Vehicular Traffic Noise Reduction using Fuzzy Logic based Active Noise Control System

Manoj Kumar Sharma, Renu Vig

Abstract: The exposure to the noise emanating from the vehicles is resulting in adverse effects on our health. This requires determined efforts for the alleviation of road noise. The implementation of noise reduction techniques is the need of the hour to safeguard ourselves from the rising traffic noise conditions. This paper aims to investigate prominent vehicular noises in peak traffic conditions in Chandigarh, India and to reduce identified noises using fuzzy logic based active noise control system. A study was conducted to record the sound pressure level at the peak traffic timings during the day using the sound level meter in Chandigarh, India. The vehicle horns are identified as major sources producing high noise levels. The horn noise signals of bus, car, two-wheeler, and three-wheeler were recorded. A Fuzzy Logic based Active Noise Control (ANC) system was developed in MATLAB software and was implemented for the reduction of recorded vehicle horn noises. The performance of the Fuzzy Logic based Active Noise Control system for noise reduction is compared on the basis of error plots, signal to noise ratio (SNR) and mean square error (MSE). The proposed Fuzzy Logic based Active Noise Control (ANC) system is successful in reducing the noise levels of a bus and two-wheeler by 23 dB(A) each. Noise is reduced by 28 dB (A) and 25 dB (A) in the case of car and three-wheeler horn respectively. The fuzzy based ANC system is successful in reducing the noise to comfortable levels which can be implemented in real-time for attaining permissible limits of noise.

***Index Terms*: Traffic noise, vehicle horn noise, active noise control, fuzzy mklogic-based ANC, horn noise reduction**

I. INTRODUCTION

The fast urbanization has resulted in manifold growth in the number of vehicles on the roads which has given birth to another major problem—traffic noise pollution. The high traffic noise has been rated as one of the most prominent cause of stress in urban areas. In developing countries, the increase in the use of vehicles is faster than the increase in infrastructure (like roads, parking, etc) development for their use. This leads to more and more population vulnerable to pollution caused due to vehicles. The studies have carried out to investigate the effect of road traffic noise on health in relation to different disease affecting mankind such as cognitive impairment in children [1] diabetes in adults [2], noise annoyance [3], sleep disturbance [4,5], Breast cancer [6]. Jordi Romeu et al.[7] had studied the effect of noise on neonates in the Neonatal Intensive care unit. The environmental and transport noise has also affected the male fertility and health [8-10].

The studies have been done to predict and mitigate the road traffic noise levels across the world [11-13]. Noise mitigation strategies include a reduction in the source, active noise control, optimized traffic operations, better infrastructure planning [14]. ANC system has been effectively implemented for noise reduction in many applications such as cockpit noise, transformer noise, server noise, etc. based active noise control (ANC) system is applied. The use of soft computing methods such as neural networks, fuzzy logic, etc with the ANC system has been applied in many applications [15, 16]. In the present work- (i) prominent traffic noise sources are identified from a field study in Chandigarh India, (ii) fuzzy logic based active noise control (ANC) is applied for noise reduction and (iii) performance analysis of technique applied is done.

II. NOISE REDUCTION OF HIGH NOISE HORN SIGNAL

There are two methods of controlling the noise i.e. passive noise control and active noise control. The passive noise control (PNC) method uses passive techniques such as enclosures, barriers, and silencers to attenuate the undesired noise. However, for low-frequency noise, the thickness required for passive absorber is large. Thus, it is not feasible in many cases. In such cases, the ANC technique is applied which is based on an adaptive algorithm. In present work, ANC system using fuzzy based least mean square (LMS) algorithm is applied for vehicular horn noise reduction.

In the present study, traffic noise is recorded with sound level meter and video recordings of traffic during office peak hours to find the cause of prominent noise sources. It is observed from recordings that vehicle horns are major culprits for peak noise pollution. Thus, to curtail the noise, it is necessary to reduce the vehicular horn noise. The observations indicate that there are many reasons for use of horns which include traffic congestion, improper stoppage, driver habit, peak office timings, etc. For the noise reduction, horn noises of the prominent vehicles i.e. bus, car, two and three wheelers were shortlisted and recorded.

III. ACTIVE NOISE CONTROL

In the active noise control (ANC) system, a noise signal is captured and the anti-noise signal is generated using a control algorithm, which is destructively interfered with the noise signal to reduce its effect. The concept of active noise control is illustrated in Fig 1.

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The noise and anti-noise signal are superimposed to have reduced noise level.

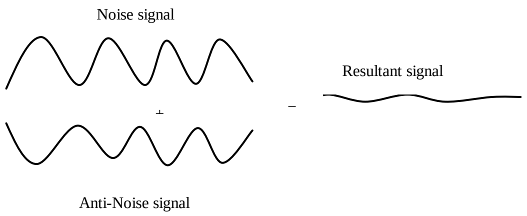

Fig 1. The concept of Active noise control

The block diagram for the active noise control system is shown in Fig 2 [15]. As shown in Fig. 2 the input noise signal x(n) is passed through the acoustic path P(z) and disturbance signal d(n) is obtained. The anti-noise signal y(n) is obtained from the secondary loudspeaker and combined with noise signal d(n) to low-frequency the error signal e(n) called residual noise. The error signal is fed to the controller to update the weights so as to generate a desirable anti-noise signal y(n). Least Mean Square (LMS) algorithm is commonly used to update weights in the active noise control system.

In LMS algorithm weights are updated as per equations (1) to (3)

$w(n+1) = w(n) + \mu(n)e(n)$ (1)

$e(n) = d(n) - y(n)$ (2)

$y(n) = d(n) - w(n)\, x(n)$ (3)

where, $\mu(n)$, $e(n)$, $d(n)$, $w(n)$ are the step size, error signal, desired signal, filter coefficients at *nth* instant respectively.

The response of ANC is greatly influenced by the value of step size chosen in the LMS algorithm. There are many variants of LMS algorithm which were developed and used to evaluate the step size which is varying in many cases [17]. The soft computing techniques such as fuzzy logic, neural network, etc. are applied to the LMS algorithm to make it more flexible and efficient [18]. The results obtained using soft computing approaches are better than the conventional techniques. Fuzzy logic has been used for calculation of variable step size of the LMS algorithm.

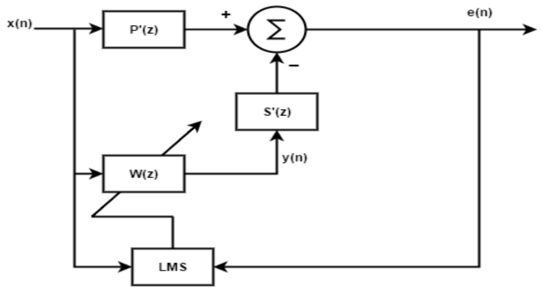

Fig 2. Block diagram of the ANC system using LMS algorithm [17].

IV. PROPOSED FUZZY NORMALISED SQUARED ERROR LMS (FNSE_LMS) ALGORITHM

The present work is intended to implement a fuzzy logic based variable step size LMS algorithm for an active noise control system for vehicle horn noise reduction. It involves normalized squared error and change in normalized squared error as antecedents with step size as consequent. The proposed algorithm, called Fuzzy Normalised Square Error LMS (FNSE_LMS) is written in general format as per equation (4)

FNSE_LMS: $\mu(n) = FIS(E(n), \delta E(n))$ (4)

where E(n) is normalized squared error of nth instant.
δE(n) changes in normalized squared error of nth instant.
n is the index for no. of iterations.
μ(n) is the step size of nth iteration.

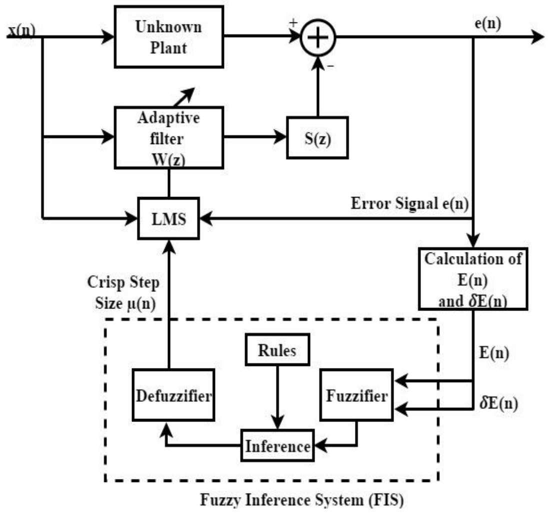

Fig 3 Block Diagram of the proposed algorithm

The block diagram of proposed Fuzzy Normalised Squared Error LMS (FNSE_LMS) based ANC system is shown in Fig.3

The Fuzzy inference system consists of two fuzzy inputs, E(n) (normalized squared error) and δE(n) (change in normalized squared error) obtained from the ANC system. The values of E(n) ranges between [0,1] and δE(n) lies between [-1,1]. The squared error E” is normalized in the range of 0 to 1. The output of FIS is step size μ(n) which is used for weight updation in the LMS algorithm. The normalization is performed as per equation (5).

$$E(n) = \frac{E''(n)}{(\beta + \max(|A|))} \quad (5)$$

where $E''(n) = e^2(n)$ is squared error at nth instant

A is array containing values of E”(n) i.e.

$$A = [E''(1)\ E''(2)\ E''(3) \ldots\ldots\ldots\ldots\ E''(n)] \quad (6)$$

β is small constant value.

| . | denotes the absolute operation.

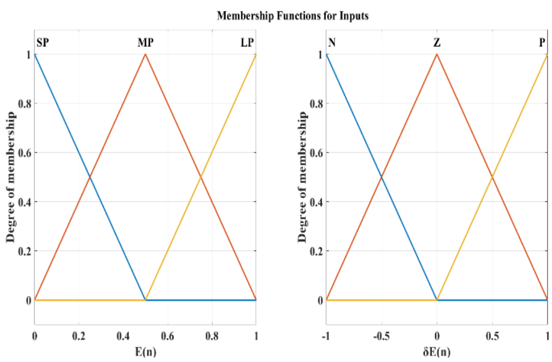

Fig. 4 Input Membership Functions

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For obtaining normalized squared error E(n), as per (5), the E"(n) squared error at the nth instant is divided by maximum value of set A. A small constant, β is added to the maximum value of | A | to avoid denominator becomes zero. The same procedure is followed to normalize the input reference signal x(n).

In the proposed active noise control system, the vehicular horn noise, x (n) is passed through the plant P(z) to obtain disturbance signal d(n). The anti-noise signal y(n) is superimposed with d(n) to get residual noise signal e(n). The anti-noise signal y(n) is obtained from LMS algorithm whose weights are updated using equation (2) which used variable step size μ(n) obtained through fuzzy inference engine.

Table 1 Rule base for proposed FIS

E(n) / δE(n)	SP (Small positive)	MP (Medium Positive)	LP (Large Positive)
N (Negative)	Z (Zero)	Z (Zero)	S (Small)
Z (Zero)	Z (Zero)	M (Medium)	L (Large)
P (Positive)	L (Large)	VL (Very Large)	VL (Very Large)

Table 1 shows the linguistic variables and their corresponding linguistic values of membership functions. The membership functions corresponding to consequents and antecedents are shown in Fig 4 and Fig 5 respectively.

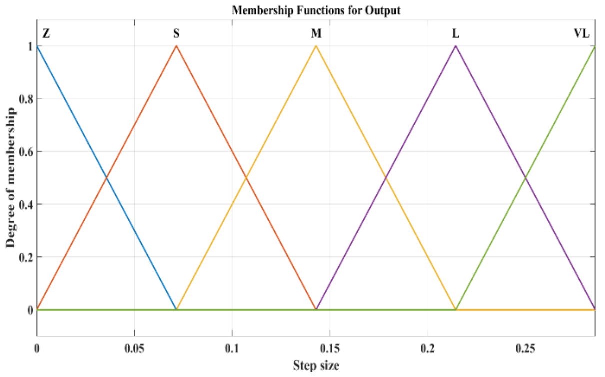

Fig. 5 Output Membership Functions

V. SIMULATIONS AND RESULTS

The results of traffic noise measurement in Chandigarh are found to be alarming. During the office peak timings in a working day, the noise level surpasses the permissible limit of 50 dB by 28 dB at traffic lights and 27 dB at the roundabout. The exposure to such a high noise in routine leads to many silent diseases like anxiety, hypertension, headache, uneasiness, etc. For the application of noise reduction technique, the most commonly plying vehicles are selected for horn noise recordings i.e. bus, car, two-wheeler, and three-wheeler. For observing to what extent noise is suppressed signal to noise ratio, SNR is calculated using equation (7).

$$SNR=10\log_{10}\left(\Sigma d^2(n)/\Sigma e^2(n)\right) \quad (7)$$

Noise Mitigation using Fuzzy based Active Noise Control System

The simulations are conducted for the recorded horn noises from different vehicles. The proposed fuzzy logic based active noise control (ANC) system is implemented on horn noises as per scheme is shown in Fig 3. The reduction of noise for all the vehicles is compared on the basis of error plots, SNR and mean square error. For simulation purpose, β is taken as 10-10, length of the input reference signal x(n) is taken as 40,000 samples and the sampling frequency is 8 kHz. The results obtained are presented as below:

5.1 Case 1: Bus horn

The first simulations concerns with bus horns signal. Within the city, buses are not allowed to use pressure horns, however, the horns being used add to the substantial noise. The bus horn noise signal and residual (error) noise signal are shown in Fig 6 and Fig 7 respectively. The fuzzy based active noise control system is successful in reducing the noise levels.

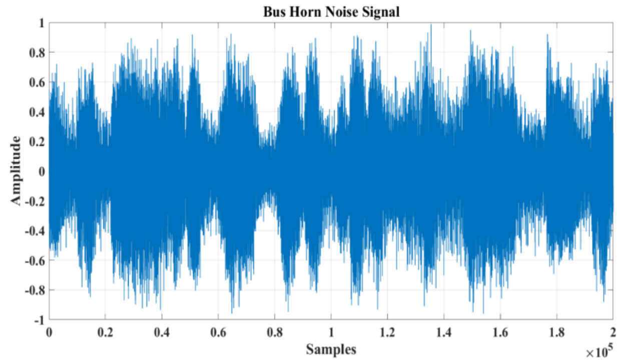

Fig 6. The plot of a bus horn noise signal.

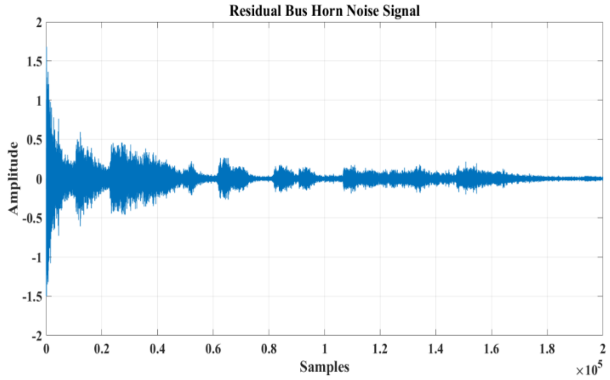

Fig 7. Residual bus horn noise signal after fuzzy based ANC implementation.

The SNR obtained is 22.9 dB which can bring the noise at a moderate level.

5.2 Case 2: Car Horn

With increasing economic standards, the number of cars has increased manifold in the city. This has resulted in long queues on the traffic lights and snarls at roundabouts. Fig. 8 presented the plot for car horn noise signal and the residual signal after fuzzy logic ANC implementation is shown in Fig 9. The signal to noise ratio obtained is 28 dB which is significant to bring the noise at a comfortable level. All the results showed that car horn noise can be successfully controlled to bring it in a quiet zone.

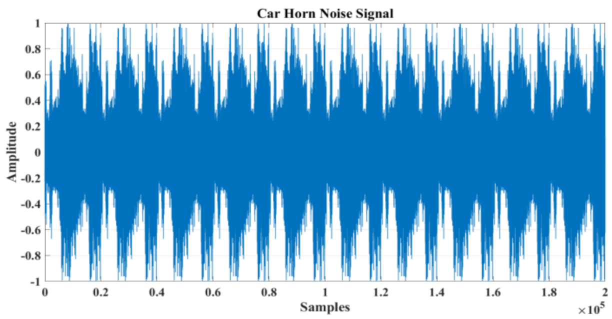

Fig 8. The plot of car horn noise signal..

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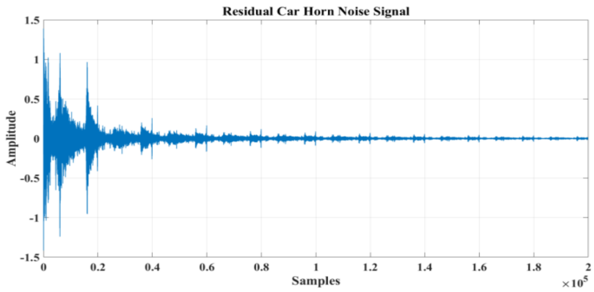

Fig 9. Residual car horn noise signal after fuzzy based ANC implementation.

5.3 Case 3: Two Wheeler Horn

The two-wheelers constitute the largest proportion of the traffic. The horn noise of typical two-wheeler generates quite high noise levels. The plot for two-wheeler horn noise signal and its residual signal when fuzzy logic based ANC is implemented is depicted in Fig 10 and Fig 11 respectively. The SNR for two-wheeler is comparable to previous cases and is 23.93 dB.

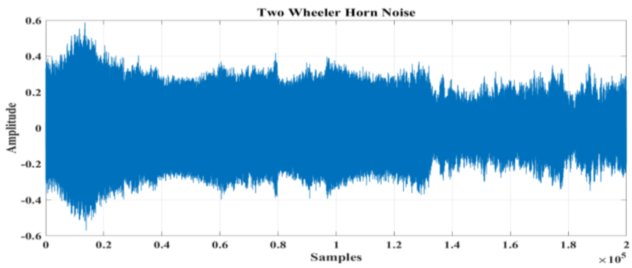

Fig 10. The plot of two-wheeler horn noise signal.

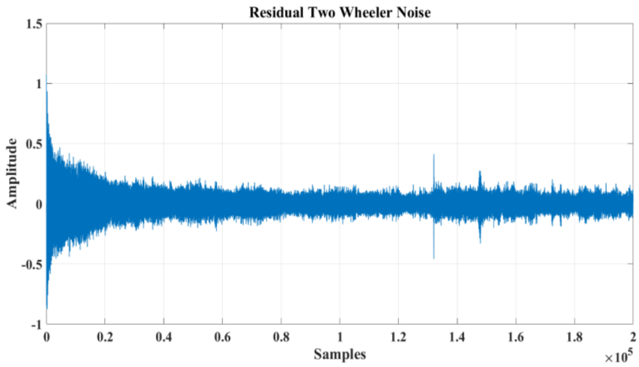

Fig 11. Residual two-wheeler horn noise signal after fuzzy based ANC implementation

5.4 Case 4: Three Wheeler Horn

Three-wheeler (auto rickshaw) vehicles are present in good numbers on the city roads. The LPG run three-wheeler has reduced air pollution level; however, the noise generated by horns is quite significant. The proposed fuzzy logic based ANC system is able to reduce the noise in this case as well and plots for signal and residual noise is shown in Fig.12 and Fig 13 respectively. The considerable value 25.28 dB of SNR is achieved.

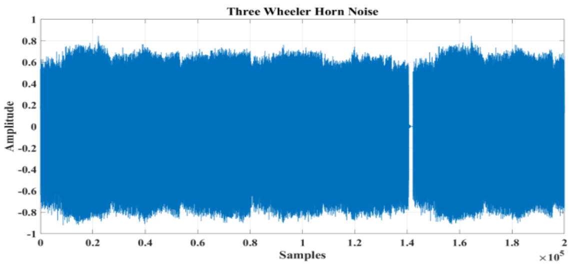

Fig 12. The plot of three wheeler horn noise signal.

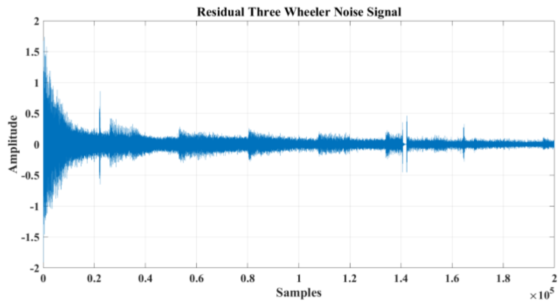

Fig 13. Residual three wheeler horn noise signal after fuzzy based ANC implementation.

Table 2. SNR values for different vehicle horn noises applying novel fuzzy logic based ANC.

Case No.	Noise Signal	SNR (in dB)
1	Bus Horn	22.9
2	Car Horn	28
3	Two Wheeler Horn	23.93
4	Three wheeler horn	25.28

The SNR values achieved for different vehicle horn noise are tabulated in Table 2 represents that proposed FNSE LMS based ANC is successful is vehicle noise reduction significantly.

5.4 Mean square errors

The plots for mean square error for all the above cases are shown in Fig 14 which shows its good convergence in all the cases. It is observed that in all the cases the actual noise level is quite higher than permissible limits set by the controlling agency. The fuzzy logic based ANC system is able to reduce their noises to a greater extent making it to a comfortable zone.

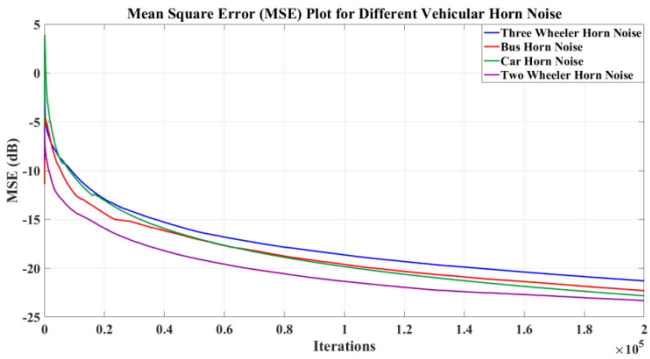

Fig 14. Mean square plot for different vehicle horn noise signals

VI. CONCLUSION

From the study, it is deduced that vehicle horns contribute to maximum traffic noise pollution and their noise reduction is of prime importance for better human health. The study is conducted on the roads of planned city Chandigarh (called the city beautiful) in India. The controlled traffic and free-flowing traffic sites were observed for noise levels at peak office timings on a working day. The use of horns resulted in most of recorded peak noise levels which surpass the permissible noise levels. For the noise reduction, horn noises of the prominent vehicles i.e. bus, car, two and three wheelers were shortlisted and recorded.

The proposed fuzzy normalized square error LMS (FNSE_LMS) based ANC system is implemented on the recorded horn noises signals for their reduction. The results obtained indicate that acceptable limits are reached in all cases. The SNR achieved is more than 23 dB (A) Leq in all cases. The study showcased that fuzzy logic based ANC technique can be implemented in real time for realization of results obtained. The good simulation results encouraged the application of a new algorithm in a real environment.

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