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RESEARCH ARTICLE

REMOVABLE NOISE FROM SOS NONLINEAR SYSTEM USING ADAPTIVE SECOND ORDER LMS VOLTERRA SERIES FILTER

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ABSTRACT

Nature of much process in industry is nonlinear. Every process of system suffered with unwanted signals called noise, if this noise randomly generated in desire system output than normal or linear filter are fail to remove it kind of noise from desire signal. This paper proposes an Adaptive Second Order Volterra Series Filter (ASVSF) for reducing noise from nonlinear system. Based on the lattice-channel structure with delayed element, updates kernel parameters. In order to reduce the computational complexity and the nonlinear distortion with no need of solving the lengthy second order nonlinear mathematics acoustic equation, the ASVSF-LMS filter is proposed. MATLAB simulations demonstrate the control performance improvement using the proposed algorithms.

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INTRODUCTION

A system is said to be nonlinear when the output signals are not directly proportional to the inputs of given system, that is, there are no linear combinations that fully represent the system. Then it is known as a Non-Linear Time-Invariant (NLTI) system. Recently, the Volterra series expansion has been applied successfully to the analysis, removal of error and identification of nonlinear systems. It is a multi-dimensional generalization form of the impulse response function.

Let H_p be the p^{th} order Volterra kernel parameters operator. The output is defined as in equation (1)

$$y(t) = \sum_p H_p\big(x(t)\big) \quad \ldots\ldots\ldots\ldots (1)$$

The Volterra operator is defined as the p-dimensional convolution of the input signal with the p-dimensional Volterra kernel h_p.

$$H_p\big(x(t)\big) = \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} h_p(\tau_1, \ldots, \tau_p)\, x(t-\tau_1) \ldots x(t-\tau_p) d\tau_1 \ldots d\tau_p \quad \ldots.. (2)$$

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If equation (2) is inserting into equation (1), we obtain:

$$y(t) = \int_{-\infty}^{+\infty} h_1(\tau_1)x(t-\tau_1)d\tau_1 + \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} h_2(\tau_1,\tau_2)x(t-\tau_1)x(t-\tau_2)d\tau_1 d\tau_2 + \cdots + \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} h_p(\tau_1,\ldots,\tau_p)x(t-\tau_1)\ldots x(t-\tau_p)d\tau_1 \ldots d\tau_p \quad \ldots\ldots\ldots\ldots (3)$$

The first element in equation (3) is recognizing a LTI system. It is the same as for linear system but remaining elements are part of nonlinear system.

Adaptive second order volterra series filter LMS (ASVSF-LMS)

The Volterra Series is employed to model and remove noise from non-linear systems. Its behavior is similar to the Taylor series if the output of a nonlinear system depends strictly on the input at that particular time, Taylor series can be use for approximating its response to a given input. In the Volterra series, the output of the nonlinear system depends on the input to the system at all other times. This provides the ability to capture the 'memory' effect of devices like capacitors, inductors. For a discrete-time and causal nonlinear system with memory, with input $x[n-m_p]$ and output $y[n]$, the Volterra series enhancement is given by:

$$y(n) = \sum_{m_1=0}^{\infty} h_1(m_1)x(n-m_1) + \sum_{m_1=0}^{\infty}\sum_{m_2=0}^{\infty} h_2(m_1, m_2)x(n-m_1)x(n-m_2) \qquad \text{……………………………… (4)}$$

Where, for simplicity considered a nonlinear model up to the second order. In the above representation of the equation (4), the functions h_i, where i = 0, 1, 2 represent the kernels parameters associated to the nonlinear operators $H_p[x[n]]$. The relation between input-output can also be written in terms of nonlinear operators (Volterra series operator) as indicated in equation.

$$y[n] = h_0 + h_1[x[n]] + h_2[x[n]] \qquad \text{……………………… (5)}$$

The nonlinear model equation described by these two relations above is called a second order Volterra model. Note that the above representation has the same memory for all nonlinearity orders but In the most general case, the first relation may use different memory for each nonlinearity order. A simple adaptive filtering is shown in Fig.1.

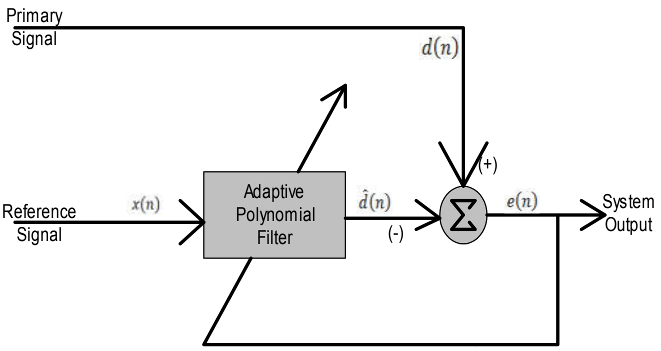

Fig. 1. Concept of Adaptive Filter to Remove Noise

The discrete form of volterra series filter is given as

$$y(n) = H_0 + \sum_{p=1}^{p} H_p x(n) \qquad \text{…………………………… (6)}$$

Where,

$$H_p x(n) = \sum_{i_1=a}^{b} \dots \sum_{i_1=a}^{b} h(i_1 \dots\dots i_p) \prod_{j=1}^{p} x(n - i_j)$$

Here a, b ∈ Z ∪ {-∞, +∞} and P ∈ N ∪ {+∞}
$h_p(i_1,,,,,i_n)$, h_0 are called Volterra kernels. If P is finite, the series operator is said truncated. If a, b and P are finite, the series operator is called doubly finite Volterra series.

System model designing of ASVSF-LMS

An adaptive second order Volterra series filter has been designed for removing noise from nonlinear system using LMS adaptive algorithm. LMS adaptive Volterra filter help for low computational complexity and less memory space to store result. In comparison with other filters, the proposed Adaptive LMS Volterra Series Filter gives best Error signal (ERS) characteristics for the nonlinear system. As shown in the block diagram in Fig. 2 of the proposed model there are two paths, primary and secondary. Primary path is called desired signal d(n) path with noise N_1 and secondary path called adaptive or learning path. This generates the output (adaptive output) y'(n) and help to find the filter output signal y(n) after take difference between d'(n) and y'(n) signal. For determine the error signal e(n), create difference between original signal d(n) and filter output signal y(n). This process will be repeated until error signal e(n) will zero or minimum. This process will two important results, Filter output signal y(n) and Error signal (ERS) with respect to number of samples called iteration.

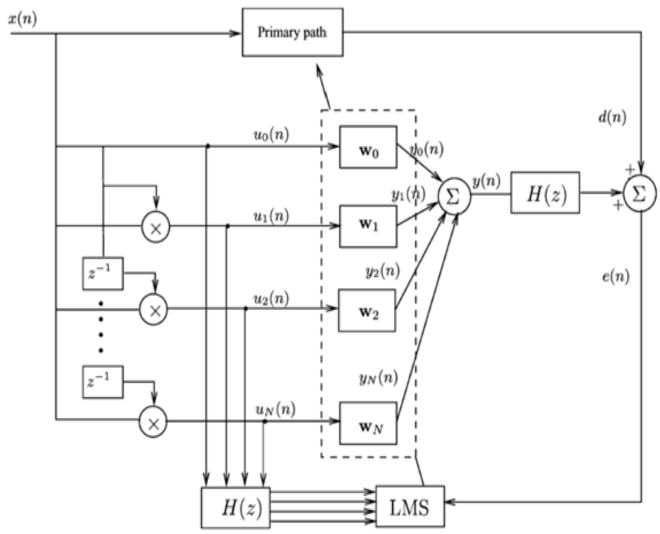

Fig. 2. Block Diagram of Adaptive Volterra Filter for Noise Reduction from Second Order System

MATLAB/SIMULINK software has been employed for the simulation purpose of the above model of the Volterra filter. The main features will be as follows:

- Identify the parameters of ASVSF for designing the model.
- Simulate the LMS algorithm (Used Step Size μ=0.0005).
- Design and simulation of ASVSF Model.
- Simulate the Step Response of Second Order System (Considered Under damped System) for natural Frequency ω_n=1 red/sec, ζ (Damping Ratio)= 0.5, Gain=50
- Implementation of LMS algorithm into ASVSF model
- Apply desire signal of second order system into designed ASVSF model.
- Analysis of the result is obtained as performance of filter output signal through ASVSF model and ERS Signal v/s sample time

Adaptive Volterra Series Filter with LMS algorithm has been designed and simulated for removing the noise of step response of second order system as shown in Fig. 3. Step response Second Order System Signal has been considered as desired signal d(n) with noise N_1 (Band Limit White Noise), has been applied in ASVSF-LMS filter through the error signal (ERS), ERS error is a difference of desire signal and ASVSF filter output signal. ASVSF filter output signal comes from difference of designed model output y'(n) and d'(n).

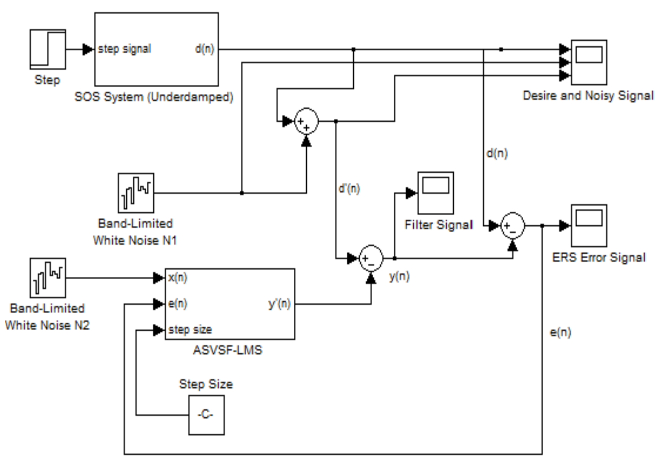

Fig. 3. SIMULINK Model of ASVSF-LMS and Measurement of ERS Error signal for Step Response of Second Order System

ASVSF model have two input name error signal (ERS) and Noise signal named as N2, which is used as reference signal for ASVSF model. For minimize the error signal (ERS) noise N1 and N2 should be equal or nearby equal. The internal structure of the ASVSF-LMS contains delayed elements, multipliers, simulation of LMS algorithm and summers for performing operations.

SIMULATION RESULT AND ANALYSIS

ASVSF-LMS filter model has been design for remove noise from nonlinear system. For testing the ability of remove noise from system, we consider a step response of second order system as desire signal. ASVSF-LMS model filter the SOS step signal is shown in Fig. 4, Step response of SOS is nonlinear in nature. Step response, the noise signal and added with noise signal shown in Fig. 5 and Fig. 6.

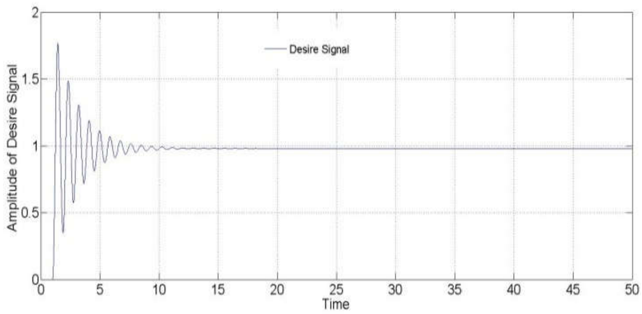

Fig. 4. Step Response of Second Order System (Considered Under damped System) for natural Frequency ω_n=1 red/sec, ζ (Damping Ratio)= 0.5, Gain=50

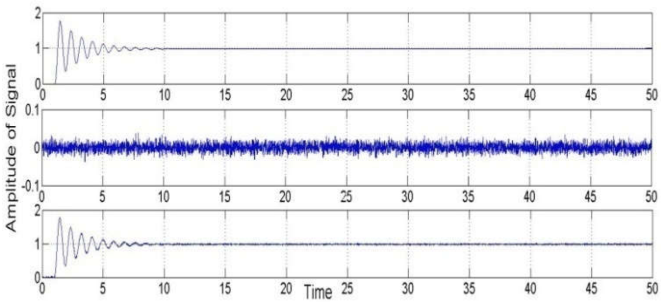

Fig. 5. Step Response of Second Order System (a) Original Signal (b) Noise Signal (c) Original Signal by the Affected of Noise signal

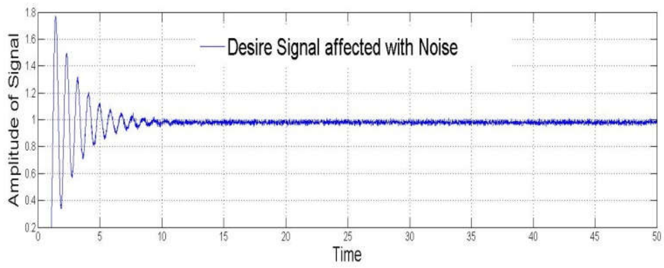

Fig. 6. Desire Signal Affected with Noise

The filter output signal y(n) of step response of SOS through ASVSF-LMS model is obtained as shown in Fig. 7. Designed filter ASVSF-LMS at MATLAB/SIMULINK gives these output waveforms and then it used for comparison of desired signal and filter signal give ERS error.

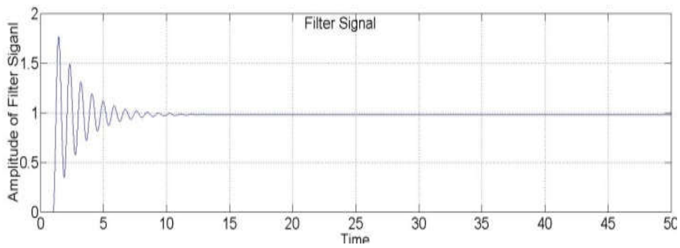

Fig. 7. Filter Signal of Step Response of SOS System through Designed ASVSF Model

The ERS is the difference of desire signal d(n) and filter signal, its measured from the system model and results of ERS is minimum or near to zero with time sample. The order of ERS error signal is $10^{-16,}$ which is near to zero as ERS error for the step size 0.0005 is shown in Fig. 8.

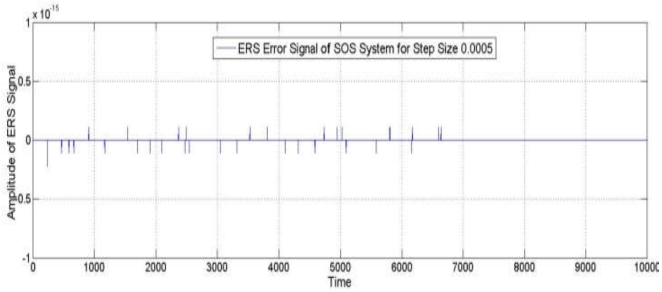

Fig. 8. ERS Error of the System Model ASVSF-LMS for Step Response of SOS System with step size 0.0005

ERS error for the step size 0.05 is shown in Fig. 9.

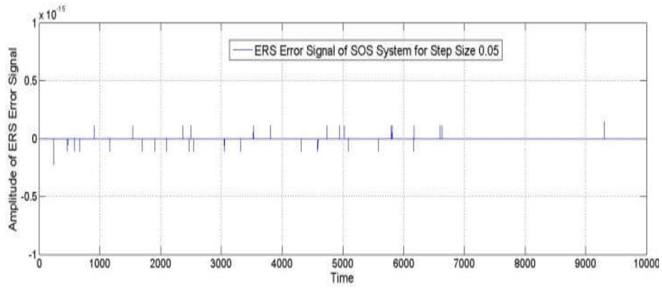

Fig. 9. ERS Error of the System Model ASVSF-LMS for Step Response of SOS System with step size 0.05

Learning rate of ASVSF-LMS model is high and its learning pattern throughout the updates kernel parameters are shown in Fig. 10

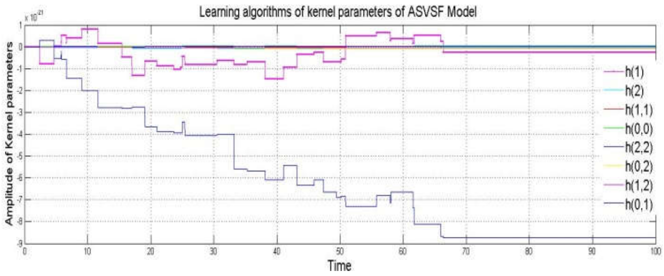

Fig. 10. Learning Algorithms of Kernel Parameters of ASVSF Model

For show the better performance of designed Adaptive Volterra Series filter, we compare the results of ASVSF model with the normalized NLMS and RLS Adaptive filter. Filter's error signal ERS and find comparatively better results. ASVSF model have advantages over another adaptive filter in less noise affected filter signal result.

Conclusion

This paper presented an Adaptive Volterra Series Filter (ASVSF) structure with Least Mean Square (LMS) algorithm for removing noise from nonlinear system like a of Step Response of SOS System. Simulation and experimental results demonstrated that the proposed structure is able to handle an equivalent ERS Error v/s Time performance of Step Response of SOS System (nonlinear system) compared with that of a Normalized LMS filter or conventional LMS filter at a much-reduced complexity. Furthermore, this new structure is able to produce a more accurate with minimum ERS error, proposed system model give advantages compared with Normalized-LMS or equality models for computational complexity, high learning rate, speed of response, less ERS error, linearity and the results of Step Response of SOS System as showed in this paper.

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