The EMvibe: An Electromagnetically Actuated Vibraphone

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ABSTRACT

The EMvibe is an augmented vibraphone that allows for continuous control over the amplitude and spectrum of individual notes. The system uses electromagnetic actuators to induce vibrations in the vibraphone's aluminum tone bars. The tone bars and the electromagnetic actuators are coupled via neodymium magnets affixed to each bar. The acoustic properties of the vibraphone allowed us to develop a very simple, low-cost and powerful amplification solution that requires no heat sinking. The physical design is meant to be portable and robust, and the system can be easily installed on any vibraphone without interfering with normal performance techniques. The system supports multiple interfacing solutions, affording the performer and composer the ability to interact with the EMvibe in different ways depending on the musical context.

Keywords

Vibraphone, augmented instrument, electromagnetic actuation

1. INTRODUCTION

The vibraphone is a keyboard percussion instrument consisting of aluminum bars mounted over tuned metal tubes which act as resonators. While the decay time of the vibraphone is long as compared with other keyboard percussion instruments, the instrument is incapable of sustaining sounds, and only certain amplitude envelopes are possible: Once the bar is struck the sound begins to decay. The tremolo, or roll, is the most common technique for creating more sustained textures on the vibraphone, but often the individual attacks are audible. Using a bow affords other amplitude envelopes, but bow changes are quite problematic, so the length of the bow limits the envelopes that can be created. Furthermore, when using a bow a single player is limited to playing, at most, two notes simultaneously (one bow in each hand) and certain passages can be quite difficult to execute because moving from the accidentals to the "white keys," for example, requires reaching all the way across the instrument. Playing overtones on the vibraphone is possible with mallets or a bow, but the technique requires two hands meaning that the performer can only play one note at a time, and only the first overtone is available. While certainly a very capable instrument, the vibraphone has its limits.

In this paper we present the EMvibe, an electronically augmented vibraphone that extends the capabilities of the standard vibraphone. The EMvibe is an acoustic vibraphone augmented with electromagnetic actuators allowing for enhanced control of the vibraphone's amplitude envelope and harmonic content. The instrument is capable of infinite sustain of up to seven pitches simultaneously as well as continuous control of the instrument's overtones. All of the sound of the EMvibe is produced by the vibraphone itself, without loudspeakers, so in terms of sound diffusion the instrument remains acoustic. An important design consideration was that the added hardware not interfere with the vibraphone's more traditional playing techniques, so in this sense the EMvibe is conceived as an augmented vibraphone.

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2. EXISTING INSTRUMENTS

The Electromagnetically-Prepared Piano is a system developed by Berdahl [1] and Bloland [3] consisting of twelve electromagnetic actuators positioned over the strings of the piano in a way that does not interfere with the normal hammer action of the piano. Each actuator is connected to its own amplifier channel and each amplifier channel has a dedicated DAC channel feeding it audio generated in Max/MSP. Using twelve actuators the researchers can theoretically cover the entire range of the piano by using overtones, although the audio signals sent to the actuators need not be harmonic.

Andrew McPherson's Magnetic Resonator Piano [6] uses a similar actuation system to the above, but covers the entire range of the piano as opposed to the Electromagnetically-Prepared Piano's twelve coils. Each actuator is driven by its own amplifier, but the system uses many fewer DAC channels than amplifier channels. Each amplifier is connected to a 16-channel multiplexer allowing any amplifier to be connected to any of the sixteen DAC channels. In terms of signal processing the Magnetic Resonator Piano employs a feedback-based approach, using a single piezo pickup on the piano soundboard as the source. The system is designed to give the pianist access to the additional capabilities by means of a standard MIDI keyboard, or an augmented piano keyboard.

Electromagnetic actuation has also been used with the electric guitar with the EBow [5] and feedback-based systems [2]. Shear and Wright developed the Electromagnetically Sustained Rhodes Piano [8] which uses electromagnetic actuators to drive the tines of a Fender Rhodes electric piano. Boutin and Besnainou [4] have done work in active control of xylophone bars.

2.1 Comparison to Previous Work

Our system is similar in approach to the Magnetic Resonator piano in that we intend to give the vibraphone player access to the enhanced capabilities the EMvibe affords, or to at least have that option. We therefore cover the entire range of the vibraphone and employ a signal routing system similar to the Magnetic Resonator Piano. The EMvibe does not currently use a feedback-based approach to audio signal generation, instead generating audio signals in the computer as does the Electromagnetically-Prepared Piano. While there are similarities to the above described systems, there are also significant differences in our implementation owing to the differences between the vibraphone and the piano.

3. VIBRAPHONE ACOUSTICS

While piano strings support a complete harmonic series, vibraphone bars supports relatively fewer harmonics. Vibraphone bars have arches cut in the underside to emphasize the fundamental frequency and tune the most prominent overtone, making it more harmonic. The first overtone is tuned to approximately four times the fundamental frequency, or a double octave. The frequencies of higher partials do not maintain a consistent relationship to the fundamental; the relationship is frequency dependent and non-harmonic. Overtones are much more prominent in the lower range of the instrument than in the upper range.

The transverse vibratory modes are the most prominent in the vibraphone. The tone bars also exhibit longitudinal as well as torsional vibratory modes which are inharmonic. In general these modes are very weak, though they may be more prominent when the tone bars are bowed.

4. ACTUATION

The EMvibe consists of electromagnetic coils under each of the vibraphone's tone bars supported by aluminum brackets that are clamped onto the outside support rails of the vibraphone frame. Because vibraphone bars are made out of an aluminum alloy they cannot be driven directly by the electromagnetic actuators. In order to be able to actuate the bars with electromagnets we affix a small neodymium magnet to the underside of each bar (Figure 1).

Each coil is driven by a dedicated audio amplifier specifically designed for this application. Amplifier input signals are generated by a computer and sent to the amplifiers via an 8-channel DAC. There are more coils than DAC channels, so our maximum polyphony is determined by the number of DAC channels. Signal routing between inputs and outputs is done using analog hardware. Each amplifier channel is connected to an 8-channel analog multiplexer and pairs of multiplexers are set by a single shift register. Voice allocation is done in software and a microcontroller is used to set the shift registers.

Amplifier and signal routing hardware for seven channels are on a single circuit board mounted on the instrument. These individual circuit boards are daisy-chained creating a hardware system that is both modular and extensible. The first board in the chain is connected to an external enclosure containing power supplies, audio connections from the audio interface and the microcontroller for signal routing. This power box is connected to the first amplifier board in the chain using DB25 connectors while the remaining boards are chained using ribbon cables. The EMvibe can be installed on a standard vibraphone within a matter of minutes and is designed to be robust enough to withstand the rigors of being moved. Figure 2 diagrams the signal flow for the system.

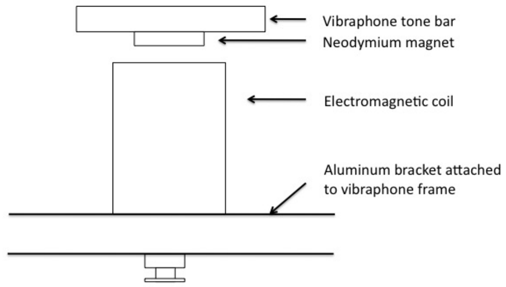

Figure 1: Placement of the electromagnetic actuators.

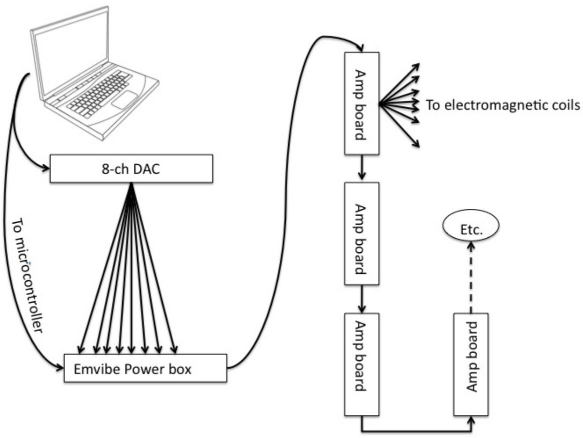

Figure 2: Signal flow for the EMvibe.

Audio synthesis and voice allocation is done on a computer running software written in ChucK and Max/MSP. Before the system can be used the tunings of the fundamentals and overtones of the vibraphone must be established. This is done by sending a single frequency to a coil and fine tuning the frequency by ear until the maximum bar response amplitude is determined. The tuning data are written to a text file which is referenced by the performance software to set oscillator tunings. This tuning procedure only needs to be undertaken once for any installation on a single vibraphone.

4.1 Amplifier design

The vibraphone's acoustic properties allowed us to create to create a very simple, cheap amplifier requiring no heat sinking. Because the bars support so few vibratory modes they effectively filter out frequencies other than those that are supported. In practical terms this means that we don't need to be concerned with the quality of the audio that we're sending to the coils, only the frequency and power. Our amplifier design produces bipolar pulse waves. The fact that the design requires no heat sinking allowed us considerable flexibility in our circuit board layouts and installation on the instrument. We wanted to keep the per channel amplifier cost as low as possible because we need 37 channels of amplification to cover the standard 3-octave vibraphone.

4.2 Signal processing

The tradeoff for our amplifier design simplicity is that we need to take special care with the input signals we feed the amplifiers; we cannot send any arbitrary waveform. We have to ensure that there is a small amount of "off-time" in our signal to avoid damaging the amplifiers.

Driving a coil with a bipolar pulse wave produces a roughly sinusoidal response from the vibraphone bar assuming the frequency of the pulse wave corresponds to one of the bar's resonant frequencies. The amplitude of the response is determined by the pulse width and our synthesis software limits the maximum pulse width to keep our amplifiers safe.

To obtain more complex responses we use multiple oscillators, one per partial, tuned to the desired frequencies. We switch between the multiple oscillators at a low audio rate. In this way we are able to generate a more complex bar response without a complex waveform. Just as we control the amplitude by varying the pulse width, we can control the spectrum by varying the proportion of time each oscillator is sounding.

By switching between multiple oscillators, as opposed to switching the frequency of a single oscillator, we ensure that the oscillators and vibraphone bar stay in phase (Figure 3). Phase is significant because, particularly for the fundamental, it takes some time for the bars to reach maximum amplitude. If we were to ignore phase we would potentially limit our amplitude because there's no way to guarantee that the oscillator is in phase with the vibrating bar when switching between partials.

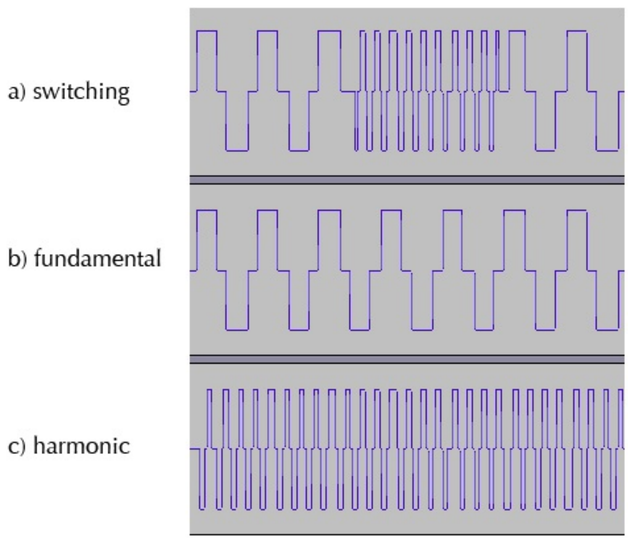

Figure 3: Switching between oscillators to maintain phase: a) shows the switching waveform, b) and c) show the two oscillators on their own. Note the "dead zones" between the positive-going and negative-going portions of the waveforms.

4.3 Measurements

Figure 4 shows the spectra of a single tone bar (A3) actuated by the EMvibe and sounded in more traditional ways. The single spectral peak in Figure 4c shows the nearly sinusoidal response of the bar to a single frequency pulse wave. Figure 4d shows the response for waveform that switches between the fundamental and first harmonic. The spectral shape is similar to that of the bowed note in Figure 4b for the fundamental and first harmonic, though it lacks the higher frequency components.

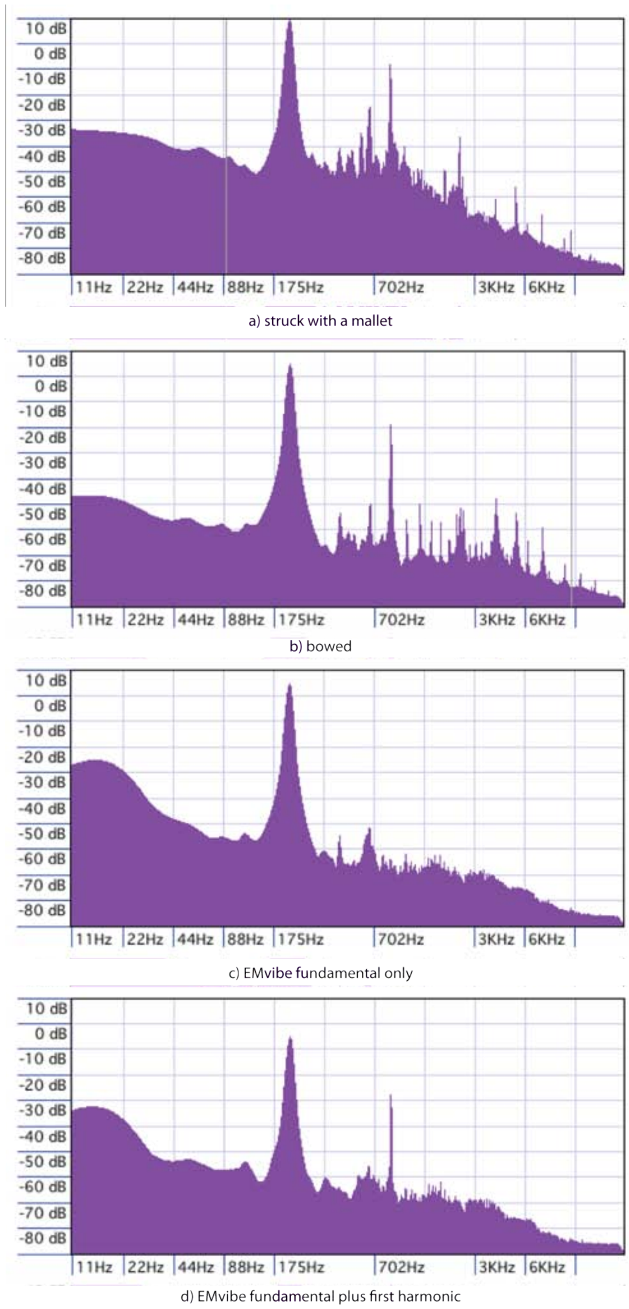

Figure 4: Spectra for vibraphone note A3 sounded four different ways.

5. AURAL DESCRIPTION

Like the other electromagnetically actuated instruments described previously, the sound of the EMvibe might best be described as ethereal. The sound is pure and the attacks are legato even at their fastest. The electromagnetic actuation is quite effective when the damper pedal depressed, but the response is extremely weak with the damper bar engaged.

The amplitude response is much stronger for the fundamental than for the overtones, although overtones respond more rapidly than do fundamentals. The fundamental is quite strong across the range of the vibraphone, but the availability of overtones diminishes at the upper range of the instrument. The diminished high frequency performance is likely due to a combination of the acoustics of the instrument and attenuation in the electromagnets. The attenuation in the electromagnets is caused by coil inductance as well as potential losses in the core at higher frequencies.

The EMvibe affords playing legato passages much more rapidly than is possible with a bow. It is also possible to sustain chords of up to seven notes. Crossfading between harmonics works well and different effects can be achieved by crossfading at different rates. An interesting forte-piano-crescendo effect can be achieved when an electromagnetically actuated bar is struck with a mallet. This technique is not completely reliable though as it depends on the phase of the bar at the moment the mallet strikes.

We expected the sound of the EMvibe to be somewhat similar to that of bowed vibraphone, and indeed there are similarities. As with bowing it is possible to generate very smooth attacks. Unlike bowed vibraphone, however, the EMvibe lacks some of the high frequency content characteristic of bowed vibraphone (see Figure 4). Surprisingly, when passages are played on the the EMvibe the sound is quite reminiscent of a flute stop on a pipe organ.

6. INTERFACE

The control parameters of the EMvibe are spectrum, amplitude, and frequency. The spectrum, or harmonic content, refers to the relative amplitudes of the fundamental and overtones, of which there are one or two depending on the range that are strong enough to be musically useful. In our implementation the number of control axes for spectrum equals the number of partials (i.e. three axes for the fundamental and two overtones). While spectrum refers to the relative amplitudes of the various partials, amplitude controls the overall level.

The EMvibe was not designed with a single interface in mind. Indeed the thought is that different pieces will demand different interfacing and mapping strategies and the exploration of various modes of interaction is motivating continued work on the instrument. There are two broad categories of use for the EMvibe, each placing the performer in a different relationship to the instrument, and thus demanding different interfacing strategies.

6.1 As a New Sound Source

Taken as a new sound source where the vibraphone player (if there is a human player on the instrument at all) does not have direct control over the extended capabilities of the instrument, interfacing with the EMvibe is fairly straight forward as the EMvibe software can be configured to respond to virtually any MIDI device.

We currently have a MIDI layer that uses Note On/Off messages to start and stop notes, and Control Change messages to set amplitude and spectrum globally. Our MIDI layer has two modes, Omni and Poly, determined by the MIDI channel. In Omni mode (channels 1-9) amplitude can be set per note using Polyphonic Aftertouch, but spectrum can only be set globally. In Poly mode (channels 10-16) both amplitude and spectrum can be set per note, using Polyphonic Aftertouch to set the amplitude and Channel Aftertouch to set the spectrum. Global parameter changes are available in both modes.

As a sound source controlled by some external physical controller the EMvibe presents no unique challenges to the user. As with any novel interface or synthesis technique the user still has to come up with a mapping strategy. The question of how to connect controller outputs to the EMvibe's inputs may have different answers depending on the musical context.

6.2 As an Augmented Instrument

As an augmented instrument, where the player gains access to the extended capabilities of the instrument, the EMvibe presents significant challenges. Augmenting vibraphone technique to control the EMvibe is challenging because: 1) the vibraphone player actively uses three of his four limbs (and the other is needed for balance) and 2) the performer cannot maintain constant physical contact with the instrument without adversely effecting the instruments ability to vibrate.

We are only in the beginning phases of this part of our research, but we suspect that camera tracking holds a lot of promise as a means to control the EMvibe. Odowichuk et al have explored such a strategy using Microsoft Kinect [7]. Sensor-based approaches where the sensors are placed on the performer could also prove interesting for certain musical contexts.

7. FUTURE WORK

With the hardware infrastructure in place we are now in a position to do the most important work: making music. We are particularly interested in exploring the performance possibilities afforded by an instrument that can, in a sense, play itself. The performer may be interacting with some automated process or other performer controlling the electromagnetic actuation, controlling the sounds himself, or any combination thereof. The performer's actions may initiate, stop, or alter sounds. Some of this work will be tied into the interfacing options we explore, though some of it will explore modes of interaction where the performer does not have direct control.

Future work with the EMvibe will proceed on the technical front as well. We are interested in exploring various interfacing possibilities, some of which were described previously and there are surely others we haven't yet considered. In addition, we are interested in experimenting with our system on instruments other than the vibraphone. Our system would work on the marimba or xylophone as it exists now and we are interested in experimenting with mbira, lujon, and steel drum. Finally, given one of the author's expertise in this area, we may eventually explore active control using a feedback-based approach.

8. REFERENCES

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