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Real-Time Application of Active Noise Cancellation for Security of Human Life and Property in concern with social well being

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Abstract

Active noise cancellation is the process of suppression of narrowband interference from a wideband signal using adaptive filtering techniques. There are several advantages of active noise cancellation over conventional passive noise cancellation techniques. Such advantages make active noise cancellation applicable to a wide range of problems and challenges posed in various real-time environments. This paper emphasizes the application of ANC on real-time problems and proposes different models for such applications where ANC can prove to be a better option as compared to passive noise cancellation. the paper proposes a real-time application of active noise cancellation in establishing noise-free communication between security personals, firefighters during an emergency fire situation or maintaining law and order in a crowded and noisy location, the paper describes the use of noise cancellation techniques in ensuring social well-being and saving innocent lives and property.

Keywords: Active noise cancellation, adaptive filtering, least mean square algorithm, echo cancellation.

1. Introduction

The field of digital signal processing has made the electronics system dynamic to the extent that no such application or problem is left which is untouched or can't be solved by the application of digital signal processing. Digital signal processing finds application in almost all the areas related to us humans and playing a key role in making our lives easy and safe. One such application of digital signal processing is active noise cancellation (ANC). Active noise cancellation is based on adaptive filtering in which the digital filters with adjustable coefficients are used to generate the canceling signal. Adaptive filters have numerous applications in the communication system some of which include the application of channel identification, intersymbol equalization in digital communication, to remove undesired interference in antenna systems, noise cancellation in audio systems, estimation of unknown characteristics of unknown systems, etc all these are some of the many applications of the adaptive filter described in the literature. The adaptive filter is adaptive due to an adaptive algorithm that optimizes the filter parameter according to variations in the signal and lets the filter adapt with the variations. The performance parameters of the adaptive algorithm are the least square criterion and the mean square error criterion. The digital filters are classified as finite impulse response (FIR) and Infinite impulse response (IIR) filters, and both can be used in adaptive filter applications but finite impulse response filter is more preferred because of more stability as compared to infinite impulse response filter which has adjustable poles and zeros. Adaptive noise cancellation involves many factors to stress upon and thus provides a vast scope of research as given by the block diagram below:

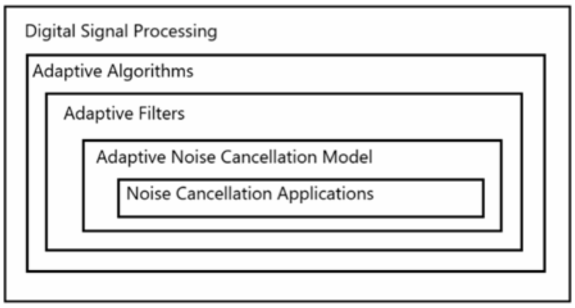

Figure.1 Active noise cancellation fields of research

Figure.1 above gives an overview of the wide range of areas involved in generating an application involving active noise cancellation. This paper lays step by step emphasis on all of the factors involved, gives a comparative analysis, and proposes a novel approach to applying active noise cancellation in real-time problems.

2. Noise Cancellatıon Applications

A thorough literature review reveals several applications of noise cancellation and describes various noise cancellation models few of which are discussed as follows.

2.1. Noise Cancellation for speech enhancement

In this application as the name suggests the noise cancellation technique is used to enhance speech signal by canceling the noise from the corrupted signal and recover the desired signal. The model proposed for speech enhancement is shown in fig.2 below:

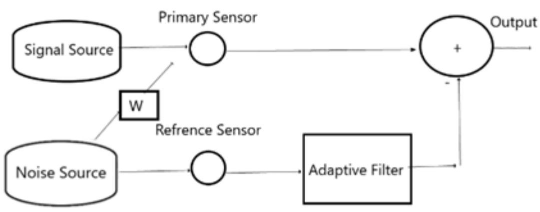

Figure.2 Speech enhancement model

Figure. 2 above shows the noise cancellation application on the speech enhancement model as shown it comprises of two sensors. The primary sensor is the speech signal sensor which records the speech signal along with the additive noise signal whereas the reference sensor is the secondary sensor that records the noise signal for reference. The adaptive filter uses the noise signal from the reference sensor to generate the replica of the noise signal. The filter has to adjust itself to minimize the error between the actual noise signal and the replica generated at the filter output. The filter coefficients are updated continuously by the adaptive algorithm to minimize the error. The efficiency of noise cancellation depends on the coherence of adaptively generated noise and actual noise. This model suffers from the limitation that the error between the noise generated by the adaptive filter and actual noise can never be zero but can only be minimized. For minimizing the error, the authors have proposed the Fast Affine projection (FAP) and the Fast Euclidean Direction Search (FEDS) as adaptive algorithms and compared the results with the conventional Least Mean Square (LMS) and Recursive Least Mean Square (RLS) algorithms and showed an improvement in the experimental results [1].

2.2 Radiofrequency cancellation in a transceiver system

Adaptive noise cancellation techniques also find application in radio frequency cancellation in the transceiver. The technique adopted is based on generating a replica of the transmitter leakage signal which is opposite in phase to the original signal. The replica signal when added with the received signal at the receiver front end results in the cancellation of the leakage signal and reduces the requirement of the passive suppression and improves the efficiency of the communication system. Figure.3 below shows the basic block diagram of the transceiver system.

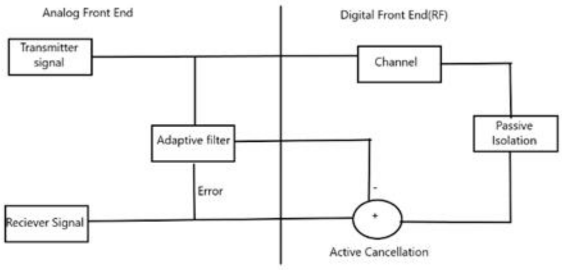

Figure.3 Basic transceiver system implementing active noise cancellation in RF signal.

A transceiver system consists of the transmitter as well as the receiver which transmit and receive simultaneously. It suffers from the problem of the transmitter leakage signal which interferes with the received signal and causes error in reception. The transmitter leakage signal can be suppressed passively but suffers from the disadvantage of high cost and low efficiency, but the use of active cancellation has resulted in an additional suppression of more than 50db at reduced cost and high efficiency. Thus, active noise cancellation has proved to be a better option as compared to the passive suppression of the radio frequency signals in a low noise amplifier input. It has also improved the flexibility of the radio frequency spectrum usage in advanced radio networks.[2]

2.3 Active noise cancellation in wave domain

Active noise cancellation application in spatial regions employs the wave domain approach. In the wave domain approach, active noise cancellation is used to cancel noise over the spatial region instead of some spatial points. Few of the applications of noise cancellation in the spatial region are in the automobile, aircraft, industrial noise cancellation, etc. The main challenges before spatial noise cancellation are that the spatial signal or the real noise fields are highly unpredictable and time-varying. It involves factors such as field energy, sensor location, sound harmonics, and the cancellation are to be performed in the 3D space. So, considering all these factors noise cancellation in the spatial region proves to be more challenging as compared to active noise cancellation applied to the communication system. The basic block diagram applied for noise cancellation in the spatial region is given as under:

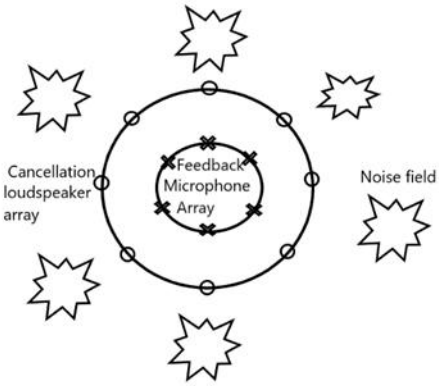

Figure.4 Active noise cancellation application in a spatial region.

Figure. 4 given above shows the active noise cancellation model in the spatial region as shown the model consists of an array of loudspeakers for generating the cancellation field to cancel the noise field generated from the surrounding noise sources. The array of reference or the feedback microphones receives the difference or error signal which acts as feedback for the active noise cancellation algorithms for updating the secondary sound field coefficients for the cancellation loudspeaker array. The number of loudspeakers used in the cancellation array plays an important role in the performance of the cancellation system. When a large number of loudspeakers are used in the control region high level of noise reduction is achieved with a fast convergence rate but when the number of loudspeakers is reduced then active noise cancellation algorithms based on cancellation of energy-based approach perform better than conventional algorithms.[3]

2.4 Noise cancellation in VLSI circuit design

The conventional application of active noise cancellation involves digital signal processors. Digital signal processors suffer from disadvantages such as high computational complexity, high power requirements, processing time, and high cost. All these disadvantages lead to the use of a microcontroller in active noise cancellation systems. Microcontrollers reduced the cost of the system to considerable levels but suffered from low cancellation performance at high bandwidth noise interference. The more advanced implementation of active noise cancellation addressing the high cost and low-performance factors is the use of VLSI circuit design. The basic block diagram of the system architecture implementing active noise cancellation in VLSI is shown in fig. 5 given below.

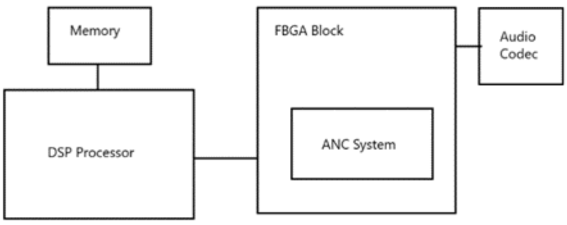

Figure.5 System Architecture for ANC in FPGA.

Figure.5 given above shows the basic block diagram of the active noise cancellation system implemented using DSP processor board and FPGA using VLSI circuit design. The results show that the implementation of ANC using VLSI circuit design has not only reduced the cost but has shown much better performance in reducing noise at various frequency bands.[4]

3 Adaptive Noıse Cancellatıon Models

Active noise cancellation can be achieved in two forms of structural models namely:

3.1 Feedback model

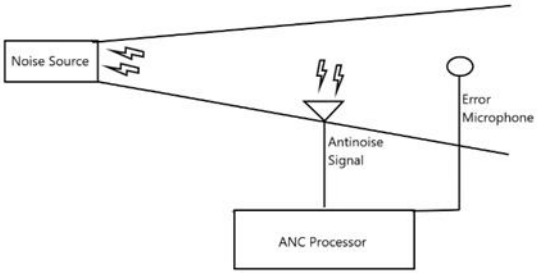

Figure.6 Feedback model

Figure.6 above shows the basic blocks of a feedback model for active noise cancellation as shown it consists of an error microphone that provides the feedback signal to the active noise control system. This feedback enables the adaptive filter to adapt with varying noise and generate the cancellation anti-noise signal.

3.2 Feedforward model

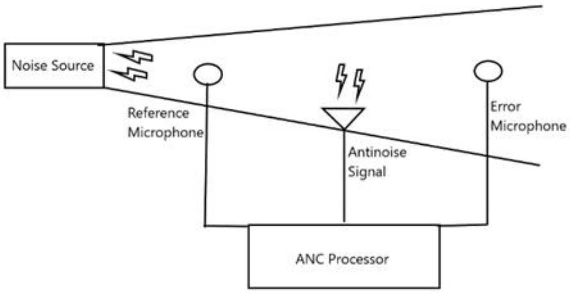

Figure.7 Feedforward model

Figure.7 above shows the basic blocks of the feed-forward model for active noise cancellation. The feedforward model is different from the feedback model in the sense that it has an additional reference microphone in the feedforward path. The reference microphone provides the primary noise signal as a reference signal to the active noise cancellation system and the error microphone gives the feedback of the residual signal. Comparison between the two-feedback model and feedforward model shows that the feedforward model uses one additional microphone as a reference microphone. This reference signal is the actual primary noise signal whereas the feedback model uses the predicted noise signal as the reference signal. Predicting a signal from an actual signal proves to be more effective as compared to that from a predicted signal thus feedforward noise cancellation is a more efficient model of noise cancellation compared to the feedback model [5].

4 Adaptıve Filters

Digital filters are classified as finite impulse response (FIR) and infinite impulse response (IIR) filters. Both FIR and IIR filters can be adaptive but FIR filter is more preferred as they are only zeros filters so only zeros have to be adjusted whereas in IIR filters both zeros and poles need to be adjusted. Figure 8 below the direct form of the FIR adaptive filter:

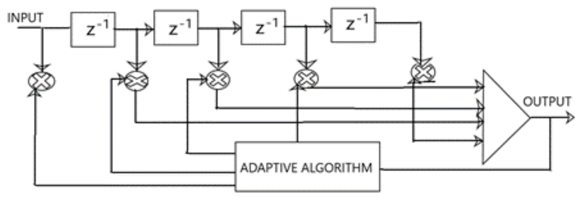

Figure.8 Direct form of adaptive FIR filter

Figure 8 shown above explains the direct form of the adaptive filter. As seen the adaptive algorithm needs to adjust only the zero coefficients and there are no poles thus reducing the complexity of the structure as compared to the IIR structure. Secondly, as there is no feedback path FIR filters are assumed to be more stable as compared to FIR filters which is another merit of FIR filter for designing adaptive filters as stability is a very important parameter in the performance analysis of adaptive filters. More is the stability of the filter more will be the filter practically realizable.[6]-[10]

5 Adaptive Algorithms

The main role of the adaptive algorithm is to adjust the filter coefficients according to the variation of the interfering noise signal so that adaptive cancellation may be achieved. The performance of the adaptive algorithm depends on the stability and the convergence rate, besides being stable it should have a fast convergence rate. Adaptive algorithms in various forms each with advanced characteristics and better efficiency than the previous have been designed and used in adaptive filtering. The most basic of all is the least mean square (LMS) algorithm. It follows the recursive approach for finding the minimum square value of error. It was first proposed by Widrow and Hoff in 1960, it is based on the stochastic gradient descent approach given by the equation below:

$$h(n+1)=h(n)+\mu e(n)x(n)$$

where $h(n)$ is the filter coefficient to be adjusted to minimize the mean square error $e(n)$ between the estimated value and the actual value of the varying signal. Step size μ is kept fixed. The LMS algorithm is quite simple in implementation but suffers from the slower convergence rate, recursive least mean square algorithm is quite complex as compared to the least mean square algorithm but providesa faster convergence rate and thus is an advanced version of the least mean square algorithm. As research is a never-ending process and nothing is final in research many new and advanced algorithms have been developed. These algorithms have proved to be more and more effective and efficient with a much better stability and convergence rate as compared to the basic least mean square algorithm. Some of these algorithms are namely normalized least mean square algorithm (NLMS), block least mean square algorithm (BLMS), variable stem size least mean square algorithm (VSSLMS), Normalized Least Mean Square (NLMS), many more are published in literature and research is still on towards making adaptive filtering more and more effective in noise cancellation application.[11]-[14]

6 Digital Signal Processing

With the development of digital computers and Integrated circuit fabrication technology digital signal processing has become a solution to many signal processing problems. The concept of noise cancellation using adaptive filtering also comes under the umbrella of digital signal processing operations. In adaptive filtering, signals are processed digitally using digital signal processors and microcontrollers which process the signal as well as noise to achieve noise cancellation from the signal in its digital form. Digital signal processing enables the development of adaptive algorithms for varying the coefficients of the adaptive filter with less complexity, more flexibility at a much lower cost as compared to analog signal processing. Advancement in IC fabrication technology is making active noise cancellation through adaptive filtering more convenient and cost-effective to be widely used in real-time applications.[15]-[17]

7 Proposed Model

The model proposed in this paper depicts a real-time application of active noise cancellation for firefighters in firefighting operation and security personal in public security at crowded places. In a fire fighting operation, a firefighter has to work in a noisy environment in which it becomes difficult to interact with each other and causes difficulty in following instructions, giving instructions for medical and other help amongst the large surrounding noise. Similar is the case with the security person who finds it very difficult to interact with other security personal or higher authorities in a noisy crowded location in a situation of security threat. Both the above conditions may be life-threatening for many innocent people if not handled swiftly and carefully. Here active noise cancellation may play the role of lifesaver by helping noise-free interaction between firefighters and security personals in a noisy environment. The model proposed gives a solution to the above-said problem. The proposed model is described herewith:

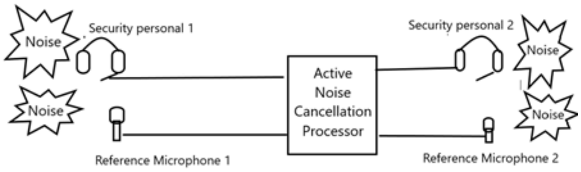

Figure.9 Proposed model for real-time application

Figure.9 above shows the proposed model for real-time application of active noise cancellation in firefighting operation and security personal in public security at crowded places, the model can be equally applied in both situations as in both cases the security person is surrounded by huge background noise and it is difficult to interact but with use of this model the background noise interference is canceled for both the security persons and thus they can communicate with each other more effectively. The active noise cancellation system with reference mic and processor can be easily installed in the security helmet along with the communication headphones and microphone. The role of the reference microphone is to record the surrounding noise and it provides the input to the adaptive filters, the parameters of the adaptive filters are adjusted according to the variations in the noise signal and further predictions are made. The adaptive filters cancel the noise and give the noiseless signal to the security personal headphone so that he may be able to listen to the given instructions clearly without the effect of the surrounding noise. Thus, the proposed models prove to be very effective in solving the problem of noisy communication and better communication may help in saving much innocent life and property in adverse conditions.

8 Simulation and Results

The active noise cancellation model proposed herewith has been simulated, tested using the Simulink tool, and the simulation results are shown below:

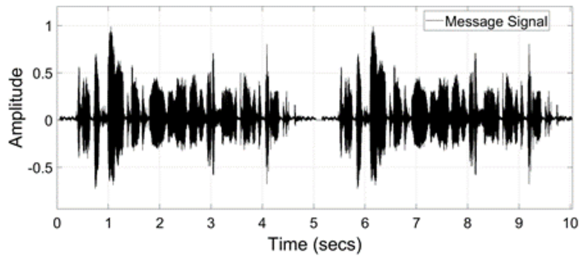

Figure.10(a) Message signal

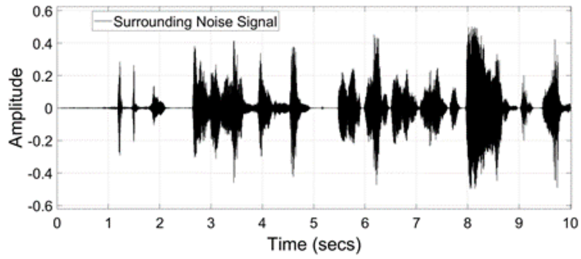

Figure.10(b) Surrounding noise signal

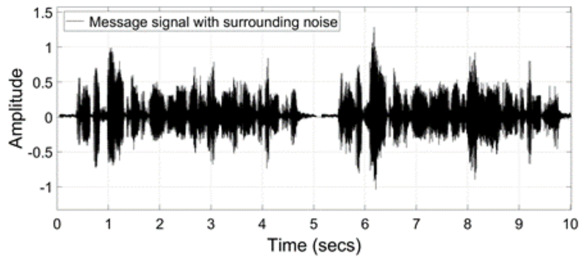

Figure.10(c) Message signal corrupted with surrounding noise

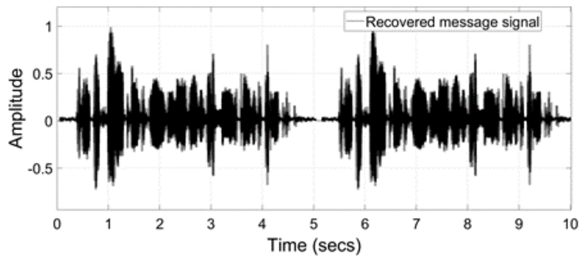

Figure.10(d) Recovered message signal after noise cancellation

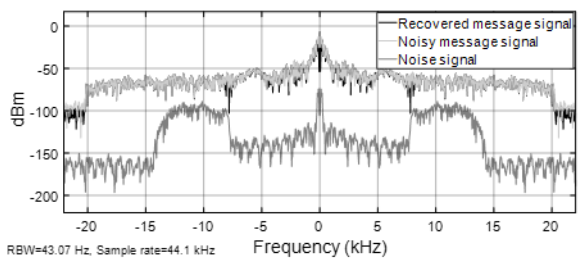

Figure.10(e) Frequency spectrum of the recovered signal, noisy signal, and surrounding noise signal

Figure.10 (a-e) shows the simulation results, Figure.10(a) shows the waveform of the message signal which is a 22050Hz, 64Kbps audio mono speech signal. Figure.10(b) is the output from the audio device reader which is the reference microphone for recoding the surrounding noise signal, Figure.10(c) shows the noise corrupted message signal which is the problem of concern as it is difficult to understand the message due to overlapping surrounding noise. This problem is rectified by active noise cancellation which is the thrust area of this paper, Figure.10(d) shows the filtered message signal after the noise cancellation processor. The difference between the noise corrupted signal and the recovered signal after noise cancellation can be easily seen through the given waveforms as well as can be analyzed listening to an audio output device such as headphones or speakers.The audio output of the headphone shows that the message signal after noise cancellation is audible despite the surrounding sound as compared to without applying the noise cancellation technique, thus solving the problem of noisy communication among security personal in adverse situations. Figure.10(e) gives the frequency spectrum of the recovered message signal, noise signal, and noise corrupted signal for further observation and analysis.

9 Conclusion

This paper gives a detailed overview of active noise cancellation, various components involved in the active noise cancellation process. It shows that the active noise cancellation technique provides vast scope for research in various thrust areas of digital signal processing such as adaptive algorithms, adaptive filtering, active noise cancellation models and it shows that there is huge space for research in the applications of active noise cancellation models in solving real-world problems. This paper also gives an analysis of various existing noise cancellation models used in a real-world application. After a thorough literature review of the theoretical and practical concepts behind the active noise cancellation technique, the paper proposes a real-time application of active noise cancellation in establishing noise-free communication between security personals, firefighters during an emergency fire situation or maintaining law and order in a crowded and noisy location. Simulation results prove the effectiveness of the proposed model in solving the said problem and thus may be implemented in a practical scenario. Further,the paper describes the use of noise cancellation techniques in ensuring social well-being and saving innocent lives and property.

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