NICO: An Open-Source Interface, Bridging the Gap Between Musician and Tesla Coil

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ABSTRACT

This paper describes the design and implementation of a new interface, Nico, which allows new and existing musical devices to control Tesla Coils. The interface uses an Arduino microcontroller to convert OSC and MIDI control data to TTL pulses that command the behavior of a Tesla Coil. This paper will give some background on the Tesla Coil, outline the design and capabilities of the interface, and will discuss the performance possibilities that Nico creates.

1. INTRODUCTION

The Tesla Coil has become a fascination of many, spawning a community of hobbyists and enthusiasts who build their own coils. As well as a strong hobbyist community, Tesla Coils have been installed in museums, schools and universities. The interest in Tesla Coils is often in their visual and physical qualities, as they can produce impressive electrical arcs, often spanning meters. These electrical arcs also produce sound, and many Tesla Coils are now built to be 'Singing Tesla Coils', also known as 'Zeusaphones'; a portmanteau of Zeus and sousaphone. These coils modulate the input to the coil, in order to control the frequency of the energy discharges.

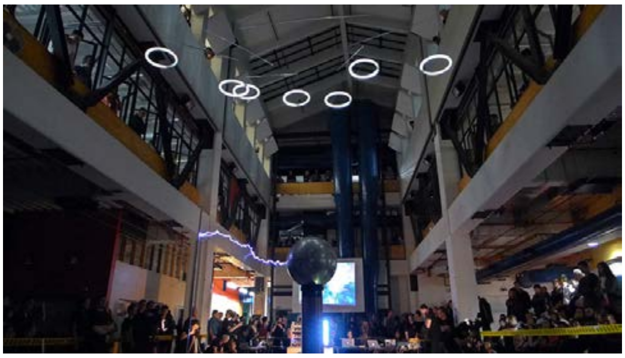

Figure 1. - A live Tesla Coil in a musical performance.

Figure 2. - *Left* - ArcAttack. *Right* - Björk performing 'Thunderbolt' live with Tesla Coil above.

Nikola Tesla originally invented the Tesla Coil during his research into electricity and wireless communication. Tesla built a small electrical resonant transformer circuit in 1891 that allowed him to demonstrate the ability to discharge high voltage energy, producing an electrical arc traversing five inches [1]. Ten years later, he was able to produce powerful discharges that traveled a thousand feet and as he put it, 'flashed a current around the globe'. This technology then became extensively used in electronic appliances like televisions, radios and ignition systems.

1.1 Previous Music Examples

The possibility of controlling the sound of the Tesla Coil has lead to a plethora of musical examples, with many people posting videos online of their coil recreating anything from the Bach's Toccata and Fugue in D minor to the Super Mario Theme tune. Often these are performed as a demonstration of the coil, and are controlled via custom-built methods to modulate the input.

One of these custom-built projects is Robert Connick's investigation into building and examining the acoustic properties of Tesla Coils [2]. A glove with embedded sensors was designed as a way to control the Tesla Coils output, converting the gestural behavior of the performer to control data.

Tesla Coils have also been used in public performances with an early example being ArcAttack's work starting in 2006 [3]. Their performances usually consist of a mixture of traditional instruments and their two large Tesla Coils, creating a visual and sonic spectacle. A stunt man often MC's the performances, and wears a chain mail Faraday suit to interact with the Tesla Coils. This suit adds to the visual feast, as electrical arcs are drawn to the Faraday suit, connecting the Tesla Coils to the MC.

In 2012, a Tesla Coil was used in a more mainstream context, with popular artist Björk using one in her song 'Thunderbolt' from her intermedia project *Biophilia* [4]. Björk has performed live with the Tesla Coil, using a range of different small coils.

Using electrical arcs to create sound has also been used in Simon Mann's 'Transcutaneous Electrical Sounding Linear Array for Keyboard-like Electrically Yielded Sound (T.E.S.L.A. K.E.Y.S.)' [5]. Created in the 1970s, the T.E.S.L.A. K.E.Y.S. consists of a series of spark gaps into which the player inserts his or her fingers to produce sound. Electrical arcs connect with the performers finger when close enough, and similarly to the Tesla Coil, these electrical arcs create sound. The pitch of the sound is predetermined, and can be set by adjusting each coils integral electrotome to create the desired pitch.

1.2 Access to Tesla Coils

One of the strongest motivations for creating Nico was the lack of accessibility for musicians to control Tesla Coils, with access for most musicians being non-existent due to multiple factors.

There have been some attempts to combine the specialized fields involved in building, controlling and performing with Tesla Coils. Lochi Yu and Fabián Abarca organized the Electrizarte project at the University of Costa Rica [6], which pushed engineering students to create art projects, including Tesla Coils. This is a rare example where Tesla Coils have been built with performance in mind.

Another factor was a lack of commercial or open-source methods of controlling Tesla Coils for musical purposes. Although there does exist some commercial interfaces that allow for the control of Tesla Coils for musical purposes [7, 8], there is yet to be a system that allows the user to have fine control over the behavior of the Tesla Coil and one that is focused on providing the user with expressive musical control. The majority of existing interfaces utilize the MIDI protocol which have the benefits of being compatible with many existing devices that are specifically designed for musical creation. However, there are still many aspects of musical expression that these existing interfaces lack. Importantly, there is yet to be an interface that provides the user with dynamic control over independent voices. Additionally, there is yet to be an interface that allows other methods of communication with Tesla Coils.

While it can be seen that there have been some interest in using the Tesla Coil as a musical instrument, so far the musical applications are still in their infancy and the range of musical control is limited. Nico provides a more expression-oriented approach, with four-voice polyphony and dynamic control over each voice. Pitch-bend functions have also been implemented and the capability of accepting OSC messages allows the user to have more control over the frequency and velocity behavior of the Tesla Coil.

This paper describes how the design of the Nico interface affords new musical expression and expands the existing musical possibilities of using a Tesla Coil as a sonic object. First, the different topologies of Tesla Coils will be examined in order to show the differences in control a user can have. Following this, the design and capabilities will be described and finally the musical application and future developments this research can provide will be discussed.

2. TESLA COIL TOPOLOGIES

Tesla Coils have many different designs, but all depend upon switches to control when and for how long power is input per second [9]. Many Tesla Coils today use IGBTs (insulated gate bipolar transistors) as switches. These coils are known as Solid State Tesla Coils (SSTCs), as opposed to original 19th century variety, which used spark gaps as switches. IGBTs require a gate signal to turn them on and off. It is the timing of this gate signal - when it is sent, and for how long, that is central to musical operation and expression.

So far, Nico has been used to control two different types of SSTCs - Offline Tesla Coils (OLTC), and Dual Resonant Solid State Tesla Coils (DRSSTC).

2.1 Offline Tesla Coil (OLTC)

The OLTC requires a high degree of timing precision over the length of the gate pulses. For the OLTC, each gate pulse needs to be predetermined length in order for it to be operated safely. This limits the control that the user has over the sound of the Tesla Coil, as the gate pulse width is strongly connected to the dynamic control. However, this does not limit the maximum polyphony.

2.2 Dual Resonant Solid-state Tesla Coil (DRSSTC)

The DRSSTC are more tolerant and can support variable pulse length. This means that each gate pulse is not limited to a predefined length and there can be individual control over each voices, or in fact each individual length of a gate pulse.

3. INTERFACE HARDWARE

Nico is based on the Arduino Mega microcontroller, which has been expanded to allow for Midi and Ethernet hardware communication. The Arduino Mega has been chosen as it uses the Atmega 2560 microcontroller, featuring six on-board hardware timers. These timers are used as the basis of the timing system of the TTL pulses and are capable of a high degree of precision.

The interface is housed in a metal box in order to shield and protect the components from the electromagnetic field the Tesla Coil produces. It features input and output connections and some basic control components to allow the user to quickly customize settings.

For input, the interface accepts a standard MIDI 5-pin DIN jack and an Ethernet port. Currently, Nico supports MIDI note on, note off, and pitch bend control messages. When in OSC mode, the ethernet connection allows for the communication of OSC messages from an external source.

4. SOFTWARE IMPLEMENTATION

The software for the Nico interface consists of software on the Arduino Mega itself and a Processing application, which is used to convert and send incoming OSC data over Ethernet to the Arduino board.

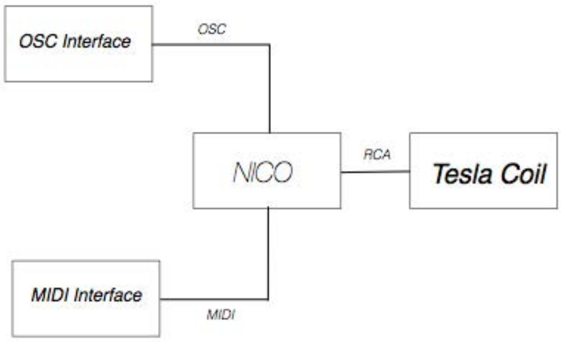

Figure 3. - Data flow.

4.1 Arduino

4.1.1 Hardware Timers

The Arduino Mega has four 16-bit timers and two 8-bit timers, which are used to control the timing and length of the TTL pulses. These timers all run from the 16 Mhz CPU that allows for control on a minute time scale.

An important consideration for any Tesla Coil control unit is safety of pulse length. If the pulse length is too great, current overload can be dangerous and damage the Tesla Coil itself and potentially other appliances in its proximity. Due to this safety consideration, one of the 8-bit timers is solely responsible for creating and terminating TTL pulses. This ensures that the length of any TTL pulse does not exceed a pre-defined length. There is also a stringent restriction on the frequency of TTL pulses. This restriction is dependent on the coil itself, but a feature has been implemented to specify a maximum cumulative frequency in order to protect the coil from excessive input voltage.

Each 16-bit timer is designated the timing control of a voice. By using the on-board timers, the computational time needed for controlling the TTL pulses are kept low which is paramount when dealing with very short time scales.

4.1.2 MIDI Functionality

When using the MIDI input, the behavior of creating and controlling oscillators is very similar to traditional MIDI keyboard instruments. The MIDI note on message is received and the pitch and velocity information is used to create a new voice. These parameters stay constant until a note off control message is received at which point the voice is terminated. The MIDI note is converted to a frequency and the velocity mapped to the length of the TTL pulse. Nico allows for variable pulse length control over each voice with a range of 0.5 to 100 µS.

The pitch bend control message can be used to modulate the frequencies of all the voices present. The range of pitch bend is an octave above and below the original note. These pitches are not quantized to equal temperament tuning so there is a continuous glide when using pitch bend.

4.1.3 OSC Functionality

The OSC implementation mirrors and expands the functionality of the MIDI control behavior. The Processing application acts as a receiver and translator of OSC messages. Each OSC message consists of an address pattern and a bundle of information. The incoming messages are differentiated by their address patterns, much like MIDI control bytes, and this information is then reformatted to a UDP package to be sent to the Arduino via Ethernet. Many music programs have started supporting OSC and are easily configurable to meet the requirements of the Processing application.

One benefit of using OSC when creating an oscillator is that the user is not limited to the equal-tempered tuning of the MIDI notes. Instead, any combination of frequencies can be produced which allows for micro-tonal compositions and for special effects like beating patterns produced from two oscillators at similar pitches.

Another benefit of using OSC is that it allows for an increase in resolution of control parameters. With MIDI, you are limited to 7-bit resolution, which allows for 127 steps of control. The resolution is vastly increased as 16-bit integers and floating-point values can be supported.

The flexibility of the OSC communication protocol also allows for other control methods. A velocity update message can be sent to change the dynamic of a voice, without the need to retrigger the note. Similarly, the frequency of a voice can be updated, which can allow for complex pitch trajectories that can be independent of one another. Currently, there is no equivalent of these behaviors in MIDI mode.

5. MUSICAL APPLICATION

Previously, Tesla Coils have rarely been used as a novel musical instrument in creating new sounds and compositions. Instead, it has been predominantly used as a novelty sound generator, often to play back famous tunes. This may be due to the visual appeal of the Tesla Coil, as well as the difficulties of creating a musically expressive Tesla Coil system. It takes high degree of technical knowledge to create and control a Tesla Coil that works efficiently and safely. This technical knowledge is often not held by artists and musicians who may want to create pieces and sonically explore the sound of the Tesla Coil if they had access.

This is one of the strongest motivations for creating an open source interface for controlling Tesla Coil. Our intent is that by creating an open source solution, musicians can easily interact with the Tesla Coil with methods that they are familiar with. They can also modify the settings themselves to create new interaction possibilities. This widens the availability of interfacing with Tesla Coils and hopefully allows for a more subtle and exploratory approach to musical creation.

The Nico interface has been tested on multiple Tesla Coils, and has also been used in a performance setting, combining fixed media with a small Tesla Coil.

Figure 4. - Mo H. Zareei and Jim Murphy performing with a Tesla Coil controlled by the Nico interface.

The performance using the Nico interface provided a range of approaches to controlling the Tesla Coil. Previously, the common approach has been to treat the Tesla Coil as a melodic instrument, an approach seen in the works by ArcAttack and Björk. The addition of control over independent voice dynamics proved to be extremely valuable, as it allows for a range of new possibilities. More expressive melodic passages can be played and the Tesla Coil becomes more of an instrument, rather than a novelty sound generator. There is more flexibility to blend the Tesla Coil with other sounds, and create more complex relationships between its own multiple voices, and other sounds as well.

The Tesla Coil is also not limited to just this approach. In contrast, a more rhythmic and percussive approach produces a new element of the Tesla Coil as an expressive instrument, as it can create complex noise gestures. Sharp bursts of noise can be created with rhythmically complex passages working well. The timbre of the passages can be controlled through density and register of pitch, and this method works well with a noise-based aesthetic.

6. FUTURE WORK

Nico allows for greater access for controlling Tesla Coils in musically interesting ways. Although the Tesla Coil has rarely been treated as a sonically interesting object, the development of interfaces and methods that allow for more subtle music control is essential to creating new musical interactions.

Future work involving Tesla Coil interfaces would involve producing more nuanced control for musical expression, as well as expanding the output possibilities of the interface. This would allow for not only novel interactions between the user and the Tesla Coil but also between each coil. The arc behavior changes substantially when two Tesla Coils are in close proximity with each other.

The development of these interfaces will be heavily dependent on the accessibility of Tesla Coils to the public and musicians, as hobbyists currently still build most of them. Projects that combine the expertise of engineers and musicians like the aforementioned Electrizarte project will help in this aspect, allowing for a greater range of people to perform with Tesla Coils and drive innovation of their control.

Future work could also be outside of a musical focus, with an improvement in control opening up new possibilities for research in arc behavior.

Acknowledgments

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