NOISE CONTROL OF ELECTRIC VEHICLES USING ACTIVE NOISE CANCELLATION TECHNIQUE

M.Tech. Thesis

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NOISE CONTROL OF ELECTRIC VEHICLES USING ACTIVE NOISE CANCELLATION TECHNIQUE

A THESIS

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **Noise control of Electric Vehicle using Active Noise Cancellation technique** in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** and submitted in the **DEPARTMENT OF MECHANICAL ENGINEERING, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from August 2020 to June 2022 under the supervision of **Prof. Anand Parey**, Professor, Department of Mechanical Engineering, Indian Institute of Technology, Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

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This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.

Prof. Anand Parey

Desai Umesh Dhanaji has successfully given his M.Tech. Oral Examination held on 24/05/2022

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With regards,

Desai Umesh Dhanaji

DEDICATION

This Thesis is dedicated to my parents, who have been my inspiration and gave me strength, continuously provided their moral, spiritual, emotional and financial support.

To my sister, relatives, mentors, friends and batchmates, who shared their words of advice and encouragement to finish this project.

And lastly, I dedicate this thesis to the Almighty God, thanking him for providing the guidance, strength, health, power of mind, protection and skill to finish this project.

Abstract

An electric vehicle (EV) has a quieter interior than a normal vehicle with an internal combustion engine. Nevertheless, the interior noise of an electric car typically comprises large high-frequency noise components created by the electric motor, which can be irritating and unpleasant to passengers. At greater speeds, structure-borne noise, tire/road noise, and wind noise will become more frequent.

Low-frequency noise sources, such as road noise or wind noise, provide a problem for traditional passive noise reduction systems, which rely on sound-absorbing materials or reflecting panels to minimize vehicle weight and interior space. As a result, the Active Noise Control (ANC) technology could be a viable choice for reducing interior noise in electric vehicles.

On the basis of the principle of superposition, active noise control (ANC) is performed by generating a canceling wave through a secondary source that suppresses the primary (undesired) noise. In this project, we used MATLAB/Simulink to simulate an Active Noise Cancelling system based on the LMS method. A reference microphone, an error microphone, and a canceling or auxiliary noise source make up an ANC system. They are linked through an electronic system. We found that the unwanted noise can be significantly reduced using ANC and noise cancellation depends on the parameters like step size and sample time.

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NOMENCLATURE

- ICE – Internal Combustion Engine
- EV – Electric vehicle
- ANC – Active Noise Cancellation
- PMSM – Permanent Magnet synchronous motor
- SPL – Sound Pressure Level
- PNC – Passive Noise Control
- SQ – Sound Quality
- LMS – Least Mean Square
- FIR – Finite Impulse Response

Chapter 1

Introduction

1.1 Background

Every year, the number of automobiles on the road expands, spurring the creation of ecologically friendly vehicles that run on renewable energy sources. Pure electric-powered cars that are environmentally benign, low-carbon, and low-emission are favorable future trends in the automobile industry. Because of these, environmentally benign and low acoustical features, pure electric-powered vehicle (EV) technology has given the automotive industry a new direction. [1].

Because an EV lacks an internal combustion engine (ICE), the general sound pressure level (SPL) of interior noise is reduced, making the interior quieter than that of a standard combustion car. Other structural and accessory noises, including the noise of the wind, noise of the motor, noise of road-tire, and noise through structure-borne vibration, become predominant without the noise overlaying effect used inside an ICE; buyers have reported that these noise sources comprise a major source of noise in EVs. [2].

For the past two decades, reducing interior cabin sound has been a major focus of study in the automotive industry. This problem was initially addressed using passive noise cancellation techniques such as structural dampening and acoustic absorption. However, as automakers strive for more cost-effective and lightweight designs, vehicle interiors have become increasingly noisy as structural vibrations have increased [4].

Active noise control (ANC) systems have been developed in an attempt to solve this problem, with secondary sources recommending reducing noise inside the cabin. In practice, in-car ANC works by creating a secondary signal that cancels out the noise emitted by the noise source. The remaining discrepancy between these two parts is measured and minimized using a microphone installed within the cabin [5].

1.2 Noise sources inside electric vehicles

In electric vehicles, many sorts of noise sources exist, such as noise through the motor, noise generated through interaction between road and tire, and aerodynamic noise, each having its own acoustic properties. This section examines the characteristics of common noise sources.

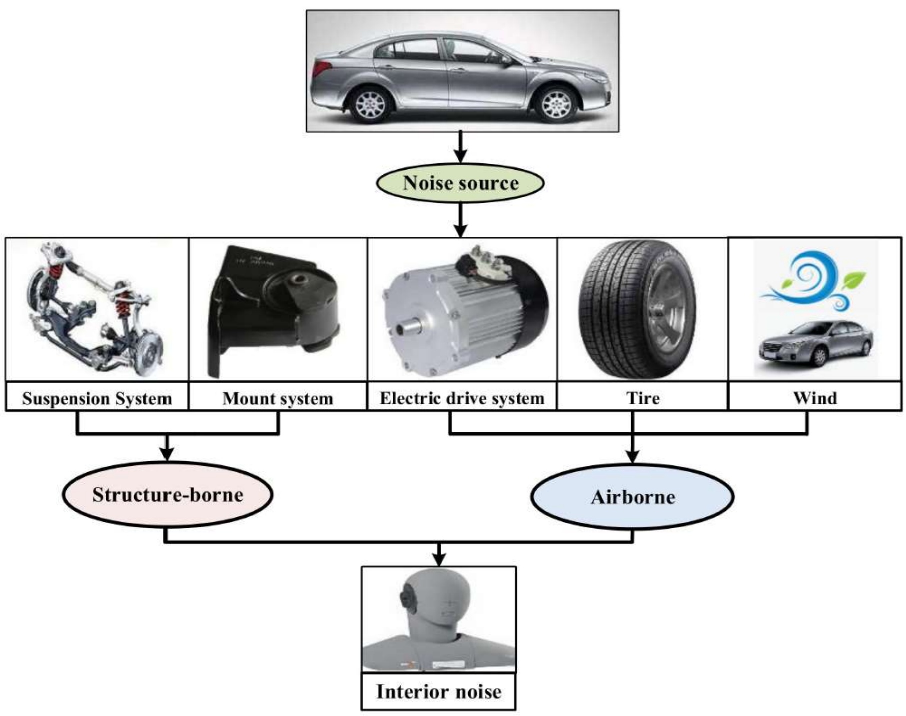

Fig. 1. Sources of noise in an electric vehicle [13]

Contribution	Suspension	Mount	Electric Drive System	Tire
Sound pressure level/dB(A)	57.8	50.3	52.7	49.1
Loudness/sone	11.4	5.1	6.5	4.5
Sharpness/acum	0.712	0.691	0.783	0.753
Roughness/asper	0.439	0.629	0.677	0.513

Table 1. Sound contribution to the interior noise of EV under 50 km/h [13]

The contribution of structure-borne road noise communicated via the suspension system is higher than the other transfer channels in terms of sound pressure level and loudness. The contribution of airborne noise conveyed by electric motor systems to sharpness and roughness is higher than other transfer paths. The proportion of high-frequency sound components is indicated by the sharpness. The electric drive system's high-frequency electromagnetic noise is extremely irritating.

- Motor Noise (Electric drive)

  Because of their high effectivity and high power/torque density, "permanent-magnet synchronous motors" (PMSM) have been widely employed to power electric vehicles. As the PMSM takes the place of the engine, noise through the motor is becoming one of the most significant sources of noise in an electric vehicle. The most common causes of vibration and noise in PMSM are electromagnetic sources, mechanical and aerodynamic. Mechanical noise is caused in large part by mechanical components such as bearings. Its supply identification science is explicit, and its usual frequency is quite low. The cooling fan is usually the source of aerodynamic noise. The electromagnetic noise produced by the typical electromagnetic force applied on the surface of the stator tooth and permanent magnets is intimately related to the electromagnetic parameters and controlling strategy of the motors. Noise through electromagnetics is the most prominent component in most PMSM [6].

- Road-tire noise

  The interaction between both the road surface and the tire produces road-tire noise, which can be divided into two types: air pumping noise and vibration-induced noise. The tire/tread pumping makes an air pumping noise when driving on a tough road surface. The type of the road, the shape of the cavities on the tire, the weight acting on the tire, and the amount of air pressure within the tire all influence the severity of this type of noise. Nonuniformity in road surfaces, fluctuations in vehicle speed, and abnormalities in tire tread patterns generate vibration-induced noise (also known as road booming noise). There are various distinct aspects of vibration-induced noise. Because it is caused by a combination of distinct vibrations from the four wheels, One or two reference sensors are used in ANC approaches are ineffective in reducing it. Second, the spectrum and properties of vibration-induced noise change as road curvature and vehicle speeds change. The nonlinear transmission function between wheel vibrations and road booming sounds is the third. ANC of road noise is more difficult to establish in real-world conditions than in lab settings since the above features are often peculiar to the vehicle of interest. [5].

- Wind noise

  At a velocity of more than 100 km/h, wind noise seems to be the major source of interior noise. It could be categorized based on the sound generating elements, which include, a low-frequency noise caused by the automobile that is driving through the turbulent air or mid-to-high-speed air airflow through the holes (e.g., the car window), and over 300 Hz impulsive noise caused by changing weather condition, and a narrow-band beating noise caused by airflow over open window glasses. Wind noise causes acoustic energy to be focused in car cabins at a frequency between 50–500 Hz [7].

1.3 Noise reduction techniques

Noise is the undesired random sound radiated by various sources, most likely at high levels. People who are exposed to excessive noise may experience irreversible hearing loss. To minimize noise levels, two strategies have been proposed: passive and active noise reduction. Passive noise control (PNC) isolates noise from the outside by placing a material able to absorb sound surrounding the noise source. This method works well for high-frequency noises (>500Hz), but it is not practicable or cost-effective for low-frequency sounds because the cost of absorbent materials rises as the frequency lowers. Active noise control (ANC) makes use of a separate sound source from the noise source. This source produces a noise-degrading sound that is used to lower noise levels. For applications below 500 Hz, ANC can provide reliable noise-canceling sound reproduction [8].

- Passive noise control

  Sound waves are absorbed using different types of sound-absorbent materials such as mufflers, silencers, and obstacles in passive noise reduction measures. At higher frequencies, this approach works well. Noise barriers are frequently porous and built across large areas, with absorbed noise being converted to heat. Stationary equipment, roadways, and railways all use passive noise control. The noise level in residential and business areas has become a severe issue as a result of the massive increase in automotive demand. As a consequence, sound barriers are constructed alongside highways and railroad tracks. On railway tracks and vehicles, passive noise devices like noise enclosures, barriers near track, and track-bed absorbers are also installed. In the industrial side of passive noise control applications, the noisy instrument or machinery is covered by a material that diminishes the unwanted noise, which is cyclic or nearly periodic because the source of noise is the spinning part of the machine (Fig. 2). It is frequently an unrealistic way if the machinery is part of the production line. [8].

Fig. 2. Tube like noise barriers and noise barriers used in industry [9].

Wooden, steel, cement-concrete, polymers, rubber, insulation wool, and composites are some of the materials used to create noise barriers. The material's structure makes it effective in high-frequency disturbances and gives it better low pass filter properties. Passive solutions, on the other hand, tend to be heavy and large when used at lower frequencies because their size and mass are typically dependent on the acoustical wavelength, trying to make them larger. [8].

- Active Noise Control

  As demonstrated in Fig. 3, the principle of active noise control is to generate 180^0 opposite phase noise to dampen the original noise. To build an ANC system, you'll need both sound apparatus and a signal processing software program. The ANC system's performance is determined by how well the chosen hardware and signal processing software fit the situation.

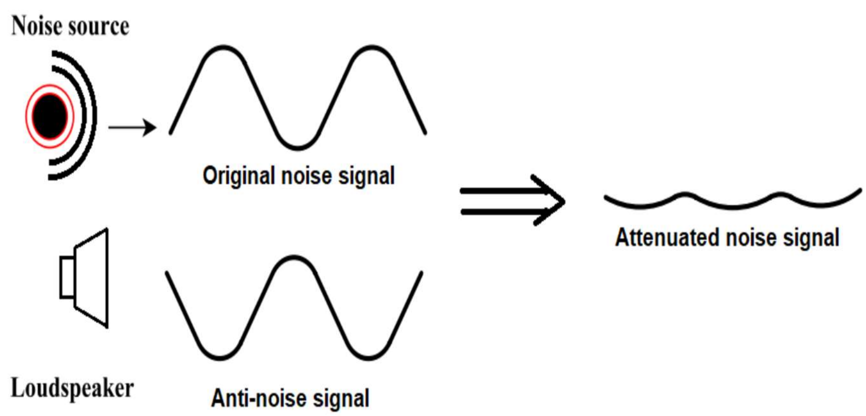

Fig. 3. ANC's effect of illustration [8]

Chapter 2

Literature Review

Huang et al. [3] worked on controlling the noise generated through the structure borne vibrations in an electric vehicle. He has proposed a new interval analysis-based noise source identification approach. This technology can reliably identify noise sources and also provide information on how to reduce interior noise. This method was implemented to capture the noise inside cabin and vibrations of suspension system components utilizing a test EV and 15 tests made through experimental design. The test vehicle's suspension structure-borne noise was mostly dispersed below 400 Hz, according to the findings. The rear shock absorber and front spring were found to be the primary contributors to suspension-related noise.

Quian et al. [13] have investigated the acoustic quality of electric vehicle's interiors based on transfer path analysis. In order to determine the interior sound transfer path and sound source of the EV, a synthesis analysis method of the interior EV noise was used. Second, the excitation signal and transfer function of each interior noise path in the EV was tested using the composition mechanism of interior noise and the basic principle of "transfer path analysis". "Transfer path analysis" and transfer path synthesis were used to create a virtual interior SQ synthesis model that blends experimental and simulation.

Kuo and Morgan [11], Focused on the control of a single broad-band feedforward, the basic adaptive technique for ANC is designed and examined in this study. This method is then tweaked to regulate adaptive feedback and narrow-band feedforward. Several examples demonstrate the use of these ideas to real-world challenges.

Samarasinghe et al. [5] have studied the recent advances in ANC inside a vehicle’s cabin. A concise lesson on ANC approaches was offered to them, along with the reviews of their applicability in decreasing unwanted noise inside autos. Recent advancements have shown considerable increases in terms of noise reduction levels, cost, and complexity of implementation. While the stated earlier strategies may each focus on a specific noise field, they all work together.

Batool et al. [14] have studied to evaluate the effectiveness of an adaptive filtering technique using a MATLAB/Simulink model, with the theme of the calculated transfer function being a time variable to achieve maximum noise reduction. The adaptive filtering active noise controller presented in this article is based on LMS. The effect of changing the filter step size on transformer noise reduction is explored.

Kato et al. [15] propose an ANC system including the installation of a small actuator on the roof of a compact electric car. In this research, they look at how a gigantic magneto-strictive actuator can reduce noise and conduct an experiment on feed-forward and feedback control systems.

Deng and Zuo [16] have discussed the state of the art and current development in vibration due to electromagnetics and noise of Permanent-magnet synchronous motors for electric vehicles in this study, with a focus on the induced mechanism, method of prediction, method of suppression, and sound quality.

Chapter 3

Active Noise Cancellation system

The notion of superposition is used in “active noise control” (ANC) to eliminate the principal (undesirable) noise. The primary noise is combined with an antinoise with the same amplitude but the opposite phase, leading to the suppression of each noise. The ANC system effectively diminishes low-frequency sound where passive techniques have failed or are too expensive or inconvenient. Because it provides for improved active noise cancellation while also decreasing cost, size, volume, and weight, ANC is gaining favor [11].

Because the features of the source of sound and the environment in which it operates fluctuate with time, the undesired noise's amplitude, phase, frequency content, and velocity of sound are time-varying. An adaptive ANC system is required to adapt to these variances. The adaptive filter which is the most popular form is a transversal filter, which employs the “Least Mean Square” (LMS) algorithm [10].

The usage of analog circuitry or digital signal processing is commonly used in modern active noise suppression. Adaptive algorithms study the background noise waveform before constructing a signal which will alter in phase or change the original signal's polarity, depending on the method. This reversed signal is amplified before being sent to a transducer and emits an audio signal that is linearly proportional to the original waveform's amplitude, permitting destructive interference. This nicely lowers the amount of audible noise.

A noise-canceling or noise-reduction speaker can be placed near the source of the noise to be reduced. It must have the same audio strength level as the origin of the undesired sound in the context of dialogue. The cancellation signal-producing transducer, on the other hand, might be put in the location where sound suppression is necessary. This method consumes less energy for cancellation and it is limited to a single user. Noise cancellation becomes more difficult when the three-dimensional wavefronts of the undesired sound and the canceling signal are compatible and cause the zones of destructive and constructive interference to alternate at other locations. Multiple microphones and speakers, as well as the measurement of the enclosure's modal responses, can be used to accomplish global cancellation in small enclosed areas (e.g., a car's passenger compartment).

3.1 Fundamental elements of an ANC system

Essentially, as shown in fig. 3 There is indeed a noise source from which the primary noise signal is obtained using the Reference microphone. (let us refer to this as x(n)), which is then analyzed by the ANC. Then it uses a canceling loudspeaker to make anti-noise (say y(n)). The error mic then picks up the remaining noise. (i.e., e(n)) and fed back to the ANC as feedback. The system's primary purpose is to reduce e(n).

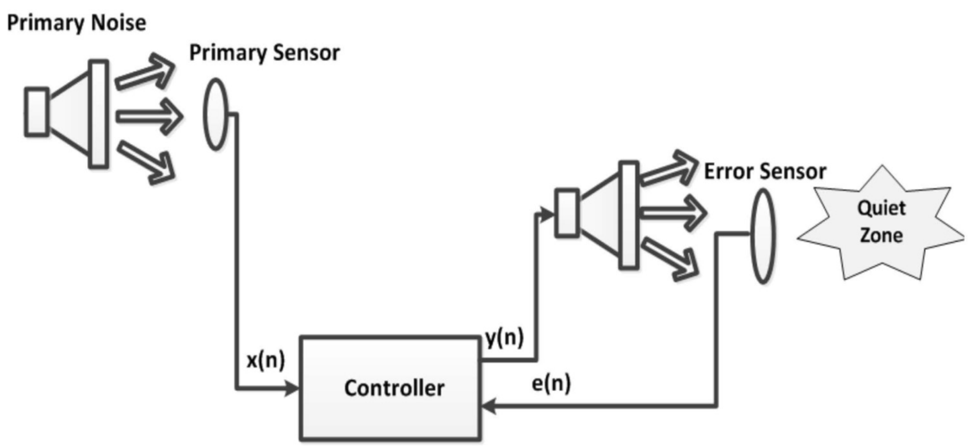

Fig. 4. General representation of an ANC [12]

Here n is the sampling frequency. When a sensor receives the signal, it does not do it in a continuous analog manner; instead, It recognizes the input at discrete times in time and stores it in its memory. So, we constantly need a better sample frequency, which relates to how many instances a sensor takes data within a second (The more frequent the sampling, the better).

3.2 System or Plant identification

An ANC system is all about generating a signal which is opposite in phase and equal in amplitude to the original noise signal. But, in a real scenario, there could be a variety of waveform additions, deletions, and mixing. Thus, our main goal is to figure out this scenario, which is referred to as a system or a plant in scientific terms. These systems can come in a variety of shapes and sizes. However, we will not explore them here; instead, we will go on to identify the system.

Identification of a system is defined as the process of a real-time acoustic system transformation into a purely mathematical equation that may then be used to describe the system as if it were a mathematical model [14].

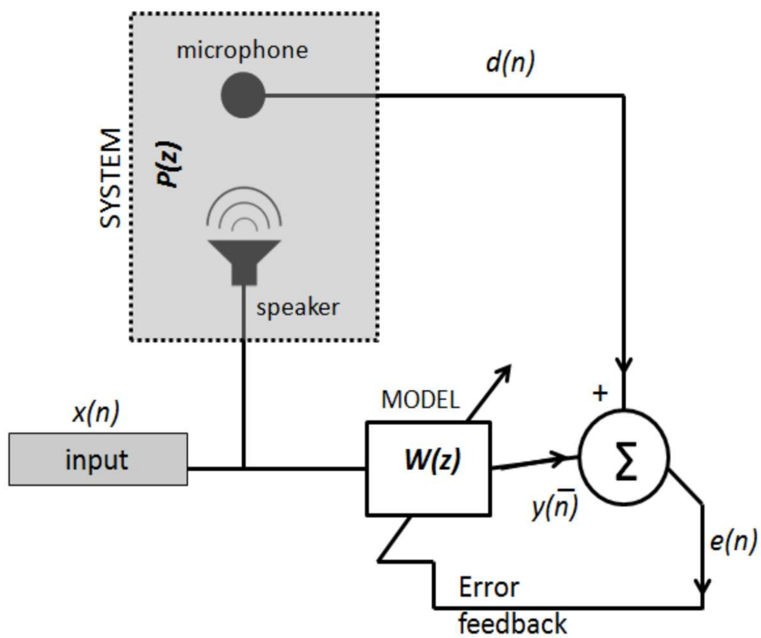

Fig. 5. The steps involved in the system identification procedure [12]

The essential steps in the system identification process are depicted in Figure 4. This is how a model of an actual system is created that may contain many complex events.

The following is an expression for a linear model with output y(n) and impending input x(n):

$$y(n) = f\,[\,x(n), x(n-1), x\,(n-2) \ldots\ldots x(n-N+2), x(n-N+1)]$$

where N is the electronic device's or filter's maximum memory length.

$$y(n) = a_0\,x(n) + a_1\,x(n-1) + a_2\,x(n-2) \ldots + a_{N-2}\,x\,(n-N+2) + a_{N-1}\,x(n-N+1)$$

(A difference equation is the name for this type of equation.)

Now we must equate our desirable output to the original system's output d(n). As a result, we use a weight equation to continuously adjust our coefficients and so acquire the appropriate coefficients utilizing the error signal. The error signal, also referred to as e (n), is the wave that stays inside the medium after the superposition of y(n) and d(n).

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

(Here, e(n) is the signal of the error mic. and d(n) is desired output signal)

And the weight update equation is,

$$w(n+1) = w(n) + \mu\; e(n)\, X \ldots$$

Where,

$X = [\,x(n), x(n-1), x(n-2) \ldots\ldots x(n-N+2), x(n-N+1)]$ and

μ is the step-size.

3.3 Adaptive filter

A computing mechanism that iteratively represents the relationship between a filter's output and input signals is known as an adaptive filter. An adaptive filter uses an adaptable algorithm to modify the filter coefficients.

Figure 2 depicts the basic adaptive filter framework. It's crucial to have an adjustable filter with an output (Y) and an input (X).

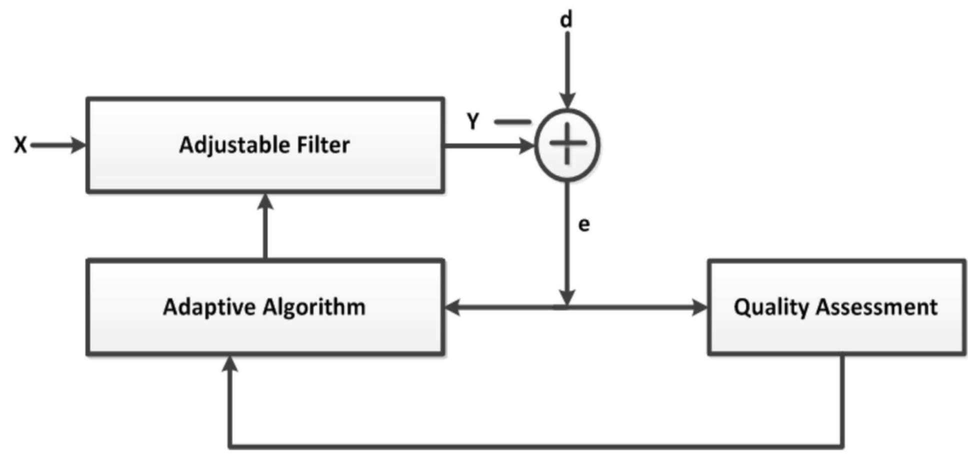

Fig. 6. The framework of adaptive filter [14]

The inaccuracy caused by a discrepancy between the target signal (d) and the output (y) should be kept to a minimum. For the best results, the FIR filter and the adaptive LMS algorithm are used. Because it is solely dependent on the input signal, the additive and homogeneous criteria are not satisfied [14].

- The LMS algorithm

  The "Least mean square" i.e., (LMS) algorithms are a sort of adaptive filter that determines the coefficients of the filter that produce the least mean square of the error signal while resembling the desired filter (difference between the desired and the actual signal).

  The computational efficiency of the LMS method is high, and its update equations are as follows:

$$w(n+l) = w(n) + \mu * e(n) * w(n)$$

where μ is the filter's step size, $e(n)$ represents the error at time n, and $w(n)$ represents the filter coefficients at time instant n.

The following equations define this algorithm:

$$y(n) = w^T(n)\, x(n)$$

$$w(n+l) = w(n) + \mu * x^{-1}(n)\, x(n)\, e(n)$$

where,

$$x^{-1}(n) = S(n)\, x(n)$$

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

The error $e(n)$ optimally represents the original signal $S(n)$.

The algorithm's goal is for the output $y(n)$ to be equal to the transposed $w^T(n)$ filter tap weight times the signal $x(n)$ [14].

3.4 Types of ANC systems

The secondary sound field must be generated by some speakers, some microphones are required to determine the residual error signal at the observation site of interest, and to drive the loudspeaker, an adaptive control system is necessary while reduce residual error. The ANC systems can be categorized as feedback or feedforward, or as narrowband or broadband, according to the operating bandwidth and whether or not reference sensors are fitted.

- Feedforward system

  Feedforward systems are using a different sensor (mechanical, acoustic, electrical or optical) to detect or make a signal that is meaningful to the noise production mechanism. In order to reduce residual error, the ANC system processes the reference signal before driving the loudspeaker. Because the primary noise's coherence with the reference signal determines feedforward ANC systems' performance, The noise source must be close to the reference sensors. The spectra of the source noise also affect the efficacy of the feedforward ANC system. The adaptive device and reference signal must continually monitor the field of primary noise if it is a randomized broadband sound field. Furthermore, if there will be a delay in the adaptive system's electrical processing (because of the processing time) acoustic delay between the reference mic and the canceling speaker is exceeded, the controller's response became noncausal, and system performance worsens. Since the reference signal is typically predictable, so, The criteria for continuous tracking and the causality condition are essentially preserved in narrowband feedforward systems.

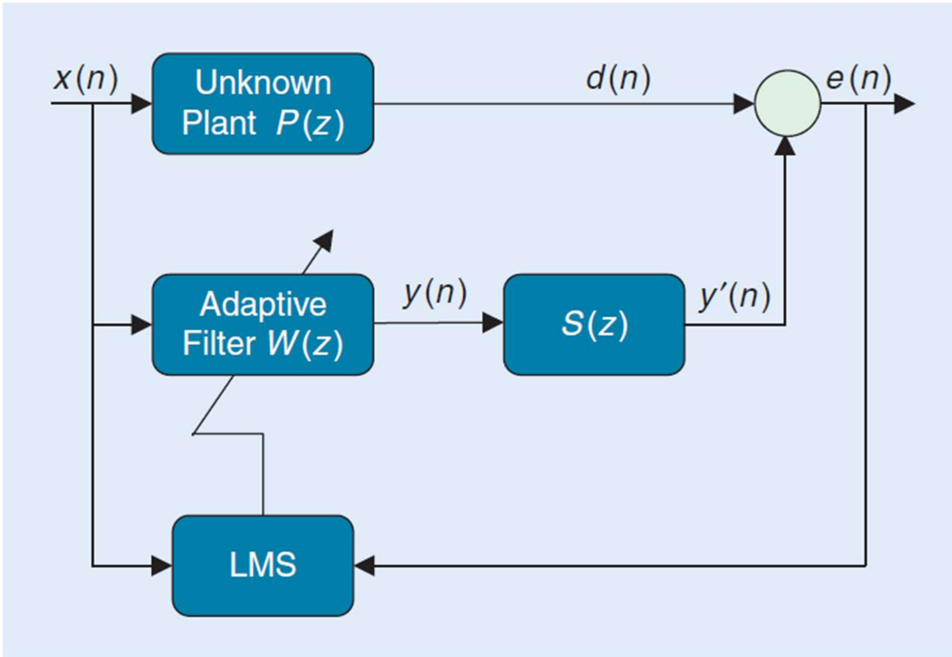

Fig. 7. Schematics of feedforward ANC system [5]

Techniques for broadband feed-forward control are employed if the dominant frequency response of the noise field is broadband. (e.g., noise of road). Identification of the structure for a basic single input – single–output broadband feed-forward control system is shown in Figure 7. The acoustic response from the reference measurement point to the error sensor is the primary path system function P(z), while the secondary path's system function S(z) is a combination of 1) the electronic response of the adaptive filter W(z) as well as the speaker system, and 2) the loudspeaker's acoustic response to the error microphone. The primary path system function P(z) is the acoustic response from the reference measurement point to the error sensor, whereas S(z) i.e., the secondary path system function is a fusion of 1) the digital response of the adaptive filter W(z) as well as the speaker system, and 2) the loudspeaker's audio response towards the error microphone. The adaptive filter W(z) detects time variations in the principal noise source (via the reference signal x(n)) and minimizes the residuals signal e(n) in a car cabin since the dominant path is usually dynamic. The transversal filter, which uses the least-mean-square (LMS) algorithm, is the most popular type of adaptive filter. The error signal's Z-transform is shown in Figure 6 is given as

$$E(z) = (P(z) - S(z)W(z))\ X(z)$$

After the adaptive filter converges in the ideal condition, E(z) = 0, meaning that W(z) = P(z)/S is the optimal filter response (z). To reach this conclusion, The adaptive filter must simulate P(z) and S(z) inversely at the same time. Because an inverse for S(z) does not exist always, there is a more effective alternative, in which an identical filter [to S(z)] was proposed to be inserted along with the path of the reference signal to the weight update of the LMS algorithm. This adjustment takes into consideration the effects of secondary paths.

- Feedback system

  The signal from the error sensor are used to regulate the secondary source(s) directly through a controller in feedback systems. The system can't be modified on a frequency after frequency basis such as feedforward control since the erroneous sensor data is fed back towards the secondary source, hence the complete frequency response (broad-band) must be considered at all times.

  The stability of feedback control systems, which mostly depends on the system delay, limits their performance.

  As a result, the distance between both the error sensor and the secondary source of noise determines feedback control systems' control bandwidth.

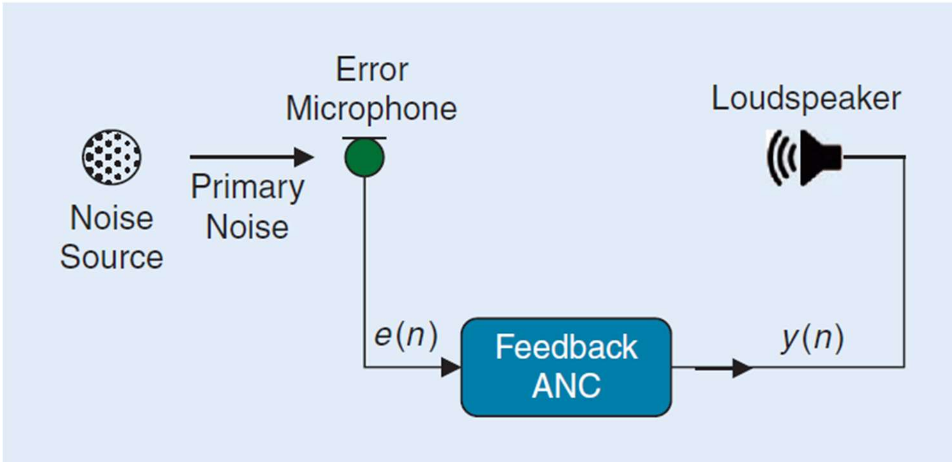

Fig. 8. Schematics of feedback ANC system [5]

Figure 8 depicts a single-channel adaptive feedback ANC system. The internal model control architecture, as well as an adaptive feedback system, should be prioritized can be considered of as an adaptive feedforward system that rebuilds or by combining the error signal with the adaptive filter output, it generates its own reference signal. This method's core idea is to assess the principal noise d(n) available at the error sensor by using it as the adaptable filter's reference signal x(n). If the S(z) is known, the primary noise signal i.e., d(n) can be synthesized using

$$X(z) / Dt(z) = E(z) + St(z)\,Y(z)$$

where the letter "t" stands for an estimated value. The synthesis of the reference signal method filters the signal of the secondary source y(n) using the secondary path estimate St (z) and blends it with e to reproduce the primary noise (n). Feedback control is most commonly used to lessen the effects of noise through road [5].

Chapter 4

Simulation of ANC system on SIMULINK

The control algorithm, two mics (primary noise sensor and an error sensor), and a signal generator for the tachometer signal are all considered. The controller is not physically attached to the sensors. The adaptable feedforward adaptive algorithm is used inside the controller. It has one error sensor input and one tachometer input. The realistic situation is examined for evaluating the ideal model by excluding the uncertain sources for the optimal noise cancellation.

The simulation is broken down into several steps, which are shown below. Three factors must be addressed while designing an ANC model: the primary noise type, the filter structure, and the adaptive algorithms.

4.1 Modeling of Primary Noise (noise source)

Primary noise is the noise signal from the main noise source, in the case of EV, it could be the noise of the motor, noise of the wind, or noise through road-tire contact. Our main focus is to reduce the primary noise.

We are going to model the primary noise in MATLAB/SIMULINK. So that it could be used in developing the model of ANC system algorithm on SIMULINK.

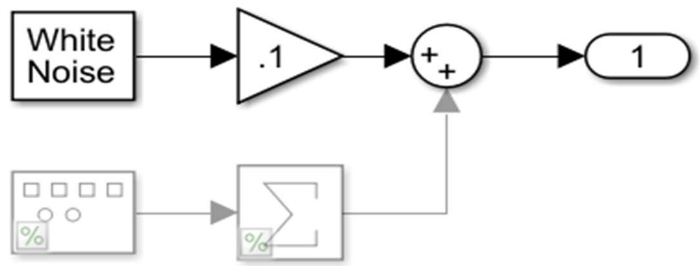

Fig. 9. Model of primary noise source in SIMULINK.

Figure 8 shows the model of the primary noise source developed in SIMULINK. To develop this model, we have used a signal generator block. It generates a signal using a sine waveform with a 150, 250, and 350 Hz frequency combination. This noise source has been used in the algorithm of the ANC system.

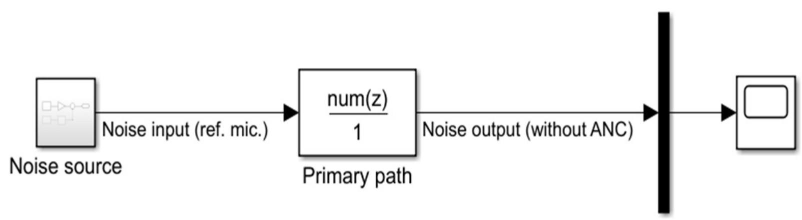

Fig. 10. Model of primary noise path in an ANC system.

Figure 9 depicts that the signal from the primary noise source is given to the discrete FIR filter. The Discrete FIR Filter block applies the given digital FIR filter to each channels of the input signal individually. Static filters with fixed coefficients and time-varying filters with changing coefficients can both be implemented using this block. After the FIR filter signal passes through a mux block. By integrating two or even more signal threads into one, a mux signal simplify the visual aspect of a model. Simulation and code production are unaffected by Mux signals.

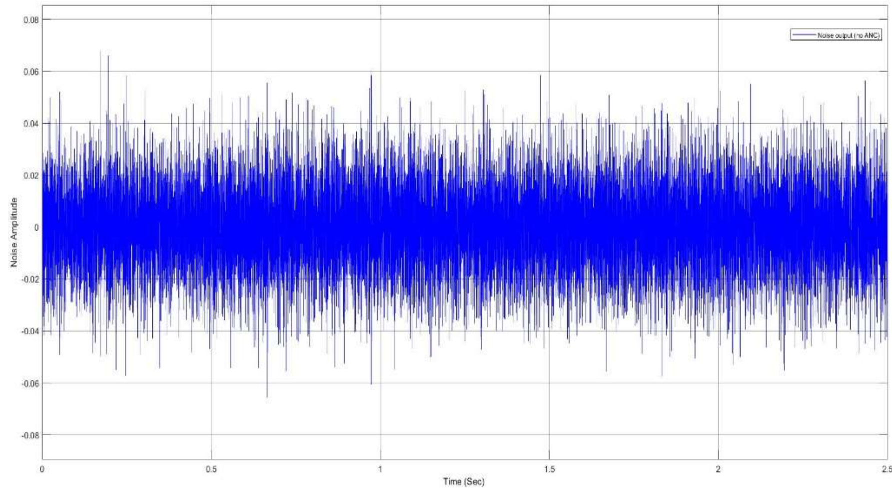

Fig. 11. Primary path of noise source.

Figure 11 shows the output of the model shown above in figure 9 which is showing the primary noise path in the ANC model simulation.

4.2 Modeling of Secondary noise

There are some disagreements in secondary noise field modeling, but they are not as common as in primary sound field modeling. To begin with, its noise domain is well-known. Another benefit is that its source must be regulated by a controller, and the total of the primary and secondary sound fields is the error sensor orientation input. As a result, separate modeling of the secondary noise field without knowledge of the model of the primary noise is impossible. As a result, secondary sound modeling is iterative. The sources of the secondary noise field should be best known first, therefore the secondary sources should be driven by the control system, and the secondary and primary sound fields total should be delivered as one input at the site of the error sensor. If the noisy main information is not provided, the individual secondary field simulation cannot be performed and is recursive. It is possible to determine the transfer function and measuring capacity of an error output sensor using secondary inputs, and the controller model could then simulate the secondary source input. Also included is the primary noise assumption. Once the secondary source inputs have been identified, the secondary field simulation can begin. Control system estimation is a basic model in practice. The error signal is a 'perfect' control system if the primary noise is stationary when there is only a secondary source. At several sites, sound pressure simulations are feasible. After specifying the transfer function between the secondary source input and the error sensor output, the controller can simulate secondary sources. The whole secondary noise field, as well as how to repeat the path of the secondary source, is thus known. Since there is only an erroneous input, the simulation only needs to model one secondary path.

4.3 Model of ANC system

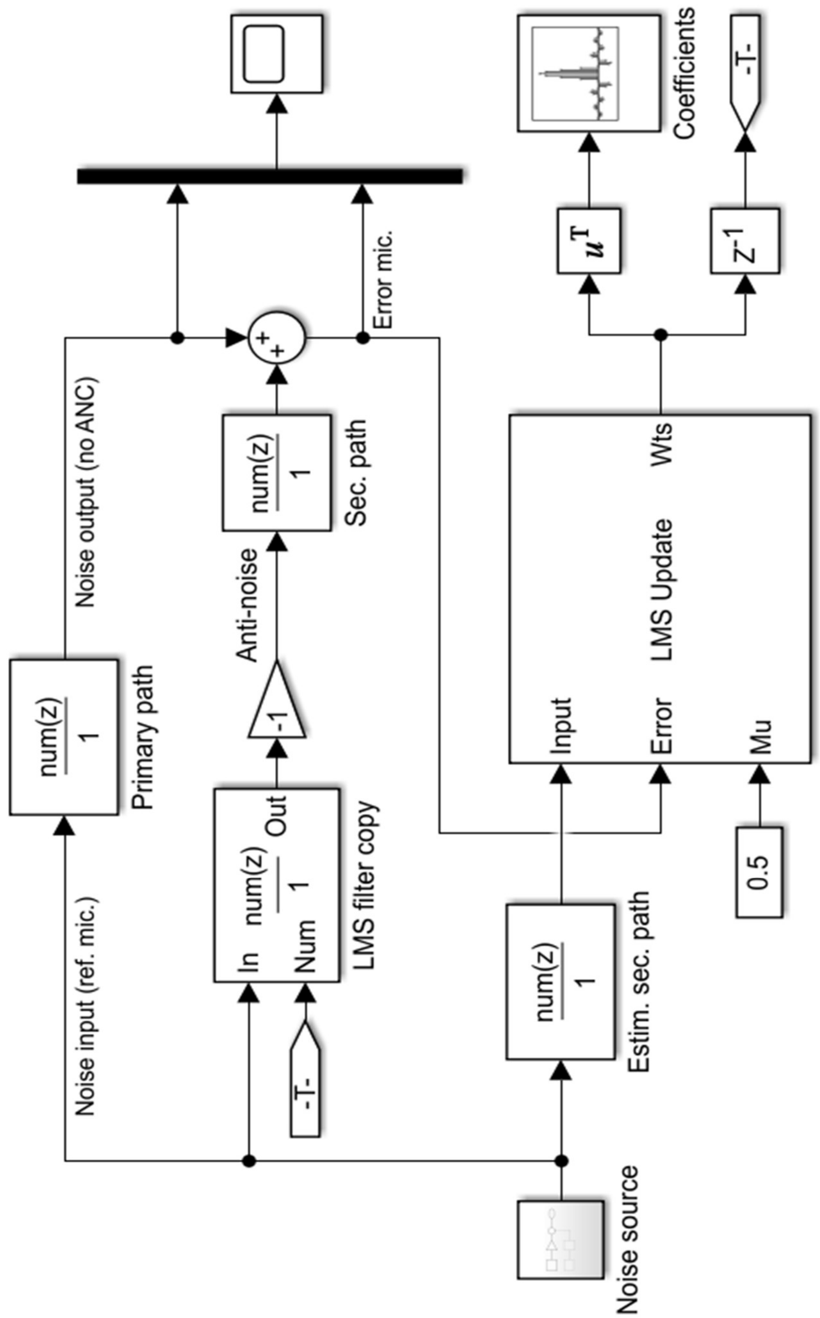

Fig. 12. SIMULINK model of ANC system.

The above figure shows the complete model of an Active noise cancellation system that could be used for controlling noise inside the cabin of an electric vehicle.

This model mainly c of sists two paths through which the noise signal travels. The first path is the primary noise source as shown in figure 9 and the second path is generated through the speaker by the control algorithm of the ANC system which is exactly opposite in phase and equal in the magnitude of the primary noise source.

The nature of the noise-canceling wave i.e., the wave transmitted through the secondary speaker is totally depends upon the sound signal captured by the error microphone placed at the user end.

When the secondary speaker generates sound, both the sound waves generated from the primary and secondary speakers get superimposed or mixed with each other. Hence the effect of both the sound waves will get canceled. This cancellation will not happen suddenly, it is an iterative process. The error mic. will catch the difference after superimposition of both the waves and it will send that signal to the LMS algorithm. The main function of the LMS algorithm is to reduce the error i.e., the sound wave left after the superimposition of primary and secondary noises. Basically, it will filter the received signal and update the weights of the equation. This updated signal will again get fed to the secondary path. So, the secondary speaker will generate a modified sound wave in the opposite phase to the original noise source. Hence again after superimposition, the error will further get reduced. In this way, we can achieve noise cancellation inside the cabin of the electric vehicle.

Chapter 5

Result and discussion

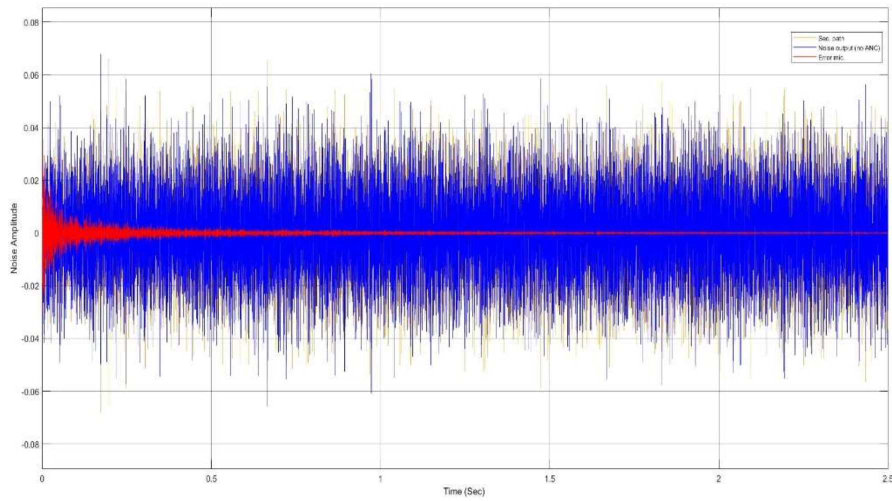

Fig. 13. The result after noise cancellation.

Figure 13 shows the result for the SIMULINK model of the ANC system shown above.

The above graph has been plotted with time (second) versus amplitude (mm). The blue-colored wave is showing the original sound wave generated by the primary speaker without the effect of the ANC system. The yellow-colored wave is the sound wave generated by the secondary speaker with the help of the ANC algorithm. The secondary wave is opposite in phase to the original noise. The red wave signal is showing the difference between both i.e., the primary noise and secondary noise after superimposition. It is the signal captured by an error microphone placed inside the cabin of the vehicle. This noise is the actual noise present at the user end i.e., inside the cabin of the EV after the application of the ANC system. The amplitude of the signal through the error microphone is decreasing with respect to time and its amplitude is less than the original noise source.

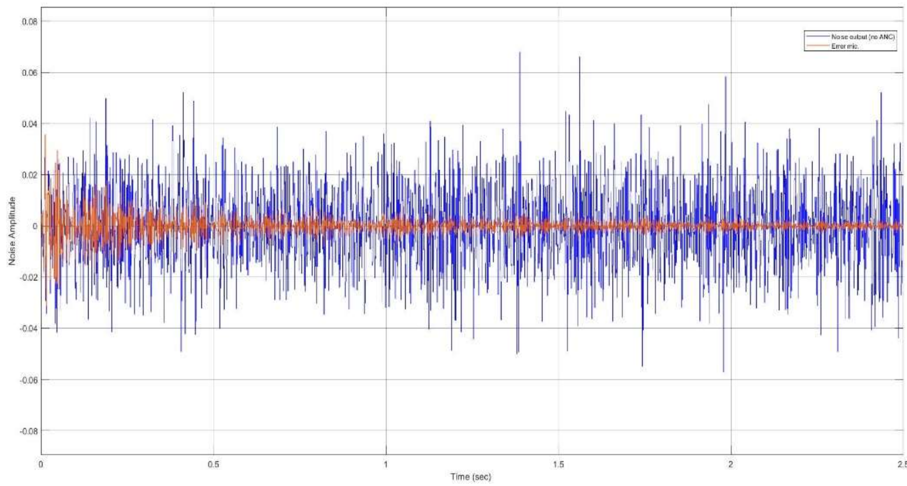

Fig. 14. Effect of ANC system at sample time of 1/1000 seconds.

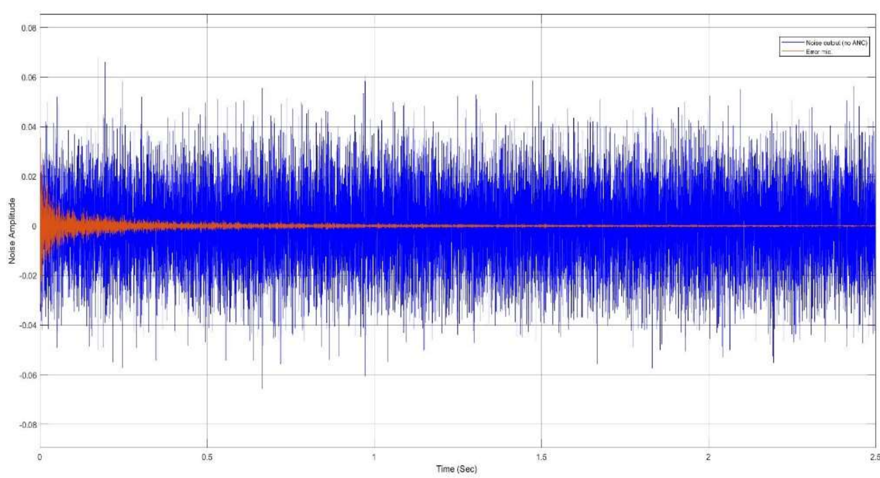

Fig. 15. Effect of ANC system at sample time of 1/8000 seconds.

The above-shown figure 14 and figure 15 reflect the comparison of the secondary path at different sample times. When sample time is very less i.e., 1/8000 error signal is reduced to nearly zero within 0.5 seconds, but in the case of 1/1000 second, it took around 1 second to reduce the error signal.

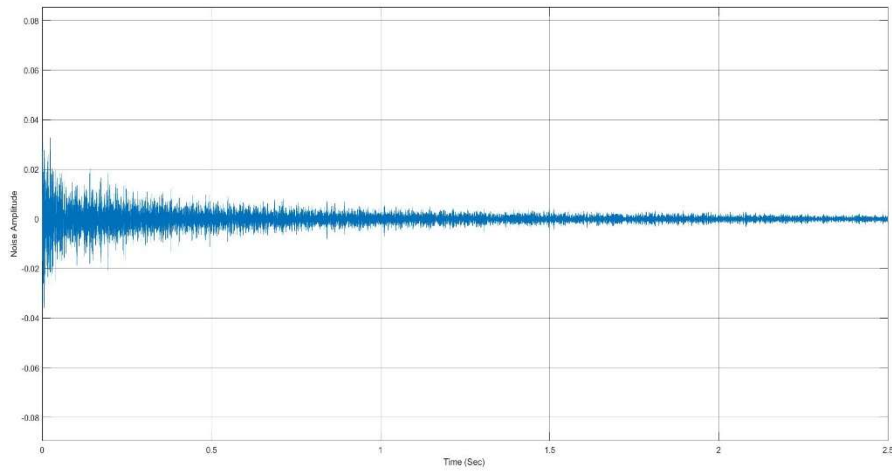

Fig. 16. Error microphone signal at step size of 0.1.

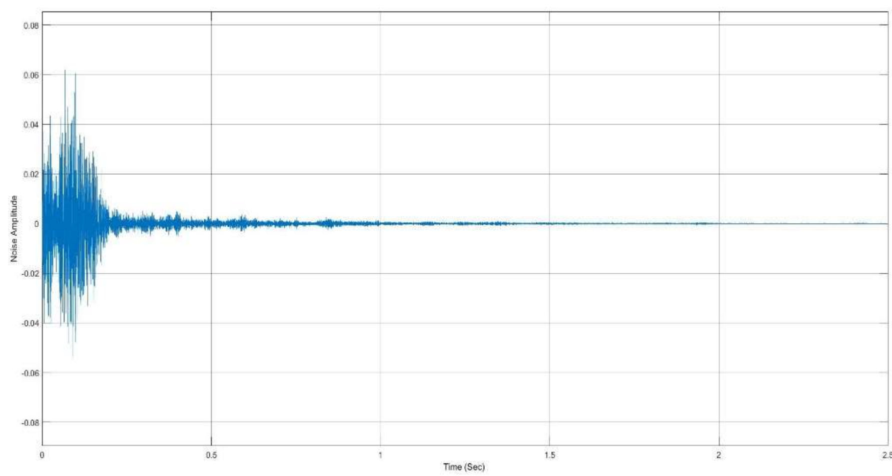

Fig. 17. Error microphone signal at step size of 0.85.

The above-shown figures 16 and 17 depict the comparison of error signal i.e., reduction in overall noise level after the application of the ANC system at different step sizes. In figure 15 it took more than 3 seconds for the error signal to nearly reduce its amplitude to zero and in figure 16 the error signal was quickly reduced to zero within 1 second but it has a lot of initial disturbance.

Chapter 6

Conclusion and scope for future work

6.1 Conclusion

MATLAB/Simulink is used to create and simulate the electric car noise reduction model. The viability of the selected algorithm, LMS, was achieved by lowering the noise level. The examination of the LMS algorithm adaption based on step size and sample time selection is also discussed. The selection of these parameters should be made in such a way that the algorithm's speed of convergence is neither exceeded nor limited. The performance of an adaptive system is inextricably tied to the step size and sampling time. Different step sizes have an impact on stability. We have studied the value of step size from 0.1 to 0.9 and found that the error signal will immediately converge to zero with less initial noise at the step size of 0.5.

If we could able to use this model practically, then it is possible to reduce the noise level inside the electric vehicle very efficiently than the conventional passive noise cancellation techniques. So, it will indirectly help to reduce the weight and size of the vehicles.

6.2 Scope for the future work

- The proposed method could be tested in the coming future in the field of electric vehicles with a real-time arrangement of various sound sources, such as speaker systems and sensors like microphones, with total noise-canceling being checked at each sensor site at different periods.
- Reducing the cost of the ANC.
- The ANC's actual implementation and commercialization.
- Regional ANC integration with upcoming in-car infotainment systems.

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