Intelligent Control System for Car Muffler

Hendro Privatman
Department of Electrical Engineering, Tanjungpura University
Department of Mechanical Engineering, Muhammadiyah University Pontianak

ABSTRACT

Muffler is sub-system attached on car and used to control exhausting sound from machine. Conventional muffler using some material to filter exhaust. With conventional muffler engine spends extra energy to push exhaust gasses trough the filter. Of these, the filtering processes produce mechanical friction, and more energy consumption. These condition decreased rehabilitee and performance from car. Active Noise Control (ANC) is sound field modification that can reduce or eliminate unwanted sound by electro-acoustical means. But ANC works best for sound fields that spatially simple. Computational intelligent are interesting achievement at control and computer theory. Some research is about neurofuzzy that has capability to control complicated system like sound field (produced by car machine). Combining ANC with neurofuzzy will attenuate noise as we desire.

Key words: Noise, Control, Muffler, Neurofuzzy

INTRODUCTION

Fuel consumption and quiet machine are two significant criteria to choose a car. Car industries now are running to produce system that can minimize energy losses also decrease machine sound. Energy losses can be decreased by: fuel burning efficiency, eliminate unnecessary activity that needs fuel or substitute fuel-wanted part with another. Sound level can control by filter or noise marking. This part builds from some material and could restrict flow of exhaust gasses. Restriction will attenuate sound level and make car quiet. But two approaches seen a contradiction. The former need free obstacle to minimize energy but the later need filter (be obstacle) to decrease sound level. Contradictions produce an idea to solve the problem. How to reduce sound or noise level without some materials that can restrict exhaust gasses? Can we replace restrictive part (known as conventional muffler) with unrestrictive but decreased sound? If we have heard about active noise control, the answer is yes, possibly we can develop muffler with active noise control. Active Noise Control (ANC) is sound field modification by electro-acoustical means. Active noise control (ANC) produce sound wave with specified characteristic to eliminate or
decreased level of unwanted sound. This concept was successfully applied. For example exhaust muffler for internal combustion engine, dishwasher, cabin noise reduction, etc.

Active Noise Control (ANC) Concept

Acoustic noise problems become more evident as increased numbers of industrial equipment such as engines, blowers, fans, transformers, and compressors are in use. Active noise control (ANC) involves an electro acoustic or electromechanical system that cancels the primary (unwanted) noise based on the principle of superposition, specifically, an anti-noise of equal amplitude and opposite phase is generate and combined with the primary noise, thus resulting in the cancellation of both noises. Basic concept of ANC can be seen as below,

![Diagram of Noise Cancellation Concept](image)

Figure 1. Noise cancellation concept

The ANC system efficiently attenuates low-frequency noise where passive methods are either ineffective or tend to be very expensive or bulky. ANC is developing rapidly because it permits improvements in noise control, often with potential benefits in size, weight, volume, and cost.

The design of acoustic ANC utilizing a microphone and an electronically driven loudspeaker to generate a canceling sound was first proposed in a 1936 patent by Lueg. Since the characteristics of the acoustic noise source and the environment are time varying, the frequency content, amplitude, phase, and sound velocity of the undesired noise are non-stationary. An ANC system must therefore be adaptive in order to cope with these variations.
Neurofuzzy

One of remarkable research at control system was computational intelligence. With capability of computational intelligence and requirement of control system to control more complex plant and requirement of knowledge based, advanced research for computational intelligence will be give significant contribution for real life.

Computational intelligence development consists of differentiated for three component:

a. Fuzzy Logic with characteristic at approximation reasoning and non-accurate value.

b. Neural Network with learning, parallel process and interpolation.

c. Genetic Algorithm and Chaos theory with uncertainty, optimization and propagation.

have given a lot of contribution to control system.

According to weakness and power form each component, now growing new concept to combine each component. One of combining is between fuzzy logic with neural network. Some reason for combining was fuzzy logic has powerful for inaccurate and approximate reasoning, and this have been used at several plants with different characteristic. But there are some weaknesses if we want to build rule base and optimize existing rule base. Fuzzy logic has no learning system so rule base are fixed after design step. Because of that, neural network was combining with fuzzy logic to give learning capability for fuzzy logic. Combining concept called with neurofuzzy. Neurofuzzy could be defined as A fuzzy system that using learning algorithm form neural network to build and tuning set fuzzy, rule base with numeric or linguistic value.

Implementation of neurofuzzy was developed at several and wide area, from economic system, engineering system and social system. Most of implementation, neurofuzzy used for time series prediction, system identification, modeling and decision support system. Neurofuzzy configuration depends on where and objective of system. Time series prediction is process to predict and make interpolation for next or future time condition based on data history, recent condition. Using neurofuzzy we could see what happen at future. Some examples at signal prediction, neurofuzzy time series prediction can predict of increasing or decreasing noise value.
and level. Neurofuzzy have capability to learn and copy knowledge from human expert. System identification and modeling is component to build model of one system (usually complex /sophisticated system). Modeling usually at mathematic form or linguistic form. Using this model, we can control or monitor system behavior.

Decision support system is knowledge based that build to give supporting system for human to make or determine some decision for several case or problem. Neurofuzzy have job to build, develop and improve knowledge base using learning capability.

**Neurofuzzy as ANC Algorithm.**

Control system (Neurofuzzy for ANC) is designed for real use. Design refers to fundamental concepts. Research will design and study application of neurofuzzy for ANC algorithm. Application will increase ANC quality and capability. Neurofuzzy at ANC used for identification tool, they will monitor noise signal and develop prediction result about noise signal that flow at exhaust duct. From these predictions, ANC will generate anti-noise signal, this concept can be seen as diagram:

![Diagram](image)

**Figure 2. Neurofuzzy as Prediction Tool**

From figure 2., digital filter $W(z)$ consist of neurofuzzy rule. The basic broad-band ANC system. The performance of ANC can be determined by frequency-domain analysis of the residual error signal $e(n)$. The auto power spectrum of $e(n)$ is given by

$$S_{ee}(\omega)=[1-C_{dx}(\omega)]S_{dd}(\omega)$$  

(1)
Where $C_{dx}(\omega)$ is the magnitude-squared coherence function between two wide-sense stationary random processes $d(n)$ and $x(n)$ and $S_{dd}(\omega)$ is the auto power spectrum of $d(n)$. This equation indicates that the performance of the ANC system is dependent on the coherence, which is a measure of noise and the relative linearity of the two processes $d(n)$ and $x(n)$. In order to realize a small residual error, it is necessary to have very high coherence $[C_{dx}(\omega) = 1]$ at frequencies for which there is significant disturbance energy. The maximum noise reduction of an ANC system at frequency in decibels is given by

$$-10 \log [1 - C_{dx}(\omega)]$$

(2)

As illustrated in Figure 3, after the reference sensor picks up the reference signal, the controller will have some time to calculate the right output to the canceling loudspeaker. If this electrical delay becomes longer than the acoustic delay from the reference microphone to the canceling loudspeaker, the performance of the system will be substantially degraded. That is because the controller response is non-causal when the electrical delay is longer than the acoustic delay. When the causality condition is met, the ANC system is capable of canceling broad-band random noise. Note that if causality is not possible, the system can effectively control only narrow-band or periodic noise. Now, we will use of Neurofuzzy concept to do filter $W(z)$ task. Capability for adaptive and identification of Neurofuzzy was an advantage for successfully doing filter $W(z)$ task. Neurofuzzy will be drawn as,

![Block Diagram of ANC System Using Neurofuzzy Algorithm.](image)

P(z) as plant/process or noise signal represented as non linear dynamic equation,

$$x^{(n)} = f(x, \dot{x}, ..., x^{(n-1)}) + g(x, \dot{x}, ..., x^{(n-1)})u$$

$$y = x$$

(3)
with \( f(x) \) and \( g(x) \) are unknown functions and \( g(x) \neq 0 \). System is normal form.

Design a control signal \( u = u(x|\theta) \) with \( \theta \) are parameter changes by limitation:

- Closed-loop system with global stability have limitation:
  \[
  x(t), \theta(t) \text{ and } u(x|\theta) \text{ finite,}
  \]
  \[
  x(t) \leq M_x < \infty, \quad |\theta(t)| \leq M_\theta < \infty, \quad |u(x|\theta)| \leq M_u < \infty \quad \text{and} \quad t \geq 0 \quad \text{with} \quad M_x, M_\theta \text{ and } M_u \text{ given.}
  \]
  - Tracking error \((e=y_m-y)\) converge to zero.

Define equation:

\[
e = (e, \dot{e}, ..., e^{(n-1)})^T
\]
\[
k = (k_n, ..., k_1)^T \in \mathbb{R}
\]

with \( k \) is polynomial coefficient

\[
h(s) = s^n + k_ns^{n-1} + ... + k_n
\]

roots of equation at left vertical axes. If \( f(x) \) and \( g(x) \) known, so could be compute control signal,

\[
u = \frac{1}{g(x)}[-f(x) + y_m^{(n)} + k^T e]
\]

substitute equation 3 will got polynomial equation at ‘e’

\[
e^{(n)} + k_ne^{(n-1)} + ... + k_ne = 0
\]

With choose value of \( k \) will be given \( \lim_{t \to \infty} e(t) = 0 \), it was control objective. The main problem is how to define ‘u’ value. One solution can be proposed as, First \( f \) and \( g \) for plant changed with neurofuzzy function:

\[
\hat{f}(x) = f(x|\theta_1) \quad \hat{g}(x) = g(x|\theta_2)
\]

control signal could be describe as:

\[
u_1 = \frac{1}{\hat{g}(x)}[-\hat{f}(x) + y_m^{(n)} + k^T e]
\]

Neurofuzzy function derived from fuzzy set and fuzzy rule and it was a mapping from input to output. Function is referring from membership function, inference
engine and defuzzifier which chosen. Derive control algorithm from neurofuzzy. Substitute ‘u’ to dynamic equation,

\[ x^{(n)} = f(x) + g(x)u \]  \hspace{1cm} (10)

will produce error equation,

\[ e^{(n)} = -k^T e + [\hat{f}(x) - f(x)] + [\hat{g}(x) - g(x)]u_1 \]  \hspace{1cm} (11)

Define matrix and vector,

\[ \Lambda = \begin{bmatrix} 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \\ -k_n & -k_{n-1} & \cdots & -k_1 \end{bmatrix} \]

\[ b_1 = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{bmatrix} \]

Equation (11) can be writing as,

\[ \dot{e} = \Lambda e + b_1 [\hat{f}(x) - f(x)] + [\hat{g}(x) - g(x)]u_1 \]  \hspace{1cm} (13)

Define fuzzy parameter \( \theta^* \) as optimal parameter, that condition where \( f \) and \( g \) approach to true value,

\[ \hat{f}^* = \hat{f}(\theta^*) \]

\[ \hat{g}^* = \hat{g}(\theta^*) \]  \hspace{1cm} (14)

Define error approximation,

\[ w = [\hat{f}^*(x) - f(x)] + [\hat{g}^*(x) - g(x)]u_1 \]  \hspace{1cm} (15)

Using Taylor series can be derived,

\[ \hat{f}(x) - \hat{f}^*(x) = \theta^*_f - \theta_f \begin{bmatrix} \frac{\partial \hat{f}}{\partial \theta_f} \end{bmatrix} + \text{h.o.t} \]  \hspace{1cm} (16)

\[ \hat{g}(x) - \hat{g}^*(x) = \theta^*_g - \theta_g \begin{bmatrix} \frac{\partial \hat{g}}{\partial \theta_g} \end{bmatrix} + \text{h.o.t} \]  \hspace{1cm} (17)

Where h.o.t is highest order term.

Error equation can be described as below,
\[ \dot{e} = \Lambda e + b(0_t - 0_t^*)^T \left[ \frac{\partial \hat{f}}{\partial \theta} \right] + (0_t - 0_t^*)^T \left[ \frac{\partial \hat{g}}{\partial \theta} \right] u_t + v \]  

(18)

With \( v = w + h.o.t. \)

Next process is define learning process to get tracking error \( e \) and parameter error \( \theta - \theta^* \) minimum. From Lyapunov function,

\[ V = \frac{1}{2} e^T Pe + \frac{1}{2\gamma_1} (\theta_t - \theta_t^*)^T (\theta_t - \theta_t^*) + \frac{1}{2\gamma_2} (\theta_t - \theta_t^*)^T (\theta_t - \theta_t^*) \]  

(19)

Where \( \gamma_1 \) and \( \gamma_2 \) are positive constant. Assume there are two matrixes \( P \) and \( Q \) positive definite and meet Lyapunov equation,

\[ A^T P + PA = -Q \]  

(20)

\[ V = -\frac{1}{2} e^T Qe + e^T Pbw + \frac{1}{\gamma_1} (\theta_t - \theta_t^*)^T (\theta_t - \theta_t^*) \left( \gamma_t e^T Pb \left[ \frac{\partial \hat{f}}{\partial \theta} \right] + \gamma_t e^T Pb \left[ \frac{\partial \hat{g}}{\partial \theta} \right] u_t \right) \]  

(21)

Minimize \( e \) and \( \theta - \theta^* \) could be done with minimize \( V \) and \( \frac{dV}{dt} < 0 \) by making algorithm of learning process or weighted adaptation to push \( V \) value minimum and \( \frac{dV}{dt} < 0 \). In neural network learning process, general equation for learning is,

\[ w(n+1) = w(n) + \eta h(w(n), x(n)) \]  

(22)

With \( h \) is a function derived from neural network structure. With controlling \( h \) will make Lypaunov equation and derivation produce objective condition. \( (V \) minimum and \( \frac{dV}{dt} < 0 \)).

**Simulation Result and Analysis**

Development for ANC concept applied for car muffler. All working refers to economical aspect and environment condition. Basic concept of ANC shown at figure below,

![Structure ANC Experiment](image)

Figure 4. Structure ANC Experiment
From ANC structure above, we can describe physical model for intelligent muffler implementation,

![Physical System Diagram](image)

Figure 5. Physical System

Control system (neurofuzzy for ANC) is designed for real use. Design refers to fundamental concepts. Research will design and study application of neurofuzzy for ANC algorithm. Application will increase ANC quality and capability. Simulation using computer software to analyze design result. Pre-study (ANC without neurofuzzy) will give output as describe at graphic below.

![Graph](image)

Figure 6. Respond for identification of source signal.(green: noise signal, blue: identified signal).

![Graph](image)

Figure 7. Respond for Canceling Process (Black: Noise Signal, Blue: Canceling Signal)

![Graph](image)

Figure 8. Respond for Residual Noise.
Basic concept of ANC applied for car muffler produce unperfected cancellation process. There are still exist residual noise, so ANC need to develop with new algorithm using neurofuzzy identification system. Simulation using computer software to analyze design result, ANC with neurofuzzy as identification tools will give output as describe at graphic below,

Figure 9. Respond for Identification of Source Signal (Red: Noise Signal, Blue: Identified Signal).

Figure 10. Respond for Canceling Process (Red: Noise Signal, Blue: Canceling Signal).

Figure 11. Respond for Residual Noise.

For all graphics, x-axis represent time value and y-axis represent noise level value.
CONCLUSION

Computational intelligent are interesting achievement at control and computer theory (neurofuzzy). Neurofuzzy that has capability to control complicated system like sound field (produced by car machine) by off-line simulation. Combining ANC with neurofuzzy will attenuate noise as we desire.

REFERENCES


