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Objective detection method of sound coloration in electroacoustic enhancement system

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Abstract

The Active Field Control (AFC) is an electroacoustic enhancement system to improve the acoustic conditions of a space. In this system, how to prevent sound coloration caused by acoustic feedback is the key procedure in a tuning process. In order to incorporate the control of coloration into the automation of tuning, an objective detection method is studied based on subjective assessment and the objective evaluation of coloration. In order to objectively evaluate the coloration, two responses are calculated from the impulse response (IR) captured in the field. One is a frequency characteristic of the Decay-Cancelled IR. The other is a moving-average frequency characteristic based on the previous response. The index parameter σ_G is calculated by the standard deviation of the ratio of these responses. Subjective assessment was carried out using IRs captured in several sound fields with AFC and it is found that σ_G can be an objective evaluation index of coloration. AFC consists of four independent acoustic feedback channels. If the peaks of the frequency characteristics in each feedback channel are suppressed below a certain level, it is considered that subjective detection of coloration might be minimized. The detection and adjustment of frequencies perceived as coloration is carried out in several steps: i) IR is measured at each open loop channel of the system; ii) Several peaks in the frequency characteristics of the late part of the Decay-Cancelled IR are selected since generally coloration is detected in the late part of the IR; iii) These peaks are adjusted at the averages of the maximum values of the frequency characteristics. As a result, subjective coloration is found to be prevented in the AFC auto tuning process with σ_G.

Keywords: coloration, electroacoustic enhancement system, active field control, AFC, tuning process

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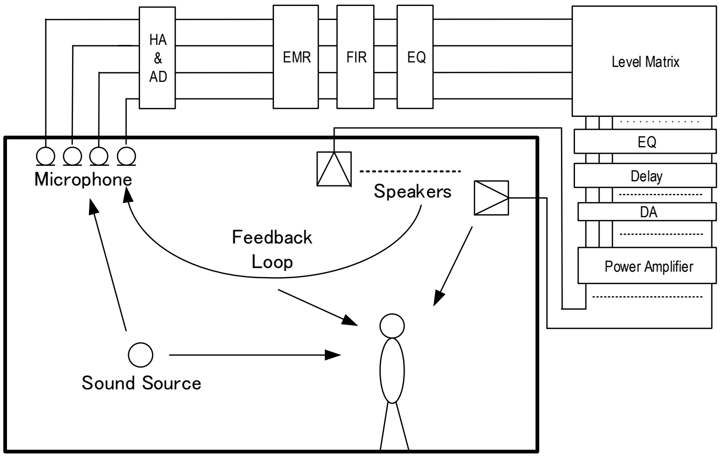
1 Introduction

The Active Field Control (AFC) is an electroacoustic enhancement system that is developed to improve the acoustic conditions of a space to match the acoustic conditions required for a variety of different types of performance programs [1]. Figure 1 shows an overview of the AFC system.



EMR: Electronic Microphone Rotator, FIR: Finite Impulse Response, EQ: Equalizer

Figure 1: Overview of AFC system

Sound picked up by microphones is amplified and processed by a signal processing unit. The signals are then amplified by amp units and reproduced through multiple speakers. Because the microphones and speakers are set up within the same space, the sound that is reproduced by speakers is picked up again by the microphones and then reproduced again by the speakers. This creates a feedback loop between the microphones and speakers. AFC actively utilizes the feedback to add energy to the sound field. Because AFC uses a diffuse sound captured by the microphones at or beyond the critical distance, AFC enhances some inherent peaks of the frequency characteristics in the field. When the loop gain of the system is increased to add energy to the field, some peaks of the frequency characteristics of the specific routes between speakers and microphones also increase. When the loop gain exceeds a certain level, those peaks are perceived as sound coloration. Generally the perceptual attributes can be divided in frequency domain perception (i.e. timbre related) and time domain perception (i.e. flutter) [2]. This paper focuses on frequency domain perception. Very long decay can be perceived at specific frequencies in the overall reverberation decay of the impulse response (IR). Figure 2 shows an example of coloration.

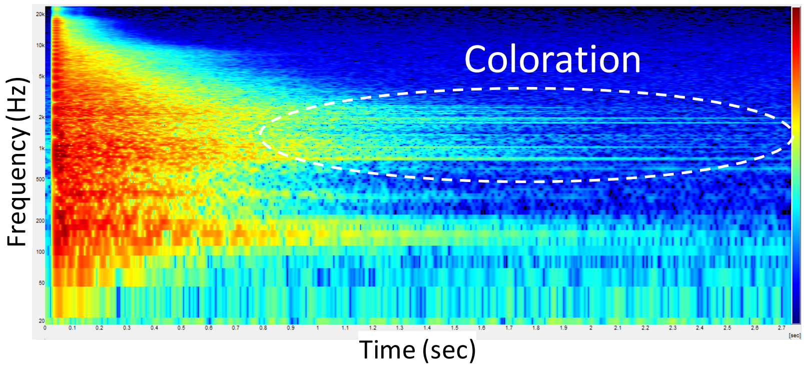


Figure 2: Example of coloration

We are developing software for the automation of system adjustments to minimize sound engineer-dependent variations in sound quality. Although the flattening of loop gain frequency characteristics is a critical control factor for a stable system, AFC can realize a stable system even in small independent channels since it applies spatial averaging control. Currently, AFC applies efficient adjustment using an auto equalizing function that flattens the frequency characteristics between the microphones and speakers in the system. On the other hand, regarding the coloration that can be perceived even in a stable system, experienced engineers have to judge whether it should be adjusted or not while listening to the sound. If the evaluation of the objective coloration can be developed, it can be applied to the tuning process of the system in order to further expand the automation of the tuning. In order to incorporate objective evaluation and control of sound coloration into the automation of system tuning, objective evaluation is performed based on subjective assessment and an objective sound coloration detection method.

2 Objective evaluation of coloration

The objective evaluation is based on the statistical nature of the frequency characteristics in a diffuse field [3]. In order to objectively evaluate the coloration, two responses are calculated from the IR captured in the field. One is a frequency characteristic that is fast Fourier transformed from a decay-cancelled IR [4]. The other is a moving-average frequency characteristic based on the previous response. The index parameter σ_G is calculated by the standard deviation of the ratio of these responses [5]. Figure 3 shows an example of frequency characteristics. In this case, the moving-average characteristic is calculated with the smoothing width of 1/3 octave band (red line in Figure 3). In a passive diffusive room, frequency response follows the Rayleigh law and the level difference between the maximum and the average of the energetic frequency curve is about 10 dB and σ_G is calculated around 0.523 [6].

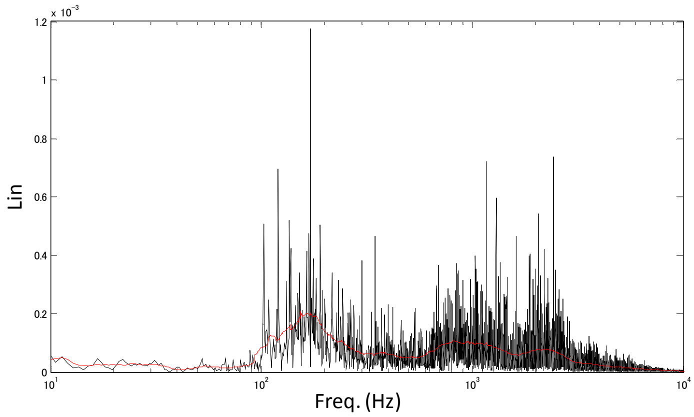


Figure 3: Example of the frequency characteristics obtained by FFT of an IR

3 Subjective experiment

Subjective assessment was carried out using IRs captured in several sound fields with AFC, listed in Table 1. Each IR was measured between a microphone and a dodecahedron speaker which were brought in the auditorium. The evaluation was performed using 21 measured IRs. The IRs categorized three different measurement conditions: 1) AFC is turned off, 2) the condition of normal tuning of AFC, 3) the condition of intentional tuning of AFC with coloration. The method that we used in the experiment was the MUSHRA (MUlti Stimulus test with Hidden Reference and Anchor) subjective test method [7]. The subjects were 15 acoustic engineers ranging from 20 to 50 years of age. The subjects all rated the perceived coloration of 21 IRs on a 101-step scale from 0 to 100 while listening to IRs reproduced from a loudspeaker. The subjects confirmed the frequency domain perception by listening to the example of coloration in advance. Figure 4 shows the relation between the mean and 95% confidence interval of statistical distribution of the assessment grades and the objective index σ_G.

Table 1: Evaluated IRs were measured in the auditoria below.

No.	Seats	Volume (m^3)	RT (sec) System Off	RT (sec) System On
1	400	1,900	0.8	1.7-2.1
2	489	1,990	0.8	1.1-3.5
3	500	3,911	1.1	1.3-2.0

As shown in Figure 4, the subjective assessment of coloration shows high correlation with the objective index σ_G. It is confirmed that σ_G is an evaluation index of objective coloration, which Meynial and Vuichard have already mentioned in their research [5]. Based on this result, if the threshold of subjective assessment of coloration is 50%, σ_G is indicated as less than 0.63. We may use this value as the threshold of objective assessment of coloration in a tuning process of the system.

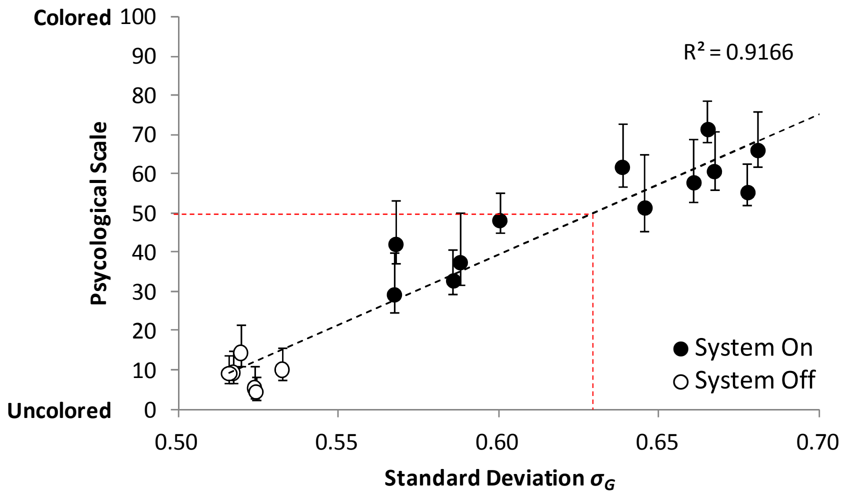


Figure 4: Subjective evaluation of coloration vs. objective index σ_G

4 Objective evaluation of coloration in the AFC configuration

Verification of whether objective assessment of coloration can be also applied using the microphones and the speakers of the AFC system in the auditoria was also performed. The assessment was carried out in the 500-seat and 400-seat rectangular auditoria where AFC systems were installed. We measured the IRs between each speaker and each microphone of the system: 32 routes (8 x 4) in the 500-seat auditorium, and 4 routes reproduced from 4 or 6 speakers simultaneously to each microphone in the 400-seat auditorium. Figures 5 and 6 show the placement of the equipment. Figure 6 also shows each combination of the measurement route. Figure 7 shows the relationship between the objective index σ_G and the corresponding level difference between the maximum and the average of the energetic frequency curve.

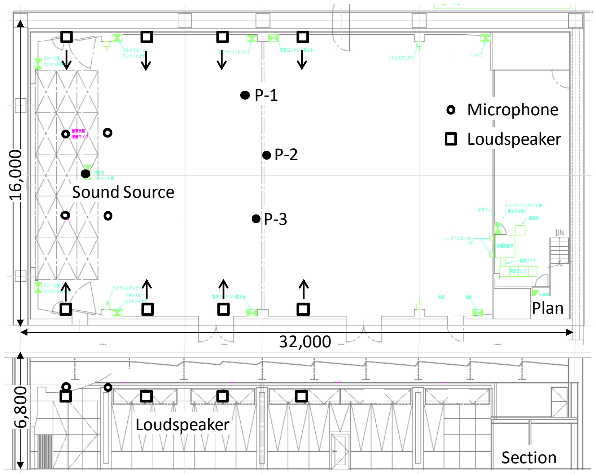


Figure 5: Equipment placement of AFC in 500-seat auditorium

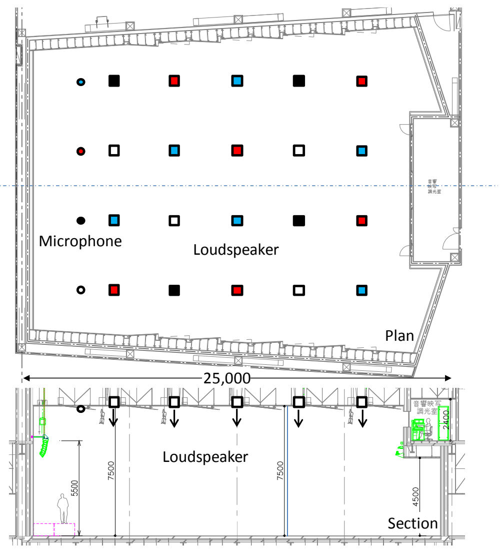


Figure 6: Equipment placement of AFC in 400-seat auditorium

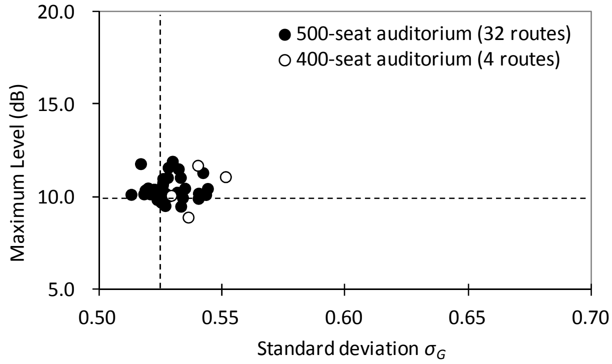


Figure 7: Measurement result of indices in auditoria

As shown in Figure 7, the values are at around 0.523 of σ_G and around 10 dB of maximum level. This means that the values calculated by the IRs which were measured using the system equipment almost follow the theoretical value. It is confirmed that the objective index σ_G can be applied to the equipment of the system. In this case, each IR should be measured at each open loop channel of the system [8].

5 Coloration removal procedure in the AFC configuration

Based on the results above, detection and adjustment of coloration are done using the microphones and speakers of the AFC system. AFC consists of four independent acoustic feedback channels. If the peaks of the frequency characteristics in each feedback channel are suppressed below a certain level, it is considered that subjective detection of coloration might be also suppressed to an acceptable level in the sound field through AFC system. Figure 8 shows the procedure of the detection and the adjustment of coloration. At first, the IR was measured at each feedback channel with open loop condition while other feedback channels closed (Semi Open Loop). And then, since coloration is detected in the late part of the IR, it applies to the period between -30 and -50 dB of the decay curve that was calculated by the IR. After the frequency response is fast Fourier transformed from the late part of the decay-cancelled IR, several peaks of the response were selected. These peaks are adjusted at the averages of the maximum values of the frequency response.

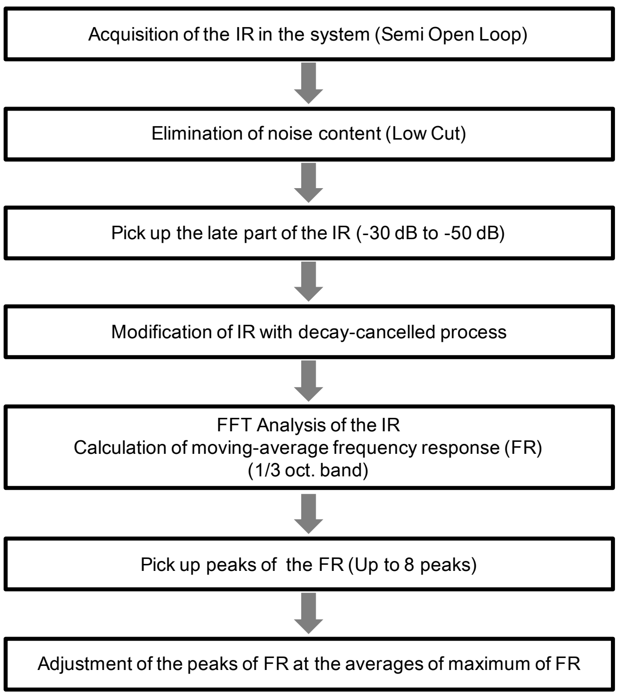


Figure 8: The procedure for the detection and adjustment of coloration

Figure 9 shows the results of σ_G that was calculated by the measured IRs in the auditorium shown in Figure 5. It was applied with/without the procedure in the tuning of the system. It is confirmed that the procedure controls σ_G. Figure 10 shows an example of spectrograms with and without the coloration removing procedure using the measured IRs. These results show that σ_G can be controlled and that subjective coloration can be suppressed with the proposed coloration removal procedure.

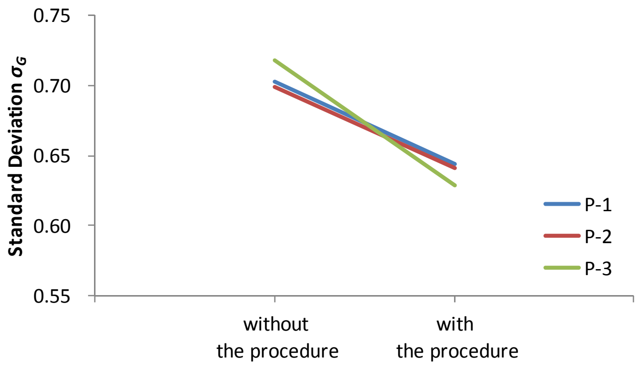


Figure 9: The results of objective index σ_G with/without the coloration removal procedure

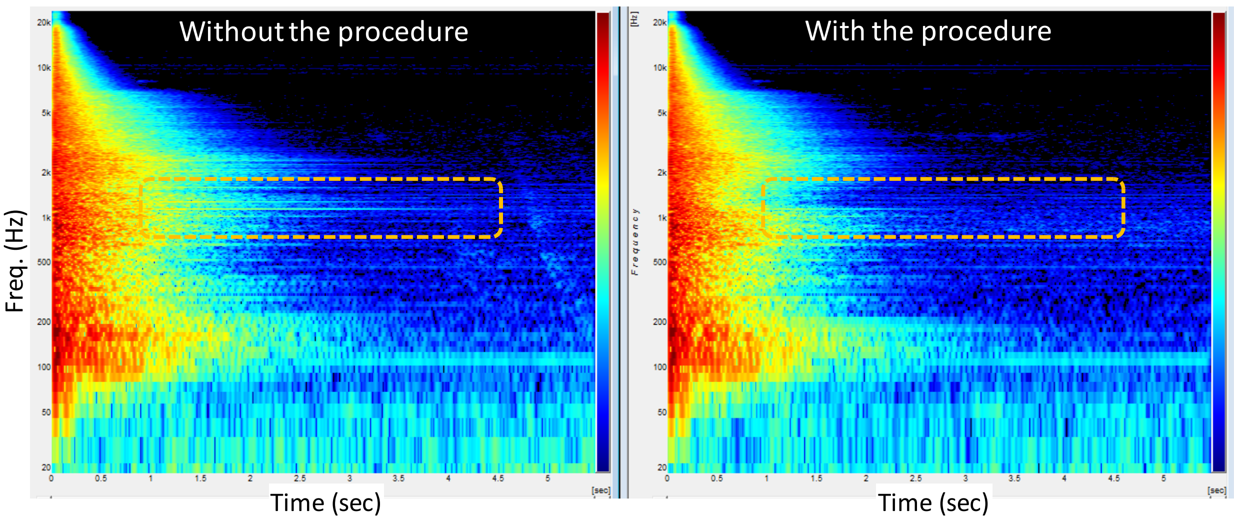


Figure 10: Example of spectrogram with/without the coloration removal procedure (P-3)

6 Conclusions

Regarding the objective assessment of coloration, we studied the index σ_G of the frequency characteristic calculated by the measured IR in the sound field and found that the subjective assessment of coloration shows high correlation with this index. We also proposed the procedure for the detection and adjustment of coloration in the tuning process of the AFC system. Based on the results presented in this paper, together with quantitative assessment of the degree of coloration, incorporation of the proposed procedure for the detection and adjustment of coloration in automatic adjustment is expected to result in minimized engineer-dependent variations in sound quality and a more easy-to-use electroacoustic enhancement system. Further investigation of the general threshold of σ_G that is not perceived as sound coloration is needed in the future.

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