Experimental Analysis on Barrel Module of Digital Camera for Noise Source Identification

Hyung-Taek Kwak, Ji-Hyun Yoon, In-Hyung Yang, Jae-Eun Jeong, and Jae-Eung Oh

***Abstract*—** Noise of digital camera has been noticeable to its users. Particularly, noise of a barrel module in Zoom In/Zoom Out operation is recorded while taking a video. Reduction of barrel noise becomes crucial but there are not many studies on noise of digital camera due to its short history of use. In this study, besides theoretical approach, experiment-based analyses are implemented to identify sources of noise and vibration because of complexity and compactness of the barrel system. Output noise is acquired in various operation conditions using synchronization for spectral analysis. Noise sources of a barrel module are first identified through spectral analysis and correlation analysis and further study on noise transfer characteristic of Zoom module is then carried out.

***Keywords*—** igital a era oise Transfer oise ource dentification pectral nal sis

I. Introduction

DIGITAL camera has been developed fast, focusing on slim and light-weighted design. In addition to taking a photograph, capturing video with comparative good quality is also important factor for customers to consider while choosing a product. However, noise generated from a barrel module of digital camera in Zoom In/Zoom Out operation is recorded while capturing a video and become noticeable to its users. In order to reduce the noise generated by a barrel module, identification of noise sources is crucial and the countermeasures against source should be considered subsequently.

At present, there are not many studies on noise of digital camera due to its short history of use. It is difficult to identify sources of the noise because a barrel system of digital camera is very complex. A barrel system consists of small various components made of plastic materials, for instance, barrel, lens, motor, gears. Further, many components work simultaneously while a barrel module is operating that makes it complicated to acquire and analyze data. The theoretical approach to the model is also challenging due to its compactness.

In this paper, identification of noise sources is first carried out and then experimental analysis of noise transfer path is studied in order to reduce noise of a barrel of digital camera.

In identification of noise sources, correlation analysis is first carried out to see correlation between noise and vibration by deriving coherence function from measurement data. Through comparison of calculated excitation frequencies to peak frequencies in the noise spectrum, several components are identified as sources for different operation mechanisms.

Among components causing noise, one is found to be Zoom module. Main features of Zoom module are gear train and Zoom motor. Characteristics of noise radiation from Zoom module is studied by measuring output noise of a barrel in several operation conditions. By comparison of spectra of the output noise, a conclusion is made on cause of the highest sound pressure level.

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II. Acquisition of Noise and Vibration of Barrel Module using Synchronization

A. Division of Operation Modes for Synchronization

To operate the barrel module disassembled from a digital camera set, a set of 9 operation modes, Operation Flow, is written by using the barrel tester, which is designed for test of barrel modules. As illustrated in Fig. 1, the Zoom In and Zoom Out operations are written as Wide-Tele mode in the second mode (b) and Tele-Wide mode in the fifth mode (e), respectively. In Operation Flow, the two modes are selected to investigate since they are most problematic operations to customers.

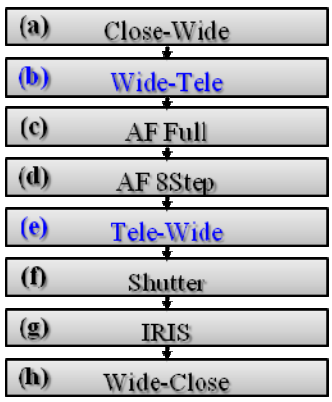

Fig. 1 Operation Flow of the Barrel Module for Test

The noise of the barrel module is not steady noise because several components are operating together at the same time. In Wide-Tele mode and Tele-Wide mode, two modules, Zoom Module and AF Module, are working in sequence. Zoom Module is a set of components for moving the barrel part back and forth while AF Module is designed for autofocus. For this reason, it is crucial to synchronise acquired data with real signals to avoid possible erroneous results. In order to synchronise, control signals from photo interrupters in both modules are acquired at the same time. Fig. 2 shows division of the control signals matched with Operation Flow.

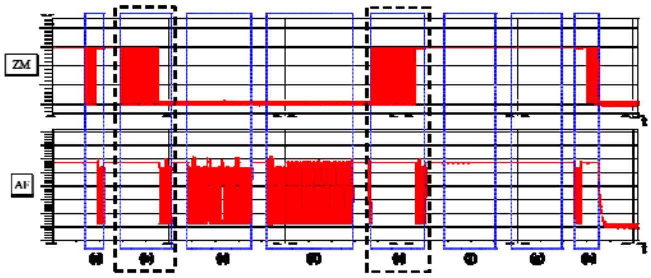

Fig. 2 Division of Operation Flow by Control Signals

B. Data Acquisition of Barrel Module Noise using Synchronisation

Fig. 3 represents an experimental setup for the barrel module. To investigate characteristics of the barrel module only while operating, the barrel module was suspended from a steel frame by strings. The frame was chosen to be much heavier than the barrel module to exclude its natural modes in the analyses. The experiments were carried out in a semi-anechoic chamber where the barrel module was located at 50 cm above the ground. A 1/2” microphone (PCB 426E01) was set at 5 cm in the back of the barrel module, which is defined as an output noise for the system. In addition, an accelerometer (ENDEVCO 27AM1-100) was placed on the pre-selected positions. By using FFT analyzer (Muller BBM PAK Mobile MK II), data of noise and vibration were acquired simultaneously in each experiment.

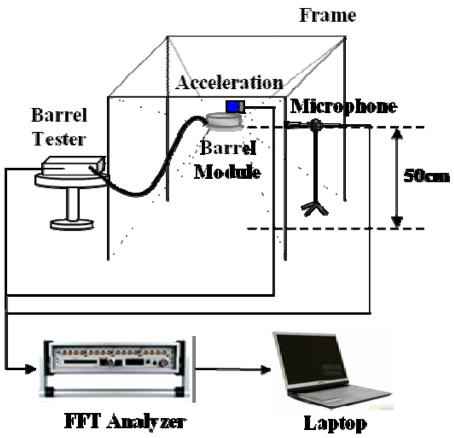

Fig. 3 Schematic Diagram of Experimental Setup

C. Experiment Results and Considerations

In Fig. 4, the upper graph is an auto power spectrum of noise when Zoom Module is operating and the other is an auto power spectrum of noise when AF Module is operating. Sound pressure level is A-weighted over the measurement frequency range.

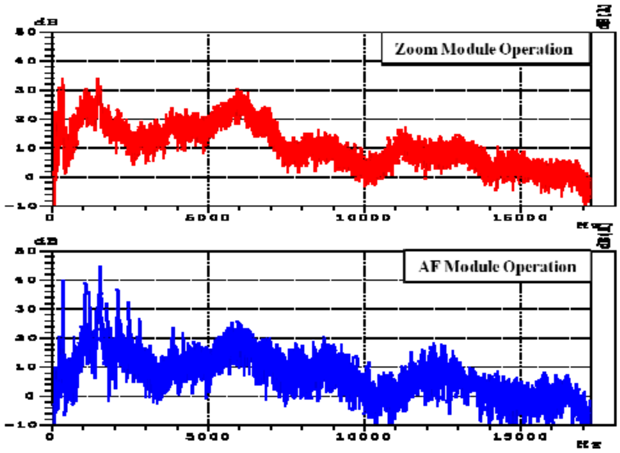

Fig. 4 Spectra of Zoom Module Operation and AF Module Operation

In the frequency range of more than 5 kHz, both spectra show similar sound pressure levels. Sharp peaks over 30 dBA occur over 0-1000 Hz in the spectrum for Zoom Module Operation while peaks are observed in the range of 0-3000 Hz for AF Module Operation. Overall sound pressure level is about 44.6 dBA, 45.4 dBA for Zoom Module Operation and AF Module Operation, respectively.

III. Correlation Analysis between Noise and Vibration

In order to investigate correlation between noise and vibration of the barrel module, coherence functions at various components are calculated from the experiment results.

A. Coherence Function

Coherence function indicates linear relationship between two signals. Coherence function is defined as (1) where $S_{xx}(f)$ and $S_{yy}(f)$ are auto power spectrum of $x(t)$, $y(t)$, respectively, and $S_{xy}(f)$ is cross power spectrum of two signals. A value of coherence function is ranged between 0 and 1. The value 1 represents perfect correlation of two signals. In reality, the value is mostly below 1 due to noise in signal.

$$\gamma_{xy}^2(f)=\frac{\left|S_{xy}(f)\right|^2}{S_{xx}(f)S_{yy}(f)} \tag{1}$$

B. Results and Considerations

Coherence functions at 5 components that are possible noise sources are obtained. The components are Zoom motor, Zoom gearbox, AF motor, AF gearbox, and Barrel. Averaged coherence function for Zoom Module Operation is greater than 0.7 over 0-1000 Hz at all components. Significantly high coherence function is derived at peak frequencies in noise spectra. Table. I contains coherence functions at the fundamental frequencies of peaks.

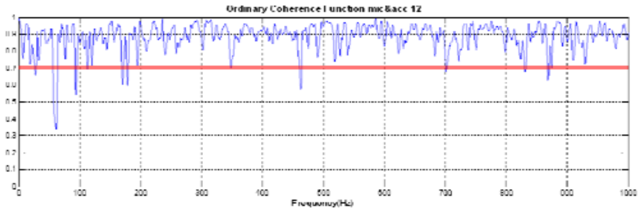

Fig. 5 Coherence Function at Position of Zoom Motor

TABLE I
COHERENCE FUNCTION AT MEASUREMENT POSITIONS

Freq.(Hz)	Zoom Motor	Zoom Gearbox	AF Motor	AF Gearbox	Barrel
98	0.8985	0.9286	0.9207	0.7574	0.9149
228-230	0.8850	0.9359	0.9256	0.8808	0.9416
288-290	0.9738	0.9402	0.8812	0.9681	0.9594

It is concluded that the noise of the barrel module is structure-borne. Moreover, generated vibrations are transferred to the whole module in Zoom Module Operation due to its size. It is necessary to investigate sources of vibrations.

For AF Module Operation, coherence function varies considerably over 0-3000 Hz at all components. Significantly high coherence function is only at peak frequencies in noise spectra. Therefore, vibrations in AF Module Operation generate noise at specific frequencies rather than wide frequency range.

IV. Source Identification of Barrel Module

The gear train of Zoom module is studied to examine possibility of source as an input to the barrel module system. Firstly, shaft frequency and gear mesh frequency is calculated base on the gear theory and then is compared with peak frequencies of experiment results.

A. Gear Meshing Frequency

Gear noise is induced by vibrations of gears and related closely to gear meshing frequency (GMF). GMF is calculated from (2) where f_m is meshing frequency, f_s is shaft frequency, and Z is a number of teeth.

$$f_m = f_s \times Z \tag{2}$$

Near the harmonic frequencies of GMF, there is side band which has harmonic frequencies of shaft frequencies involved. Harmonics and side band generally have adverse effects on human ear.

B. Source Identification for Zoom Module Operation

GMFs and shaft frequencies, including Zoom motor's, are compared with peaks frequencies observed in the noise spectrum. First two GMFs are dominant in the spectrum and they match with the experiment results within 3 frequency bands. This is because first two pairs of gears are driven at greater rpm than others due to the high gear ratio used. Therefore, noise sources are identified to be gear meshing and rotation of Zoom motor for Zoom Module Operation.

C. Source Identification for AF Module Operation

GMFs and shaft frequencies, including AF motor's, are compared with peaks frequencies. Different from Zoom module, harmonics of the shaft frequency of AF motor is dominant in the spectrum and they match with the experiment results within 2 frequency bands. This is because purpose of AF gear train is only to transfer power, not to use high gear ratio. As a result, noise source is identified to be rotation of AF motor for AF Module Operation

TABLE II
PEAK FREQUENCY IN ZOOM MODULE AND AF MODULE OPERATION

Module	Peak Frequency (Hz)								
Zoom Module Operation	98	229	285	342	456	569	681	794	849
AF Module Operation	347	697	1045	1395	1745	2092	2440	2786	

V. Transfer Characteristic Analysis of Zoom Module Operation Noise

Besides noise sources for peak frequencies, there are frequency bands with considerably high reference level. For Zoom Module Operation, the level of the band, near 1.2 kHz, is greater than levels of peaks. Therefore, transfer characteristic analysis is implemented to identify the source of the band, measuring output noise in various rpm condition.

A. Output Noise of Zoom Module at Various rpm

Zoom Module is disassembled from the barrel module. To operate Zoom motor, a power supply was used and the voltage induced to Zoom motor is set to change from 0.6 V to 3.0 V per 0.3 V. The voltage range is selected to include all rpm used in digital camera operation.

The Zoom Module was placed on soft foam and 1/2" microphone was set to be at the output noise position. Data acquisition of the output noise was carried out with FFT Analyzer at each rpm. Maximum frequency for FFT is chosen to be 9.4 kHz.

Output noise spectra at all cases are plotted in Fig. 6. As rpm is going up, overall sound pressure level increases and trend of spectrum becomes divided into two kinds of frequency band. Over the band ranging from 0 to 4 kHz, peaks at GMF and Shaft frequencies appear significantly. The levels of the peaks are lower than those of the barrel module since there in no load to the gear train.

Sound pressure level of a frequency band near 8 kHz is increasing as rpm is growing. The noise of this band is considered to be air-borne noise that is generated from friction of gear pairs.

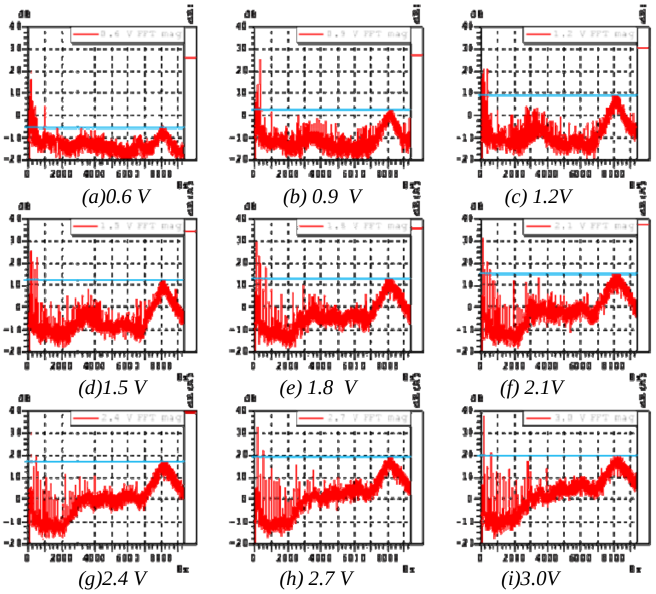

Fig. 6 Noise Spectra of Zoom Module Operation

B. Output Noise of Barrel Module at Various rpm

The same procedure is applied to the barrel module to investigate the transfer characteristics of Zoom Module, which is thought to be an input to the barrel module system. The same rpm was set to the barrel tester and the output noise is acquired in Wide-Tele mode. Since distance from the position of Wide to the position of Tele is constant, the operation time varies according to each rpm.

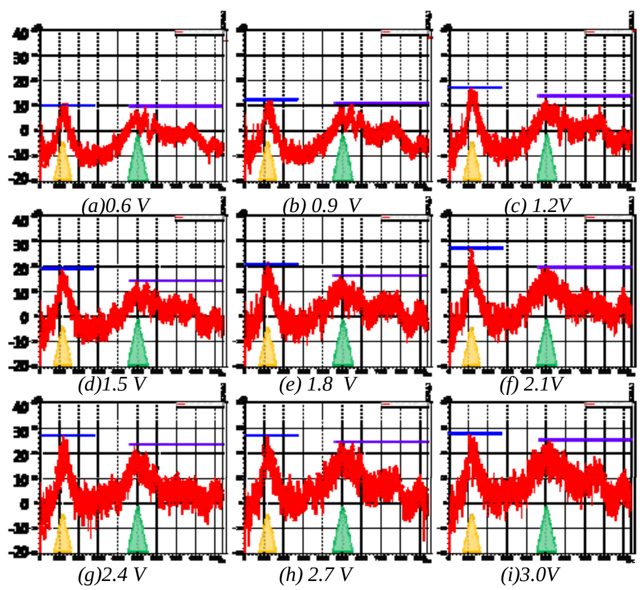

Fig. 7 Noise Spectra of the Barrel Module

As shown in Fig. 7, reference sound pressure level increases considerably over the frequency bands near 1.2 kHz and 5.0 kHz. The band near 1.2 kHz has the highest level over the measurement frequency range and doesn't shift when rpm changes. Therefore, it can be concluded that the noise at the band is generated from the structure of the system. It is important to identify exact causes of the noise of the frequency band near 1.2 kHz.

C. Instantaneous Spectrum of Output Noise of Barrel Module

In order to confirm the noise characteristic during Zoom Module Operating, output noise spectra are obtained by averaging every 0.2 sec. In Fig. 8, 8 noise spectra are plotted in sequence of time, from left to right in the first row and left to right in the second row. Blue plot represents the averaged spectrum in the whole interval. Particularly, the level over the frequency band near 1.2 kHz continues to be highest in the measurement frequency range. It reaches a conclusion that Zoom module excites the barrel module system so its structural noise is generated continuously.

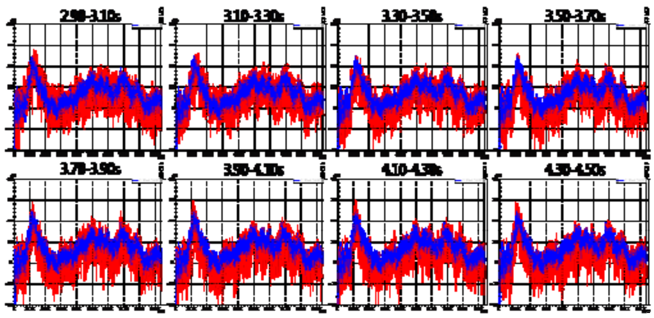

Fig. 8 Instantaneous Noise Spectra of the Barrel Module

VI. Conclusion

In the study, experimental approaches are made to investigate noise sources of the barrel module. Firstly, through the correlation analysis, the noise of the barrel module is found to be structure-borne noise. Based on that, by comparing GMFs and shaft frequencies with peaks frequencies in measured noise spectra, gear meshing and rotation of Zoom motor is identified as sources for Zoom Module Operation in Wide-Tele mode while rotation of AF motor is confirmed to be the main cause of noise for AF Module Operation. That structure-borne noise appears to be sharp peaks with considerably high sound pressure level.

In order to identify the cause of the frequency band near 1.2 kHz for Zoom Module Operation, several experiments were implemented for both Zoom module and the barrel module. From the results, the noise of the band is independent of operating frequency as well as operating time. However, its level is affected by power of Zoom motor. Therefore, it is concluded that the noise is structural noise, which is dependent of the system.

Countermeasures should be considered in two ways. The first is to reduce level of excitation of noise sources. The other is to modify transfer paths from noise sources. For the barrel module, the former approach would be more effective even though it is known to be costly.

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