Augmenting chordophones with hybrid percussive sound possibilities

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Abstract

In this paper we describe an approach for introducing new electronic percussive sound possibilities for string instruments by "listening" to the sounds of the instrument's body and extracting audio and data from the wood's acoustic vibrations. A method for capturing, localizing and analyzing the percussive hits on the instrument's body is presented, in connection with an audio-driven electronic percussive sound module. The system introduces a new gesture-sound relationship in the electric string instrument playing environment, namely the use of percussive techniques on the instrument's body which are null in regular circumstances due to selective and exclusive microphone use for the strings. Instrument body percussions are widely used in the acoustic instrumental praxis. They yield a strong potential for providing an extended soundscape via instrument augmentation, directly controlled by the musician through haptic manipulation of the instrument itself. The research work was carried out on the electric guitar, but the method used can apply to any string instrument with a resonating body.

Keywords: augmented instrument, chordophone, electric guitar, electronic percussion

1.Introduction

The core question in the development of hybrid acoustic-electric/electronic chordophones has traditionally been the capture of the string's vibration. In order to "electrify" a string instrument, one needs to pick up an optimum quality audio signal from the strings. Efficient solutions have been developed, including the electromagnetic pick-up, contact microphones (piezoelectric or condenser-transducer), and optical pick-ups. While enabling to capture a signal from the strings, the pick-up systems used are exclusive in their character: they only provide audio from the strings, leaving the instrument body virtually mute. Even with contact microphone systems, there is always a trade-off between string signal quality and capturing the "whole" instrument [1]. This emphasis on the strings creates a very significant difference between acoustic instruments and their electric counterparts: in the acoustic instrument the whole object can be played with and touched, offering a variety of sound creating possibilities, whereas the electric instruments have clearly active and inactive regions. Our working hypothesis is that there is an interesting expressive potential in the muted bodies of the electric instruments which can be activated via an augmentation process. An example of support for this vision is provided by musicians using the percussive possibilities of acoustic instruments, in particular the acoustic guitar and double bass percussion techniques widely used in the jazz/world idiom. On this basis, we have initiated an experimental percussive augmentation project for the electric guitar.

1.1 Prior work

The work presented here is part of the "augmented instruments" paradigm which aims to enhance the sonic possibilities of traditional instruments by technological means. Significant prior work has been carried out in the area of instrument augmentation [2] [3], and an active instrument augmentation community constantly outputs exciting research on the subject [4] [5]. The use of augmented percussive gesture has been studied with different approaches. Attack localization was investigated with "Time Delay Of Arrival" and "Time Reversal" methods [6] [7] . Hybrid percussion instruments have been constructed using convolution [8] and timbre recognition via machine learning [9].

2. Augmented instruments and gesture-sound relationship

2.1 Sound vision

Our augmentation project is motivated firstly by a sound vision: the introduction of new percussive sound possibilities into the expressive range of hybrid acoustic-electric/electronic chordophones. The project aims to provide a varied percussive soundscape in the chordophone playing environment, triggered and controlled by percussive attacks on the instrument's body itself. We are looking for a sensitive correlation between the timbre and amplitude of the percussive gesture and the sonic output of the system. Furthermore, we seek to achieve different sonic results depending on where the instrument is hit, through localization of the attacks. The system thus provides the musician with three gestural control parameters: attack velocity, timbre and localisation, designed to provide a multidimensional and musically rewarding working environment for the player.

2.2 Gestural motivations for technological solutions

Musicianship in traditional instruments is a lot about touching: expert instrumentalists are trained specialists in haptic manipulation of vibrating objects. The musician's intimate relationship with the instrument makes for a strong a priori regarding the type of "augmented" gestural controls one may successfully incorporate into the instrument's playing environment. There is an expectancy for a certain haptic quality and complexity of the interface [5]. Our project is strongly motivated by a concern to provide the augmented instrument with interfaces which are of comparable tactile quality with the traditional instrument. We are looking for a haptic homogeneity between the acoustic and the augmented parts of the instrument, thus hoping to create interfaces that a trained musician can readily understand and incorporate within his/her instrumental praxis.

3. System description

3.1 Overview

The system is designed to activate the instrument's body by listening to its internal soundscape and using the acquired information to control an audio-driven percussive sound module. In order to achieve this, a network of contact microphones is placed on the instrument, and each signal's power spectrum is analysed at correlated attack time points. The obtained results are used to determine the type of attack (plucked string or percussive hit) and its approximative location on the instrument. In case of a percussive attack, the detected spectral characteristics are used to drive a real-time cross synthesis percussion sound module.

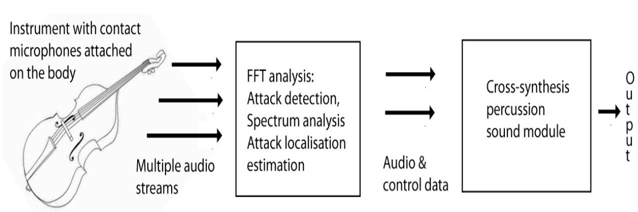

Figure 1. System architecture

3.2 Placing the contact microphones

The system is based on five contact microphones attached to the guitar; four on the body and one on the headstock. The microphones used were AKG 411 condenser-transducers. The four body microphones operate as a group designed to cover the entire body, one block of wood, while the neck microphone is intended to look for percussive signals on the fretboard, neck, and headstock. The four body microphones form a rectangle of approximatively 30x25 cm, and the head microphone is 70 cm away from the nearest body microphone.

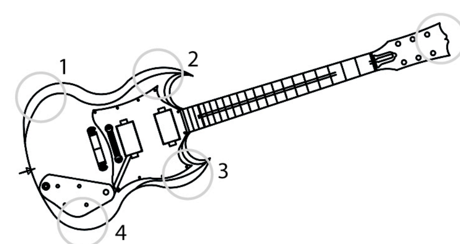

Figure 2. Contact microphones placed on the guitar.

3.3 Signal analysis

The instrument's body is a resonating element with a high degree of simultaneous acoustic activity such as sound energy from the strings as well as from handling noise, and in the case of the present augmentation, from percussive attacks. In order to utilize the soundscape of the instrument's body, one needs to be able to categorize the different sounds according to their source. In our project this mainly means being able to determine whether the sound source is a plucked string or a percussive hit on the body. Working in a real-time environment, the categorization of the attacks must be done with minimum latency, directly at the onset of the detected attack. Due to this time constraint, the analysis must be conducted within the first few milliseconds of the sound, corresponding to the signal's transient phase and ruling out the use of its periodic part [10]. Whether on the strings or on the body, the attacks are characterised by sharp relative changes in the spectrum [11]. By looking for differences between the spectrums of the two types of sounds, one may construct a model representing their typical spectral characteristics. As shown in figure 3., the percussive attacks on the instrument body show a more even energy distribution across the spectrum than the string attacks, which present energy concentration on specific frequency regions. On this premise, we constructed an analysis model based on the energy distribution within the spectrum for determining the sound's source. The bonk~ msp object was used for the analysis, providing eleven filter values across the spectrum and operating with a 256 sample (5.8 msec at 44.1 kHz) analysis window size.

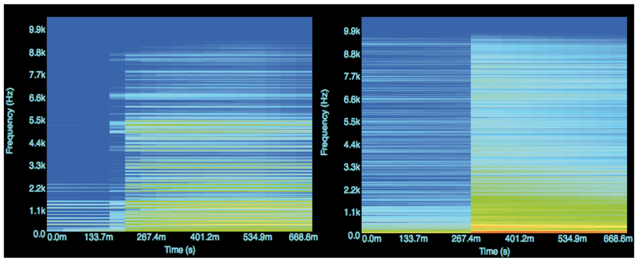

Figure 3. Spectrogram representing typical spectra of a plucked string attack (left) and of a percussive hit (right) from a contact microphone attached to the guitar body.

3.4 Multiple contact microphone network and signal analysis

Each of the five contact microphones produces an audio signal corresponding to the instrument body's vibration at the location of the microphone. The acoustic energy resulting from the plucking or hitting travels through the instrument at high speed (ex : 4411 m/sec in maple, along fibre [12]). The different signals present significant differences in the power spectrum of each signal according to the localization of the microphone in relation to the sound's source. This change in spectrum corresponds to the loss of energy as the sound wave propagates through the instrument. The wood opposes a mechanical resistance (acoustic impedance) to the vibration which travels through it, resulting in a gradual extinction of the acoustic wave. The difference in magnitude is clearly measurable between the signals of the contact microphones placed as far as possible from each other on the instrument. After multiple trials on the guitar, we opted for a network of four contact microphones on the guitar body, operating as two couples each forming an "axis", plus the neck microphone operating alone. On each axis, the signal amplitudes of both microphones are weighed at a given time and their differences calculated, resulting in a pair of coordinates which represent a rough localization of the percussive attack on each axis. This relatively simplistic system was adopted for the first experimental phase of the project, and it provided convincing proof of concept. In our tests, we were able to localize up to ten different attack zones on the guitar body and, through a trade-off between the number of discrete zones and detection accuracy, stabilizing a system of seven discrete zones with a 90% success rate. Since each zone has extended sound possibilities due to the spectral analysis of the percussive hits (see 3.6), the instrument acquires a varied percussive soundscape, controlled by the attacks' localizations and gestural characteristics. The overall latency of the system is between 10 and 20 milliseconds, depending on the desired quality (fft size) of the cross-synthesis module.

3.5 System tuning and guitar acoustics

Our experimental system was built on a standard Fender Stratocaster solid-body electric guitar, without heavy luthier intervention. Our experimental system was clearly aimed at producing musical results, and many key issues underlying the guitar's internal acoustics were intentionally left aside. For instance, the propagation and decrease of the acoustic wave in an irregular and composite object was not modeled, nor did we measure the resonant modes of the particular guitar used in order to determine its proper spectral response to different types of acoustic stimulation. Instead, we chose to tune the microphone network sensitivity and analysis criteria through trial and error in order to achieve desired results.

3.6 Audio driven percussive sounds

The fundamental motivation of our project is to provide a percussive dimension on hybrid acoustic-electric/electronic string instruments, controlled by the musician through direct manipulation of the vibrational state of his/her instrument. In electronic percussion, a common method is to use attack velocity sensing pads driving a drum synthesizer or a sampler. This method lacks the tactile quality instrumentalists are used to working with on their acoustic instruments: the system takes only into account the velocity of the hit, ignoring timbre characteristics.

Our approach seeks to overcome this limitation by using the actual sound of the hit to drive a sound module where a triggered sample is cross-synthesized with the incoming signal. Moreover, the spectral characteristics of the attack signal are mapped to a filter module affecting the triggered sample, which enhance the feeling of continuity between the hitting gesture and its sonic result. The design of the sound module was inspired by the work on hybrid percussion by Roberto Aimi [8]. We also implemented an amplitude-dependent reverb and delay in order to achieve dramatic sound effects on particularly emphasized hits. Physical modeling-based percussion synthesis instead of sample-triggering was also considered, but its implementation is still underway.

4. Augmentation descriptions and musical applications

4.1 Guitar body percussions

The contact microphone network on the guitar body was used to define seven zones on the instrument, each corresponding to a specific sound type. The musician can produce a variety of timbres for each sound type by controlling the spectral content and velocity of the hit. The musician is thus able to control the sound by direct haptic interaction with the wood of the guitar body. Hits with different parts of the hands and fingers (soft parts, knuckles, nails...) provide different sound results. Combined with the localized sound zones on the instrument, the system provides an extensive soundscape which felt inspiring and rewarding for the exploring musician. We used the percussive mode in combination with normal finger-style guitar playing, offering the possibility of a percussive counterpoint to the melodic and harmonic discourse. We also connected the percussive module to a live looping system, where the musician was able to record a percussive "rhythm track" on the fly, and superpose the regular playing on it.

4.2 Fretboard tapping percussions

In this augmentation we used the contact microphone placed on the guitar's headstock to detect left hand "tapped" notes on the fretboard. The tapping technique consists of attacking the string with a sharp strike using the fingers of the left hand, without right hand plucking. The sound produced is similar to a plucked string sound, despite the energetic gesture used. The augmentation was designed to make use of the tapping energy for new sonic results, introducing a new playing technique on the guitar. The analysis and the sound module are the same as in the guitar body percussion augmentation, but tuned to work with the acoustic specificities of the guitar neck environment. The outcome is a pitched percussive soundscape, where the triggered percussive samples are cross-synthesised with the pitched audio signal from the tapping on the strings. The musician can switch from percussive sounds to normal string sounds just by choosing his/her playing technique, being able to provoke percussive accents at will within the harmonic and melodic discourse.

5. Conclusions and future work

The percussive augmentation described in this paper produced a promising proof of concept for a consequent development effort. The simultaneous use of contact microphones to localize attacks and the introduction of new gesture-sound relationships into the instrument playing environment appear to be an interesting augmentation method. While the adopted system allows for an expressive control of the hybrid instrument, future work points to enhancing the localization tracking accuracy and robustness. After an unsuccessful implementation of attack point recognition using cross-correlation, we are looking into a time-based system with a sufficiently high samplerate to operate in a tonewood environment. The electric guitar's homogenous body offers little data for timbre-based localization, although this approach appears interesting for other hollow-body chordophones. The simultaneous use of time difference, timbre and amplitude tracking methods in one system seems to offer interesting perspectives for future development

6. Acknowledgments

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Figure 4. The author playing neck tapping percussions on the augmented guitar.

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