Exploiting Swarm Aesthetics in Sound Art

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Abstract

As robots move from our imagination into our lives and with modern advances in electronics, more new applications have become possible. Over the past 40 years, many artists, musicians, and researchers have used robotics and mechatronics to create novel sound art. We review current robotic interventions in sound art and discuss the characteristics of similar works. Then we introduce Liminal Tones (A / Autumn Swarm) – a series of experimental sound compositions made by multiple mechanical objects that sync and swarm together, and generate noise music. Our goal is to investigate swarm aesthetics, and collective and emergent behaviors to create chaotic and patterned sounds.

Keywords

Swarm Aesthetic, Noise Music, Sound Compositions, Swarm Intelligence, Collective Behavior, Emergence, Particle Swarm Optimization, PID Controller

Introduction

Sound as a conceptual medium is influencing our art culture. Many contemporary artists have begun to explore sound in its pure state, simultaneously bridging and blurring the notion of sound, noise, and music. In the past few decades there have been several approaches, using robotics, mechatronics and artificial intelligence (AI) to develop musical improvisations, sonification, orchestras, and sound art. The goal in most cases is to push the boundaries of conventional music and explore the infinite possibilities of randomness, chance, noise-sounds, and glitches. Robotic and electromechanical machines with embedded automation and performative capabilities have extended the musical creation process.

We discuss the related art about mechatronic sound objects and musical robots in Section 2, using a number of examples, followed by the emerging interest in noise in Section 3. In Section 4, we discuss the aesthetic value of chaos and swarming techniques in sound art. In Section 5 we present Liminal Tones (A / Autumn Swarm), its sound mechanism, technical features, swarm dynamics, and architecture. Finally, in Section 6, we discuss our initial results and future work.

Background

A key pioneer in the renewed interest in musical robots is Gottfried-Willem Raes, the founder of the Logos Foundation (1968). Logos was influenced by anti-authoritarianism, opposition and radical denial of serialism and post-serialism in music. As Raes argues, this refusal was rooted in the musical trends in the late 1960s and the "desire to conquer the hierarchy of power involving music and its producers" (1992, 29). Another music roboticist and key figure is Trimpin, who used mainly physical objects, actuated mechatronic systems, and obsolete machines to create sonic environments and drumming apparatuses (Murphy, Kapur and Carnegie 2012).

Both Raes and Trimpin's artistic practices laid a rich foundation for contemporary sound art and inspired a few of the current musical trends. Murphy, Kapur and Carnegie categorized these practices into three separate streams: “works making use of found objects, works consisting of purpose-built instruments, and sculptures using automatophonic instruments” (2012, 43).

Sound sculptor Gordon Monahan (2011) creates sound sculpture, installations, and sonic environments exemplifying the subfield of found-object musical robotics. For example, in his installation *Trembling Antennae for Henning Christiansen* (2013), Monahan used electric motors as sound diaphragms to amplify audio signals in the exhibition space. Similarly, Jon Pigott (2011) explored sound, technology, and material systems in sonic art and noise music.

Other works in this group are the solenoid-based instruments of Chris Kaczmarek and the noise-making assemblages of Peter William Holden. Prominent in this category is Nicolas Bernier, the winner of Prix Ars Electronica Golden Nica in Digital Music & Sound Art (2013) for his artwork *Frequencies (A)* (fig. 1). Bernier’s sound performances and practices over the years evolved from a chaotic noise-based approach to a more minimal and pure focus on sounds and exploration about the relation between music, conventional mediums, and new technology. His works echo the interplay between digital sounds and light to create an elegant balance between the logical and the sensual. Similarly, Moritz Simon Geist makes electronic musical robots (fig. 2) and vibraphones to push and extend the boundaries of music, and explores the unknown and futuristic world of techno robotics. Geist questions our perception of technology and AI in a playful and entertaining style.

In a different approach, a group of artists have created purpose-built noise systems. Examples of using mechatronic sound-objects can be found in works of Zimoun (fig. 3), who combines visual, sonic, and spatial elements to create sound sculptures, sound architectures, and installations.

Zimoun and Pe Lang usually use a large number (generally hundreds) of mechanical elements, such as DC motors, and other actuators, as sound-producing objects. They refer to these elements as “prepared DC motors or actuators”, which often resemble biological systems and evoke an eerie or uncanny feeling (Stoddart, 2015).

Fig. 1. *“Frequencies (A)*”, Sound performance of mechanically triggered tuning forks with pure digital soundwaves. Nicolas Bernier, 2013.

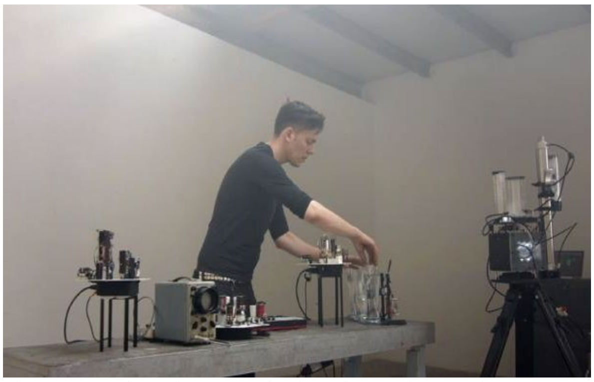

Fig. 2. A shot from “Robotic Electronic Music (R.E.M)”, using music robots, mechanics and sound devices. Moritz Simon Geist 2019.

In a third approach, sound artists create automatophonic sound sculptures made of altered instruments, such as the *Mechanical Orchestra of França Xica*, an interconnected web of altered instruments by Roger Aixut, and *Felix's Machines*, by Felix Thorn.

Although these artists seem to have different tastes in form and approach, all of them seem motivated by a desire to explore sounds and sonic characteristics of space that are not otherwise accessible through traditional music (Murphy, Kapur and Carnegie 2012). For example, both Monahan and Zimoun focus on exploring acoustic sounds in space (Muecke and Zach 2007).

Noise as Music

Since the late 20th century, there has been an emergent aesthetic and musical phenomenon known as “Noise Music.” More recently, various artists have used noise to create audiovisual performances (e.g. Frank Bretschneider, Michael Kummer and Ryoichi Kurokawa), compositions (e.g. Aoki Takamasa and Mika Vainio), and installations and sound sculptures (e.g. Ryoji Ikeda, Nicolas Bernier and Mo Zareei, fig. 4).

These works share some common features, such as dodging harmonic material and embracing sounds, otherwise known as "extra-musical," including concrete sounds, noise, and sonic glitches. Also, they have a minimal approach and often use multiple sound-objects, pulse-based rhythms, complex noisy timbres, repeated patterns, recurring images, or stroboscopic visuals (Zareei 2016).

Fig. 3. Installation using 51 prepared DC-motors, 241m of rope, and 25-cm-long cardboard sticks, Museum of Contemporary Art MAC, Santiago de Chile. Zimoun, 2019.

Fig. 4. *Material Music*, a sound installation consisting of a linear array of eight kinetic sound- sculptures, at the International Symposium on Electronic Art (ISEA). Mo H. Zareei 2020.

Order, Chaos and Sonic Swarms

Throughout the history of Western music, many composers and musicians have used natural sound as a source of inspiration in their work, particularly the sound of wind, water, and birds. This interest in mimicking natural sounds is also manifested in the works of a few contemporary sound artists, such as Nelo Akamatsu, Pe Lang, and Zimoun.

Nelo Akamatsu takes a minimal approach to sound art, which is rooted in Japanese culture and their delicate perception of nature. He often uses a few elements, such as water, tumblers, and wires to create sounds. These gentle sounds, multiplied by several hundred, create an organic symphony and a minimal expression of perceived nature (reminiscent of natural swarms) in a mythical, magical, and repetitive pattern.

Pe Lang and Zimoun create sound sculptures and installations with rhythms and flow using a large number of basic mechanical components as sound objects. In their practice, both together and individually, they create analogue rhythms and flow, and study the creation and degeneration of patterns. Inspired by generative systems and swarm behaviors, their works display both simplicity and complexity. The emergent and intricate behaviors of these sound objects (in sound and motion) appear to be organic and alive, and sound like "the acoustic hum of natural phenomena" (Schlatter 2013).

Liminal Tones

Concept

Liminal Tones (A / Autumn Swarm) is a series of sound compositions generated by eight vibration motors, wires, and actuators. We used a swarming technique and a specific control loop mechanism to regulate the DC motors and make the wire move, twist, and turn. The moving wires make tiny sounds, which are accompanied by the noise of the DC motors and form rhythmic sounds that are both organized and chaotic.

System Overview

We used a laptop, an Arduino Uno board, and a multi-channel driver board (8 channel DC 5V relay module). The output signals are generated by the Arduino in response to the incoming MIDI velocities, which in turn, drive the DC motors and attached wires (figs. 7 and 8). To control the frequency and speed of the DC motors, we used a swarm control loop, known as a PSO-based PID controller.

PSO-based PID Controller

It is inherently difficult to tune proportional-integral derivative (PID) loops and their parameters. Normally, the tuning process is done through trial and error. To automatically control multiple DC motors, we adapted a heuristic algorithm known as particle swarm optimization (PSO) from Hashim and Mustafa (2020). A PSO-based PID controller is a robust, nonlinear parameter-tuning process for synchronising and stabilizing E.

PID controllers have been widely used to control the speed fluctuation and frequency of DC motors in different control systems, such as process control, motor drives, and magnetic and optical memory. In the most simplistic terms, the PID controller calculates the P, I, and D parameters and multiplies each by an error (e) and then calculates the sum as a control variable (CV) (fig. 5). The proportional term (Gain or K_P) is a ratio that controls how fast the DC motors responds. The integral term (I Constant or K_I) determines how fast the error is removed. Finally, the derivative term (D Constant or K_D) predicts the rate of change in the process variable (PV). The PID controller is described as:

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt}$$

where $e(t) = r(t) - y(t)$ represents the tracking error and the difference between the desired input value and the actual output. The main advantage of the PSO algorithm is that it is an auto-tuning method, and it does not require a detailed mathematical process to find the K_P, K_I and K_D and tune the PID process control parameters (fig. 6).

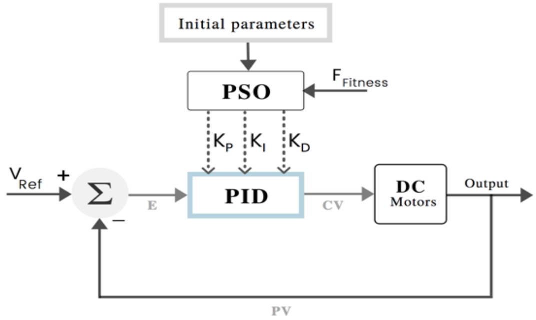

Fig. 5. Block diagram of our PID controller with PSO algorithm. Adapted from Hashim & Mustafa (2020).

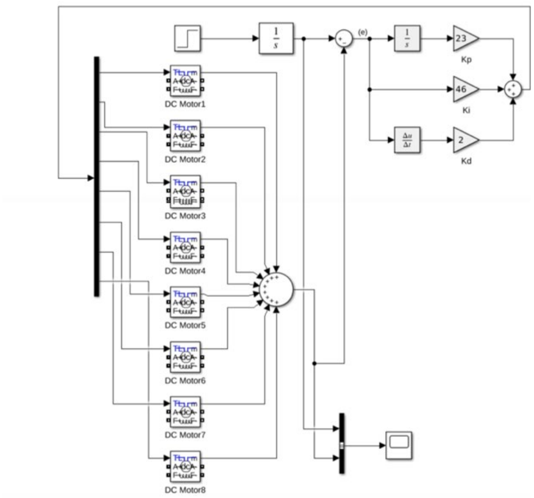

Fig. 6. Simulink block diagram of our PID controller and 8 DC motors.

Particle Swarm Optimization

Particle swarm optimization (PSO) is a heuristic optimization technique, which was developed by Kennedy and Eberhart in 1995, inspired by the social behavior of animals such as birds in flocks and fish in schools.

PSO begins by creating a number of artificial particles and assigning them initial velocities. Then it explores the space of the objective function and adjusts the trail of each agent (or particle). The position of each particle is updated, based on the agent's history (current and best previous locations), other members of the swarm (the global optimizer value), and some random perturbations (Brownlee 2012). The new position of each particle is computed as the sum of its previous position with a quantity that is estimated using several factors, depending on the PSO variant and eventually the swarm flock around the desired area. The particle position in PSO can be modeled as:

$$x^i = [K_P, K_I, K_D, K_{PS}, K_{DS}]$$

where x is the particle position, and K_P, K_I, K_D are the proportional, integral, and derivative values of the PID controller to control speed, torque, and voltage of the DC motors, respectively, and K_{PS} and K_{DS} are the proportional and derivative values of the PID controller to control the oscillation. The particle initialization is computed using:

$$x^i = x_{min} + rad(x_{max} - x_{min})$$

where x_{min} and x_{max} are the minimum and maximum values in the search space. Each particle is assessed by fitness function and particles, with a minimum fitness value compared to the best local and global values and updated. Each particle represents a candidate solution for PID parameters. A good set of PID controller parameters can yield flocking behavior and optimal control of DC motors (Allaoua et al. 2009).

Compositional Strategy

Our approach can be used both for both an interactive music performance accompanying a performer, or to generating sound compositions. Repetitive, and complex patterns of *Liminal Tones (A / Autumn Swarm)* are reminiscent of works by Pe Lang, and Zimoun, regardless of the choice of material or the architecture that drives the outputs (figs 7 and 8).

These common and key features are: the minimalistic approach and the use of multiple mechanical elements, following simple principles and resemblance to natural systems (in sound and motion). However, instead of an analogue, and un-controlled approach, which is common in Pe Lang and Zimoun works, we used an auto-tuning controller as a feedback loop to digitally mediate the movement of the wires and the patterns of sounds.

Discussion and Future Works

Swarm Aesthetic

Swarm intelligence (SI) is one of the most beautiful and unusual phenomena in nature, which emerges from the interaction between a group of decentralized simple agents and their environment. Widely recognized examples of swarms include flocks of birds, bacterial growth, schools of fish, and the societal superorganisms of ant colonies (i.e. foraging). Natural swarms are often perceived as a single entity or “super-organism,” which exhibits cognitive behavior and emergent intelligence (Passino et al. 2011).

Swarm systems inspired by swarm intelligence and natural ecosystems present unique frontiers for art. Many artists have used artificial swarm systems in their practice and utilized swarming principles such as self-organization and emergence (Barrass 2006; Beyls 2007) to create novel aesthetics.

Self-organization is a spatio-temporal process resulting from multiple interactions, positive or negative feedback, amplification of fluctuations, or randomness (Bonabeau et al. 1999). Another unique capacity of swarms is emergence, a complex collective phenomenon that arises from relatively simple lower-level interactions.

In addition, the aesthetic richness of swarms and their compositional properties are often the result of two core qualities: (1) swarm agents are autonomous and therefore useful for creating generative art systems (e.g. Shiffman 2004; Blackwell & Jefferies 2005; Bisig & Unemi 2005 and 2009); and (2) artificial swarms or “complex symbolic systems” act like organic or living entities, which makes them particularly attractive in ALife Art (e.g. Correll et al. 2013; Greenfield and Machado 2015).

A Complex Multibody

As AI and robotics have advanced, their influence in the cultural imagination and art have become inevitable. This poses ontological questions: Can machines be creative? What is creativity? What new aesthetics can or will emerge?

To respond to these questions and challenge the music traditions of using fixed instruments, we present *Liminal Tones (A / Autumn Swarm)*, a series of sound compositions with a multibody architecture, consisting of identical mechanical elements (figs. 7 and 8) that sync and swarm together, inspired by the colony behaviors of social insects (e.g. foraging ants).

Our goal is to explore a performative ontology and the potential aesthetics of swarm agents in sound art. To achieve this objective, we followed two criteria: (1) exploring chaotic and emergent behaviors, and (2) embracing imperfections and errors. *Liminal Tones (A / Autumn Swarm)* is an attempt and critical reflection of a still-emergent field of work.

6.3 Synchronous Speed Control and Spectrogram Analysis

For quantitative assessment and influence of the PSO-based PID controller, we evaluated the PID performance of the overall group behavior of multiple DC motors (speed and fluctuation). We chose the PID parameters using random values for K_P, K_I and K_D followed by the step response calculation, which resulted in unstable control.

Then we tuned the initial values using a PSO algorithm to reduce the peak overshoot and synchronize the DC motors, as shown in Table 1. Our primary results illustrated that to eliminate high fluctuations and synchronize DC motors, the PID values should be in range of $K_P \in [20, 75]$, $K_I \in [18,50]$ and $K_D \in [1, 40]$.

Parameters	Motor 1&2	Motor 3&4	Motor 5&6	Motor 7&8
K_P	23	35	51	67
K_I	46	18	20	23
K_D	2	14	27	39

Table 1: PID values for multiple identical DC motors and synchronous speed control

For qualitative assessment and the role of materiality in *Liminal Tones (A / Autumn Swarm)*, we analyzed six samples (fig. 9), which presents the spectrum of acoustic sound objects, and their pitch and timbral qualities on different surfaces (wood, ceramic and granite). Vertical lines reveal the rhythmic structures, and horizontal lines the harmonic structures across frequencies. For some sound categories, the audio samples are very noisy, meaning that all the frequencies are pretty much present, while others have fewer frequencies and show step intervals and rhythmic cycles, which resulted from vibrating patterns, and turning and twisting of the motors or errors (on-off). The speeding patterns can be identified too, in which the sound amplitudes vary with distance and result from fluctuations in the batteries.

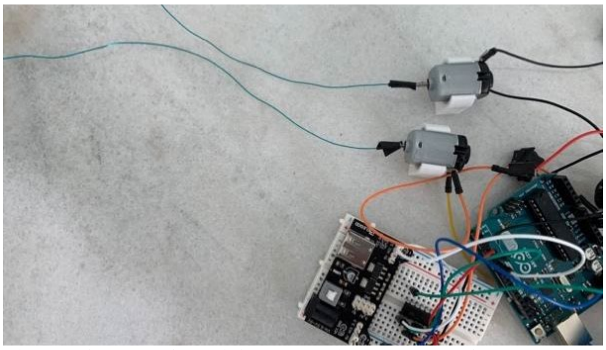

Fig. 7. Close-up shot of the *Liminal Tones* control system using an Arduino board.

Fig. 8. *Liminal Tones* in action, 8 DC Motors swarming together.

Moreover, each material shows different timbral signatures. For example, wood resonates in all frequencies, while ceramic absorbs sounds in a dry fashion and absorbs low and mid frequencies.

In general, *Liminal Tones (A / Autumn Swarm)* generated rhythmic patterns with high jumps between different frequencies and exhibited similarity to the combination of constant and rhythmic patterns of heavy hail and the noisy profile and calming pattern of sleet.

Combining the qualities of different materials helps broaden the resulting timbre and frequency domains and enrich the audio expressivity. Considering the inherent autonomy of swarms, it will be feasible to simultaneously engage multiple groups in the format of an ensemble with relatively wide timbral and frequency ranges, such as a mechatronic noise-ensemble.

Therefore, with respect to future works, our plan is to investigate multi swarms and a large number of DC motors as sound objects (100 or more) and further explore the collective behavior and swarm aesthetic with relatively wide timbral and frequency range and mechanical tones.

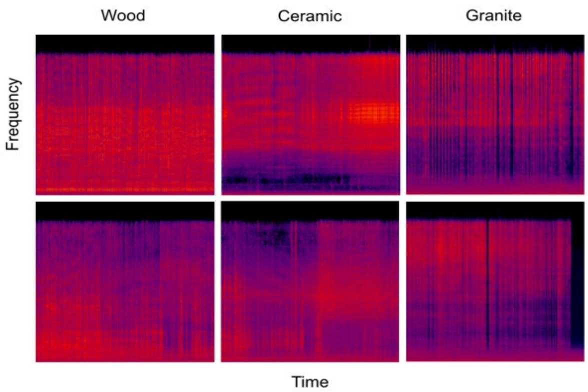

Fig. 9. Spectrograms of six sound compositions (each ranging from 15 to 30 seconds). Note the constant noisy profile of wood, and the mid-level frequencies and orders of ceramic or resonance of granite. Some samples have different characteristics, such as rhythmic patterns and high-low pass, while others are noisy.

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Biographies

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