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Selection Process of a Transform Selective Interference Suppression Algorithm

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ABSTRACT

The transform selective interference suppression algorithm (TSISA) has been proposed earlier for excising interfering signals in different transform domains. The proper domain is selected using a compression gain metric, and the interference excision is done using the forward consecutive mean excision (FCME) algorithm in that domain. This paper investigates the domain selection process of the TSISA via computer simulations. Interfering signal types considered are impulses, sinusoids, chirps and band-limited binary phase-shift keying (BPSK) communication signals. The results confirm that the TSISA is capable to choose the most suitable transform for the interference excision. The stronger the interfering signal is the more frequently the TSISA is able to choose the most suitable transform domain.

1. INTRODUCTION

Communication systems may suffer from different kinds of interfering signals. Interference causes performance degradation, and need for interference excision methods arises. There exists a large variety of interference suppression algorithms, but many of these are incapable to suppress wideband interfering signals. Computationally simple excision algorithms are targeted to suppress only one kind of interfering signal. The use of the recursive least squares (RLS) filter [1] provides a decent performance against different kinds of interferences but the computational complexity is high and the numerical stability is poor in some cases [2]. Good interference excision method should be able to handle several types of interfering signals with a reasonable computational complexity.

Some of the interfering signals are easiest to be excised in the frequency domain, some in the time domain and some in other transform domains. The problem is how to select the most suitable domain. The transform selective interference suppression algorithm (TSISA) proposed in [3] makes the selection between the domains before the interference suppression. This reduces the computational complexity considerably. Selection process is based on a compression gain (CG) metric. The CG [4] has been used previously, e.g., in image processing, where it is known as a coding gain. Selection is based on a fact that in an optimal domain, interference is the most concentrated on the fewest number of samples. In the TSISA, the forward consecutive mean excision (FCME) algorithm [5] is used to suppress interfering signals in the selected domain. The FCME algorithm is blind and it does not need to know the noise level. The performance of the FCME algorithm has been investigated in [5, 6].

It was illustrated in [3] that the bit error rate (BER) performance of the TSISA is very auspicious. In this paper, the domain selection process of the TSISA is investigated. The ability of selecting the most suitable domain is the performance criterion. The performance of the domain selection process is demonstrated via simulations. Four types of interfering signals and three types of excision domains are considered.

2. SYSTEM AND INTERFERENCE MODEL

The received signal is

$$r(n) = s(n) + w(n) + i(n), \tag{1}$$

where $s(n)$, $w(n)$ and $i(n)$ are the direct sequence (DS) signal to be detected, a complex white Gaussian process with a one-sided power spectral density N_0 and an interfering signal, respectively. Signal-to-noise ratio (SNR) is defined as E_b/N_0, where E_b is the energy of the DS signal per bit.

Four interfering signal types are considered, namely impulses, sinusoids, chirps and binary phase-shift keying (BPSK) communication signals. Impulses are a set of Dirac delta functions. In the simulations, impulses with random pulse repetition were used. The ratio of the number of corrupted samples to the total number of samples is called the contamination ratio.

A discrete sinusoidal signal has form

$$i(n) = \sqrt{I} \exp\left[j(\omega_0 n + \theta)\right] \tag{2}$$

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where I, ω_0 and θ are the interfering signal power, frequency-offset from the center frequency of the DS signal and the initial phase of the interference, respectively. The interference-to-signal ratio (ISR) is defined per sinusoidal in this case.

A frequency sweeping sine wave, a discrete chirp signal, can be expressed as

$$i(n) = \sqrt{I} \exp\left[j(\omega_0(n)n + \theta)\right], \ n = 0, 1, 2, \cdots, \quad (3)$$

where $\omega_0(n)$ is the time-varying frequency-offset.

BPSK signal can be expressed as

$$i(n) = \sqrt{I} \sum_{k=0}^{\infty} a_k q(n - kT_i) \exp\left[\delta_\omega n + \theta_i\right], \quad (4)$$

where $a_k \in \{-1, 1\}$ is binary data, $q(n)$ is the pulse waveform, T_i is the symbol interval, δ_ω is the offset frequency in radians and θ_i is the random carrier phase uniformly distributed in $[0, 2\pi]$. The used BPSK signal is band-limited by a root raised cosine (RC) filter with roll-off factor 0.22 [7].

3. INTERFERENCE EXCISION

Three different transform domains are considered as in [3]. These are the Fourier domain, the fractional Fourier domain and the time domain. The fractional Fourier transformation (FrFT) is a generalization of the ordinary Fourier transform (FT) with an order parameter a. In the FT, $a = 1$ [8].

The used transform is selected based on the compression gain [4]

$$\text{CG} = \frac{\frac{1}{N}\sum_{n=1}^{N} |r(n)|^2}{\sqrt[N]{\prod_{n=1}^{N} |r(n)|^2}}, \quad (5)$$

where N and $r(n)$ are the block length and the received signal sample, respectively. The CG is calculated in each domain. The larger the CG is, the more the energy is concentrated in less number of samples [4]. Because the interference is much stronger than the information signal and the noise, it can be assumed that the energy is from the interference. The FT and its CG are calculated before the calculation of the FrFT, because the order parameter of the FrFT is determined using the FCME algorithm [3]. The domain with the largest CG is chosen. After that, the interference excision is done using the FCME algorithm [5].

The FCME algorithm uses a threshold parameter which is calculated a priori by using a desired false alarm probability and statistical properties of the signal in a noise only case [9]. The FCME algorithm rearranges the samples in the ascending order according to their energies. Due to the rearrangement, the FCME algorithm requires sorting. The n smallest terms in the sorted set are selected to belong to the initial set assumed to be free of interference ('clean set'). The size of the initial set can vary from one element up to 10 % of the whole data set. The smaller the initial set is, the higher is the possibility that the initial threshold is too small and the algorithm does not operate at all. On the other hand, the higher the initial set is, the higher is the possibility that the initial set is not clean. The FCME algorithm iteratively calculates new mean and a new threshold until there are no new samples that are below the threshold [5]. Since the FCME algorithm is a forward excision method, the threshold increases in every iteration.

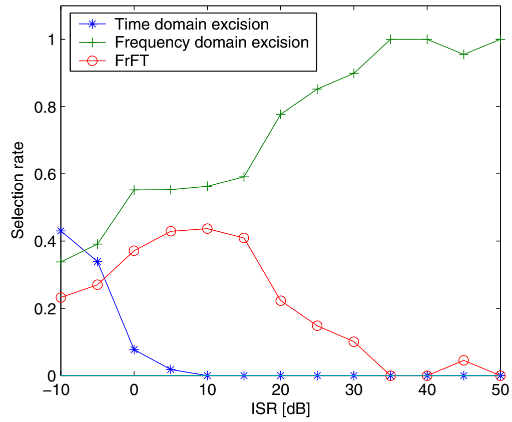

Fig. 1. TSISA selection rate vs. ISR, with sinusoidal interference. Number of sinusoidal signals is 2.

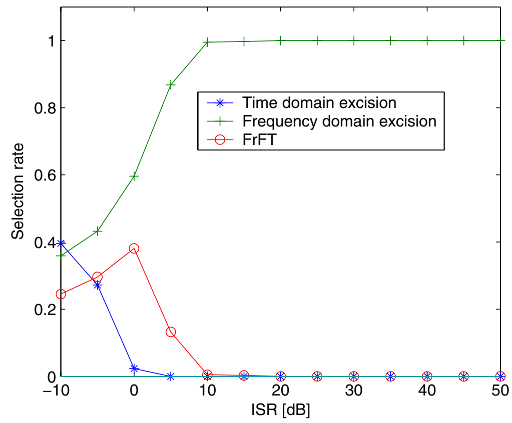

Fig. 2. TSISA selection rate vs. ISR, with sinusoidal interference. Number of sinusoidal signals is 5.

4. SIMULATION RESULTS

In the simulations, the modulated data was multiplied with a 64-chip Gold sequence. One sample per chip was taken. The FCME threshold value was 2.97 [9] and the size of the initial set in the FCME algorithm was 10 % of samples. With the both Fourier transforms, a 4-term Blackman-Harris window was used as a temporal window that is required to reduce spectrum leakage [9]. The order parameter of the FrFT was calculated based on the knowledge of the interfering signal.

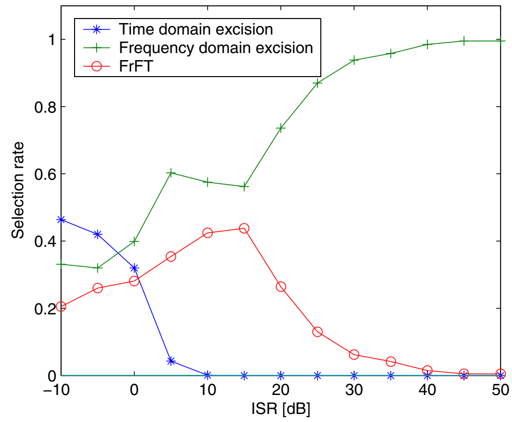

Fig. 3. TSISA selection rate vs. ISR. Interference is RC-BPSK with relative bandwidth 20 %.

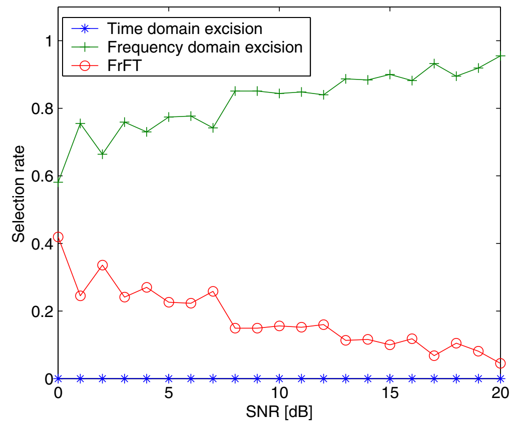

Fig. 4. TSISA selection rate vs. SNR. Interference is RC-BPSK with relative bandwidth 40 %. ISR=30 dB.

According to [3], impulses are easiest to remove in the time domain and other interfering signals in the Fourier domains. When considering RC-BPSK and sinusoidal interfering signals, the ordinary Fourier transformation is the best choice. The FrFT is the best choice for the chirp signal.

The selection process of the TSISA is presented with different numbers of sinusoidal interfering signals as a function of ISR in Figs. 1 and 2. When interference is sinusoidal, the more sinusoidal signals, the more frequently the TSISA chooses the ordinary Fourier domain. With only a few sinusoid signals, the FrFT is close to the ordinary FT. This is because the total bandwidth, which defines the order of the FrFT, is relatively narrow in that case. Thus the excision in both domains provides nearly equal performance [3].

In Figs. 3 – 5 the TSISA selection process is studied when the interfering signal is a RC-BPSK signal. The stronger the ISR is, the more frequently the TSISA selects the ordinary Fourier domain which is the most suitable choice for that kind of interference excision. From Figs. 4 and 5 it can

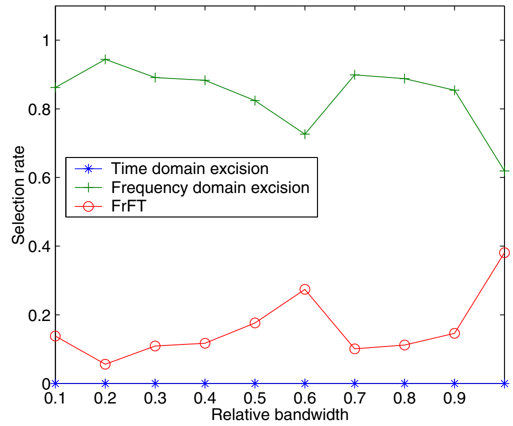

Fig. 5. TSISA selection rate vs. relative bandwidth, with RC-BPSK interference. ISR=30 dB.

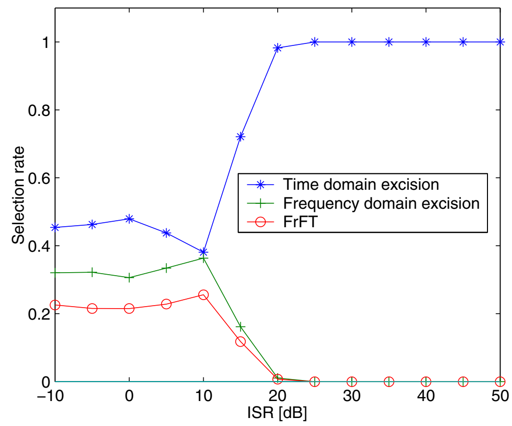

Fig. 6. TSISA selection rate vs. ISR, with impulse interference. Contamination ratio is 0.7.

be seen that SNR and the relative bandwidth of the signal have only small influence to the domain selection process. Note that when ISR is relatively large, say over 10 dB, the selection process of the TSISA discards the time domain totally.

Results for the impulse interfering signals are presented in Figs. 6 – 8. The higher the contamination ratio is, the more ISR is needed before the TSISA chooses the time domain. It can be observed from Fig. 8 that the TSISA is able to select the time domain even if the contamination ratio is 80 % of all the samples.

At the chirp interference case, the results are presented in Figs. 9 and 10. The most suitable excision domain for the chirp interference is the fractional Fourier domain. The TSISA selects the fractional Fourier domain when interfering signal is strong enough. It can also be noticed that the narrower the relative bandwidth of the chirp signal is, the stronger the chirp signal has to be before the TSISA can find the most suitable domain.

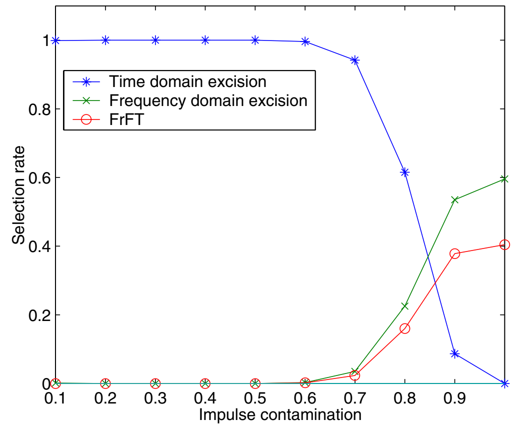

Fig. 7. TSISA selection rate vs. contamination ratio, with impulse interference. ISR = 10 dB

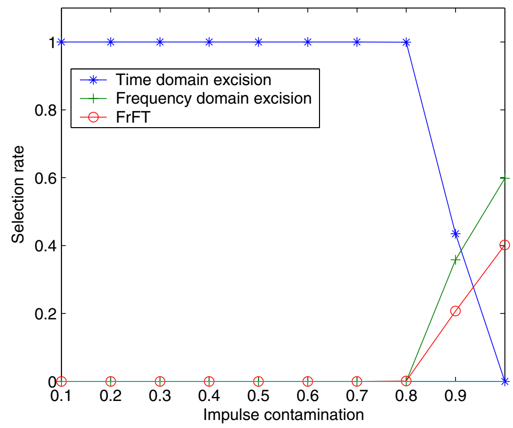

Fig. 8. TSISA selection rate vs. contamination ratio, with impulse interference. ISR = 30 dB

5. CONCLUSIONS

The selection process of the transform selective interference suppression algorithm was investigated. The transform domains were the Fourier, fractional Fourier and time domains. There were four kinds of interfering signals. The simulation results showed that the stronger the interfering signal is the more frequently the transform selective interference suppression algorithm is able to choose the most suitable transform. The results also indicate that when the interference is impulse, the algorithm is capable to choose the most suitable domain even if the contamination ratio is 80 % of samples.

6. ACKNOWLEDGEMENT

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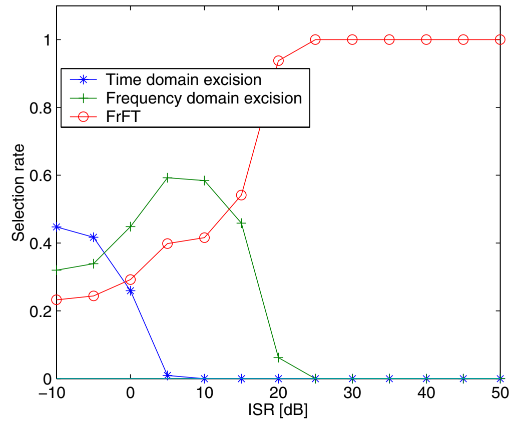

Fig. 9. TSISA selection rate vs. ISR, with chirp interference. Relative bandwidth is 50 %

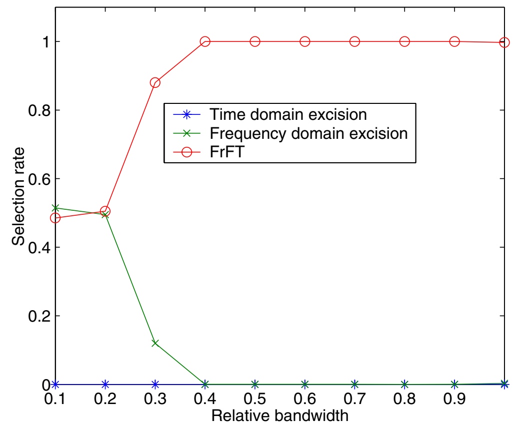

Fig. 10. TSISA selection rate vs. relative bandwidth, with chirp interference. ISR=30 dB.

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