DIGITL
A Reduction of Guitar

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ABSTRACT
This paper presents the *Digitl*, a digital processing system using a reduced electric guitar as control input. The physical design is based on three fundamental elements: String, Body and Electromagnetic Pickup. The main characteristic of the instrument lies is the linear matrix x-y configuration of the strings and frets. The purpose of the instrument is the application of individual signal processing at each X-Y position.

It is described the technical aspects of the *Digitl*, including the design of the matrix configuration and the digital signal processing algorithms. Specifically, a set of Max/MSP patches that routes the signals from the strings to the processing engine.

The experimental results confirm the importance of the design and configuration of musical instruments in the context of expressive performance.

Author Keywords
Strings, Digital Processing, Microsound, Numbers

CCS Concepts
• **Applied computing → Sound and music computing**; Performing arts;

1. CONTEXT
Electric guitars are one of the most popular and versatile instruments in modern music. They have undergone numerous technological developments in the past decades, including the introduction of solid-body designs, active pickups, and digital processing. These innovations have expanded the expressive range of the guitar, allowing for the creation of new and diverse sounds.

In this context, the *Digitl* reduces the electroacoustic nature of the guitar to the minimum expression, and the focus is placed on the "augmented" computer aided processing. The interface of control features a linear matrix configuration of the strings and frets (see Figure 1). Recent studies [1] [2] confirm the convenience of grid configuration. Multiple efforts related with augmented nylon guitars [3] and augmented electric guitar [4] are in continuous development.

The instrument is designed to be played standing up, so it is attached to a stand that can be adjusted in height, angulation and tilt.

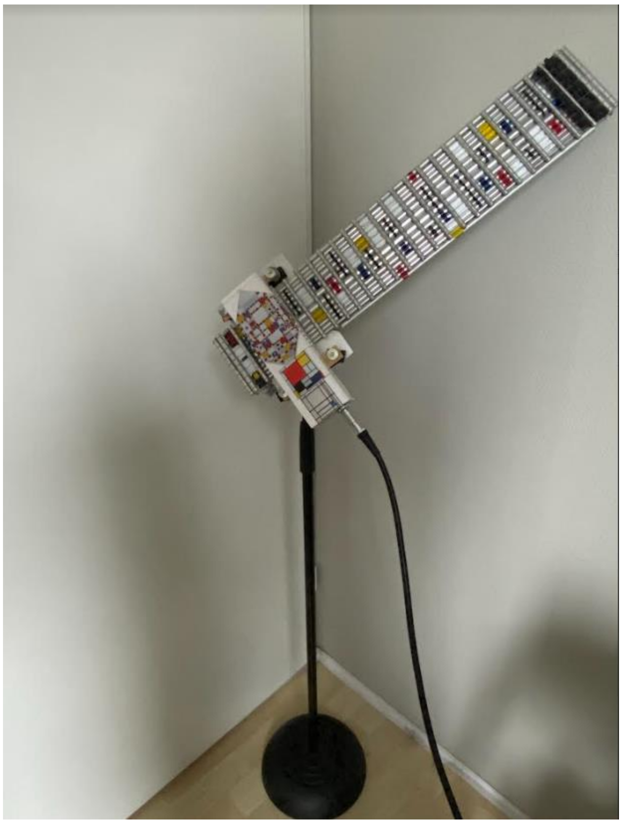

Figure 1. The *Digitl*

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This simple mathematical idea of the matrix is already in the treatise *On Playing the Vihuela* published in 1555[5] (see Figure 2). In the first page of the named book *"… or they change the music to suit the instrument, or they change the instrument to suit the music…"* reflects the circumstances of a fretted instrument like guitar with 12-Tone Equal Temperament (12-TET). Notice that in the example the 6th string is tuned in Gamma Ut , the lowest note in medieval music notation, that corresponds to the actual G2 ("Ut" was the denomination of the hexachord's tonic, and it could adopt the form of G, C or F depending on the hexachord). In our days, computers can modify these circumstances.

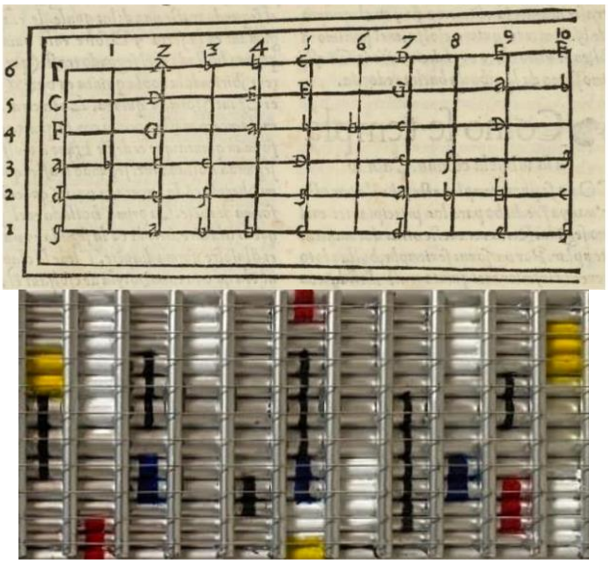

Figure 2. Matrix X-Y in *Digitl*

2. THE *DIGITL*

2.1 *Digitl*

The instrument is based on the fundamental principle of real-time signal processing, both serial and parallel, in order to transform the sound. The vibration of the strings is captured by the pickup module, and after analog-digital conversion, the signal is processed with MAX/MSP. The signals are sent to the virtual audio loopback driver BlackHole and 16 digital channels are received on the DAW, where each channel is processed individually until the final mix is routed to the sound system. This configuration allows multiple processing and manipulation of audio data in real-time, offering a great amount of creative control to the user. The mappings between the pressed positions of the matrix X-Y and specific sounds or pitches are designed to allows an intuitive and expressive interaction for the user. These mappings are highly customizable, allowing users to adapt the instrument to their individual needs and preferences.

2.2 Materials

2.2.1 Body. Aluminium

The instrument is built with materials of a DIY Store. Aluminium rods of 6, 8 and 10 mm, were bonded with epoxy adhesive in order to obtain 2 cm of separation between frets and 1 cm between strings. The use of aluminium increase the intrinsic sustain of the vibration of the strings (see Figure 3).

Figure 3. Lattice of *Digitl*

2.2.2 String. Cobalt

String is the substantial component of the instrument, and during the design of *Digitl*, several experiments were conducted to determine the optimal material for the strings, ultimately leading to the selection of cobalt. This decision was based on an analysis of the spectrogram of nickel and cobalt (see Figure 4).

It was observed that the intrinsic resonance is higher in nickel than in cobalt, and there is presence of acoustic energy in the harmonics above 20 KHz. This fact generates aliasing during more than 20 milliseconds after the attack, and this is something not aligned with the main interest of this project. Also, the temporal resolution that relates with the musical control is better in the case of cobalt for the same reason.

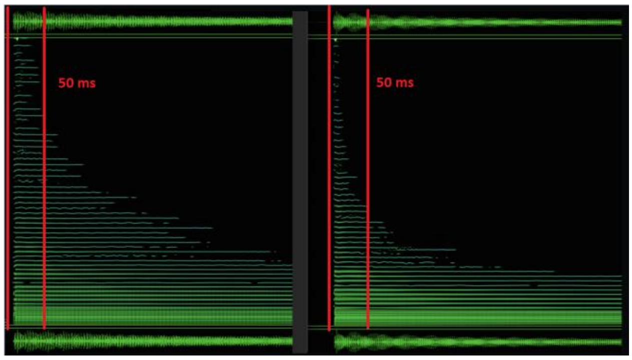

Figure 4. Nickel vs Cobalt Spectrogram

2.2.3 Electromagnetic Pickup. Nu

Digitl uses the Nu capsule from Cycfi Research, a monostring electromagnetic pickup built with low impedances coils and an integrated preamplifier, that gives a flat response proportional to the vibration of the string.

The ten Nu Capsules were mounted in a module built with bamboo that contains the breakout board and the multichannel connector (see Figure 5).

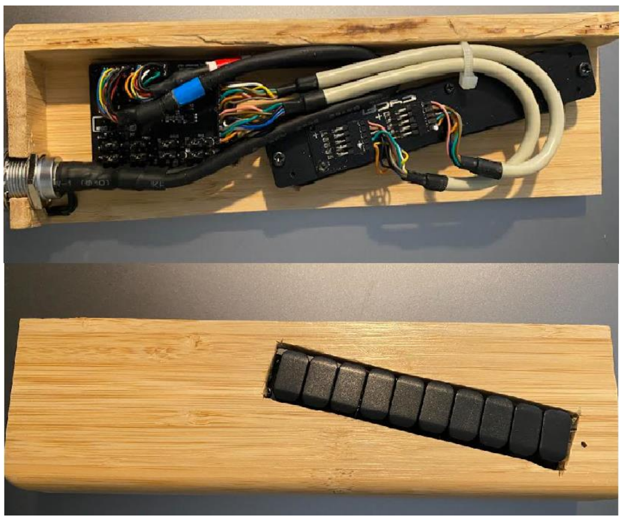

Figure 5. A group of 10 Pickups in *Digitl*

2.3 Technical Aspects

2.3.1 *General Diagram*

The following general diagram represents the signal path from the string to the sound system (see Figure 6). The signal path configuration is identical for the 10 strings. Inside MAX/MSP, the signal from the string is directed to the frequency analysis stage, which determines the pitch produced by the string.

The output of the frequency analysis stage is used in a switching algorithm, using multichannel objects of MAX/MSP, in order to route the signal to different channels depending on the pitch range detected. Each channel is processed using a feedback-based technique similar to a simple Karplus-Strong. An individual amplitude envelope is applied to the original signal, and another envelope is applied to the feedback factor. There are 20 processors for every string, a matrix of (x=20 Frets) x (y=10 Strings), making a total of 200 processors with independent parameters.

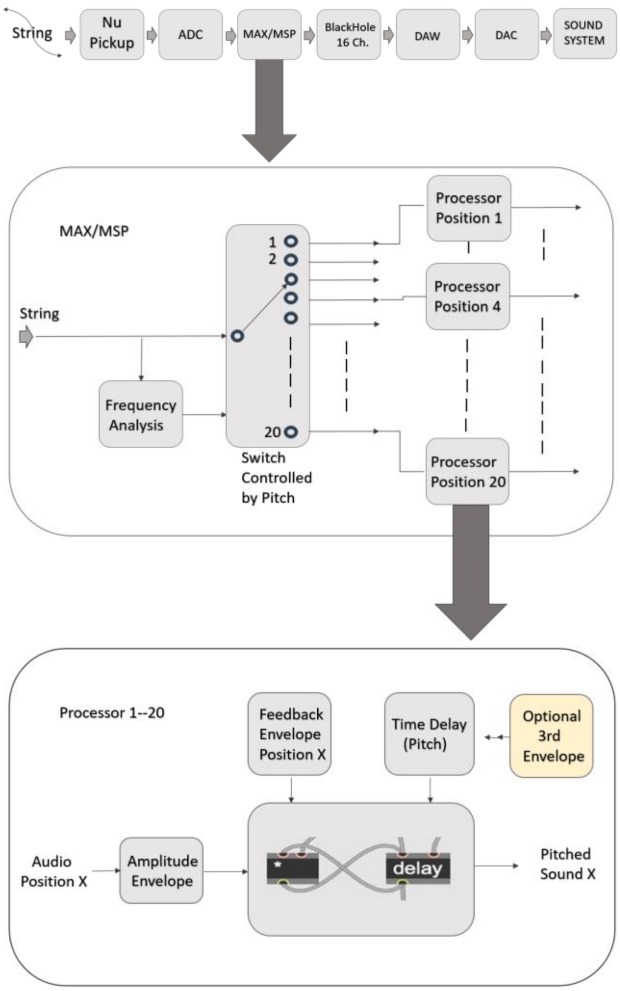

Figure 6. General Diagram of *DIGITL*

2.3.2 *Frequency Analysis. FFT*

In *Digitl*, it was selected a string size of 0.022", and for ergonomic considerations the type is "wounded". The Pitch Tracking algorithm is based on FFT, and the window size is 512 samples, which gives a latency of around 10 milliseconds. Alternatively, it is possible to design the instrument with "unwound" strings, and for example 0.012" size. In that case, would be possible to have a window size of 256 samples, and obtain a latency of the Pitch Tracking FFT algorithm on the range of 5 milliseconds.

The decision was based on the desired tension and tuning of the string. It was selected the Frequency 261Hz, that corresponds to C4, middle C in 12-TET, for tuning the strings. In the 10th fret, all the strings are tuned to match C4 (see Figure 7).

MIDI NOTE	54.5	55.3	56.1	57	57.9	58.9	60	61.1	62.4	63.7	65.1	66.6	68.3
PITCH (Hz)	190	199	208	220	231	245	261	278	300	323	351	383	422
X	3	4	5	6	7	8	10	11	12	13	14	15	16

Figure 7. Correspondence Pitch Range and X position

Due to the linear spacing of the frets at intervals of 2 cm, the pitch difference between two adjacent frets is not one semitone. Depending on the direction, this difference is bigger or smaller. The actual values were measured empirically.

The algorithm needs to generate the correct X position in order route the input signal to the corresponding X channel (see Figure 8).

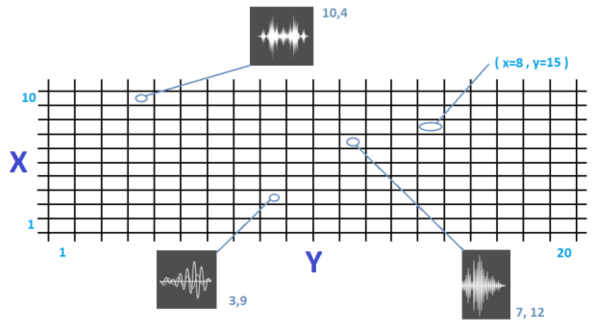

Figure 8. X-Y based sound capture

2.3.3 *Processor*

With this setup, each channel is processed individually with a single feedback loop, similar to the basic Karplus-Strong algorithm. The input signal is processed with two envelopes, one controlling its amplitude and the other regulating the feedback factor. Additionally, a time delay is used in order to adapt the pitch.

By using this approach, each channel can generate a unique sound that is shaped by the interplay between the amplitude and feedback envelopes, as well as the delay time. The feedback loop enhances certain frequency ranges and creates a resonant effect, while envelopes control the overall loudness and decay of the sound.

This method allows the creation of dynamic and expressive sounds, with a wide range of pitch and tonal variations.

The interaction between the amplitude and feedback envelopes in this processing scheme plays a key role in shaping the resulting sound. Adjusting the amplitude envelope, we can create sounds that are short and percussive or long and sustained. On the other hand, the feedback envelope regulates how the frequency components are emphasized or suppressed over time. Adjusting the feedback envelope, we can create sounds that can change their tonal content, from bright and resonant to dark and mellow.

For example, we can create plucked-string like sounds with a quick attack and short decay by setting a low value for the amplitude envelope and a high value for the feedback envelope. Conversely, we can create bowed-string-like sounds with a slow attack and long decay by setting a high value for the amplitude envelope and a low value for the feedback envelope. This basic algorithm permit an individual tone and character of each channel (X-Y position), and in total there are 200 channels running in parallel. Independent resonant actions with long decay times are possible, and can be obtained particular combinations.

2.3.4 The Third Envelope

The previous setup is the configuration that generates traditional and pitched tonal sounds, normally using a 12-TET mapping. A third envelope in the time delay adds more sonic complexity. We can create a range of interesting effects such as modulation, flanging and phasing. The interplay between the three envelopes increases the complexity, but allows the creation of nuanced, intricate and engaging sounds.

Changing the delay time from 0 to some value in a few milliseconds, together with high feedback, can produce intense percussive sounds as well. This technique could add impact and energy to one specific action. By modulating with dedicated envelopes, we can further refine and shape these percussive sounds. For example, by using an envelope with sharp attack and short decay time, we can create a tight sound. Conversely, by using an envelope with longer release time, we can create a more sustained and booming sound .

3. TOPOLOGIES OF THE MATRIX.

3.1 Mapping strategies.

The instrument is named *Digitl*, a neologism inspired from Nahuatl language. The word draws the meaning from the latin term “digit”, “finger” in English. The term “digital” is related to both fingers and numbers, as fingers are used for counting. Mesoamerica cultures developed complex methods of counting and measuring time, and their mathematical and astronomical understanding of the concept of “Cyclicity” [6] [7] is beyond our reasoning [8]. *Digitl* honors this cultural legacy by integrating the traditional finger counting method with modern digital technology in relation with Music.

The *Digtl* starts with his 3 basic elements: Body, String and Electromagnetic Pickup (Aluminium, Cobalt and Nu). Then the main Processor unit is based on 3 Envelopes (Amplitude, Feedback and Time-Delay), and now, the mapping strategies of the matrix X-Y, are based on the faculty of counting (1,2,3) from one Reference point, the Zero.The fingers movements creates their own dancing-like harmony.

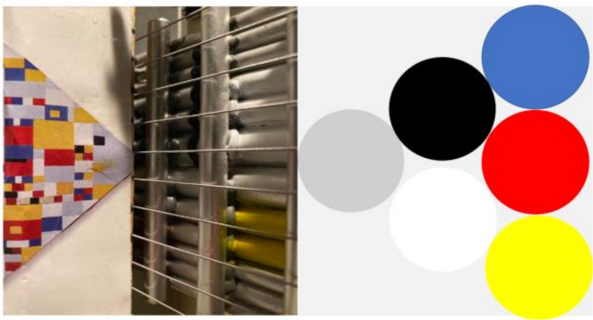

Figure 9. Unity detail in Mondrian in *Digitl*

The cell, the basic unit of life, represents the cycle of the One, the mitosis process of division that is a multiplication at the same time. The concept of Two and Three are generated both in One. *“Appearing in opposition, nature is unity….”* Mondrian *(1945*) [9] (see Figure 9). In *Digitl*, the mapping is open. It can go from same pitch-different timbre (x-y), to different pitch (x-y)-same timbre, or a combination.

3.2 Playing Techniques.

The purpose of the previous explanations is just to create a relationship between harmony theory and the playing techniques of the instrument. The instrument is normally played using 8 fingers tapping style (see Figure 10)., but any other technique proper of guitar could be used. Considerations about guitar-like instruments can be found in [10] . The counting process of 1, 2, 3 that generates a combination of movements in hands and fingers configures the mechanical and dynamic control of the sound. One specific movement on the matrix, can produce an infinite possible combinations of pitches and sounds, because the movements are not mapped a priori, and there are no limits in the program of the digital world. The default selected mapping is a 12-TET system with 1 semitone between frets, and 5 semitones between strings. But the finger movements are considered the containers of the musical expression, and the digital postprocessing of the sounds with computers can produce a complete detachment of the actions from the sound.

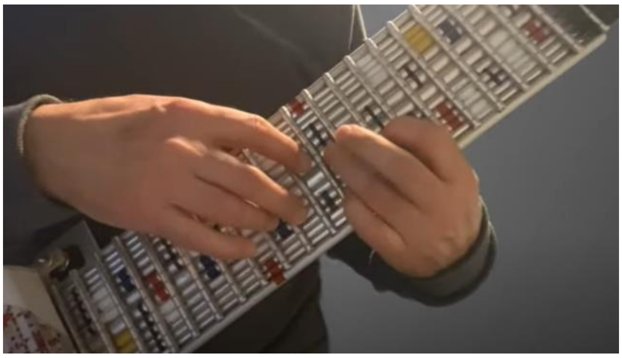

Figure 10. Tapping technique of *Digitl*[1]

4. FUTURE DEVELOPMENTS

4.1 Musical Instruments Digital Audio Transmission Protocol

Digitl has in digital domain the virtual channels corresponding to the (x,y) audio event and the metadata of analysis. It is proposed a protocol for digital audio transmission of 16 concurrent digital audio channels, multiplexing by demand all the virtual digital audio channels (20 frets x 10 string = 200), with the label of the coordinate (x,y), in order to be demultiplexed in another processor. Transmission between processors needs to be done in less than 1 millisecond, following the standard AES67. The purpose of the protocol is to maintain in the digital domain the audio data information linked with the action of the instrumentalist, like an extension of MIDI 2.0. More than one communication protocol between synthesizers, it’s proposed a communication protocol between processors (instruments) with real audio data. The technology for this purpose is not simple, because real-time here needs to be maintained in the range of the microseconds, but the actual technologies of digital data communication systems are more than enough to reduce the cost of this implementation.

4.2 Convolutional process in parallel.

Another technological emergence is the generalization of GPU’s for audio processing. One can imagine an instrument like *Digitl*, with 200 positions X-Y with independent audio data, and apply one independent convolution with an specific impulse response, in parallel, in real-time.

[1] Video-Demo: https://youtu.be/tZjB5cAAnBc

5. CONCLUSION

The results are more than satisfactory. The playability of the instrument is complete, without intrinsic defects. The development of the digital processing part of the instrument is fully functional; however, this part of the instrument is by definition an endless process in continuous “change”.

6. ACKNOWLEDGMENTS

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7. ETHICAL STANDARDS

There are no observed conflicts of interest. The software is used under License, or is public domain.

8. REFERENCES

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