Local Performance Recording and Reproduction: Application to a String Quartet

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A technique of musical reproduction is being developed that differs from traditional stereophonic sound reproduction in that it attempts to bring the performance to the listener. Recording and reproduction must be coordinated to accomplish this. The current application attempts this method for a string quartet.

INTRODUCTION

Local performance recording and reproduction (LPR/R) is a new technique that uses different recording and playback methods than normal stereophonic recording. Specifically, LPR/R seeks to record and reproduce instruments individually. The reproduction process is handled through transducers in the listening room. The playback devices are designed to recreate and simulate as accurately as possible the frequency responses and radiation patterns of the original instruments.

This technique differs significantly from normal stereophonic recording. Stereo recording, in the case of live performances, includes within it all the frequency dependent acoustical information from the surrounding environment such as sound reflections from the floor, ceiling, and walls. In the case of studio recordings where room information is purposely removed, synthetic reverberation and echo effects are added. In both cases, considerable crosstalk between instruments is possible. The goal of stereo playback systems is delocalize the recorded sound and fill the room as effectively as possible. Stereo does attempt to create an accurate spatial imaging, but since the sound is delocalized it is very sensitive to a listener's position in a room. The resultant imaging is often pleasant, hence stereo's success, but it is not completely accurate.

LPR/R has a radically different goal. No room information is desired in the recordings, so a set of contact microphones or tight miking is employed.. Consequently, LPR/R minimizes interactions between individual instruments. The resulting sound from each simulated instrument is very localizable, and the final radiation emanating from the transducers resembles the radiation emitted by the real instruments. By preserving genuine radiation patterns, LPR/R likewise preserves the original directional characteristics of the sound. Therefore, the reflections and other room effects that the listener hears are those of his or her own room. It seems as though the performance is local and comes from within the room. It is in this way that the performance is brought to the listener.

The Michigan State University Psychoacoustics group has been working since 1997 on the specific application of the LPR/R technique to a string quartet. Aside from our work on cross correlations within individual instruments and our attempts at equalization, very little quantitative analysis has been performed. Still, we have come very far in recording a string quartet and reproducing that music with LPR/R using specially mounted and calibrated loudspeakers. This report will describe the group's work toward this end, and more specifically some of the contributions I made to the project.

I. THE LPR/R TECHNIQUE

Since the LPR/R technique differs so fundamentally from traditional stereophonic recording, the resulting sound has a number of interesting properties. Many of these are consequences of the fact that the channels from each instrument are kept isolated and treated independently.

The feature that is probably most notable in an LPR/R playback system is that the sound quality heard by the final listener is directly related to the local room environment. LPR/R recordings are relatively independent of location. It is even possible to do the recording in a reverberant environment, room information will still be removed using LPR/R. Because of this flexibility, a number of recording options within LPR/R are possible. In fact, since LPR/R uses separated channel recording, the editing process can be done very precisely, with the errors of one person correctable on an individual basis.

Another important feature of the LPR/R system is the removal of intermodulation distortion. According to Hartmann (1998), distortion, particularly nonlinear distortion, is an inevitable quality of loudspeaker systems. Typical audio devices take an input voltage which can be described as a function $x(t)$ and convert it into an output pressure we can call $y(t)$. The output function can be written as a simple power series of the input function. Intermodulation distortion occurs when signals having more than one spectral component are input into such a nonlinear device. If two tones, called f_1 and f_2, are placed into a nonlinear device, the power series output results in the creation of sum and difference tones which are simple linear combinations of the two frequencies. The difference tones are particularly important since they are of low frequency and the human auditory system is sensitive to low frequencies. Intermodulation distortion is a serious problem in normal audio systems, and the fact that LPR/R eliminates it is a great boon.

This technique of recording and reproduction can be very practical for educational purposes. Since each instrument is handled individually, one can change the tone quality of a specific instrument to highlight it within a group. Also, since the final product appears to be local in origin, members of an ensemble can mute their own musical position within the group and fill it in themselves. LPR/R then essentially creates a “music-minus-x” system where x is any number of ensemble members.

One of the most important features of the LPR/R system is that it attempts to recreate the radiation pattern of each individual instrument. Traditional stereophonic recording makes no such attempt. This radiation simulation is a crucial step in the LPR/R process since that kind of output information is needed if a local performance is to be generated. Different kinds of instruments behave quite differently in terms of output radiation. Brass instruments radiate strongly in one direction. An LPR/R representation of a brass instrument would simply require a single circular piston transducer. Woodwinds are much more complicated. Since the radiation primarily emanates from the first open tone hole on a woodwind, it would be tricky work to get that pattern right in simulation. The piano is an interesting case because it could theoretically require 88 separate channels. Since this is unfeasible, an LPR/R user would have to be clever in assigning multiple channels.

Stringed instruments have proven to be a moderately difficult and very interesting case in radiation simulation. The body of a stringed instrument such as a violin exhibits complex behavior when vibrations are induced within. Different parts of the stringed instrument’s body will oscillate with different modes of vibration and give the instrument a distinct directional response (Meyer, 1978). Therefore, the LPR/R technique needs to sample the vibrations of the instrument body and mix them in a reasonable way. If the technique succeeds in doing this, accurately simulated radiation will generate interference patterns that give stringed instruments their unique directional characteristics. An example of these characteristics can be seen with the violin: the fifth harmonics of the G (392 Hz) and G# (415 Hz) notes can be shown to radiate in radically different directions.

Clearly, accurate recording and reproduction of music using the LPR/R technique can be quite a challenging process. Since the goal is to simulate rather than just play back a signal, many more steps are involved. However, at a basic level the simulation is possible, and it comes with numerous rewards and unique benefits.

II. APPLICATION TO A STRING QUARTET

The MSU psychoacoustics group began preliminary work on this project in 1997 with a much simpler goal: to simulate a single cello. It was not difficult to extend the idea and try to apply the LPR/R technique to a string quartet. There are many reasons that a string quartet is ideal for the LPR/R technique. The four instruments in our application require eight channels, a number that presses the limits of commonly available digital devices yet is small enough to handle reasonably. Also, the musical literature available for string quartets is quite diverse and extensive. In addition, a large enough market exists consisting of quartet enthusiasts and performers that may be willing to support development of this technique.

For our application of LPR/R, we decided to take the four instruments (two violins, a viola, and a cello) and record two channels for each instrument. Contact pickups were used. In order to get a fairly complete picture of each instrument’s vibrations, one pickup was placed directly under the instrument’s bridge and another was placed near one of the f-holes. Our next step was to record some music, so our goal was to get enough recordings and signals set to digital media so we could manipulate the channels at will.

In September of 1998, our group employed a string quartet to place contact pickups on their instruments and perform some music. The quartet was placed in room 10 of MSU's Communication Arts building, and they performed Mozart's K458 quartet, "The Hunt". Afterwards, each individual member went into our reverberant room and recorded several minutes of scales while their instruments were still being recorded using the contact pickups. The recordings were input and digitally stored on an Akai digital recorder. A normal DAT recording using air microphones was simultaneously made for purposes of comparison on a Tascam DAT recorder. Later, the Akai recordings were transferred to a computer as audio files using Cubase VST software and the Layla 8 channel recorder.

If one takes the analog signals made from bridge and f-hole pickups on quartet instruments, amplifies them, and puts them directly into speakers, he or she would get output that poorly imitates real instruments. The issue, then, is what to do with the instrument signals so a more realistic output is achieved.

For several weeks, I worked on wiring a mixer box that would help us handle the signals for each instrument. A section of the mixer is devoted to each instrument. The segments of the mixer are electrically identical for each instrument, and the four instruments are isolated. A drawing of one of the mixer segments can be found below. Each section uses four potentiometers and three switches. RCA inputs are used on the back of the box so bridge and f-hole signals can be brought into the mixer. The output for each instrument consists of alpha and beta channels. The two top potentiometers control the amount of bridge and f-hole signal that is sent to the alpha output. The bottom potentiometers perform the same function for the beta output. Both alpha and beta sections have a switch that will invert the f-hole input with respect to the bridge input. The third switch in each section inverts the entire beta output with respect to the alpha output.

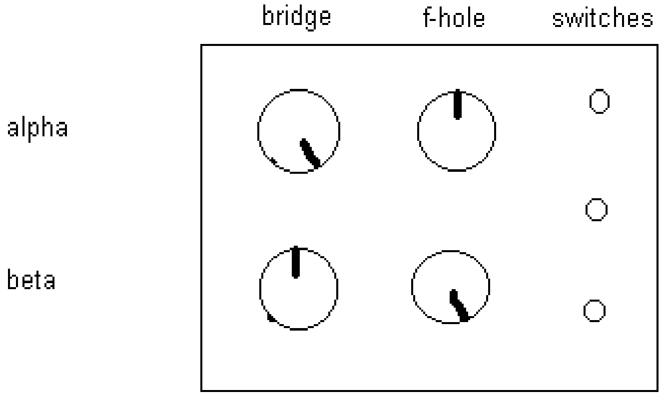

Figure 1: This is what one instrument looks like on the mixer panel as described above.

In practice, this mixer is used in order to ensure that we get output signals that contain pieces of bridge and f-hole vibrations. A nominal setting we use has one output receiving full input from the bridge and half input from the f-hole. The other output is reversed: it receives the full input from the f-hole and half of the input from the bridge. We have found that this mixer setting allows us to hear some of the interesting spatial characteristics we expect from a stringed instrument’s sound.

After the mixer was finished, we focused on constructing the loudspeaker systems we would use to simulate the real instruments. We decided to use speakers that were slightly larger in radius than necessary; large speakers radiate sound with much more interesting directional characteristics (Crocker 1997). The cello was made by stacking two large speaker cabinets on the floor. The other three instruments were constructed using similar processes. For the violins and viola, a wooden board was mounted on a DJ speaker stand. Using a metal mounting bracket, two loudspeakers were mounted on top of the board. The viola used slightly larger speakers than the violins since we figured the viola's lower frequencies may require such speakers.

Our last step was equalization. Even though we take signals resulting directly from violin vibrations, putting these into speakers does not necessarily entail that the loudspeakers have the same frequency response as the instruments. If we want these speaker systems to sound like real instruments, some equalization is needed to make the frequency responses identical. The reverberant chamber is an excellent room for making frequency response measurements in since one gets a good representative sampling of frequencies no matter where the speaker system or microphone is placed. This is why our quartet members played scales in this room. As mentioned above, Akai and DAT recordings were made. What we did was to put the Akai recordings through the mixer and power amplifiers to the appropriate speakers, and then we did a spectrum measurement of our simulated instrument. This was compared to the frequency spectrum of the DAT recording. Since our DAT recording was the canonical response, we equalized the channels of the instruments using parametric equalizers on our computer's Cubase software so the frequency responses matched. Parametric equalizers are often difficult to deal with, so this process took several iterations before we were satisfied with the resultant sound. A drawing of the process is shown below.

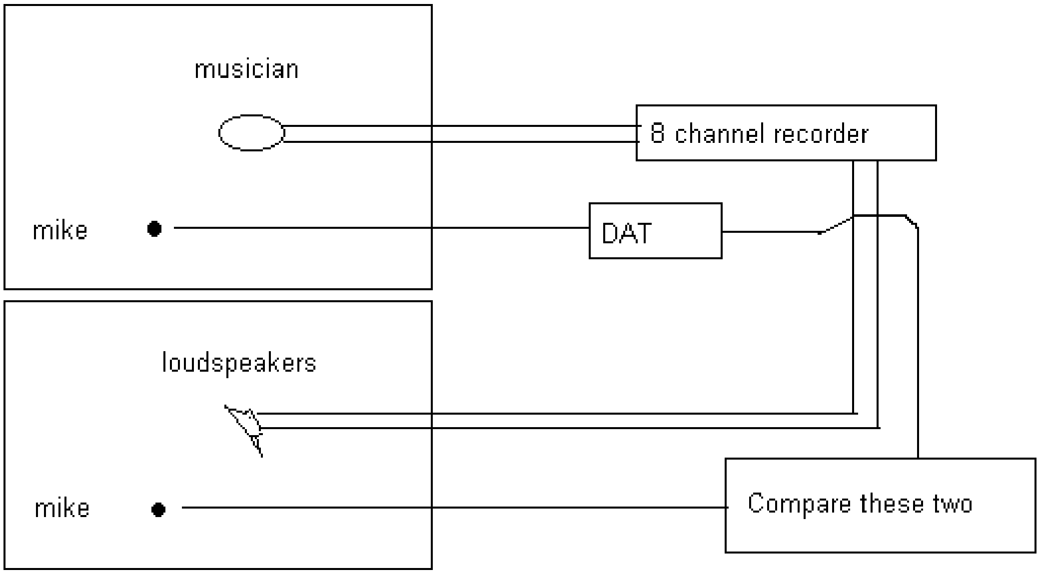

Figure 2: This is our equalization process. All sounds are played and recorded in the reverberant room. The same microphone is used in both recording situations.

Finally, the instruments were adjusted in terms of level so that the levels of the simulated instruments matched level measurements we took of the real instruments. The quartet was then ready to run. The appropriate recordings were on the computer and our equalizations were complete, so we ran the music through the eight channels and listened to the quartet. Qualitatively speaking, the result sounded very realistic. The instruments were clearly isolated and our loudspeaker systems sounded much like their true counterparts. The quartet was successfully demonstrated at the author's presentation of the LPR/R technique on August 11, 1999.

III. CONCLUSIONS

The LPR/R technique is a method of recording sound that differs in both method and goal from traditional stereophonic techniques. It attempts to create a local performance using a calibrated loudspeaker system for each instrument. Recording is done carefully so the instruments are isolated, a good representative signal is attained, and signals are mixed appropriately. Once an equalization process is completed, the loudspeakers emit radiation in a manner similar to the real musical instruments. This technique, when applied to a string quartet, provided an effective reproduction of the original sound. A demonstration of our string quartet showed that we achieved many of the goals we thought the LPR/R technique should achieve.

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