The Machine Lab: A Modern Classroom to Teach Mechatronic Music

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ABSTRACT

This paper presents the Machine Lab, at the California Institute of the Arts, as a novel modern classroom for the instruction of mechatronic music. A unique curriculum consisting of classes in composition, music theory, musicianship skills, electrical engineering, programming, and mechatronic construction provide students with the skills needed to compose new music for the permanent ensemble of mechatronic instruments in the Machine Lab, as well as build mechatronic instruments of their own design. The Machine Lab acts as the central hub for both the Music Technology department and Digital Arts minor. The instructor and student expertise are augmented with the guidance and mentorship of permanent guest artists who create an unrivaled environment for the creation of both new mechatronic robotic instruments and compositions written for those instruments.

1. INTRODUCTION

In the 21st century, there has been a steady increase in the adoption of mechatronic systems for musical performance [1–4]. With the rise of the easy to learn, open source, Arduino microcontroller platform, released in 2005, the world of physical computing and mechatronics became vastly more accessible [5, 6]. Additionally, the Maker Movement, and the revitalization of STE(A)M education, has fueled interest in robotics and mechatronics in educational institutions all around the world [7–9]. Concurrently, the consumerization of industrial fabrication techniques bringing about the availability of modern additive and subtractive fabrication, has made these technologies increasingly common in art and music schools [10–12]. What does this all mean to the composer and the music technologist?

The educational needs for the modern music technologist has drastically changed over the past few decades. Among the traditional skills required by the field of study, Music Technology is increasingly an interdisciplinary industry and graduates are expected to command skills such as: programming, interface design, digital signal processing, electrical engineering, and mechanical engineering. To accommodate this newfound need, these topics are becoming increasingly common in music schools and mechatronic music is emerging in computer music curricula around the world [13, 14].

In this paper, the mechatronic music education curriculum at the California Institute of the Arts (CalArts) is discussed. The Machine Lab is then presented as the central hub for the Music Technology program and the creation of new mechatronic compositions and instruments. Next, the visiting artist program maintained by the department is presented as a driving force for inspiring students and faculty alike. Lastly, difficulties of running this program and maintaining the Machine Lab instruments are discussed.

2. MECHATRONIC MUSIC CURRICULUM

This section discusses the curriculum for teaching mechatronic music at CalArts. The overall course track for Music Technology students at CalArts is outlined, the Composing for Robots and Mechatronic Arts class structures are discussed, and lastly, opportunities available to students after they finish the standard curriculum are presented.

2.1 Curriculum Architecture

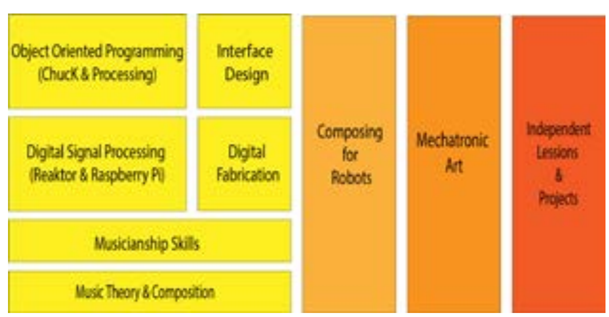

Figure 1: Curriculum Architecture for the Music Technology department at CalArts.

Students in the Music Technology department are required to exhibit competency in programming, physical computing, electrical engineering, mechanical engineering, and a variety of fabrication techniques. As members of the School of Music, they are additionally required to master musicianship, performance, rhythmic, compositional, and music theory skills. During the first half of their studies, students learn object oriented programming through the ChucK[1][15] and Processing[2] [16] languages. They learn musicianship skills, music theory, and composition in a variety of courses required by all graduates of the music school.

After building a foundation in programming, composition, and music theory, students are introduced to rapid prototyping techniques, physical computing, and electrical engineering through the Interface Design and Digital Fabrication classes. Next, in the Composing for Robots class, students are taught how to compose new music for mechatronic instruments. In Mechatronic Art, the class builds a new mechatronic instrument. Advanced students are encouraged to propose independent study projects to develop their own mechatronic compositions or build mechatronic instruments of their own design with one-on-one guidance from a mentor.

2.2 Composing for Robots

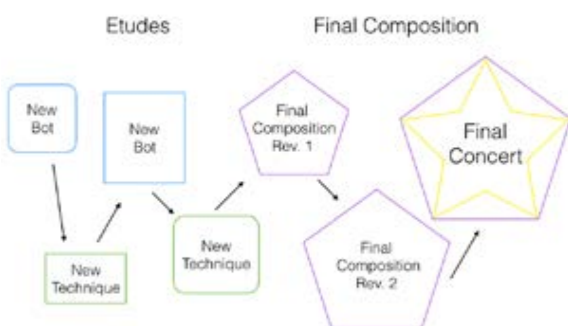

Figure 2: Composing for Robots assignment progression.

Composing for Robots is a course concerned with writing new music for the mechatronic instruments residing in the Machine Lab. During the first two thirds of the class, students compose weekly etudes that 'unlock' a newly introduced robot, compositional approach, or mechatronic extended technique. Students are not allowed to go ahead and are only permitted to utilize techniques and instruments that have been formally introduced. Students familiarize themselves with the technical aspects of performing with mechatronics with the focused bite-sized assignments. This allows the class to address questions such as:

- How is composing for mechatronic instruments different than composing for humans?
- What are the limitations and affordances of each instrument?
- How do we compositionally embrace these instruments and leverage their individual traits?

In the second section of the class, students are broken into groups to develop a single final composition for the end-of-semester capstone concert. The groups of students learn how to perform within a human-mechatronic ensemble and are required to write a composition that is at least three minutes long. This portion of the class focuses on larger questions such as form, presentation, and aesthetics.

2.3 Mechatronic Art

In the Mechatronic Art class, students, faculty, and guest artists work together to build a new, fully functioning, mechatronic instrument for the Machine Lab. The instruments created in the class abide by the following design constraints:

- Affordability
- Feasibility
- Uniqueness

The project has limited funds and students are required to design and build the instrument economically, a typical real world scenario. Additionally, it is important that the scope of the project reflects the number of students in the class and the caliber of the of students. The instrument must be fully functional at the end of the semester for a capstone concert or installation and the technical and physical scale of the instrument must be minimalized to ensure success. With nine robots currently residing in the Machine Lab, it is important each new creation is novel, and provides something new to the compositional palette. This ensures both the faculty and students learn something new each year and the program continues to address new challenges and ideas in mechatronic music.

2.4 Independent Lessons/Projects

Figure 3: Examples of mechatronic instruments originating from independent study projects (top left clockwise): Eric Heep's *Animal;* Nathan Villicaña-Shaw's *Hedonism Bot;* Carl Burgin's Relay Instrument 4

After completing the standard curriculum, students are free to partake in independent lessons to actuate their own mechatronic project. They work with a mentor to build a set of limitations and guidelines that cater to their individual interests and goals. The opportunity to freely explore under expert guidance helps students develop their own personal approach for integrating mechatronics into their musical or artistic practice (see figure 3).

[1] Available at chuck.stanford.edu (March 2017)
[2] Available at processing.org (March 2017)

3. THE MACHINE LAB

This section details the hardware, software, and resources available in the Machine Lab for teaching mechatronic music. The mechatronic instruments residing in the Machine Lab are introduced along with the network infrastructure. The section concludes with a brief overview of select digital teaching tools and resources available to both the students and instructors.

3.1 The Instruments

Figure 4: From bottom left clockwise: one of the 20 Clappers, BreakBot, MalletOTon, StringThing.

There are nine mechatronic musical instruments inhabiting the Machine Lab at CalArts. BreakBot is a hanging percussion instrument that features a kick drum, a crash cymbal, and a snare[3] [17]. Spread throughout the entire room, hidden in the ceiling grid, are twenty Clappers: each consisting of a single solenoid, with a blue LED inside of a ping-pong ball. MalletOTon is a mechatronic marimba that features 48 rotary solenoid actuated rubber headed mallets striking its keys [18]. StringThing is made up of three steel strings picked by DC motors with plectrum mechanisms as well as steel post dampener mechanisms activated by solenoids.

Figure 5: RattleTron on left, GanaPati on upper right, and MahaDevi on bottom right.

RattleTron is a percussion instrument that includes an assortment of hand percussion instruments along with three pipes struck with solenoids. MahaDeviBot is an Indian percussion robot that consists of a total of twelve solenoid actuators that strike frame drums, gongs, bells, wood blocks, and finger cymbals. GanaPatiBot is a percussion robot that features five plastic drums of various sizes each with multiple solenoid powered beaters.

Figure 6: From bottom left clockwise: Lydia, JackBox, and Tammy.

Lydia is a standup piano with twenty solenoids that strike the strings percussively, sixteen DC motors which ring the strings via custom rubber strikers, and a hacksaw which is sawing through a large steel bolt at the base of the instrument. JackBox is both a percussion and string instrument which features twelve guitar and bass strings, three cymbals, eleven German beer glasses, an eight key xylophone, and three plastic drums which are all activated using dozens of solenoids[4]. Tammy consists of six brass bells struck with steel posts and six custom cut wooden keys directly actuated by solenoid plungers [17].

Together the robots in the Machine Lab create an expressive, and varied, orchestra of mechatronic instruments that grant students great opportunity for installation, performance, and composition.

3.2 The Network

The server architecture connecting the mechatronic instruments in the Machine Lab with students, instructors and each other is discussed in the Server section. Next, student and instructor clients are presented. Lastly, the role of the network endpoints is discussed. To learn more about the evolution of the Machine Lab network look at [19] and [20].

[3] All are actuated with solenoid beaters. The crash symbol has two dampening mechanisms. The snare has a brush, which can be rubbed on the membrane, as well as a beater.

[4] The glasses, xylophone, cymbals and drums are directly struck by tubular push-pull solenoids. The guitar and bass strings each have their own picking mechanism, a string dampener, and five possible fret positions.

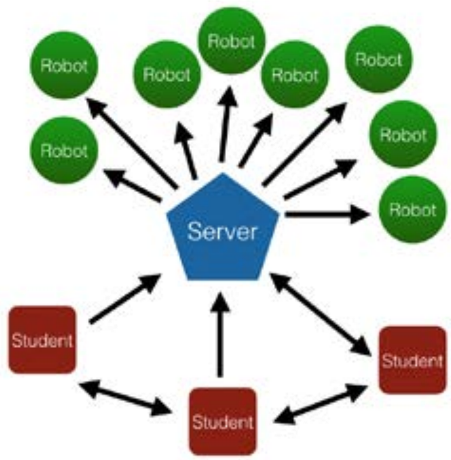

Figure 7: Machine Lab network architecture.

3.2.1 The Server
The Machine Lab has a dedicated server for networking the mechatronic instruments with student and instructor clients. The server is programmed in the ChucK language and is host to nine mechatronic instruments, as well as any number of student and instructor clients.

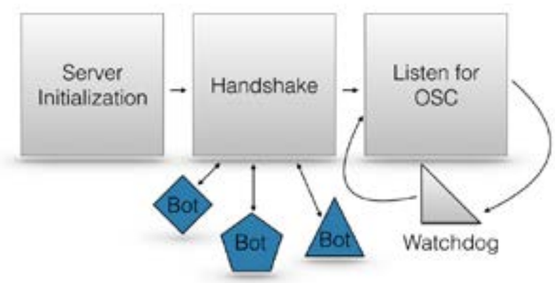

Figure 8: Machine Lab server initialization routine.

When the server is initialized, it launches a handshake routine that requests an identification number (ID) from each USB device connected to the server computer. Mechatronic instruments connected to the computer respond with their unique ID. The server uses this ID to assign a corresponding OSC address to the instrument's USB port number. After the initialization and handshake is complete, the server starts listening on the network. If the server recognizes a valid OSC address that also includes valid arguments, it proceeds to forward the message to the appropriate instrument using either serial or HIDUINO communication protocols [21]. This simple yet flexible system allows for the easy addition of any number of clients while also providing a standardization for interfacing with the instruments.

3.2.2 Clients

Students and instructors are able to join the dedicated network either wirelessly or directly via one of the many Ethernet jacks lining the Machine Lab's walls. Clients who wish to use MIDI for their command protocol are able to download the MIDI-to-OSC ChucK program provided by the department. The program automatically maps MIDI running through a virtual bus on the client's computer to OSC output the server expects. Consequently, students are able to control the Machine Lab's instruments with any environment that is capable of transmitting MIDI over a virtual bus, or OSC messages over a network. This gives composers the freedom to control the mechatronic instruments in whatever environment they are most creative[5].

3.2.3 Mechatronic Instrument Endpoints
Each of the mechatronic instruments are assigned an endpoint by the network during the handshake. The expected structure of a matching OSC message is standardized to be "/botname i,i" where "botname" is the name of the instrument, the first argument is an integer that corresponds to the actuator number on the instrument, and the second argument is an integer which corresponds to the velocity of the event.

3.3 Teaching Tools

A diverse code base of example compositions and extended techniques is maintained and available in the form of a GitHub repo[6]. There is a growing number of tutorials, starter code, etudes, and full compositions presented in a variety of programming languages and digital audio workstations. This corpus provides a valuable launching pad for students who are starting to write music for mechatronic instruments but are new to either programming or mechatronic composition.

4. VISITING ARTIST: THE TRIMPIN EFFECT

The CalArts Music Technology department builds longstanding relationships with experts in the field. Trimpin, one of these experts, has been visiting CalArts for over 10 years to advise, inspire, and mentor the construction of new mechatronic instruments both in and outside of the classroom.

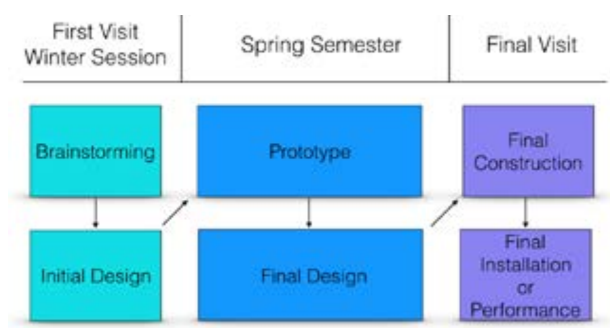

Figure 9: Trimpin visit schedule.

[5] In recent years, students have written compositions using ChucK, Processing, SuperCollider, Pure Data, Max-MSP, Ableton Live, ProTools, Python, and Reaktor.
[6] Available at https://github.com/MTIID/robots (March 2017)

4.1 Design Visit

Trimpin visits CalArts during the winter session in January for the design phase of the project. As someone who has dedicated his life to the creation of mechatronic and kinesthetic sound art, Trimpin's expert guidance, experience, and mastery inspires both students and faculty to push their creative and technical limits. During the design visit, he works with students to reach a general consensus on the design of the instrument. Trimpin's guidance of the initial design over the winter session allows the Mechatronic Art class, in the spring semester, to focus on the implementation and construction of the instrument.

4.2 Construction Visit

At the end of the spring semester, Trimpin returns to assist with the final instrument construction and the creation of an installation/performance featuring the instrument. Trimpin provides valuable critique as a successful large scale installation artist and mechatronic inventor [22]. He is able to provide a valuable real-world counter point from outside academia. His presence inspires, motivates, and encourages both students and facility to push the limits of creativity and innovation.

With the long standing relationship CalArts has built with Trimpin, each year the program tries to experiment with a new technique, challenge, and projects. We have standardized our parts, software, and process through Trimpin's guidance allowing us to push our creative and technical limits each year.

5. CHALLENGES AND EXPERIENCES

This section addresses the many challenges related to both maintaining the mechatronic instruments in the Machine Lab as well as the mechatronic music courses offered at CalArts. Issues related to instrument maintenance, software updates, hardware upgrades, power consumption, student expertise, and logistics are discussed.

5.1 Instruments Break

Mechatronic instruments require consistent maintenance to be kept in working condition. The specifics differ from instrument to instrument, but with no exception they all require attention at a steady interval. CalArts maintains at least one student Technical Assistant on payroll to conduct the required tightening, replacing, upgrading, and general maintenance the instruments require.

5.2 Technology Evolves Quickly

By nature, technology is constantly evolving: programming languages are updated, new algorithms are discovered, and new hardware is engineered. The Machine Lab and its tools require periodic updates and upgrades: the programming languages we use evolve, and our approach to hardware construction develops [23, 24]. As result, no two robots are technologically the same. This can be somewhat daunting and confusing for some students to learn the capabilities of each of the instruments. To combat this, retrofitting outdated and retired instruments with new circuit boards, firmware, and mechanics is a common summer project for current students and recent CalArts alumni.

5.3 Power

As the number of instruments increase over the years, the power requirements of the Machine Lab increases as well. When designing new instruments, it is important for the team to minimalize power consumption whenever possible and to be aware of the peak current draw of the system as a whole.

5.4 Student Expertise Evolve

Students come into the program with their own unique interests and throughout their studies develop those interests into skills through personal and class projects: such as the robots built in the Machine Lab. Once the student graduates, the expertise about the projects they developed vanish. Consequently, it is important to use similar skills, and approaches, when creating new instruments; we use the same software, libraries, hardware, boards, and maintain a consistent approach so there can be overlap from project to project, cohort to cohort.

5.5 Logistics

It can be difficult for students to find times when the Machine Lab is not in use. The Machine Lab is the hub for mechatronic music, the primary classroom for the Music Technology department, as well as the focal point for the Digital Arts Minor at CalArts and thus is constantly occupied by classes, tutoring sessions, and rehearsals. To compound this issue, the R.O.D. Concert Hall, a major performance space at CalArts, is constructed directly above the Machine Lab. When a performance is scheduled upstairs, students are unable to use the Machine Lab's mechatronic instruments due to noise contamination. All of these factors limit the amount of time students are able to secure to experiment with the instruments and develop their compositions.

6. CONCLUSION

The Machine Lab was presented as a modern classroom for teaching mechatronic music and building mechatronic instruments. An overview of the mechatronic music curriculum offered at CalArts was discussed. The Machine Lab was presented as a hub for community and the creation mechatronic music. Trimpin was discussed as a source for inspiration, motivation, and innovation throughout the process of designing and building mechatronic instruments.

6.1 Future

While the majority of the mechatronic instruments in the Machine Lab are in the percussion family, the department is diversifying the variety of instruments built. The near-future focus is to develop a modular infrastructure to support wind instruments.

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