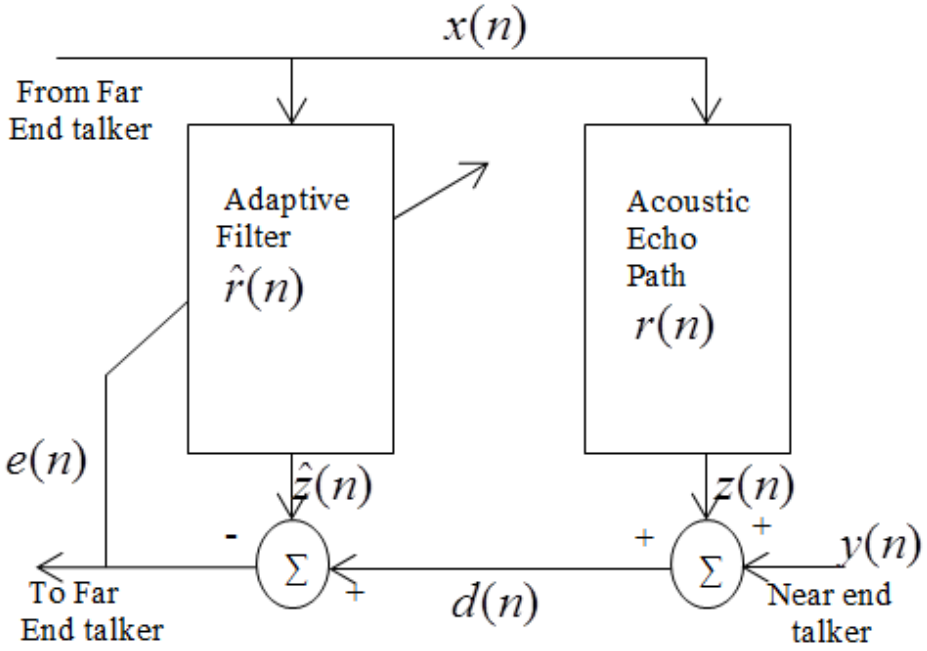
Development of Adaptive Filtering Algorithm for Acoustic Echo Cancellation in Hands Free Communication System



In teleconferencing conditions, the end speaker voice is picked up by the microphone placed at near end and is again being sent back to far end as an echo.. Adaptive Filters use an algorithmic procedure which aims to identify the acoustic path between loudspeaker and microphone and tries to develop the replica of echo path that is to be removed from the output of the microphone. Figure 2 shows the model for Acoustic Echo Cancellation (AEC). The input signal $x(n)$ is passed through an adaptive filter $\hat{r}(n)$ which gives the estimated echo $\hat{z}(n)$, $\hat{r}(n)$ tries to match the transfer function to echo path (acoustic echo path) $r(n)$.The echo signal $z(n)$ is produced when $x(n)$ passes through echo path. The echo $z(n)$, plus near end talker $y(n)$ constitutes the desired signal $d(n)$, adaptive canceller [2].

$$d(n) = z(n) + y(n)$$

The estimated echo signal $\hat{z}(n)$, is subtracted from the desired signal $d(n)$ to get an error signal $e(n)$.

$$e(n) = d(n) - \hat{z}(n)$$

The ideal case, $e(n) = y(n)$ represents the adaptive echo canceller is accurate.

Results

Table no.1 LMS output for Audio file 1

Filter order	Step size	Mean Square Error (MSE)	Echo Return Loss Enhancement (ERLE)dB
2	0.01	0.3939	07.5004
	0.04	0.1954	10.6393
	0.06	0.1388	12.5106
	0.1	0.0852	15.8362
	0.3	0.0286	27.9363
	0.5	0.0172	32.7673
	0.9	0.0096	35.6783
	1	0.0087	36.0074
	2	0.0044	37.3124
4	0.01	0.3939	7.4995
	0.04	0.1954	10.6388
	0.06	0.1388	12.5135
	0.1	0.0852	15.8551
	0.3	0.0286	27.9316
	0.5	0.0172	32.7822
	0.9	0.0096	35.6737
	1	0.0087	35.9967
	2	0.0044	37.3365
8	0.01	0.3939	7.2969
	0.04	0.1954	10.6429
	0.06	0.1388	12.5022
	0.1	0.0852	15.8348
	0.3	0.0286	27.9486
	0.5	0.0172	32.7890
	0.9	0.0096	35.6497
	1	0.0087	35.9937
	2	0.0044	37.3479
16	0.01	0.3939	7.5008
	0.04	0.1954	0.6436
	0.06	0.1388	12.5048
	0.1	0.0852	15.8473
	0.3	0.0286	27.9450
	0.5	0.0172	32.7935
	0.9	0.0096	35.6423
	1	0.0087	36.0156
	2	0.0044	37.3120
32	0.01	0.3939	7.4975
	0.04	0.1954	0.6419
	0.06	0.1388	12.4875
	0.1	0.0852	15.8392

	0.3 0.5 0.9 1 2	0.0286 0.0172 0.0096 0.0087 0.0044	27.9348 32.7752 35.6643 36.0041 37.3206
64	0.01 0.04 0.06 0.1 0.3 0.5 0.9 1 2	0.3939 0.1954 0.1388 0.0852 0.0286 0.0172 0.0096 0.0087 0.0044	7.4944 10.6483 12.5015 15.8497 27.9238 32.7750 35.6498 35.9900 37.2198

Results of Audio file 1 for comparison of ERLE and MSE characteristics and output error cancellation at filter order 16 for LMS is given below:

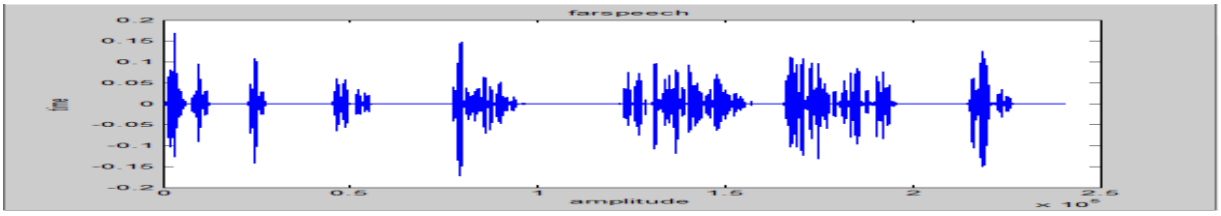


Fig 1 Near speech signal

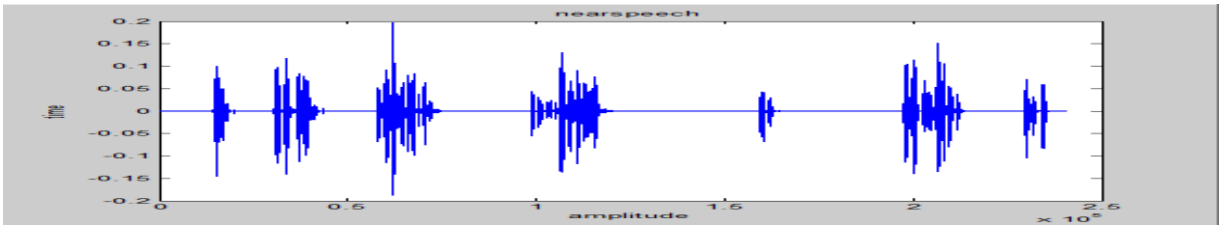


Fig 2 Far speech signal

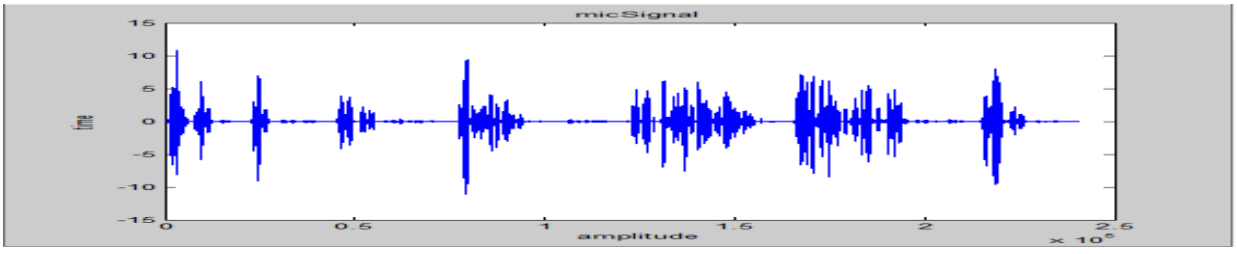


Fig 3 Microphone signal

Table no.2 LMS output for Audio file 2

Filter order	Step size	Mean Square Error (MSE)	Echo Return Loss Enhancement (ERLE)dB
2	0.001	1.3555	07.4673
	0.01	0.7018	11.0498
	0.02	0.4132	14.5624
	0.04	0.2133	20.3929
	0.06	0.1425	25.3794
	0.09	0.0951	31.3758
	0.1	0.0856	32.8061
	0.2	0.0430	37.8065
	0.3	0.0288	39.0078
4	0.001	1.3555	7.4756
	0.01	0.7018	4.0531
	0.02	0.4132	14.5560
	0.04	0.2133	20.3764
	0.06	0.1425	25.3629
	0.09	0.0951	31.3685
	0.1	0.0856	32.8003
	0.2	0.0430	37.7890
	0.3	0.0288	39.0211
8	0.001	1.3555	7.4697
	0.01	0.7018	14.0447
	0.02	0.4132	14.5632
	0.04	0.2133	20.3921
	0.06	0.1425	25.3754
	0.09	0.0951	31.3673
	0.1	0.0856	32.8111
	0.2	0.0430	37.7862
	0.3	0.0288	39.0054
16	0.001	1.3555	7.4638
	0.01	0.7018	11.0375
	0.02	0.4132	14.5505
	0.04	0.2133	20.3762
	0.06	0.1425	25.3679
	0.09	0.0951	31.3900
	0.1	0.0856	32.7909
	0.2	0.0430	37.7810
	0.3	0.0288	39.0034
32	0.001	1.3555	7.4609
	0.01	0.7018	11.0491
	0.02	0.4132	14.5604
	0.04	0.2133	20.3736
	0.06	0.1425	25.3744
	0.09	0.0951	21.3654

	0.1 0.2 0.3	0.0856 0.0430 0.0288	32.8196 37.7841 38.9977
64	0.001 0.01 0.02 0.04 0.06 0.09 0.1 0.2 0.3	1.3555 0.7018 0.4132 0.2133 0.1425 0.0951 0.0856 0.0430 0.0288	7.4670 11.0413 14.5724 20.3918 25.3674 31.3788 32.7964 37.7911 38.9962

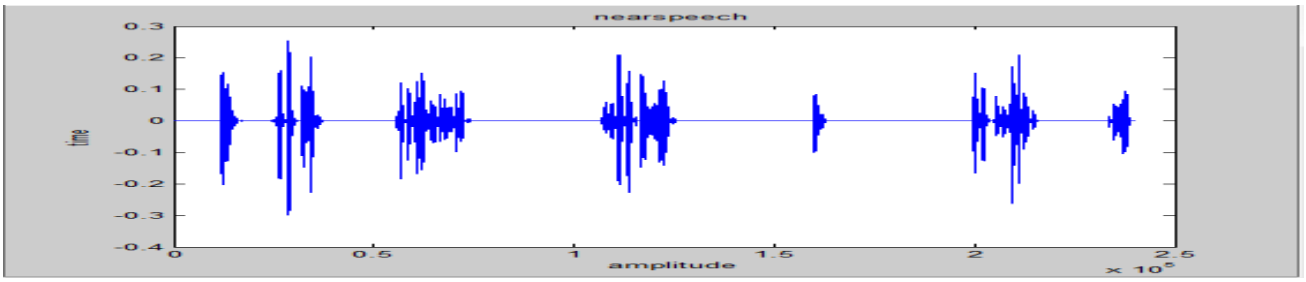


Fig 1 Near speech signal

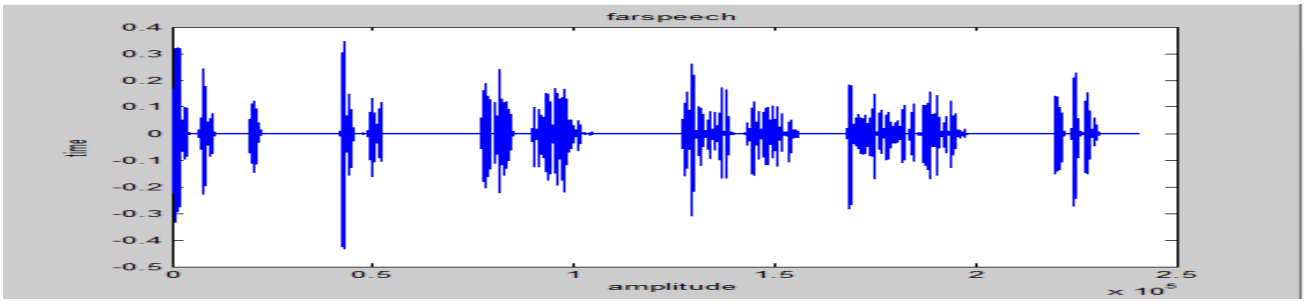


Fig 2 Far speech signal

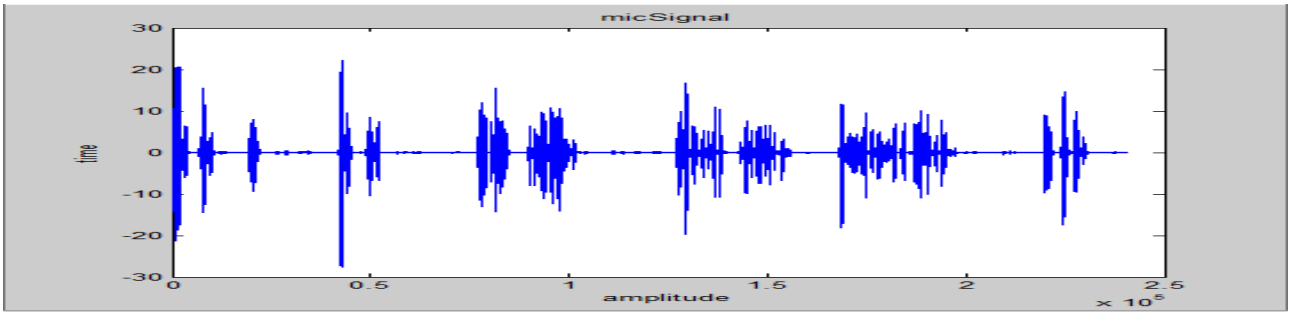


Fig 3Microphone signal

Table no.3 LMS output for Audio file 3

Filter order	Step size	Mean Square Error (MSE)	Echo Return Loss Enhancement (ERLE)dB
2	0.001	6.0429	8.1023
	0.004	2.1181	14.3250
	0.006	1.4220	17.6375
	0.008	1.0674	20.5786
	0.01	0.8543	23.2690
	0.02	0.4279	33.9113
	0.03	0.2857	37.9351
	0.04	0.2146	39.0864
4	0.001	6.0429	8.1019
	0.004	2.1181	14.3233
	0.006	1.4220	17.6354
	0.008	1.0674	20.5583
	0.01	0.8543	23.2905
	0.02	0.4279	33.8983
	0.03	0.2857	37.9345
	0.04	0.2146	39.0953
88	0.001	6.0429	8.1008
	0.004	2.1181	14.3074
	0.006	1.4220	17.6353
	0.008	1.0674	20.5868
	0.01	0.8543	23.2898
	0.02	0.4279	33.9017
	0.03	0.2857	37.9444
	0.04	0.2146	39.0973
16	0.001	6.0429	8.1042
	0.004	2.1181	14.3091
	0.006	1.4220	17.6311
	0.008	1.0674	20.5621
	0.01	0.8543	23.2838
	0.02	0.4279	33.8967
	0.03	0.2857	37.9354
	0.04	0.2146	39.1031
32	0.001	6.0429	8.0969
	0.004	2.1181	14.3182
	0.006	1.4220	17.6284
	0.008	1.0674	20.5618
	0.01	0.8543	23.2871
	0.02	0.4279	33.9110
	0.03	0.2857	37.9466
	0.04	0.2146	39.1043
64	0.001	6.0429	8.0962
	0.004	2.1181	14.3209

	0.006	1.4220	17.6297
	0.008	1.0674	20.5663
	0.01	0.8543	23.2650
	0.02	0.4279	33.9038
	0.03	0.2857	37.9498
	0.04	0.2146	39.1187

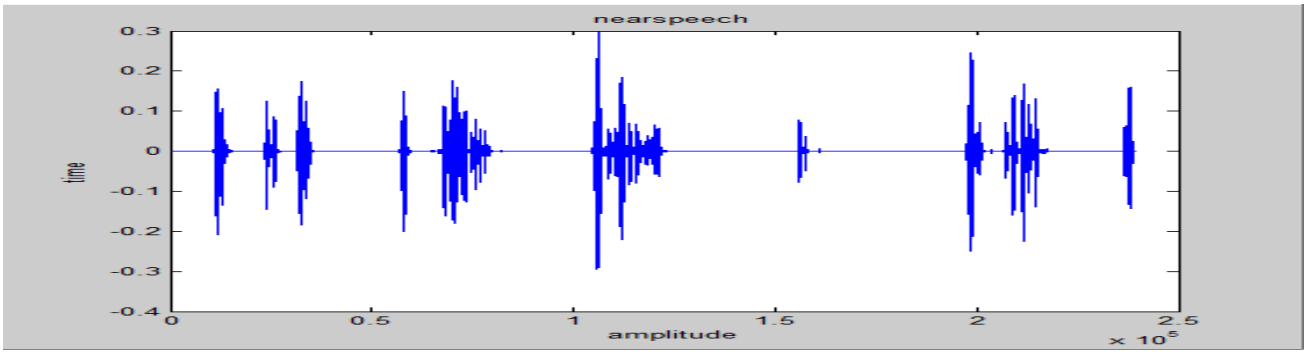


Fig 1 Near speech signal

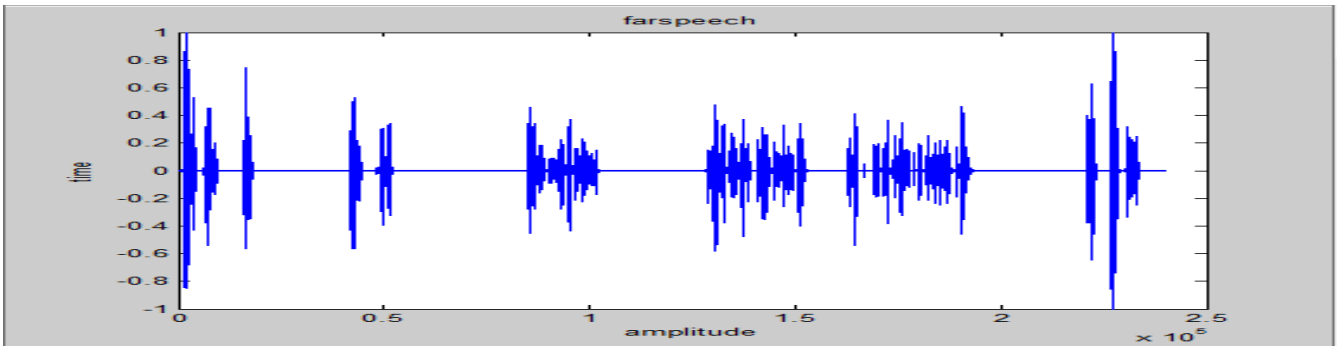


Fig 2 Far speech signal

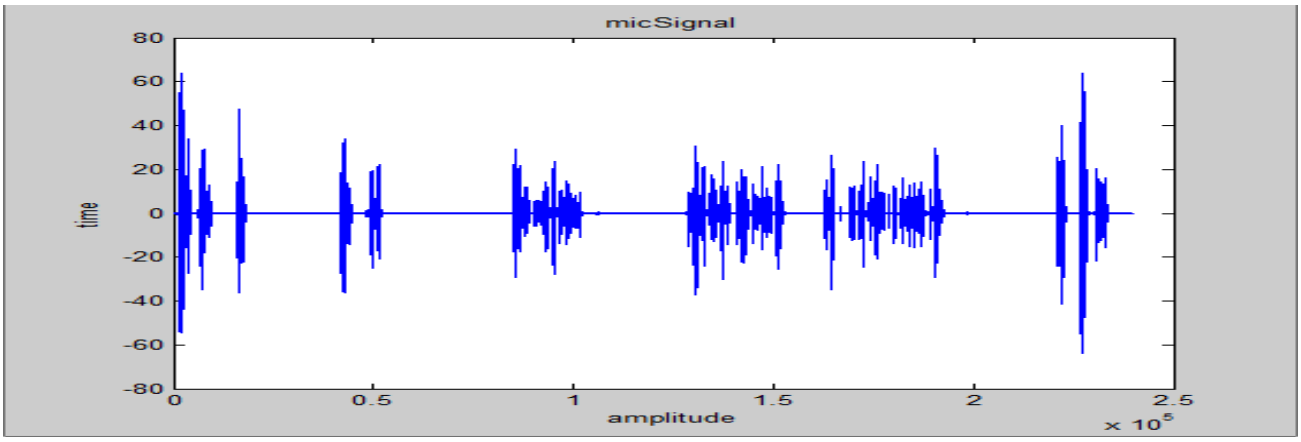


Fig 1 Microphone signal

Table no.4 NLMS output for Audio file 1

Filter order	Step size	Mean Square Error (MSE)	Echo Return Loss Enhancement (ERLE)dB
2	0.0001	0.4225	07.2183
	0.0008	0.1398	12.4890
	0.002	0.0580	19.5662
	0.004	0.0289	27.8526
	0.008	0.0141	33.7875
	0.01	0.0111	34.9302
	0.04	0.0026	37.6830
4	0.0001	0.4225	7.2121
	0.0008	0.1398	12.4920
	0.002	0.0580	19.5713
	0.004	0.0289	27.8534
	0.008	0.0141	33.8058
	0.01	0.0111	34.9301
	0.04	0.0026	37.6895
8	0.0001	0.4225	
	0.0008	0.1398	7.2127
	0.002	0.0580	12.4906
	0.004	0.0289	19.5958
	0.008	0.0141	27.8725
	0.01	0.0111	34.9322
	0.04	0.0026	37.6781
16	0.0001	0.4225	7.2182
	0.0008	0.1398	12.4992
	0.002	0.0580	19.5782
	0.004	0.0289	27.8765
	0.008	0.0141	33.8087
	0.01	0.0111	34.9134
	0.04	0.0026	37.6988
32	0.0001	0.4225	7.2165
	0.0008	0.1398	12.4897
	0.002	0.0580	19.5807
	0.004	0.0289	27.8631
	0.008	0.0141	33.8141
	0.01	0.0111	34.9283
	0.04	0.0026	37.6801
64	0.0001	0.4225	7.2150
	0.0008	0.1398	12.5059

	0.002	0.0580	19.5761
	0.004	0.0289	27.8584
	0.008	0.0141	33.7795
	0.01	0.0111	34.9364
	0.04	0.0026	37.6615

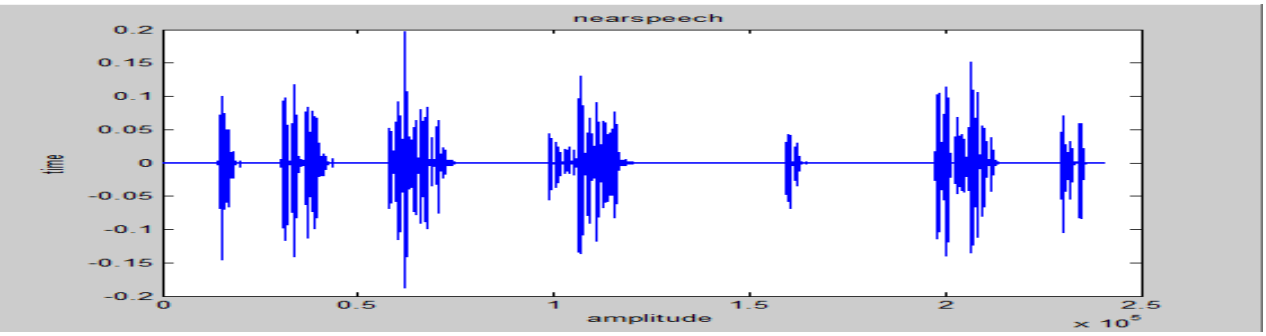


Fig 1 Near speech signal

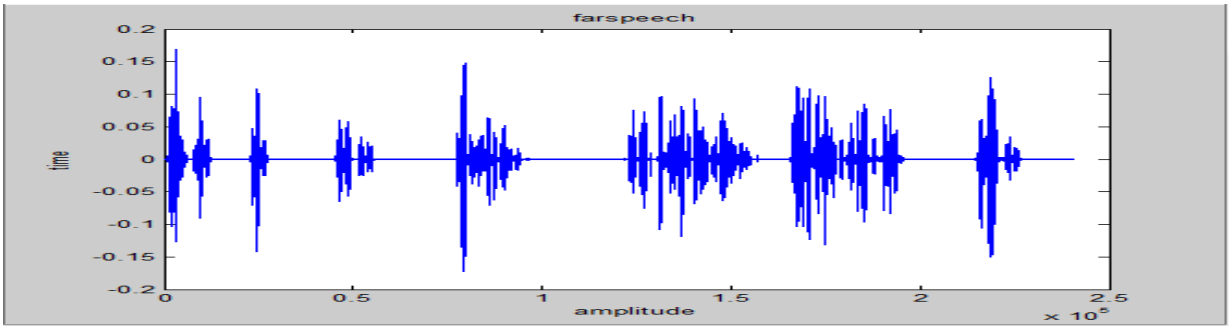


Fig 2 Far speech signal

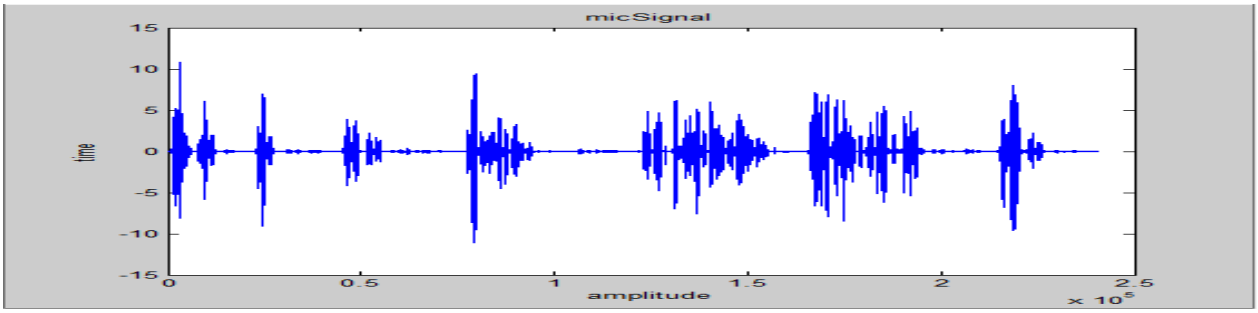


Fig 3Microphone speech signal

Table no.5NLMS output for Audio file 2

Filter order	Step size	Mean Square Error (MSE)	Echo Return Loss Enhancement (ERLE)dB
2	0.0001	1.0253	8.9966
	0.0004	0.4858	14.1547
	0.0008	0.2813	19.6821
	0.0001	0.2335	22.1374
	0.002	0.1270	31.5551
	0.004	0.0647	36.6302
	0.006	0.0421	38.1248
4	0.0001	1.0253	8.9917
	0.0004	0.4858	14.1497
	0.0008	0.2813	19.6694
	0.0001	0.2335	22.1521
	0.002	0.1270	31.5540
	0.004	0.0647	36.6554
	0.006	0.0421	38.1335
8	0.0001	1.0253	8.9945
	0.0004	0.4858	14.1555
	0.0008	0.2813	19.6785
	0.0001	0.2335	22.1504
	0.002	0.1270	31.5505
	0.004	0.0647	36.6556
	0.006	0.0421	38.1185
16	0.0001	1.0253	8.9984
	0.0004	0.4858	14.1431
	0.0008	0.2813	19.6721
	0.0001	0.2335	22.1456
	0.002	0.1270	31.5386
	0.004	0.0647	36.6296
	0.006	0.0421	38.1212
32	0.0001	1.0253	8.9975
	0.0004	0.4858	14.1436
	0.0008	0.2813	19.6780
	0.0001	0.2335	22.1370
	0.002	0.1270	31.5451
	0.004	0.0647	36.6387
	0.006	0.0421	38.1289
64	0.0001	1.0253	8.9918
	0.0004	0.4858	14.1357

	0.0008	0.2813	19.6761
	0.0001	0.2335	22.1321
	0.002	0.1270	31.5608
	0.004	0.0647	36.6318
	0.006	0.0421	38.1192

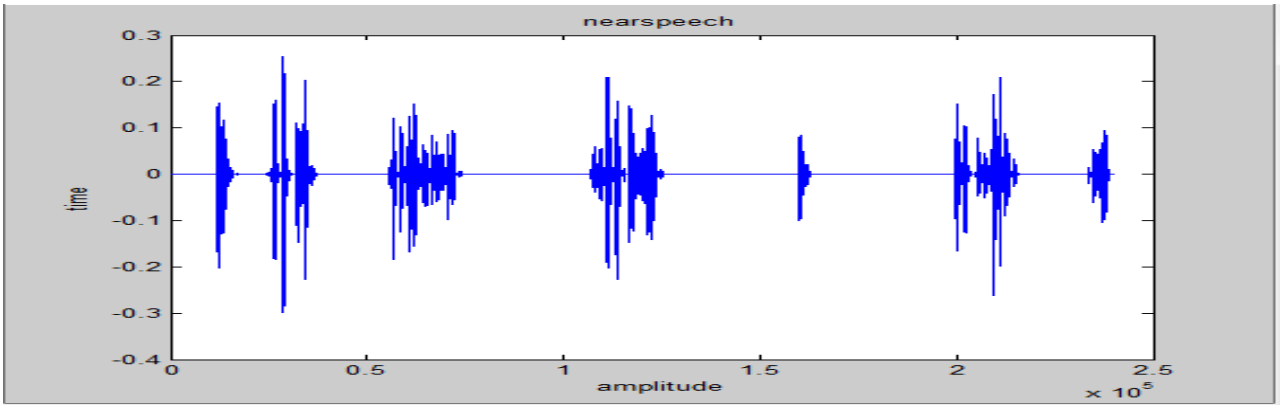


Fig 1 Near speech signal

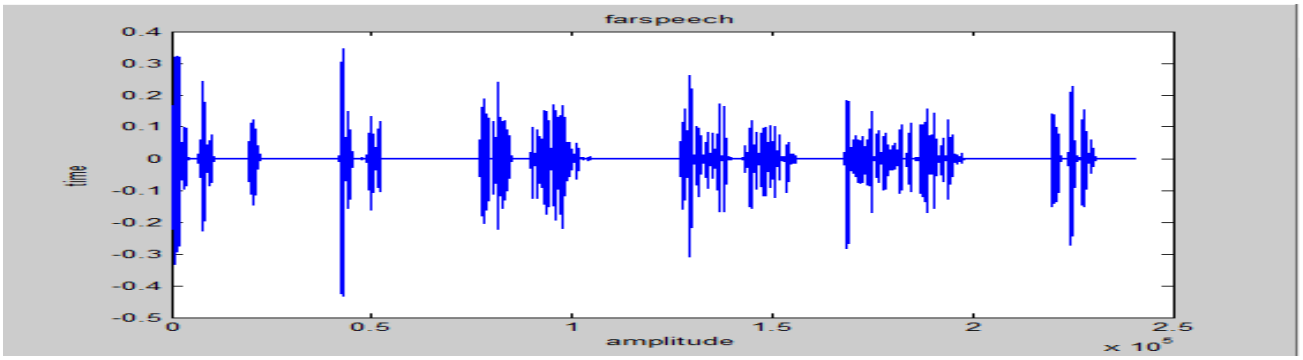


Fig 2 Far speech signal

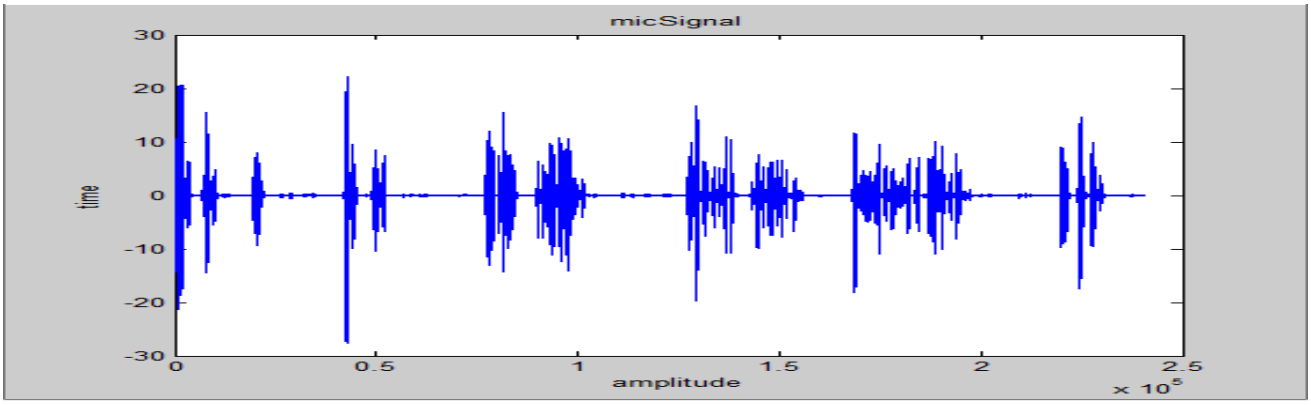


Fig 3 Microphone signal

Table no.6NLMS output for Audio file 3

Filter order	Step size	Mean Square Error (MSE)	Echo Return Loss Enhancement (ERLE)dB
2	0.0001	4.2427	10.5036
	0.0002	2.7688	14.4333
	0.0003	2.1613	17.8212
	0.0006	1.3961	26.3524
	0.0008	1.1467	30.6398
	0.001	0.9741	33.3310
	0.004	0.2525	39.3500
4	0.0001	4.2427	10.4764
	0.0002	2.7688	14.4496
	0.0003	2.1613	17.8220
	0.0006	1.3961	26.3278
	0.0008	1.1467	30.6405
	0.001	0.9741	33.3377
	0.004	0.2525	39.3706
8	0.0001	4.2427	10.4825
	0.0002	2.7688	14.4275
	0.0003	2.1613	17.8094
	0.0006	1.3961	26.3539
	0.0008	1.1467	30.6409
	0.001	0.9741	33.3336
	0.004	0.2525	39.3633
16	0.0001	4.2427	10.4969
	0.0002	2.7688	14.4242
	0.0003	2.1613	17.8145
	0.0006	1.3961	26.3352
	0.0008	1.1467	30.6389
	0.001	0.9741	33.3119
	0.004	0.2525	39.3702
32	0.0001	4.2427	10.4922
	0.0002	2.7688	14.4275
	0.0003	2.1613	17.8204
	0.0006	1.3961	26.3382
	0.0008	1.1467	30.6393
	0.001	0.9741	32.3283
	0.004	0.2525	39.3769
64	0.0001	4.2427	10.4959
	0.0002	2.7688	14.4292

	0.0003	2.1613	17.8148
	0.0006	1.3961	26.3410
	0.0008	1.1467	30.6498
	0.001	0.9741	33.3258
	0.004	0.2525	39.3654

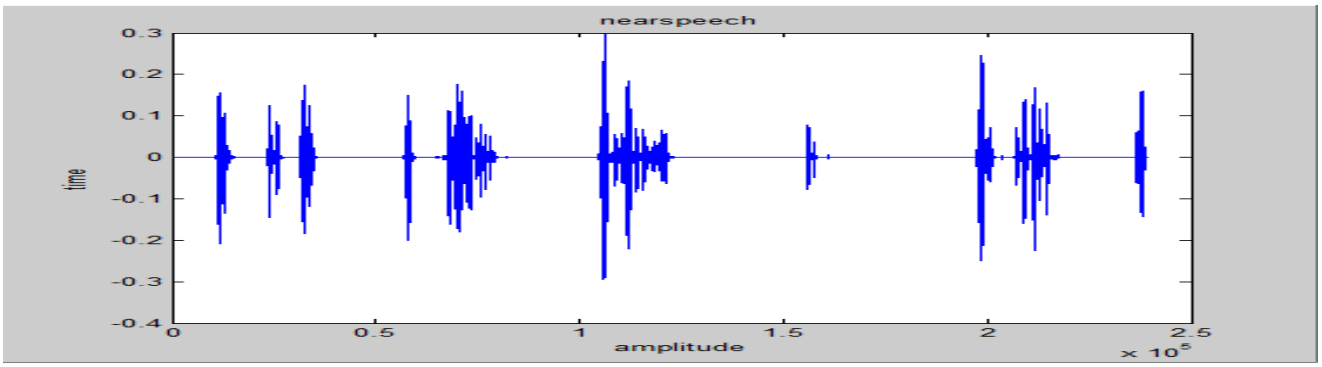


Fig 1 Near speech signal

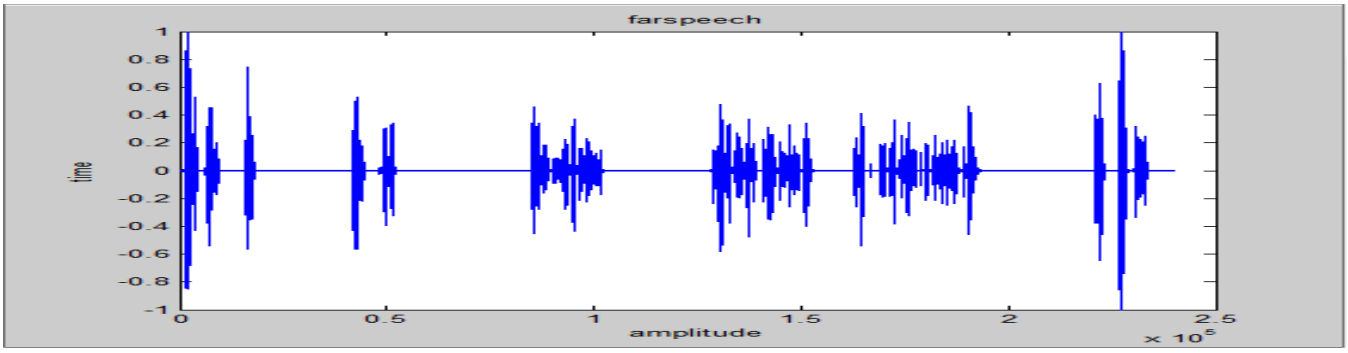


Fig 2 Far speech signal

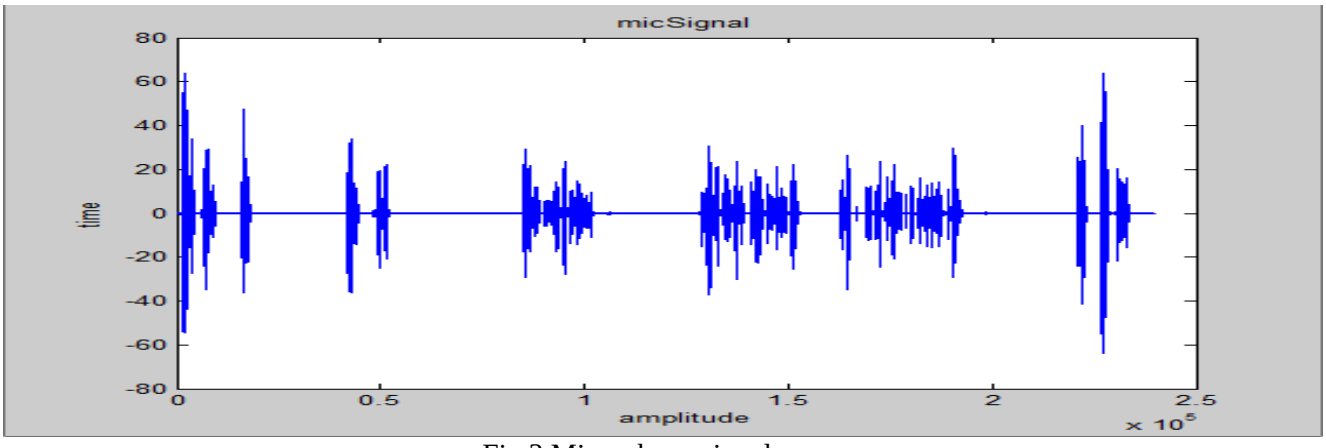


Fig 3 Microphone signal