Music and Technology in Death and the Powers

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ABSTRACT

In composer Tod Machover's new opera *Death and the Powers*, the main character uploads his consciousness into an elaborate computer system to preserve his essence and agency after his corporeal death. Consequently, for much of the opera, the stage and the environment itself come alive as the main character. This creative need brings with it a host of technical challenges and opportunities. In order to satisfy the needs of this storyline, Machover's Opera of the Future group at the MIT Media Lab has developed a suite of new performance technologies, including robot characters, interactive performance capture systems, mapping systems for authoring interactive multimedia performances, new musical instruments, unique spatialized sound controls, and a unified control system for all these technological components. While developed for a particular theatrical production, many of the concepts and design procedures remain relevant to broader contexts including performance, robotics, and interaction design.

Keywords

opera, Death and the Powers, Tod Machover, gestural interfaces, Disembodied Performance, ambisonics

1. INTRODUCTION: DEATH AND THE POWERS

The new opera, *Death and the Powers* [2], by composer Tod Machover, brings numerous artistic and technological innovations to the stage. In this show, the main character is the rich, powerful inventor and businessman, Simon Powers. Simon finds that he is dying and thus seeks to extend his life, legacy, and ability to interact with the world by uploading his consciousness, memories, and essence into a computer system built into his house. Powers' transformation from human being into the pervasive "System" occurs at the end of the first scene in the opera. The other characters in the opera—Powers' third wife Evvy, his daughter Miranda, his research assistant Nicholas, and representatives from the world at large—must learn how to relate to Simon in his new form. They question whether he is still alive and still the same person, and finally decide whether they wish to come join him in "The System."

While this story and the theatrical production involve a significant amount of technology, we wanted the story to be the primary focus. The technology needed to be in service of the story, not the story in service of the technology. Additionally, the technology had to be considerate of the needs of live theater: it had to be flexible, be expressive, and facilitate creativity.

This opera was developed by Machover's Opera of the Future group at the MIT Media Lab in collaboration with experts from the worlds of theater and film, including theater and opera director Diane Paulus and production designer Alex McDowell. Machover and the Opera of the Future group (formerly Hyperinstruments) have extensive experience with creating large-scale musical performances that incorporate significant technological innovations, including *Valis* [10], *Brain Opera* [15], and *Toy Symphony* [9]. The authors are students working with Machover at the Media Lab and were responsible for significant technical contributions to *Death and the Powers*.

The premiere performances of *Death and the Powers* were in Monte Carlo, Monaco in September 2010, with additional performances in Boston in March 2011 and Chicago in April 2011.

2. CONTEXT: TECHNOLOGY IN THE OPERA

As computer-based technology is such a a significant part of daily experience, it is now not unusual to introduce cutting-edge technology into performance. In fact, theater and performance artists have often been early adaptors of technologies from electric lighting to the Internet to digital video [5]. Technology has also found a place in the relatively new performance form of opera. While music, dance, and theater have been practiced for millennia, opera has its roots in 16th Century Italy. In fact, opera can be seen as a fairly new model of performance, still developing and still free for experimentation and exploration. Opera is also conducive to the integration of new technologies due to its history of incorporating elements from a variety of other performance traditions, combining musical performances, narrative storylines, theatrical design elements such as costume and scenic design, and occasional dances. Thus, a variety of opera productions and new operas have also incorporated technological performance elements into the medium. For example, Tod Machover's *Valis* [10] used two early hyperinstruments to create the musical score, with computer-generated music extending the live performance of a digital piano and a percussion instrument. *Lost Highway*, an opera based on the film of the same name by David Lynch, uses intricate live and prerecorded video streams and a rich synthesized soundscape to translate a complex movie into a compelling live musical performance. This production was directed by Diane Paulus with video design by Philip Bussman [6]. *StarChild* (1996) is an example of a "multime-

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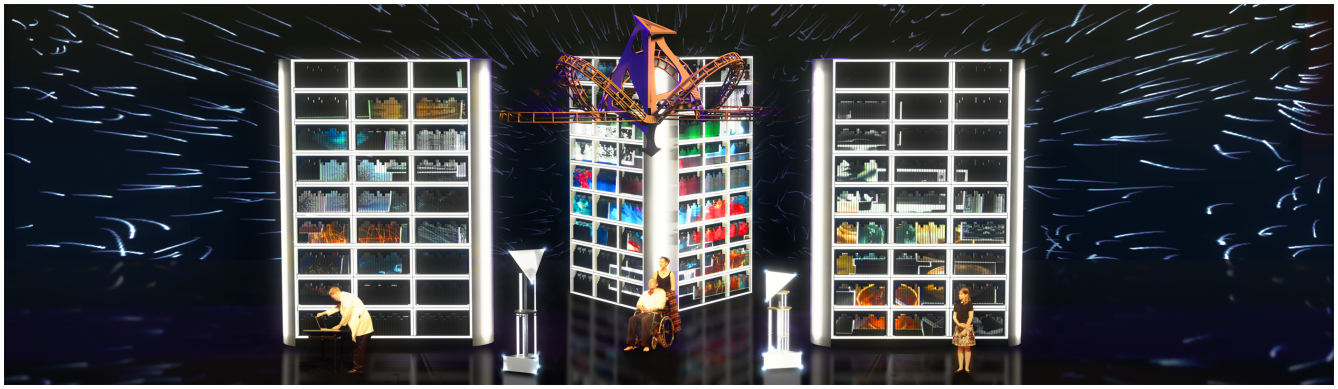

Figure 1: A rendering of the stage environment for *Death and the Powers*.

dia opera," incorporating surround-sound technology, planetary data sonification, and precise synchronization between a number of audio and video streams [12]. The Canadian director Robert Lepage has also brought interactive performance technologies into the world of opera, with works including his 2008 staging of Hector Berlioz's *La Damnation de Faust* for the Metropolitan Opera. This production used microphones to capture the pitch and amplitude of the performers' voices and the orchestra's music, as well as infrared lights and cameras to capture motion. The data from these sensors was used to shape projected images in real time, such as projected curtains waving behind dancers or giant projected flames that varied based on the singer's voice [14]. In contrast to many productions where single inputs are tied directly to independent outputs, we take a more abstracted approach to deriving expressive performance output from multiple live input streams. In examining the technology designed for *Death and the Powers*, it is also important to remember that most "high tech" theatrical performances simply use projection on screens and perhaps live camera feeds. If onstage performers' actions are measured, as in [4] and [14], that data typically is used to shape sound or visuals that share the stage with the measured performer. Additionally, theatrical technologies usually consist of discrete, disconnected systems. *Death and the Powers* features a distributed control system, an offstage performance translated into an expressive onstage presence, and a chorus of robotic characters. Through these elements and others, *Powers* extends the range of existing theatrical and operatic performance.

3. DISEMBODIED PERFORMANCE

One of the most unique theatrical challenges presented by the storyline of *Death and the Powers* is that, for the majority of the 90-minute opera, the main character is not represented by a physical actor onstage, but by the theatrical set. Powers' primary manifestation within the set takes the form of three fifteen-foot tall wall structures, or periaktoi. The structures can rotate and move freely about the stage. The walls represent book shelves and each book spine forms an LED display surface. The character of Simon Powers is expressed through a visual language created for this display surface, a language which develops and grows as Powers becomes more at home in The System.

A core performance issue is how to transform the character of Simon Powers from the physical form of our lead performer (James Maddalena in the premiere performances) into the theatrical environment. The stage must breathe, react, be emotionally expressive, and be as compelling as a human performer. One could have pre-recorded the singer's voice and have the behavior of the set and visuals on the stage be pre-scripted and triggered for separate scenes; however, we felt that it this would be constraining to the other performers and the orchestra and not expressive or conducive to the story or the performance. We determined it was a theatrical necessity to keep the power and presence of the singer's live performance, even though he would not be physically on the stage. Therefore, in our approach, the behavior of the scenic elements, including lighting, visuals, and robotics, are influenced in real time by the singer's performance.

Through a technique that we call Disembodied Performance, the singer's gestures, breath, and voice are observed and used to shape the output media on the stage in expressive and active ways. The Disembodied Performance System (DPS) consists of four separate layers: performance capture sensors (including both on-the-body sensors and audio sensors); data analysis software that transforms the raw data from performance capture system into meaningful abstractions; a mapping layer that relates the abstracted input parameters to parameters for output control; and an output layer, including visual, audio, and robotic elements, that shapes its behavior based on the control parameters. This system addresses a variety of questions about how to map a performance from one expressive modality, the human body, to a variety of other modalities, including non-anthropomorphic visual representations, lighting, movement, and sound [13].

3.1 Performance Capture and Analysis

3.1.1 Wearable Sensors

In order to measure the vitality and expressivity of a singer's physical performance, it was necessary to thoughtfully choose a set of performance capture sensors that would allow us to collect important features of the performance while not restricting the performer. We found that one of the key aspects of this physical presence is the performer's breath. The breath delivers information about musical phrasing, emotion, and a sense of life that would be evident to audiences watching the performer live on stage. Therefore, part of the sensor system includes a flexible band around the performer's chest that detects his inhalations and exhalations. The fabric band contains a stretch sensor located in a region of elastic fabric at the performer's back. As the performer inhales, his chest expands and therefore stretches the elastic region and the sensor. This simple sensor was found to detect information about the breath of the performer and his vocal phrasing that was more detailed than the information obtainable from audio or the score.

Accelerometers on the arms and the backs of the hands

are used to obtain information about the performer's gestures as he sings. Importantly, drawing on our group's background in Hyperinstrument design, we wanted to allow the singer to perform as he normally would onstage, with his training in how to use his body to convey a character's emotions. We thus chose not to capture specific gestures; more important was the overall character and expressive quality of his natural motion while singing expressively. We thus process the movement data into a set of higher-level parameters drawing on features of accelerometer data related to the quality of the movement (sharply changing, smooth, sudden, etc.). Such parameters are related to some of Rudolf Laban's qualities of movement, as discussed in the next subsection. All wearable sensors collect data with Funnel I/O microcontrollers and send that data wirelessly using the XBee protocol to external computers for analysis.

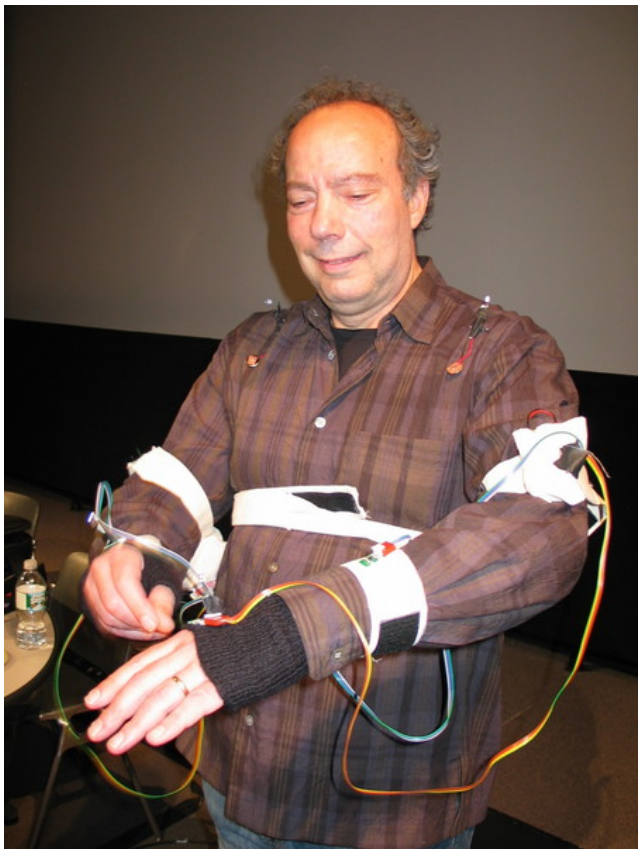

Figure 2: James Maddalena (Simon Powers) wearing prototype Disembodied Performance sensors.

3.1.2 Laban Effort Notation

In our analysis of movement data, we decided that the performer should not be required to use any particular movement vocabulary (essentially, his performance should not be choreographed); instead, the system should adapt to the performer's personal style of expression and augment his normal performance. We therefore chose to transform live movement data into information about the performer's emotionally-driven quality of movement.

We analyzed the qualities of movement using concepts borrowed Laban Effort Notion. Rudolf Laban held that the quality of any movement could be viewed as a point in a four-dimensional space, described by the four axes of Time, Weight, Space, and Flow [8]. The Time axis describes the speed at which a particular movement is being performed, from very fast and sudden to very slow and sustained. The Weight axis describes movement on a scale from firm to gentle. Firm movements are forceful, strong, resisting, heavy; gentle movements are relaxed, unresisting, light, weightless. Importantly for detecting this quality from sensor input, Weight is also a measurement of how much energy is being put into the movement. The third quality that Laban discusses is that of Space, which explores the way in which a movement travels through the space around the body, whether it moves directly or indirectly from one point to the next. Movement ranges on this axis from direct (moving in a straight line) to flexible (moving in curved, varying lines). The final quality of motion, Flow, is primarily descriptive of the amount of freedom of energy in a particular movement, reflecting how smoothly and continuously the movement is changing. This quality is on an axis from "fluid" movement to "bound" movement. In the Disembodied Performance System, immediate movement data and data trends are analyzed to locate the performer's movement in a three-dimensional quality space based on Laban's theories and defined by the axes of Time, Weight, and Flow, using techniques laid out in [7].

3.1.3 Vocal Processing

Additionally, vocal data from the performer was collected using microphones and used as input for audio processing. This vocal data, including both sung and spoken sounds, was analyzed for such audio parameters as amplitude, pitch, timbre, and purity of sound (consonance). These parameters, along with the parameters calculated from the breath data and movement quality analysis, are used as the inputs to the mapping system. In this way, the emotional content and quality of the actor's performance can be retained, but abstracted into a parameter space that is not tied to his physical body.

3.2 The DPS Mapping System

Interactive performances, where the live actions of a performer are captured by technology and used to shape visual, audio, or other aspects of a performance piece in real time, have a rich tradition in performance. In most interactive pieces, a pervasive and vitally important question is how the inputs from the live performance—sound, movement, location on stage, etc.—are mapped to parameters of the interactive output media. However, the systems that exist for creating these mappings are frequently limited by the small number of different mappings that can be created during the course of a particular piece, as well as by their focus on low-level sensor input rather than more meaningful abstractions of the input data. During our work on *Death and the Powers*, we developed a general-purpose mapping system to address these issues while additionally remaining sensitive to the needs of this particular piece and of the theater more broadly.

It was necessary for this mapping system to be very flexible and react appropriately to the fast-paced theatrical rehearsal process. The opera's systems are capable of creating an enormous variety of representations of Simon Powers; as those representations change from scene to scene and are developed during the course of rehearsals, the way that they are controlled by the live performance has to change as well. Additionally, the system needed to allow us to adjust the mappings between the live performance and the visuals immediately when given directions from the stage director Diane Paulus or visual notes from the production designer Alex McDowell, without having to stop the program or interactive output to make changes.

We developed a node-based flow interface that allows a user to create mappings by connecting streams of input

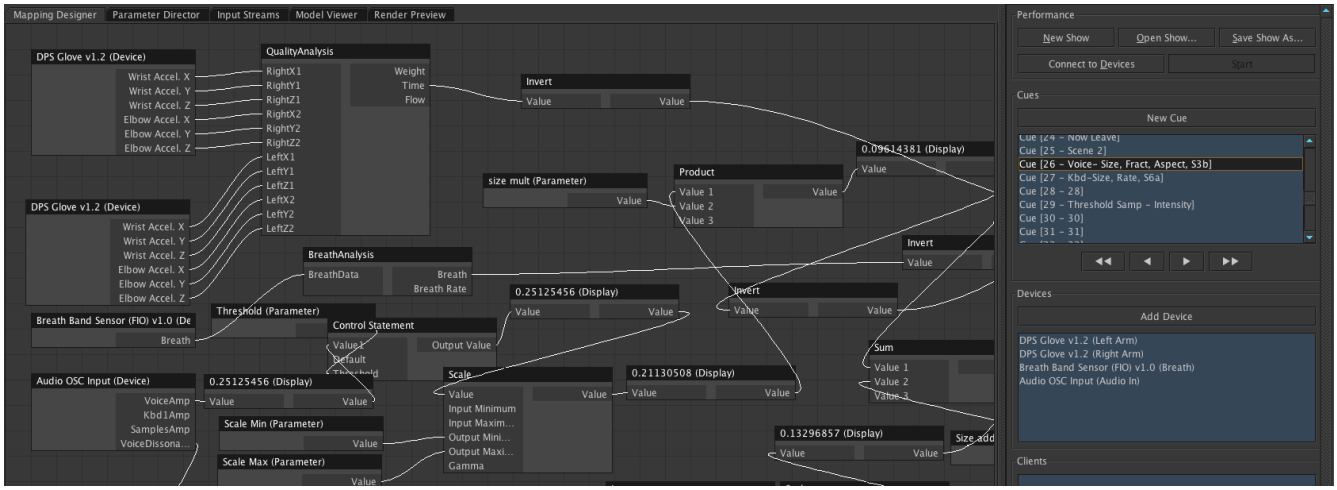

Figure 3: Mapping System screenshot.

data to outputs. Data analysis and arithmetic nodes allow for the creation of sophisticated transformations of performance data. All mappings can be manipulated and edited in real time. Each mapping between input and output data can be saved in a cue, allowing for mapping modes to be changed as needed during the performance. This mapping software, together with the performance capture sensors and a specially-designed visual display system, constitutes the Disembodied Performance System.

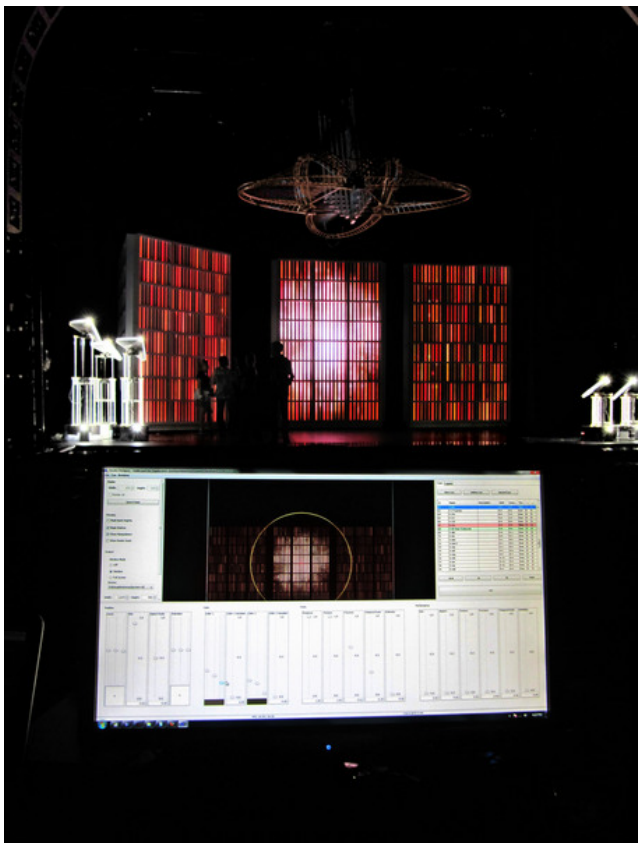

Figure 4: The Disembodied Performance System translates James Maddalena's performance into visuals on the walls.

3.3 The DPS Visualization System

As the primary representation of Simon Powers is through the visual displays on the three bookcase periaktoi, it was necessary to develop a system for creating visual content that could be not only shaped and developed with the production designer during the rehearsal process, but also modified in real time by live performance parameters. We accomplished this through the creation of a novel visual rendering system. This rendering software incorporates elements of a video compositing and animation environment, with the major organizing principle being the cue. Each cue can include compositions of procedural animation primitives, images, and pre-rendered video content. Additionally, triggering each cue puts the system into a particular mode where the live data from the performer procedurally shapes the generation of specific graphics and image. An operator can then mix the visual influence of the live performance on the preshaped cues using an Apple iPad during the performance. The result is a non-anthropomorphic manifestation of the actor's performance throughout the set.

4. OPERABOTS

Death and the Powers features two principal types of robots. The robots have multifaceted roles as set pieces, lighting elements, individual characters, and part of the manifestation of Simon Powers. The main periaktoi set pieces previously mentioned are three large robots. In addition to these robotic walls, the opera features nine smaller wireless Operabots, designed and fabricated at the MIT Media Lab. These robots, with triangular heads and bodies made of thin rods, can extend from four feet tall up to seven feet in height, have articulated heads, and use a holonomic omnidrive system that allows them to translate and rotate independently across the stage. Each Operabot has 11 expressive channels of LED lighting, including the bases, heads, and acrylic rods. The computational core of each of these robots is the small, efficient, and inexpensive One Laptop per Child XO computer.

In the context of the story, the Operabots serve as a Greek chorus, both characters in the action and commenting on it. In a prologue and epilogue, performed entirely by the robots, it is revealed that the robots habitually retell the story of Simon Powers, though they are still attempting to understand the idea of death. The Operabots also appear as figures throughout the main storyline.

As these robots play such major roles in the story, it was necessary to create a system for choreographing their

Figure 5: The nine members of the Chorus of Operabots.

behavior and movement that could allow the robots' performance to be shaped and developed along with the human performers during the rehearsal process. As Diane Paulus and choreographer Karole Armitage created choreography on robots, it was necessary for the robot system to quickly adapt to the demands of the moment and not limit the rehearsal process. The robots needed to be as flexible as the human performers. In order to accomplish this, we developed a new type of automation and control system specifically for theatrical robotics. The system combines timeline playback and parameter curves, familiar from typical animation software programs, with cuing, autonomous operation, procedural behaviors, and live control from a multitude of sources. This system has proven effective in choreographing the fast and complex Operabot movements and lighting, as well as the graceful repositioning of the three wall structures. Additionally, operators can assume control over any robot at any time, overriding any of its programmed behaviors. A 3D graphical simulation module in the choreographic software is included for assistance not only with monitoring the system during live control scenarios, but also to allow for offline programming and choreographing without needing to use the physical robots [11].

An ultra-wideband RFID absolute positioning system encompassing the stage tracks the location of operabots, walls, and singers, and communicates position information to each of the robots. This allows the robots to autonomously navigate along a predetermined trajectory and avoid each other and actors onstage, ensuring safe and robust operation. The nine Operabots may also be puppeteered as needed by operators situated above the stage, using commercially available video game controllers.

5. AUDIO SYSTEM

Death and the Powers is performed by a small ensemble with lightly amplified voices and accompanied by a 15-piece orchestra and electronic sound. To locate Simon Powers in The System, this production relies on sonic transformations in addition to visual transformations. To help express Powers' new omnipresence, his voice must be able to appear from anywhere, shifting location from moment to moment. The audio infrastructure to support this movement is quite extensive, utilizing two formats of surround sound, real-time performance control and several custom effects engines; all with the goal of achieving a smooth continuum ranging from acoustic to amplified textures. The large dynamic range in the audio system allows the most basic characteristics of the sound to follow Simon's emotions very closely.

5.1 Architecture

The heart of the *Death and the Powers* audio system is a digital signal processing (DSP) engine based on CoreAudio AudioUnits plugins running inside Digital Performer 7. This engine performs processing on the production's 350 audio inputs and 250 audio outputs. Custom plug-ins implement 3rd order ambisonic encoding and decoding and wave field synthesis (WFS) encoding and decoding. All DSP systems connect via three 64 channel bi-directional MADI fibre optic trunks to a Studer Vista 5SR mixing console, where the production is mixed on 12 VCAs. Each of the Duran Audio Axys loudspeakers in the front Left-Center-Right audio system runs additional DSP internally to manage crossovers, system-wide equalization and time alignment.

5.2 Localization Techniques

Death and the Powers uses two methods for localizing sound: ambisonics and WFS. The ambisonic system reproduces a consistent 3-dimensional sound-field over a large range of venues and speaker configurations. It is used to move voices and orchestral textures around the perimeter of the audience. The WFS system generates a wave-front where the origin of the wave is a location on stage. The WFS system is used with the tracking system to provide realistic reinforcement of the voices and robots. Natural amplification radiates from the location of the performers, instead of the WFS speaker array located along the front of the stage.

5.3 Seating Zones

Surround sound is an essential part of *Death and the Powers*, so it is critical for the entire audience to experience it. This presents a challenge in theaters where seating areas may be acoustically isolated (i.e. upper balcony or box seats). In this case, it is necessary to have a speaker system for each acoustic zone. In *Death and the Powers*, each zone contains a small surround sound system as well as supplementary front speakers. The system's DSP is tailored for the size and shape of the zone through the weighting of harmonic orders for the ambisonic decoders on each output. This maintains apparent resolution of each zone's surround system. For the premiere performance, 143 unique speaker outputs were used.

5.4 Control

All routing of sources to speakers is managed intelligently by the DSP engine and controlled live by streaming Open Sound Control (OSC) protocol [3] messages from Apple iPads and from the same RFID tracking system that tracks the robots. The DSP system utilizes a central shared memory where coordinates and audio are made available to all encoders and decoders. A network daemon listens for OSC and writes DSP parameters to the shared memory. An external system accepts tracking, cuing and remote control data, smooths it and defines which data is forwarded to the DSP network daemon.

6. THE CHANDELIER

Another of Simon Powers' manifestations in his environment is through the form of the Chandelier, a large stringed set piece that serves as a lighting element and, in a romantic scene in the middle of the opera, a musical instrument. For the first several scenes of the opera, the chandelier remains aloft and unmoving over the stage. As Simon's wife Evvy attempts to communicate with her husband in his new form, Simon inhabits the Chandelier and descends to wrap around Evvy. As she touches the Chandelier, it reveals itself to be a musical instrument. The Chandelier's primary sound is a complex electronic mix created from Simon's voice. When

Evvy strokes and strums the Teflon strings of the Chandelier, she controls this rich sound - bringing it out, dampening it, as if she's physically touching and manipulating his voice. Additionally, when she plucks the strings, she adds more processed string-like sounds to the mix. Stretch sensors wrapped around the tops of the Chandelier's strings detect the vibrations of the strings as they are played, allowing the performer in the role of Evvy to interact in a highly physical and sensual manner with the instrument.

Figure 6: Patricia Risley as Evvy with the Chandelier.

7. UNIFIED CONTROL ARCHITECTURE

All of the elements of the theatrical set—from the movement or robotic elements, spatialized sound, lighting, and visuals—must act in synchrony if they are to provide a consistent impression of a single expressive character. To accomplish this, the distributed show control systems are networked and interact by sharing data and interfacing with traditional theatrical controls. Data is exchanged over a common IP-based network infrastructure using OSC so that any system can respond to input from any other. Our protocol borrows from MIDI Show Control for cue-based and timeline navigation, as well as the Architecture for Control Networks (ACN) protocol [1]. Although robust ACN implementation was not readily available at the time we began creating the control systems for *Powers*, we did implement an ACN-inspired form of device description language and autodiscovery. Using OSC also meant that our novel systems could immediately exchange data with off-the-shelf audio software suites used in the production as well as user interfaces such as TouchOSC for the iPad. Additionally, the ranges of all data and control instructions are normalized into a range from -1.0 to 1.0 so the systems can logically communicate. With this system, gestures can be created across media: the sound of Powers' voice can match the movement of a visualization on the walls, or a robot's lighting can be driven by a performer's voice. The individual systems can be treated as parts of an artistic whole.

8. FUTURE DIRECTIONS

The technologies developed for and used in *Death and the Powers* have been designed so that they can be generalized for other performance contexts as well. The mapping system designed as part of the Disembodied Performance System can easily be adapted to allow the rapid development of mappings between any performance inputs and any control parameters for interactive systems. In fact, the Disembodied Performance mapping system has already been used in a piece for solo cello written by Tod Machover. In this work, "Spheres and Splinters", the sound of the cello and various properties of the cellist's bowing are used as inputs to the mapping system, which transforms those inputs into control of sonic transformations applied to the cello, and movement of sound in an ambisonic setup.

Additionally, many of the concepts and software systems developed for the opera are applicable for fields such as remote presence, storytelling, personal expression, and robotic control. For example, remote presence tools could be greatly enhanced the ability to capture emotional information about a person's movement and transform that to a set of expressive parameters for visual control. With tools such as those developed for *Death and the Powers*, subtleties and evocative details of physical movement can be used to create even richer interactions, performances, stories, and experiences: experiences that use and benefit from digital technology, but which are still inexorably linked to very human stories.

9. ACKNOWLEDGMENTS

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