Assessment Techniques for New Mechatronic Instruments as Applied to speaker.motion.

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ABSTRACT

The field of mechatronic instrument design has developed substantially over the past decade. With these new instruments the common musical assessment techniques that are generally applied to western art music are no longer sufficient as the instrument builders need to assess the design and production of the mechatronic instrument itself as well as the way it might be used musically and expressively by composers and performers. This paper introduces ideas about the new approach to the assessment of mechatronic instruments that is needed to fully assess them. After introducing the new assessment technique principals and discussing why a holistic approach is needed in this particular field the authors then go on the provide a case study on the speaker.motion mechatronic loudspeaker system that has been assessed in the proposed way. The paper provides details on both a qualitative and quantitative assessment of the speaker.motion system and how the combination of the two studies is what allows a full assessment of the instrument, and of its expressive potential..

1. INTRODUCTION

The past decade has seen a vast expansion of the field of mechatronic instrument design. These new instruments have been created with a range of design goals and approaches however there are some common threads with the design approach and creative goals of the development of these new instruments. In the design goals of the instruments there can be seen a common thread of increasing the expressive potential of the instruments. Expressivity can be a difficult attribute to measure and has been the topic of much discussion throughout the NIME field. Dobrian and Koppelman provide an in-depth discussion on expressivity in electronic music and particularly in the discussion of whether a machine can be expressive [1]. While many of the mechatronic instruments of the past decade would be considered machines in this discussion of expressivity it is more relevant to the expressive intentions of the performer. In this case the instrument builders have not always attempted to give the machine itself the autonomy of expressivity but more to give the machine a complex enough mechanical structure that allows nuanced performance by the human controlling the instrument, thus allowing the performer a higher level of expressivity. Murphy's Musical Robotics in a Loudspeaker World provides an overview of mechatronic instruments and in particular the ideas behind their expressive potential [2].

In the design approaches of these instruments there can be seen a common thread of the multidisciplinary approach that includes an iterative design methodology abstracted from computer science and mechanical engineering fields. This paper proposes that given the complex nature of the assessment of new mechatronic instruments that cross multiple disciplines, a similar approach to that taken in the design phases could be applied to the assessment of these instruments. The design phases take approaches from many disciplines in order to build these instruments, broadly speaking taking equal weight from mechanical engineering/computer sciences and from creative and musical arts. Through further combining these approaches to the assessment of the instruments one might gain a new approach to assessment that will help maintain the iterative design methodology and provide a more thorough assessment of both the new technology itself, and the ways in which it might be deemed expressive by composers. This approach to the assessment of new mechatronic instruments has been applied to the development of the speaker.motion project that will be used throughout this paper as a case study for the assessment approach. By applying both a quantitative and qualitative assessment of the speaker.motion system the authors are able to provide detail on areas for improvement in the design of the instrument but also to begin to understand the expressive potential of the speaker.motion system and how composers and performers might explore this expressivity in creative applications.

With the developments in the field of mechatronic instruments taking place so rapidly there are currently relatively few works written for these instruments that would enable an analysis of them in a traditional musical analysis context. Therefore, to continue the development of the instruments and the field creative technologists designing new musical interfaces have had to decipher new ways to assess the tools they are creating.

Murphy, and Long have both implemented numerous techniques in the assessment of their mechatronic instruments [5, 6]. Throughout the assessment techniques implemented in this field it becomes clear that no single techniques is appropriate across the range of instruments as each instruments design features need to be assessed in unique ways. However, there is a common trend in instruments designed for use by composers outside of the design team which involves an assessment not only of the capabilities of the instrument, but also of the interaction techniques employed composers who might use the instrument.

2. THE SPEAKER.MOTION SYSTEM

speaker.motion is a mechatronic loudspeaker system featuring four loudspeakers which are capable of dynamic directionality changes across two axes [7]. The system was developed as a way for composers and performers of electronic music to further increase the ways they engaged with the physical space in the performance environment. By dynamically adjusting the directionality of the loudspeakers in performance the composer is able to activate the physical space and use the spatiality as an expressive mode throughout the performance.

2.1 Speaker.motion system design

The speaker.motion system includes four identical units that can be used individually or daisy-chained together. Figure 1 shows a single speaker.motion unit; each unit features a Genelec 8010 loudspeaker mounted in a custom-built mechanical structure. The loudspeaker itself is mounted inside a gimbal-like cage-type structure that gives the loudspeaker the desired rotational and tilt control parameters. The loudspeaker's tilt is controlled by a miniature servo mechanism mounted on one side of the cage, and the rotation of the entire cage is driven by a stepper motor. By rotating the full cage structure, speaker.motion is able to adjust both the tilt and the rotation simultaneously. Where possible, the moving parts are all mounted inside the enclosure underneath the cage. This design helps with structural stability, protection of the mechanical parts, and safety of limiting access to moving parts, as well as for visual aesthetics.

Figure 1. All four speaker.motion mechatronic loudspeakers.

2.2 Speaker.motion interaction design

The MIDI protocol was selected for its ease of use and reliability, as well as for its prominence within electronic music communities. A further benefit of MIDI is the ability to run MIDI cables over long distances without a loss of signal integrity. This opens the speaker.motion system up to a much wider variety of performance configurations and performance spaces. Each loudspeaker unit runs on a separate MIDI channel (1, 2, 3, 4), with the individual MIDI channel for each particular unit labeled on the base of the unit.

The flexibility and modularity of the system allows a wide range of user interaction methods. This was intended to ensure a wide range of live electronic musicians could use the system. A design goal is that anyone with some familiarity with a DAW can use the speaker.motion system to its full potential without needing an understanding of how the mechatronics or the firmware works. As previously stated, the speaker.motion units respond to specific MIDI messages, which could be configured in any number of ways. In essence, speaker.motion can be controlled by anything able to craft and send MIDI messages. The modularity of the system and daisy-chaining style of the MIDI IN and MIDI THRU also means that composers may choose to physically arrange the speaker.motion system in many ways depending on their aesthetic needs. Performances have taken place using one, two and four speaker.motion units, with a number of examples of all four loudspeakers used in a variety of configurations.

3. MECHATRONIC INSTRUMENT ASSESSMENT TECHNIQUES

In order to assess the ability of the speaker.motion system to create variation in the way audio travels through a performance space, an impulse response experiment was conducted. The experiment involved rotating the speaker.motion unit to different angles of rotation and tilt to excite a room in varying ways. In addition to assessing the behavior of speaker.motion, the resultant impulse responses allow composers/performers to begin to realize the extent to which directionality of a loudspeaker affects the way audio is perceived by the audience members. This information shows the potential benefit of being able to automate such movements in performance to increase spatial expressive potential throughout the piece. The following subsection explains how the experiment was conducted and provides a discussion of the results that were gathered. It also provides a discussion of what may be concluded about the validity of the speaker.motion system and its design criteria from these results.

3.1 Quantitative Approach

In order to assess the ability of the speaker.motion system to create variation in the way audio travels through a performance space, an impulse response experiment was conducted. The experiment involved rotating the speaker.motion unit to different angles of rotation and tilt to excite a room in varying ways. In addition to assessing the behavior of speaker.motion, the resultant impulse responses allow composers/performers to begin to realize the extent to which directionality of a loudspeaker affects the way audio is perceived by the audience members. This information shows the potential benefit of being able to automate such movements in performance to increase spatial expressive potential throughout the piece. The following subsection explains how the experiment was conducted and provides a discussion of the results that were gathered. It also provides a discussion of what may be concluded about the validity of the speaker.motion system and its design criteria from these results.

3.1.1 Experiment Methodology

The impulse response experiment was conducted in the Adam Concert Room, as it is the primary concert space for performances at the New Zealand School of Music. The space itself is quite complex with an open mezzanine level providing access to the lighting rig system, as well as a pipe organ and two grand pianos permanently stored in the room. Stripping the room of these acoustic resonators would be impractical also leaving the room as it was commonly configured would give a more accurate depiction of the likely concert scenario. The experiment was conducted at night to minimize any outside noise that might occur with general use during the day.

The room itself is 14.5 meters x 13.35 meters (see Figure 64). The speaker.motion unit was placed 4 meters in from each wall at a height of 1.1 meters (measured to the loudspeaker cone). The microphone was placed on a standard microphone stand in the exact center of the room, at a height of 1.2 meters. This configuration was designed to mimic the approximate height of the ear level of an audience member while seated for a concert. The microphone used was an AKG 414 set to an omnidirectional polar pattern at 0 dB with all in-built roll-off removed. The microphone was connected to an audio interface via a balanced 10 metre XLR cable. The audio interface used was a PreSonus Firestudio Project, set to 24-bit, 96 kHz. The same microphone input level was used for all recordings, ensuring any amplitude difference is a result of the loudspeaker's directionality.

An audio chirp was used as the input to the room. The chirp had a frequency range of 60 Hz to 20 kHz, aligning with the frequency response of the Genelec loudspeaker, with the sweep taking place over 2 seconds. The chirp consisted of 20 frequency sweeps back to back, allowing each sample to be averaged to remove extraneous noise. The output of the audio interface set at 45% of full capabilities, this level resulted in no noticeable distortion of the loudspeaker's output at any frequency. The audio output level was the same for all loudspeaker directions, ensuring that any amplitude difference evident in the results is due to the directionality of the loudspeaker and its interactions with the space.

Recordings were taken with the loudspeaker pointed at eight different rotational angles. Each of these was taken at four different tilt angles, giving a total of 32 positions recorded. Table 3 shows the complete list of recordings that were made, with the angles of horizontal rotation and vertical tilt of speaker.motion at the time.

3.1.2 Experiment Methodology

By comparing the recorded response of various takes, the difference in the audio recorded through loudspeaker directionality changes is evident. Variation can be observed in changes on both axes. The results from each individual take are different, with no two takes appearing exactly the same. While related response changes may be obtained using other effects techniques (spectral filtering), the results depicted in this section's figures show that *speaker.motion* allows the room itself to become the effect; these observed results highlight the extent of variation possible with just one *speaker.motion* unit.

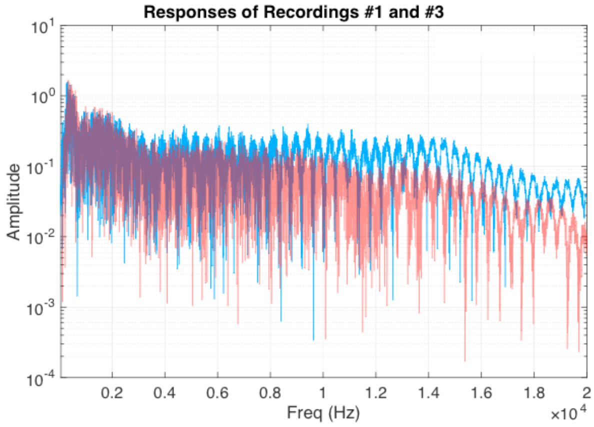

Figure 1. The response with the loudspeaker positioned at the same tilt (in this case 45°) with one recording featuring the loudspeaker facing directly across the room and one with the loudspeaker facing directly down.

Of particular interest was the difference between directionalities that sent the primary sound trajectory either directly length ways or width ways, as shown in Figure 66. Due to the shape of the room, which is longer than it is wide, comparing the two directionalities shows a great deal of variation. This suggests that the ability to manipulate the loudspeaker's directionality, particularly in non-square rooms, can have an affect on the reception of sound.

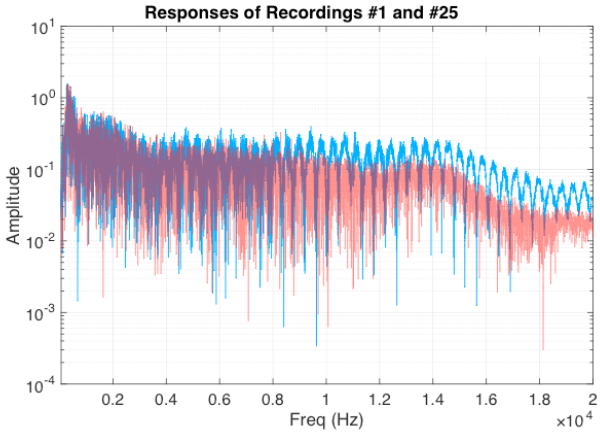

Figure 2. The response with the loudspeaker positioned at the same azimuthal angle (in this case 0°) but with one recording featuring the loudspeaker facing down towards the ground and the other with the loudspeaker tilted almost directly up towards the ceiling.

Similarly, the responses with the loudspeaker aimed in the same rotational angle but at varying vertical tilts show a great deal of variation. Figure 67 shows this variation by comparing a recording whose vertical tilt was 45° (with a 0° tilt being that facing directly towards the floor and a 180° tilt directly towards the ceiling), with a recording whose vertical tilt was at 170°.

While the figures above show some of the more extreme juxtapositions evident from these recordings, it is also of interest to compare the recordings taken with less extreme variation in the directionality of the loudspeakers.

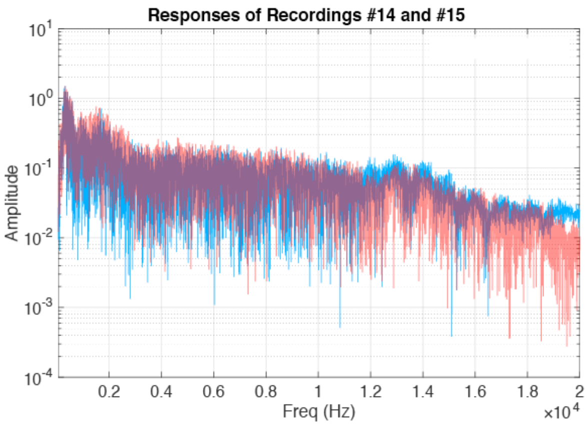

Figure 3. The responses of Recordings 14 (blue) and 15 (red). Both recordings featured the loudspeaker aimed at a vertical tilt of 90°. Recording 14 had a horizontal angle of 235°; Recording 15 had a horizontal angle of 270°.

Figure 68 compares Recording 14 with Recording 15. Recording 14 has an angle of 235° and a vertical tilt of 90°, while Recording 15 has the same vertical tilt and an angle of 270°. These two recordings represent the smallest difference in directionality of the loudspeaker of the positions that were used. Even in these relatively similar speaker configurations, significant variation in the response of the room is evident. Some variation can be seen across the full frequency spectrum, but there is a much greater level of variation in the mid-high to high-frequency bands.

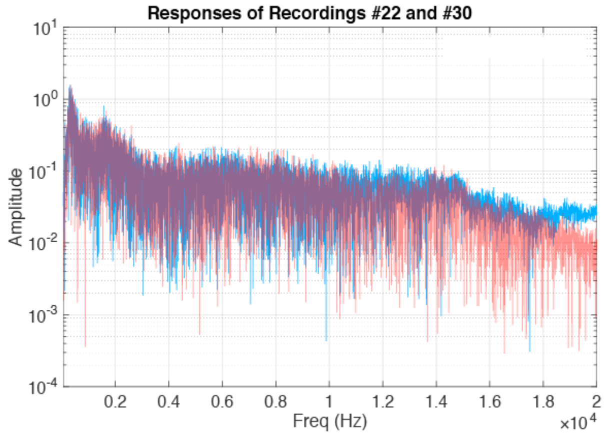

Figure 4. The responses of Recordings 22 (blue) and 30 (red). Both recordings featured the loudspeaker aimed at a vertical tilt of 90°.

Figure 69 compares Recording 22 and Recording 30. These recordings were taken at the same angle of 235° but represent minimal change in the vertical tilt. Recording 22 had a vertical tilt of 125° and Recording 30 had a vertical tilt of 170°. In a similar way to Figure 68, the resulting audio shows that even those recordings taken with smaller amounts of variation in the directionality of the loudspeaker show variation in the resulting audio.

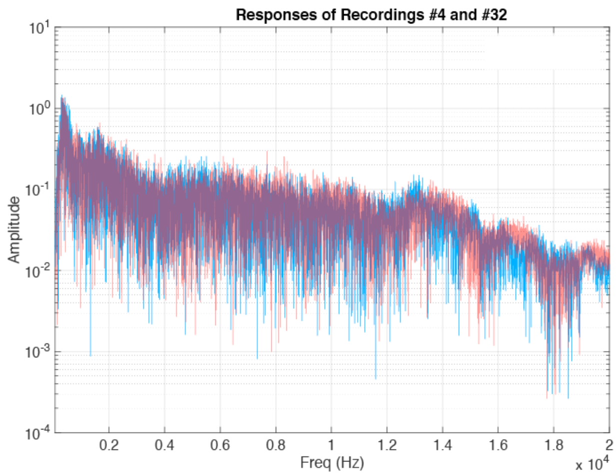

Figure 5. The responses of Recordings 22 (blue) and 30 (red). Both recordings featured the loudspeaker aimed at a vertical tilt of 90°.

Comparing Recording 4 with Recording 32 provides an example of the loudspeaker aimed in the most opposing positions possible; this comparison is shown in Figure 70. In Recording 4, the loudspeaker is placed at 125° with a vertical tilt of 45°, aiming the speaker cones towards a far corner of the Adam Concert Room and towards the floor. Recording 32 is placed at 325° with a vertical tilt of 170°, aiming it in the opposite corner much closer to the speaker.motion unit, and pointing towards the ceiling. These results are interesting, as one might assume that they should exhibit the most drastic variation between recordings; however, this is not the case. In fact, Figure 70 shows less variation than many of the other graphs presented in this section. One possible explanation for this is that both of these positions of the loudspeaker would cause any audio to bounce from a number of surfaces in the room before reaching the microphone and, therefore, the audience. The resulting audio might be more representative of the overall resonance and activation of the room caused by positioning the loudspeaker in this way. This information supports the suggestion that the use of speaker.motion in dynamically adjusting the directionality of the loudspeaker affords the composer the ability to actively engage the physical performance space as the signal processor.

The variation in data shown in Figures [66–70] suggests that the ability to manipulate the loudspeaker's directionality across multiple axes, particularly in rooms of non-square shape, can have an effect on the reception of sounds. This implies that the potential for manipulation for aesthetic and compositional reasons warrants further exploration. While this experiment recorded a diverse selection of potential directionalities of the loudspeaker in performance, the speaker.motion unit is capable of moving to a great deal more positions than were measured. The performer has access to a much wider range of positions in performance, and is able to explore the extremes of differing directions (as is represented by much of this data), but also has the freedom to make more subtle explorations of all the less variant spaces in between. The resulting audio of the impulse response experiment highlights the potential for manipulation of loudspeaker directionalities for aesthetic and compositional reasons.

3.2 Qualitative Approach

While the impulse response experiment provides quantifiable results about the effects of changing the directionality of a loudspeaker, it neither determines whether a composer might find this to be useful nor qualifies the potential for aesthetic spatial engagement. Therefore, a user study was also conducted that asked composers who had performed with the speaker.motion system to qualitatively describe their experiences and assess the validity of the system.

3.2.1 Experiment Methodology

Six composers of electronic music completed the user study anonymously, each of whom had performed with the speaker.motion system. The composers all came from a background in electroacoustic composition and had all performed with other custom-built instruments before. After performing with speaker.motion, the composers completed a questionnaire that asked a range of questions about how they utilized the system and the aesthetic considerations they made both spatially and through their wider compositions. They were also asked questions about their experience as audience members participating in concerts utilizing speaker.motion. Further details about specific performances, concerts and aesthetic considerations can be found in [8].

The response from the user study was positive. All of the composers felt that speaker.motion had changed the way they that thought about space in their compositions and that, having used the speaker.motion system, a heightened level of spatial engagement would now continue in their future compositions. Selected composer statements in response to questions about this area include:

Spatial elements have been a strong element in my compositional process, but what speaker.motion affords is a more complex, dynamic and controllable interaction and intention within the spatial parameters of ideas

Even without speaker.motion, I feel that I have now been made more aware of the great potential afforded by using non-traditional speaker configurations

It is possible that the physicality and visual phenomenon of seeing the loudspeaker actually rotate helps to draw attention to the spatial elements of a piece and their compositional intent. These comments suggest that having deepened their spatial awareness through their use of the speaker.motion system, the composers will now continue to think about the spatial aspects of their music in that depth, even when they are not using the speaker.motion system.

All of the composers felt that there were aspects of their piece that they would not have been able to achieve without the speaker.motion system. All of the study participants also described ways in which they used the speaker.motion system to engage with the physical space in which they performed, which validates a key design goal of the system. Some composer comments related to this include:

I was able to aim the speakers specifically at the various reflective surfaces in the space. I also found that, by aiming at the more absorbent audience, I could affect timbral change.

By having two symmetrical pairs of rotating speaker, which rotated in different phases, some very interesting phasing effects were created (with the same source sent to each pair).

Five out of six composers also felt that the speaker.motion system drew their attention to spatial attributes as a listener or audience member.

The way composers used space as a compositional tool was much more evident then traditional speaker setups.

The visual coupling led me to consider their use of space more than with a traditional loudspeaker array.

The speakers were brought to life as a very important aspect of the composition, so was the space itself.

When given an opportunity to suggest changes to the system, all of the composers felt that they would like to see the system explored with larger loudspeakers; this is an avenue that will be explored in subsequent iterations. Many composers also suggested that they would like to see further dampening of the mechanical sounds created by the system, another aspect that is intended to be addressed in future versions of the system.

4. CONCLUSIONS

The field of new mechatronic instruments is continuing to grow and there is now more and more performances occurring where the performers are not always the instrument builders. In order to assess these new mechatronic instruments assessment techniques that differ to traditional musical assessment need to be developed so that it is the capabilities of the instrument and its affordance to be controlled expressively by a performer that is assessed rather then just the musical output. In order to effectively assess new instruments in these ways the approach must vary for each instrument however it is through ensuring the instrument is assessed both qualitatively and qualitatively that the instrument designer can gain a full picture not only of how the instrument functions and what it might be capable of achieving musically but also of how the new instrument might be actively used by composer and performers.

Having applied this assessment framework to the speaker.motion system the authors now intend to look at other mechatronic instruments that have been built by the community to apply further assessment techniques in order to approach their assessment from a holistic perspective to further encourage the use of new mechatronic instruments particularly by users outside of the community of instrument builders.

5. ACKOWLEDGEMENTS

The authors would like to thank Massey University College of Creative Arts and Victoria University of Wellington for their financial support of this research. Also Paul Teal, Jim Murphy, James McVay, Jason Edwards and Tim Exley for their technical support during the development of the speaker.motion system. Very special thanks also go to all the composers who participated in the user study and who continue to embrace the use of the speaker.motion system in their work.

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