THE GALLERY AS AN INSTRUMENT: USING REMOTE SENSING TECHNOLOGY TO INTERFACE WITH MUSICAL ROBOTICS

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ABSTRACT

This paper describes the study and use of proximity sensors as a method of control for musical robotic systems. Through the use of such sensors, installation viewers can interact with musical robotic systems in an organic, highly gestural manner. The non-synthetic nature of musical robot timbres is discussed, as are the highly specific options for sound spacialization in a musical robotic installation setting.

Throughout the paper, we describe the creation of a testbed-style installation called *Metal+Motors*. A variety of remote sensing options are presented, as well as reasons for our decision to use ultrasonic transducer rangefinders. Test results verifying the suitability of the ultrasonic rangefinders are shown, followed by an in-depth discussion of the spacialization and modes of interaction used in *Metal+Motors*. Finally, options for future work in the field of interaction with robotic musical systems in an installation context are presented.

1. INTRODUCTION

Modern widespread availability of remote sensing technologies allow for the creation of highly expressive musical environments. Using physical computing platforms and such devices as ultrasonic transducers, infrared sensors, and hall effect sensors, artists can explore the possibility of using audience and performer position to affect audiovisual elements of a work.

Remote sensing presents an interesting set of creative possibilities to artists who work in the domain of musical robotics. Through the use of the aforementioned sensing technologies, the artist can allow the installation viewer to directly interact with the mechatronic components of a robotic sculpture, opening up heretofore unexplored methods of human/robotic interaction. Viewers, for example, can experience their physical movements become translated in real time into timbres which morph as a result of the viewers' movements within a space. In this manner, then, the audience interacts with sensing technologies and musical robots to turn a gallery space into a single cohesive instrument: one played with the viewers' motions and projected throughout the space by the organic localization offered by mechatronic musical assemblies.

This paper explores a robotic sound art installation (entitled *Metal+Motors*) in which viewers interacted with musical robotics through physical motions which were collected via ultrasonic sensors. After a section focusing on the history of musical robotics and an examination of sound art as a potentially organic and immersive experience, the remote sensing technologies used in the aforementioned installation will be discussed, along with tests undertaken to determine a variety of sensors' suitability. Section 4 focuses on the localized and organic aspects of the soundscapes generated in Metal+Motors, as well as a detailed examination of the piece's methods of audience interaction. Finally, avenues for future work are discussed.

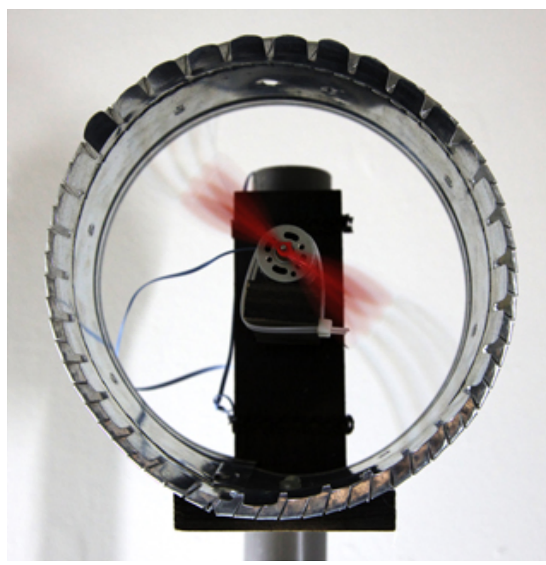

Figure 1. A Robotic Appendage from *Metal+Motors*

2. RELATED WORK

While there has been much work done on the musical potential of remote sensing technologies [1], the literature holds few examples of such technology being utilized in an installation environment involving musical robotics. The goal of the research undertaken in this paper was to combine the intense sonic localization possible with musical robotics with the spacial expressivity available through the use of remote sensors. The subsequent two subsections focus on the history of musical robotics and on remote sensing in interactive sound art.

2.1 A Very Brief History of Musical Robotics

Sound artist Trimpin is one of the early explorers in the field of both musical robotics and interactive kinetic art installation. Since the mid-1970's, Trimpin has created a diverse array of sonic artworks often based on found objects and surplus materials, often making use of novel forms of audience interaction [2]. Trimpin's work has provided an underlying current for much subsequent activity in the medium of musical robotics, and was a major inspiration for both the robotic and interactive components of *Metal+Motors*.

Other significant early workers in the field include Godfriend-Willem Raes [3], a builder of both installation-based and performance-oriented mechatronic sculptures, the California-based Survival Research Laboratories [4], and the group of robotics researchers at Waseda University [5]. Australia-born performance artist Stelarc [6] has explored noise-oriented kinetic sound art. Stelarc's installations and performances will be discussed in more detail in the next subsection. Recent workers in the field of musical robotics include the second author [7] and Gil Weinberg [8], both of who have engaged in extensive work on human-robot interaction and performance scenarios, New Zealand-based musician Greg Locke, and the New York-based installation and performance artist Eric Singer [9].

While all of the above have contributed greatly to the field of musical robotics, few have explicitly explored the potential for remote sensing technologies to be used as a means of controlling the spacialization of sounds generated by musical robotic assemblies.

2.2 Sound Art as an Immersive Experience

Kinetic installation art has a rich history of innovative systems of interaction, some of which were highly inspiring during the inception and execution of Metal+Motors. Performance and installation artist Stelarc [6], for example, makes extensive use of nontraditional methods of interaction with his artworks. In addition to electrodes and pressure sensors, he has explored computer vision technology to allow for remote audience interaction with his sculptures.

In a more traditional musical context, sculptor and instrument builder Patric Flanagan, creator of the JAZARI african robotic percussion ensemble, has made use of wireless accelerometers to enable highly gestural and unrestrictive control of his creations [10].

While many sound artists choose to focus on the use of loudspeakers, some eschew such techniques in favor of highly organic physical means of sound generation. Sound artist Zimoun, a key inspiration for Metal+Motors, makes use of highly dense clusters of actuators, solenoids, and other novel noisemaking devices [11]. Such arrays allow for unprecedented density in sound and specificity in spacialization, enabling audiences to become truly immersed in a soundfield.

The above are merely a few workers in the diverse field of interaction and spacialization, we have made an effort to draw upon their work to create a dynamic sculpture wherein the entire gallery space becomes a playable instrument featuring localized families of timbres.

3. REMOTE SENSING

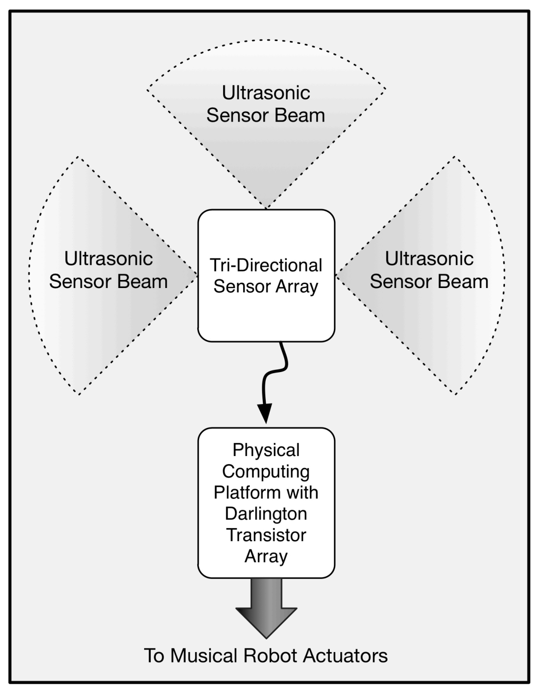

Figure 2. Remote Sensing Apparatus as used in *Metal+Motors*

3.1 Remote Sensing Technologies

In this context, the term “remote sensing technology” applies to non-contact sensors: sensors which don't involve a direct physical connection between user and sensor. We explored a variety of sensor technologies with a focus on photoresistors, infrared distance sensors, and ultrasonic transducer rangefinders. Photoresistors have a long history of use in musical interfaces: Geoff Rose's 1977 Laser Harp [12] and Szajner et Al's MIDI Laser Harp [13] date back to the early days of electronic musical interfaces and make use of photoresistors to detect the presence of absence of light.

More recently, Leila Hassan's Terminova [14] and Meason Wiley's MLGI [15] use modern analog to digital conversion technology to detect different levels of light reaching a photocell, allowing for variable control and proximity sensing. Photoresistors, though, were found to be highly susceptible to interference from ambient light sources and for this reason were determined to be unacceptable for use in a lighted gallery space.

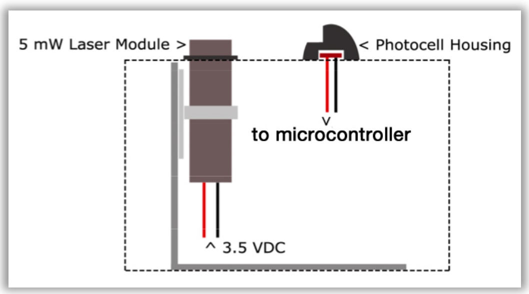

Figure 3. Laser Proximity Sensing using 5mW laser and photocell. Diagram courtesy of Meason Wiley.

While photoresistors are highly susceptible to visible light interference, infrared-based sensors behave much more predictably under normal lighting conditions. For this reason, we closely examined the possibility of using infrared sensors in the *Metal+Motors* installation (see section 3.3). Infrared sensors typically function by measuring beam angle as it is reflected off of an object.

A myriad of infrared sensors are available: many are manufactured by Sharp, including the popular GP line of sensors. Infrared sensors have found their way with much success into numerous mass-market musical instruments and interfaces including Roland's D-Beam. In academic circles, IR sensors have likewise found wide use: Ivan Franco's Airstick [16] and Chikashi Miyama's Peacock [17] both make use of arrays of IR sensors to provide non-contact interaction with musical systems.

Ultrasonic rangefinders were the third family of remote sensors closely examined for use in the *Metal+Motors* project. These sensors function by emitting a high frequency pulse and timing the duration between pulse emission and receipt of reflection signals. Like the aforementioned infrared rangefinders, these sensors are not susceptible to ambient light interference. Numerous models of ultrasonic rangefinders are available, including bare-bones transducers driven with user-built software from a parent microcontroller, surplus units salvaged from camera rangefinder equipment, and purpose-built modules complete with a dedicated microcontroller. Section 3.2 details the sensor test process and discusses our final sensor choices.

3.2 Sensor Tests

The use of non-contact sensors in a gallery environment presents a unique set of challenges compared to the above uses of such sensors in self-contained musical interfaces. Unlike the above interfaces, we were interested in receiving data over a much larger range: while Miyama's Peacock sensor, for example, is intended to pick up signals less than a meter from the emitters, we required much greater ranges on our sensors to permit gallery attendees to interact with the installation over ranges of more than three meters. In order to determine the suitability of sensors for use in the *Metal+Motors* installation, we began by examining manufacturer-provided datasheets to choose which sensors were worthy of closer study. Table 1 provides data for four such sensors.

Table 1. Exemplar Proximity Sensors

Sensor Name	**Sensor Type**	**Range**	**Linear**
GP2Y0A2YK0F	Infrared	1.52m	No
GP2Y0A21YK	Infrared	0.8m	No
Maxbotix LV-EZ0	Ultrasonic	6.45m	Yes
Maxbotix XL-EZ4	Ultrasonic	7.65m	Yes

The relatively short range and lack of linearity of infrared sensors quickly ruled them out: greater range and a more linear response curve were desired. While we experimented with applying a linearization transform function to the output values of an infrared sensor, the short range nonetheless resulted in our choosing to make use of ultrasonic rangefinder units in the *Metal+Motors* piece.

Price differences and differences in beam width led to our choice of the LV-EZ0 over Maxbotix’s XL-EZ4. To verify our decision to use the LV-EZ0, we conducted a range and data linearity test of the sensor. Table 2 illustrates the test results.

Table 2. Ultrasonic Sensor Output Compared to Measured Distances

Measured Distance	**Sensor Output Result**
100cm	95cm
200cm	191cm
250cm	252cm

As shown in Table 2, the measured distance differs slightly from the actual sensor output. In practice, though, the differences were felt to be negligible: high levels of precision were not required for the installation. Additional precision could possibly be obtained by sending data via serial or pulsewidth modulation rather than raw analog data: the analog data likely contains additional noise and jitter which would not be present in a serial signal transmitted from the LV-EZ0's onboard microcontroller.

3.3 Ultrasonic Sensor Placement

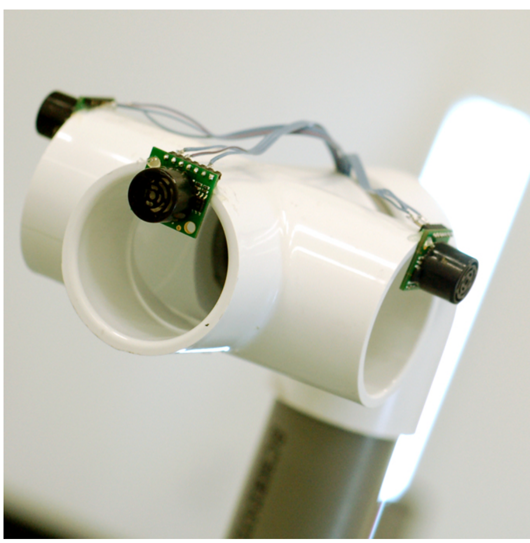

Figure 4. Tri-directional Ultrasonic Sensor placement

In order to allow viewers to more fully interact with the dimensionality of the gallery space, we decided to utilize a tri-directional sensor placement technique (see figure 2 and figure 3). Three sensors were placed at 90 degree angles to one another, each of which controlled a subset of robotic musical appendages. The wide-ranging area covered by the use of three sensors allowed for a deeply organic mode of interaction: once the three sensors were placed in the space, a large percentage of the gallery space became usable as a gestural performance space wherein audience members could convert their movements to real-world sounds created on the musical robot assemblies.

While we decided early on in the build process to utilize a three-sensor arrangement, we encountered technical issues specific to ultrasonic transducers: the use of multiple rangefinders resulted in interference as one rangefinder's pulse emission was picked up by another sensor. To overcome this, we made use of a feature on the LV-EZ series of sensors: multiple sensor units can be connected such that their pulses are emitted in a predictable manner and therefore do not produce interference with one another. Once the trio of sensors were connected in such a manner, the issue of interference vanished.

4. LOCALISED SOUND, INSTALLATION, AND VIEWER INTERACTION

4.1 Localised Sound Through Musical Robotics

The conceptual underpinning of the *Metal+Motors* installation was that of non-synthetic objects creating highly spacialised sound in response to audience interaction with non-tactile sensors. Robotic instruments by their nature allow for quite specific localization of sound: since the sounds are being physically produced in an organic, non-synthesized manner, each instrument's sounding body occupies a very real piece of physical space. Through creative placement within the gallery space, then, we were able to create a spatially diverse array of localized sounds.

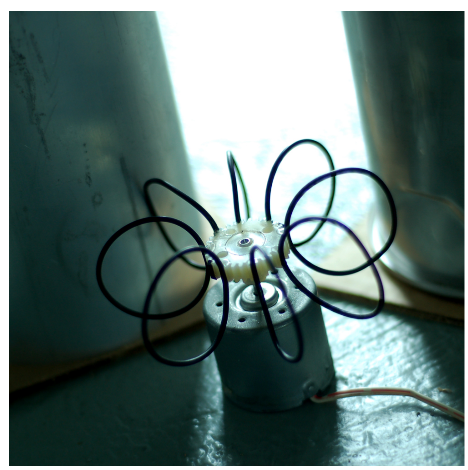

Figure 5. *Metal+Motors* consisted of a variety of DC motor actuators striking metallic objects in response to ultrasonic sensor data. Above is a DC motor bowing assembly shown striking two tuned metal pipes.

4.2 Installation and Interaction

Metal+Motors consisted of three zones of robotic instruments with each zone under the control of an ultrasonic rangefinder. The zones were spaced throughout the gallery, with each zone's corresponding sensor aligned in such a manner that a viewer interacting with a specific sensor would be affecting the zone's instruments in his or her field of vision. In this manner, then, three discrete zones of interaction were created: the gallery was not merely one instrument but rather three separate ones. Figure 2 illustrates the sensor arrangement and corresponding connection between the sensors, the microcontroller unit, and the robotic actuators.

The sensors were mapped into discrete zones: each zone was 100cm in depth and was connected to a variety of robotic arms. As audience members moved through the different zones on each sensor, the musical robots would produce differing sounds. Users were observed to quickly learn the different zones and become able to, in essence, play the sculpture by moving their bodies in and out of different detection zones. Through this mode of interaction, a wide variety of metallic and organic timbres were produced.

5. FUTURE WORK

While we were happy with the combination of the highly localized organic timbres and the deep level of audience interaction and expressivity obtained during the installation of *Metal+Motors*, much work remains to be done on the concept of using a gallery's space as an expressive instrument. While the use of non-contact sensors prevented any form of haptic feedback, we hope to explore such force feedback systems in future installations and performances. Haptics have the possibility of further immersing viewers and performers in musical robotic soundscapes and creating a deeper connection between performer and instrument.

Additionally, we plan on extending the concepts explored in *Metal+Motors* to the use of other non-synthetic objects such as wood, stone, and water as timbal sources. Finally, we intend to make use of the knowledge gained during the research and development of *Metal+Motors* to further enrich performance-oriented musical robotic scenarios, such as Kapur and Darling's Machine Orchestra.

6. CONCLUSION

Metal+Motors proved to be an excellent testing ground for proximity sensors in an installation context. We found ultrasonic transducers to be a highly satisfactory solution for detecting and tracking the position of installation viewers: their relatively long ranges and predictable response curves allowed us to map robotic programs to various points in their response zone. We feel that the non-synthetic sounds produced by physical objects being controlled in a deeply gestural manner led to the creation of interesting organic and metallic soundscapes which warrant much further exploration.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] Cook, P 2001. *Principles for Designing Computer Music Controllers* ACM CHI Workshop in New Interfaces for Musical Expression (NIME), Seattle, April 2001.

[2] Trimpin, *Portfolio*. Seattle, Washington. 2011.

[3] Raes, G. *Portfolio*. Flanders, Belgium. 2011.

[4] Survival Research Laboratories. *Survival Research Labs.* Website. Viewed 16 February 2011. <http://srl.org/petaluma/>

[5] Kato, I, et Al. *The Robot Musician 'WABOT-2.'* In Robotics, Volume 3, Issue 2, June 1987. Pages 143-155.

[6] Stelarc 2010. Keynote Speech International Conference on New Interfaces for Musical Expression. Sydney, Australia, June 2010.

[7] Kapur, A., *Digitizing North Indian Music: Preservation and Extension using Multimodal Sensor Systems, Machine Learning and Robotics*. VDM Verlag Dr. Muller, Germany, 2008.

[8] Weinberg, G., S. Driscoll, and T. Thatcher. *Jam'aa - A Middle Eastern Percussion Ensemble for Human and Robotic Players*. In *International Computer Music Conference*. 2006. New Orleans.

[9] Singer, E., et al. *LEMUR's Musical Robots*. In *International Conference on New Interfaces for Musical Expression*. 2004. Hamamatsu, Japan.

[10] Flanagan, P. *JAZARI*. Website. Viewed on 16 February 2011. <http://jazarimusic.com/>

[11] Zimoun. *Z I M O U N.* Website. Viewed on 16 February 2011. <http://zimoun.ch/>

[12] Laser Spectacles. *The Mysterious Laser Harp.* Website. Viewed on 17 February 2011. <www.laserspectacles.com/pages/harp.htm>

[13] The Laser Harp Pages. *The Midi Laser Harp.* Website. Viewed on 17 February 2011. <www.laserharp.org/readarticle.php?articleid=7>

[14] Hasan, L., Yu, N. and Paradiso, J., *The Termenova: A Hybrid Free-Gesture Interface*, Proceedings of the 2002 Conference on New Instruments for Musical Expression, Dublin, May 2002.

[15] Wiley, M., Kapur, A. *Multi-Laser Gestural Interface: Options for Cost-Effective and Open Source Controllers.* Proceedings of the 2009 Conference on New Instruments for Musical Expression, Pittsburgh, June 2009.

[16] Franco, I., *The Airstick: A Free-Gesture Controller Using Infrared Sensing*, Proceedings of the 2005 International Conference on New Interfaces for Musical Expression, Vancouver, May 2005.

[17] Chikashi, M, *Peacock: A Non-Haptic 3D Performance Interface*, Proceedings of the 2009 International Conference on New Interfaces for Musical Expression, Sydney, June 2010.