paper, the ICFWD is applied to detect noisy single component and bi-component linear frequency-modulated (LFM) signals through the output signal-to-noise ratio (SNR) inequality modeling and solving with respect to the ICFWD and WD. The expectation-based output SNR inequality model between the ICFWD and WD on a pure deterministic signal added with a zero-mean random noise is proposed. The solutions of the inequality model in regard to single component and bi-component LFM signals corrupted with additive zero-mean stationary noise are obtained respectively. The detection accuracy of ICFWD with that of the closed-form ICFWD (CICFWD), the affine characteristic Wigner distribution (ACWD), the kernel function Wigner distribution (KFWD), the convolution representation Wigner distribution (CRWD) and the classical WD is compared. It also compares the computing speed of ICFWD with that of CICFWD, ACWD, KFWD and CRWD.

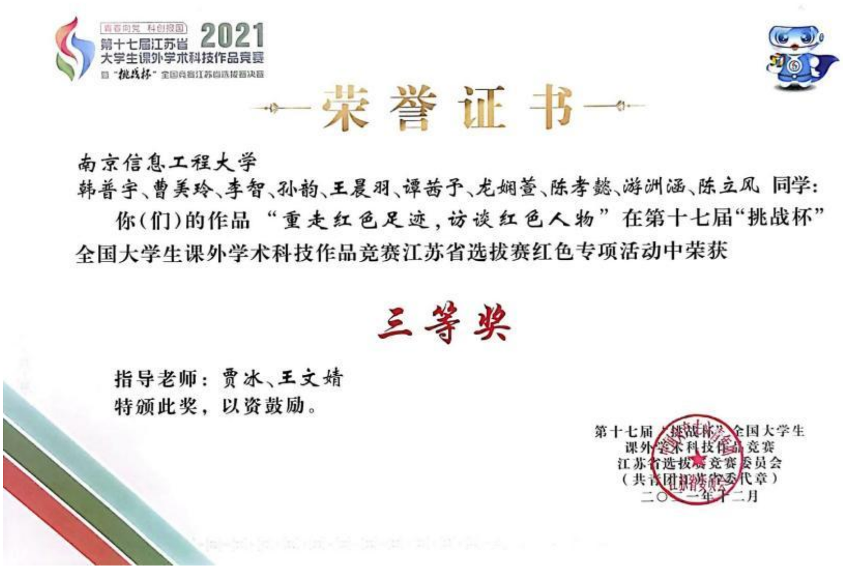
Keywords: Computational complexity, Detection accuracy, Instantaneous cross-correlation function, Linear canonical Wigner distribution, Weak signal detection

1 Introduction

In recent decades, the linear canonical transform (LCT) has been attracted much attention due to its significance in optics propagation [1], time-frequency analysis [2], and signal processing [3]. Some well-known integral transformations, including Fourier transform (FT) [4], fractional Fourier transform (FRFT) [5–9], Fresnel transform [10] and Lorentz transform [11], are special cases of the LCT. The generalizability of LCT enables it to be a representative integral transformation. The LCT has three free parameters, which outperforms the FT without any degrees of freedom and the FRFT with only one degree of freedom in non-stationary signal analysis. Indeed, the LCT

6.2021 年 12 月 国家奖学金

7.2021 年 12 月 第十七届“挑战杯”红色专项省级三等奖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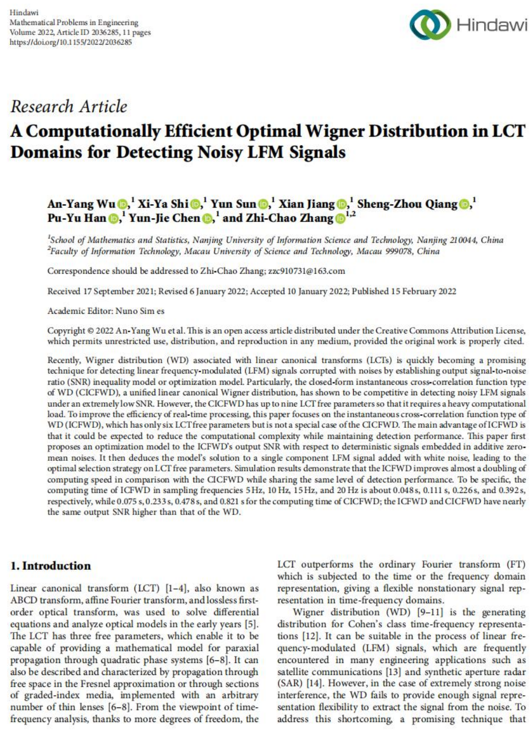
二〇二一年十二月

8.2022 年 2 月 发表 SCI 论文：A Computationally Efficient Optimal Wigner Distribution in LCT Domains for Detecting Noisy LFM Signals


Hindawi
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Research Article

A Computationally Efficient Optimal Wigner Distribution in LCT Domains for Detecting Noisy LFM Signals

An-Yang Wu,[1] Xi-Ya Shi,[1] Yun Sun,[1] Xian Jiang,[1] Sheng-Zhou Qiang,[1] Pu-Yu Han,[1] Yun-Jie Chen,[1] and Zhi-Chao Zhang[1,2]

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Recently, Wigner distribution (WD) associated with linear canonical transforms (LCTs) is quickly becoming a promising technique for detecting linear frequency-modulated (LFM) signals corrupted with noises by establishing output signal-to-noise ratio (SNR) inequality model or optimization model. Particularly, the closed-form instantaneous cross-correlation function type of WD (CICFWD), a unified linear canonical Wigner distribution, has shown to be competitive in detecting noisy LFM signals under an extremely low SNR. However, the CICFWD has up to nine LCT free parameters so that it requires a heavy computational load. To improve the efficiency of real-time processing, this paper focuses on the instantaneous cross-correlation function type of WD (ICFWD), which has only six LCT free parameters but is not a special case of the CICFWD. The main advantage of ICFWD is that it could be expected to reduce the computational complexity while maintaining detection performance. This paper first proposes an optimization model to the ICFWD's output SNR with respect to deterministic signals embedded in additive zero-mean noises. It then deduces the model's solution to a single component LFM signal added with white noise, leading to the optimal selection strategy on LCT free parameters. Simulation results demonstrate that the ICFWD improves almost a doubling of computing speed in comparison with the CICFWD while sharing the same level of detection performance. To be specific, the computing time of ICFWD in sampling frequencies 5 Hz, 10 Hz, 15 Hz, and 20 Hz is about 0.048 s, 0.111 s, 0.226 s, and 0.392 s, respectively, while 0.075 s, 0.233 s, 0.478 s, and 0.821 s for the computing time of CICFWD; the ICFWD and CICFWD have nearly the same output SNR higher than that of the WD.

1. Introduction

Linear canonical transform (LCT) [1–4], also known as ABCD transform, affine Fourier transform, and lossless first-order optical transform, was used to solve differential equations and analyze optical models in the early years [5]. The LCT has three free parameters, which enable it to be capable of providing a mathematical model for paraxial propagation through quadratic phase systems [6–8]. It can also be described and characterized by propagation through free space in the Fresnel approximation or through sections of graded-index media, implemented with an arbitrary number of thin lenses [6–8]. From the viewpoint of time-frequency analysis, thanks to more degrees of freedom, the LCT outperforms the ordinary Fourier transform (FT) which is subjected to the time or the frequency domain representation, giving a flexible nonstationary signal representation in time-frequency domains.

Wigner distribution (WD) [9–11] is the generating distribution for Cohen's class time-frequency representations [12]. It can be suitable in the process of linear frequency-modulated (LFM) signals, which are frequently encountered in many engineering applications such as satellite communications [13] and synthetic aperture radar (SAR) [14]. However, in the case of extremely strong noise interference, the WD fails to provide enough signal representation flexibility to extract the signal from the noise. To address this shortcoming, a promising technique that

9.2022 年 2 月 发表 SCI 论文：Unique Parameters Selection Strategy of Linear Canonical Wigner Distribution via Multiobjective Optimization Modeling

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Xiya SHI, Anyang WU, Yun SUN, Shengzhou QIANG, Xian JIANG, Puyu HAN, Yunjie CHEN, Zhichao ZHANG

Citation: Xiya SHI, Anyang WU, Yun SUN, Shengzhou QIANG, Xian JIANG, Puyu HAN, Yunjie CHEN, Zhichao ZHANG, Unique Parameters Selection Strategy of Linear Canonical Wigner Distribution via Multiobjective Optimization Modeling, Chinese Journal of Electronics, in press, 1–12. doi: 10.1049/cje.2021.00.338.

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二〇二二年五月

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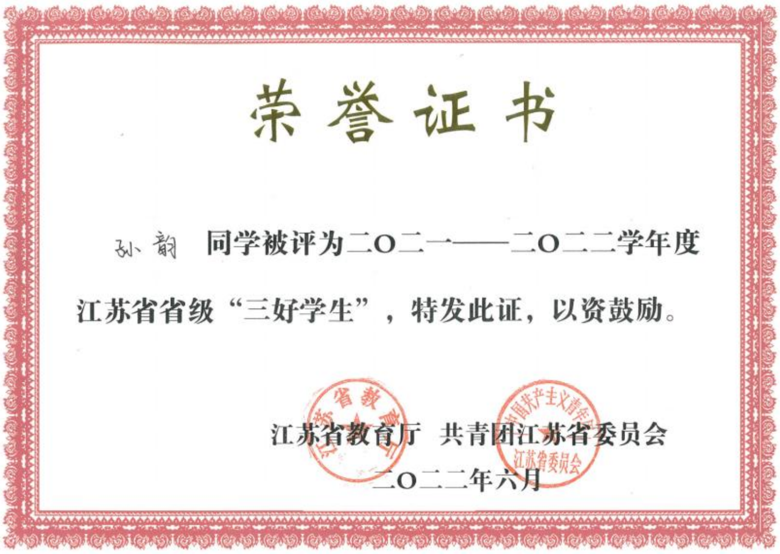
二〇二二年五月

13.2022 年 6 月 江苏省三好学生



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二〇二二年六月

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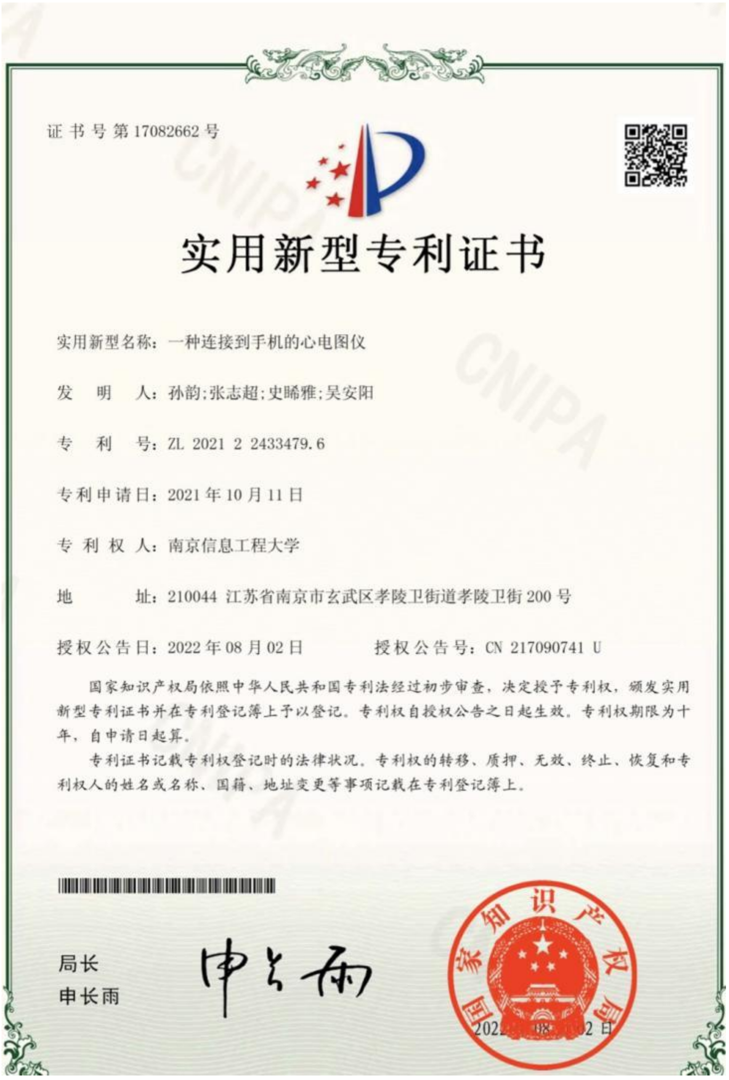

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二〇二一年五月

2.2021 年 5 月 优秀共青团干部

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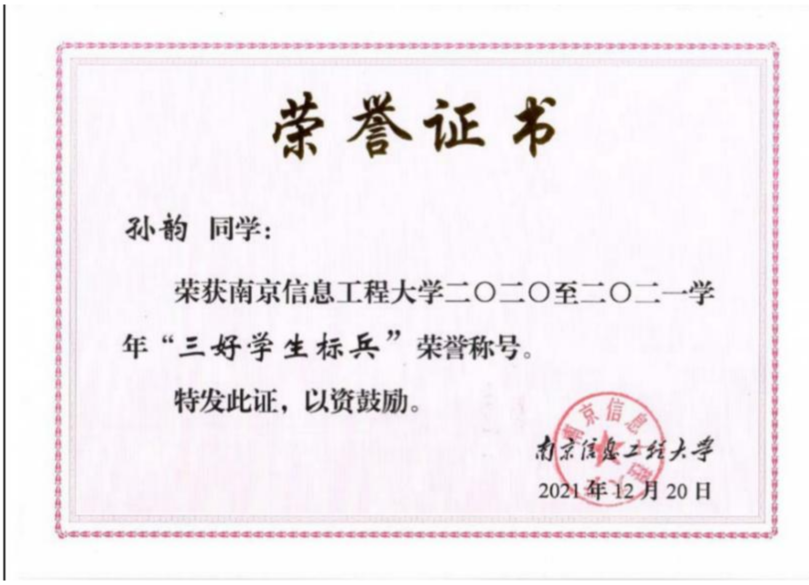
2021 年 5 月

3.2021 年 12 月 三好学生标兵



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