ACTIVE NOISE CONTROL FOR SMALL-DIAMETER EXHAUSTION SYSTEM

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Abstract. *The active noise control system based on adaptive filter theory was developed in the 1980s. However, only with the recent introduction of powerful but inexpensive digital signal processor hardware has the technology become pratical. This work considers broadband feedforward ANC systems that have a reference sensor, single secondary source, and single error sensor. The main reason is related to the adaptation algorithms to the active noise control for small-diameter exhaust system. A modification of the well-known LMS algorithm, the filtered-X LMS algorithm, will be presented. Contrasts between passive and active noise control are decribed.*

Keywords: *Active Noise Control, Feedforward Control*

1. INTRODUCTION

For low-frequency noise problems applied to exhaustion system, traditional passive noise control techniques often require size, mass and money. Also, these passive devices cause an energy loss in the exhaustion system. Although active noise control appear to be a promising alternative in the treatment of low frequency tonal noise propagating in exhaust duct. Recent works are discussing about its successful application in many noise control problems, according "Li *et al. (2006)"*, "Jones *et al (2006)*", "Yuan, *(2004)*", "Donadon *et al.* (2003)", "Wong *et al. (2003)" and "Yuan, (2002)"*. The variation of temperature, the large diameter of the duct and the resulting propagation of higher order modes at frequency to be controlled, mean that the application of noise control is particularly challenging with fixed loudspeakers and error microphones locations. This in turn results in large fluctuations in sound pressure with time at any specified location in the duct.

The objective here is not starting a discussion about what the type of active control is best to be implemented, but to give some information about the method that will be used and present the first steps to the design of an active noise control system for tonal noise propagating at the small diameter exhaust duct using adaptive filtering. The economic comparison between passive and active noise control is discussed.

Thus, in the majority of the control noise problems, the application of active noise control means to apply the control in a time-variant system and it is possible to obtain a reference of the primary source. An active control method that uses these characteristics is known as the filtered-X LMS (FXLMS), "Kuo, 1996". It is a control method based on the adaptive filtering theory using a feedforward scheme.

Single-channel broadband ANC system are ideal for one-dimensional ducts used in heating, ventilation, and air conditioning, "Kuo, 1996". The ANC system can be installed quickly and does not require major modifications to the duct structure, does not require cargo moving with the use of cranes.

2. ACTIVE NOISE CONTROL METHOD USING ADAPTIVE FILTERING

Application of a broadband single-channel ANC system to attenuate the acoustic noise propagating in a duct is presented. Broadband single-channel feedforward systems have a single reference sensor, single secondary source, and single error sensor. The reference signal is picked up by a reference microphone placed upstream of a secondary loudspeaker in a small diameter duct. The reference signal is processed by the ANC system to generate a canceling signal that drives a secondary loudspeaker. The error microphone placed downstream of the duct is used to monitor the performance of the ANC system, "Kuo, 1996".

The block diagram for off-line secondary-path modeling is presented in Fig. 1, where $S(z)$ is the secondary path represented by IIR filter, $x(n)$ is an internally-generated white noise, $d(n)$ is the output of $S(z)$, $S\hat{}(z)$ is an adaptive filter that models the secondary path, $y(n)$ is the output of $S\hat{}(z)$, and $e(n) = d(n)-y(n)$ is used by the LMS algorithm to update $S\hat{}(z)$. The FXLMS algorithm requires knowledge of the transfer function $S(z)$. Assuming that the characteristics of $S(z)$ are time-invariant but unknown, off-line modeling can be used to estimate $S(z)$ during an initial training stage. At the end of the training interval, the estimated model $S\hat{}(z)$ is fixed and used for ANC operation. White noise is an ideal broadband training signal in system identification because it has a constant spectral density at all frequencies.

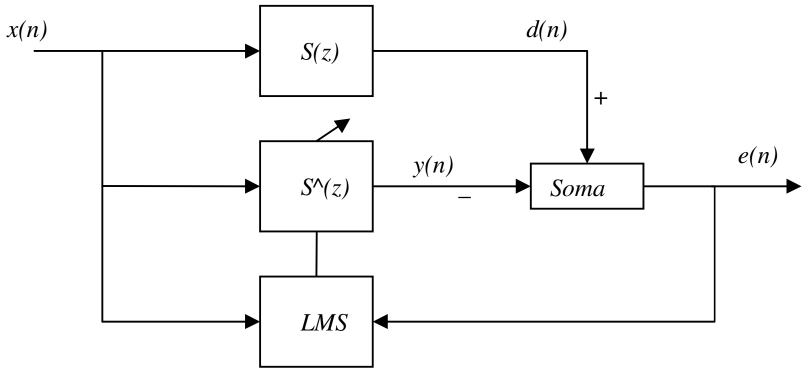

Figure 1. Block diagram for off-line secondary path modeling

The off-line modeling procedure is summarized as follows:

1. Generate sampled White noise signal *x(n)*;
2. Obtain desired signal *d(n)* from error sensor;
3. Compute adaptive filter output:

$$y(n) = \sum_{l=0}^{L-1} \hat{s}_l(n)\, x(n-l) \tag{1}$$

where $\hat{s}_l$ (n) is the lth coefficient of the secondary-path estimation filter *S^(z)* at time *n.*

4. Compute error signal

$$e(n) = d(n)\text{-}y(n) \tag{2}$$

5. Update coefficients using the traditional LMS algorithm

$$\hat{s}_l(n+1) = \hat{s}_l(n) + \mu\, x(n-l)\, e(n), \qquad l = 0,1,\ldots,L-1 \tag{3}$$

6. Go to 1 for next iteration until adaptive filter *S^(z)* converges to optimum solution, that is, until the power of *e(n)* is minimized, “Kuo, (1996)”.

After convergence of the algorithm, the adaptation is stopped and coefficients $\hat{s}_l, l = 0,1,\ldots,L-1$ are used in the ANC system.

The block diagram of ANC system using the FXLMS algorithm is presented in Fig. 2, where *x(n)* is the reference signal, *P(z)* is the primary path, the duct, represented by an IIR filter, *d(n)* is the output of *P(z)*, *W(z)* is the adaptive filter updated by the FXLMS algorithm, *y(n)* is the output of *W(z)*, *S(z)* is the secondary path represented by an IIR filter, *y’(n)* is the output of *S(z) e(n) =d(n)-y’(n)* is the error signal, *S^(z)* is the fixed FIR filter from the off- line modeling mode, and *x’(n)* is a filtered reference signal used by the FXLMS algorithm.

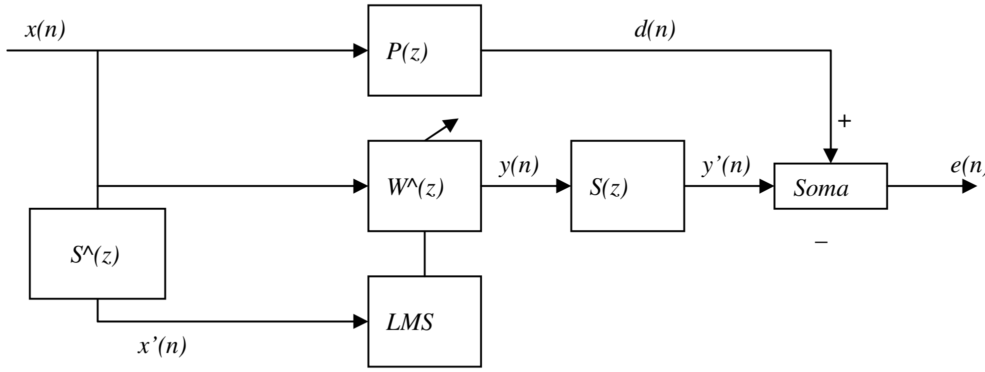

Figure 2. Block diagram of ANC system using the FXLMS algorithm

The FXLMS algorithm is thus an alternative form of the LMS algorithm for use when there is transfer function in the secondary path following the adaptive filter. To ensure convergence of the algorithm, the input to the error correlator is filtered by a estimate of this secondary-path transfer function, "Kuo, (1996)". The FXLMS algorithm is:

$$\vec{w}(n+1) = \vec{w}(n) + \mu \, \vec{x}\,'(n) e(n), \qquad (4)$$

where, $\vec{w}$ is the coefficient vector, μ is the step, $\vec{x}\,'$ is the filtered signal output by the estimated filter $\hat{S}(z)$, and $e(n)$ is the error signal at the output of the duct.

3. TECHNICAL COMPARISON BETWEEN PASSIVE AND ACTIVE NOISE CONTROL

3.1. Noise reduction using a resistive system

The acoustics silencers are systems designed especially to allow, in certain environments or confined equipments, an adequate supply of air or exhaustion, without permitting that high levels of sound pressure leave the enclosure space.

The silencers use highly porous and / or fibrous absorption materials which cover its internal surfaces and divide the fluid conduction channel through lamellas that are equally made of lightweight absorption materials, where the basic mechanism of absorption involves conversion of the kinetic and potential energy of incident acoustic waves to thermal energy, Figure 3.

The specific parameter normally measured which qualifies the effective absorption is the flow resistance.

Such materials are very effective in high frequency operations, usually over 500 Hz. On the other hand, in order to get reasonable noise reduction the dimensions of the devices must be related to the wave length of the main frequency. Thus, for frequencies under 500 Hz, devices of excessive size and weight must be used making the referred solution very expensive and impracticable.

Figure 3. Noise silencer for exhaustion system

3.1.1. Features of the resistive system

- Reduces the noise coming from exhaustion system using low density porous materials;
- These materials are acoustic absorbent;
- Such materials are very effective in high frequency operations, usually over 500 Hz;
- The use of a noise silencer reduces up to 25 dB the sound pressure global level;

- To get a reasonable noise reduction the dimensions of the devices must be related to the wave length of the frequency to be attenuated;
- For frequencies under 500 Hz devices of excessive size and weight are used;
- For high frequency levels the passive noise control is a worldwide accepted solution for its low cost and high performance;
- Requires skilled labor for the production of the silencer / transition set;
- The installation costs should be considered;
- Imposes energy losses to the exhaustion system;
- Causes increase in the system energy consumption;
- Its life span is around 5 years;
- This solution is a totally developed and mastered technology.

3.2. Noise reduction using an active noise control

With the coming of new generations of digital processors (DSP, PIC, FPGA, MOTOROLA HC, and others), the ANC techniques became possible. There are several ways of implementing the ANC for a typical noise problem. However, depending on the control strategy used, the proposed systems may not be always efficient. Thus, optimum control has been searched to improve the stability of the noise reduction process. The ANC is efficient for reduction of low frequency noise. This technique is developing very fast as it allows improvement in the noise treatment with benefits in size, weight, volume, and lower costs.

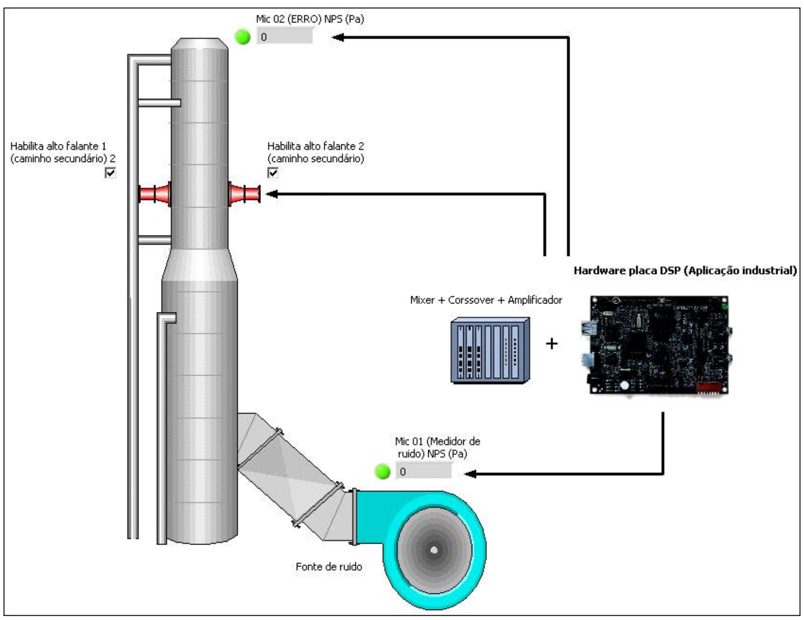

Figura 4. ANC system for the exhaust stack

3.2.1. Features of the ANC system

- Reduces the noise coming from exhaustion system introducing a secondary wave into the duct;
- There is necessity of a digital system;
- The digital system is a mastered technology;
- There is necessity of a audio system with low distortions;
- The main component of the ANC system is its control algorithm;
- Requires skilled labor for the development of the system;
- The costs of ANC design is higher than the costs of silencer design for low frequencies;
- There is not cargo moving with the use of cranes;
- The ANC does not cause an energy loss in the exhaustion system;
- It is a technology in development;

4. FXLMS ALGORITHM USING LABVIEW EMBEDED LANGUAGE

Next is presented Fig. 5 which refers to the algorithm used for ANC in a small diameter finite length duct, considering a tone noise coming from a fan.

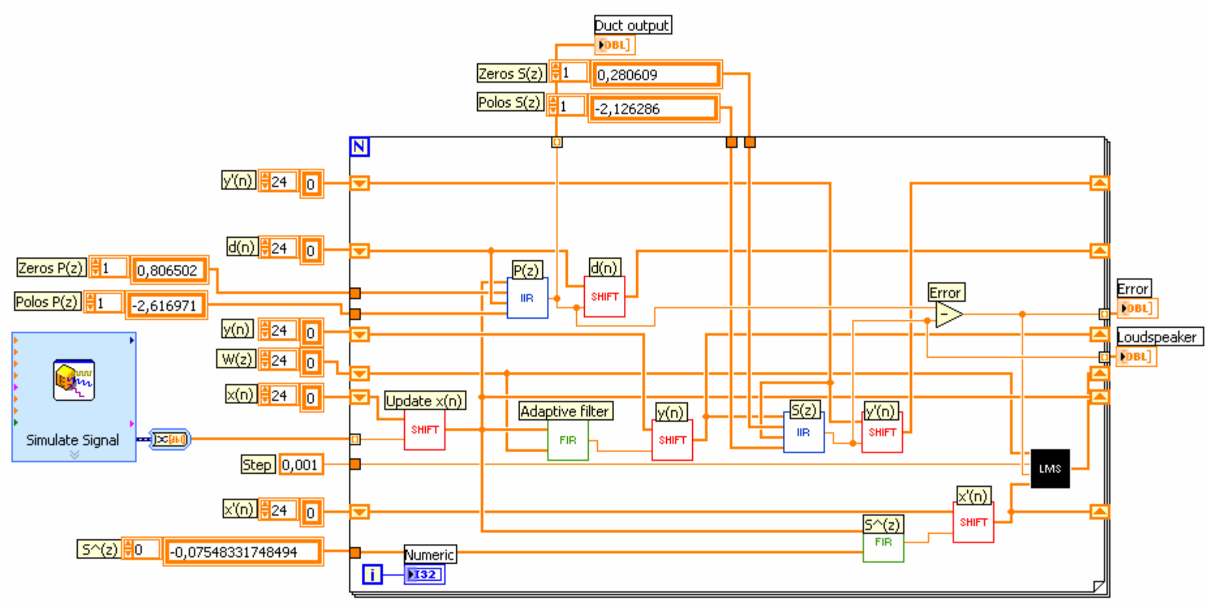

Figure 5. On-line FXLMS algorithm

Next Tab. 1 presents the coefficients of IIR digital filters representing the acoustic models of main duct and secondary duct respectively. The secondary duct model includes a loudspeaker.

Table 1. Transfer functions coefficients of the structural / acoustic system and ideal control source

TRANSFER FUNCTIONS COEFFICIENTS			
P_P	**P_Z**	**S_P**	**S_Z**
1,0000	-0,2375	1,0000	-0,0738
-2,6170	0,8065	-2,1263	0,2806
5,8681	-1,8826	4,2374	-0,7789
-10,2540	3,6018	-6,9646	-0,3219
16,4728	-5,9388	10,6833	2,5639
-23,5743	8,7344	-14,5538	-5,8767
31,5781	-11,6018	18,8774	11,5043
-39,1809	13,9897	-22,7459	-18,1143
46,1259	-15,2185	26,2265	25,9671
-51,0490	14,6616	-28,5747	-33,8719
53,9503	-11,9432	29,8797	41,3451
-54,0551	7,0907	-29,6743	-47,0700
51,8452	-0,8012	28,2965	50,7855
-47,2050	-5,3110	-25,7458	-51,8637
41,2345	11,0856	22,4704	50,0431
-34,1438	-15,1547	-18,6251	-45,9908
27,0838	16,9277	14,6946	39,7866
-20,1760	-17,2064	-10,9641	-33,0788
14,3951	15,1418	7,7483	25,6927
-9,4739	-12,4201	-4,9807	-18,8616
5,9028	8,9713	2,9699	12,7819
-3,2589	-5,7557	-1,5076	-8,1748
1,6554	3,2785	0,7193	4,5679
-0,6561	-1,1553	-0,2669	-2,0768
0,2082	0,3031	0,0556	0,7287

5. PRELIMINARY RESULTS OF THE FEEDFORWARD ANC SYSTEM PERFORMANCE

Figure 6 presents the white noise adaptation, where the white signal represents the IIR filter output and the black signal is the adaptive filter. This technique uses the off-line modeling secondary-path.

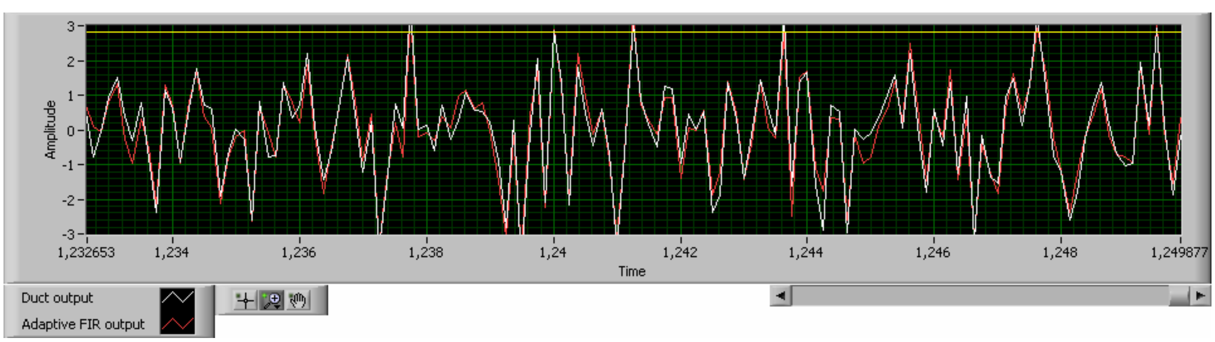

Figure 6. Off-line modeling secondary-path

For an ANC system with one control source, one error sensor and 2000 samples, the error signal comes from the sum of the primary sound and the control sound at the error sensor. The control sound is generated by the linear convolution of the control signal and the transfer function from the control source to the error sensor. Thus, the Figures 7, 8, and 9 represent the primary signal, with a 500 Hz frequency, the output of loudspeaker, and the error signal respectively. The FXLMS algorithm considered a step μ = 0,001 and digital filters with n =25 coefficients. Figure 9 shows the noise reduction at the duct output.

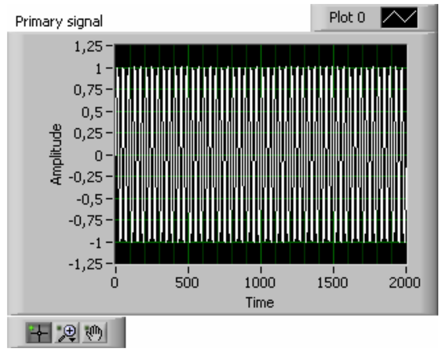

Figure 7. Primary signal of the exhaust, 500Hz, μ = 0,001, n = 25

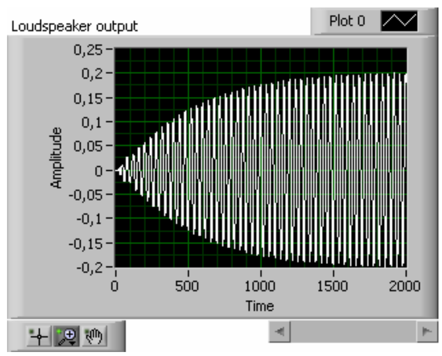

Figure 8. Output signal of the loudspeaker located inside of the duct

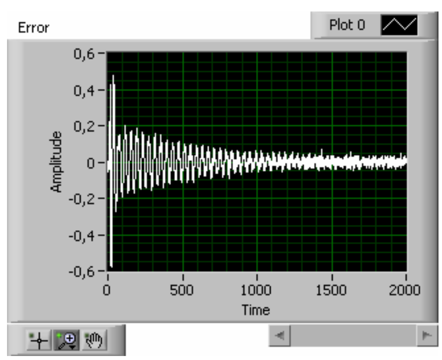

Figure 9. Error signal in the microphone located downstream of the loudspeaker

Figures 7, 8, and 9 represent the primary signal, with a 250 Hz frequency, the output of loudspeaker, and the error signal respectively. The FXLMS algorithm considered a step μ = 0,001 and digital filters with n =25 coefficients. Figure 12 shows the noise reduction at the duct output.

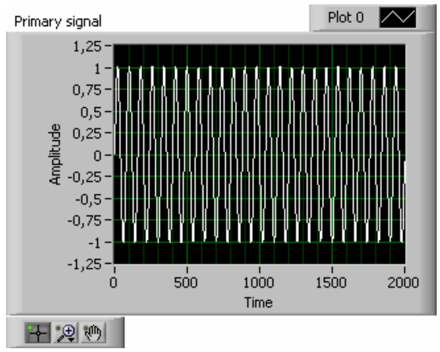

Figure10. Primary signal of the exhaust, 250Hz, μ = 0,001, n = 25

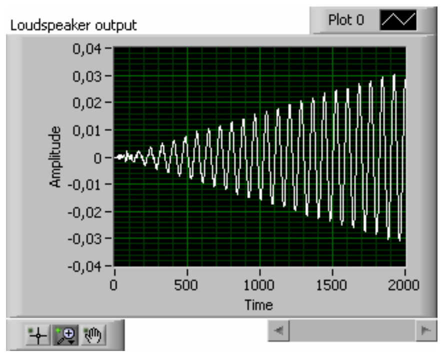

Figure 11. Output signal of the loudspeaker located inside of the duct

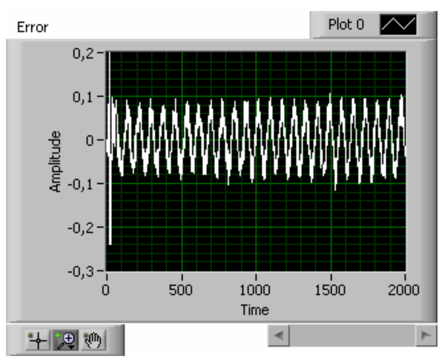

Figure 12. Error signal in the microphone located downstream of the loudspeaker

7. CONCLUSIONS

In this work, the first steps of an active noise control are developed for an exhaustion system. The FXLMS algorithm can help an ANC system to have a high level of noise attenuation regardless of the single-tone noise source. The active noise control system was simulated using microphones as reference sensor and error sensor.

8. REFERENCES

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