Mechanisms for Controlling Complex Sound Sources: Applications to Guitar Feedback Control

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ABSTRACT

Many musical instruments have interfaces which emphasise the pitch of the sound produced over other perceptual characteristics, such as its timbre. This is at odds with the musical developments of the last century. In this paper, we introduce a method for replacing the interface of musical instruments (both conventional and unconventional) with a more flexible interface which can present the intrument's available sounds according to variety of different perceptual characteristics, such as their brightness or roughness. We apply this method to an instrument of our own design which comprises an electro-mechanically controlled electric guitar and amplifier configured to produce feedback tones.

Keywords

Concatenative Synthesis, Feedback, Guitar

1. INTRODUCTION

Concatenative sound synthesis (CSS) is a technique for synthesizing sound by assembling a sequence of short segments of digital audio and concatenating them together (see, e.g. [1] and [2]). There are two parts to a CSS system. The first is a database of digital audio from which segments can be extracted. The second part is a selection procedure which governs which sound segments are selected from the database and in which order they are concatenated together. In this paper we consider a method for creating sound which is similar to CSS, but in which the audio database is not made up of segments of digital audio, but of the finite set of sounds which can be produced by a given physical sound-making device. We introduce a set of tools which we are developing, which enable a user to audit all of the possible sounds which can be produced by a given sound-making device and organise them according to a variety of perceptually salient features.

These tools are presented in application to a particular instrument of our own design. The instrument comprises an electric guitar and amplifier combination configured so that feedback arises between the amplifier and the strings of the guitar. The electric guitar is fitted with computer-controlled electro-mechanical augmentations which allow a slide to be moved up and down the length of the fret board

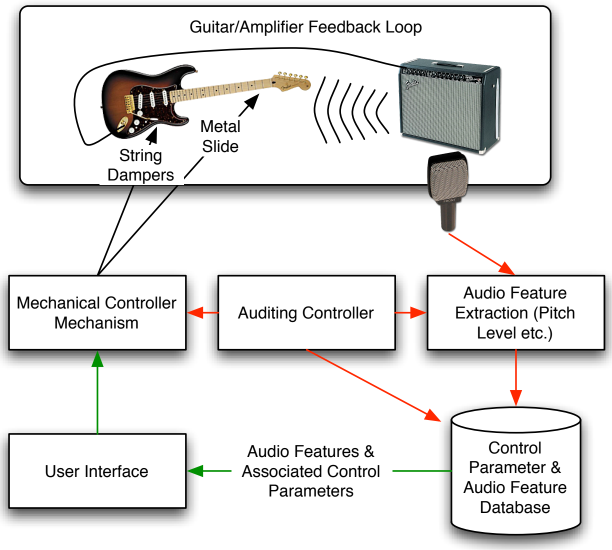

Figure 1: A block diagram of the system.

changing the effective length of the strings, and which allow certain strings to be damped so that they are not free to resonate. We chose this instrument for two reasons. First, feedback-based instruments can produce sound with very interesting timbral qualities. Musicians as diverse as David Behrman [3], Glenn Branca and Jimi Hendrix have explored feedback-produced timbres in their compositions. Second, an electric guitar producing feedback is a difficult instrument to manipulate accurately to achieve desired notes or timbres. Our computer-based tools can make this easier by providing the musician with computer-based control by which they can obtain a particular sound by pressing a button. A block diagram of our entire system comprising the feedback instrument and control system is shown in Figure 1.

This work is an adaptation of CSS to a situation in which the sound is produced by a physical device, but it is also related to the automatic orchestration work of Carpentier et al., where the aim is to find a combination of orchestral sounds which will be perceived as close to a specified target sound [4]. Other relevant work is that Botros et al [5], who describe the construction of a database of the fingerings required to produce various different multiphonics (multiple pitches from a single fingering) on a flute. When required to produce a certain multiphonic, a flute player may consult the database and find the necessary fingering.

Other researchers have conducted research on electro-mechanical guitar instruments. Singer et al [6] designed the LEMUR GuitarBot and Jordà's *Afasia* [7] involved a guitar-

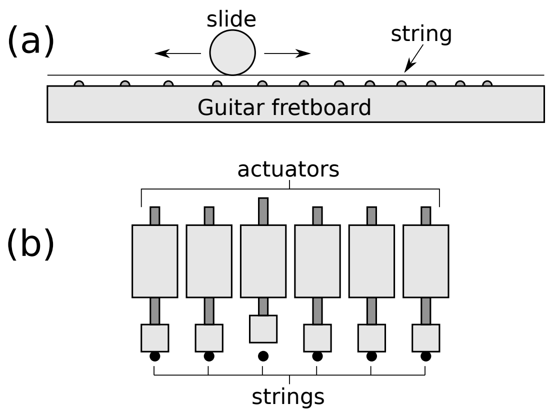

Figure 2: (a) The slide sits in contact with the six strings. It is attached to a belt and can move up and down the fretboard, changing the effective length of all six strings by doing so. (b) There is a felt damper sitting on each string. The damper is attached to an actuator. When the actuator is activated, it lifts the damper off the string, allowing the string to vibrate freely.

playing robot. In neither of these, however, was feedback the primary sound-producing mechanism.

In the sections which follow, we first describe the instrument in detail. We then describe its control system which allows CSS techniques to be used with a physical sound-making device. Finally, we examine the possible applications and extensions of this work.

2. GUITAR FEEDBACK INSTRUMENT

The instrument which we designed comprises an electromechanically controlled electric guitar connected to a guitar amplifier. The guitar is horizontally mounted. The amplifier stands in its normal orientation such that the acoustic centre of the speaker is about 50 cm from the pick-ups of the guitar. There is a metal slide in contact with the strings. The slide is attached to a belt drive that is positioned parallel to the guitar fretboard. The belt drive is driven by a stepper motor. This allows the slide to be precisely positioned on the guitar fretboard. In this version of the instrument, the slide can only move to a position directly over one of the first six fret wires of the guitar (see Figure 2 (a)).

In addition, there is a pad made from felt resting on each string and preventing the string from vibrating. Each pad is attached to an actuator. When a current is applied to the actuator, the pad is lifted off the string, allowing the string to vibrate freely (see Figure 2 (b)). Only one actuator may be activated at a time, so only one string can be allowed to vibrate at a given time.

The stepper motor which moves the slide is controlled as follows. A computer sends an instruction to an Arduino[1] interface board. The instruction contains a direction for the motor to turn, and a number of steps. The Arduino then controls a circuit which drives the stepper motor.

To control the actuators, a computer sends an instruction to a separate Arduino interface board. The instruction identifies which actuator to activate. The Arduino then controls a circuit which applies a current to the desired actuator.

We refer to the assembly comprising the electric guitar, the slide mechanism (including the Arduino and stepper motor circuit), the damping mechanism (including the Arduino and actuator circuit) and the amplifier, as the *guitar feedback instrument*. The guitar feedback instrument can be played by connecting the Arduino interface boards to a computer and using the computer to send instructions to the Arduino to manipulate the slide and dampers as desired. Using this method of playing the instrument, the performer manipulates the instrument by selecting the string and the slide position.

We now present an alternative method of playing the instrument, where the performer manipulates the instrument by selecting the *sound* they desire, specifying it according to its perceptual characteristics. We refer to the hardware and software system which allows the instrument to be controlled in this manner as the *control system*. It is described in detail in the next section.

3. THE CONTROL SYSTEM

The control system comprises a computer, an audio interface and a microphone. The computer is connected to the two Arduino interface boards of the guitar feedback instrument. The microphone is placed close to the guitar amplifier and connected to the computer via the audio interface. The computer is running a piece of software which we refer to as the *control program*.

The control program has two functions. The first is to perform a systematic audit of all of the sounds which can be made by the guitar feedback instrument. The results of this audit are compiled into an audio database. The second function is to present the database of available sounds to the user, according to the perceptual characteristics of the sounds. When the user chooses a particular sound the control program configures the damper mechanism and the slide so that this sound is produced. Here we focus on the first of these functions– the construction of the audio database.

3.1 Audio database construction

To construct the audio database, the control program first makes a digital recording of all of the sounds that can be produced by the guitar feedback instrument. It then analyses each sound and stores a set of four scalar values describing its perceptual characteristics. These two steps are now described in detail.

Six available configurations of the damper mechanism are available; one for each actuator which can be activated. There are 6 possible positions for the slide. This means that the guitar feedback instrument has 36 different configurations. For each of the 36 configurations a 3-second digital recording is made. Since the feedback produced can be affected by (i) the acoustics of the room and (ii) the relative positions of the guitar and amplifier, all of these must be kept constant throughout recording and use of the instrument.

Digital analysis is performed on each 3-second recording using the PsySound3 [8] package, which is a collection of acoustic and psychoacoustic tools programmed for the Matlab platform and made freely available[2]. For a given recording, PsySound3 produces data showing how each of a set of psychoacoustic parameters varies with time over the duration of the recording. From the set of available psychoacoustic parameters we chose use four for this prototype system because we have previously found them to be useful descriptors. The parameters are sound pressure level (SPL), pitch, roughness and spectral centroid. PsySound3 uses the YIN algorithm [9] to calculate pitch. It uses the Daniel and Weber model [10] to calculate the perceptual

[1]http://www.arduino.cc

[2]www.psysound.org

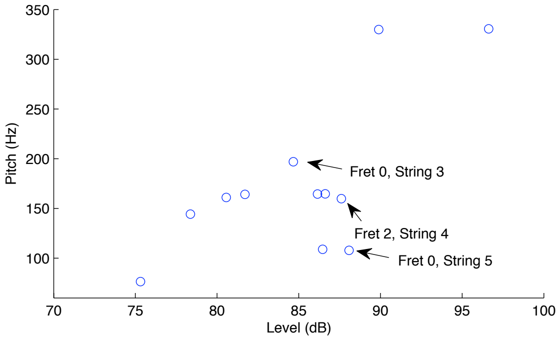

Figure 3: The co-variation of uncalibrated sound pressure level and pitch. Each point represents one combination of fret position and string. To recreate the particular pitch and sound pressure level the user need only select the particular string and fret using the control program.

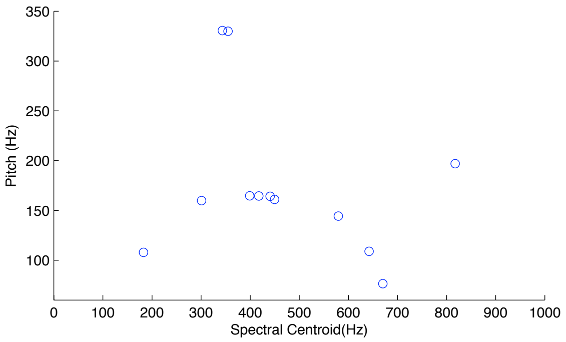

Figure 4: The co-variation of spectral centroid and pitch comparison for each fret and string combination.

roughness of a sound. The spectral centroid (a quantity which gives an indication of the perceptual 'brightness' of the sound) is calculated directly from the short term Fourier transform. For each recording, the analysis results in four 1-D vectors describing the variation of SPL, pitch, perceptual roughness and spectral centroid, respectively, over the duration of the recording. From this analysis data, we store five scalar values for each recording: (i) the median SPL, (ii) the median pitch, (iii) the median roughness, (iv) the median brightness, and (v) the interquartile range of the SPL.

3.2 Audio database example

We now present an example audio database constructed by the control program. During the recording a number of combinations did not feed back sufficiently and these are omitted from the results. The five-dimensional data set can be visualised as a set of two-dimensional plots showing the co-variation of pairs of variables. Figures 3-6 show a selection of such plots. In each plot, there is one circle for each analysed recording. Figure 3 shows the co-variation of uncalibrated SPL and pitch. It can be seen that some pitches resonate more strongly than others.

Figure 4 shows the results for combination of pitch and spectral centroid. Two contrasting types of sound can be seen in this plot. Sounds with pitch values in the middle of the range and high spectral centroid values have rich

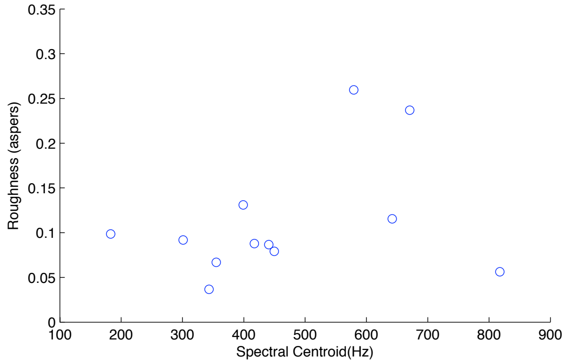

Figure 5: The co-variation of perceptual roughness and spectral centroid for each fret and string combination.

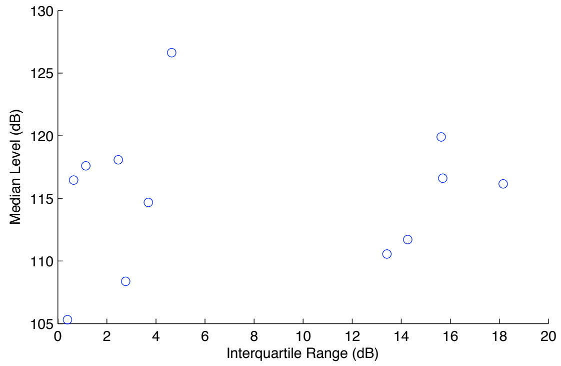

Figure 6: The co-variation of interquartile range and median SPL. There is a clear clustering of high interquartile range string and fret combinations, which are likely to be long rise time envelope sounds.

timbral characteristics, with many strong partials. Sounds with similar values of pitch and spectral centroid are much closer to pure tones.

Figure 5 describes the co-variation of perceptual roughness and spectral centroid. The perceptual roughness values are quite low throughout; all but two of the values are below 0.15 aspers. There is no clear relationship between the two variables. By examining the co-variance of the median SPL and the interquartile range of the SPL, we can see how the dynamics of each sound changed over time (see Figure 6). Those with a high interquartile range increased slowly to a stable value from the start to the end of the sound (we assume that SPL only increased over the duration of the sound). Those with a low interquartile range remained relatively constant over the duration of the sound. These two groups are clearly visible in the plot.

3.3 User interface

A graphical user interface is used to interact with the control program. The set of available sounds is displayed as a graphic. The graphic can be re-ordered so that the sounds are displayed according to increasing or decreasing pitch, SPL, roughness, brightness or interquartile range. When the user selects a particular set of perceptual characteristics, the slide and dampers are re-configured to produce the sound that is associated with these characteristics.

4. DISCUSSION

We have introduced a new approach to the manipulation of a musical instrument. The musician is separated from the natural interface of the instrument and presented instead with a way of choosing the sound based on its perceptual characteristics. In this way, the creative possibilities of corpus-based systems like CSS can be explored with real physical sound making devices.

We have applied this approach to our guitar feedback instrument. Analysis of the resulting audio database showed the different sounds which can be produced using the limited set of 36 configurations. Examination of the co-variation of pairs of psychoacoustic measures revealed particular groupings of sounds. Using a simple interface the sounds available can now be chosen according to their perceptual attributes, such as brightness or roughness. This contrasts with the natural interface to a guitar, which emphasises the pitch produced over other, timbre-related characteristics. This separation of interface from sound-producing body is also useful since the instrument is difficult to manipulate manually.

4.1 Further Research

We envisage a number of extensions to this research. First, a more intuitive user interface is required, which presents the user with the available notes and timbres. In addition, it would be interesting to increase the size of the control parameter space. This can be done by increasing the number of possible slide positions, and by allowing more than one damper to be raised at a given time, but also by allowing electro-mechanical control of other parameters such as the gain control on the amplifier and the tone control on the guitar. The number of possible sounds increases combinatorially, as parameters are introduced, so it may be necessary to offer the user only a subset of the possible parameters for a given performance.

Another direction for this research is to characterise feedback in terms of physical principles and their relationship to perceptual characteristics. The ability to automatically audit an amplifier and guitar combination allows the rapid investigation of the relationship between particular control parameters. This may be used simply to choose the most effective amplifier and guitar settings for performing with the system, or it may be used for the improvement of the perceptual quality of guitar feedback.

This system could also be controlled by a complex generative network system, for instance along the lines of the feedback network systems described by Burns [11], or the neural oscillator networks investigated by [12]. In these cases the system may consist of multiple feedback producing combinations of guitar and amplifier, and these networks may also employ a real-time supervisory audio input extracted from the output audio.

5. CONCLUSION

We have introduced a new approach to the exploration of the sounds available from an electro-acoustic instrument. The first step is to create a database of all of the sounds that the instrument can make. The sounds are then analysed and arranged according to their perceptual characteristics. Finally, they are presented in this arrangement to a user who can then explore the sonic capabilities of the instrument using the perceptual characteristics as dimensions of interaction. We have described a system comprising software and hardware components which implements this approach in relation to a guitar feedback instrument.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] D. Schwarz, "The caterpillar system for data-driven concatenative sound synthesis," *Proceedings of the COST-G6 Conference on Digital Audio Effects (DAFx)*, pp. 135–140, 2003.

[2] S. Ferguson and D. Cabrera, "Exploratory sound analysis: sonifying data about sound," *14th International Conference on Auditory Display, Paris, France*, 2008.

[3] M. Nyman, "Experimental music: Cage and beyond, 2nd ed.," *Cambridge University Press*, 1999.

[4] G. Carpentier and J. Bresson, "Interacting with symbol, sound and feature spaces in orchidée, a computer-aided orchestration environment," *Comput. Music Journal*, vol. 34, no. 1, pp. 10–27, 2010.

[5] A. Botros, J. Smith, and J. Wolfe, "The virtual flute: An advanced fingering guide generated via machine intelligence," *Journal of New Music Research*, vol. 35, pp. 183–196, Jan 2006.

[6] E. Singer, K. Larke, and D. Bianciardi, "Lemur guitarbot: Midi robotic string instrument," *Proceedings of the 2003 conference on New interfaces for musical expression*, p. 191, 2003.

[7] S. Jordà, "Afasia: the ultimate homeric one-man-multimedia-band," *Proceedings of the 2002 Conference on New Interfaces for Musical Expression*, p. 6, 2002.

[8] D. Cabrera, S. Ferguson, and E. Schubert, "Psysound3: software for acoustical and psychoacoustical analysis of sound recordings," *Proceedings of the 13th International Conference on Auditory Display, Montreal Canada*, 2007.

[9] A. de Cheveigne and H. Kawahara, "Yin, a fundamental frequency estimator for speech and music," *J Acoust Soc Am*, vol. 111, pp. 1917–1930, Jan 2002.

[10] P. Daniel and R. Weber, "Psychoacoustical roughness: implementation of an optimized model," *Acustica*, vol. 83, pp. 113–123, 1997.

[11] C. Burns, "Emergent behavior from idiosyncratic feedback networks," in *Proceedings of the International Computer Music Conference*, (Singapore), 2003.

[12] K. Beilharz and S. Ferguson, "Gestural hyper instrument collaboration with generative computation for real time creativity," in *Creativity & Cognition 07*, (Washington DC, USA), 2007.