



UNIVERSITI PUTRA MALAYSIA

***REAL TIME NONLINEAR FILTERED-X LMS ALGORITHM
FOR ACTIVE NOISE CONTROL***

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**REAL TIME NONLINEAR FILTERED-X LMS ALGORITHM
FOR ACTIVE NOISE CONTROL**



By

MOUAYAD ABDULREDHA SAHIB

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

May 2012

DEDICATION

To my dear Parents, Brothers, and Sisters

To my Wife and my Son Mustafa



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Faculty: Engineering

Active noise control (ANC) is an effective noise reduction method capable of reducing unwanted low frequency noise (typically below 500Hz) electronically. In practical ANC applications, nonlinearity effects degrade the performance of conventional linear control algorithm. The nonlinearity sources could originate from the noise process, primary and secondary acoustical propagation paths, or from the transducers consisting of loudspeaker, microphone or amplifier. The saturation of the loudspeaker amplifier is considered as the main source of nonlinearity in many ANC systems.

In the nonlinear ANC literature, various nonlinear algorithms have been introduced. These nonlinear algorithms were employed to improve noise reduction performance. The performance of these algorithms is usually compared with the standard linear filtered-x least mean square (FXLMS) algorithm. A review of these algorithms has shown that the nonlinear FXLMS (NLFXLMS) algorithm produces high level of cancellation while keeping the computational complexity low. However, unlike the other algorithms, NLFXLMS cannot be implemented in real time. The NLFXLMS algorithm is a stochastic gradient algorithm that incorporates the derivative of a

nonlinear plant model which is represented by the scaled error function (SEF) in the controller design. The SEF has been extensively used to model the saturation nonlinearity. A major drawback of using the SEF function lies in its theoretical nature such that for a finite integration limit, the SEF become non-elementary integral and requires infinite series or numerical methods for evaluation. In addition, the identification of the exact SEF parameter used to scale the strength of saturation nonlinearity becomes impractical. Consequently, the practical applicability of the NLFXLMS algorithm is limited by this drawback.

In this work, a new method of modelling the saturation effect of the amplifier based on tangential hyperbolic function (THF) of the nonlinear part of a Hammerstein model structure is proposed. The THF is derived to represent a wide range of nonlinear distortions and replace the SEF with a certain degree of accuracy. The advantage of replacing the SEF with the THF is the ability of the latter to be realised in a nonlinear modelling scheme. Subsequently, the THF modelling scheme can be incorporated into an established real time NLFXLMS algorithm termed THF-NLFXLMS algorithm.

The developed THF-NLFXLMS algorithm is tested by means of simulation and implemented experimentally using FPGA-based real time controller for a nonlinear ANC application. The application involves the reduction of a traffic noise that affects the pressure field in a bedroom. The ANC architecture implemented is a single channel internal model control (IMC) based feedback ANC system. Simulation and experimental results have shown that the developed THF-NLFXLMS achieves additional noise reduction of 19% from that being achieved by the linear FXLMS algorithm.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**MASA NYATA TIDAK LINEAR TAPISAN-X LMS ALGORITHM
UNTUK KAWALAN HINGAR AKTIF**

Oleh

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Kawalan bunyi aktif (ANC) ialah satu kaedah pengurangan hingar berkesan di mana berupaya mengurangkan hingar berfrekuensi rendah yang tidak dikehendaki (lazimnya di bawah 500Hz) secara elektronik. Dalam praktikal aplikasi ANC, kesan ketaklelurusan akan mengurangkan prestasi algoritma kawalan linear yang konvensional. Sumber ketaklelurusan boleh berpunca daripada proses hingar bunyi, perambatan akustik laluan primer dan sekunder, atau daripada transduser yang mengandungi pembesar suara, mikrofon atau amplifier. Ketepuan pada penguat pembesar suara merupakan sumber utama ketaklelurusan dalam kebanyakan ANC.

Dalam kesusasteraan ANC tak linear, pelbagai algoritma tak linear telah dikaji. Kesemua algoritma tak linear tersebut telah digunakan sebagai satu alternatif dan dibandingkan dengan piawai algoritma linear tapisan-x kurangnya purata persegi algorithm (FXLMS). Satu kajian semula terhadap algoritma-algoritma ini telah membuktikan yang tidak linear FXLMS (NLFXLMS) menghasilkan peringkat tinggi pembatalan sambil mengekalkan kerumitan pengiraan yang rendah. Walau bagaimanapun, tidak seperti algoritma lain, NLFXLMS tidak boleh dilaksanakan dalam masa nyata. Algoritma NLFXLMS adalah algoritma kecerunan stokastik yang menggabungkan terbitan fungsi skala ralat (SEF) dalam reka bentuk pengawal. SEF

telah digunakan secara meluasnya untuk memodelkan ketaklelurusan ketepuan. Satu kelemahan utama menggunakan fungsi SEF bohong dalam sifat teoretisnya sedemikian yang untuk had integrasi terhingga, SEF menjadi tidak kamiran permulaan dan memerlukan siri tak terhingga atau kaedah-kaedah berangka untuk penilaian. Tambahan pula, pengenalpastian parameter SEF tepat digunakan untuk berskala kekuatan ketaklelurusan ketepuan menjadi tidak praktis. Akibatnya, kebolehgunaan praktikal algoritma NLFXLMS ada keterbatasannya oleh kelemahan ini.

Dalam kajian ini, satu kaedah permodelan baru kesan ketepuan amplifiler berdasarkan fungsi hiperbolik mentangen (THF) dalam bahagian tak linear struktur model Hammerstein yang dicadangkan. THF diterbitkan untuk mewakili kepelbagaian pengerotan tak linear dan menggantikan SEF dengan tahap ketepatan yang tertentu. Kelebihan menggantikan SEF dengan THF ialah keupayaan terkemudian untuk disedari dalam skim peragaan tak linear. Kemudiannya, skim permodelan THF dalam talian boleh digabungkan ke dalam masa nyata mantap tak linear algoritma tapisan-x min kuasa dua (THF-NLFXLMS) dalam reka bentuk pengawal.

Algoritma THF-NLFXLMS yang dibangunkan diuji secara simulasi dan dijalankan secara eksperimen menggunakan pengawal masa nyata berasaskan FPGA untuk penggunaan ANC tak linear. Aplikasi ini melibatkan pengurangan kebisingan trafik yang menjejaskan tekanan di dalam sebuah bilik tidur. Senibina ANC yang digunakan merupakan satu saluran model dalaman kawalan (IMC) berdasarkan maklum balas sistem ANC. Hasil simulasi dan eksperimen adakah membuktikan yang THF-NLFXLMS maju mencapai pengurangan hingar tambahan 19% dari yang dicapai oleh algoritma FXLMS linear.

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I certify that a Thesis Examination Committee has met on _____ to conduct the final examination of **Mouayad Abdulredha Sahib** on his thesis entitled “**Real Time Nonlinear Filtered-X LMS Algorithm for Active Noise Control**” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.



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Date: 28 / May / 2012

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