THE PROSTHETIC MBIRA: PROSTHESIS AS DESIGN STATEGY

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ABSTRACT

This paper addresses the development of a hybrid mbira (African thumb piano) through the notion of prosthesis as design strategy. Aspects of the concept of prosthesis have direct consequences for the development of the prosthetic mbira in particular the relationship between the acoustic (natural) and the electronic (prosthetic). The acoustic layer of the mbira is extended with an electronic layer, that mimics the acoustic and suggests a number of musical interactions and behaviours. The paper describes the design process and the implementation of a prototype which addresses challenges such as real-time polyphonic pitch detection. The implications of prosthesis as a design metaphor are explored in the context of the development of a hand-held instrument with relatively simple interaction. The principal aim to the project is to investigate the design of electronic extensions to traditional instruments through the use of audio as the principal modality for sensing and interaction.

1. INTRODUCTION

This project addresses the relationship between traditional acoustic instruments and live electronic capabilities in a performance context. The mbira is used as an example of a user-friendly instrument with a relatively simple mechanism and modes of interaction. The mbira is a polyphonic musical instrument with metal bars attached to a wooden board (see Figure 1). The bars are put into vibration by stroking the free end with the thumb or forefinger, with each key producing a distinct musical pitch. [1] The mbira (also known as kalimba) is found in multiple forms in many countries across the African continent [2]. For this project a modern kalimba with 15 notes was used. Instead of a wooden board the bars are attached to a sound box which provides a characteristic resonance to the instrument.

The prosthetic mbira implements design strategies relating to the interplay between the acoustic and the electronic in self contained instruments previously discussed by Rebelo and van Walstijn (2004) [3], and Rebelo (2005) [4]. Previous work implementing similar strategies includes the prosthetic conga [5]. To create a hybrid instrument, the acoustic layer of an existing instrument is extended by an electronic layer developed within a computer system and reproduced through the instrument itself. The instrument is intended to retain the traditional modes of play afforded by the mbira while accessing fine tuned live processing without the need for external control of the computer system. This allows the performer to focus on the playing with the computer reacting automatically according to a series of behaviours.

The use of a design strategy based on the concept of prosthesis has consequences for the development of the hybrid mbira. The challenges encountered relating to the implementation of synthesis and of pitch analysis will be discussed in detail.

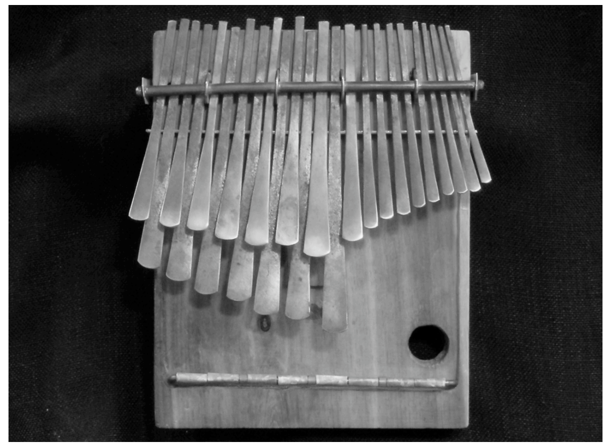

Figure 1. a mbira

2. PROSTHESIS AS METAPHOR

The use of prosthesis in the human body provides us with potent metaphors for the relationship between natural and artificial parts of an organism. A human prosthesis can be described as a part attached to or incorporated in the body resulting in number of complex interaction. A prosthesis is commonly designed to look human (e.g. artificial limbs) or at least to blend in with the body (e.g. hearing aids). The notion of mimicry then becomes an important aspect for the development of prosthetic parts which aim to replace, augment or enhance natural body parts.

The relationship between the artificial and the natural in human prosthesis can be compared with the electronic and acoustic layers in a prosthetic musical instrument. A prosthesis is connected to or hosted by the body part just as the electronic layer is connected to or hosted by the acoustic layer. Hence, instead of using external loudpspeakers, a Rolenstar transducer speaker is physically connected to the instrument and transfers the sound-waves to the body. In this way both layers, electronic and acoustic sound, come out of the sound box of the mbira, creating an opportunity for blending the artificial with the natural.

Some human prosthesis react to muscle impulses as if listening to behaviour of the natural body. Translating this to the hybrid instrument results in the electronic layer using the acoustic layer to react to. This was accomplished by creating a system in which the computer listens to the natural sound of the instrument, captured by a contact microphone (AKG C 411) for estimation of pitch. A pitch detector is used to let the system identify which tones are played and the system automatically reacts to these by extending them with synthetic tones, hence blending in a continuation of the natural sound and expanding the natural duration of sound events in the instrument. The electronic layer extends the acoustic layer, as a prosthesis on a human body extends the human's capabilities for a specific task.

Since the typical prosthesis looks human, the electronic sound should sound and act acoustic. For the synthesis the spectrum values of the acoustic tones together with the envelope are used to mimic the sound of the mbira.

The reproduction of the electronic layer is then based on the integration of the transducer speaker and contact microphone with the instrument itself (see Figure 2). By using the acoustic soundboard of the instrument to reproduce synthetic sounds, the electronic sound is able to merge with the acoustic sound in a way that would not be possible with an external speaker. A contact microphone instead of a normal microphone is used, because of its constant angle and distance to the sound source which facilitates spectral analysis.

Given the relatively long duration of mbira tones (between 1 and 2 seconds), it is common for various pitches to sound simultaneously. Accurate estimation of pitch was achieved through a polyphonic pitch detector.

Figure 2. kalimba with transducerspeaker and contact microphone

3. SYSTEM ARCHITECTURE AND IMPLEMENTATION

Given the design criteria described above the development of a prototype focused on creating an effective blend between the natural timbre of the mbira and synthesis. The development of the prototype has four distinct elements: Spectral analysis, Realtime polyphonic pitch detection, realtime synthesis based on resonant models of the mbira, and the Graphical User Interface.

3.1. Spectral Analysis

Each individual mbira tone is sampled and analysed for its spectral envelope in Spear [6]. The noise partials of the attack are then removed and the rates of the remaining partials are extracted. A custom algorithm calculates the ratios from the extracted partials and indicates all the similar ratios, which become the spectral model later used for the synthesis.

3.2. Realtime polyphonic pitch detection

The polyphonic pitch detection system was planned in Supercollider though due to a limitation in FFT objects, other methods are developed.

With a view to address the needs of polyphonic pitch detection, a test system is build with fifteen convolutions, one for each tone (see Figure 3). In each convolution a short fragment of a recorded sample of one tone is loaded. In this way a wavelet system with extreme high overlapping is created. This system works to an extent although it is prone to errors such as failure to estimate some of the tones sounding simultaneously or detecting tones that are not played at all. To try to improve the system, sinewaves tuned to the frequencies of the tones of the mbira are used instead of fragments of the recorded samples. This improves pitch estimation although the system still detects tones that are not played. While hitting the same tone, mostly the same wrong tones are detected. This defect is due to the sympathetic resonance of other tones while playing a particular key.

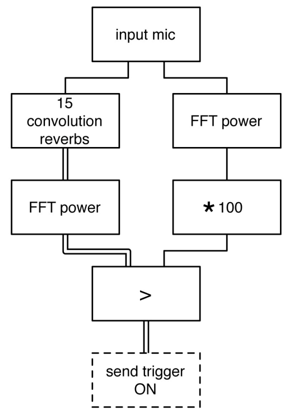

Figure 3. multipitch detector with convolution reverbs

To minimize the detection of extra resonant tones, a Supercollider object is added to the system to detect sharp attacks, but without a positive effect. Struck tones always have a sharp attack, resonating tones commence slowly. In order to only detect struck tones, the slope of the attack of a tone can be tracked. When the slope of an attack is above a certain threshold, the tone is estimated. Supercollider only contains an object that analyses the slope per second, but for this system a smaller time period is needed. A new slope object for Supercollider is written in C++ so that the time period can be adapted by the user. After adding the new slope object to the system there is still no improvement due to the convolution smoothing the signal for sharp attacks to be detected.

Using the slope object as point of departure, a new system is created. While testing the new slope object, before adding it to the convolution system, it perfectly detects the attack of a struck tone in the incoming signal. So if the incoming signal is separated in 15 signals, one for each tone, it is possible to detect a struck of a specific tone. For the separation of the incoming signal a double set of 15 bandpass-filters is used, each tuned to a pitch of a tone of the mbira. A double set of filters is used because this provides more accurate separation than a single set of filters. A slope object is added to each of the fifteen filtered channels. This system works better then the previous system based on convolution and is also a lot less cpu demanding.

The new system is developed as part of a process that is able to detect three different actions. It detects a strike of a tone, by checking if the computed slope value of each filtered signal is above a threshold (see Figure 4). This threshold is based on the threshold of the incoming main signal, limited by a minimum value. Because of the adaptation of the threshold, the minimum value can be lower, without the occurrence of incorrect detections. And with a lower threshold value, softer struck tones are detectable.

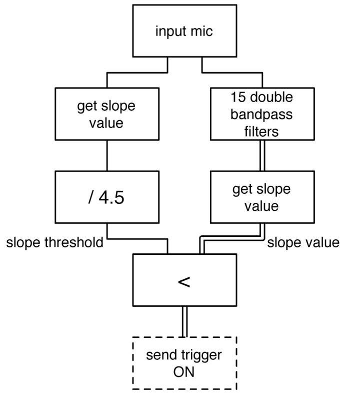

Figure 4. detection of the strike of a tone

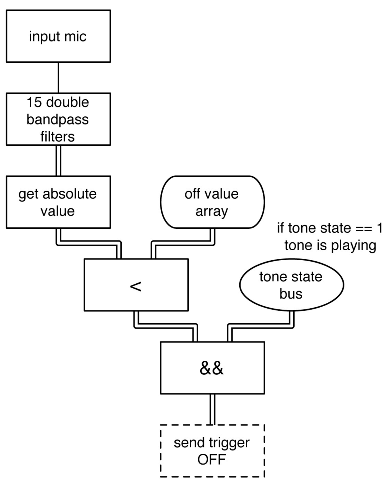

Figure 5. detection of the end of a tone

By comparing the mean absolute value of each filtered signal with a predefined value, the system can detect when a tone ends (see Figure 5).

The system is also able to detect when a tone is stopped by the performer. The system does this by checking if the computed slope value of each filtered signal is below a negative threshold. This threshold is based on the loudness of the sounding tone (see Figure 6). The reason for the use of an altering threshold is the same as discussed above for the detection of a strike of a tone.

3.3. Realtime synthesis based on resonant models of the mbira

Different synthesis algorithms are introduced to create the artificial layer of the instrument. Additive synthesis and substractive synthesis produce the best results from the point of view of merging with the acoustic sound of the mbira.

Given the hardware setup of the instrument, the synthesis gives rise to a feedback problem. The synthesis played over the transducer speaker is picked up by the contact microphone and this causes feedback in the system. Without solving this problem, the system is reacting to the synthesis instead of only reacting to the playing of the performer. Supposing there is no alteration of the sound by the acoustic properties of the mbira, the solution would have been to subtract the outgoing synthesis signal from the incoming signal. But this is not the case, the signal of the speaker does get altered by the resonance of both the bars and the sound box.

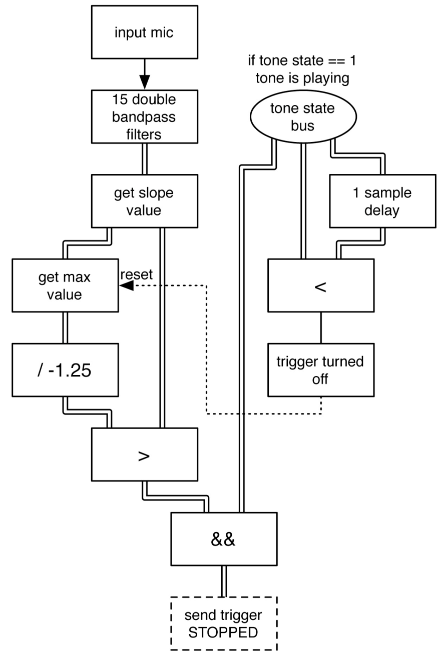

Figure 6. detection of a stopped tone

To reduce the feedback a convolution algorithm is used. Through convolution we can imitate the alteration of the played signal and in this way create a signal that is (almost) the same as the signal picked up by the contact microphone. This signal can then be subtracted from the incoming signal to cancel out the feedback.

For the convolution an impulse response of the mbira is used, which is created with the transducer speaker and contact microphone. This impulse response is loaded into the convolution that is altering a copy of the outgoing synthesis signal. This altered signal is then subtracted from the incoming signal. In this way the feedback is reduced to 10% - 20%, a reduction of 12 to 18 dB. Part of this variation is due to the changes in the position of the hands.

The added convolution reduces the feedback to a level that makes the system operate successfully. The system does not detect the synthesized tones when they are played while the real tones are sounding but when the real tone is not sounding and the synthesized tone contains an extreme short attack, the system still reacts to this. To solve this problem a gate for each tone is added to the detector. When the attack of the synthesis is set below 0.01 seconds and a delay is used, the gate is turned on during the attack of the synthesized tone (see Figure 8). Because it is not impossible that while the gate is closed the same tone is played on the mbira, this solution can be improved. Instead of using a gate, the height of the threshold for the detection of a struck tone can be raised during a attack of a synthesized tone.

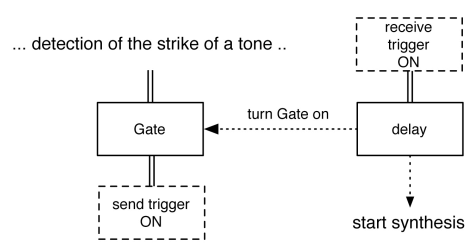

Figure 7. the use of a gate while using a delay

3.4. Graphical User Interface

During the development of the polyphonic pitch detector a GUI was written to generate visual feedback of the detection. In order to check whether the correct tone is detected, visual feedback works clearer and faster than console messages in Supercollider. For the visual feedback a simplified image of the bars of the mbira is used (see the right of Figure 9). This image shows when a struck tone is detected by the system, by changing the corresponding bar to green. The small buttons above the bars change to green when the synthesis of the corresponding tone is played by the system. With these buttons the synthesis can be stopped which is important during the testing.

The option to change the parameters of the synthesis is also added to the GUI (see the left of Figure 9). In this part of the GUI the synthesis type can be selected and the envelope can be adjusted. In addition, a delay can be used and the number of tones can be chosen, one tone, or two tones with an interval of a third, or even chords. There is also an option to change the triggers for the syntheses to start and to stop. There are four available triggers. 'Note on", in this case the trigger is a struck tone. 'Note off', with this option the trigger is the end of a tone. 'Note stopped' and '2 x stopped', in those cases the triggers are a single stopped tone or two stopped tones.

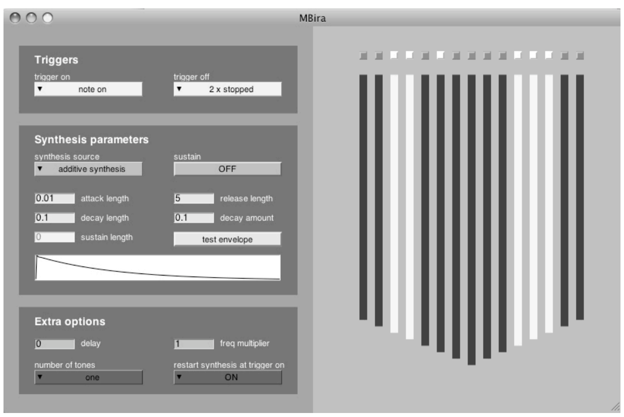

Figure 9. GUI

4. FINAL PROTOTYPE AND RESULTS

First The final prototype addresses many of the intended aims in the design of a hybrid instrument using music prosthesis as a metaphor. The electronic layer merges well with the acoustic layer blurring the distinction between manually triggered tones and synthetic extensions. Because of this, the tones of the mbira are extended in a natural sounding way. With a slow attack for the synthesis, the tones of the mbira swell in a way that significantly expands the articulation capabilities of the mbira. The lengthening of the tones allows the performer to play with the tone colour, by combining tones and letting them sound together. It also gives the performer more time to change the tone colour by moving his thumb in and out of the sound hole to produce acoustic resonance effects through damping.

The design strategy based on the concept of a prosthetic instrument provided an important framework for addressing the relationship between the acoustic and the electronic. The key propositions that address the exploration of prosthesis in this context can be summarised in three main points.

The use of the transducer speaker assures that the acoustic projection of both natural and artificial layers remain in the instrument itself. The use of audio input as sensor (in contrast to extra controllers or sensor devices) strengthens the relationship between performed action and sounding result. Finally, the close coupling between the acoustics of the instrument and the synthesis parameters addresses the notion of prosthetic mimicry and allow for the natural resonance of the soundboard to colour the synthetic sound and hence provide some natural richness. The close relationship between the acoustics of the instrument and the synthesised extensions is key to achieving new modes of articulation such as the combination of a natural attack expanded swell of the same pitch or a more complex cluster of pitches.

The use of the design strategy based on the concept of human prosthesis has demonstrated promising results, and therefore can be seen as a valuable design strategy. Further work in better integrating the hardware into the instrument could be explored with a view to retaining the natural weight and size of the instrument and to some extent making the prosthesis transparent. The use of this prototype in a performance context can now be evaluated and more sophisticated design of reactive behaviours could be explored from a compositional point of view.

5. REFERENCES

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