PRACTICAL ACTIVE NOISE PROFILING IN A PASSENGER CAR

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1 INTRODUCTION

Active Noise Profiling (ANP), as an evolution of Active Noise Control (ANC), is to profile the selected periodic noise orders to some pre-defined target levels instead of attenuating them to the minimum values. Similar solutions have been proposed by Kuo [1 ~ 3], Rees and Elliott [4], Gan and Wang [5, 6], and Oliveira [7] in their research work.

The main obstacle to put ANP into practice is the efficiency of the developed profiling algorithm which is based on the well-known Filtered-x Least Mean Square (FXLMS) algorithm, namely the accuracy of the plant estimate, the convergence speed, the computational efficiency and the robustness of the algorithm. In this paper, based on the previous research [8], a modified FXLMS algorithm is implemented successfully into a 4-channel ANP system with one single floating point DSP processor in order to practically profile the 5 selected noise orders inside a Ford C-MAX passenger car. To evaluate the practical performances, the ANP system has been well tested in both laboratory experiments and road tests.

2 PRACTICAL IMPLEMENTATION

2.1 The ANP system

Figure 1. The Ford C-MAX passenger car under experiments

According to the previous research, there are 5 dominant periodic noise harmonics, namely the 2nd, 3.5th, 4th, 5th and 6th orders, which can be clearly detected throughout the whole engine RPM range. Furthermore, a 4-channel ANC system has already been developed in a Ford C-MAX car (in Figure 1) [8]. The ANP system consists of 4 error microphones, 4 secondary loudspeakers and a subwoofer, a reference sensor to get the tacho and load information from the car engine, and an electrical control system to assemble the components together for conducting ANP inside the passenger car. The theoretical demonstration of the ANP system is shown in Figure 2 and the practical setup of the system is shown in Figure 3, respectively. In Figure 3, 4 secondary loudspeakers are mounted on the roof approximately above the driver's and co-driver's heads; 4 error microphones are attached to the both sides of the headrests of the driver's and co-driver's seats; the subwoofer is located in the trunk. The locations of the error microphones and secondary loudspeakers have been well designed and optimized so as to enable the adaptive controller to carry out its work effectively.

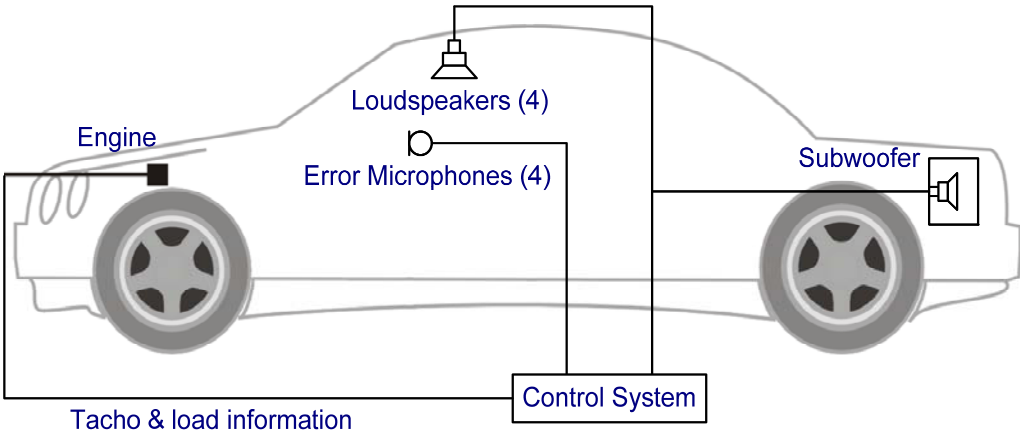

Figure 2. The theoretical demonstration of the practical ANP system

a) Loudspeakers on the roof

b) Microphones on the headrest

Figure 3. The locations of secondary loudspeakers and error microphones

As shown in Figure 4, the electronic control system is assembled into a small box and consists mainly of a high-performance DSP (Texas Instrument TMS320C6713), a multi-channel signal processing board, output signal amplifiers, and a power supply unit. A remote control box is constructed to easily manipulate for passengers inside the car.

a) Control system with remote box

b) Rear panel of control system

Figure 4. The electronic control box of the ANP system

2.2 The algorithm implementation

In order to effectively profile all the 5 selected engine orders with the 4-channel ANP system, a modified 5-order 4-input/4-output FXLMS algorithm with the narrowband feedforward strategy is implemented to the control system. Special efforts are made to improve the accuracy of plant estimate, the convergence speed and the robustness of the algorithm. As shown in Figure 5, an offline system identification process (System_ID) can optimize the plant estimate and the convergence speed; the adjustable stepsize (StpSz_m) and another stability process (Stbl_Prcs) can improve the robustness of the algorithm and also the convergence speed during the real-time profiling process. The look-up tables are developed to improve the computational efficiency of the ANP algorithm. In practice, the optimized algorithm can run on the 4-channel ANP system at a sampling frequency 2 kHz effectively.

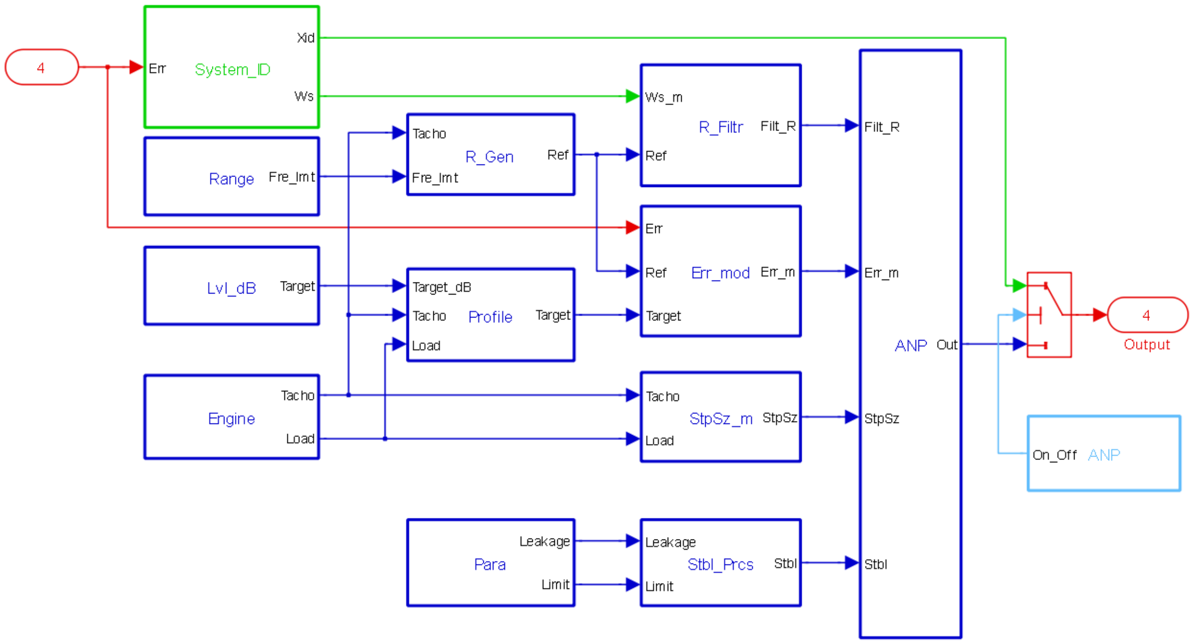

Figure 5. The simplified block diagram of the ANP algorithm implementation

3 EXPERIMENTAL EVALUATION

To evaluate the practical performance, the ANP system has been well tested in both laboratory experiments and road tests. During the experiments, the noise inside car cabin is recorded with an 8-channel RION DA-40 recorder. The recordings are made with binaural microphones installed in the artificial head and torso simulator located at the co-driver seat. The signal from the left ear is used in the analysis. A typical result of road tests is chosen to illustrate the performance of the practical ANP system. As shown in Figure 6, the selected color map represents the noise spectra inside the car cabin during one practical road test, and the corresponding engine speed and load information is also shown below the color map accordingly.

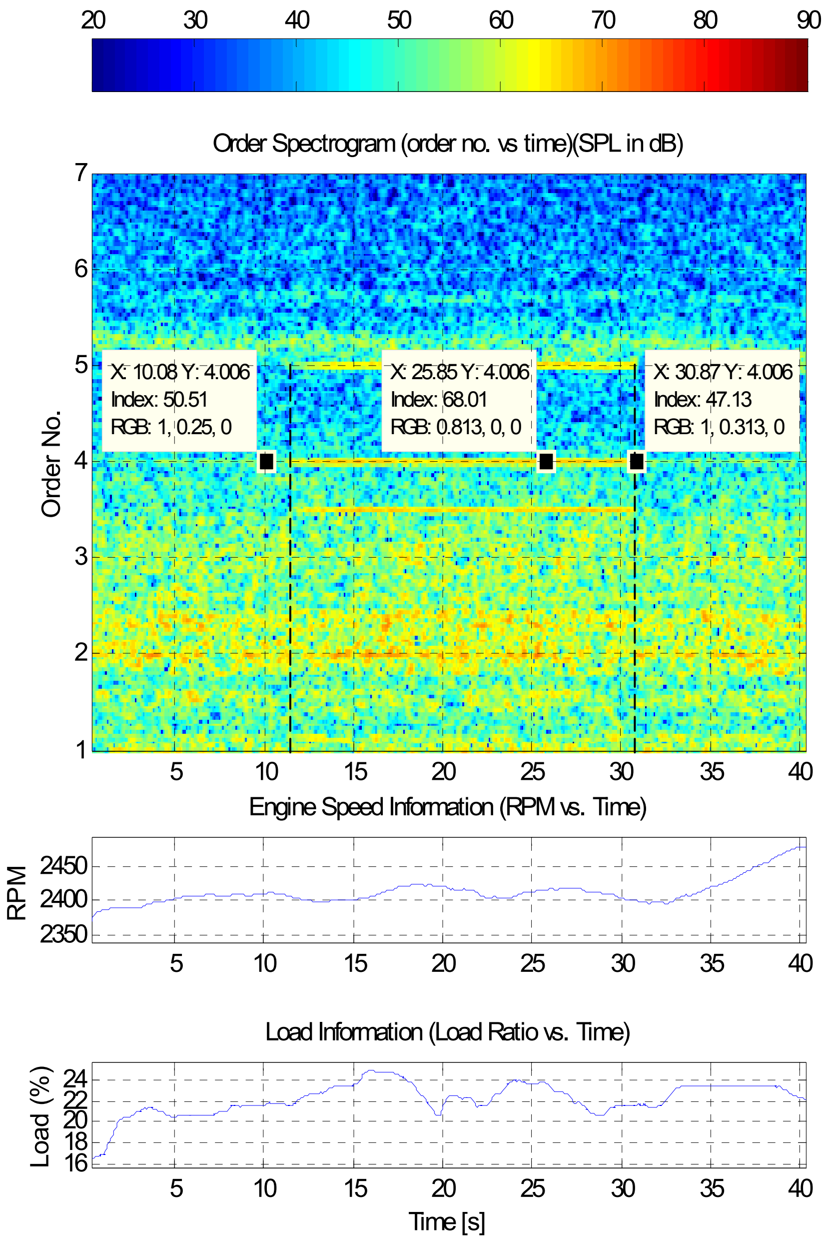

Figure 6. The practical performance of the ANP system during road test

During the chosen road test, the car engine is running at constant speed around 2400 RPM with ANP off-on-off (indicated with 2 bold dash lines in Figure 6) on a public motorway at a car speed of 80 km/h, and the clear difference of selected noise orders can be seen when the ANP system works at different conditions. Specifically, according to the look-up table provided by the car manufacturer, the profiling target of the 4th order is 65 dB when the engine speed is around 2400 RPM and the engine load is around 22%. In this case, the noise levels of the 4th order are around 50 dB at the 10th second and 47 dB at the 30th second when the ANP system is switched off. However, when the ANP system is switched on, it can effectively profile the noise level near to the pre-defined targets, 68 dB at the 26th second.

As an example shown in Figure 7, the detailed performance of the ANP system under this test condition can be seen clearly from the noise spectra of the 4th order. The acceptable profiling tolerance is set as 5% here, which indicates the acceptable range of profiling is practically from 61.75 dB to 68.25 dB. As shown in the figure, it takes only 0.35 seconds for the ANP system to profile the 4th-order noise level to the lower limit of the target tolerance. Furthermore, during the profiling period, the profiling order is mostly within its own acceptable tolerance. That means the ANP system can work effectively, stably and robustly during the testing period.

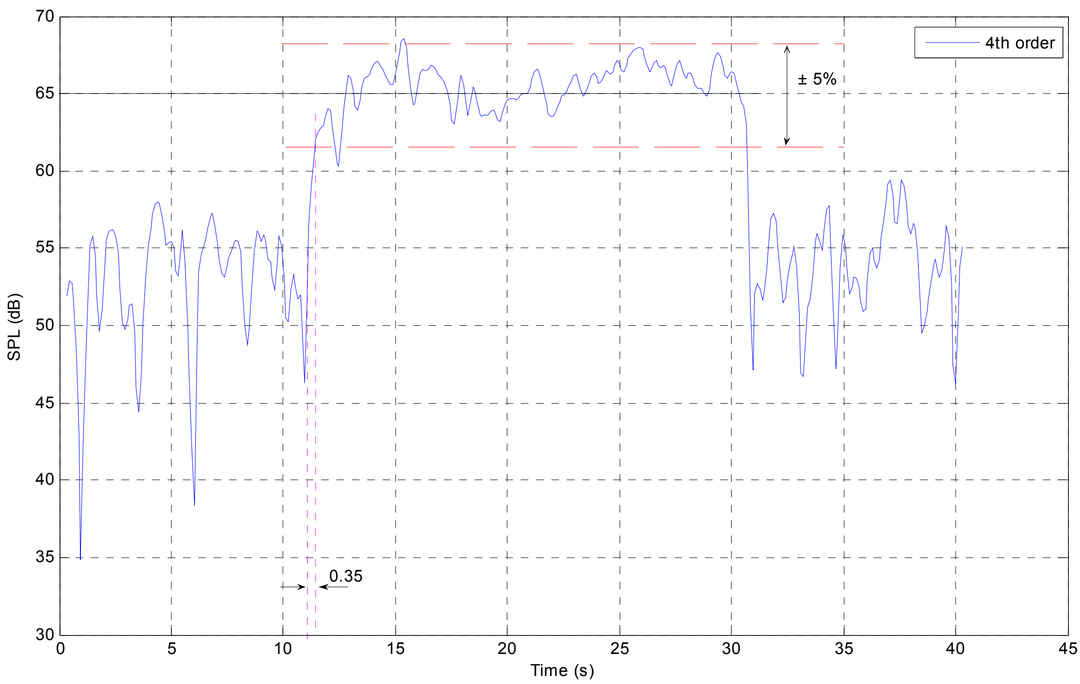

Figure 7. The practical ANP performance of the 4th order at 2400 RPM and 22% load

4 CONCLUSION

A 4-channel narrowband feedforward ANP system is developed to optimize the noise spectra inside a passenger car. To practically achieve a better performance, special efforts are made to improve the accuracy of plant estimate, the convergence speed and the robustness of the ANP algorithm. Furthermore, in order to evaluate its practical performances, the ANP system has been well tested in both laboratory experiments and road tests. The experimental results show that the ANP system can work effectively and robustly under different engine conditions in the whole RPM range, especially from 2000 RPM to 5000 RPM.

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