PROCEEDINGS OF SCIENCE

An Evaluation of a New Method of Calculating RFI with Kurtosis

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1. Abstract

This paper presents a novel method for calculating spectral kurtosis called Frequency Separated Spectral Kurtosis (FSSK) that eliminates the need for Fast Fourier Transform (FFT) by leveraging Software Defined Radio (SDR) technology to directly separate and analyze frequency components. Traditional methods involve converting In-phase and Quadrature (IQ) data using FFT before computing kurtosis, a process that can be computationally intensive and time-consuming. Our approach, however, performs kurtosis analysis on already parsed frequency data, significantly enhancing efficiency.

The primary advantage of this method is the ability to identify Radio Frequency Interference (RFI) in real time, which is critical for applications requiring immediate RFI detection and mitigation. This experiment captures data from radio frequency (RF) sensors deployed at a radio astronomy site. This evaluation aims to detail the implementation of the new method, compare its performance against traditional techniques, and explore its broader implications for real-time spectral analysis.

2. Introduction

Radio Frequency Interference (RFI) is a significant, worsening problem in an increasingly digital world. Detecting RFI in real time, as quickly and as computationally efficiently as possible, is therefore of utmost importance. Real-time detection enables prompt mitigation measures, safeguarding sensitive radio astronomy observations and communication systems from disruptions caused by unwanted radio signals. Spectral kurtosis, as a method capable of identifying and characterizing RFI signatures in the frequency domain, plays a pivotal role in these efforts. By leveraging advanced signal processing techniques such as spectral kurtosis, this work aims to enhance the resilience of radio systems against the growing challenges posed by RFI.

In the most idealized scenario, such as at an RA facility, where the signal environment is exceptionally quiet, it is hypothesized that the results of spectral kurtosis measurements will exhibit minimal variation across different methods of calculation. This is predicated on the absence of any distinct frequency-specific content, which would otherwise cause certain frequency channels to exhibit disproportionately high kurtosis values. Additionally, in such a noise-dominated environment, all frequency channels are expected to approximate Gaussian distributions, thereby minimizing the impact of the specific method used to compute kurtosis. Consequently, in these conditions, the spectral kurtosis should yield consistent results, irrespective of the computational approach employed.

3. Background

Spectral kurtosis was developed in the 1980s for detection of Non-Gaussian signals in sonar systems by Dwyer [1]. However it is a known effective method for detecting RFI in other environments [2] [3]. Multiple papers showed that SK offers advantages over Power Spectral Density calculations in certain applications as "it indicates at each frequency bin, if the signal contains nonstationary, stationary harmonic or mixing process" [4]. Smith et al. evaluates the effectiveness of spectral kurtosis (SK) as a statistical method for detecting and mitigating radio frequency

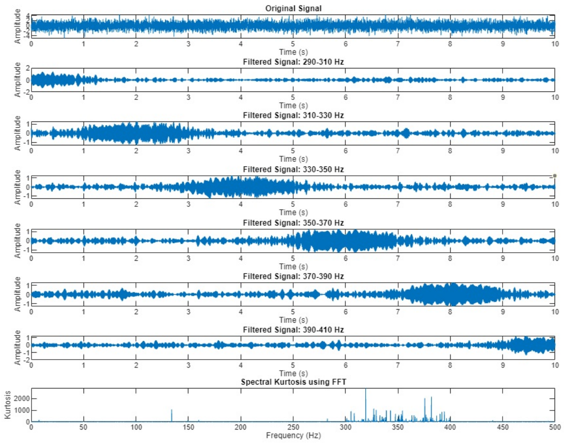

Figure 1: Predicted Spectral Kurtosis from Simulated Data

interference (RFI) against realistic simulated RFI signals of various modulation types, data rates, duty cycles, and carrier frequencies [5]. Wang et al introduced kurtosis wavelet analysis in which the signal is decomposed into components at various scales (or frequencies) using wavelet transforms [6]. This process provides a multi-resolution analysis, capturing both low-frequency and high-frequency details.

The spectral kurtosis equation is as follows:

$$K_z(m) = \frac{\kappa_4 \{X^t(m), X^t(m), X^t(m), X^t(m)\}}{[\kappa_2 \{X^t(m), X^t(m)\}]^2} \tag{1}$$

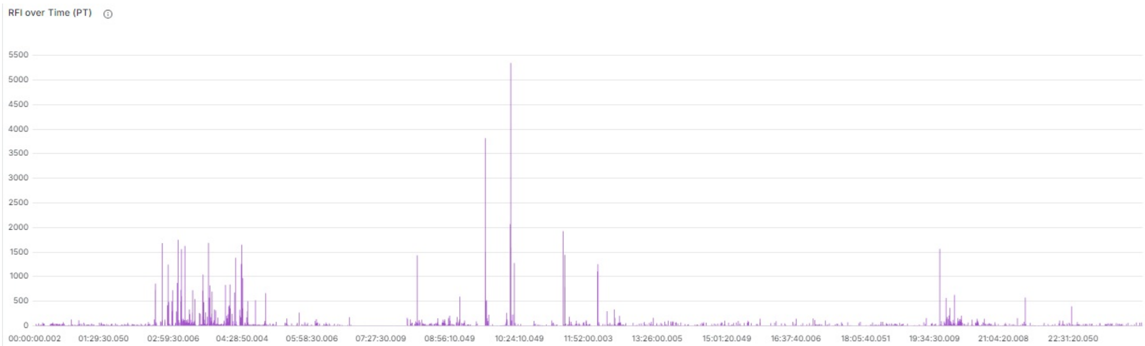

Figure 2: Real-Time Kurtosis Gathered from RF Sensors Deployed at an RA Site at 915 MHz over a 26 MHz Bandwidth During an RFI Event

The equivalence between separating frequencies with a Software Defined Radio (SDR) and subsequently calculating kurtosis versus performing a Fast Fourier Transform (FFT) followed by spectral kurtosis calculation hinges on their handling of the signal's frequency-domain representation. When an FFT is applied to a time-domain signal, it decomposes the signal into its constituent frequency components, each characterized by amplitude and phase information. Spectral kurtosis, in turn, quantifies the peakedness or flatness of the spectral distribution at each frequency component.

4. Methodology

There are several different ways of calculating kurtosis in signal processing, both with and without the use of a Fast Fourier Transform (FFT). The SDR/Analog Front End processes incoming signals and applies frequency-based filtering. As shown in Figure 3, this results in I/Q voltage values, which are then used to compute time-domain voltage kurtosis [1]. From the I/Q values, instantaneous power values are derived, and time-domain power kurtosis [2] is calculated. Additionally, integrated power values lead to another form of time-domain power kurtosis [3]. These methods are applied using an RPi (Raspberry Pi) with the role of handling the sampling frequency. FFT is applied to the signal, splitting it into individual frequency channels. For each channel, a kurtosis value is calculated. The collection of these channel-specific values forms the spectral kurtosis [4], which provides more detailed frequency-domain information on signal interference.

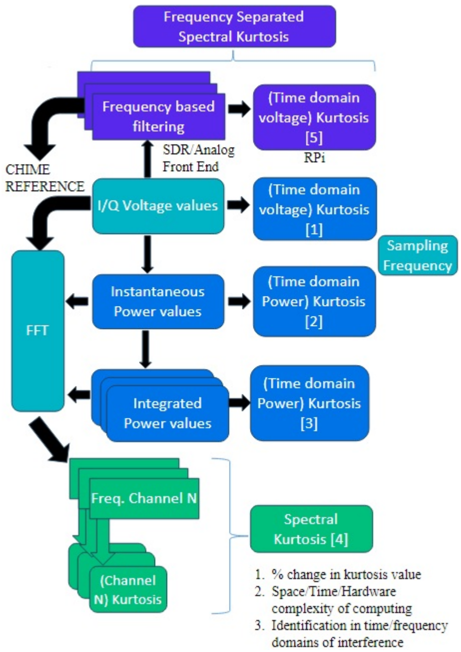

Figure 3: Relationship of different ways of calculating kurtosis in signal processing

5. Analysis

The results shown in Figure 4 illustrate the computational and analytical advantages of Frequency Separated Spectral Kurtosis (FSSK) compared to traditional Spectral Kurtosis (SK). On average, FSSK is at least five times faster than SK, as reflected in the time factors shown, primarily due to its direct access to amplitude information and frequency separation via SDR, bypassing the need for FFT computation. Despite the differences in methodology, both approaches are mathematically equivalent, with an approximate 90% similarity between their calculated values, demonstrating consistency in characterizing the spectral properties of the signal. This computational efficiency makes FSSK particularly suited for real-time signal processing, offering a practical solution for applications requiring rapid analysis without sacrificing accuracy.

Metric	Spectral Kurtosis	Frequency Separated Spectral Kurtosis		
2.046735e+00	2.45918	2.18936		
...	...	...		
2.439569e+00	2.46723	2.83296		
2.664974e+00	2.66297	2.72098		
2.739112e+00	2.73273	2.73852		
2.742324e+00	2.74814	2.75221		
2.754027e+00	2.75561	2.75685		
2.757193e+00	Time taken (seconds)		0.00709	0.00136
Time factor	Filtered calculation is 5.2225 times faster than direct calculation			
Average Percentage Similarity (%)	98.87097			

Figure 4: Computational calculation between FSSK and SK

6. Conclusion

The Frequency Separated Spectral Kurtosis (FSSK) technique offers significant advantages for applications requiring real-time analysis, such as communications monitoring or interference detection in radio astronomy. Compared to traditional Spectral Kurtosis (SK), which relies on computationally intensive Fast Fourier Transforms (FFTs), FSSK is less resource-demanding and more efficient in terms of processing time. This reduced computational cost, combined with the availability of relatively inexpensive Software-Defined Radios (SDRs), makes FSSK a viable and easily implementable solution for these applications. Furthermore, the new method for calculating SK enhances its practicality, enabling its integration into a wide range of real-time signal processing systems.

References

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