PIRANHA FILTER FOR COMMUNICATION SYSTEM ROBUSTNESS

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ABSTRACT

The designed rejection filter is of recursive prediction error (RPE) form and uses a special constrained model of infinite impulse response (IIR) with a minimal number of parameters. The so-called PIRANHA Filter is made up independent cascaded adaptive cells realising high rejection at certain frequencies. The convergent filter is characterised by highly narrow-bandwidth and uniform notches of desired shape. Results from simulations illustrate the performance of the algorithm used in the PIRANHA Filter under a wide range of conditions and situations. This paper intends to give a description of the PIRANHA Structure, the mechanism of its interference detection monitoring and the filter stability control. The PIRANHA Filter has shown to be an efficient solution for detection, tracking and elimination of multiple high power CWIs and Narrow Band Jammers.

Keywords: DSP for Communications, Anti-Jamming, Adaptive Filters.

1. INTRODUCTION

In many applications using Digital Signal Processing, it is desired to estimate the unknown frequencies of a set of sinewaves (or narrow-band signal) from noisy data to reject them. Examples of applications are in the areas of sonar, radar, communications, control, biomedical engineering and others. A practical situation is the case where a narrow band signal from an external RF source of emission get the antenna of a GPS spread spectrum receiver. In fact, it is well known that RF Interference can result in degraded navigation accuracy or complete loss of the receiver tracking mode. In this work, the PIRANHA Filter is used to analyse and study the tracking behaviour of the Interference Doppler. The paper will focus on the description of the PIRANHA cell structure and the algorithm principle to explain the signal processing. Some simulation studies are also carried out and results are presented to show the nature of the parameter misadjustment on interference acquisition, tracking and rejection.

2. DESCRIPTION OF THE PIRANHA FILTER STRUCTURE

The principle of the PIRANHA Filter is based upon the independence of the cascaded form of Notch Filter. The block diagram of the corresponding adaptive filter is given Figure 2-1.

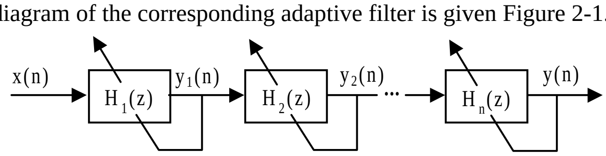

Figure 2-1: Cascaded Form of the Adaptive Notch Filter.

To exploit the decoupling effect analysed in [9], the filter coefficients for each cell are updated using the output of that same cell. The LMS algorithm has been commonly used in adaptive transversal filtering [3]. In our adaptive algorithm, the estimated signal for each data interval is computed and subtracted from the desired signal to minimise the output power.

It is shown [10] that an adaptive notch filter based on least mean squares (LMS) algorithm can be implemented in a cascaded form to efficiently identify a set of sinusoids over all the spectrum.

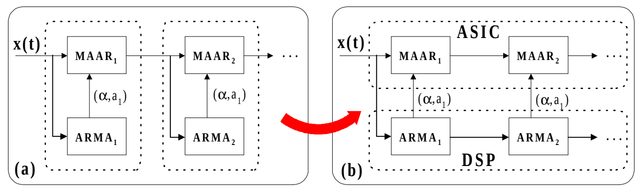

Figure 2-2: From Conventional to PIRANHA Structure.

Our filter uses a cascaded MAAR (Moving Average Auto Regressive) structure for the elimination block and ARMA adaptive NLMS algorithm for the interference detection and tracking. One particularity of our structure (Figure 2-2) is that the input of each ARMA cell been the output of the previous one.

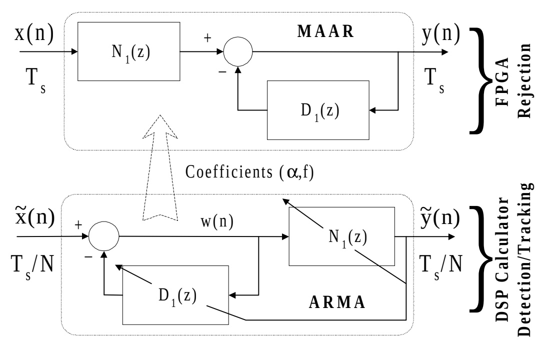

Figure 2-3: Main Structure of the PIRANHA Cell $H_1(z)$.

Or course, this is possible because of the filter function separation. Consequently, the cascaded MAAR notch cells can be easily implemented in one ASIC and the software ARMA Cells in a common DSP. The transfer function of the filter with M sections in cascade has been considered in many papers [2][3][4]:

$$H(z) = \prod_{k=1}^{M} \frac{1 - 2\cos\omega_k z^{-1} + z^{-2}}{1 - 2\alpha_k \cos\omega_k z^{-1} + \alpha_k^2 z^{-2}} = \prod_{k=1}^{M} H_k^{N/D}(z) \qquad \textbf{(2-1)}$$

where:

ω_k represents the polar normalised notch frequencies,

α_k the corresponding pole contraction factor ($0<1-\alpha<<1$).

The poles of the filter in (2-1) are slightly displaced towards the origin by the contraction factors α_k which are close to but smaller than unity. The α_k determine the bandwidths of the notches which are proportional to $1-\alpha_k$.

One other advantage is that the PIRANHA filter don't need the a priori information of the interference spectral shape except its central frequency. In fact, only the centre-frequency dependant coefficients of this filter are adapted to tune the notch and they are transferred to the elimination block for interference rejection.

3. INTERNAL MECHANISM OF THE PIRANHA FILTER

3.1 The DSP Doing Recursive NLMS Algorithm

In our application, the NLMS algorithm scheme imposes a critical limit on its implementation. For example, in high sampling rate applications of adaptive transversal filtering algorithm, a certain delay in the new coefficient updating the active notch filter is something required. The behaviour of the Delayed LMS (DLMS) algorithm is studied in [6].

Each Software PIRANHA Cell of the DSP (detection and tracking algorithm) apply NLMS of the following form:

$$\begin{cases} w_n = x_n - \alpha \cdot a_1 \cdot w_{n-1} - \alpha^2 \cdot w_{n-2} \\ y_n = w_n + a_1 \cdot w_{n-1} + w_{n-2} \end{cases} \quad \textbf{(3-1)}$$

with $a_1^{n+1} = a_1^n - \dfrac{2 \cdot \mu \cdot (y_n \cdot w_{n-1})}{|w_n|^2 + |w_{n-1}|^2 + |w_{n-2}|^2 + \varepsilon}$

and μ the step-size adaptive parameter ($0<\mu<1$).

For our fast sampling rate system, the DSP will not be able to converge for all cells. One studied solution consists to process the input samples by block or using under sampling method. Both of them were found to be precise and fast enough to reduce the calculation by a factor of 100.

3.2 The Stability Control and Parameters Adjustment

Precision of the DSP detection & tracking algorithm depends, among other things, on the adaptive factor μ and on the pole contraction factor α. A common choice of μ in the convergence phase is a constant somewhat smaller than unity but an adaptive scaling factor μ approximately 10 times greater than in the tracking scenario where the precision is needed. Also concerning the value of α which has to be small enough to give a sufficiently large notch bandwidth to obtain a large interference attenuation. On the other hand, it is desirable to have α as close to one as possible for the best central frequency estimation accuracy to allow good tracking performance of the input sinewaves.

The convergence time constant of the NLMS algorithm is fonction of μ:

$$\tau_{NLMS} \approx \frac{M}{\mu} \quad \textbf{(3-2)}$$

In fact, the larger μ is chosen, the faster the algorithm will detect the interference (Figure 3-1). But both μ and α have to be chosen as a compromise between fast acquisition, tracking sensibility and accuracy. Also concerning the filter attack time, when applying a sinusoid at the entrance of the notch filter, its rejection will occur depending of the filter time constant:

$$\tau_{filtre} = -\frac{1}{\ln\alpha} \quad \textbf{(3-3)}$$

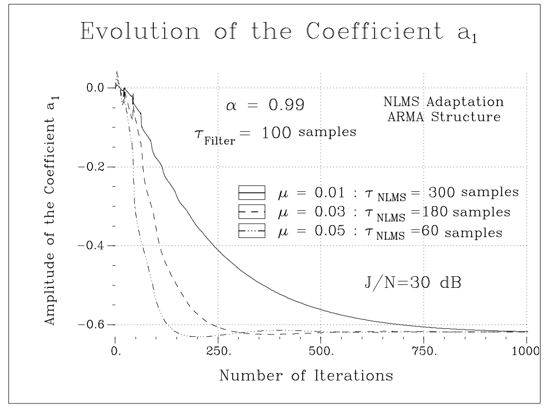

Figure 3-1 Convergence of NLMS Adaptation.

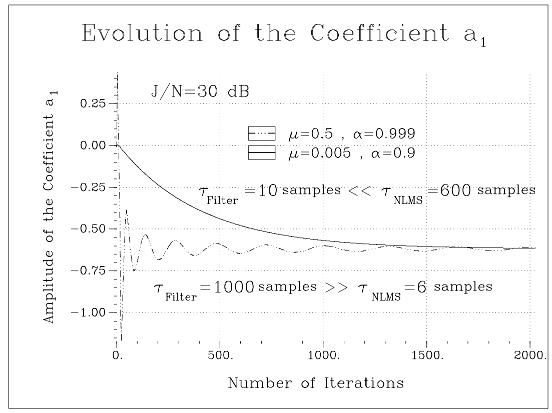

Figure 3-2 Transition Mode of the Adaptation.

The prevision of the time convergence and filter attack time can be evaluated and optimised by the equality of these 2 times constants (Figure 3-2).

3.3 The Detection Monitoring & Cell Activations

Our PIRANHA filter incorporates a robust detection monitoring to allow rejection filter activation at proper time and situation. The pole at the entrance of the ARMA cell will amplify the noise according to (3-4) and the gain on the sinusoid is given by (3-5).

$$|H_{1/D}|^2 = \frac{1+\alpha^2}{1-\alpha^2} \frac{1}{1+\alpha^4 - 2\alpha^2 \cos(2\omega_o)} \quad \textbf{(3-4)}$$

$$|H_{1/D}|^2 = \left| \frac{1}{(1-\alpha^2)} \frac{1}{\sin(\omega_0)} \right|^2 \quad \textbf{(3-5)}$$

At the moment of the detection, the Interference to Noise ratio (J/N) augmentation is constant over all the spectrum and they are reported to Table 3-1 for some values of the parameter α. To decide of the interference detection or not, one defines a detection threshold obtained from the variance measurement of signal w(n) (Figure 2-3).

α	**0.9**	**0.95**	**0.99**	**0.995**
Gain on J/N	10dB	13dB	20dB	23dB
Detection Threshold	8dB	11dB	18dB	21dB

Table 3-1: Gain on J/N Ratio & Detection Threshold.

4. PERFORMANCES OF THE PIRANHA FILTER

4.1 Rejected Bandwidth and Attenuation per Cell

As desired, the magnitude of the transfer function of each PIRANHA Cell is approximately one everywhere, except at the true sinewave frequencies where it is zero. The pole at the frequency of each cell will adjust the width of the rejected band.

The Table 4-1 reports the rejected bandwidth of notches at several attenuation (sampling rate of 20Msamples/sec).

	NOTCH BANDWIDTH (KHz) at 20Msamples/sec			
α	-3dB	-20dB	-30dB	-40dB
0.95	297.0	31.2	9.8	3.1
0.96	240.9	25.1	7.9	2.5
0.97	183.2	18.9	6.0	1.9
0.98	123.9	12.7	4.0	1.3
0.99	62.9	6.4	2.1	0.62
0.995	31.7	3.2	1.2	0.30

Table 4-1: Rejected Notch Bandwidth at -3, -20, -30 & -40dB.

Figure 4-3 shows the measured attenuation which can be obtained over all frequency of the spectrum. Of course the real attenuation will mostly depends on the signal quantification (ADC) and the PIRANHA cells implementation on the ASIC.

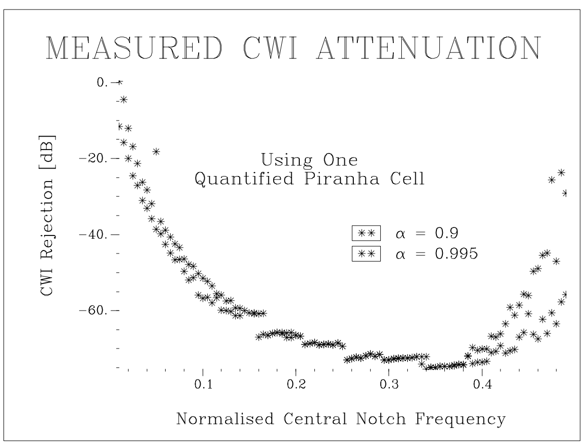

Figure 4-3: Measured CW Interference Attenuation (dB).

4.2 Complete Scenario of Rejections

The PIRANHA filter is fully programmable and the parameters represented in Table 4-2 are those which have been used for the simulations.

DETECTION		TRACKING		ELIMINATION
α	μ	α	μ	α
0.95	0.10	0.995	0.01	0.99

Table 4-2: PIRANHA Operation Parameters.

First, Figure 4-4 shows the spectrum at the entrance of the PIRANHA Filter. Its consists of a gaussian noise mixed with 4 fixed CWI (J/N=20dB). The second curve shows the residual spectrum of these interference after the filter convergence.

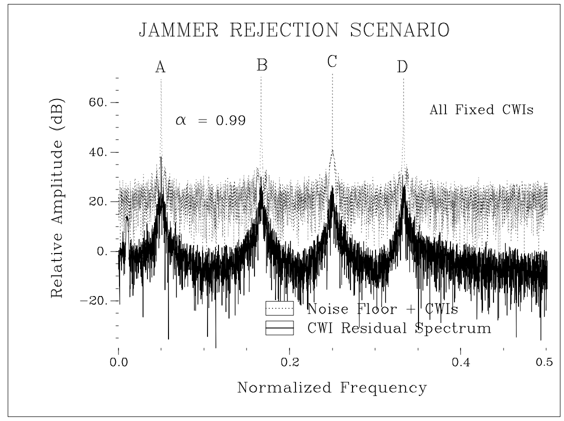

Figure 4-4: Vue of the Input and Residual Signal Spectrum.

Figure 4-5 represents the real time coefficients of the first 6 PIRANHA Software Cells. The steady state is reached after 2000 samples (1msec). The fifth and sixth cells follow their detection procedure looking for interference over all the spectrum.

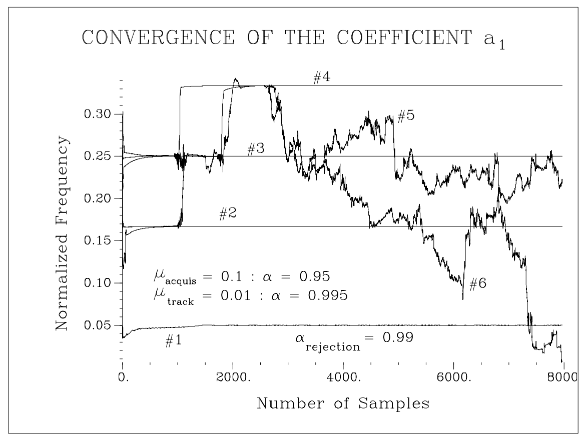

Figure 4-5: Coefficients of the PIRANHA Filter.

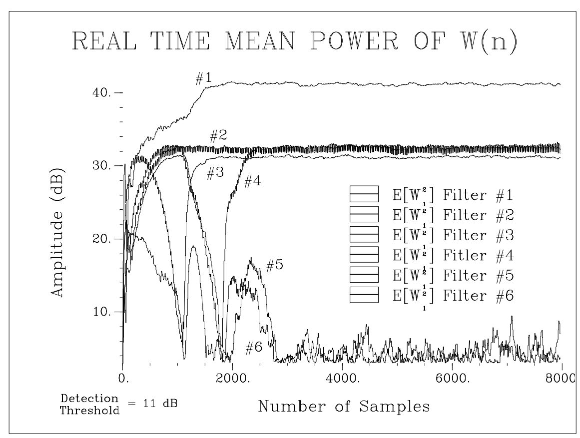

Figure 4-6: Signal w(n) for Cells Activation/Desactivation.

Finally, the decision of the cell activation is based upon the results from Figure 4-6. Each ARMA cell measures an estimation of the w(n) signal variance. After the detection threshold been reached, the DSP transfers the coefficient to the Hardware filter.

5. General Conclusion

The developed filter has shown to possess several advantages compared to the fully cutband adaptive filters. The advantages include high computational efficiency, high stability, simple stability monitoring and low parameter noise. Furthermore, the PIRANHA filter do not require any reference for enhancement of useful signal, even in the presence of interference.

In fact, this paper leads to several advantages of the proposed algorithm in comparison to previous treatment, part of which were mentioned in the introduction. They can be summarised as follows.

① **Accurancy:** For sufficiently large data lengths, the accuracy of the interference central frequency will be control by the filter's parameters α and μ.

② **Numerical Robustness:** In our application, each coefficient on H(z) are user-controlled to prevent overflow in the MAAR structure and numerical problems due to near pole-zero cancellations on the unit circle (structure constraint $D(z)=N(\alpha z)$).

③ **Stability:** The Normalised Constrained LMS Algorithm exhibits high stability and saves computations needed to monitor the stability and convergence. The constrained algorithm allows the use of poles highly close to the unit circle, which result in significantly sharper notches than normal mode of calculation (stability constraint $\alpha<1$).

④ **Fast Convergence:** Using differents α and μ during the interference detection give a relatively fast convergence performance. When signal acquisition is obtained, α and μ are switched on tracking value for precision in the calculation of the central notch frequency.

⑤ **Notch Filter Performance:** The high accuracy of the sinewave frequency estimates is important to guarantee that the narrow notches will cancel the input sinewaves. The -3dB bandwidth of the notches created by each pole-zero pair of H(z) is given by $B_{3dB}=(1-\alpha)/\pi$. For any desirable value of α, we can therefore get any arbitrary notch bandwidth (Table 4-1).

⑥ **Computational Efficiency:** Normalised LMS algorithm needs the minimum number of addition/multiplications which is proportional to the order of H(z). Thus, we need about 4 instructions per notch for the calculations. Moreover, using block processing or under sampling principle, the calculation is reduced in the order of 100.

⑦ **Linear Phase:** By the symmetry of the numerator N(z) in (2-1) and the symmetry of the denominator D(z), the out of band notch filter can be characterised as being close to linear phase.

In the tracking scenario, the Notch Bandwidth of the filter must be sufficiently large in order to enable good tracking. The notch bandwidth is entirely determined by the user-chosen pole contraction factor α du to the special model structure used.

In addition, the PIRANHA Filter may be designed to be easily inserted into a variety of existing GPS or any spread sprectrum receivers.

Against non-intentional interference as well as intentional jammers, the PIRANHA Filter will play the role of a monitoring equipment which will indicate the presence of interference. Two solutions are then possible: First, one or many PIRANHA Cells can be activated to reject the interference and clean the spectrum. The other possibility is to indicate to the Numerical Receiver that an interference is actually present in the incoming signal. This can be interpreted as a new RAIM function.

In the future, Spread Spectrum System will be more and more used in many applications. We will have to pay the price to detect unwanted high power signals in the weak useful signal and we think that the PIRANHA Filter may certainly play a strategically role in monitoring & mitigate the full frequency spectrum.

6. References

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