MARIE: Monochord-Aerophone Robotic Instrument Ensemble

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ABSTRACT
The Modular Electro-Acoustic Robotic Instrument System (MEARIS) represents a new type of hybrid electroacoustic-electromechanical instrument model. Monochord-Aerophone Robotic Instrument Ensemble (MARIE), the first realization of a MEARIS, is a set of interconnected monochord and cylindrical aerophone robotic musical instruments created by Expressive Machines Musical Instruments (EMMI). MARIE comprises one or more matched pairs of Automatic Monochord Instruments (AMI) and Cylindrical Aerophone Robotic Instruments (CARI). Each AMI and CARI is a self-contained, independently operable robotic instrument with an acoustic element, a control system that enables automated manipulation of this element, and an audio system that includes input and output transducers coupled to the acoustic element. Each AMI-CARI pair can also operate as an interconnected hybrid instrument, allowing for effects that have heretofore been the domain of physical modeling technologies, such as a "plucked air column" or "blown string." Since its creation, MARIE has toured widely, performed with dozens of human instrumentalists, and has been utilized by nine composers in the realization of more than twenty new musical works.

Author Keywords
musical robots, robotic musical instruments, plucked string instruments, aerophones, hybrid instruments

ACM Classification
H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.1 [Information Interfaces and Presentation] Multimedia Information Systems.

1. INTRODUCTION
The Modular Electro-Acoustic Robotic Instrument System (MEARIS) represents a new type of hybrid electroacoustic-electromechanical instrument model in which individual robotic musical instruments can function as tunable acoustic filters in an interconnected multi-module signal chain. Monochord-Aerophone Robotic Instrument Ensemble (MARIE), the first realization of a MEARIS, comprises one or more matched pairs of Automatic Monochord Instruments (AMI) and Cylindrical Aerophone Robotic Instruments (CARI). In designing MARIE, we employed the MEARIS paradigm to create an ensemble of versatile robotic musical instruments with maximal registral, timbral, and expressive ranges that are portable, reliable, and user-friendly for touring musicians.

MARIE was commissioned in 2010 by bassoonist Dana Jessen and saxophonist Michael Straus of the Electro Acoustic Reed (EAR) Duo, and designed and built by Expressive Machines Musical instruments (EMMI)[1] for a set of tours through the US and Europe. The first prototype of the instrument was created in early 2011 [5], and has since been field tested and refined through many performances with the EAR Duo (Figure 1) and numerous other composers and performers.

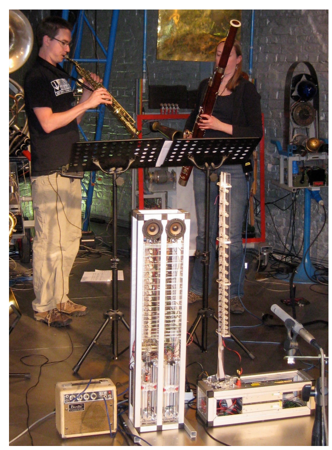

Figure 1. EAR Duo performs with MARIE at the Logos Foundation in Ghent, Belgium.

2. RELATED WORK
The contemporary field of musical robotics spans a wide range of research and creative activities [6]. Within this diverse field, we can distinguish between 1) *emulative* machines that help researchers better understand and/or replicate human performers, and 2) *inventive* machines developed by composer-builders seeking new vehicles for musical expression. EMMI's work is largely focused on this second category.

Numerous existing robotic instruments influenced MARIE's design, including those created by Trimpin, Roland Olbeter, Eric Singer, and most significantly, Godfried-Willem Raes. In addition to musical robotics, MARIE is influenced by the parallel field of active control of acoustic musical instruments, as described by Berdahl, Niemeyer, and Smith at CCRMA [1].

[1] www.expressivemachines.com

AMI was conceived as an updated version of EMMI's first robotic string instrument, PAM (Poly-tangent Automatic multi-Monochord), which itself was influenced by LEMUR's GuitarBot [14], Trimpin's Jackbox [6], and Raes' <Hurdy> [11]. AMI's updated features also draw upon ideas from Roland Olbeter's Fast Blue Air [10] and Raes' <Aeio> [7]. James McVay's MechBass [8] as well as Raes' <SynchroChord> and <Zi> [11] are notable robotic string instruments that have been created between the development of our initial prototype (early 2011) and the present.

CARI builds upon a number of robotic aerophones that have previously been developed for both research and creative purposes. Instruments such as the WF-4RV flutist and WAS-1 saxophonist robots of Waseda University's Takanishi Lab [15, 16]; Roger Dannenberg's robotic bagpipe player McBlare [3]; and the robotic clarinet created by NICTA and UNSW's Music Acoustics Laboratory [13] have been inspired by human performance models and thus exemplify the *emulative* category described above. Though these instruments helped shape our approach, CARI is primarily influenced by the numerous *inventive* monophonic aerophones developed by Raes including <AutoSax>, <Korn>, and <Ob> [7]. Since the creation of the first CARI prototype in 2011, Raes has developed several other related aerophone instruments, including his automated clarinet <Klar> [11]. His electroacoustic organ <Hybr> [12] shares acoustic features with CARI as both are cylindrical air columns set into resonance by an audio-rate driver.

3. CONCEPTUAL ORIGINS OF MARIE: THE MEARIS PARADIGM

3.1 Inspiration

The MEARIS concept was inspired by Raes' automated monophonic aerophone instruments, which operate as automatically tunable acoustic filters. While the vast majority of prior robotic instruments focus upon note actuation (i.e., act as impulse generators), the electromechanical control systems of Raes' aerophones alter the acoustic resonances, which shape the source sounds over time. With the MEARIS paradigm, we seek to expand upon this work in order to further explore the expressive possibilities enabled by connecting robotic impulse and filtering "modules" in a variety of ways, as one would do with a modular synthesizer.

3.2 Elements of a MEARIS

Figure 2 displays the basic elements of a MEARIS module. At the center of the module is an acoustic element: a resonant body (vibrating string, air column, membrane, etc.) that is activated, modified, and sensed by the control and audio systems. The control system communicates via the MIDI protocol and drives automated mechanisms that excite or alter the acoustic element. The audio system uses input transducers to force the acoustic element into resonance, and output transducers to capture the vibrations of the resonant body. The audio system can also include automated mixing circuitry and onboard analog or digital effects. Signals can be routed from one MEARIS module to another to create rich hybrid instrumental timbres. To make the sound producing/altering gestures as visually salient as possible, instruments' actions are amplified through cameras and projection, as well as through onboard lighting displays that illuminate form and action.

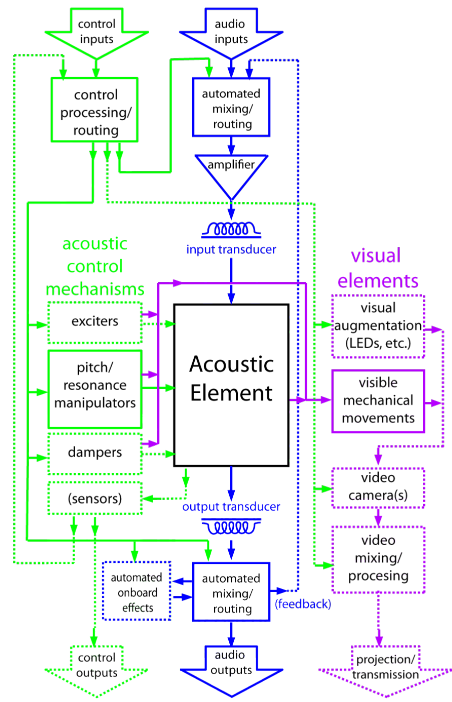

Figure 2. Funtional diagram of a MEARIS, with acoustic element (center), control system (green), audio system (blue), and visual elements (purple).

4. MARIE DESIGN

MARIE represents the first realization of a MEARIS. Each of MARIE's modules (each AMI and each CARI) contains a resonant acoustic element that can function as a filter and a control system with automated electromechanical actuators that excite, tune, and dampen this acoustic element. Each module also features an audio system with input and output transducers and automated input and output matrices.

4.1 Instruments

4.1.1 AMI

AMI is a robotic monochord instrument with automated mechanisms to articulate the string and alter its vibrating length; an electromagnetic bowing mechanism (input transducer); a pickup (output transducer); automated analog mixing and effects circuitry; and programmable LED display. AMI's acoustic element is an electric guitar string that is manually tunable with a standard guitar tuning machine. Produced sound is transduced by a flexible contact microphone and sent to either an on-board or an external amplifier/speaker. The frame is divided vertically into two equal halves, each of which can house a single instance of AMI. Figure 3 diagrams AMI's acoustic, control, audio, and visual elements.

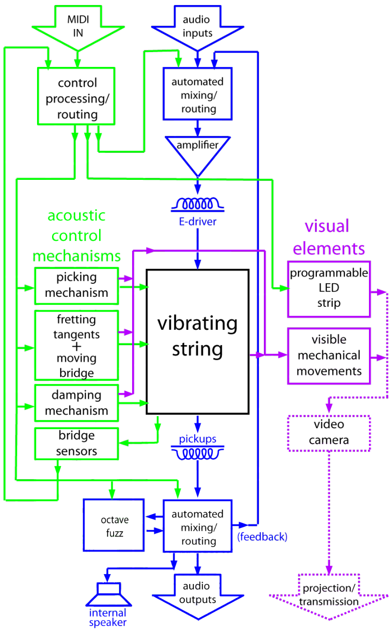

Figure 3. Functional diagram of AMI.

4.1.2 CARI

CARI is a cylindrical aerophone modeled on the clarinet. Rather than retrofitting an existing acoustic instrument, we re-imagined the instrument itself. Because an automatic instrument does not need to accommodate the hands of human performers, the encumbrances of traditional keying mechanisms can be avoided. As a result, CARI's 19 toneholes are arranged linearly. Each tonehole is independently operable via a solenoid-driven keying valve. Sound is produced by an audio signal routed to the compression driver, which is directly coupled to the cylindrical air column. Figure 4 diagrams CARI's acoustic, control, audio, and visual elements.

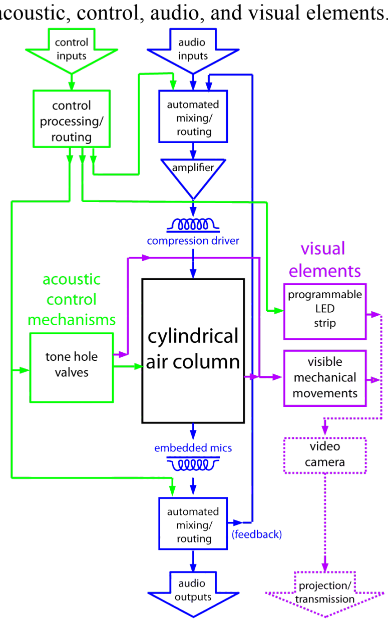

Figure 4. Functional diagram of CARI.

4.2 Control Systems

AMI's acoustic control system includes mechanisms to pick and damp the string. AMI's 17 solenoid driven tangents are positioned at fixed equal tempered half step intervals, giving a range of pitches from E2-A3. The tangents can be used to articulate notes without picking (hammer-ons). Varying the duty cycles of trills and tremolos of tangents above 20Hz produces timbral shifts. The tangents operate in conjunction with a moving bridge to allow both discrete and continuous control of string length.

CARI is outfitted with 19 solenoids that change the length of the air column by opening and closing toneholes. These actuators can achieve trills and tremolos up to 55 Hz. In addition, thousands of "fingering" configurations are possible, many of which would be inaccessible to a human performer on a standard clarinet.

4.3 Audio Systems

4.3.1 Input and Output Transducers

AMI and CARI's acoustic elements can be utilized as automatically tunable acoustic filters when driven by onboard audio-rate actuators. AMI's string can be excited via a custom-built electromagnetic "bowing" mechanism (E-driver) [11, 2, 4]. CARI's cylindrical air column can be excited by a compression driver to which it is coupled. In typical usage scenarios, an input audio signal will be tuned to match resonant frequencies of the acoustic element, which are manipulated by AMI and CARI's pitch control mechanisms. By tuning an input signal to harmonics of a fundamental frequency (CARI's odd harmonics; both even and odd string harmonics on AMI), the instruments' ranges can be extended well above the fundamental frequencies, giving each instrument a range of more than five octaves.

4.3.2 Inter-instrument Connections

Interconnections between AMI and CARI (Figure 5) allow audio to be routed between the two instruments to create instrument hybridizations that have previously been accessible only in the virtual realm of physical modeling. For example, the plucked string sound from AMI can be used to drive CARI's air column, creating a "plucked air column." Conversely, sound from CARI's air column can be sent to AMI's E-Driver to create a "blown string."

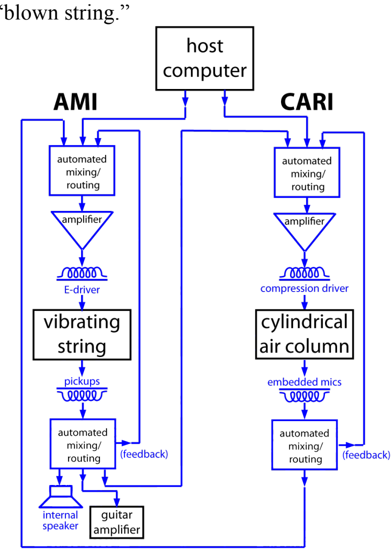

Figure 5. The interconnected audio systems of AMI and CARI that together constitute MARIE.

4.4 Software Control of MARIE

MARIE can be controlled by any software or hardware capable of generating audio signals and MIDI messages. However, in order to access the more sophisticated features of the instruments, we have developed a control panel based in Cycling 74's Max environment. The Max MARIE Console centralizes control over the instruments' acoustic, audio, and visual systems and allows for automation of note generation and shaping, signal mixing and routing, and lighting functions. The panel manages the timing of various messages and simplifies complex control operations, such as generating the combination of MIDI messages and audio signal modulations necessary to produce a note on CARI.

5. MUSICAL EXPLORATIONS OF MARIE

EMMI is dedicated not only to the design and construction of novel robotic instruments, but also to composing music that takes full advantage of these instruments' capabilities. The authors, as well as several other composers, have created new pieces for MARIE that explore the specific features of this instrument.[2]

5.1 EMMI's Compositions for MARIE

In addition to hyper-virtuosic speed and rhythmic complexity, as displayed in *From Here to There* (Barton), *Push for Position* (Barton), and *Microbursts* (Kemper), MARIE is capable of dynamic and timbral control, intra- and inter-instrument feedback, and the decoupling of sound source and resonator. These new possibilities have been explored in *In Illo Tempore* (Kemper), *MARIE Explorations* (EMMI) and *Phantom Variations* (Rogers). Rogers' *Improvisation X* series unifies all of the performance concepts described here as an interactive framework for real-time free improvisation with human performers.

5.2 SMC 2012 Curated Concert

One indicator of an instrument's successful design is the ability for other musicians to be creative with it. EMMI achieved this milestone in 2012, hosting a curated concert of new pieces for MARIE and Transportable Automatic Percussion Instrument (TAPI) for the 2012 Sound and Music Computing conference in Copenhagen [17]. Composers from the U.S., Canada, and the U.K. were invited to write new pieces for MARIE. The resulting works utilized a variety of software systems and consisted of acoustic instruments and MARIE (*Nebula Squeeze*—Lane), interactive systems (*Untitled*—Trail, *Détente*—Miller), and algorithmic systems (*Coming Together:EMMI*—Eigenfeldt, *Blues for Nancarrow*—Collins).

6. FUTURE DIRECTIONS

Given MARIE's immense parameter space, along with its status as an actively touring instrument, some of the original design concepts have yet to be fully implemented and explored, including the moving bridge, digitally controlled on-board effects circuitry, and on-board video. We continue to optimize and improve upon AMI's pickup and picking mechanisms, and may incorporate additional features such as automated string tuning in future iterations [9].

7. ACKNOWLEDGMENTS

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Video of MARIE: https://youtu.be/KOIUvFIPfts