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Noise source separation of diesel engine by combining binaural sound localization method and blind source separation method

Jiachi Yao, Yang Xiang *, Sichong Qian, Shengyang Li, Shaowei Wu

School of Energy and Power Engineering, Wuhan University of Technology, Wuhan 430063, China
Key Laboratory of Marine Power Engineering and Technology, Ministry of Communications, Wuhan University of Technology, Wuhan 430063, China

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ABSTRACT

In order to separate and identify the combustion noise and the piston slap noise of a diesel engine, a noise source separation and identification method that combines a binaural sound localization method and blind source separation method is proposed. During a diesel engine noise and vibration test, because a diesel engine has many complex noise sources, a lead covering method was carried out on a diesel engine to isolate other interference noise from the No. 1–5 cylinders. Only the No. 6 cylinder parts were left bare. Two microphones that simulated the human ears were utilized to measure the radiated noise signals 1 m away from the diesel engine. First, a binaural sound localization method was adopted to separate the noise sources that are in different places. Then, for noise sources that are in the same place, a blind source separation method is utilized to further separate and identify the noise sources. Finally, a coherence function method, continuous wavelet time-frequency analysis method, and prior knowledge of the diesel engine are combined to further identify the separation results. The results show that the proposed method can effectively separate and identify the combustion noise and the piston slap noise of a diesel engine. The frequency of the combustion noise and the piston slap noise are respectively concentrated at 4350 Hz and 1988 Hz. Compared with the blind source separation method, the proposed method has superior separation and identification effects, and the separation results have fewer interference components from other noise.

1. Introduction

Nowadays, noise pollution from diesel engines is a very serious problem. It can annoy people and seriously affect their physical and mental health. Thus, it is essential to control the noise of diesel engines. The main noises of a diesel engine are mechanical noise, combustion noise, and aerodynamic noise [1]. Mechanical noise consists mainly of piston knock noise, valve train knock noise, gear noise, and fuel injection pump noise. Combustion noise is caused mainly by the intense transformation of cylinder pressure. Aerodynamic noise mainly includes intake noise and exhaust noise.

In order to reduce the noise of a diesel engine, the first step is to separate and identify the noise sources. Then, a noise reduction plan can be created. At present, the blind source separation (BSS) method is widely used to separate the noise sources of the diesel engine. For example, Servière et al. [2] used a blind source separation method based on a convolutive model of nonstationary mixtures to separate the combustion noise and piston slap noise of a diesel engine. Hao et al. [3] and

* Corresponding author at: School of Energy and Power Engineering, Wuhan University of Technology, Wuhan 430063, China.
E-mail address: yxiang@whut.edu.cn (Y. Xiang).

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Wang et al. [4] both employed an independent component analysis (ICA) algorithm, fast Fourier transform (FFT), and wavelet transform technology to separate and identify the noise sources of a six-cylinder diesel engine. Lin and Lin [5] adopted an improved blind source separation algorithm to identify the engine noise sources.

In addition, there are some other methods to separate the noise sources. For example, Badaoui et al. [6] utilized cyclic Wiener filtering to separate the combustion noise and piston slap noise of a diesel engine. Junhong and Bing [7] used sound intensity techniques to analyse engine front noise. Shu and Liang [8] adopted a coherent power spectrum to analyse the noise sources of a complex diesel engine. Pruvost et al. [9] utilized an improved spectrofilter to separate the combustion noise and mechanical noise of a diesel engine. Antoni et al. [10] adopted a speed-varying filter to separate the combustion noise of internal combustion engines using a cyclo-non-stationary regime.

The blind source separation method has some limitations in separating the noise sources of a diesel engine. The blind source separation method requires the number of measurement channels to be greater than or equal to the number of separated components. However, a diesel engine has many noise sources, and it is very difficult to determine the specific number. Thus, determining the number of measurement channels is a complex problem. In addition, the traditional blind source separation method requires the statistical independence of source signals. However, owing to the secondary effects of mechanical mixing sounds, the mixed signals do not meet the assumption of statistical independence. Thus, the blind source separation results will appear to have large errors. Moreover, some other methods require many acoustic sensors to measure the noise signals, and the cost of acoustic sensors is usually high. This will increase the cost of diesel engine tests.

To solve these problems, the computational auditory scene analysis (CASA) method is applied to separate the mixed signals. The traditional blind source separation method requires the mixed signals to satisfy the independence and Gaussian hypothesis. However, the CASA method does not have to meet these assumptions. In addition, the CASA method generally uses dual channels, which can reduce the number of sensors and improve the computational efficiency.

Currently, the CASA method is usually used to separate and identify speech signals. For example, Rickard et al. [11–14] used the degenerate unmixing estimation technique (DUET) to separate mixed signals. Mahmoodzadeh et al. [15] used the binaural speech separation method to separate speech signals. Alinaghi et al. [16] used binaural cues and the blind source separation method to separate speech signals in reverberant conditions. May et al. [17] adopted a binaural scene analyser to identify speech signals.

In reality, diesel engine noise signals and speech signals are aliasing sound signals that can be separated. However, the mixed method and transfer method for diesel engine noise signals are more complex than those for speech signals. Thus, it will be more difficult and challenging to separate the noise sources of a diesel engine.

At present, there are very few research studies that used the CASA method to separate the noise sources of a diesel engine. The binaural sound localization method is one of the CASA methods, and it is widely used to separate mixed signals. Moreover, the binaural sound localization method mainly separates noise source signals that are in different places. The blind source separation method can separate noise source signals that are in the same place. Thus, in this study, the binaural sound localization method and the blind source separation method are combined to separate and identify the noise sources of a diesel engine.

The paper is organized as follows. In Section 2, basic theory methods (such as the binaural sound localization method and the blind source separation method) are described. In Section 3, a diesel engine noise and vibration test is introduced. In tion 4, separation and identification methods are utilized to separate the noise sources of a diesel engine. Finally, Section 5 presents conclusions and summarizes the paper.

2. Basic theory method

2.1. Binaural sound localization method

2.1.1. CASA system architecture and separation clues

CASA is a sound source separation method based on physiology and psychology. It consists mainly of three stages: decomposition stage, feature extraction and organization stage, and synthesis stage.

Table 1
Sound classification clues of CASA.

Number	Sound classification clues
1	Onset/Offset
2	Cross correlation of different channels
3	Fundamental frequency autocorrelation
4	On harmonic spectrum peak
5	Interaural time difference (ITD)
6	Interaural intensity difference (IID)
7	Sound source characteristics of similarities
8	Sound sequence of events in periodic time interval