MalletOTon and the Modulets: Modular and Extensible Musical Robots

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ABSTRACT

This paper presents two new musical robot systems and an accompanying driver electronics array. These systems are designed to allow for modular extensibility and ease of use with different instrument systems. The first system discussed is MalletOTon, a mechatronic mallet instrument player that may be re-configured to play a number of different instruments. Secondly, the Modulet mechatronic noisemakers are presented. These instruments are discrete modules that may be installed throughout a space in a wide variety of configurations. In addition to presenting the aforementioned new instruments, the Novalis system is shown. Novalis is an open-ended driver system for mechatronic instruments, designed to afford rapid deployment and modularity. Where prior mechatronic instruments are often purpose-built, the robots and robot electronics presented in this paper may be re-deployed in a wide-ranging, diverse manner. Taken as a whole, the design practices discussed in this paper go toward establishing a paradigm of modular and extensible mechatronic instrument development.

Author Keywords

NIME, musical robotics, mechatronic instrument

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, I.2.9 [Artificial Intelligence] Robotics—Operator interfaces, H.1.2. [Information Systems] User/Machine Systems.

1. INTRODUCTION

Many contemporary musical robots are highly integrated systems. These complicated mechatronic assemblages often feature device-specific electronics, a wide array of actuator types and drivers, and robot-unique communications schemes. While such device specificity can lend itself to intricate control and complex behavior, there exists a need for the opposite of this: a rapidly-deployable hardware interface allowing for flexible actuator placement. A modular approach to this problem has been taken in the research presented in this paper: each actuator module is connected to a driver module. The driver module features an integrated communication module, allowing a PC or other MIDI device to interface with the plug-and-play actuator modules.

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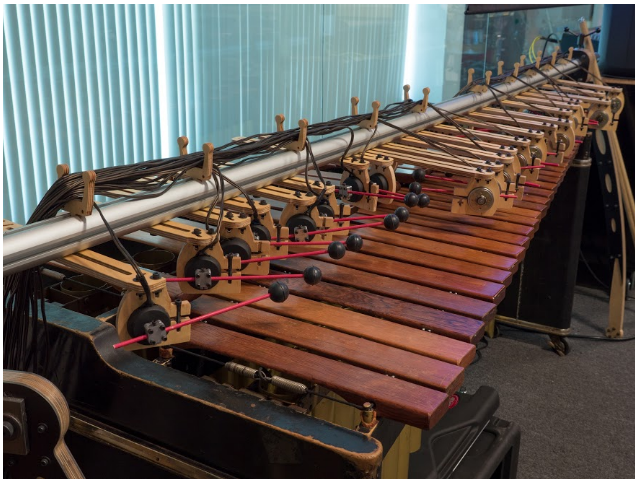

Figure 1: MalletOTon, a new modular and extensible mechatronic mallet instrument player.

The communications, power, and driver systems are integrated into a single rack-mountable module (called Novalis). Novalis can convert received commands from a host device into logic-level signals used to drive an array of power MOSFETs. Each MOSFET is connected to an output jack; actuator modules (solenoids, DC motors, or other similar actuators) can be driven connected to the output jacks.

As a demonstration of the Novalis, two new musical robot systems have been built. The Modulet system consists of an array of solenoid actuators, each in their own physical assembly. These may be placed throughout a location, turning the entire location into a spatialized meta-instrument. The second instrument, MalletOTon, is a mechatronically augmented marimba. It consists of an array of rotary solenoids attached to a framework. MalletOTon's solenoids are configured to strike a traditional marimba. Each solenoid is attached to an output jack on a Novalis interface. MalletO-

Ton may be rapidly reconfigured to play mallet instruments of different dimensions.

After a brief overview of other significant musical robotics ensembles designed with a modular intent, the hardware and firmware of the Novalis interface will be described in detail. Following an overview of Novalis, the Modulet system is presented. After this, MalletOTon's hardware, actuators, and software are described. The paper concludes with a discussion of the performance, installation, and educational possibilities of modular robotics systems, alongside details of future work.

2. OTHER MODULAR MUSICAL ROBOTS

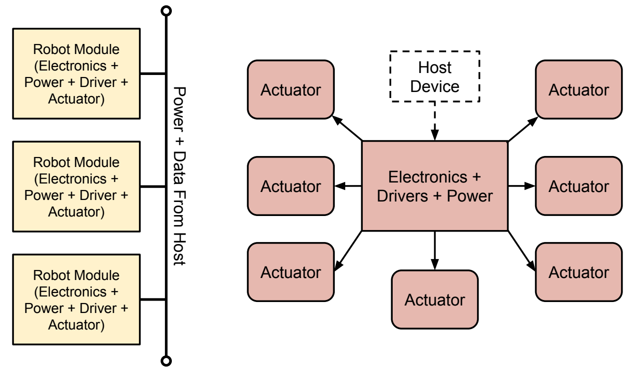

Figure 2: Modular musical robots: bus-style (left) and star topology (right).

While many musical robots are built with some degree of modular intent, this work focuses more on modular robotic systems. These systems are defined here as arrays of actuator modules which can be configured on the fly; the actuators are driven in turn by driver modules which can be connected as modules to a master device. Thus, while systems such as those in [11] and [10] likely contain modular elements, the works discussed here are focused not only on modular actuators or electronics but on systems that use their modularity to afford rapid reconfiguration and extension. The following subsections focus on such systems: first on those using a MIDI bus topology and next on those using a star network topology with a single MIDI client at its center.

2.1 MIDI Bus Modular Musical Robots

A MIDI bus, as illustrated in Figure 2, allows for a series of potentially dissimilar musical robot modules to be plugged into the same network. Many robot builders choose this approach for modular systems: Many of sound artist Trimpin's sculptures (discussed in [2] and [7]) as well as many of the LEMUR robots built by artist Eric Singer (such as the Guitarbot [8] and [9]) use this approach.

While such bus-based topology allows for rapid additions to the musical robot, it has one primary drawback: complicated electronics requirements. Each added element needs not only its actuators, but also an accompanying MIDI-capable controller. Further, MIDI's limitations place an upper limit on the number of modules able to be added.

2.2 Star Topology Modular Musical Robots

A star topology modular musical robot (as defined here and illustrated in Figure 2) uses a single device at its center hub. [6] has used such systems in many of its mechatronic sculptures. Each actuator module is connected to a central hub, which in turn communicates with a master MIDI device. Whis this allows for the inexpensive addition of more actuators, it places a potentially low upper limit on the maximum number of actuators.

The modular musical robotics system described in this paper takes the best of both aforementioned approaches. From the bus topology approaches, the Novalis system allows for the connection of multiple communications modules. From the star topology approach, "headless" actuator modules may be connected rapidly. The drawbacks of each are reduced: for small setups, only a single master controller is needed, minimizing electronics costs and wiring complexity. For larger setups, additional modules may be added on the fly.

3. NOVALIS: ELECTRONICS

Figure 3: Novalis front and back views. Novalis contains 48 MOSFET drivers to control actuators.

Novalis, which serves as a hub for numerous actuators, is itself a modular device whose configuration as presented can be modified for different tasks. Currently, Novalis (shown in Figure 3) consists of a power supply, microcontroller, two actuator driver boards, and accompanying input and output interfaces. A block diagram of Novalis is shown in Figure 4

Novalis uses a power supply capable of outputting 24V DC. The 500 watt power supply was chosen as its output voltage matches the majority of solenoid actuators used by the authors' projects; the power supply's current rating could handle switching potentially large number of actuators connected to the Novalis interface.

A microcontroller handles communications with a host MIDI device and outputs control voltages to the power MOSFET actuator drivers. Due to its ease of programming, abundant documentation, and open source philosophy, an Arduino microcontroller was chosen. The microcontroller assembly implements Dimitri Diakopoulos's HIDUINO framework [1], allowing for driverless MIDI over USB: when plugged into a host PC, the Novalis appears as a MIDI HID device with no need for driver installation.

The microcontroller assembly is connected to actuator driver modules. These driver modules allow for the switch-

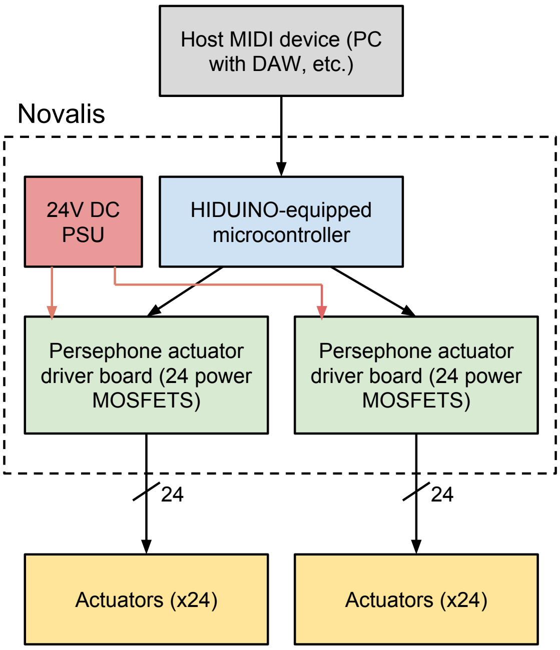

Figure 4: A block diagram of Novalis; additional Novalis modules may be connected to the host MIDI device.

ing of power MOSFET devices using the low current logic-level signals output by the microcontroller. The driver boards, which are custom-built assemblies called Persephone boards, each contain 24 FDB 7030-BL power MOSFETs. In its current configuration, each Novalis interface contains two Persephone driver modules. The Persephone modules interface with the microcontroller via the Niobe PCB, a custom-built connector board.

As a meta-module whose role is to easily connect actuator modules with a host device, the means by which the Novalis interfaces with host devices and actuators is important. To interface with host devices, a USB cable is used; actuators are connected via 5 mm barrel-type jacks which are wired to the Persephone boards.

While Novalis may be used with any compatible actuators, two new systems were developed to utilize its rapid deployability and ease of use. These systems, the Modulets and MalletOTon, are described in detail below.

4. MODULETS

The modulets, shown in Figure 5 are simple, minimalist mechatronic noisemakers. Designed to be rapidly-buildable and rapidly-deployable, the Modulets are intended to serve as basic demonstrators of the Novalis electronics system.

4.1 Physical Construction and Interfacing

Each Modulet consists of a clapper-style solenoid actuator attached to a length of aluminum extrusion. The hollow square-profile tubing serves two purposes. Firstly, it functions as a resonator for the module's solenoid actuator. In this role, it amplifies the solenoid's clapping sound produced upon actuation. Secondly, the extrusion serves as an attachment point for a hanging assembly, allowing the Modulet to be equipped with a wire braid hanger. With this hanger, each modulet may be attached to wire trusses or other mounting systems common in gallery spaces.

Up to 48 Modulet units may be connected and individually controlled by a Novalis unit. Each Modulet has a Molex-style connector attached to the end of a lead that extends from the aluminum frame.

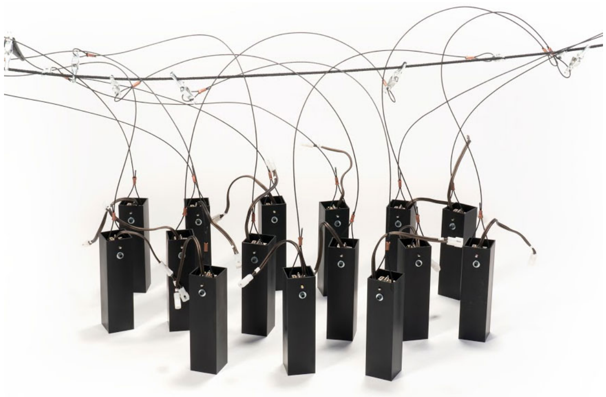

Figure 5: An array of Modulet units.

5. MALLETOTON

Figure 6: MalletOTon's actuator array positioned above a marimba. The actuators may be repositioned for use with other instruments.

One potential use case for modular robotics is exemplified by the Modulet system: a very simple, easy to configure array of actuators that may be deployed in a free-form manner in a space. A second Novalis use-case involves the use of modular musical robotic fixtures to augment an existing musical instrument.

Many musical robots are attached to existing instruments, changing what was designed as a human-played instrument into a mechatronically actuated one. These robotic augmentations are often instrument-specific, requiring significant modification to adapt the robot to another instrument (as exemplified by [3] and [5]).

The MalletOTon (images of which are shown in Figures 1, 6, and 7) was designed and built as an exemplar instrument: a musical robot using modular components and executed in such a manner as to universally fit any marimba-type instrument. MalletOTon, then, addresses the problem of instrument-specific robots by allowing the placement of modular-type actuators to be rapidly adjusted based upon the instrument's physical characteristics. While there exist many examples of mechatronic marimbas and xylophones, the MalletOTon is likely easier to affix to a second related instrument than the existing works.

5.1 The Instrument and Structure

In its current configuration, MalletOTon consists of 48 rotary solenoids, each of which strike one of 48 marimba bars. MalletOTon, like the first and second authors' other robotic augmented instruments [5], does not require the original instrument to be modified in a permanent or damaging manner. This allows MalletOTon to be easily removed from its current instrument and attached to another marimba or metallophone. The actuators are mounted on brackets to a length of T-profile aluminum extrusion, allowing for easy repositioning of the actuator modules.

5.2 Actuators

MalletOTon uses 48 rotary solenoid actuators. Such rotary solenoid actuators are the simplest type of robotic percussion end effector, and were chosen due to their ease of implementation. Attached to the shaft of the solenoid is a rubber-tipped mallet. Upon application of voltage to the solenoid, the mallet rotates into contact with the marimba's bar.

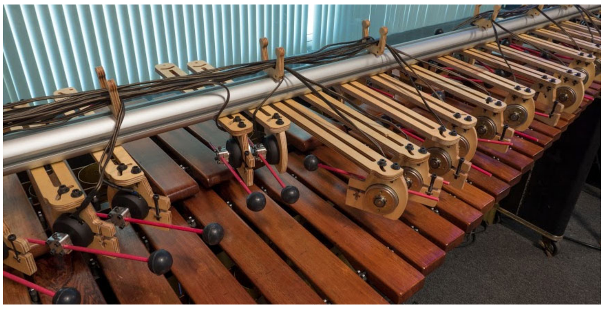

Figure 7: MalletOTon positioned above a marimba.

5.3 Interfacing with Novalis

Conceived of as a testbed for the modular robotics paradigm afforded by the Novalis interface, each of MalletOTon's 48 solenoid actuators is affixed with a cable terminiting in a 5 mm barrel-type connector, allowing for attachment to the power MOSFET outputs on Novalis. Connected to a Novalis interface, MalletOTon can be addressed as a driverless MIDI HID device, programmable from any DAW on a host computer. The plug-and-play nature of the Novalis interface allows for the simple addition or removal of actuators to fit the number of bars on the marimba or metallophone.

6. CONCLUSIONS: USING MALLETOTON, THE MODULETS, AND NOVALIS

A key advantage of modular mechatronic instruments is in their flexibility and ease of deployment. As such, both Novalis and MalletOTon have been utilized in a range of applications. An early use of the MalletOTon units was as part of Colin Honigman's 2013 *The Third Room* installation [4]. In *The Third Room*, the Modulets were arranged in a grid-like structure in the installation space and were configured to actuate when spatially-relevant events occurred. This deployment resulted in a low-cost, easily configured spatially-accurate actuator array whose modularity allowed for straightforward reconfiguration in different spaces.

Additionally, the Modulets have been used during a TedEx presentation, demonstrating their flexibility in deployment and ability to rapidly respond to user input[1]. Similarly, Novalis and MalletOTon have been used at the 2015 ISEA conference and at the CalArts Digital Arts Expo[2].

The authors' experiences in using Novalis, MalletOTon, and the Modulets in performance and installation contexts has emphasized the effectiveness of easily-deployed mechatronic instruments. While other avenues of mechatronic instrument development focus on the development of increasingly complicated apparatus and interfacing techniques, the utility in a "real-world" environment of a rapidly-installable instrument is undeniable.

Future avenues of research will focus on the addition support for other actuator types to Novalis-like systems. Additionally, other means of user-supplied input will be supported, including Open Sound Control [12] and control voltage signals. Finally, efforts will be made toward rendering higher-degree-of-freedom systems as easy-to-use as the Modulets and MalletOTon.

[1]http://karmetik.com/tedx-calarts

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