Guitar Chord Identification and Display on a Six String Guitar

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Abstract

The following project has been engineered to help a person who is new to guitar to learn the instrument quickly. It will help the new learner to recognize the chords played in a music piece and guide the learner to play the respective chords with the help of LED matrix. The project is divided into two parts; Part 1 of the project deals with the task of identifying the chords of guitar from an audio piece, and Part 2 concentrates on displaying these chords with the appropriate finger position on a six string acoustic guitar with the use of colorful LED’s placed beneath each string on the fret board. Experimental results show that the algorithm developed to recognize the chords perform very well on the audio file which has only a single instrument (guitar, piano) though the chords recognized are not 100% accurate.

Keywords: Notes, Chords, Scale, Harmonic, Fret, Arduino, Short Time Fourier Transform, Pre-Processing, Analysis, Post-Processing.

1.0 INTRODUCTION

INTRODUCTION TO MUSIC THEORY:

Music is an artistic form of communication incorporating instrumental or vocal tones in a structured and continuous manner. Musical instruments are means to generate sounds which have a particular auditory frequencies. When we pluck a single string on a guitar, what we hear is a particular fundamental frequency and its respective harmonics. Each such frequency is called a note. For example the frequency of 440 Hz belongs to note A, and is the 4th Harmonic of the fundamental frequency which is 28 Hz. A chord is a combination of notes in a particular predefined manner. For example the A (Major) chord contains the base note A, and the other notes are the 3rd (C#) and the 5th (E). Therefore in order to identify the chords, we first need to recognize the notes that are played with a window of specific duration like 1 second (say) and then compare these notes with the set of predefined chord.

CHORD THEORY:
The notes that make up a chord can be related to the major scale of that chord’s root note e.g. for a D chord – the D major scale. The basic major ‘triad’ chords (e.g. A, Bb, B, C etc.) are made up of the 1st, 3rd and 5th notes from their respective major scales. In other types of chords notes are either adjusted slightly, as in minor (m) chords where the ‘3rd’ is flattened.
by a half-step (commonly referred to as a b3,) or extra notes are added as in major 7 (maj7) chords where the 7th note of the major scale is added to the basic triad. Sometimes both these things happen at the same time, for instance in a 7 chord the 7th is added to the chord but flattened at the same time, so it is called a b7 within the chord.

In the first table below you can see chord formulas relating to the major scale for various types of chords. The examples use C as the root note but you can use the second table, showing all the major scales, to work out the notes used in chords of other keys.

This is a relatively basic way of thinking about how chords are constructed. It doesn’t explain everything but hopefully it will help you on your way to a better understanding of how scales and chords relate to each other.

1.2 THEORY ON GUITAR:
The guitar is the most common stringed instrument, and shares many characteristics with other stringed instruments. For example, the overtones potentially available on any stringed instrument are the same. Why, then, does a guitar sound so much different from, say, a violin? The answer lies in which overtones are emphasized in a particular instrument, due to the shape and materials in the resonator (body), strings, how it’s played, and other factors. In the course of studying the overtones, or harmonics of a string fixed at both ends, we will uncover the overtone series for strings, which is the basis of Western harmony.

You can see in Figure 1 that there are 72 fret positions, but the Table 1 above shows only 37 unique notes. Therefore you have multiple ways to finger identical notes on a guitar. This fact is frequently used to get all of a guitar’s strings tuned. For example, you can tune A on the first string (5th fret) to 440 Hz. Then you know that E at the 5th fret on the second string is the same as the open first string, so you match those two notes up by tuning the second string. Similarly:

- The 4th fret on the 3rd string (B) is the same as the B on the open 2nd string.
- The 5th fret on the 4th string (G) is the same as the G on the open 3rd string.
- The 5th fret on the 5th string (D) is the same as the D on the open 4th string.
- The 5th fret on the 6th string (A) is the same as the A on the open 5th string.

2.0 ALGORITHM AND SOFTWARE
As mentioned earlier in order to identify the chords we first need to identify the notes in a music sample. In order to do so we use a threefold process which consist of Pre-processing, Spectral Analysis using the Fast Fourier Transform algorithm and Post-Processing.

Figure 1
2.1 PRE-PROCESSING:
PRE-REQUISITES:
INPUT FILE FORMAT: The input file format used for analysis part for this project requires to be in “.wav” format.
SOFTWARE: MATLAB.
FILTERING (For music containing several instruments):
The frequency range of the guitar lies from 80 Hz to 1200 Hz, all the other frequencies are therefore removed from the given audio sample using a band pass filter as they do not contribute towards the chord identification process. We have to use noise, vocal and other instrument’s sound removal techniques.
SEGMENTATION: We divide the audio sample into audio windows frames of a particular time so that we can analyze the frequency spectrum and in turn identify the chords which are played during that instant in time. For example we divide a 60 second audio clip into 60 frames of 1 second each.

2.2 ANALYSIS:
SHORT TIME FOURIER TRANSFORM: In order to obtain the frequency spectrum we make use of Discrete Fourier Transform (FFT). The sample frequency spectrum obtained for each of the frame of time 0.5 seconds and the peaks in the spectrum represent that that particular note was played within the interval. Note that the transform is linearly spaced and plotted so that it can be compared to the analog frequencies (0-20kHz).

2.3 POST-PROCESSING:
HARMONIC ADDITION: Every instrument however precise cannot play a note having only one frequency and almost always harmonics of a particular fundamental frequency are present. These harmonics are related to the fundamental frequency f by the relation
Harmonic frequencies = 2 x n x f
Where n is a positive integer. We use this property of the musical instruments to our advantage by taking the sum of amplitudes of all the harmonic frequencies present in that sample. Mathematically it can be represented for note A as follows
Note A = \sum_{i=1}^{6} Y(i \times 110)
Where Y(i) is the Fourier Transform Matrix of the sample signal and 110 Hz is the fundamental frequency of the note A.
The summation varies from 1 to 6 in the sense that we are adding the first 6 harmonics. Now we know that we don’t get the peak amplitudes on exactly only one frequency therefore we add a range of frequencies to A instead of just one frequency.
Mathematically,
\text{note A} = \sum_{i=1}^{6} \Delta Y(i \times 110)
Where \Delta Y (i) represents frequencies 10 Hz above and below i.
Once we obtain the magnitude of each note in this manner we then sort all the array that has 12 notes and select the top 3 notes because
most of the chords are made of either 3 or at the most 4 notes.

ASSOCIATION & LABELING: Once we are able to find the top 3 notes we then assume these 3 notes as the triad of the chord in the particular frame and compare these notes with the standard table of chords and try to identify which chord was played.

3.0 HARDWARE IMPLEMENTATION
3.1 ARDUINO UNO:
We decided to use this board because it provided the simple interfacing of MATLAB with the LED matrix also we selected it with special care based on the characteristics like connectivity, available I/O. The microcontroller offered all the features we needed to develop the project.

ATMega 328 has a flash memory of 32 KB, SRAM of 2 KB, EPROM of 1 KB and clock speed of 20 MHz. The Arduino can be powered through the USB connections or with an external power supply. Additionally the Arduino platform was particularly attractive because of its open source physical computing platform based on a simple I/O board and the development environment that implements the Processing/Wiring language.

ATMega 328 has two 8 bit and one 16 bit timer/counter, real time counter with separable oscillator, 6 PWM channels, and execution of the instruction per clock cycle. In order to Maximize the parallelism, the AVR uses Harvard Architecture – with separate memories and buses for program and data.

3.2 SMD LED:
Since the space between strings and the fret board is very less we decided to opt for smaller LED’S. 0805 SMD LED’S satisfy the required constraints.

4.0 WORKING
4.1 FUNCTIONS
We shall now discuss in brief what the purpose of various function in MATLAB code is:

1. Number array filtering:
   This function allows us to remove the undesired peaks obtained in the recognized signal (music piece). After filtering we get a smooth without burst signal as an output.

2. PinMode function:
   This function set’s up the Arduino I/O port and acknowledges the USB port through which communication is going to occur. It also creates object (here object ‘a’) for MATLAB-ARDUINO interfacing.

3. Display’s position of each chord on the fret board of guitar using ‘digital write ()’ operation.

4. Grouping Frequency
   This function takes ‘.wav’ file input. With it the appropriate sampling frequency (fs) is taken into account. Dividing the input music piece into several frame for analysis is done by taking frame size from the user (1 sec for project).

5. After frame formation, FFT operation is performed on each frame. FFT operation gives the frequency content knowledge of the individual frame. After analysis each set of notes is provided with an appropriate chord from available 24 set of chords. An unknown chord is assigned a previous chord.

6. Identify Chord
   This function uses if and else conditional statement to identify the chord. It assigns a single chord to a set of three individual notes by comparison of their amplitude.

7. Sorting Notes
   Sorting of notes according to their amplitude value in order to collect only the highest three notes for processing is done in this function.

8. Since most of the information is in the highest amplitude value.

9. Display Chord
   Displaying the chord by assigning there accepted notations for easy understanding to guitar player is done in this function. Chords like C#, D, A# are more informative than simple numbers.
Sum Amplitude
When a single note is played its harmonics always exist with it. So the summation of the 10 harmonics of each note is taken into account by adding their amplitudes. And the float values are converted to integer by using ‘ceil’ in MATLAB.

4.2 MATLAB TO ARDUINO INTERFACING:
Once we have identified the required chords in a music piece, we will now need to show the chord position on the fret board. For this we require this information to be sent to the Arduino which is then connected to the LED matrix.

A MATLAB to Arduino interface takes into account the transmission rate of data. This requires the “adio.pde” to be compiled and downloaded on the Arduino Uno kit. After installing this file we can directly control the I/O ports of Arduino from MATLAB.

4.3 ARDUINO TO FRET BOARD:
Arduino offers us with 13 GPIO ports from which we will use only 11 to construct a LED matrix of 6x5. 6 because the guitar is 6 string and 5 because we are only concentrating at songs played at a particular pitch at a time in this project.

Once we are done with the interfacing part of the project another aspect of the project involves glowing the LED’s on the fret board in accordance with the chords that are played.

PUTTING COLOUR MARKER ON THE FINGERS:
The colour marker are used to guide the player of the finger positioning that is used in different chords as shown in Figure 2.

4.0 RESULTS
In order to test the performance of our algorithm we shall use the following parameter.

A – Accuracy.

C – Number of correct chords identified in all frames.

T – Total number of chords in all frames.

i – i\textsuperscript{th} song, there are n such songs.

Then, the mean Accuracy is given by

\[
A = \frac{\sum_{i=1}^{n} A_i}{n}
\]

Note:
1. All the music piece used contain only pure guitar sounds and no other instruments were playing in the background nor were there any vocals in the songs.

In the example below we have tested the accuracy of the algorithm with a frame size of 0.5 seconds. The chords being played in the music piece had been synthesized and hence were previously know.
Frame number. | Detected Chord | Expected Chord | Status of detected Chord |
---|---|---|---|
1 | C Minor | C minor | Correct |
2 | C Minor | C minor | Correct |
3 | C Minor | C minor | Correct |
4 | C Minor | C minor | Correct |
5 | C Minor | C minor | Correct |
6 | C | C | Correct |
7 | C | C | Correct |
8 | C | C | Correct |
9 | C | C | Correct |
10 | D | D | Correct |
11 | D | D | Correct |
12 | D | D | Correct |
13 | D | D | Correct |
14 | E | E | Correct |
15 | E | E | Correct |
16 | G minor | E | Incorrect |
17 | G minor | E | Incorrect |
18 | F | F | Correct |
19 | F | F | Correct |
20 | F | F | Correct |
21 | G | G | Correct |
22 | G | G | Correct |
23 | G | G | Correct |
24 | G | G | Correct |
25 | A | A | Correct |
26 | A | A | Correct |
27 | A | A | Correct |
28 | B | B | Correct |
29 | B | B | Correct |
30 | B | B | Correct |
31 | B | B | Correct |
32 | C | C | Correct |
33 | C | C | Correct |
34 | C | C | Correct |
35 | C | C | Correct |
36 | C | C | Correct |
37 | C | C | Correct |
38 | C | C | Correct |
39 | C | C | Correct |
40 | C | C | Correct |
41 | C | C | Correct |
42 | C | C | Correct |
43 | C | C | Correct |
44 | C | C | Correct |

\[ A = \frac{42}{44} \times 100\% = 95.45\% \]

Therefore for this song the accuracy produced by the song has been obtained as 95.45%. Similarly for other songs we were able to obtain the accuracy as follows.

<table>
<thead>
<tr>
<th>SONGS NAME</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Song 1</td>
<td>100</td>
</tr>
<tr>
<td>Song 2</td>
<td>92.22</td>
</tr>
<tr>
<td>Song 3</td>
<td>98.44</td>
</tr>
<tr>
<td>Song 4</td>
<td>85.80</td>
</tr>
<tr>
<td>Song 5</td>
<td>95.45</td>
</tr>
<tr>
<td>Song 6</td>
<td>89.34</td>
</tr>
<tr>
<td>Song 7</td>
<td>92.11</td>
</tr>
</tbody>
</table>

The mean accuracy of the algorithm is therefore at 93.33 %

5.0 FUTURE SCOPE

We can use this project for a complete well composed music piece containing several instruments by using special filtering techniques and training algorithm to enhance the analysis and recognition process.

SMD LED matrix can be manufactured and placed already inside the fret board of the guitar to make it more convenient for the guitar player/learner.

All the existing chords in music literature can be identified by using a more sophisticated algorithm.

A wireless fret board LED matrix can be developed instead of current wired one in order to increase the mobility of the instrument.

6.0 REFERENCES

[5]. http://audio.ibeat.org/?ccm=/people/DaDeMo