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Comparative Analysis of Feed-forward and Feedback FxLMS Algorithms

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Abstract: *Noise has always been a problem in communication systems and therefore many researches are going on for its elimination. Primary research was done for passive noise control, and then it is shifted to Active noise control (ANC) system for noise control at low frequency. Many algorithms have been developed till now, but at present FxLMS (filtered X least mean square) and its variants are mostly preferred algorithms for active noise control. Researches are going on for improving FxLMS algorithm. In this paper, we have compared two basic FxLMS architectures, ie. Feed-forward FxLMS and Feedback FxLMS. Results have been generated for noisy signals corrupted by car , machine gun and babble noise at -5dB, 0 dB and 5dB input SNR level. Simulation is done using Matlab. For analysis various parameters are evaluated like Mean square error (MSE), Signal to noise ratio (SNR), Noise rejection ratio (NRR), Time complexity, Residue, Convergence rate (CR) and it's mean. It is found that performance of Feed-forward FxLMS is better than Feedback FxLMS algorithm.*

Keywords: *ANC, FxLMS, Feed-forward FxLMS, Feedback FxLMS, Secondary path estimation, Mean square error, Noise rejection ratio, Convergence rate, SNR.*

1. INTRODUCTION

Need for Active noise control (ANC) came into existence because Passive noise control system was not efficient at low frequency (at low frequency, passive noise control system becomes heavy and expensive whereas ANC is compact and cheap). Researches for ANC was started since 1970's and from then many algorithms has been proposed. Basic concept for developing ANC is to generate anti noise signal ie. signal with same amplitude as that of noise signal but out of phase. When original noise signal and it's corresponding anti signal are superimposed then noise can be cancelled [1]. ANC uses adaptive filters which can update their weight coefficients with changing environment. However, if ANC is realized using fixed coefficient filters like low pass or high pass filters, then after some time with changing environment, they will not be able to serve motive of ANC system. Mostly FIR (Finite impulse response) filters are preferred to implement ANC due to it's add on advantages (like easy implementation and stability) over IIR (Infinite impulse response) filters. Usually, FxLMS (filtered X least mean square) algorithm is a good choice to implement ANC [1], which is a modified form of LMS (least mean square) algorithm and is computationally simple and also includes Secondary effect. Secondary path includes effects of devices like digital to analog (DAC) converter, reconstruction filter, power amplifier, loud-speaker, acoustic path from loudspeaker to error microphone, error microphone, preamplifier, anti aliasing filter, and analog to digital converter (ADC), (ie. the effects of devices which are included in ANC system). It's modeling can be done Offline (secondary path is estimated before operating ANC system and is preferred when secondary path is not time varying) or Online (secondary path is estimated simultaneously while ANC system is under operation and bears complex structure).

Feed-forward and Feedback FxLMS algorithm

FxLMS architectures are basically of two types, Feed-forward FxLMS and Feedback FxLMS. Feed-forward FxLMS ANC system is shown in Fig. 1 [2], Such a structure needs basically a noise source and a noisy signal corrupted by noise correlated with the noise present in the noise source. This structure uses two sensors ie. reference sensor and error sensor [1] [2]. It enjoys the advantage of having simple structure but it has a problem that in many cases, the anti noise signal generated by ANC system may also reach the input microphone and so can disturb the working of ANC system. A simple structure of feedback FXLMS for implementing ANC is shown in Fig 2 [2]. It can be seen that such a structure does not have a noise source rather noise is internally generated within the structure. This structure contains only error sensor and no reference sensor. Input to this structure is just a noisy signal. It is difficult structure to implement when compared with feed-forward FxLMS. This structure is used when noise source is not available or in cases when it is difficult to mount reference sensor closer to noise source or in case of predictable noise [1] [2].

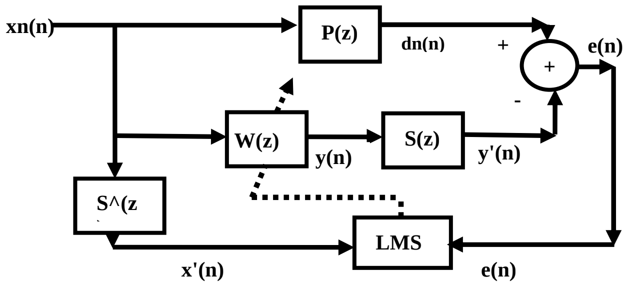

Fig. 1. Feed-forward ANC system.

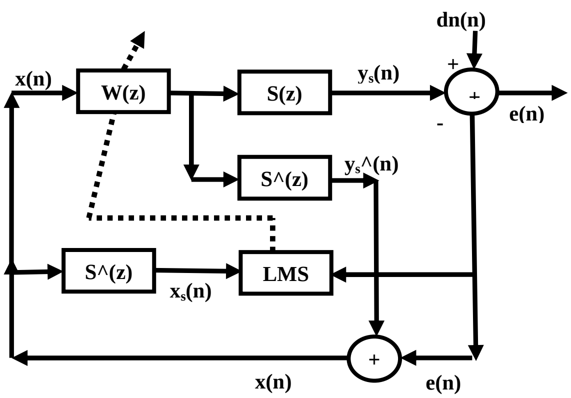

Fig. 2: Feedback ANC system

2. EXPERIMENTAL SETUP AND RESULTS

In this experiment car noise, babble16, machine gun [3] has been artificially added to clean sentence "dhuban jab sokar uthti, toh dekhti ki chooka saafh pada ha, aur bartan majah hua ha" [4] to produce noisy signal of -5 dB, 0 dB and 5 dB input SNR level. Secondary path has been estimated through laptop by playing a white noise of length 44100 samples and then it is recorded. Using these two signals (white noise and it's recorded signal), S(z) is constructed (at a convergence rate of 0.001 and filter order of 6). The estimation of secondary path *S^(z)* is done using system identification using LMS algorithm (at a convergence rate of 0.001. Finally *S(z)* and *S^(z)* are used to implement circuits shown in Fig. 1 and Fig. 2. MATLAB version R2008a is used for simulation. Various parameters are calculated including Mean square error *(MSE)*, Signal to noise ratio *(SNR)*, Time computation, Noise rejection ratio *(NRR)* [5], Convergence rate *(CR)* [6] and it's mean *(CRmean)*. Lesser the *MSE* value, more closer is the output to a clean signal. '*SNR*' is ratio of signal power to noise power. Higher is *SNR* value, better is the output quality. 'Time computation' is the time taken to simulate the complete program. Higher this value, higher will be the computation complexity of the algorithm. '*NRR*' shows the capability of algorithm to reject noise from output. Lesser the value of '*MSE*', higher is the *NRR* value. So high value for '*NRR*' is desired. Convergence rate shows that how quickly algorithm optimizes it's weight coefficients. '*CR*' should show decreasing nature with time. Therefore, '*CRmean*' should me more negative with reducing MSE. Therefore, '*CR*' and '*NRR*' are parameters related to '*MSE*'. Simulation is done for orders 10, 30, 50. Results are formulated in a tabular form as shown in Table. 1 and Table. 2 for Feed-forward FxLMS and Feedback FxLMS Analysis respectively at different convergence rates (*mu1*).

Table 1: Feed-forward FxLMS analysis in terms of MSE, SNR (dB), NRR (dB), CRmean (dB).

Feed Forward FxLMS, xn= car noise, mu1= 0.0001					
M	xn	M.S.E	SNR(dB)	NRR(dB)	CRmean(dB)
10	-5	0.000546	26.3094	19.488195	-39.3673
	0	0.000179	33.9355	21.141781	-44.2105
	5	0.000064	38.3009	23.816036	-48.8529
30	-5	0.000506	31.4134	19.823753	-40.0503
	0	0.000198	33.2050	20.710031	-44.5049
	5	0.000102	36.1158	21.791421	-48.5129
50	-5	0.000592	27.6278	19.140697	-39.2998
	0	0.000277	33.0554	19.261918	-43.4232
	5	0.000177	37.6633	19.382307	-47.0186
Feed Forward FxLMS, xn= babble16, mu1= 0.01					
M	xn	M.S.E	SNR(dB)	NRR (dB)	CRmean(dB)
10	-5	0.003679	39.0801	11.247254	-30.8160
	0	0.001526	38.3932	11.893153	-34.9069
	5	0.000845	38.1493	12.638185	-38.4020
30	-5	0.004432	39.0223	10.438667	-30.1776
	0	0.002423	38.3736	9.885693	-33.5456
	5	0.001789	38.1449	9.378279	-36.2618
50	-5	0.005478	39.0267	9.518020	-29.3828
	0	0.003442	38.3672	8.361437	-32.3759
	5	0.002799	38.1339	7.433851	-34.7626
Feed Forward FxLMS, xn= machine gun, mu1=0.01					
m	xn	M.S.E	SNR(dB)	NRR (dB)	CRmean(dB)
10	-5	0.001409	45.5370	15.356252	-55.4046
	0	0.000614	46.2738	15.778915	-57.7944
	5	0.000363	45.1055	16.249554	-59.0403
30	-5	0.002385	46.3254	13.070494	-52.1707
	0	0.001190	43.5791	12.905652	-53.1595
	5	0.000802	48.0187	12.802163	-54.3744
50	-5	0.003351	44.0330	11.594396	-52.8798
	0	0.001743	45.9653	11.248552	-54.1930
	5	0.001217	47.5060	10.993586	-53.3228

It can be seen from Table. 1, that *MSE* is least for car noise and maximum for babble16, for all orders of filter and for all input SNR level (-5, 0 and 5 dB). Output *SNR* is maximum for machine gun (for all filter order and input SNR level) but is lest for car noise (except for order 10, at 5 dB SNR level). *NRR* (dB) is highest for car noise and least for babble16, for all filter order and input SNR level. *CRmean* (dB) is maximum for machine gun and least for babble16, for all filter order and for all input SNR level. Fig. 3 shows output waves (recovered signal, residue, *CR* (dB), *NRR* (dB)) for babble16, for order 10 at 5 dB SNR level and time taken to simulate this algorithm (with noise as babble16, order 10, input SNR level 5 dB) is 41.3715 seconds.

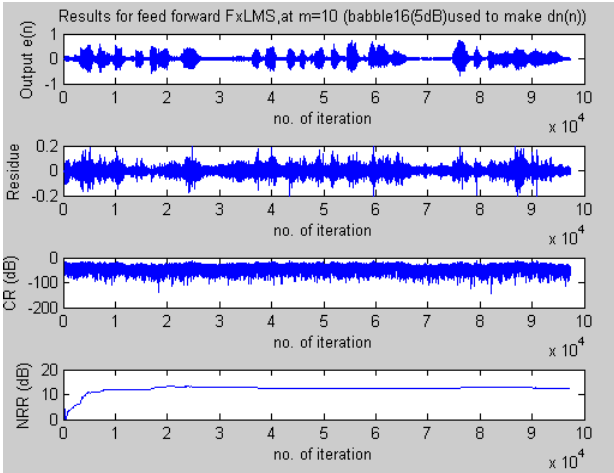

Fig. 3: Output waves for Feed-forward FxLMS algorithm (with noise as babble16, order 10, input SNR level 5 dB).

Table 2: Feedback FxLMS analysis in terms of MSE, SNR (dB), NRR (dB), CRmean (dB).

Feed Back FxLMS, xn= car noise, mu1=0.0001					
M	xn	M.S.E	SNR(dB)	NRR(dB)	CRmean(dB)
10	-5	0.008332	25.1454	7.656245	-30.8741
	0	0.007057	30.2044	5.195555	-31.5815
	5	0.005654	32.6750	4.340090	-31.8943
30	-5	0.007537	30.0593	8.091778	-30.5456
	0	0.006411	29.7748	5.612911	-32.0507
	5	0.005705	34.5097	4.300906	-33.0888
50	-5	0.007857	27.3699	7.911136	-30.5690
	0	0.006608	29.7389	5.481158	-31.9395
	5	0.005910	33.1179	4.147517	-32.9762
Feed Back FxLMS, xn= babble16, mu1=0.0001					
M	xn	M.S.E	SNR(dB)	NRR(dB)	CRmean(dB)
10	-5	0.018721	39.7837	4.181133	-23.3939
	0	0.009674	37.4572	3.873641	-26.6005
	5	0.005946	36.1315	4.162010	-29.5889
30	-5	0.018682	39.6178	4.190253	-23.4077
	0	0.010136	37.2377	3.670755	-26.4153
	5	0.006560	35.8037	3.735599	-29.1553
50	-5	0.018886	39.5475	4.142957	-23.3682
	0	0.010498	37.1310	3.518397	-26.2521
	5	0.007002	35.6361	3.452107	-28.8949
Feed Back FxLMS, xn= machine gun, mu1=0.0001					
M	xn	M.S.E	SNR(dB)	NRR(dB)	CRmean(dB)
10	-5	0.011832	30.8787	6.114950	-31.9929
	0	0.007962	34.0570	4.650526	-33.7617
	5	0.005765	39.6566	4.237494	-35.2892
30	-5	0.011961	30.2343	6.067909	-31.8350
	0	0.008494	33.8941	4.370006	-33.3364
	5	0.006403	33.8654	3.781667	-34.7140
50	-5	0.011805	25.6449	6.124888	-31.0556
	0	0.008717	29.2206	4.256965	-32.6664
	5	0.006770	33.2600	3.539763	-34.0652

It can be seen from Table. 2 that least *MSE* is found for car noise and maximum is found for babble16, for all filter order and for all input SNR level. *SNR* is maximum for babble16 (for all filter order and input SNR level) and least for car noise (except for order 50, input SNR level -5 and 0 dB). *NRR* is maximum for car noise and least for babble16, for all filter order and input SNR level. *CRmean* is maximum for machine gun and is least for babble16, for all filter order and at all input SNR level. Fig. 4 shows output waves for babble16, for order 10 at 5 dB SNR level and time taken to simulate this algorithm (with noise as babble16, order 10, input SNR level 5 dB) is 42.5567 seconds.

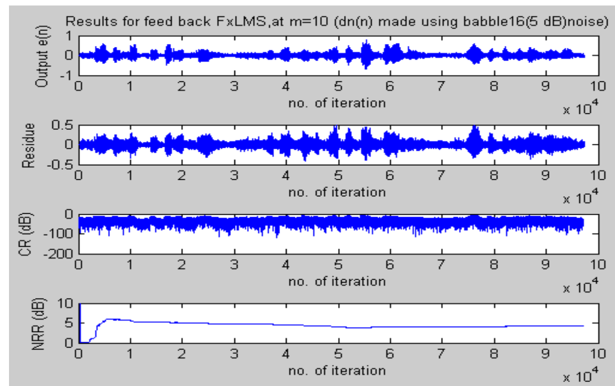

Fig. 4: Output waves for Feedback FxLMS algorithm (with noise as babble16, order 10, input SNR level 5 dB).

Comparing Feed-forward and Feedback FxLMS, it can be stated that performance of Feed-forward FxLMS is better than Feedback FxLMS, when comparing all the parameters. Also computational complexity of Feedback FxLMS is higher than Feed-forward FxLMS (based on time taken to simulate algorithm). The analysis and comparisons of algorithms can be seen diagrammatically. Fig. 5 shows average *MSE*, Fig. 6 shows average *SNR* (dB), Fig. 7 shows average *NRR* (dB), Fig. 8 shows average *CRmean* (dB). All these figures are for order 10.

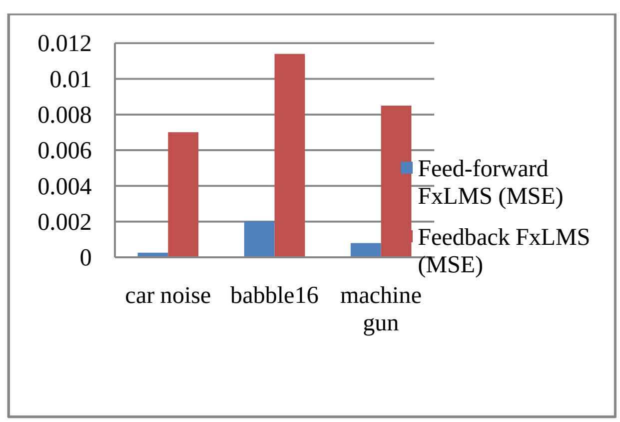

Fig. 5: Comparative Analysis of Feed-forward and Feedback FxLMS (average MSE for SNR level at -5, 0 and 5 dB) at order 10.

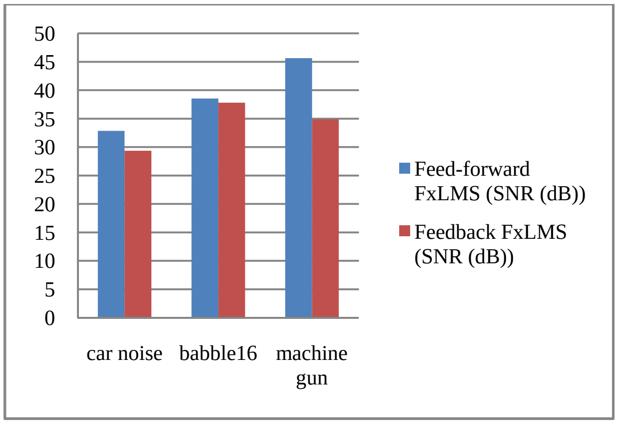

Fig. 6 Comparative Analysis of Feed-forward and Feedback FxLMS, for SNR (dB) (average SNR (dB) for input SNR level at -5, 0 and 5 dB) at order 10.

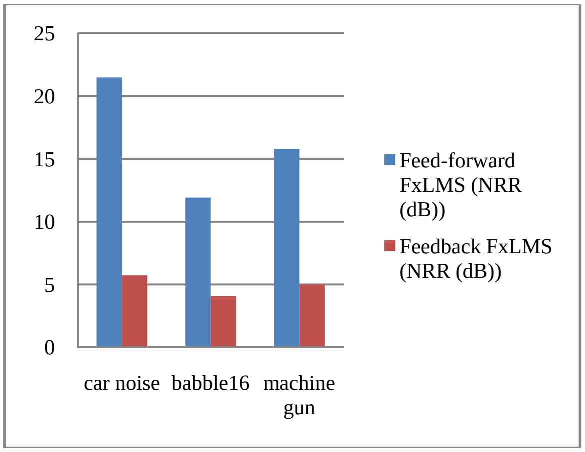

Fig. 7: Comparative Analysis of Feed-forward and Feedback FxLMS, for NRR (dB) (average NRR (dB) for input SNR level at -5, 0 and 5 dB) at order 10.

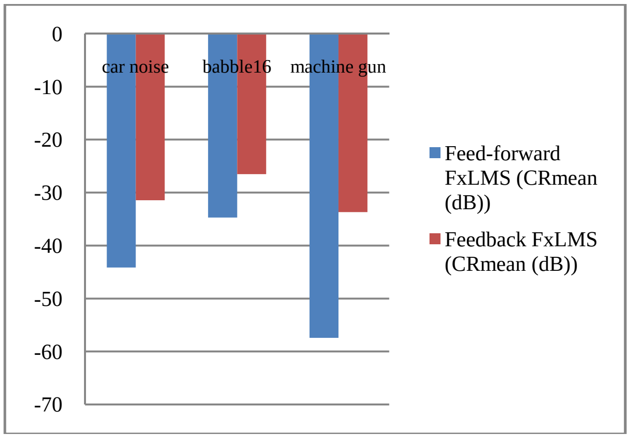

Fig. 8: Comparative Analysis of Feed-forward and Feedback FxLMS, for *CRmean* (dB) (average *CRmean* (dB) for input SNR level at -5, 0 and 5 dB) at order 10.

3. CONCLUSIONS

Feed-forward and Feedback FxLMS algorithms has been implemented and results are compared based on parameters including Mean square error *(MSE)*, Signal to noise ratio *(SNR)*, Time computation, Noise rejection ratio *(NRR)*, Convergence rate *(CR)* and it's mean *(CRmean)*. It has been found that Feed-forward FxLMS gives superior performance than Feedback FxLMS. However, despite of so many disadvantages, advantage of Feedback FxLMS is that it is used where noise source is not available.

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