Active sound design for a passenger car based on adaptive order filter

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ABSTRACT

The paper presents an adaptive order filter for the sound design of a passenger car. The engine speed is calculated by using the pulse signal detected at engine speed sensor such as cam shaft position sensor (CSPS) or engine ignition position sensor (EIPS). Nowadays, the pulse signal of engine speed is delivered to the engine management control unit (ECU) system. The ECU supplies the engine speed data to the display throughout a high speed gateway. The ANC system can also use this data for the generation of reference signal. Most of reference signals used for the noise control of an engine are the sine wave at the instant frequency (rpm/60). This sine wave is discretely changed with the increment of engine speed but not continuous. Therefore, the ANC system using this reference cannot work when the engine speed is changed rapidly form 1000rpm to 6000rpm but work well at the fixed rpm. In this paper new adaptive order filter (AOF) for the ANC system of interior noise of a car is proposed. The new algorism uses the continuous reference signal instead of the sine wave. This ANC system is also applied for the active sound design (ASD). The AOF is very excellent algorithm for the ASD of a vehicle.

Keywords: Active Noise Control(ANC), Adaptive Order Filter(AOF), Active Sound Design(ASD)

1. INTRODUCTION

A new noise and vibration technology is needed to improve the fuel economy. Therefore, the electronic control technology using active noise reduction has emerged as a new alternative. Active control may now allow a reduction in the weight of conventional passive methods of low frequency noise control, helping the push towards lighter, more fuel efficient, vehicles (1-6). In this paper, we consider the active sound design (ASD) system for a passenger car to control the engine sound quality (ESQ) based on ANC. Most of algorithm used for the ANC of the interior noise in a car is the filtered-X LMS algorithm (FXLMS) (7). In order to control the ESQ inside of car, such as booming and rumbling (8), the reference signal is required in the FXLMS algorithm (9). The reference signal should be synchronized with engine speed. The engine speed is calculated by using the pulse signal detected at engine speed sensor such as cam shaft position sensor (CSPS) or engine ignition position sensor (EIPS). Nowadays, the pulse signal of engine speed is delivered to the engine management control unit (ECU) system. The ECU supplies the engine speed data to the display throughout a high speed gateway. The ANC system can also use this data for the generation of reference signal. Most of reference signals used for the noise control of an engine are the sine wave at the instant frequency (rpm/60). This sine wave is discretely changed with the increment of engine speed but not continuous. Therefore, the ANC system using this reference cannot work when the engine speed is changed rapidly form 1000rpm to

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6000rpm but work well at the fixed rpm. For this reason, new reference signal which adapt to rapidly changed rpm is needed and the new reference signal, which is called adaptive order filter, is developed. New developed ANC system with AOF is work very well and its performance is excellent to reduce the sound pressure of the interior noise related to the harmonic components of engine rotating speed (10). In this paper new adaptive order filter (AOF) for the ASD system of interior sound of a car is proposed.

2. ADAPTIVE ORDER FILTER FOR ACTIVE SOUND DESIGN

2.1 Command FXLMS Algorithm with Adaptive Order Filter

The purpose of active noise control is to reduce interior noise of a passenger car. However, in active sound design, the target is to enhance the gain of certain engine orders, as well as reducing other engine sound. This target can be achieved using the command-FXLMS(C-FXLMS) algorithm, which requires the error signal, e(n) to tend towards a given command signal, c(n), instead of zero (3). This is done by subtracting the command signal from the error signal and creating a new pseudo-error signal. The pseudo-error is then used in the calculation of the gradient term, so that the FXLMS algorithm minimizes the pseudo-error. The block diagram of the command-FXLMS algorithm with adaptive order filter is shown in Figure 1. The command signal is denoted as c(n) and the pseudo-error is e'(n). The weights of the adaptive order filter are updated as

$$\mathbf{w}[n+1] = \mathbf{w}[n] - \mu e'[n]\mathbf{x}'[n] \tag{1}$$

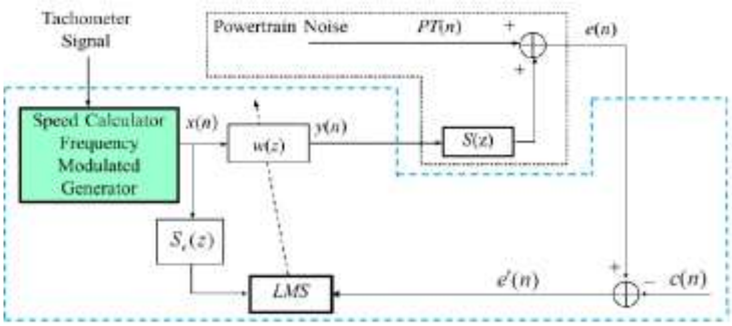


Figure 1 – Block diagram of the command filtered-x LMS algorithm with AOF.

In active sound design, the command signal values are determined using a psychoacoustic profile. In the profile, the desired sound pressure levels for each controlled engine order are specified at each frequency. The profile can be implemented as a lookup table where the desired amplitude values for c(n) are stored as a function of frequency. The command signal is created from the reference signal, which ensures that its frequency components are the same as those of the disturbance signal and could, for example, be scheduled on the engine speed and load. The command signal is multiplied by the desired amplitude at that specific frequency (11).

3. ACTIVE SOUND DESIGN IN THE CABIN OF A PASSENGER CAR

3.1 Experimental Setup and Procedure

A sport utility car is used for the interior noise control. The 2.2L diesel engine is used for powertrain of this car. The instrument of the active noise control is loaded inside a car. Figure 2 shows the block diagram for active noise control and active sound design of this car.

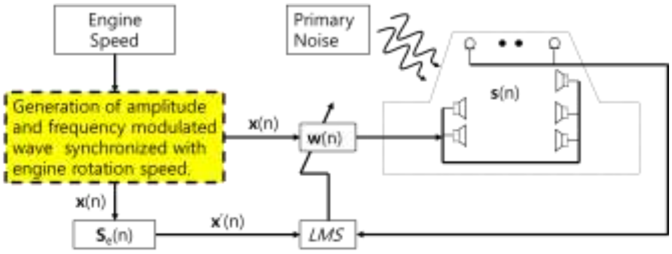


Figure 2 – Block diagram of active noise control and active sound design of a test car.

The equipment for ANC is illustrated as shown in Figure 3. Four microphones are used for the measurement of error signal and are attached to the roof of a teat car. Five speakers are used to generate the secondary sound sources to cancel the primary noise sources. The error signals are transfer to the input channels of dSPACE control board via the ICP amplifier (PCB Company). The pulse signal including the information of speed of engine is detected by the cam shaft position sensor and transfer to the input channels of dSPACE control board. Both input data are transfer to the control computer via A/D converter inside of dSPACE control board. The pulse signal is used for the calculation of the instantaneous frequency and the reference signal x(n) which is the frequency modulated signal. The reference signal is convolved by the estimated impulse response of the secondary path. The signal is the input x′(n) of LMS algorithm. The adaptive filter w(n) is updated by using error data e(n) and input data x′(n).

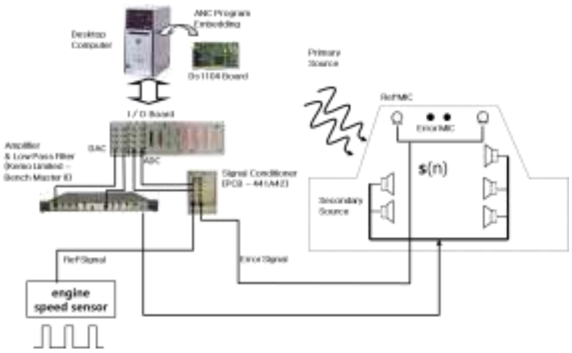
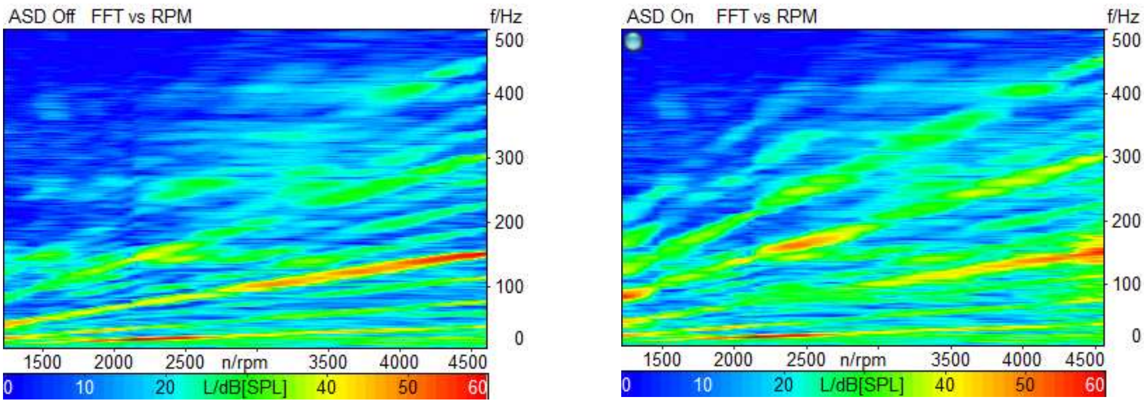


Figure 3 – Equipment for ANC system for active control of interior noise of a test vehicle

3.2 Result of Active Sound Design

The goal of active sound design is to enhance the gain of certain engine orders, as well as reducing other engine sound. So, in this test, 2nd order component generally related the booming noise is reduced and 4th order and 6th order components are enhanced.

Figure 4 shows the color map for the sound pressure level of interior noise when the ASD system is turned off and on.



(a) (b)

Figure 4 – Color map plot of the interior noise in the test vehicle (a)when the ASD is turned off (b)when the ASD is turned on.

There are obvious differences when the ASD system works and does not work. Comparing between figure 4(a) and figure 4(b), 2nd order component is reduced, 4th order and 6th order components are enhanced. It means booming noise is eliminated and new interior sound is generated at the same time. Thus, if ASD system is used, engine sound can be designed freely.

4. CONCLUSIONS

In the paper, the new FXLMS algorithm with AOF is developed. This is developed based on the generation of the reference wave associated with the harmonic orders of the engine rotating speed. A SUV is used for the test of the ANC system with this algorithm. The sound pressure level of interior noise actively controlled by this algorithm is reduced to 15dB. The performance of the new developed ANC system is very excellent. Based on this new algorithm, ASD system is developed and it is confirmed engine sound can be designed.

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