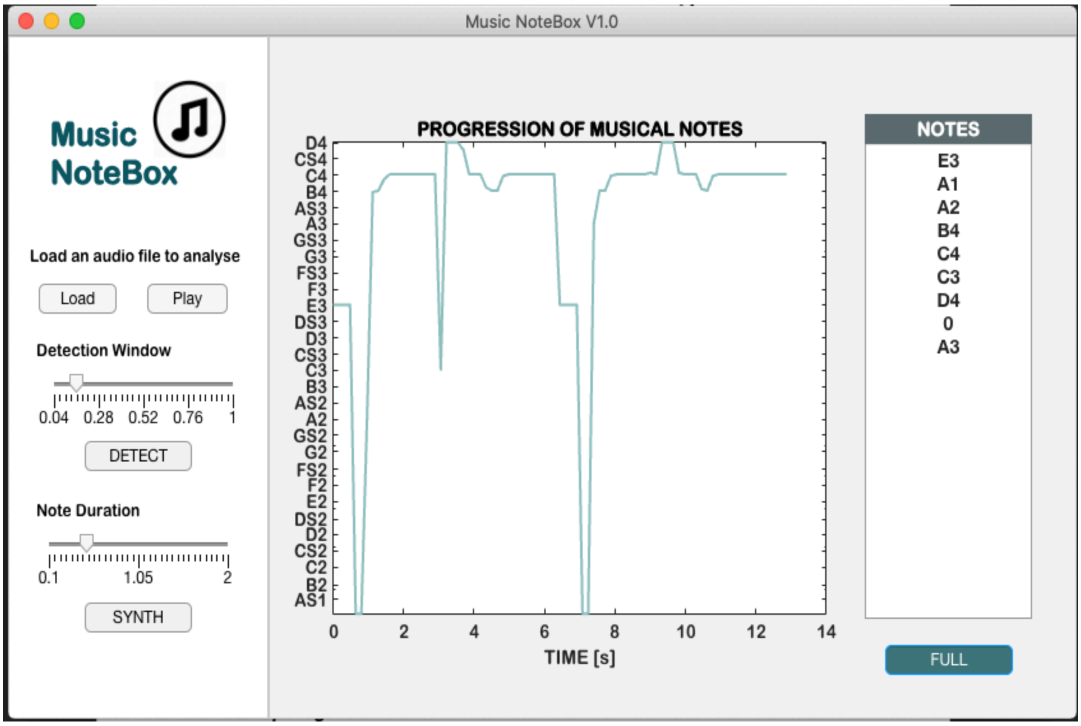
Berner Fachhochschule

Musical notes detection, identification and Synthesis

using MATLAB and MATLAB App Designer



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2 Introduction

Music plays a fundamental role in our lives and it has been a fascination to the humankind in general and the scientific community in particular. The ability to extract features from songs such as pitch and harmonic characteristics can be a “trivial task for trained musicians”, but it can be a frustrating activity for ordinary people. And while enjoying the complexity of musical compositions doesn’t necessarily require trained ears, the process of making, studying and teaching Music does benefit of extensive training as well as analysis methods and tools.

3 Objectives

The primary goal of this project is to create a simple tool using signal processing features of MATLAB to detect, identify and display some musical features like tones and note progression. A secondary goal is to implement both audio player and a synthesizer’s features in the Application

4 Theory and background information

4.1 From sound to music

Sound propagates as a pressure wave through transmission mediums such as gases, liquids or solids. Human auditory organ perceives such waves (between 20 Hz and 20KHz) as sound. Music on the other hand is “an art form and a cultural activity whose medium is sound”. The study of music involves, among other things, the analysis of its characteristics and features such as pitch, timbre, volume, duration and form.

4.1.1 Musical tone vs musical note

Traditional western music defines a tone as a periodic steady sound (sinusoidal) characterized by its duration, pitch, intensity (loudness) and timbre while a musical note can be more complex and may “include aperiodic aspects” such as attack, vibrato etc.

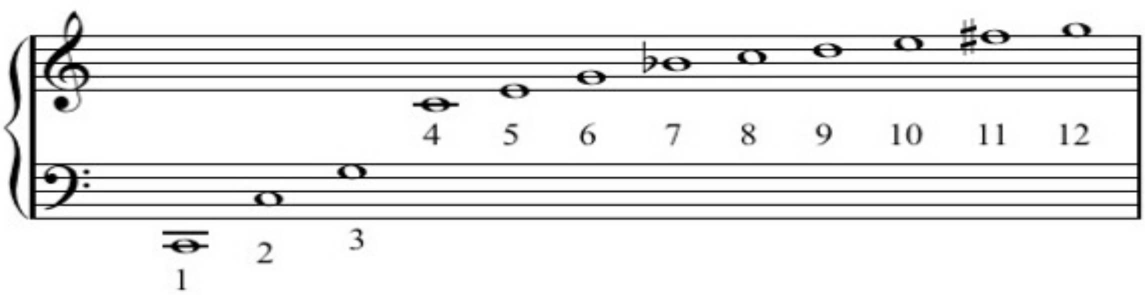


Figure 1: Musical notes and their respective fundamental frequencies

4.1.2 Musical tuning, frequency and pitch

Musical tuning involves ordering a set of frequencies (tones) to establish intervals based on a reference point (ex: A = 440 Hz). A pitch is an auditory sensation and an attribute of musical tones that allows “the judgement of sound as higher and lower in association with musical melody”.

In “twelve tone equal temperament” tuning system, the octave is divided into 12 equal parts spaced by semitones meaning “the frequency interval between two adjacent notes is twelfth root of two.”

$$\sqrt[12]{2} = 2^{\frac{1}{12}} \approx 1.059463$$

This is equivalent to:

$$e^{\frac{1}{12}\ln 2} \approx 1.059463$$

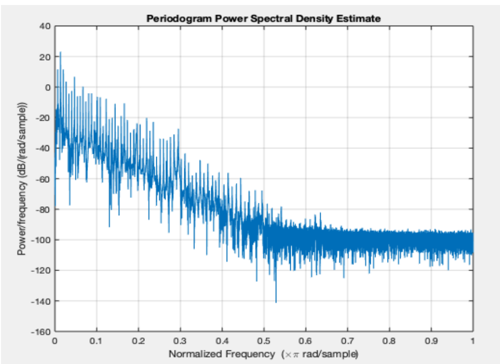
Note	Hz	Note	Hz	Note	Hz	Note	Hz	Note	Hz	Note	Hz	Note	Hz
C1	32.7	C2	65.4	C3	130.8	C4	261.6	C5	523.3	C6	1046.5	C7	2093.0
C#1	34.6	C#2	69.3	C#3	138.6	C#4	277.2	C#5	554.4	C#6	1108.7	C#7	2217.5
D1	36.7	D2	73.4	D3	146.8	D4	293.7	D5	587.3	D6	1174.7	D7	2349.3
D#1	38.9	D#2	77.8	D#3	155.6	D#4	311.1	D#5	622.3	D#6	1244.5	D#7	2489.0
E1	41.2	E2	82.4	E3	164.8	E4	329.6	E5	659.3	E6	1318.5	E7	2637.0
F1	43.7	F2	87.3	F3	174.6	F4	349.2	F5	698.5	F6	1396.9	F7	2793.8
F#1	46.2	F#2	92.5	F#3	185.0	F#4	370.0	F#5	740.0	F#6	1480.0	F#7	2960.0
G1	49.0	G2	98.0	G3	196.0	G4	392.0	G5	784.0	G6	1568.0	G7	3136.0
G#1	51.9	G#2	103.8	G#3	207.7	G#4	415.3	G#5	830.6	G#6	1661.2	G#7	3322.4
A1	55.0	A2	110.0	A3	220.0	A4	440.0	A5	880.0	A6	1760.0	A7	3520.0
A#1	58.3	A#2	116.5	A#3	233.1	A#4	466.2	A#5	932.3	A#6	1864.7	A#7	3729.3
B1	61.7	B2	123.5	B3	246.9	B4	493.9	B5	987.8	B6	1975.5	B7	3951.1

Figure 2: Musical notes and their respective fundamental frequencies

4.2 Detecting fundamental frequencies

4.2.1 Pitch Detection Algorithm (PDA) in music

An algorithm “designed to estimate the pitch or fundamental frequency” of a musical note or tone. A typical PDA estimates the period of a signal then calculates the reciprocal to give the frequency.



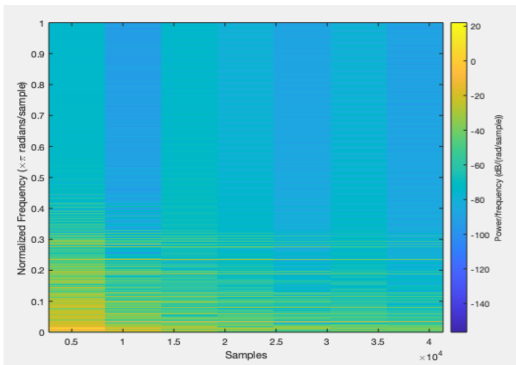


Figure 3: Periodogram and Spectrogram of a Piano D4 note in MATLAB

4.2.2 Frequency-domain approach

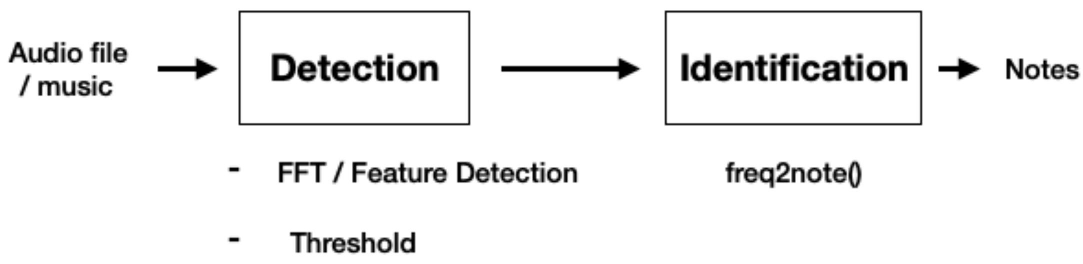
This approach uses a periodogram (estimate of spectral density) to analyze the frequency spectrum of a signal. It relies on the concepts of Fourier transform and time averaging.

4.2.3 Spectral / temporal approach

Here a combination of time domain (autocorrelation) and frequency domain signal processing techniques are used.

5 Methodology

In this project I implement techniques from DSP as well as knowledge acquired in the "Applications of MATLAB/OCTAVE" module to fulfill the requirements of the final application.



5.1 Detection

The first attempt to do the detection was performed using MATLAB's FFT followed by a peak detection using MATLAB's findpeaks () function. This approach allows detecting fundamental frequencies of single notes but doesn't provide information about note duration and progression. Investigating single notes using this technique shed light on the harmonics contributing to the timbre of every musical instrument. *See test_1.m*

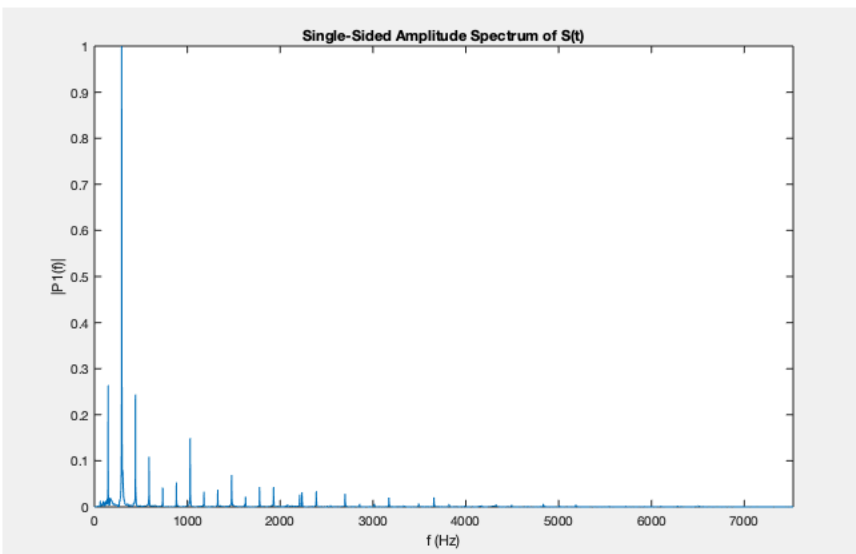


Figure 3: FFT of Piano D4 note showing fundamental frequency as well as harmonics.

A second approach was chosen to detect fundamental frequencies as well as time information (note progression). Using the audioFeatureExtractor one can extract pitch information as well as time information necessary to represent the note's progression on a timeline.

```
aFE = audioFeatureExtractor( ...
        "SampleRate",Fs, ...
        "Window",hamming(round(val*Fs),"periodic"), ...
        "OverlapLength",round(0.002*Fs), ...
        "mfcc",true, ...
        "mfccDelta",true, ...
        "mfccDeltaDelta",true, ...
        "pitch",true, ...
        "spectralCentroid",true);
```

5.2 Identification

The function frq2note () converts the detected frequency to the corresponding note representation. The identification is carried out in tow steps:

- First generate all fundamental frequencies for the twelve tones (C to B) and for a given number of octaves based on theory.

```
%   fn = f0 * (a)n
%   where
%   f0 = the frequency of one predefined fixed note . A common choice (A4) at f0 = 440 Hz.
%   n  = the number of semitones/half steps away from the fixed note.
%   At a higher note, n is +ve. At a lower note, n is -ve.
%   fn = the frequency of the note n one semitone away.
%   a  = (2)^1/12 = the twelth root of 2
```

- An iteration loop to compare input frequencies (detected) to frequencies generated by the function. The comparison accommodates for some error on the detection and defines a variable tolerance value that changes based on the same equation used for the frequency generation.

5.3 Synthesis (secondary objective)

The attempt to recreate / synthesize the input melody is done using frq2sound function. The function takes two parameters as input, namely the frequency and the duration then constructs a sinusoidal based on input parameters. In a next step the function synthesizes the tone using the MATLAB sound() function

5.4 User interface

The user interface was designed using MATLAB App designer and includes the following elements:

5.4.1 Tests and audio test material

- Load Button: to import/select audio file to analyze
- Play/Stop: to play and stop the music
- Detect Window Slider: Detection accuracy (FFT Window)
- Detect Button: to initiate detection
- Note Duration Slider: for the synthesis function
- Synth Button: to synthesize the detected note progression (melody)

5.4.2 Display output data

- Display notes vs time plot
- Display list of detected notes
- Unique Button: to display unique notes only (no repetitions)

6 Conclusions

Automatic detection of musical notes presents a set of challenges including the not well defined constrains on the input (complexity of composition), accuracy of detection and the usability of output data (data visualization).
The primary objective of this project was achieved to a reasonable extent taking in consideration the project constrains and the lake of know-how on such a complex topic.
The synthesis objective was achieved to a much less satisfying extent and serves only as a proof of concept.
A future update could include showing the name of the audio file being analyzed!

7 Acknowledgments

7.1 Tests and audio test material

The music content for testing include both single notes as well as melodies with short duration played on the piano.

7.2 Quotations

All quotations present in this document are taken from different WIKIPEDIA articles in connection with the theory and background information.