ON THE USE OF ASYMMETRIC WINDOWS FOR REDUCING THE TIME DELAY IN REAL-TIME SPECTRAL ANALYSIS

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ABSTRACT

The idea of asymmetric windowing as a way of reducing time delay in spectral analysis is explored. Traditional windows are analyzed in relation to time delay. Then, some asymmetric windows are introduced and a comparative analysis with traditional windows is made. It is shown that it is possible to reduce the time delay up to about 25% of the analysis window size. Application on LP speech coding is analyzed, and the experimental results of using an asymmetric window on a Standard LPC vocoder are presented.

1. INTRODUCTION

The use of windows in spectral analysis has long been studied, the work of Harris [1] being a comprehensive reference. Although the use of windows has always the objective of reducing the effects of the spectral leakage, specific interests (e.g. resolvability, detectability, accuracy, etc) determine the selection of a window. In view of this, many windows have been recently proposed [2]-[3] that optimize specific parameters, but no window is the best in all aspects. All of these windows have been constructed or derived with the common restriction of being real, even, and non-negative (when refering to the window in time domain).

Nevertheless, recent DSP hardware progress, broadening the application of DSP in real-time systems, has brought importance to an almost neglected parameter: the time delay implicit in the windowing of a non-stationary signal. So, with the attention focused on time delay, we decided to relax the requirement of eveness, in such a way that we could obtain a window that uses recent samples of the signal with greater weight, using as many as necessary past samples, with low weights, to improve its spectral characteristics.

Windows can be viewed as a compromise between spectral leakage and time leakage. The idea of asymmetric windowing, introduced in this paper, is to concentrate this time leakage in the past history of the signal, instead of having it equally distributed between its past and future history, as it is done with traditional (symmetric) windowing.

In this paper we analyze windows with relation to time delay. After selecting an appropriate criterium for implicit delay, we comment on the delay implicit in some traditional windows. Then, we introduce some asymmetric windows and a comparative analysis is made. The final part of the paper deals with the application of asymmetric windowing to speech coding.

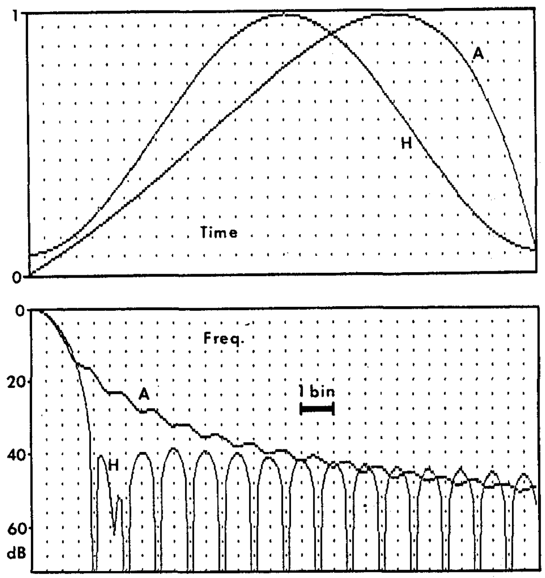

Fig. 1 - Time and Frequency domain plots of an Asymmetric Window (A) and a Hamming window (H)

2. DEFINING IMPLICIT DELAY

In order to allow for a comparison, we need to define a concept for implicit delay. This definition should be such that take into consideration the different overlapping necessities of each window. We have found that an appropriate criterium for comparing time delay among windows is a time delay index (TDI), based on an average time delay with size normalization. That is, we compute an average time delay and then adjust it with relation to the 95% power interval, i.e.:

$$TDI = -I^{-1} \int_{-\infty}^{0} t.w^2(t)dt$$

where I is the smaller time interval that concentrates 95% of the window power, i.e.:

$$I = \min [b-a], \quad \text{such that:}$$

$$\int_a^b w^2(t)dt=0.95 \int_{-\infty}^{0} w^2(t)dt$$

Table 1 contains the average time delay (in relation to the window length) and corresponding TDI for several windows.

3. COMPARING SPECTRAL CHARACTERISTICS

Spectral characteristics of windows are usually analyzed through comparing spectra of windows with the same length. This is not appropriate for evaluating the trade-off between spectral leakage and time leakage, because different windows, with the same length, have different time leakage characteristics. This way, we have used an alternative criterium for comparing spectral characteristics: multilevel "bandwidths index" (BWI). BWI is the bandwidth adjusted with relation to the 95% power interval, i.e., the product between the bandwidth and the 95% power interval. This is done to account for the fact that if the window has a small power interval we could use a window with a greater length, and each bin would represent a smaller frequency interval.

This BWI criterium has brought to attention some interesting data. We have found, for example, that the rectagular window, normally considered as the narrower 3 dB bandwidth, does not have this characteristic with relation to 3 dB BWI. The comparison between the Hamming and Hann windows is also interesting. When BWIs are analyzed, the Hamming window is superior just in a small interval around 40 dB. Although a more detailed analysis would have to be done, it looks like in many applications the Hamming window may not be a better choice than the Hann window.

A specific comment on the use of BWI is of concern. When using this concept, we are in fact comparing windows of different lengths, what may imply in different computing loads. This has not been taken in account in the present work.

It is important to note that the non-linear-phase characteristic of the asymmetric windows, a direct consequence of their asymmetry, is not a relevant factor in power spectrum analysis.

Table 1 shows the bandwidth and the BWI (95% power interval) for several attenuation levels. The BWIs may be easily computed for other power intervals, in order to adapt the data to specific application analysis.

4. SOME ASYMMETRIC WINDOWS

Traditionally, finite length windows are symmetric. When asymmetric windows are used, they are usually infinite windows, as is the case in the recursive windowing [4] and in some algorithms where an exponential window is implicit, and they are not viewed as windows, but as filters. Although infinite windows may yield good delay characteristics, they are not appropriate for several applications, e.g. when a FFT has to be computed. In order to better evaluate the potencial of finite asymmetric windowing, we have constructed and evaluated some asymmetric windows. We will now look into some of them.

4.1 COMPOSED HANN

The idea is to use a composed function, of the kind w(p(t)), where w(t) is a Hann window, and p(t) is a polinomial. Table 1 shows this window for the case where $p(t) = (1-a).t + a.t^4$, for a = 0.10; 0.25; 0.50 and 0.75 (letters D-G in table 1).

4.2 TRUNCATED SWEEP-EXPONENTIAL

The recursive window [4] has a good balance between time delay and spectral behavior. To obtain a finite window with similar characteristics, we have truncated a sweep-exponéntial, i.e.:

$$w(t) = t.\exp(-a.t).G_1(t),$$

$$\text{where } G_1(t) = \begin{cases} 1 & \text{for } 0<t<1, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

Letters H to J in Table 1 present the parameters for these windows.

4.3 PARABOLIC EXPONENTIAL

In order to eliminate the discontinuity in the final border in the previous window we introduced an additional term, obtainning a parabolic-exponential window, i.e.:

$$w(t) = t.(1-t).\exp(-a.t).G_1(t),$$

where $G_1(t)$ is defined in 4.2. Letters K to N in Table 1 represent the parameters for these windows.

4.4 CONVOLUTIONAL WINDOWS

A way of obtainning new windows is through convolution. As the spectrum of the new window will be the product of the spectra of the two convolved windows, it can be easily predicted. Convolving an asymmetric window, e.g. the parabolic exponential, with any window with good spectral behavior will produce an asymmetric window with reasonable TDI and spectral behavior. As an example, we have computed the parameters of the convolution between the Hann window and a truncated exponential for several proportions between their lengths. Letter O and P in table 1 represent the data of the convolution of them with relation 1:1 and 5:3 in length.

ref. code	WINDOW	Bandwidths (bins) and bandwidth indexes (%) 3 dB	6 dB	10 dB	20 dB	30 dB	40 dB	50 dB	60 dB	delay and tdi	power intervals 90%	95%	99%
TRADITIONAL (SYMMETRIC) WINDOWS													
1	HANN	1.4 .77	2.0 1.10	2.5 1.38	3.3 1.82	3.7 2.04	5.6 3.1	9.1 5.0	13.3 7.3	.5 91	.48	.55	.69
2	HAMMING	1.3 .78	1.8 1.08	2.3 1.38	3.1 1.86	3.5 2.10	3.8 2.3	29.1 17.5		.5 83	.52	.60	.77
3	TRIANGULAR	1.3 .83	1.8 1.15	2.2 1.41	2.9 1.86	6.5 4.16	10.6 6.8	22.1 14.1	38.3 24.5	.5 78	.55	.64	.80
4	BLACKMAN-HARRIS 3 sample - minimum	1.7 .82	1.8 .86	2.9 1.39	3.9 1.87	4.6 2.21	5.2 2.5	5.5 2.6	5.8 2.8	.5 104	.41	.48	.61
5	RETANGULAR	.9 .86	1.2 1.14	1.5 1.43	5.4 5.13	19.1 18.15				.5 53	.90	.95	.99
INFINITE (ASYMMETRIC) WINDOWS													
A	EXPONENTIAL	- .47	- .86	- 1.48	- 4.9	- 17				- 33	- .76X	- X	- 1.46X
B	RECURSIVE	- .65	- 1.02	- 1.45	- 3.1	- 5.8				- 44	- .83X	- X	- 1.33X
FINITE ASYMMETRIC WINDOWS - see text													
D	ASYMMETRIC HANN a = .10	1.4 .78	2.0 1.12	2.5 1.40	3.3 1.85	4.9 2.74	6.9 3.9	9.4 5.3	13.4 7.5	.5 84	.49	.56	.70
E	ASYMMETRIC HANN a = .25	1.4 .78	2.0 1.12	2.5 1.40	3.4 1.90	5.2 2.91	7.5 4.2	11.3 6.3	15.5 8.7	.4 75	.48	.56	.70
F	ASYMMETRIC HANN a = .50	1.5 .78	2.1 1.09	2.7 1.40	4.8 2.50	7.0 3.64	10.0 5.2	14.6 7.6	21.1 11.0	.33 63	.44	.52	.66
G	ASYMMETRIC HANN a = .75	1.6 .64	2.5 1.00	3.6 1.44	6.2 2.48	9.2 3.68	13.2 5.3	19.0 7.6	27.3 10.9	.25 63	.34	.40	.53
H	TRUNC. SWEEP EXP. a = 2.5	1.1 .94	1.4 1.19	1.7 1.45	3.8 3.23	9.6 8.16	25.6 21.8			.50 59	.77	.85	.95
I	TRUNC. SWEEP EXP. a = 5.0	1.2 .74	1.7 1.05	2.3 1.43	5.2 3.22	9.7 6.01	19.6 12.2	43.4 26.9		.29 47	.52	.62	.81
J	TRUNC. SWEEP EXP. a = 7.5	1.5 .63	2.4 1.01	3.5 1.47	7.3 3.07	13.7 5.75	25.7 10.8	57.3 24.1		.20 48	.34	.42	.56
K	PARABOLIC EXP. a = 2.5	1.2 .74	1.7 1.05	2.2 1.36	4.2 2.60	7.8 4.84	14.0 8.7	26.2 16.2	56.0 34.7	.33 53	.54	.62	.77
L	PARABOLIC EXP. a = 5.0	1.4 .64	2.2 1.01	3.0 1.38	6.2 2.85	11.4 5.24	21.4 9.8	43.3 19.9		.23 50	.39	.46	.61
M	PARABOLIC EXP. a = 7.5	1.9 .67	2.8 .98	4.2 1.47	8.4 2.94	15.9 5.57	30.5 10.7			.17 49	.29	.35	.47
N	PARABOLIC EXP. a = 10.0	2.3 .64	3.5 .98	5.3 1.48	10.8 3.02	20.7 5.80	41.7 11.7			.13 46	.23	.28	.38
O	CONVOLUTIONAL 1 see text	1.7 .66	2.5 .98	3.9 1.52	5.5 2.15	6.5 2.54	9.2 3.6	10.5 4.1	14.4 5.6	.34 87	.32	.39	.62
P	CONVOLUTIONAL 2 see text	1.7 .75	2.3 1.01	3.2 1.41	4.8 2.11	5.7 2.51	7.9 3.48	11.2 4.93	12.2 5.37	.40 91	.37	.44	.62

Table 1 - Delay and spectral characteristics of some windows.

5. USE ON SPEECH CODING

As an immediate application, we have simulated the effects of using an asymmetric window on a standard LPC vocoder. Informal listening tests have shown the overall speech quality to be equivalent to that obtained using a Hann window, with a slight improvement in the reproduction of plosive phonemes sometimes observed. In this simulation we have used a 32 ms Hann window and a 32 ms parabolic exponential window (a = 3.5), on a 16 ms frame basis. Although the delay in the vocoder using the asymmetric window was clearly smaller, it varied very much according to the transition localization. In order to better evaluate the time delay reduction, we have simulated the same vocoder with a 2 ms frame size. In this case the time delay reduction was reasonably constant , and we estimated that it was about 5 ms, which is very close to the theoretical value (5.5 ms). Figure 2 shows the reproduction of a plosive phoneme with these 2 ms frame size vocoders. It should be noted that similar results would have been observed in the work of Harris on recursive windowing [4], if time delay had been analyzed in that work.

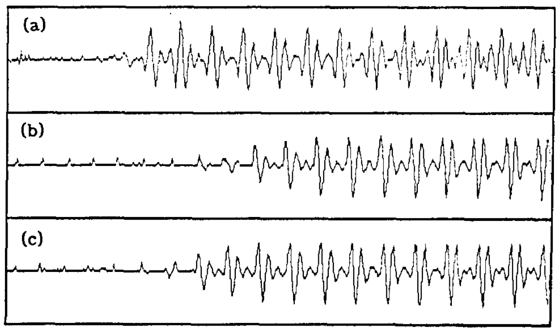

Fig. 2 - Use on a LPC vocoder. (a) original speech. (b) synthetic speech using Hann window in the analysis. (c) idem using an asymmetric window. Note the smaller delay in (c).

Asymmetric windowing can also be of large use is the vocoders, like CELP. In this case, the use of an asymmetric window will permit to use a spectral estimate based on more recent samples. This is specially important when backward adaption is used, as is the case with the AT&T LD-CELP [5]. In this algorithm, the recursive windowing, recently introduced for substituting the Hamming window, has an equivalent effect, but we believe that using an specifically designed finite asymmetric window could yield even better results.

6. CONCLUSION

We have presented the idea of asymmetric windowing as a way of reducing the time delay in real-time spectral analysis. Some asymmetric windows have been introduced and analyzed. We have shown that, with appropriate selection of the window, significant reduction in the time delay may be obtained. As an immediate application, we have commented on the use of these windows in speech coding. A reduction in time delay of about 5 ms has been found when compared to a 32 ms symmetric windowed LPC vocoder. We are presently working on some optimization problems in order to obtain new window families, with better spectral characteristics, as well as trying to get more information on other effects of these windows on LP speech coding, specially on CELP and LD-CELP vocoders.

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