Cristóvão Diniz Trevisan, Viktor Volochtchuk

Guitar Digitizer

Brazil

2017, v-0.0.1

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Guitar Digitizer

Project presented as graduation material for the course of Electronic Engineering at UTFPR

Federal University of Technology - Paraná – UTFPR

Electronic Engineering

Graduation Program

Supervisor: Gustavo Benvenutti Borba

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Project Approved. Brazil, October 9, 2017:

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This work is dedicated to those who supported our way into through enginnering course, even more when ourselfs tried to give up.

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Abstract

Guitar are one of most popular instruments today, but there is one big disadvantage to use it: there is no good and affordable way to digitalize it's music. The biggest problem with this is the cost to annotate music, as it needs to be done by manually. This project tries to build one such system, building from passive hardware (hexaphonic pickup) to modern signal processing (pitch detection), attempting to produce a cheap and effective equipment for guitar music annotation by means of generating MIDI format data.

Key-words: guitar. digitizer. MIDI. pitch. detection. hexaphonic.

Resumo

Violões e guitarras estão entre os instrumentos mais populares da atualidade, mas existe uma grande desvantagem em os utilizar: não há um meio barato e eficaz para digitalizar sua música. O grande problema com isso é o alto custo para transcrever partituras, que atualmente é um processo manual. Esse projeto tenta construir um sistema com esse propósito, criando desde sensores passivos (captador hexafônico) até processamento digital de sinais moderno (detecção de nota), visando um produto barato e eficaz para anotação musical através da geração de dados no format MIDI.

Key-words: guitarra. digitalizador. MIDI. nota. detecção. hexafônico.

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List of abbreviations and acronyms

MIDI	Musical Instrument Digital Interface
UI	User Interface
GUI	Graphical User Interface
API	Application Programming Interface
USB	Universal Serial Bus
DOM	Document Object Model
n.d.	No Date
fft	Fast Fourier Transform
ifft	Inverse Fast Fourier Transform

List of symbols

Ω	Ohm resistance unit

Contents

Introduction

Part I

Hardware

Part II

Firmware

Part III

Software

1 Tools Selection

1.1 Top Level Requirements

The exact implementation of each of the items will be discussed later, but to simply set our requirements a general list of them is:

a) Desktop GUI

b) Efficient signal processing (for pitch detection)

c) Real time graph visualization of the signals (oscilloscope like)

d) Access to *libusb* (LIBUSB, n.d.) API

e) Access to MIDI API

1.2 Language Choice

1.2.1 Java

The first choice was Java, as it meets all requirements. Desktop GUI can be done using Swing, a good library for pitch detection is also available (called TasosDSP (SIX; CORNELIS; LEMAN, 2014)). There is also a binding to libusb called usb4java and native MIDI support.
Following that idea a functional prototype was built, but a few problems came to rise. The first is that usb4java high-level API had bugs and was not working correctly. The solution was to fall back to the lower level API, but that made things much more complicated as threading and synchronization problems had to be dealt with. There was no good library for real time visualization either, which made really hard to both debug and tune the frequency detection algorithm. On top of that Swing is at least non-pleasant compared to more modern UI programming, so a second approach came to be.

1.2.2 JavaScript

In alignment with both current work experience and world programming tendencies JavaScript was taken as a choice. We will see that requirements fit much better now, for the following reasons.
For the desktop GUI, JavaScript has a few nice and mature Desktop GUI frameworks, like Electron and NW.js.
JavaScript is an interpreted language, and for that has a low efficiency when compared

to C++ or Java. That is huge problem, but there is an easy overcome. As this project tries to build a desktop application, Node.js will be used ultimately, and it has support for C++ bindings. That means the JavaScript code can call a compiled C++ library to calculate the pitch, thus solving the problem.
Graph visualization should not be a problem either as there are a lot of libraries for that. The most problematic requirement in Java was *libusb* support. It is available in JavaScript using *node-usb* (NODE-USB, n.d.), and a few simple tests returned good results with a much simpler API. MIDI was also tested and worked just fine.

1.3 Desktop Framework

Now that JavaScript is set as our final selection we need an environment to run it. There are two already listed really mature and popular choices: Electron and NW.js.
At first Electron was used to build a test application, because it is the most popular of the two (in fact even the editor used to write this words is built with it), but the pitch detection call was running slowly. As a mater of fact it was running much faster using pure JS code rather than the C++ library. A deeper research was needed, and the way Electron worked was getting in our way, but first it's necessary to know what Node.js is.

1.3.1 Interpreter

JavaScript is a interpreted language and thus needs an interpreter. The most common one is Google V8, which happens to be the same one used in most web browsers as well as in Node. The difference between browsers and Node is simply the API that comes with them. Web needs firstly to access the UI (html) and ways to modify it, it also needs secure and limited access to hardware and internet calls. Of course that means web JavaScript code cannot use C++ libraries directly.
On the other hand Node is a more pure version of V8, it also gives the possibility to write and call C++ code (feature needed for this project), which ultimately makes it as capable as any desktop program can be. Node also comes with a hand-full set of native resources (like file system and full communication access), but it does **not** provide any kind of GUI. Knowing that it is possible to have a better understanding on how the two desktop environments work.

1.3.2 Electron

Electron by design has at least two processes running (HOW. . . , 2017), one for the "web" and other for Node access. The answer for how the web process access native resources is also to why the execution of the C++ processing library was slow: it uses inter-process communication (IPC). IPC makes things a lot slower, which ultimately makes impossible to use Electron in this project.

1.3.3 Node Webkit

Differently from Electron, NW.js (NODE..., n.d.; HOW..., 2017) takes the Node environment and combines it with Chromium into a single process, removing the use of IPC. Initial tests reported that the pitch detection library has fast execution as expected.

1.4 Architectural Tools

NW.js will go only as far as to give access to both Node and DOM API's. But that is too crude, and not what we wanted by given up on Java Swing. Again based on current work experience and world tendencies the setup chosen is React + Redux.

React (REACT, n.d.) is a library created by Facebook and world wide used for UI applications. It uses a declarative component-based system that makes it easy to build scalable and reusable code.

React only go as far to help building the UI, but we also need to pass the state of the application to the UI components, and that is where Redux comes in. It keeps all the application state stored in a single place, described by transition functions. That makes the storage system easy to be tested and used, because all actions (that modify the state) must be well defined and it doesn't rely on the UI (React), making it easy to test.

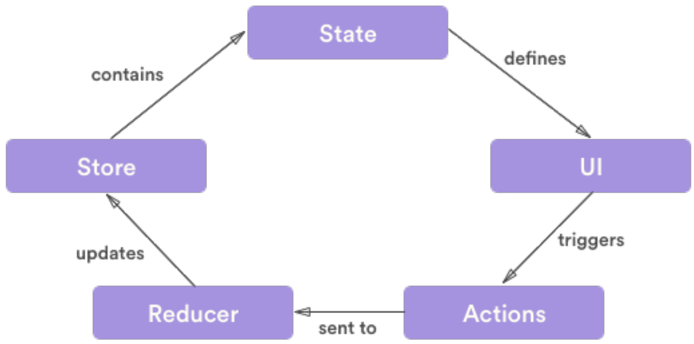
Figure 1 shows the flow of an application that uses React + Redux. It is obvious to see the simplicity it has, a single path must be followed. This simplicity is what makes it much easier to use against other frameworks like Java Swing.

There is still the choice of the visual library to use, and the chosen one is Semantic UI React (SEMANTIC..., n.d.). It has some nice and robust React components to build a well designed application.

1.5 Fast Signal Processing

Pitch detection is a heavy problem to solve, and good implementations are time consuming, so we need efficiency to run it real-time. The library already said to be used didn't actually existed, the only one available was a pure JavaScript library (PITCHFINDER, n.d.) which is not suitable for this project. The solution was to build our own library based on both the pure JavaScript one and TarsosDSP (SIX; CORNELIS; LEMAN, 2014). Implementation details discussed further on chapter 2.

Figure 1 – React Redux Flow Diagram



Source: Getting... (2016)

1.6 Real Time Visualization

There are lots of charting libraries available for use with web interfaces (and by extension NW.js), unfortunately none was good fit for real time high density signals such as audio. The solution was again to build one, since all other things are looking to run smoothly in JavaScript, implementation details on TODO-REF.

2 Pitch Detection

Pitch detection is simply frequency detection with the restriction of note quantization, Table 1 shows the base frequency for each of the 12 existent notes. Multiples of the same frequency are seen as the same note on a different range, known as octave.

Table 1 – Notes Frequencies

Note Name	Frequency
A	440.00
A#	466.16
B	493.88
C	523.25
C#	554.37
D	587.33
D#	622.25
E	659.25
F	698.46
F#	739.99
G	783.99
G#	830.61

Source: made by authors

Even though the quantization makes things simpler it's still a hard task, even more for instruments where there is the presence of harmonic series. Harmonic series notes are multiples of the fundamental frequency (most important note) produced by integer sections of the instrument vibration. Figure 2 shows an visual representation of why there exist. The existence of them as well as the presence of both inter-signal and white noise makes necessary the use of non-trivial algorithms for pitch detection, and two of them will be discussed next.

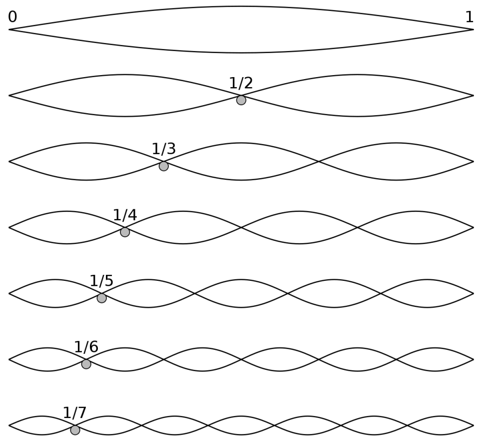
2.1 YIN algorithm

Autocorrelation is a well know function to calculate a signal's fundamental frequency, but it gives too much error for this project use case. YIN (CHEVEIGNÉ; KAWAHARA, 2002) is a method that uses a few improvements to the autocorrelation method, achieving a much higher precision. It also can be implemented with logarithmic growth as the autocorrelation can be calculated using the fft and ifft algorithms. The algorithm can be divided in 6 steps, as follows:

1. Autocorrelation

2. Difference

Figure 2 – Harmonic Series



Source: Wikipedia (2017)

3. Cumulative mean normalized difference
4. Absolute threshold
5. Parabolic interpolation
6. Best local estimate

It's important to notice that the absolute threshold is a controlled attempt to regulate the error introduced by the harmonic series (as in Figure 2), it thus gives preference to lower frequencies (below the threshold).

2.2 MacLeod algorithm

MacLeod (MCLEOD; WYVILL, 2005) goes for another approach, using the square difference function. More precisely it uses a special normalized version of it. The best result is then calculated by means of using a parabolic interpolation of the highest peak and its two neighbors, this process also gives a threshold constant that limits the detection of the neighbors, thus the possibility of some tuning. As we will see this gave the best results for our project after some tuning.

2.3 Implementation

Part IV

Results and Dicussions

Conclusion

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Appendix

APPENDIX A – Quisque libero justo

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Annex

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