AN ELECTRO-ACOUSTIC ENHANCEMENT SYSTEM FOR REHEARSAL ROOMS

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ABSTRACT

This paper discusses the theoretical and practical aspects of electro-acoustic enhancement systems for rehearsal rooms. First we review the acoustics on the concert hall stage and then we discuss some advantages and problems of electro-acoustic enhancement systems. We also introduce one possible system configuration for a rehearsal room in which electro-acoustic enhancement is applied to achieve as natural concert hall acoustics as possible.

INTRODUCTION

Music rehearsal rooms are sometimes used, instead of concert halls, by symphony orchestras in everyday rehearsals. The biggest problem in these rooms is that acoustical conditions differ a lot from the actual hall of the performance. This is not an acceptable situation because the interpretation of music as well as ensemble playing depends on the acoustics of the concert hall. If the orchestra can practice only once before a concert in the hall of performance the players are not able to give the best performance. Another problem with rehearsal rooms is an increased sound pressure level, caused by too small space for the orchestra of hundred players. This is nowadays a severe problem because hearing degradation is an increasing problem among music professionals.

To understand the acoustical requirements of rehearsal rooms, we first review the acoustical conditions which occur on the stage. Then we introduce some general features of electro-acoustic enhancement systems which are studied, e.g., in [1-5]. We will also discuss different methods to diminish acoustical feedback which is an evident problem in reverberation enhancement systems. Finally, we will present one possible solution of an electro-acoustically enhanced rehearsal room. Also preliminary simulation results of the proposed rehearsal room are presented and some future guidelines for research are introduced.

ACOUSTICS ON THE STAGE OF CONCERT HALL

The room acoustic properties of the orchestra platforms are not a widely researched area. This is surprising because it is an important element from the musician's point of view.

The concert hall can be considered as an extension of players' instruments, through which they perceive the sound quality of their own and co-players' performance. Musicians adjust level, tempo, phrasing, timbre and intonation – i.e., their means of musical expression – according to what they hear [6].

Meyer [7] has defined three different quality levels of the acoustical conditions on stage:

1. First of all, a player must be able to play correctly. If a musician hears him/herself too loudly when compared to the others, he can still play with correct intonation but the rhythmic precision of ensemble playing suffers. In the opposite case if a player does not hear his/her own sound he/she can play in rhythm but the control of intonation is impossible.

2. A player must be able to create sound of good quality. Ease of singing or a good response of his/her own instrument supports the musician's security and enhances the accuracy of tone onsets and articulation. Ease of hearing other players helps also in well-balanced playing and enlarges the dynamic range, because ensemble playing also in pianissimo is possible.

3. The highest quality level contains the demands for creating an integrated entire sound of an orchestra. This kind of sound is formed when musicians can, without pushing, produce collective articulation of chords and a commonly formed temporal fine structure of the dynamics. The acoustical conditions at the conductor's position is important because the conductor finally co-ordinates the ensemble playing.

The recent research project, we found, about acoustical conditions on the stage of the concert hall has been done almost ten years ago by Gade [6,8,9]. He has tried to find the relationships between subjective room acoustic requirements of the performers of classical music and the objective properties of the sound field on orchestra platforms. In these papers Gade has found a few objective attributes, e.g., early support (ST_{early}), total support (ST_{total}), and late support (ST_{late}), which can be calculated from the impulse response measurements and which correlate well the subjective opinions of musicians. ST_{early} describes the ease of ensemble playing (hearing other orchestra members). The attribute ST_{total} stands for support of the room from the musicians' own instruments, in other words how well a musician perceives his/her own sound. Last attribute ST_{late} describes the impression of reverberance. Also the ratio between ST_{late} and ST_{early} tells the degree of the masking of ensemble information by loud reverberation. The calculation methods and the measurement procedure of these stage acoustics parameters are explained in [9].

Based on Gade's survey, keeping in mind Meyer's quality levels, we may conclude the following. Regardless of weak early reflections on stage, the experienced players are able to play in tempo, but the intonation suffers because the acoustics of the stage does not support the players. This situation is exactly the same than in Meyer's definition in the lowest quality level. If there exist also supporting early reflections on the stage, playing is easier (it does not need so much pushing) and the second quality level is fulfilled. The most effective way to provide early reflections to the players is to use overhead reflectors which, however, need to be designed with great care in order to avoid coloration phenomena [8]. The highest quality level is reached when the direct sound, early reflections and late reverberation are in good balance with each other. In this case the acoustics supports the interaction between the musicians that makes the high quality performance possible.

In a rehearsal room the highest quality level is hard to accomplish. With rigid surfaces early reflections have enough energy but late reverberation level might rise too high because of the lack of space. The ensemble playing becomes difficult and the hearing of the musicians might be damaged in the long run. The reverberation time could be shortened, e.g., by adding some absorptive materials to the walls, but then useful early reflections might be lost and absorption of low frequencies is difficult to achieve in small spaces. Additionally, absorptive materials make the rehearsal room too dry and it does not sound anymore like a real concert hall. As a summary, in small rooms (compared to the volume of concert halls) there is not enough space for sound of good quality that the classical music requires.

ELECTRO-ACOUSTIC ENHANCEMENT SYSTEMS

Nowadays acoustic properties of a certain space can be changed with electro-acoustic enhancement systems. Usually these systems are installed in concert halls which are considered to be too dry. That might be the reason why these systems are also called reverberation enhancement systems. Another general reason to use reverberation enhancement is the need of multi-purpose halls. Especially in small cities a multi-purpose hall is practical, because it can be used as a performing arena for theatre plays, pop music, and classical music or opera, which all need different acoustical conditions. A good presentation of the theoretical aspects of reverberation enhancement system can be found in [2] and a review of available systems can be found in [1].

Although reverberation enhancement systems seem to be very useful, they have several problems [1]:

- Subjective effects and conflicts between sonic and visual appearance. Our multi-modal perception is dominated by vision and if a room sounds different than is expected by visual cues, the room might sound unnatural. That of course limits the use of reverberation enhancement systems, especially with classical music.
- Localization artefacts. If the reverberation enhancement adds too much energy to the room or some loudspeaker is too close to the audience area the sound might be localized to a direction different from the actual sound source. These localization artefacts can be avoided by increasing the number of loudspeakers, but this naturally increases the complexity and price of the system.
- Coverage patterns. By careful design the audience area might be evenly covered with reverberant sound, but this also requires large amount of loudspeakers mounted far enough.

However, the main problem in reverberation enhancement systems is the acoustic feedback, which is always present when interconnected microphones and loudspeakers are in the same space.

Consequences of acoustic feedback

Acoustic feedback is present if sound that is captured with microphones is emitted from loudspeakers in a same space. Because of transfer function between loudspeaker and microphone is not ideal (even in good concert halls), strong resonance frequencies are emphasized more than other frequencies in a feedback loop. These emphasized peaks are, on the average, approximately 10 dB above the average level of transfer function [2]. This limits the possible loop gain severely. Close to the instability, the enhanced peaks are heard as a timbre chance in sound or as ringing tones. Ringing tones are formed because sharp peak frequencies have longer decay time than other frequencies. The phenomenon is called coloration and it might be heard already on the level of –12 dB before the instability [10].

The highest acceptable amount of coloration is very hard to define. It depends on the instruments and music played as well as subjective opinions of the listeners. However, some objective methods are proposed to measure coloration. Rindel [11] has introduced a method with cepstrum analysis to measure the coloration. Menyial and Vuichard [12] have found a few attributes that can be calculated from room impulse responses.

Solutions to avoid feedback artefacts

The easiest way to avoid feedback is to position the microphones as close to sound sources as possible. By this way the ratio of reverberant sound emitted from loudspeakers to the direct sound can be minimised. This microphone technique is not very practical with the symphony orchestra because of the need of huge amount of microphones and practical difficulties to use them (mounting the contact microphones etc.). That is the reason why the reverberation enhancement systems usually use microphones that are located outside the critical distance from the sound source. The critical distance is a distance outside of which the sound pressure level is always the same regardless of the placement of the microphone. The other technique to avoid feedback is to use directional microphones and loudspeakers.

The most effective method in avoiding feedback is to use time-varying algorithms with artificial reverberation. With time-variance the loop transfer function of the system is varying continuously and that prevents the rise of self-generating peaks. The more time-variance exists the more gain before instability is achieved. However, time-variance should not be audible and this limits its use.

Nielsen and Svensson [13] have studied the performance of time-varying systems and they have found that linear time-varying systems avoid a build-up of coloration tones in the frequency domain by smoothing the loop gain, and in the time domain by varying the phase of the loop gain. They have studied modulation techniques such as frequency shifting (FS), phase modulation (PM), and delay modulation (DM). Experiments show that delay modulation works well with mid and high frequencies but gives too little protection against instability for low frequencies. Phase modulation gives more gain before instability, but it is tricky to implement.

As a summary, it can be said that coloration can be avoided by running the system at sufficiently low loop gain. Also the use of time-varying filters or adaptive notch filters (for equalising the frequency response of feedback loop) reduces coloration. The time-variance is always more or less audible in sustained tones but is efficient in avoiding coloration. The audibility of different time-variance techniques has been studied by Svensson [2] and Nielsen [10].

AN ELECTRO-ACOUSTICALLY ENHANCED REHEARSAL ROOM

Symphony orchestras have not always a possibility to rehearse in the concert hall. Anyway, the concert hall can be considered as an extension of players' instruments and musicians should be able to practice to play this "instrument". Usually rehearsals are held in smaller rehearsal room, which might have good acoustics, but not the same acoustics than the concert hall. This was the starting point for the present study to implement a rehearsal room for symphony orchestras. The ultimate goal has been a rehearsal room, which cannot been distinguished from a real concert hall if a musician is playing with his/her eyes closed.

The first design aspect was to create a similar early response than in the concert hall. The easiest way to achieve this goal is to construct a copy of the stage to the rehearsal room. By this way the early reflections should be exactly the same than in the real hall. If there exits a platform for a choir or some seats behind the stage, they should be constructed also. With this idea only the late reverberation part of the hall response have to be created artificially. We call this approach the "truncated hall" concept.

The truncated hall can be realized with a highly absorbing wall in the position of first seating rows. Thus only sound coming from audience area back to the stage is created with an electro-acoustic enhancement system (see Fig. 1). The height of the rehearsal room is also smaller than the height of the concert hall. Fortunately some hanging reflectors (often called "clouds") are nowadays used in most of the concert halls. These reflectors have to be constructed also to the rehearsal room, but the space above them might be taken off and replaced with an absorbing ceiling.

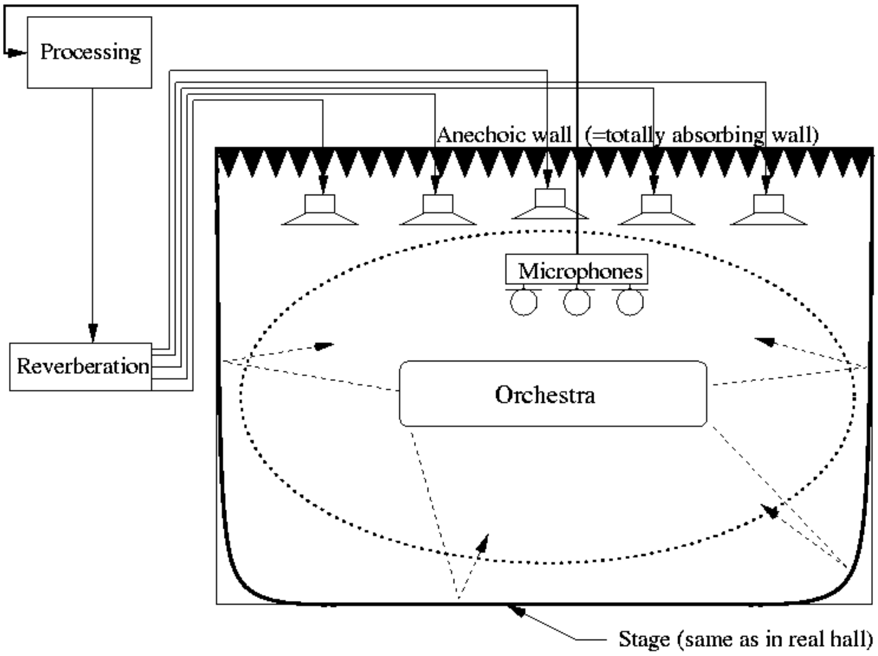

Figure 1: The truncated hall concept. The stage is a copy of a real hall stage and the late reverberation coming back from audience area to the stage is created with a reverberation enhancement system.

Preliminary analysis of a truncated hall

Ray-tracing simulation has been applied (with DIVA software [14]) to study the behaviour of early reflections in a truncated hall. We made two simplified models, one of a complete hall and another of a truncated hall (see Fig. 2). Both halls had exactly the same wall material properties, except the front wall of the truncated hall which had absorption coefficient 1.0 at all frequencies.

The results of the ray-tracing simulations from an omnidirectional source to five omnidirectional receiver positions are depicted in Fig. 3. Energy-time curves show that the early parts of responses are identical in both halls, but after about 200 ms the reflection density in the truncated hall decreases rapidly and only a few reflections are left after 400 ms. Time limits are, of course, dependent on the dimensions of the stage.

Despite of the limitations of the ray-tracing simulation, it gives us a hint how the truncated hall might work without a reverberation enhancement system. It tells us also that if a rehearsal room is an exact copy of the real hall stage, the early responses should be identical. The construction of the anechoic wall should be possible with wedges, usually applied in anechoic chambers, or with several curtains (having different acoustical properties). The design of the wall has to be realised with great care especially at low frequencies.

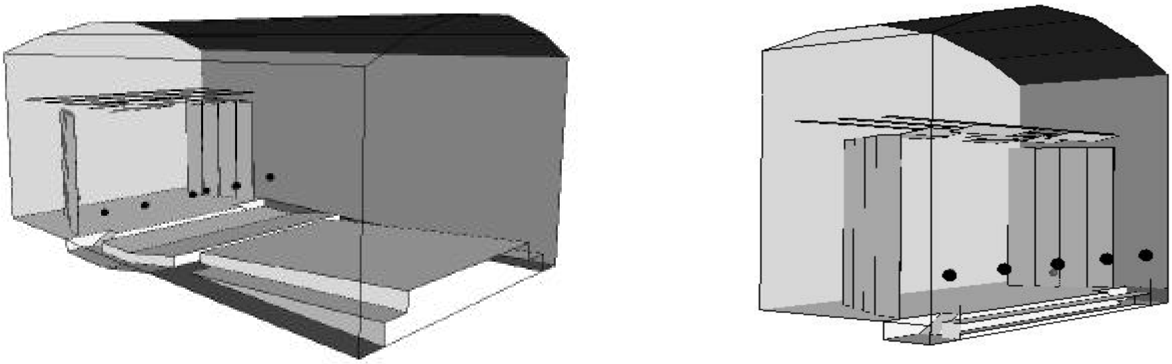

Figure 2: The complete hall (on the left) and the truncated hall (on the right) for the ray-tracing simulations. There is one omnidirectional source point on the stage and five omnidirectional listening points on top of the

first seating row.

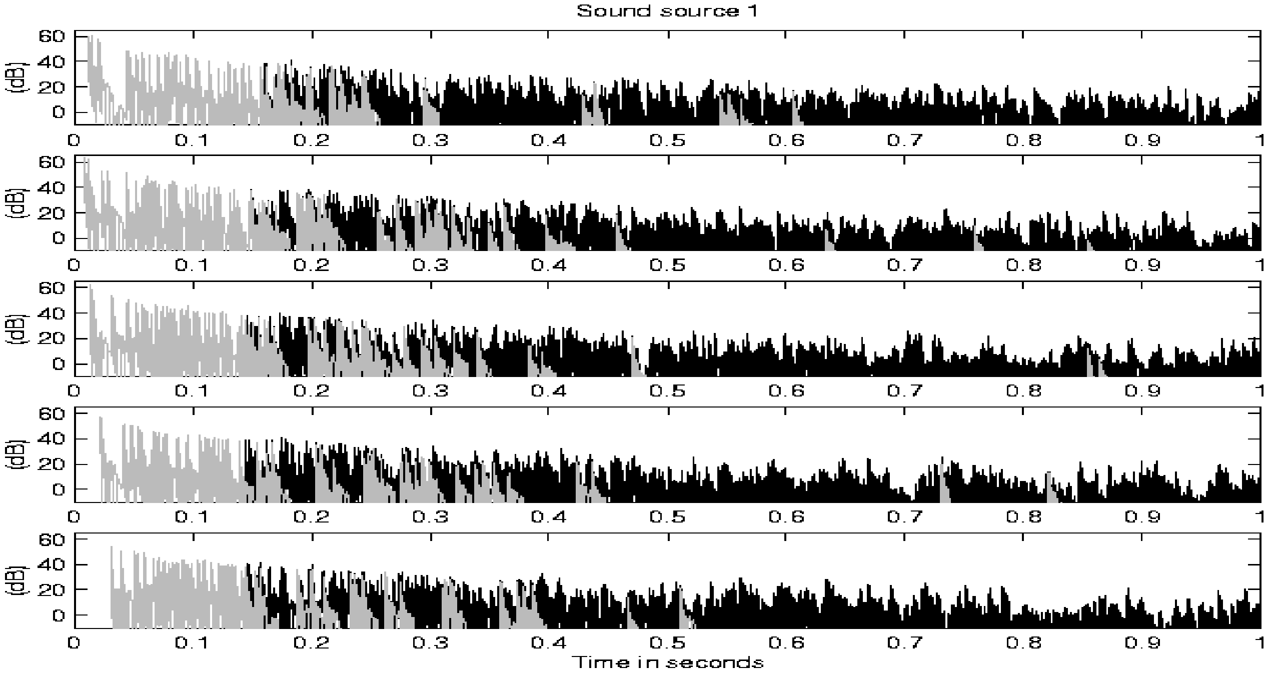

Figure 3: Simulated energy-time curves (five omnidirectional listening points) from the truncated hall (grey response) and from the complete hall (black response).

Design aspects to be considered

The first problem to be solved is the positioning of microphones which capture the sound to be fed to a reverberation unit. Of course the microphones have to be easy to use, so the contact microphones are out of question. One solution is to record the whole orchestra with an array of microphones, which can be placed either in front of the anechoic wall or on top of players. However, the problem in this approach is that instruments have different radiation characteristics. For example, a tuba radiates most of the energy towards ceiling, while trumpets and trombones have the main radiation axis towards the audience. The most attractive solution is to use only two or four directional microphones on top of the conductor’s position. In theory, the balance of the orchestra should be at its best in the conductor’s place and this place should be ideal to capture the signals for late reverberation generation.

The dynamic range of music extends from about 110 dB to less than 15 dB in the best conventional concert halls [1]. This means that all the equipment - loudspeakers, microphones, amplifiers, converters etc. - should be of high quality and their noise level has to be very low. Loudspeakers should not be very directional in order to create an uniformly distributed sound field. The placement of loudspeakers is also critical in avoiding feedback.

One open question is the reverberation algorithm to be used. Fortunately, there exists already quite natural sounding reverberators, but the need of time-variance to prevent feedback makes things more complicated. One interesting idea is to use impulse responses measured in the real hall as a reverberation response. The implementation can be realized with FIR filters and efficient convolution technique [15].

CONCLUSIONS AND FUTURE WORK

A new idea of electro-acoustic enhancement system for a rehearsal room has been presented. As background information, the acoustical conditions on concert hall stage are reviewed and general pros and cons of reverberation enhancement systems are discussed. The proposed concept is called truncated hall, in which the audience area is replaced with a totally absorbing wall and a reverberation enhancement system. In this approach there are several advantages over the conventional reverberation enhancement systems. The early part of impulse response, the direct sound and early reflections, are identical with the real hall.

This means that only the reflections and reverberation coming from the audience area have to be created artificially. One large highly absorbing wall helps also in keeping the sound pressure level in a rehearsal room at an acceptable level.

In the near future we will build a prototype of the proposed electro-acoustically enhanced rehearsal room. We will install a LARES system [3] to one big recording studio (dimensions of which are 20x13.5x7 meters). One wall (20x7 m) of the studio will be covered by several heavy curtains so that it should be nearly anechoic. With this prototype we can evaluate the proposed system with measurements and also with musicians who will play with the system turned on and off. The prototype is also useful in testing the microphone and loudspeaker positions as well as some time-variant reverberation algorithms.

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