

DESIGNING SIMULACRA OR THE ELECTRONIC REPLICATION OF A MECHANICAL INSTRUMENT

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ABSTRACT

Specific requirements of certain works of music, especially in the field of contemporary experimental music of the 19th century, are sometimes hard to meet when it comes to the performance. Special instruments or technologies are necessary and often no longer available, broken or their documentation is insufficient. This paper addresses this problem of performance practice in contemporary music by exploring the design of an electronic replacement of a mechanical instrument for the performance of the piece “Mouvement - vor der Erstarrung” by Helmut Lachenmann. The simulacra developed consist of a musical interface, a software for sound synthesis and a loudspeaker system. A focus is put on the challenge of synthesising and projecting the sound as close as possible to the original instrument and to fit the musical requirements of the piece. The acoustic integration of the electronic instrument into an ensemble of acoustic instruments was achieved by using an omnidirectional loudspeaker. For the sound synthesis, a hybrid approach of sampling and additive synthesis was chosen. The prototypes developed were proven to be robust and reliable and the simulacra were generally well-accepted by performing musicians, surrounding musicians, conductor and audience.

1. INTRODUCTION

The performance of “Mouvement - vor der Erstarrung” by Helmut Lachenmann requires three modified bell keyboards (“Klingenspiel”), which basically are small toy pianos (a.k.a. frog pianos) adapted with an additional control of the power supply of the electric motor. Fig. 1 shows a picture of the instrument.

Unfortunately, the bell keyboards modified specifically for Lachenmann’s compositions are not suitable for reliable operation anymore and therefore appropriate replacements were sought. Because their sound plays a key role in the piece, the alternative version using a special spring bow technique combined with scratching behind the bridge of violins is considered as a last resort. Also a mechanical replication or repairing of the instruments was not desired

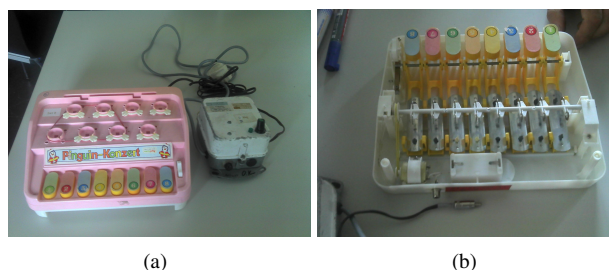


Figure 1. Picture of the bell keyboard (“Klingenspiel”). In (a) the keyboard is seen with the power supply where the speed control of the motor is placed on. In (b) the interior of the bell keyboard can be seen.

due to inflexibility. This led to the task of finding an at least equivalent, functional replacement.

The problem just described is one of performance practice in contemporary music. Some composers used and use new or non-traditional ways to express their ideas by applying new technologies or instruments. As time passes, the tools employed can be simply out-of-date, no longer available or a precise documentation of the functions and mechanisms is not preserved and therefore the performance of these works is made difficult.

It has to be made clear that it is not intended to create a new instrument but rather to create a replication of an instrument, that is more than just a simulation or emulation - a so called “simulacrum”¹. A simulacrum has the advantage that the characteristics of the instrument can be isolated and therefore be shaped independently. Further a generally higher flexibility gives more room for the interpretation of the piece. Designing simulacra using today’s computer resources can be a powerful tool for replacing rare or cumbersome instruments.

The main criteria for the high demands of the composer, the ensemble and the conductor to realize a simulacrum are found to be:

- **Sound quality:** Simulation of the sound quality as precise as possible

¹ Simulacrum (plural: simulacra), according to Jean Baudrillard. The essential characteristics are being recreated but not the form of appearance. Focussing only on software this would be an emulator. But as the physical interface and the acoustical behaviour in context of an ensemble are also considered, the term simulacrum corresponds better to what is aimed at here [1].



Figure 2. Small section of the score of “Mouvement - vor der Erstarrung” showing the part of the bell keyboards (“Klingelspiel”).

- **Playability:** Similar way of the playing and controlling the parameters
- **Robustness:** Simple handling and robust and compact transport
- **Acceptance:** Physical integration into the ensemble as a locatable instrument
- **Sustainability:** Simple reproducibility and reusability

In this paper we present the approach we have taken to design simulacra for the bell keyboards of Lachenmann's work. The development was focused on considering a concert situation and the integration of the instrument into an ensemble for contemporary music. In section 2, a detailed analysis of the characteristics of the bell keyboards is presented and the conclusions drawn for the design are discussed. In section 3, the implementation is presented. The prototypes were tested in two concerts of the *Klangforum Wien*. One at the Mumuth in Graz, Austria, on 28 June 2011 and the other at Konzerthaus Wien (Mozartsaal) on 29 September 2011. The impressions of these concerts concerning the instrument are discussed at the end of the paper.

2. INTRODUCING... THE “KLINGELSPIEL”

As the task is not to create a new digital music instrument but to recreate one with digital means a profound analysis of the bell keyboard was made. The aim is to get enough information about the musical intentions and the physical properties of the instrument so that the electronic replication serves the intentions of the original instrument. We divided the analysis into three parts, a musical-, a physical- and an intentional analysis. In the musical analysis we discuss all properties that are connected to the musical practice of the instrument, i.e., the pitch range, how it is played, role in the score and the ensemble, etc. The physical analysis provides information on the technical properties, i.e., mechanism, temporal and spectral characteristics, loudness, directivity. In the intentional analysis, we discuss the musical intentions of the instrument in this particular piece, after consultation of the composer.

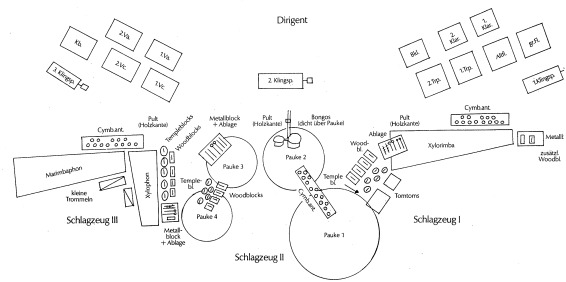


Figure 3. Disposition of the instruments in “Mouvement - vor der Erstarrung” by Helmut Lachenmann.

2.1 Musical analysis

The bell keyboard was modified specifically for Lachenmann's compositions by adding a control to the electric motor using a regulator for the power supply. These instruments do not only appear in “Mouvement - vor der Erstarrung” but also in a piece called “Harmonica (81/83)”. The score reveals that there are three different bell keyboards, each having 8 keys, in diatonic scale from G1-G2². According to the preface of the score, the volume is varied using the regulator for the motor speed. It is also mentioned that the motor should be started just before playing because of the noise it produces. In Fig. 2 a short passage of the score is shown. It can be seen that three bell keyboards are used polyphonically and a continuous and fast change in dynamics is demanded. The musician has to use one hand to press the keys and the other hand to regulate the motor. Fig. 3 shows the plan for the disposition of the instruments. The keyboards are distributed throughout the stage and therefore are fully integrated into the ensemble.

Listening to the original instrument, the sound is a rattling and chattering reminiscent of a fluttering movement including irregularities. However, a certain pitch is perceivable. According to the score, the sound is only controlled by the rotational speed of the motor and no dynamics in keystroke are notated even though it is possible to change the sound by varying the keystroke depth. Further, by simultaneously pressing several keys the motor is slowing down and hence the sound is altered.

2.2 Physical analysis

The Klingelspiel consists of a small keyboard of 8 keys and each key is connected to small tuned metal tone bars (Fig. 4). Pressing down a key causes the metal plate to raise and hit the rotating actuator. The actuator consists of two metal rings, fixed loosely on plastic spokes fixed on a rotating metal shaft. The shaft is driven by the motor over a belt drive. Thus, while holding a note, the metal tone bar is randomly hit twice in one full rotation. The eight tone bars are all of same thickness, width and length. They are tuned mainly by mechanical embossings on both ends.

Fortunately, we had access to a bell keyboard which was almost intact. Therefore, we were able to record the sound

² In case the keyboards are not available there is a reduced version notated for only one keyboard

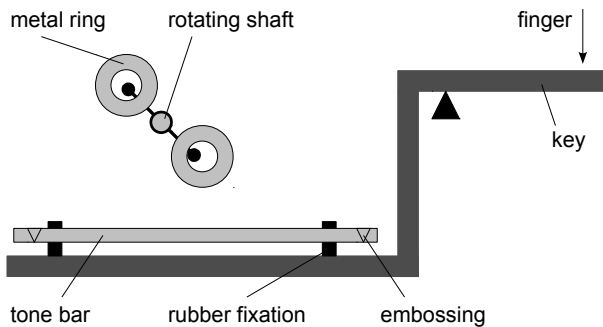


Figure 4. Drawing of the mechanism of the bell keyboard.

to analyse the acoustic behaviour. First we measured the loudness using a sound pressure meter. The SPL in one meter distance was around 70dBA for the closed instrument and in between 75-85dBA for the uncovered instrument, measuring the different keys.

The temporal behaviour is determined by the rotating metal piece. The attack and decay of the sound are fast and the sustain obviously lasts as long as the key is pressed. The release is also fast. In Fig. 5 the waveform of one tone is shown. It can be observed that the amplitude is higher and lower alternatively. Apparently one side of the metal piece hits the tone bar softer than the other one.

The spectral characteristics are shown in Fig. 6 on a linear frequency scale. Four keys are played in series from low to high. It can be observed that harmonics are present up to very high frequencies. Further there is one harmonic around 6 kHz which is almost constant and strong for every key which seems to be due to the same dimensions of all the tone bars.

In order to get an impression of the radiation directivity characteristics, the bell keyboard was recorded placing four microphones in different directions referring to the corners of a tetrahedron. The four directions showed a quite equal frequency response which led to the conclusion that the directivity can be seen as roughly omnidirectional.

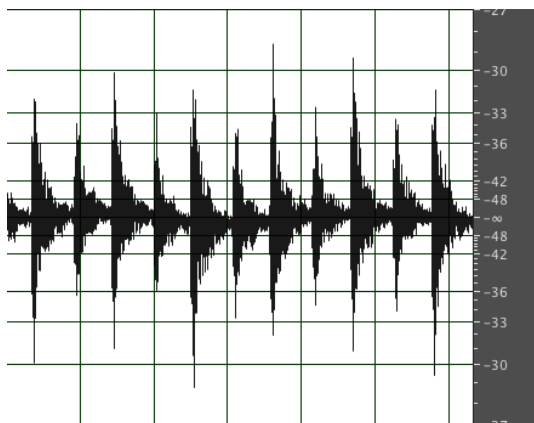
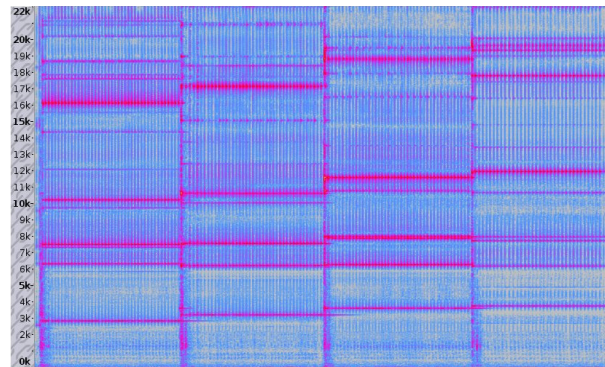
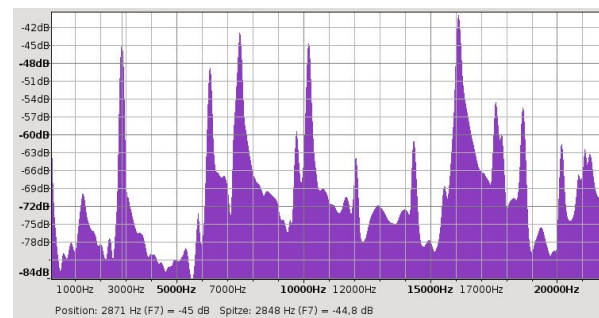


Figure 5. Waveform of the recorded signal of one key.



(a)



(b)

Figure 6. Spectrogram (a) of 4 notes and spectrum (b) of the first note in (a).

2.3 Intentional analysis

The development of the simulacra aimed mainly at the application for this particular piece, and therefore it was important to reveal its musical intentions. The goal was to understand which aspects are of importance, which are not so delicate and which are maybe even unwanted and should be dropped.

The person with the most knowledge on this is the composer himself. Therefore, Helmut Lachenmann was contacted and a short interview has been done [2].

In this Interview the composer emphasised the important effect of the randomly repeated dirty sound of an electromechanical instrument. He also mentioned, that the sound produced by the motor itself is not desired and is only distracting. The tones do not necessarily have to be in exact tune and rather can be roughly in the same range of the notated pitch.

Further, according to Lachenmann, the mix of the bell keyboards with other instruments being played in parallel and the distribution throughout the ensemble is of high importance. The resulting spatial effect was the reason why he orchestrated three of them.

3. IMPLEMENTATION

The bell keyboard is obviously a provisional implementation of the composer's ideas and not a profoundly designed instrument. This gave room for the design of a "simulacrum" in which only the most important elements had to be recreated. The goal was to develop a compact instru-

ment that replicates the bell keyboards electronically. The implementation splits up into three main parts:

- Musical Interface
- Sound Synthesis
- Sound Reproduction

The goal was a kind of plug-and-play instrument for simple handling, that can be maintained by the musicians themselves. Therefore, the demand on the dedicated computer system was to conduct the processing of all multiple instruments simultaneously, for simplicity. Another design criteria was that after an exception like a power failure, it can be operational after a short time. Our setup incorporated a laptop computer and an external multichannel audio interface³.

For data processing and sound synthesis, the graphical realtime programming environment PureData was chosen, as this is open-source and free software and therefore relatively future-proof and available on most operating systems. It was mainly developed for robustness and long-term compatibility of the cm-software targeting systems with low latency. As graphical programming language the source code of the implementation is also important for documentation and future implementations. Further, software does not degrade in the way physical objects do. We tested and used our system on a small laptop (netbook) running Debian GNU/Linux [3] as well as on a MacBook running OS X⁴.

The Software provides a modular graphical interface to adjust the sound characteristics and playability parameters for specific performances and musicians (Fig. 7). Additionally, a remote control for the main computer on stage was implemented using Open Sound Control (OSC) [4] over network like WLAN. This enables the fine-tuning of the sound for technicians during rehearsals or even concerts.

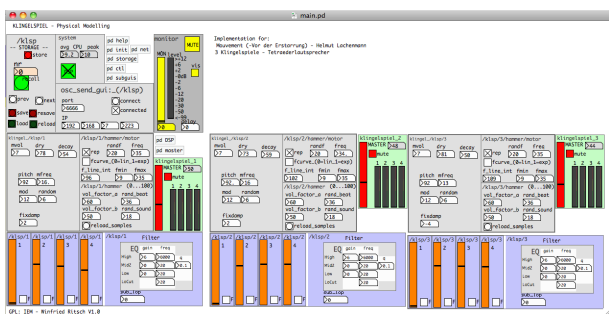


Figure 7. PureData patch GUI frontend.

3.1 Musical Interface

The obvious approach to design a musical interface for the control of the bell keyboard synthesis is to stay as close as possible to the original model in terms of the feel of

³ First performance: ESI Gigaport HD. Later: RME Multiface

⁴ MacBook and OS X are trademarks of Apple Inc., registered in the U.S. and other countries.

playing (Spielgefühl). As there are no musicians that are trained in this particular instrument, another approach would be to design an interface that is as intuitive as possible to learn. In our case, for playing single notes, a keyboard is the most intuitive solution, as most musicians are familiar with the piano keys, even if they are smaller. Also the size of the interface should be minimized for transportation and ease to use.

The behaviour as a machine, as Lachenmann told us, is an important aspect. Therefore, the motor is always hammering and the keys only turn on and off the sound. This is in opposition to piano-forte where the individual velocity of each key is important and polyphonic aftertouch is needed.

According to these requirements, we decided for a miniature USB MIDI keyboard with a ribbon-controller for the motor speed (Fig. 8). Volume was controlled musically by the variable motor speed. The three independent USB MIDI keyboards were connected to the computer through an active USB hub.

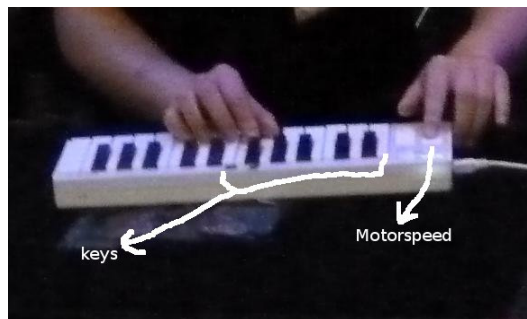


Figure 8. MIDI keyboard and controller.

3.2 Software Simulation

First, a physical modelling approach was tried using digital waveguides. For high frequencies, this method is computationally very intensive because of the required oversampling for the highest modes [5]. From the analysis, we saw that most of its output lies in frequencies beyond our hearing capabilities. Therefore, the physical modelling approach was thought to be unfeasible and a more elementary approach based on sampling and additive synthesis was implemented (Fig. 9).

For each note, three samples were recorded: One attack sample for the initial note actuation and one sample for each of the two hammer impacts of the motor rotation. These samples were then reduced to their noise part by filtering out all sinusoidal/tonal elements of the sound. The applied FFT-based algorithm separates tonal and noise parts via coherence measurements between the input signal and two archetype signals (white noise and sine wave).

When a note is triggered, at first, the attack sample is played back, then, while a key is pressed the two hammer samples are played back alternately triggered by the motor clock generator until the key is released. Having the original model in mind, the attack sample is played back using velocity sensitivity, while the rotating hammers are only

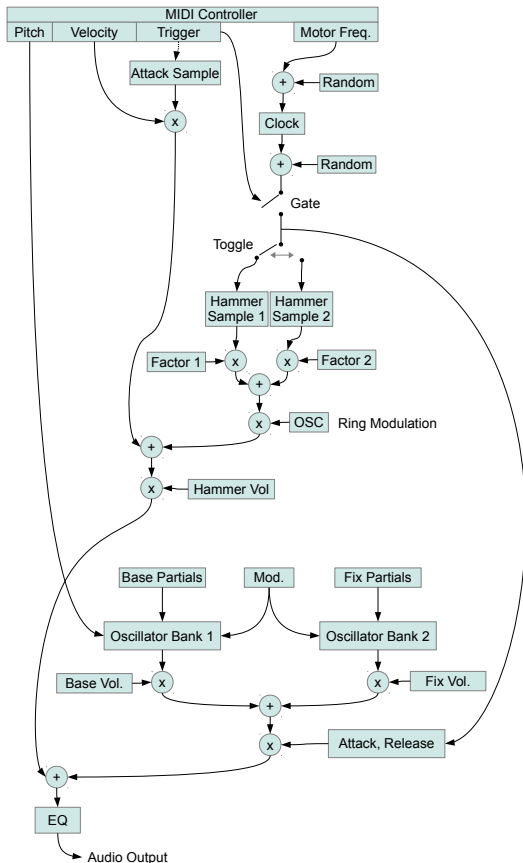


Figure 9. Block diagram of the sound synthesis

controlled by the motor. The motor speed is controlled using the interface but also gets modulated randomly according to the mechanical actuation model (See Fig. 4).

The partials representing the tonal part of the sound are created by two oscillator-banks through additive synthesis. The two oscillator banks represent the base partials, tuned by the MIDI note values of the keyboard and the fixed partials that remain constant for all notes. The partials are also in sync with the motor clock generator, as it triggers a basic attack/release envelope. Their frequency values are adjustable and set to match the result from the spectral measurements for each note. In order to have a slight variation between the three instruments these frequencies are altered slightly for each of them which results in a more natural sound while they play simultaneously.

Finally a ring modulator is used to degrade the clean ringing sound to a more dissonant character. Apparently, introducing random modulation in several stages of the synthesis helps to keep a natural and volatile sound.

3.3 Loudspeaker System

Using electronic instruments a typical approach is to use a PA system to address the audience while the musicians hear themselves via specific stage monitors. As the PA is generally mounted outside the ensemble a proper localisation of the instrument on stage and the connection between musician and sound is not given⁵. This especially holds

⁵ except using sophisticated systems like Wave Field Synthesis

in this piece because Lachenmann deliberately positioned the three bell pianos across the full width of the ensemble. Therefore, for proper reproduction of the composers intentions the simulated instruments must be localised accurately at the positions indicated in the score and also the loudness of the instrument has to be set appropriately. The goal is also to enable a natural musical interaction between the musicians.

Further the room acoustics take a vital role in the mix of the ensemble and therefore the simulacra need to excite the room acoustics similar compared to the other instruments. The reproduction should shift from the “electronic realm” to the “acoustic realm” [6]. Also a natural perception by the surrounding musicians must be established.

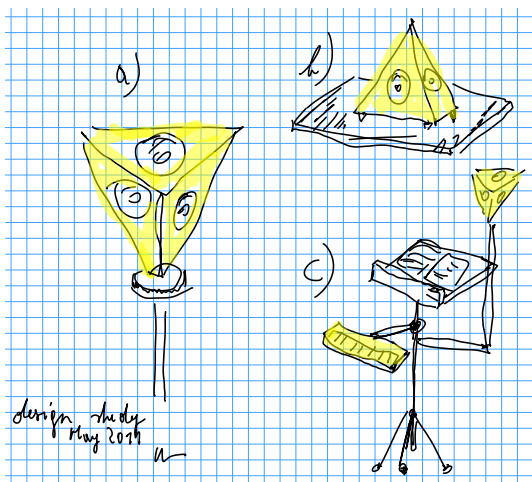
Our approach is to place compact loudspeaker systems inside the ensemble and treat them equivalent to the acoustic instruments.

Experiments with existing PA or studio loudspeakers led to unsatisfactory results. These kinds of loudspeakers produce an extremely directive response, high sound pressures causing different radiation in the concert hall and unacceptable nearfield behaviour and are therefore not suitable. Hence, we decided to construct a custom omnidirectional loudspeaker array specifically for our requirements. A tetrahedral shape was chosen, which is the most elementary of the platonic solids, and thus requires the fewest speakers to approximately cover all space. This attribute makes it very cost and work efficient, while providing a basic omnidirectional sound emission characteristic⁶. Using speakers having a radiation angle of approximately 120° and placed at the faces of the tetrahedron yields a roughly consistent radiation in all directions. We tested several speaker chassis under by simple listening for their frequency response and chose small speaker chassis to fit onto the tetrahedron and still cover a wide frequency range up the very high frequencies. By using soft suspended membranes a preferable near-field behaviour in contrary to PA speakers is expected. The speakers are passive and amplified by an external four channel amplifier so that each speaker of the tetrahedron can be driven individually. The directional behaviour is adjustable through software. A special output stage was implemented to include individual filters and volume characteristics for each of the four channels.

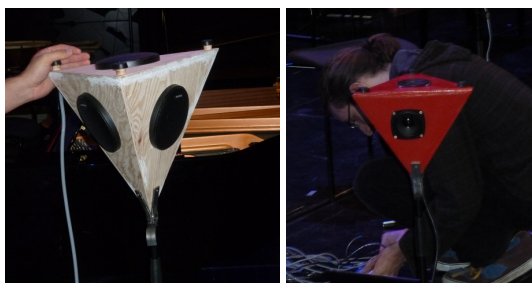
Three tetrahedron loudspeakers were built with an edge length of approximately 20cm for the smaller ones and 25cm for the bigger one. The loudspeakers are designed to be mounted in different ways, as is seen in Fig. 10 (a). By using long cables for the loudspeakers, the musicians could also reside at one central position, while their instruments are still localised distributed over the stage, according to the speaker positions. Two membranes should face forward to address the musicians in the front and on the sides as well as conductor and audience. The top membrane could be used to support monitoring for the musicians and also to make use of ceiling reflections for a wider range of coverage, depending on the specific room acoustics. The rear membrane is used for monitoring for the mu-

⁶ This approach is a very practical one where it is not intended to synthesise directivity patterns as represented by the spherical harmonics. For more information on that cf. [7] and [8].

sician and other musicians behind, as well as for rear wall reflections, if desired. Overall, this results in an acoustic behaviour that is competitive with the original instrument.



(a)



(b)

Figure 10. In (a) a conceptual drawing of the loudspeaker system is shown and in (b) two of the built loudspeaker arrays are shown.

This 4-channel speaker system aims at a broader field of application and to serve as a general acoustic interface for the simulation of small acoustic instruments. Listening impressions tell that the biggest of the three tetrahedron loudspeakers (Fig. 10 (b), left) would be sufficient for reproducing the volume equivalent to a cello, while the smaller ones (Fig. 10 (b), right) correspond more to a violin or viola. For future applications, an active version with digital input is planned, to improve flexibility and reduce cabling.

4. FEEDBACK AND EXPERIENCES

The simulacra were successfully tested in two concerts, where the second one took place without any of the developers present which proves the robustness of the design and its straightforward operation. Fig. 11 shows the simulacra on stage at the first concert. Further, the conductor of the second concert (Johannes Kalitzke) demanded a few adjustments of the synthesis towards a more micro-tonal sound. The musicians themselves were able to adjust the correspondent parameters and therefore the sound of the simulacra could be easily influenced to serve the interpretation of the conductor.

When asking for opinions, the sound of the synthesis was

generally received to be too fine and clear and a more rattling, fluttering sound was desired. This indicates that the synthesis should include more non-linear effects in the generation process of the sound. The musicians reception of the instrument integrated in the ensemble was still dominated by the “electronic” sound of the synthesis but the sound impression in the audience area was credible concerning the interaction with other instruments and the room acoustics. However, the authors had the impression that the simulacra were generally well-received and served their purpose.

5. CONCLUSIONS

This paper presented the development of simulacra for the “Klingenspiel” of Helmut Lachenmanns piece “Mouvement - vor der Erstarrung”. The instrument was first analysed for its role in the piece and then for its technical function and mechanisms. Starting from the results of the analysis a system was designed where the main challenges were the creation of an interface for the musicians, the sound synthesis and the reproduction of the sound in space. The interface was chosen similar to the original using a small MIDI keyboard. For the synthesis a simple approach based on samples and additive synthesis was taken. The reproduction part was addressed by using three compact loudspeaker arrays in shape of a tetrahedron built for basic control of sound radiation. The system proved to be robust in handling and transport and the repeated usage was successful.

The approach presented in this work to address a problem of contemporary music is intended to be a resource for similar attempts and maybe even as a benchmark for the design of new digital instruments. The build simulacra in the context of the problem task proved to be successful and even the publisher of the piece showed interest in distributing the system with the score. The software and a documentation of the system in german can be found at the project webpage [9].



Figure 11. The final simulacra installed on stage and being played by the musicians.

Acknowledgments

This work is based on a seminar entitled “Instrumental music and live electronics” held in summer term 2011 at the Institute of Electronic Music and Acoustics (IEM) of the University of Music and Performing Arts, Graz, Austria. The development was a collaboration of the students Wen Liu, Clara Hollomey, Marian Weger and Fabio Kaiser under the supervision of Winfried Ritsch. The tetrahedron loudspeakers were built at Atelier Algorhythmics [10]. We also want to thank Klangforum Wien, especially Dimitrios Polisoidis, for the support in organization, the publisher “Breitkopf & Härtel” for their support, Matthias Hartmann who originally worked with the bell keyboards and last but not least Helmut Lachenmann who supported the project with good advice.

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