ROBUSTNESS IN THE RFI DETECTION FOR TIME-BLANKING

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ABSTRACT

The radio astronomical observation is more and more frequently polluted by digital telecommunication signals. One solution is to detect these signals and suspend the measures. Such signals have cyclostationarity properties that can be revealed by Hilbert filtering producing a periodic signal [2]. The idea is to detect the periodic signal when its period is unknown using Hinich's method. An experimental study of the Hinich's detector is carried out. Finally, the complete procedure is applied for detecting GLONASS type signals showing encouraging results.

BACKGROUND IN RFI DETECTION

Nowadays, a great part of the Radio Frequency Interferences (RFI) come from powerful telecommunication systems like GLONASS or GPS or mobile phone spread spectrum signals. These signals may dramatically disturb the radio astronomical observations by wrongly influencing the spectrum estimation as shown on figure 1. However, the induced pollution is often transient for the radio astronomy observation, which needs recording stopping for a correct estimation of the spectrum. This technique named as the "Time-Blanking" operation, remains efficient as long as RFI are "well" detected: the detector qualities are its performance, its velocity for a real-time processing and its robustness to miscellaneous interferences.

Most of the methods are specific to the interferences because rely on the comparison of the measured spectrum with a known standard spectrum family. These methods therefore suffer from their specificity and are restrictive since they have not the ability of detecting new kinds of interferences [1].

In practice, a great part of interfering signals are widespread spectrum digital signals presenting cyclostationary properties. Therefore, a mean to detect the interferences is to detect a cyclostationarity presence or not.

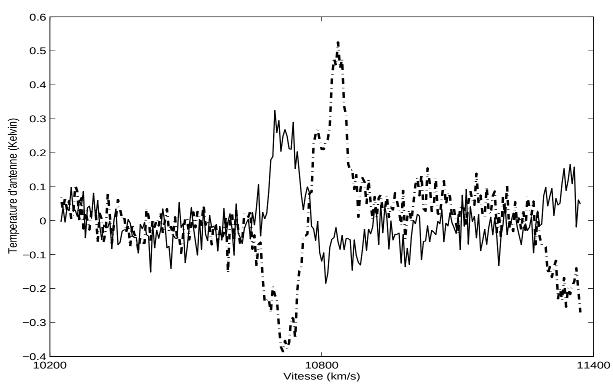

Figure 1 Spectra of the OH radical measured with the Nançay decimetric radio telescope and polluted by spread spectrum RFI (thick line for the expected profile and thin line for the contaminated one).

A signal is cyclostationary if its autocorrelation function $R(t,\tau)$ is periodic in *t* (time). Let us quote T this periodicity called hidden periodicity. For instance, in digital communication, the hidden periodicity can stand for the elementary duration of transmitted symbols.

Rodolphe Weber proposed in [2] a cyclostationary signal detector relying on simple real-time implemented operations like filtering and quadrature. More precisely, it realises in the temporal domain the equivalent of a cyclic spectrum projection on the cyclic frequency axis. By this manner, it converts a cyclostationary signal with a hidden periodicity T in a T-periodical signal. This last one can then easily be detected by a simple synchronous mean or a comb filter. This detector gathers the qualities of performance and velocity but assumes the hidden periodicity is exactly known: The detector fails in the case of other cyclostationary interference because of its insensitivity to any other hidden periodicity. The detector is not robust.

In this paper, an extension of this detector is proposed in the cases where cyclostationarity signals have an unknown hidden periodicity. The method is based on the *harmogram* estimation proposed by Hinich[3].

IMPLEMENTING THE LINE SPECTRUM DETECTOR: TIME AND FREQUENCY VERSIONS

We want to compare the detector in [2] (time version) vs. the proposed detector (frequency version) based on the *harmogram*.

The solution investigated in [2] consists in using a comb filter to detect the T-periodical component contained in $y(t)=|x_a(t)|^2$ where $x_a(t)$ is the analytic signal of the signal to analyse x(t). Let us call *Cyclodet* this temporal approach. Let Y(f)=TF{y(t)} the Fourier Transform of the N points signal y(t). P harmonics are significant. Let us estimate the weighted energy of the M first spectrum lines

$$H(f_j) = 2\sum_{m=1}^{P} \frac{\left|Y(mf_j)\right|^2}{\hat{S}_b(mf_j)} \qquad (1)$$

for a set of fundamentals f_j with $j = 1,\cdots,[N/2P]$. In this expression, $\hat{S}_b(mf_j)$ is a noise only power spectrum estimation. The procedure of detection is made by comparing a threshold with the maximum of the *harmogram* values $H(f_j)$. Let us call *Cycloharm* this frequency approach.

EXPERIMENTAL STUDY OF THE ROBUSTNESS

The interest of the Hinich algorithm is the robustness. In the following study, the signal to detect is modelised by a set of P weighted harmonics $y(n) = \sum_{p=1}^{P} \sin(2\pi p n f_0 + \phi_p)/\sqrt{p},\ 0 \le n \le N-1$ where f_0 is the fundamental and ϕ_p a [0-2π] uniform random phase. The signal is polluted with stationary white noise.

Let us study the influence the fundamental f_0 may have on the detection probability (Pd).

First of all, the fundamental varies on the frequency grid values. For the simulation, we consider signals with N=512 points sampled at f_s=512 Hz. The harmonic number P is set to 3. The fundamental is an integer frequency between 1 and 128 Hz. The signal to noise ratio (snr) is –12 dB and the false alarm probability (Pfa) equals 5%. The Pfa and snr values are maintained for all other simulations.

Figure 2 shows variations of Pd for both detectors *Cyclodet* and *Cycloharm*. The thick curve (*Cycloharm*) displays poor variations of Pd as a function of f_0. Of course, when f_0.P> f_e/2, the last harmonics are no more taken into account and Pd falls. The thin curve is obtained with *Cyclodet*. The comb filtering corresponds to the following z transfer function $(1-a)/(1-az^{-T})$ with a=0.995 and T=32 points. *Cyclodet* is then adjusted on the harmonics of f_s/T=16 Hz. Consequently, the only fundamentals which are multiple of 16 Hz lead to a correct detection.

Moreover, the numerical implementation of *Cyclodet* forces the fundamental values to be a multiple of the sample frequency f_s. In our example, when f_0 sweeps frequencies that are integer between 1 and 128 Hz, only the fundamentals f_0 such that f_0.f_s is integer can correctly be detected. Figure 3 displays this other advantage of *Cycloharm* on *Cyclodet*.

These first simulations are advantageous for the Hinich detector since the fundamental frequencies are exactly adjusted to the frequency sampling grid.

Finally, a frequency zoom is realised in the 48-64 Hz range with a fine frequency grid (cf. Figure 4). In the *Cycloharm* case, Pd regularly oscillates. The maxima are located around integer frequencies which is in relation with the preceding results. On the other hand, the performance is minimal around half-integer frequencies. Indeed, if the fundamental lies between k et k+1, the Mth harmonic is located in one of the Mk, Mk+1, …, Mk+M channels when only the Mk and Mk+M channels are taken into account in the summation (1). Therefore, the frequency sweeping of the fundamental is not sufficient. By comparison, *Cyclodet* does not give more reliable results.

To solve this drawback, two solutions have been investigated:

a) The first one consists of a finer frequency sweeping of the fundamental at a 1/Q step instead of a unitary step. In the *harmogram* computation, the number of visited fundamental frequencies is multiplied by Q. In order to compensate the fact that the harmonics may spread on a few samples on the frequency grid making the affected points not necessarily regularly spaced, the power of the harmonics will be estimated on pairs of adjacent channels $H(f_j) = \sum_{m=1}^{P} \left|X(mf_j)\right|^2 + \left|X(mf_j + 1)\right|^2$ with $f_j = j/QN,\ 0 < j < QN/2M$ and considering the entire part of mj/Q.

b) The second one simply consists of oversampling the spectrum by the well known zero-padding technique.

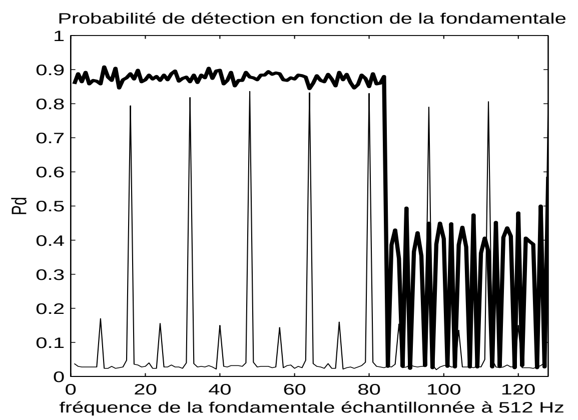

Figure 2 Detection performance as a function of the fundamental frequency from 1 to 128 Hz (unitary step). *Cycloharm* in thick lines and *Cyclodet* in thin lines.

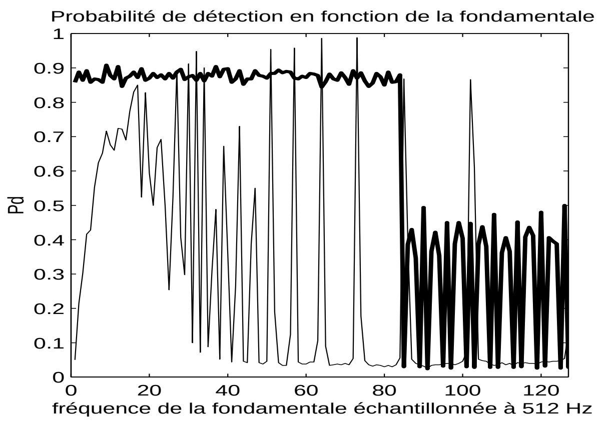

Figure 3 Pd as a function of f_0 compared with the temporal detector adapted to each frequency. *Cycloharm* in thick lines and *Cyclodet* in thin lines.

The panel (a) of the figure 5 simply shows that a finer sweeping of the harmonics prevents a too important fall of Pd. Notice that a step less than ½ does not really improve Pd further.

On the other hand, a high oversampling (cf. Figure 5.b) reduces the oscillations of Pd between integer harmonics and increases then mean rate of good detections. In return, the system necessitates to place the FFT results in memory on QN points.

ELABORATING THE DETECTOR

In the complete procedure of detection for cyclostationary signals, the analytic signal of the observed noise is first computed, and squared after taking its modulus.

In radio astronomy, the input noise is supposed to be gaussian $\mathcal{N}$ (0,1) and white on the frequency band $[-B, B]$.

Let us calculate the new spectral density shape $\hat{S}_b(f_j)$ which is used to normalise the Hinich detector (1). In the noise only case, the real and imaginary parts of the analytic signal $x_a(t)$ are decorrelated and therefore independent since gaussian. The signal $y(t) = |x_a(t)|^2 - 2$, centred, then follows a χ^2 distribution with two degrees of freedom.

Higher-order statistics properties for a gaussian lead to a triangular spectral density. In the digital version, B=1/2 and $S_b(f_k) = 8\ tri(2 f_k)$, $f_k = k/N$, $k = -N/2, \cdots, N/2$. In practice, the channels close to the Nyquist frequency are not normalised to prevent an explosion of the estimation variance of the periodogram.

SIMULATIONS AND RESULTS

Experimental Receiver Operating Characteristics (ROC) curves for an snr of 0 dB have been plotted for three interference examples based on GLONASS system signals. Hidden periodicities equal T=3.82/N seconds (case **a**), T=66/N seconds (case **b**) and T=8/N seconds (case **c**) where N is the number of measure samples, i.e. N=512.

The case **c** (period T pointed on both time and frequency grids) is in favour of the 2 methods contrarily to the case **a**. The case **b** is advantageous for *Cyclodet*. Case **a** does not give any problem to *Cycloharm*, even if the harmonics number is incorrect. Case **b** shows that the Hinich detector brings a little gain in good detections by oversampling.

By comparison, ROC curves have been drawn for a detector taking the maximum value in a collection of *Cyclodet* receivers, each one adapted to periods between 4 and N/4 (case *Cyclodet //*). Case **c** shows that the performance when the hidden periodicity is unknown (*Cycloharm*) is close the detector built when the hidden periodicity is perfectly known (*Cyclodet*). The quality of detection is increased if the number of spectral lines is correct.

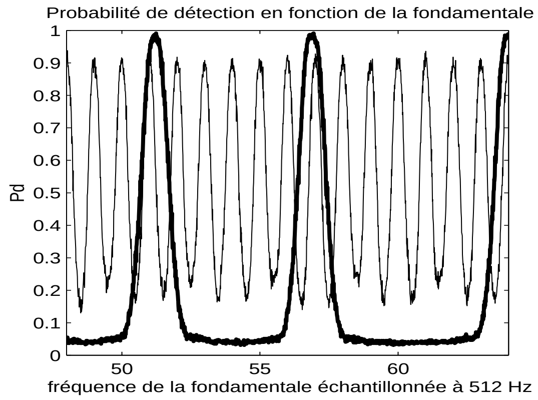

Figure 4 Performance of detection as a function of f_0 between 48 Hz and 64 Hz (0.01 Hz frequency step). *Cycloharm* in thin lines and *Cyclodet* in thick lines.

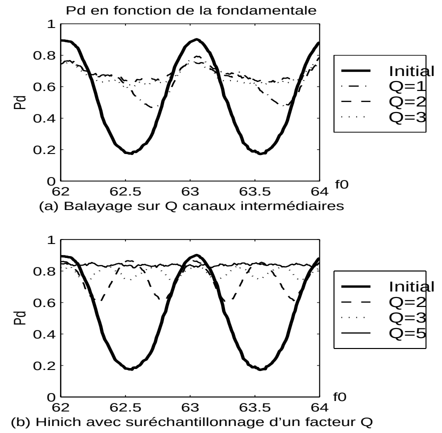

Figure 5 Improvement of the performance for *Cycloharm* by finer frequency sweeping (a) or oversampling (b) (zoom between 62Hz and 64 Hz)

Let us note several practical points:

- It is disadvantageous to take into account all the possible harmonics in the spectrum. Harmonics are often not present in the whole band with a high intensity, a limitation to the first ones is correct.
- Experimentally, an oversampling is more efficient than a finer frequency sweeping.

The stationary noise is supposed to be known. In practice, it is possible to estimate the noise power in the noise only case [5], otherwise on the complementary part of the harmonics, for each harmonic [4].

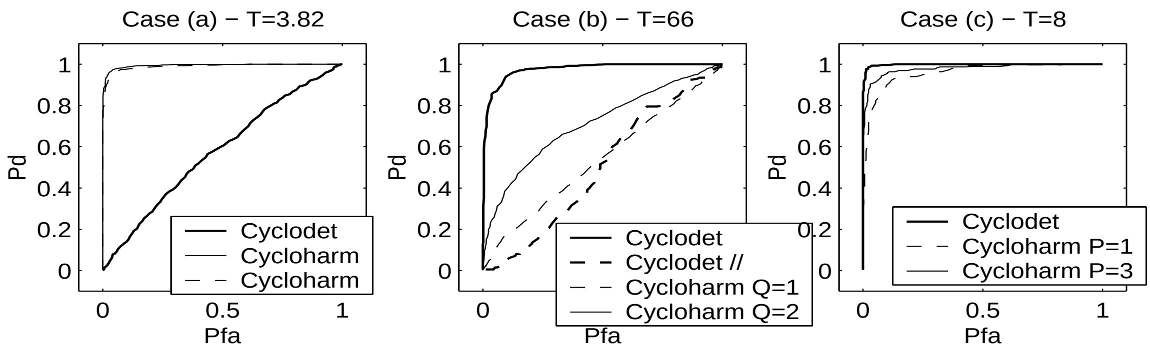

Figure 6 Performance of detection for 3 disturbances with different hidden periodicities.

A robust cyclostationarity detector has been proposed, when the hidden periodicity is unknown. The detector is based on the robust detection of harmonic lines. A detector adapted to the true period gives better results, for a certain number of singular points but remains mostly below the performance of the proposed detector.

The Hinich detector assumes that the number of harmonics is known. A good estimation of the spectral lines number will guarantee robustness with a correct performance. This correct estimation remains the main difficulty of the proposed algorithm.

Globally, the obtained results are sufficiently robust to cope with the detection of scramblers in radio astronomy.

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