A Computationally Efficient Multi-coset Wideband Radar ESM Receiver

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ABSTRACT

The problem of efficient sampling of wideband Radar signals for Electronic Support Measures (ESM) using a parallel sampling structure is investigated in this paper. The wideband radio frequency sampling, which is a necessary component of modern Radar surveillance systems, generally needs a sampling rate at least twice the maximum frequency of the signals, i.e. Nyquist rate, which is generally very high. However, when the signal is highly structured like Radar signals, we can use the fact that signals do not occupy the whole spectrum and instead, there exists a parsimonious structure in the time-frequency domain. Here, we characterise a novel low-complexity sampling system with a recovery guarantee, assuming that the received RF signals have a particular structure. The proposed technique is inspired by the compressive sampling (CS) of sparse signals and it uses a multi-coset sampling setting, while it does not involve a computationally expensive reconstruction step. In a contrast to the current rapid frequency sweeping technique, the new framework continuously monitors the spectrum, which makes it much more robust to the short pulse misdetection. Another advantage of the proposed technique is that the output of sampler can be easily fed to the standard Nyquist rate, TF based parameter encoders.

1.0 INTRODUCTION

The Radar ESM signals are wideband and they normally exceed the sampling-rate/dynamic-range specifications of standard (single-unit) ADC's. One approach to sample such signals is to use a bank of sub-Nyquist ADC's, each delayed with a distinct factor. This type of ADC's are called Time-Interleaved ADC's [1]. The most important practical issues with such a large bank of parallel channels are: a) the feasibility of implementation, i.e. in terms of Size, Weight And Power (SWAP), and b) calibration. It is generally preferred to use only a few channels to compromise the accuracy with complexity.

Time sharing techniques are among the techniques which use a single, or a few parallel channels. In a channelised time-sharing technique, which is also called the rapid frequency sweeping technique, we use a bank of bandpass filters and consecutively sample the output of one or a few channels. The main drawback of channelised time-sharing techniques is that it only monitors a particular part of spectrum, at each time period. This fact makes it very sensitive to the short-pulse detection.

The time-sharing techniques fit in the more general framework of sub-Nyquist sampling methods. However, the time-sharing is one of the simplest, but not the most effective, approaches. There already exist other sub-Nyquist techniques for the general setting of signal sampling [2]. These techniques partially compensate the aliasing artefact, caused by the sub-Nyquist sampling, using a non-uniform periodic sampling scheme. Since a linear reconstruction technique is used, there would remain some aliasing error in the sampled signal.

A new approach to the problem of sub-Nyquist sampling is based on the compressive sampling [3-4] of the signals. Different variations of this method have been reported for the sub-Nyquist sampling of continuous-time signals [5-7]. We adapt one such framework, i.e. [7], to the problem of wideband RF signal sampling, which we finally use it for the radar ESM application. Since most of the CS based sub-Nyquist sampling techniques need some non-linear reconstruction techniques, many canonical reconstruction techniques are not suitable for large scale problems like radar ESM, for their high computational complexities.

2.0 PROPOSED LOW-COMPLEXITY MULTI-COSET SAMPLING

We here use only a few ADC's, which is called a multi-coset sampling system [7], and propose a low-complexity algorithm for the recovery of full-band input signals. A schematic of the proposed system is presented in Figure 1, where TF can be an appropriate Gabor Time-Frequency transform, which includes a large class of TF transforms, see [8] for more details. The standard TF transform is slightly modified here to compensate the applied delay in the analog part of each channel. These delays appear as some fractional delays in the discrete time domain, where their separate implementation can be challenging. The combination of the TF transform and the digital fractional delays can be easily done, if the generating kernel of the transform is continues domain, e.g. Gabor TF transforms [9].

The subband classifier includes a linear transform, followed by a simple max-absolute operator. The linear operator can be interpreted as an analysis operator which maps the aliased signals to the analysis space. The operator here is a Harmonic Tight Frame, while the generating parameters are coming from the selected channel delays. The delays in the proposed framework are selected to guarantee the robustness to the misdetection, using the parameters of a maximally incoherent harmonic frame. The existence of such frames is guaranteed for some MC sampling settings.

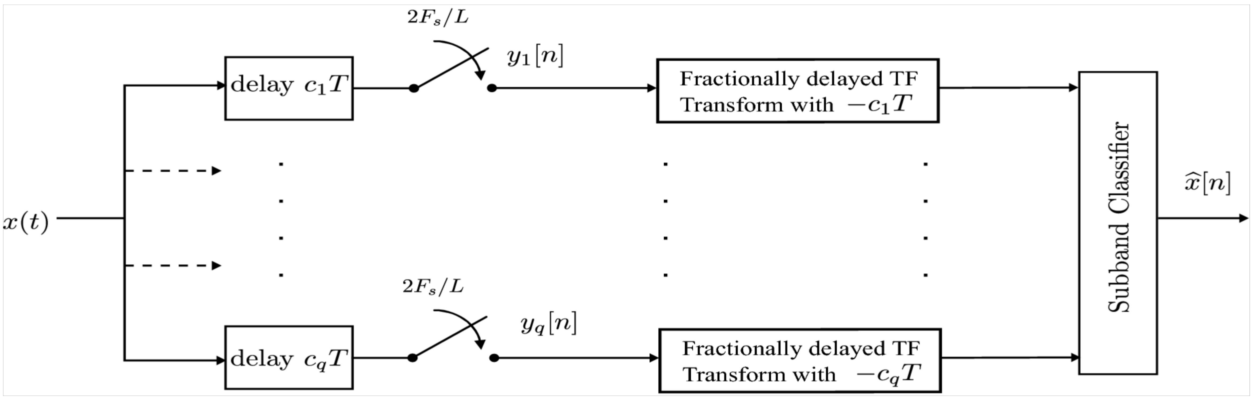

Figure 1: The proposed low-complexity sub-Nyquist sampling system.

3.0 SIMULATION RESULT

For the demonstration, we used 4 channels and a simulated ESM signal[1], which was undersampled with a factor of 13 in each channel. This setting is proved to have the most suitable harmonic tight frame. We thus use the delay parameters of one of such frames for our simulations, i.e. c = [6, 7, 10, 12]. In Figure 2, we have shown the original noisy signal in the top left panel, the noisy signal in the top-middle and one of the aliased channels in the top right panel. In the second row, we have shown the reconstructed signals using the proposed method in the left panel and the subspace method of [7], in the middle panels. We have also reconstructed the signal using a rapid frequency sweeping technique in the bottom right panel. The magnified versions of two TF areas in the reconstructed signals of Figure 3 are shown in Figure 4. In this figure, we have shown a stream of pulses and a single chirp in the top and bottom rows. In this simulation, we used two channels which samples at a rate of 6 times slower than Nyquist. We therefore have a similar overall rate of sampling, i.e. $13/4 \approx 6/2$. While the proposed method is computationally cheaper, it performs better than the canonical methods, in the SNR of sampled ESM signals. The denoising effect of using the proposed method is coming from the fact that we assume a type of structure for the input signal,

[1] The pulse information was kindly provided by Thales UK

called the Approximate Disjoint Aliased Support (ADAS). In this model we assume that the signal is not very crowded in the TF domain and the pulses do not overlap after sub-sampling. If a few pulses overlap after down-sampling, we can recover the dominant pulses, and possibly compensate the missing pulses using some post-processing step, which has been left for the future work.

We also observe that the channelised receiver loses some short duration pulses and the processing gains of the Chirped pulses are reduced. The continuously monitoring property of CS based sub-Nyquist techniques will be an important factor for many current and future wideband electronic surveillance systems, when the current monitoring band-width increases.

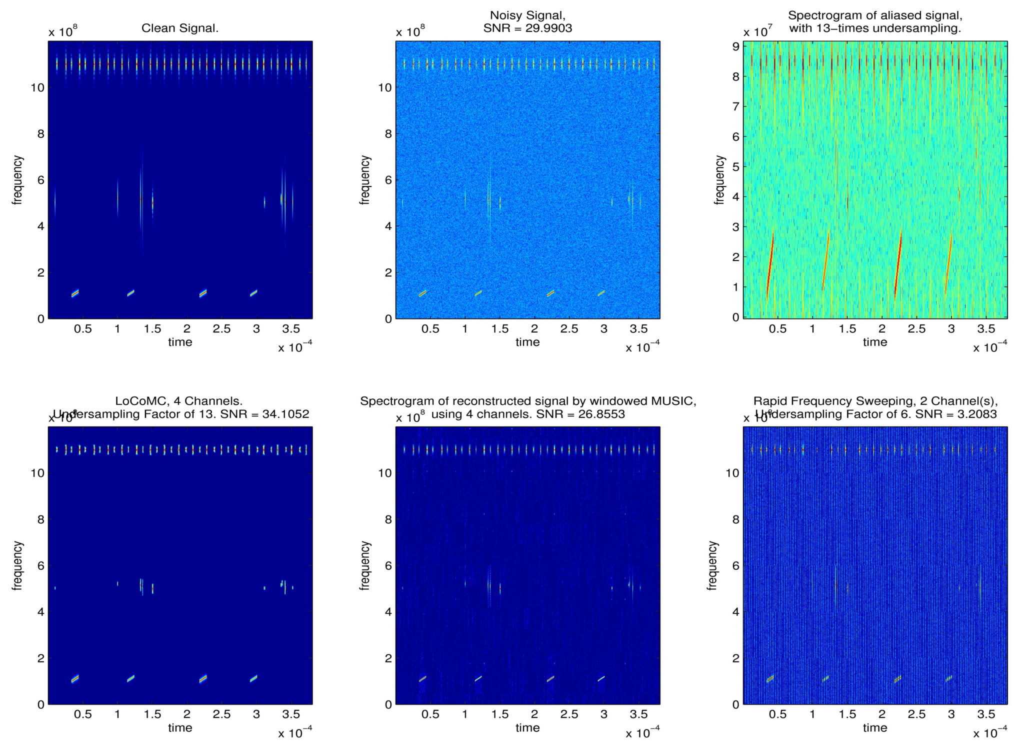

Figure 2: ESM signal reconstruction using proposed method (bottom left) a subspace method (bottom middle) and rapid frequency sweeping (bottom right). The original noisy signal, noisy and down-sampled signals are respectively shown in the top row from left to right.

4.0 CONCLUSION AND FUTURE WORK

We presented a low SWAP technique for wideband analog to digital conversion, which is inspired by the compressive sampling technique. The advantage of the proposed technique is that the non-linear reconstruction part of the framework can be implemented very efficiently, using some filter-banks. We also demonstrated using some simulated data, that the proposed framework can even outperform canonical sub-Nyquist sampling techniques, while it denoise the output signals.

We are currently investigating the possibilities of using overcomplete analysis operators, e.g. Chirplet, as they can better explore the ESM signal structures. While the goal of ESM systems are mainly detecting the threats, embedding such a post signal analysis is also left for future work.

5.0 ACKNOWLEDGEMENT

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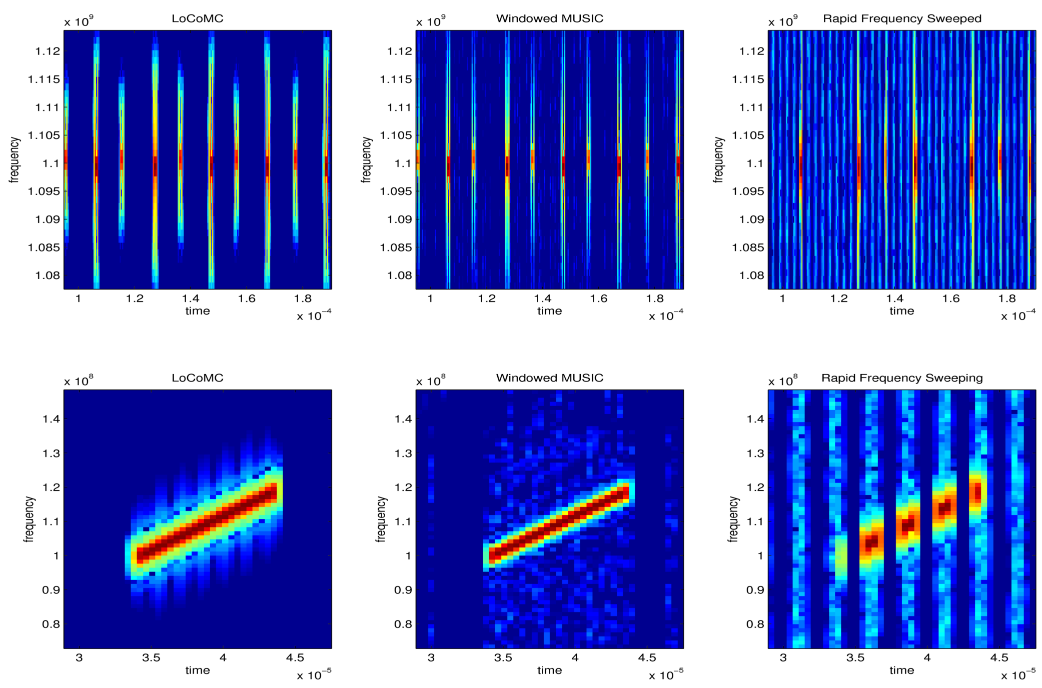

Figure 3: ESM signal reconstruction using proposed method (left) the subspace method (middle) and rapid frequency sweeping (right).

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