# The KarmetiK NotomotoN: A New Breed of Musical Robot for Teaching and Performance

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## ABSTRACT
This paper describes the KarmetiK NotomotoN, a new musical robotic system for performance and education. A long time goal of the authors has been to provide users with plug-and-play, highly expressive musical robot system with a high degree of portability. This paper describes the technical details of the NotomotoN, and discusses its use in performance and educational scenarios. Detailed tests performed to optimize technical aspects of the NotomotoN are described to highlight usability and performance specifications for electronic musicians and educators.

## Keywords
Musical Robotics, Music Technology, Robotic Performance, NotomotoN, KarmetiK

## 1. INTRODUCTION
The field of musical robotics has long been in the domain of highly specialized one-of-a-kind instruments. Such instruments are typically only played by their creators, while those unfamiliar with the robotic instrument would likely be faced with a confusing system which is highly specific to the given instrument. With the KarmetiK NotomotoN, we aimed to address these issues by creating a user-friendly robotic music system with plug-and-play ease-of-use, a highly modular design, and high-performance components. Our ultimate goal for the NotomotoN was to create a teaching and performance tool that can serve both as an introduction to musical robotics for those unfamiliar with the field and as a powerful instrument that pushes the boundaries of robotic music performance.

The NotomotoN's ease of use lies in part in its use of the new Arduino-based USB MIDI handler. Users can simply plug into the robot's USB jack and select the robot as a standard MIDI device. Unlike many previous robotic music systems, highly specialized custom software is not needed. Section 2 focuses on the MIDI handling as well as custom-designed high-performance hardware utilized in the NotomotoN. Section 3 presents a detailed performance analysis of the solenoid striker assemblies utilized on the NotomotoN, with special focus dedicated to striker latency, force, and rate of action. Finally, section 4 focuses on live-performance and educational uses of the NotomotoN.



### 1.1 Robotic Percussion: Related Work
Automated percussion systems can be traced back to mechanically sequenced instruments related to player pianos. However, Trimpin is one of the pioneers of computerized robotic percussion instruments and since the 1970's has created a diverse array of percussion works [8]. Another significant early innovator in the field is Godfried-Willem Raes of the Logos Foundation: his works from the early 1980's, though, were "soundsculptures in the full sense: not real musical instruments, and not playable[1]".

The 1990's and 2000's saw an explosion in robotic percussion research with a focus on interactivity: Eric Singer's LEMUR creations were truly live-performance capable [7], and both the first author [4] and Gil Weinberg [10] explored performer/robot interaction. In recent years, such performances as Trimpin's 2007 collaboration with the Kronos Quartet and the KarmetiK Machine Orchestra [2] have highlighted the benefits of fully integrated robotic music systems which do away with the need for in-depth calibration and focus on ease of configuration. The success of Pat Matheny's Orchestrion[2] with Eric Singer's instruments has proven that the public is ready for robots on stage. The KarmetiK NotomotoN builds on the previous work done in the field of musical robotics to further allow for faster deployment time and ease of use.

## 2. TECHNICAL DETAILS
The KarmetiK NotomotoN is a robotic drum featuring twin drum heads, a metal body, and 18 solenoid beater assemblies (see Section 2.2). Each NotomotoN is a fully integrated unit: all power supply components and electronics are self-contained within the drum's body, and all beater assemblies are mounted to the robot's dual circular superstructures. The NotomotoN is intended to be usable as a desktop unit.

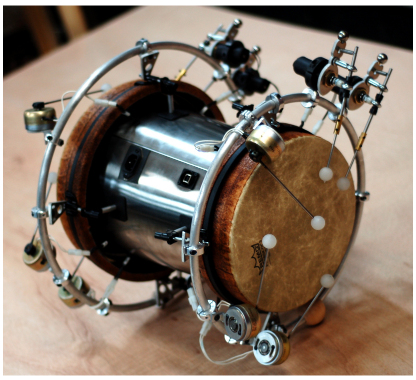

**Figure 1. The KarmetiK NotomotoN**

[1] http://www.logosfoundation.org/g_texts/ibart-leonardo.html
[2] http://www.patmetheny.com/orchestrioninfo/

## 2.1 Hardware

The NotomotoN has two types of beater assemblies each utilizing a different actuation technique (see Section 3.1). The two types of beaters used were called the TrimpTron and the KalTron. The solenoid beater assemblies utilized CNC manufacturing techniques to allow for interchangeability, precision, and consistency. In addition to the listed solenoid drumbeater assemblies, extra electronics and wiring have been allocated to allow for the attachment of additional actuators.

### *2.1.1 The TrimpTron*

The TrimpTron makes use of a rotary solenoid mounted perpendicular to the NotomotoN's drumheads. Its aluminum mounting bracket can be rotated on the robot's superstructure, allowing for a wide variety of timbres as the drum head is struck in different places.

**Figure 2. TrimpTron Solenoids**

### *2.1.2 The KalTron*

The KalTron drumbeater (See Figure 3) assembly uses a modified pull-type solenoid arranged such that its linear motion is converted to rotational motion. The pull solenoids used in the KalTrons allow for very rapid-fire actuation: high-speed rolls are possible using the KalTrons.

**Figure 3. KalTrons on the NotomotoN's Superstructure**

### *2.1.3 Additional Actuators*

In addition to the TrimpTrons, and the KalTron, the NotomotoN has electronics and wiring for up to six additional actuators. The use of additional actuators can prove greatly useful in a teaching environment, as discussed in Section 5.2.

## 2.2 Power and Electronics

A chief design objective in the conception of the NotomotoN was the integration of a 12V DC power supply and electronics in the main body of the drum. Prior experience indicated that, in a teaching and performance environment, having numerous external enclosures for power and communication resulted in a highly entropic cabling situation. The NotomotoN, on the other hand, needs only two cables: one for power and a USB cable for communication. This highly flexible configuration allows for those lacking extensive experience with musical robotic systems to simply plug in and begin composing and performing.

### *2.2.1 MIDI Subsystem*

The AVR-based Arduino physical computing platform was chosen as the means of communication between users' computers and the NotomotoN's actuators. The Arduino was chosen due to its open-source nature, extensive documentation, and compact size. A custom-developed daughterboard was utilized to convert 5V control voltages from the AVR to 24V actuator signals. The daughterboard (dubbed the KarmetiK Trinity board) connects to the Arduino as a shield, sitting directly on the header pins of the Arduino board. The Arduino and Trinity board combination proved quite compact, allowing the entire assembly to rest next to the power supply, completely concealed inside the NotomotoN's drum body. To communicate with the Arduino board, users plug in to a USB jack on the NotomotoN's outer shell.

### *2.2.2 Power Subsystem*

In order to allow for the 24V DC power supply to fit within the NotomotoN's body, an aluminum cradle assembly was built. The cradle seats the power supply and is secured to the drum body's sides. As with the communication assembly, all power components are concealed within the NotomotoN's metal body. To power the actuators on the NotomotoN, users plug in to the female IEC connector.

## 2.3 Software

In an effort to enable plug-and-play ease-of-use on the NotomotoN, MIDI was chosen as the main communication protocol between the robot and performers' computers. Thanks to the Arduino's adoption of the user-configurable ATMega8U2 USB to serial converter, MIDI over USB HID proved possible. For performance and educational use, custom-build middleware is used. This middleware allows users and administrators to customize outgoing messages, preventing potentially harmful messages from reaching the NotomotoN and allowing messages to be analyzed and rerouted as desired. Additionally, this middleware serves as an OSC to midi translator, opening up the possibilities of communicating with the NotomotoN from many other software and hardware platforms.

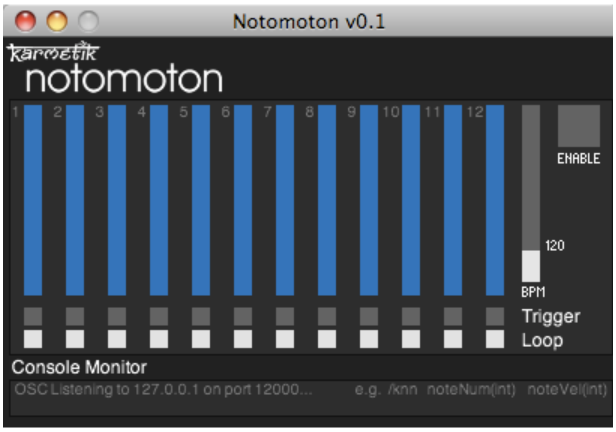


**Figure 4. KarmetiK NotomotoN Software GUI**

# 3. PERFORMANCE ANALYSIS

In order to optimize the actuators' behavior, experiments testing the drumbeaters' speed, dynamics, and latency were conducted. These experiments allowed us to understand the advantages and disadvantages of both beater types (see Section 3.4) and optimize their use in an educational and performance context. All tests were conducted with the beaters striking 20mm away from a piezo sensor on a 20cm diameter drum head. Tests involving the TrimpTron were performed with the drum beater 15mm above the drum head. Due to design differences, KalTron tests were performed with the drum beater 10mm above the drum head.

## 3.1 Actuator Speed Test

To test the frequency at which the actuator assemblies were capable of striking surfaces, we conducted actuator speed tests. Incrementally decreasing intervals between MIDI Note On events were sent to the NotomotoN, with the fastest strike frequency recorded. Table 1 and Figure 5 illustrate the data.

**Table 1. TrimpTron and KalTron Actuator Strike Frequency**

| MIDI Velocity | TrimpTron Strike Frequency | 4. KalTron Strike Frequency |
|---|---|---|
| 127 | 18.69Hz | 20.40Hz |
| 64 | 30.21Hz | 43.10Hz |
| 50 | 39.9Hz | 68.90Hz |

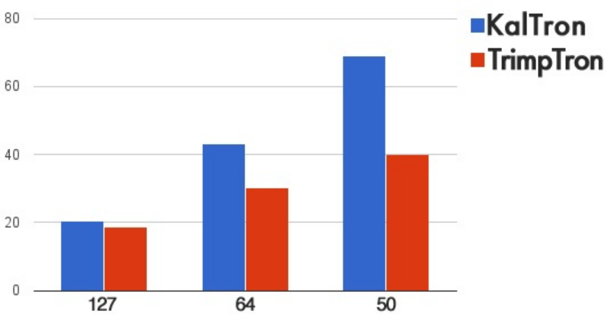


**Figure 5. Actuator Speed Tests (X-axis = MIDI velocity; Y-axis = Strikes/Second)**

## 3.2 Actuator Dynamics Test

Figure 6 illustrates output velocity plotted against the actual velocity of the actuators. The purpose of this experiment was to determine the response curve of the actuators as output velocities increased in order to better understand the real-world behavior of the actuators. MIDI notes were sent 1 second apart to allow for the system to return to equilibrium before subsequent note on events were sent.

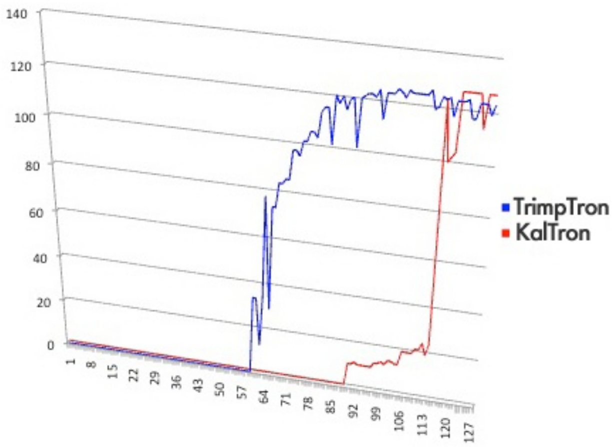


**Figure 6. Actuator Velocity vs. Measured Output Velocity (X-axis = output velocity; Y-axis = Actuator velocity)**

## 3.3 Actuator Delay Test

Actuator latency is defined here as the time between a MIDI message being sent from a server to the time at which the actuator makes contact with the surface to be struck. Table 1 shows the results under testing conditions (20mm above the drum head on the TrimpTron and 10mm above the drum head on the KalTron).

**Table 2. Actuator Delay Time With Differing Velocities**

| MIDI Velocity | TrimpTron Latency | KalTron Latency |
|---|---|---|
| 127 | 0.041 seconds | 0.034 seconds |
| 64 | 0.052 seconds | 0.032 seconds |
| 50 | 0.058 seconds | 0.029 seconds |

## 4.1 Test Conclusions

The Trimpin Rotary Solenoid Assembly was found to compliment the KalTron: while the KalTron is capable of very rapid strike frequencies, its dynamic response curve is less consistent than the TrimpTron. The TrimpTron, then, can serve as a more dynamically expressive actuator while the KalTron plays the role of performing high speed drum rolls.

# 5. PERFORMANCE AND EDUCATION

## 5.1 Live Performance Use

Through testing and use in a live musical context, the NotomotoN has been found to excel as a performance tool thanks to its ability to respond rapidly and dynamically to user commands (see Section 3) as well as its compact size and fast setup time. In a live performance context, the NotomotoN has been tested and played with a diverse array of software and hardware-based musical interfaces, including the RadioDrum [5], the Kinetic Engine [1], the ESitar [4], the Helio [6], and the

Arduinome [9]. Thanks to its ability to respond subtly to parametric control, the NotomotoN was found to be highly expressive when used by the greatly differing above performance interfaces.

## 5.2 Educational Applications

The NotomotoN was designed to serve as the centerpiece for a musical robotic education curriculum [3]. The unit works both as a completely integrated robotic instrument with multiple beater types and as a central module onto which six additional drum-beater mechanisms can be attached. In its role as a central module with external actuators, the NotomotoN serves as a means by which students can rapidly test new beater designs and test existing actuators against new materials such as found objects and drums. In an educational context, the NotomotoN has been used to introduce students to musical robotics and allow them to begin composing for them rapidly.

# 6. CONCLUSION

The KarmetiK NotomotoN is a new breed of musical robot allowing for rapid deployment and heretofore unseen ease of use in a self-contained package. For performance scenarios, the NotomotoN's consistent and high-performance actuators allow for highly expressive musical performance capable of taking advantage of the expressivity offered by new musical performance interfaces. While the NotomotoN excels in performance situations, it also serves as an excellent educational package due to its ease of use and extensible actuator options. To foster further work in the field of musical robotics, the KarmetiK NotomotoN has been made available to all performers and educational institutions. Please visit http://www.notomoton.com for further information about the KarmetiK NotomotoN.

# 7. REFERENCES


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