RASPER: a Mechatronic Noise-intoner

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ABSTRACT

Over the past few decades, there has been an increasing number of musical instruments and works of sound art that incorporate robotics and mechatronics. This paper proposes a new approach in classification of such works and focuses on those whose ideological roots can be sought in Luigi Russolo's noise-intoners (intonarumori). It presents a discussion on works in which mechatronics is used to investigate new—and traditionally perceived as "extra-musical"—sonic territories, and introduces Rasper: a new mechatronic noise-intoner that features an electromechanical apparatus to create noise physically, while regulating it rhythmically and timbrally.

Keywords
Rasper, Noise-intoner, Mechatronic Soundsculpture

1. INTRODUCTION

From a conceptual perspective, it can be suggested that there have been two different approaches towards the integration of robotics, mechatronics, and automatic apparatuses in the design and construction of new musical instruments. The first one is an effort to replace the human performer with machines in order to explore the full potential and push the boundaries of conventional musical instruments, while the other tries to investigate the machine itself not only as a performer, but also as a source of new sounds. In other words, in the first scenario, electromechanical machines have been used to create augmented musical instruments with extended performative capabilities, and in the other, they are used as extra-musical sound-objects utilized in a musical context.

Although there is no rigid distinction between the two approaches and the dividing line here is blurry, in the context of this paper, such classifications help clarify the author's motivation in highlighting certain works and artists in the next two sections. Therefore, while conceding that the terminology is somewhat indistinct, these two strands it represents are useful in clarifying differences between "musical robotics" and "mechatronic sound-objects".

A brief overview of musical robotics is presented in section 2, and—considering the focus of this paper— mechatronic sound-objects are discussed in more detail in Section 3, using a number of examples. Section 4 introduces Rasper, discussing

the sound production mechanism, technical features, and some timbral and frequency characteristics of the instrument. Section 5 is dedicated to a discussion on the future works.

2. MUSICAL ROBOTICS

Semantically, musical robotics is perhaps best explained via automatophonics: a term used by Charles Fowler to describe "mechanisms that replace the human performer, but not the instrument itself" [1]. According to Fowler, the production of these types of mechanical musical instruments—which are as old as the water organ built in 875 C.E.—reached its climax after the Industrial Revolution, the player piano being most significant instrument within this domain. As Murphy argues, since these early generations of automatic musical instruments were primarily built as tools for the reproduction of music, they gradually died out in the early 20th century with the advent of the phonograph [2]. However, during what Murphy calls "the 1970s Renaissance" a new movement, which over the past decade has been led by forerunners like Eric Singer, Gil Weinberg, and Ajay Kapur, was resurrected. According to Murphy, this movement was an effort to create "a reality consisting of real world production of sounds, forgoing the loudspeaker in favor of mechatronically facilitated actuation techniques capable of truly localized sound"[2]. For instance, the founder of the League of Musical Urban Robotics (LEMUR), Eric Singer's musical robotic works "focus on augmented instruments and new instruments inspired by existing designs" [2]. As Murphy describes, among LEMUR's numerous musical robotic projects[3], Singer's "Guitarbot"[4] is one of the most significant examples in the field. Other examples can be found in Weinberg's work. In his article "Towards Robotic Musicianship", he explains in details the design and construction of his robotic percussionist "Haile" from a musicianship perspective [5]. Furthermore, the Karmetik Machine Orchestra—an ensemble of laptop performers and a set of networked robotic idiophones and membranophones designed by Ajay Kapur, Michael Darling, et al. [6]—is another example of robotic instruments that are capable of performance in areas (e.g. speed and precision) beyond human performers' abilities.

In addition to the significant examples above, Phil Dadson's instruments[1] (created in the 1980s), Jim Murphy's recent works on robotic guitars [7], and the other works described in Kapur's article "A History of Robotic Musical Instruments" [8] are among numerous other examples of the musical robotics field; one that was certainly inspired by groundbreaking works of Godfried-Willem Raes and Trimpin whose diverse contributions—from musical robotics and electroacoustic instruments to kinetic soundsculptures and mechatronic sound-objects—are also responsible for blurring the boundary line

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[1] See "From Scratch" archive at www.sonicsfromscratch.co.nz (Retrieved on September 2, 2013).

between musical robotics and mechatronic sound-objects[2].

3. MECHATRONIC SOUND-OBJECTS

It is reasonable to regard Luigi Russolo's *Art of Noises* and his intonarumori (noise-intoners) as the conceptual cornerstone of the mechatronic sound-objects trend. In his Futurist Manifesto, Russolo asserts that "the evolution of music is comparable with the multiplication of machines" and calls for artistic investigation of the noises of the machines in order to expand the "limited variety of timbre" provided by the orchestra at the time [10]. As first instances of the conventionally "extra-musical" sounds of the machine integrated in a musical setting, his intonarumori continue to influence the artists and musicians in the realm of experimental and art music to this day. One of the main precursors of the contemporary mechatronic sound art and the founder of the Logos Foundation, Gottfried-Willem Raes, openly expresses his fascination for Russolo's instruments [11]. Influenced by the anti-authoritarianism of the day, Logos was founded in the late 1960s by Raes and a number of other artists and instrument designers. Raes' goal was to defy what he regards as the authoritarianism of music-production industries by pushing the boundaries of music and sound art through design and construction of new instruments and integration of these instruments and electromechanical technologies in his various works of sound art [11]. Another key figure, whose contributions to the field of mechatronic sound art, according to Murphy, "either directly or indirectly, […] significantly influence the majority of subsequent work in the field", is Trimpin [2]. Murphy describes Trimpin's work as a full "rejection of the loudspeaker through the use of physical objects actuated mechatronically and placed throughout an installation space"[2]. A selected number of Trimpin's sound art works are presented in *Trimpin: Contraptions for Art and Sound* complied and edited by Anne Focke [12].

One of the main principles in Trimpin's work has been the sonic recycling of found objects and obsolete machines through mechatronics in order to create kinetic soundsculptures.[3] This practice can be traced through works such as Gordon Monahan's *Multiple Machine Matrix* in addition to a number of others cited in Murphy's article [2]. *Multiple Machine Matrix* is a "multi-functional performance and installation environment of automated machine sculptures built from electronic surplus and trash [in which] MIDI signals […] control the movement of mechanical/robotic devices such as voltage modulated steel sheets of various sizes, pulse-controlled bi-directional metal sheet Doppler spinners, and percussion-activated furniture"[14]. Peter Garland writes on this work—which was also titled as *Sounds and the Machines that Makes them*—that it is the sound that is "the source of amazement and pleasure", and gives life to the machine, not vice versa [15].

Remarkable examples of using mechatronics as the source of sound itself can be found in works by the Swiss artists Zimoun and Pe Lang. A significant majority of their solo works, as well as those that they create in collaboration with one another, are large-scale sound installations that comprise significant numbers of what they refer to as "prepared DC motors or actuators" as sound-objects (see Figure 1). According to Murphy, "Zimoun's and Lang's works have much in common with those of other artists who create their own instruments:

Many such works involve reductionist sculptures that pare sound-making elements down to their pure forms" [2]. By simultaneous sonification of a large number of sound-objects (i.e. small actuators attached to cardboard boxes, wires, cotton balls, etc.), these artists immerse the space in a deep sonic sea that gently moves through pulsating timbral waves.

Figure 1. 450 prepared pendulum motors on the wall by Zimoun and Pe Lang

A direct homage to Russolo's instruments is *La chambre des machines*: a project by a Canadian duo Nicolas Bernier and Martin Messier in which "machines made of gears and cranks are manipulated to produce a sound construction at the crossroads of acoustics and electronics" [16]. The project is in fact a live act consisting of the duo and their mechanical noise instruments where "each performer approaches his apparatus like a technician" [17] (see Figure 2).

Figure 2. *La Chambre des machine* by Nicolas Bernier and Martin Messier

Both instruments are of course inspired by Russolo's intonarumori, and although they both generate sound physically and mechanically, the exclusive use of autonomy and mechatronics is not investigated here as it is in the artists' solo projects. Bernier's award-winning *Frequencies (a)* "is a sound performance combining the sound of mechanically triggered tuning forks with pure digital sound waves. The performer is triggering sequences from the computer, activating solenoids that hit the tuning forks with high precision. Streams of light burst in synchronicity with the forks, creating a not-quite-minimal sound and light composition" [18]. Similarly, Messier's *Sewing Machine Orchestra* (see Figure 3) is an audiovisual performance in which "computer processing transforms the functional sounds of eight 1940s Singer sewing machines, mounted on stands, into a vivid, dancing weave of hums, whirrs, and beats, accompanied by suitably pulsating lights" [17]. The emphasis on the audiovisual expressivity in these works is perhaps best explained by Fowler: "many of these mechanical instruments are clever gadgets and novelties–

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[2] Sound sculptors such as Jean Tinguelly, Joe Jones, and Martin Riches—whose works are discussed in Alan Licht's *Sound Art* [9]—could also fall into this liminal space.

[3] In fact, as Jean Strouse writes, "He moved to the United States largely because Americans throw out a lot of more of the high-tech junk he uses in his work than Europeans do" [13].

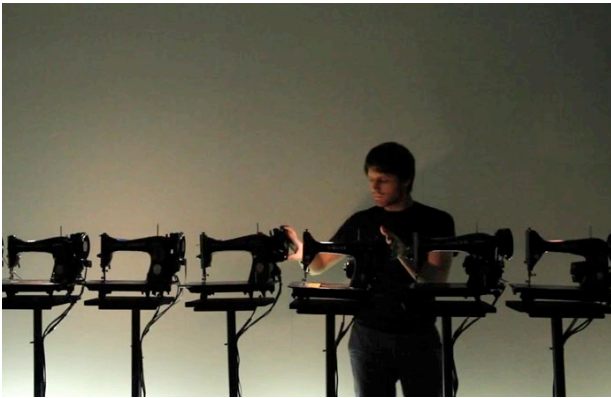–jewel boxes and the like—intended for looks as much as for sound" [1].

Figure 3. Messier's *Sewing Machine Orchestra*

To summarize, even if we do draw a line to conceptually differentiate between the "mechatronic sound-object" trend that is rooted in Russolo's *The Art of Noises,* and the one devoted to the development of robotically augmented conventional musical instruments, there still exists a strong connection between the two. After all, it cannot be denied that many of the technical developments of the "mechatronic sound-objects" trend have been induced by the intensive research and engineering that has been done on the works that, in the above classification, would fit among the "musical robotics" trend.

4. RASPER

The mechatronic sound-objects discussed above perhaps share an ideological ground with the modern laptop-based noise/glitch music. Regardless of the different mediums they employ, mechatronic sound-objects and glitch music both try—in some way—to draw attention to the potential aesthetics of the "extra-musical" phenomena associated with the technologies they use, making "noise" accessible and part of the signal again[4]. Mechatronic sound-objects accomplish this by emphasizing the bodily effect and the physicality of the noise production, using a significant degree of visual aid. On the other hand, a substantial portion of laptop-based glitch music uses pulse, beats, and grid-based rhythmic patterns as a framework to achieve such accessibility [20]. Using a hybrid of these two methodologies, Rasper is a new mechatronic noise-intoner that somehow bridges the gap between the physically-produced noise in works of mechatronic sound-object and the pulse-based digital noise of laptop-produced glitch music. It employs some basic mechatronic elements and converts their electromechanical energy into a "rasping" sound that is produced acoustically. The idea behind building Rasper was to bring the ignored and unwanted noises of the machine back to the domain of aural attention by regulating their irregularity through a rhythmic grid of pulses and metric rhythms, while preserving—and even highlighting—their physicality and corporality. Therefore, mechatronics was chosen as the tool/mechanism to achieve the above objectives, considering that:

1. Mechatronic machines are noisy in essence.
2. They are perfectly capable of creating pulsating and recurring motions.

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[4] In the eyes of information theory, noise is any information that is extraneous to the transmitting message [19].
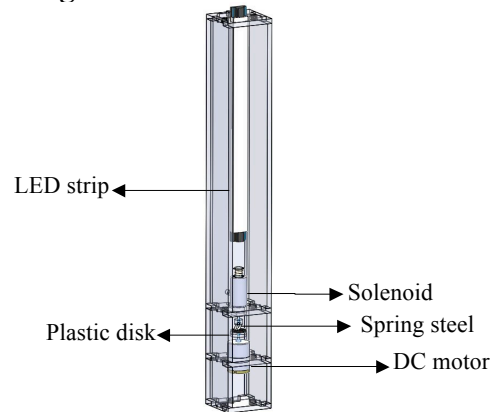
4.1 Design

Figure 4. Rasper's 3-D model

As shown in Figure 4, Rasper is comprised of a DC motor, a push solenoid, a 3D-printed plastic disk, a piece of spring steel, and an LED strip. These components are all held together in an open-faced enclosure made of clear acrylic (see Figure 5). As a result, all the parts, components, and the entire sound-generating mechanism are completely visible. In order to further boost the audiovisual expressivity, Rasper uses an array of LED strip, which corresponds to the sound-generating unit, providing an immediate visual feedback to each aural event. The enclosure was designed using CAD and rapid prototyping workflow.

Figure 5. Rasper

The instrument's sound-generation unit incorporates mechatronics and microcontroller programming and the instrument is capable of functioning both automatically and interactively, i.e., with or without human real-time interference. Nevertheless, the sound generating mechanism itself was— to some degree—inspired by the one used in several Russolo's noise-intoners (e.g. Crackler). The sound generating control system implements the two main principles that were used by his intonarumori:

1. Controlling the speed of vibrations
2. Controlling the tension

In several of Russolo's noise-intoners, the speed of vibrations was changed using a crank that was attached to a spinning disk, which was in contact with a string. The performer was in charge of the speed of string's vibrations by turning the crank, while controlling the tension of the string by a lever, creating different tones and timbres. In Rasper, the crank is replaced with a DC motor, the vibrating material—i.e. the string—with a small piece of spring steel, the lever with a solenoid, and the system is automated through microcontroller programming. The noise is produced when the spring steel makes contact with the spinning 3D-printed disk that is attached to the DC motor: as the solenoid pushes out and the sharp tip of the bent spring steel touches the spinning disk, it vibrates rapidly and generates a high frequency rasping sound (see Figure 6).
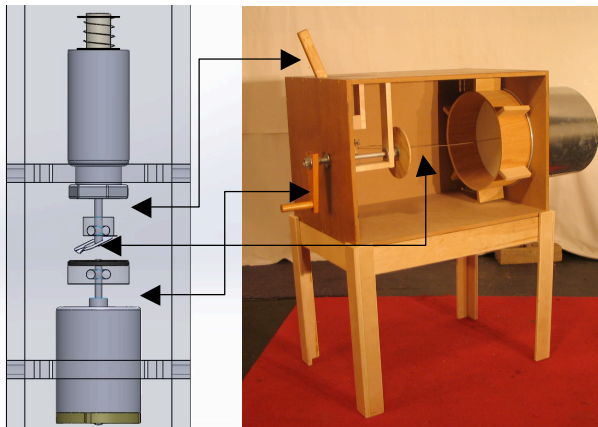

Figure 6. Noise-generating mechanism in Rasper (left) contrasted to the one used in a recent model of Russolo's Crackler developed by New Music Co-op[5] (right).
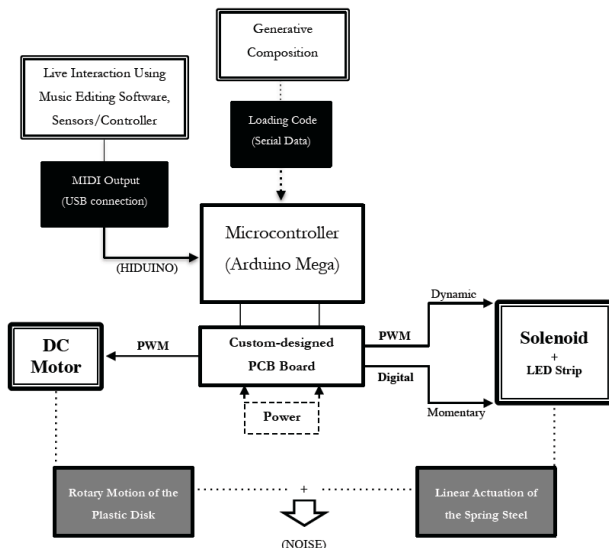
4.2 System Overview

Figure 7. System Overview

Figure 7 shows a flowchart of different parts of the system and demonstrates the process of sound production. A 12V push solenoid is used to switch the contact between the spring steel and the spinning disk on and off. Therefore, system's rhythmic behavior—simple or sophisticated patterns, pulses, and pauses–

—is determined by solenoid movements. The amount of force applied by the solenoid is the main factor in determining the amplitude of each event, and modulation in the speed of rotation creates a timbral range and introduces a subtle and relative sense of variety to the pitch domain. The disk's revolutions are actuated by the rotary motion of the motor shaft, and the LED strip lights up the entire unit once there is an event (a contact between the spring steel and the disk). The luminosity of the LED strip corresponds to the loudness of each event. The solenoid, the motor, and the LED strip are all controlled via a microcontroller (an Arduino board), driven by a custom-designed PCB board that functions as an Arduino shield (see Figure 8). The board is capable of driving up to 16 motors, solenoids, or LED strips once powered up by a 12V DC power supply. The code is uploaded onto the Arduino board using Arduino programming. It is possible to interact with the instrument in two different modes:

1. **Client Mode:** Flashing the Arduino board to a MIDI device using Hiduino firmware [21]: Receiving MIDI messages from software/controller.
2. **Autonomous Mode:** Uploading serial data onto the Arduino: Using generative algorithms to create evolutionary patterns and generative compositions.
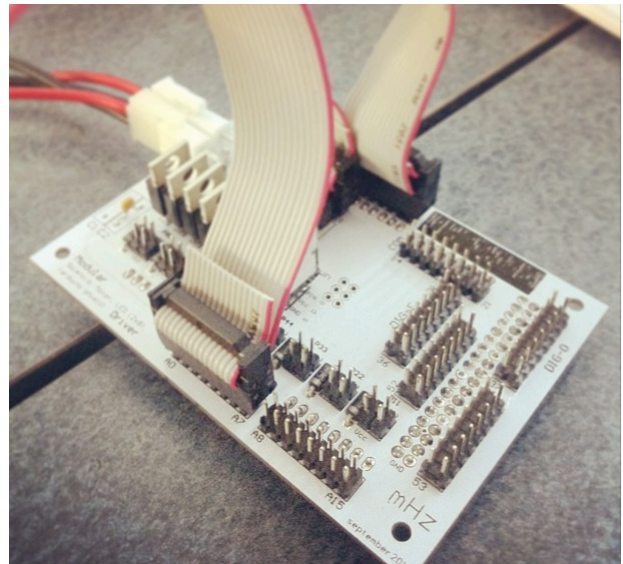

Figure 8. Rasper's driver board

4.3 Evaluation

The primary principle regarding the essence of sound production in these mechatronic instruments is to avoid a definite pitch and maintain the richness and noisiness of the signal. This is demonstrated in the figure below, where FFT analysis results of three different recordings of the instrument have been collected. These recordings varied in terms of the motor's speed of rotation—i.e. the speed of vibrations—and are ordered from a slow to a fast speed.
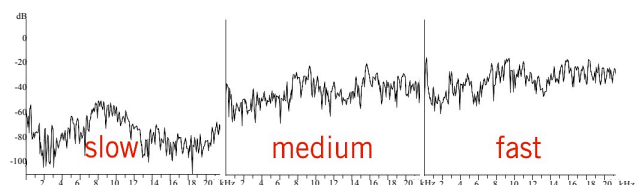

Figure 9. Average FFT results of the recordings of Rasper at a slow, a medium, and a fast speed.

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[5] See www.newmusiccoop.org/index.php (Retrieved on July 31, 2013).

Figure 9 is of course a rough demonstration, extracted from average FFT analyses of recordings of three different speeds, to negate the presence of a dominant pitch and verify the noisiness of the generated sound. Regardless of relatively different spectral distribution, there does not appear to be any signs of important peaks, periodicity, or harmonic distribution[6].

In a more detailed series of tests, a number of key feature extractions of the recordings of the instrument were complied in order to study the frequency domain characteristics of the instrument. During the recording process, in order to narrow down the study to frequency related features, the contact force between the vibrating spring steel and the spinning disk was kept constant by applying the same amount of power to the solenoid while changing the speed of the disk's rotations. Speed variation was achieved through applying different MIDI velocities to the motor. MIDI velocities less that 71 did not create a sufficient force to drive the motor as the solenoid's contact was applied. Therefore, 29 recordings of different rotation speeds were collected by sweeping the MIDI velocities every two steps from 71 to 127. A small diaphragm cardioid condenser microphone (Neumann KM 184) was used to provide the high-frequency response. Considering the relative unpredictability and noisiness of the instrument, the feature extraction tests were carried out on average FFT data of one-second-long recordings, with the following specifications:

- Sample Rate: 44100 sample/s
- Window Function: Hanning
- Window Size: 1024 samples

Each MIDI velocity value is therefore calculated as the average of approximately 43 samples ($44100/1024 \cong 43$).

As demonstrated in the Figure 10, the spectral centroid and spectral roll-off graphs show the center of the mass and the power distribution of the audio signal in the high frequency domain. For the speeds extracted from MIDI velocities higher than 90, these features are limited within a relatively narrow band of high frequencies (approximately between 11kHz and 13kHz).
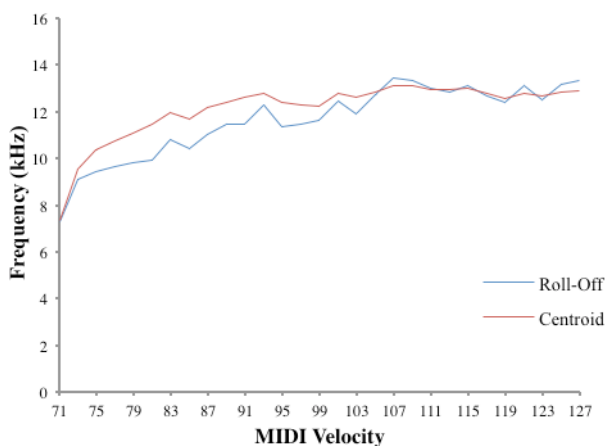

Figure 10. Spectral Roll-Off and Spectral Centroid

The zero-crossing graph displayed in Figure 11 can deliver a rough sense of the instrument's pitch behavior. Again, except for the lower speeds—where due to the inability of the system

to create high amplitude vibrations, the sound of motor buzzing becomes considerable itself—the number of zero-crossings is limited within a relatively narrow band of high frequencies. Although the audio signal is noisy and this number does not represent an absolute pitch, the relatively unwavering number of zero-crossings at higher speeds can be interpreted as a "subtle sense of pitch" that fluctuates between 11kHz and 13kHz.
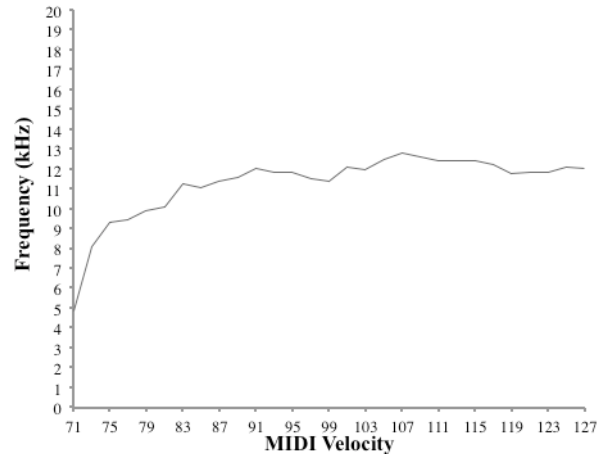

Figure 11. Number of Zero-Crossings

Lastly, the relative stability of the change of the audio signal in higher speeds can also be extracted from the spectral flux graph showed in Figure 12. As the speed goes higher, there can be noticed a threshold where the wavering flux of the signal is smoothed out. Therefore, for higher speeds, as the speed of the motor changes, the numeric derivative of the change of the audio signal becomes relatively consistent, i.e., the change is linear and somehow predictable.
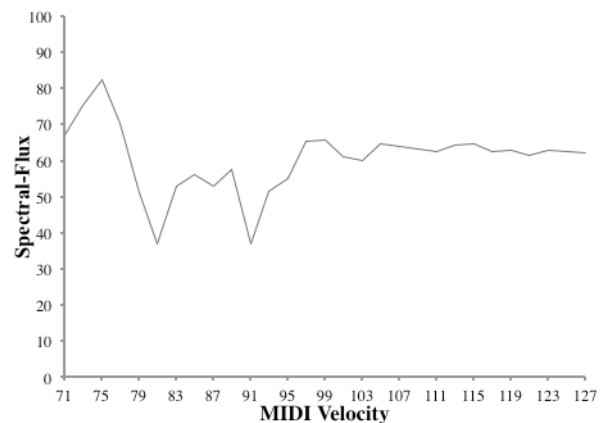

Figure 12. Spectral Flux

The information extracted from these graphs verifies that:

- Acoustically, the instrument is generating noise rather than pitches[7].
- The generated noise lies in the high frequency audio domain—especially for higher speeds.
- Depending on the software settings specified by the user, relatively consistent results could be achieved

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[6] Except for the local maxima in the middle of the slow graph, which is possibly due to the fact that at slow speeds the noise-generating unit is relatively quiet and the sound of the motor buzzing becomes considerable.

[7] Hermann Helmholtz argues that the differences between noises and musical tones are rooted in our aural perception, stating that musical tones are perceived as periodic, and noises are perceived as non-periodic motions [22].

when working with MIDI velocities higher than a certain threshold.

- Variations in the frequency of vibrations do not correspond to a significant or meaningful pitch behavior, but rather to a limited timbral variety.

Considering that Rasper is a new instrument, the information provided by these kinds of analyses can be helpful for the users/composers to acquire a better understanding of the instrument.[8]

5. DISCUSSION AND FUTURE WORKS

This paper presents a new mechatronic noise-intoner built to highlight the potential aesthetics of the mechanically produced noise and make the "extra-musical" accessible. In order to achieve this objective, an instrument was designed with the following strategies in mind:

1. Structuring the noise rhythmically
2. Flaunting the noise-production mechanism

The instrument is a "noise" instrument and its pitch domain behavior is not of great consideration. However, its restricted variety of frequency range and timbre at higher speeds of rotation—where the more consistent results are achieved—might come as a limiting issue in certain compositional contexts or live-performances. Therefore, with respect to future works, the plan is to investigate the design and construction of other iterations of this instrument in which different material and/or different vibrating mechanisms are used. Combining these different types of instruments will help broaden the resulting timbre and frequency domains and enrich the audiovisual expressivity. Considering the instruments' inherent autonomy, it will be feasible to simultaneously engage multiple instruments in the format of an ensemble with relatively wide timbral and frequency ranges: a mechatronic noise-ensemble that can be utilized in both interactive and automatic—i.e. performance and installation—modes.

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[8] Video documentation of Rasper can be found at the following URL: www.m-h-z.net/rasper