Pentatonic Harmonics in Fourier Transforms: Why the Blues are Blue

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ABSTRACT

Why do the Blues make one blue? It is commonly known and accepted throughout the world that upon hearing a Blues song, one will feel a certain sadness and the melancholy experienced by the composer. We choose the blues musical scale to illustrate and propose a new methodology of understanding why certain parameterized waveforms upon entering a human's ear's cause that human to experience an emotion of sadness. Furthermore, the aforementioned methodology's data output is conducive to KDD applications in that it includes feature extraction and decision model construction. The discussion of analyzing waveform combinations as set forth in this paper will provide progress in the optimization of emotions in sound representation. We believe that further research in this area would provide background for mining automatic multimedia content description in terms of emotion.

Keywords: knowledge discovery in databases, music content processing, Fourier transforms, pentatonic scale

1 INTRODUCTION

Managing large collections of digital music documents requires effective computer-based music information retrieval systems where documents relevant to a user query can be retrieved quickly. To address the task of automatic content-based search, some descriptors have to be assigned at various levels to segments of musical files. Because of the nature of the musical sounds, methods concerned with time series analysis seem to be of a special interest. These methods can be applied to extract various types of musical information, like melody or timbre. It is difficult to find a numerical description of timbre characterizing musical instruments sounds that allow correct classification of instrument for sound of various pitch and/or articulation. Listener needs transients to correctly classify musical instrument sounds, but during transients the sound features change dramatically and they usually differ from the sound features for the (quasi-) steady state. The time domain analysis can describe not only features applicable to any sounds, like basic descriptors from MPEG-7, but also certain emotions.

The "*Blues*" is a music genre most likely to produce a specific emotion to humans assimilated with western culture. Conversely, the musical genres of Jazz, Classical, Country and Rock include musical structures and instances that can make some humans happy but others excited. Psychologists structure emotion in terms of core affect [ref(1)], emotion, mood, attitude [ref(2)], and temperament [ref(3)]. Certain instances make some humans agitated [ref(4)] while making others feel motivated [ref(5)]. Indeed, Ledoux [ref(6)] discovered a bundle of neurons directly connecting the thalamus with the amygdale that initiate an emotional response before the cortical centres are even engaged . Certain instances make some humans mellow while making others excited and so on [ref(7)]. However, the Blues is different. We choose to analyze the Blues scale because for the most part, it is generally accepted that it has a greater chance, over other scales, to induce a specific emotion. Webster's 1913 Dictionary defines the blues as

1) a type of folk song that originated among Black Americans at the beginning of the 20th century; has a melancholy sound from repeated use of blue notes; and

2) a state of depression; as, he had a bad case of the blues.

Nevertheless, what is the mathematical explanation for this anomaly? In other words, what is happening in the mathematical interpretations of waveforms emitted from a blues scale that invokes human emotions of sadness or melancholy? Many have doubts this can be attained [ref(8)].

2 BLUES

In the famed blues songwriter W. C. Handy's autobiography he references an itinerant player who played a Blues song and used a knife as a guitar slide sometime around 1900 [ref(9)]. Before synthesizing the Blues' scale this paper acknowledges that Blues music, as a whole, contains three attributes:

1. Rhythm closely associated to African rhythms; [ref(10)]

2. Pentatonic sounding music accentuating its flattened III and VII [ref(11)]; and,

3. "Call and Response" structures similar to European and English folk music using the same three chords over a diatonic scale.

Blues rhythms can easily be associated to African rhythms because it originated with the African slaves in North Mississippi Delta prior to the Civil War of the United States. There is a myth, which this paper contends is not too far from the truth: Blues folklore states that the slaves would hear the piano of their white owners playing and try to replicate it in their guitar playing field hollers, ballads and spiritual/church music. However, they either:

1. Never quite got it right; or,

2. They purposefully flattened the III and VII because in their state of sadness and depression - it simply "felt" better.

Blues lyrics, are not part of the mathematical structure of notes that emit emotions, but suffice to say, it typically encompass misfortunes and trouble. With the aforementioned in mind, we now look a little deeper into the musical structure.

3 MUSICAL WAVEFORMS

Humans characterize sound waves by three parameters: Pitch, Loudness and Quality.

Loudness is measured in a logarithmic scale ("decibels"), defined a as ten times the exponent of 10 for the loudness value. The threshold of hearing is defined as 0 decibels. 10 decibels is ten times as loud, while 20 decibels is 100 times as loud, and 30 decibels is 1,000 times as loud. Typical sounds of traffic are about 70 decibels, while the noise of a nearby jetliner is about 140 decibels. [ref(12)]

Quality describes, regardless of tone, the kind of sound we hear. regardless of tone. For example, "Middle C" played on a guitar sounds different in *Quality* to "Middle C" played on a Oboe.

Pitch is the frequency of musical "notes" arranged on a musical "scale". Western culture's "equitonic" scale consists of "octaves", each containing 8 whole notes "A", "B", "C", "D", "E", "F", "G", and "A". The equitonic, as displayed on a piano keyboard shows 12 keys in each octave. Here, the seven white keys are the ' 'whole" notes and five black keys, or "sharp and flat notes" and "flat notes". The Blues scale is a subset of the equitonic scale.

Notes in scales make up melody, defined as an auditory object that emerges from a series of transformations along six dimensions: pitch, tempo, timbre, loudness, spatial location, and reverberant environment [ref(13)].

An octave is a doubling of frequencies. Here, each "octave" of eight notes below Middle C is half of the previous frequency, with those above it being doubled.

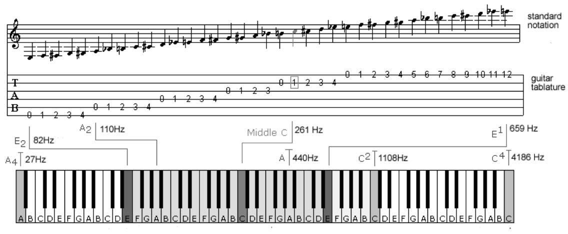

Figure 1: Western Musical Domain

Table 1: Octaves

-C"	33 hertz
-C"	66 hertz
-C'	132 hertz
MIDDLE C:	264 hertz
+C'	528 hertz
+C"	1,056 hertz
+C"'	2,112 hertz
+C""	4,224 hertz

Scales and chords utilize harmonics and overtones. In order to understand the blues scale one needs to also appreciate scales and harmonics.

A ***harmonic*** exists when one multiplies a notes' frequency by a whole number. Harmonics and overtones are the same thing labelled differently. For example, the first overtone of a frequency equals the second harmonic. This paper will refer to harmonics for the sake of consistency. Note that the second harmonic is a note with twice the frequency, or, commonly known as an octave.

The most ***common scale*** is the major scale and its seven modes which simply start at different points on the seven "*white keys*" of the piano. These are their names, along with the starting note:

Table 2: Seven Modes

Tonic note	Name of mode
f	*f* Lydian
c	*c* Ionian (or major)
g	*g* Mixolydian
d	*d* Dorian
a	*a* Aeolian (or natural minor)
e	*e* Phrygian
b	*b* Locrian

These seven modes do not have to be played only the way described above, one may start at any note but then will have to also play some black notes to maintain the integrity of the mode.

It is said that each of the seven modes has a distinct emotion to it. Westerners find that the most familiar sonority is the major and minor triads which measures the tonal profiles of sonorities, including perfect fifth and major thirds also known as simultaneous dyads [ref(14)].

The major or Ionian is for happy music. The minor, or Aeolian and Dorian scales that have roots on the 2nd and

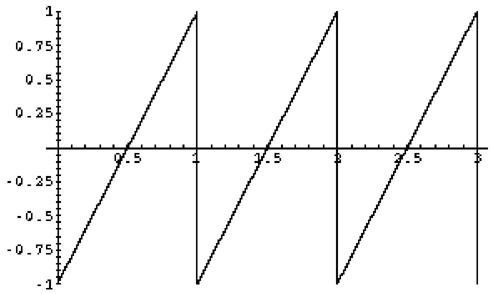

Figure 2: Blues Scale

6th notes of the major are for sad or dark music. The Blues scale, which is based on the Pentatonic is found using the same method as the Aeolian and Dorian scales except it only incorporates four notes after the root.

However, in modern music we say the Pentatonic has 6 notes because we include the playing of the root, one octave higher as being part of the scale. The African slaves began copying and then either mistakenly or purposefully flattening its III and VI notes over this pentatonic scale. Something, yet fully understood by science, inherent in the aforementioned sound formation evokes a human to feel sad.

4 PHYSICS OF MUSICAL WAVEFORMS

This paper asserts that the answer lies within an understanding of the physics, Fourier transforms and harmonics of waveforms. To understand harmonics, consider a simple sinusoidal wave having the form

$$y = Asin(\omega t)$$

Where A is the amplitude. A is also periodic, meaning that the wave having a frequency, f, repeats itself with a period, T.

$$f = frequency = 1/T$$

$$T = period = 1/f$$

When sounds emanates from an instrument there is a fundamental frequency accompanied by integer multiples of the fundamental frequency called overtones. As mentioned above, overtones that are integral multiples of the fundamental are called harmonics. We can express a waveform $F(t)$ simply as the series addition of harmonics:

$$F(t) = \sum_{n=1}^{\infty} A_n \sin(2\pi f_n t)$$

Some of these harmonics, when paired with others give westerners a sense of a good sounding notes These musical intervals include:

It is standard practice to express these ratios as a value between 1:1 and 2:1. Similarly, modulating five times by

‘

Table 3: Intervals

Unison 1:1	Major Third 5:4	Octave 2:1	Minor Third 6:5
Fifth 3:2	Major Sixth 5:3	Fourth 4:3	Minor Sixth 8:5

the interval yields 3:2 a note very close to the third - 81:32. Strictly speaking called the Pythagorean comma.

Table 4: Modulations

Note	C	D	E	F	G	A	B	C′
Freq.	f	(9/8)f	(5/4)f	(4/3)f	(3/2)f	(5/3)f	(15/8)f	(2)f

Accordingly there are groups of waveforms consisting of three or more notes that also have nice or agreeable responses to westerners and we call these chords. Major chords have three notes in a ratio of 4:5:6 The ratio of the frequencies of the major diatonic scale f is the frequency of the root or tonic

5 CONTEMPORARY THEORY: MUSIC & EMOTIONS

We acknowledge that a major chord has a natural and pleasant sound. Mathematically, this makes sense in that there is perfect integration of each harmonic's patterns. For example, in A Major, the sixth harmonic is between F# and G, and the seventh is A again three octaves up. Contemporary notions describe the aforementioned as "Happy". We believe this is not completely correct. Contemporary notions believe that the "sad notes" of the blues are simply realized by a slight shift in the harmonics. For example, if one moves from the "happy" harmonics of a C Major chord (C E G) to the C minor chord.

Contemporary thought believes that the induction of a darker feel is based completely on the minored shift in the E to a D# as this results in a "missing harmonic" thus creating a darker feel. We propose that this is not completely correct in that it is, as will be demonstrated, too simplistic and overly broad:

Table 5: "Happy" harmonics of a C Major chord

C	261.6	523.2	784.9	1046.5	1308.1	1569.7
E	329.6	659.2	988.9	1318.5	1648.1	1977.7
G	392.0	784.0	1176.0	1568.0	1960.0	2351.9

Table 6: "Darker" harmonics of a C Minor chord

C	261.6	523.2	784.9	1046.5	1308.1	1569.7
E♭	311.1	622.3	933.4	1244.5	1555.6	1866.8
G	392.0	784.0	1176.0	1568.0	1960.0	2351.9

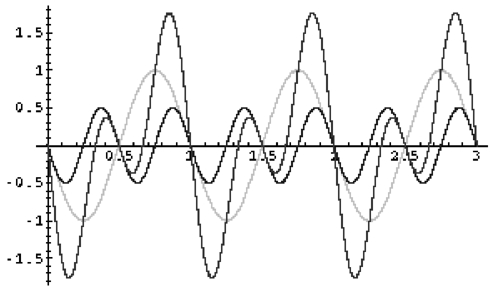

Figure 3: Fourier: Fundamental

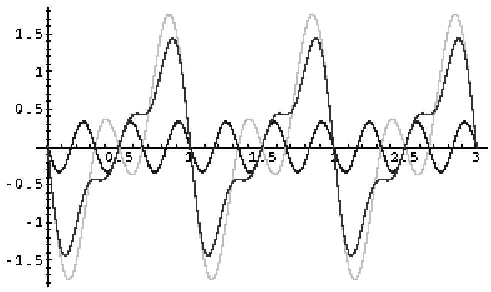

Figure 4: Fourier: Next overtone

6 FOURIER AND THE HUMAN EAR

The human ear takes the complicated sound waves, as illustrated above in the shift from a C major to a C minor, and measures the relative amplitudes phases of their overtones into a perception of the *timbre* of the note. Fourier proved that any vibration can be represented mathematically. Looking at "*sawtooth*" wave:

Fourier takes the fundamental and the first harmonic and adds them together.

In the next step Fourier takes sum, as shown above and adds it to the next overtone:

Fourier continues the aforementioned until one gets to the 9th overtone as it is close to the desired saw tooth shape

The Final sawtooth requires an infinite number of partials. Our hearing range is limited and reaches about 20 kHz; therefore, we can stop the Fourier analysis at 20 kHz, or even earlier. In our work so far [ref(15)] on emotion extraction, we finished our analysis at 10 kHz, assuming that higher partials do not contribute much to the perception of timbre or emotions.

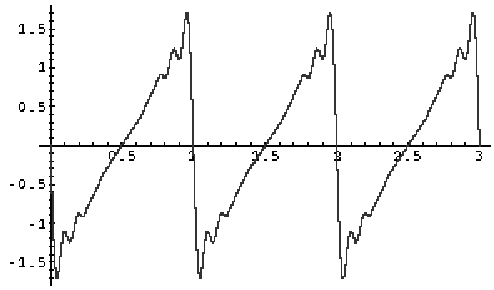

Figure 5: Fourier: 9th Overtone

7 A SEED FOR THOUGHT

The dichotomy of researching for the mathematical validation of emotions invoked from sound waves entering the ear is that subjects who know nothing of the aforementioned can indeed be "experts". We say this because, in fact, every human is an expert on emotions they personally perceive after absorbing sound waves into their eardrums.

It is here that our research, "stepped back" and viewed the forest for the trees. The small study was conceived when during previous research, our team pondered how long each sample should be. It became evident that on samples where chord changes shifted rapidly, the team sometimes opted for a smaller sample times [ref(15)]. Conversely, on longer songs, where the chord changes were long and drawn out, particularly on Mozart's Requiem, the team agreed on a much longer sample rate. Why? We decided to flip former methodologies of playing samples to subjects and blindly asking them what emotion they felt and decided to rather:

1. Induce or suggest what the emotion for a sample should be based upon what others thought. Where "*other*" was contemporary theories such as Huron;
2. Induce or suggest what the emotion for a sample should be based upon what others thought. Where "*other*" was the **inverse** of contemporary theories such as Huron; and,
3. Measure the results of the aforementioned in terms of four degrees:
   (a) Distance from a chord change,
   (b) Distance from a tonal change,
   (c) Acceptance of contemporary notions,
   (d) Acceptance of the inverse.

We agree with contemporary thought and believe that perception of emotions depends in a high degree on the sequence of chords or notes. Where we now focus on it where exactly is the critical areas of a song? The whole song, certain portions only, and if the latter is true, then where exactly. Herein, is the bases for our testing.

8 ELEVEN SUBJECTS

The eleven subjects, small as the sample base was, were well spread out over the board in terms of knowledge of Music Theory, their ability to have a musical "ear" and their "professional" (hereinafter "Pro") level.

Table 7: Eleven Subjects

#	Status	Name	Theory	Music ear	Pro
1	Male 35	Bass Player	5	5	2
2	Male 37	Trumpet Player	4	5	5
3	Male 31	Drummer	2	2	5
4	Female 33	Vocalist	4	5	5
5	Female 29	Bongo Player	2	3	4
6	Female 19	Music Student	5	4	3
7	Male 42	Electrical Engineer	1	1	2
8	Male 19	History Major	1	1	1
9	Female 81	Retired	2	2	1
10	Female 17	Student	2	2	1
11	Male 32	Lawyer	1	1	1

We rated the scale of Music Theory, Music ear, and Pro from 1 being the lowest and 5 being the highest as follows. We first determined if the subject could pass level one and then worked our way to the level 5, meaning that a level five also knew or fulfilled all the criteria of the previous levels.

Table 8: Music Theory

Play and Differentiate between a minor or major pentatonic scale.	5
Play and augment and suspend a major chord.	4
Understand what a seventh chord is	3
Understand what a chord is.	2
n/a	1

For **Music Theory**, we required that the subjects actually have the ability to play in person in front of us on an instrument of their choice.

Table 9: Music Ear

Identify Middle C out of 3 notes , C, G, E	5
Sing harmony to a C major.	4
Hear a half tone off of a previous tone.	3
Hear a whole tone off of a previous tone	2
n/a	1

Table 10: Professionalism

Play on stage at least twice a month for pay.	5
Play on stage at least twice a month for free - open mike	4
Go to a live concert twice a year.	3
Sang in a choir once in their life.	2
n/a	1

9 FOUR ELEMENTARY TESTS

TEST 1.1: Play C major at Middle C for 5 seconds should, according to contemporary notions in musical emotions, mean - happy but certainly not sad.

TEST 1.2: Play C major at Middle C for 20 seconds should, according to contemporary notions in musical emotions, mean - happy but certainly not sad.

Table 11: Test I

Test I	% correct	% wrong to correct	% stay wrong
1.1	81.82%	50.00%	50.00%
1.2	72.73%	66.60%	33.40%

TEST 2.1: Play C minor at Middle C for 5 seconds should, according to contemporary notions in musical emotions, mean - a little darker than happy but certainly not agitated.

TEST 2.2: Play C minor at Middle C for 20 seconds should, according to contemporary notions in musical emotions, mean - a little darker than happy but certainly not agitated.

Table 12: Test II

Test I	% correct	% wrong to correct	% stay wrong
2.1	72.73%	33.30%	66.70%
2.2	72.73%	100.00%	0.00%

TEST 3.1: Play C minor with a blues bass line at Middle C for 10 seconds, changing to a F minor and asking them 2 seconds after the change should, according to contemporary notions in musical emotions, mean - melancholy or blue but certainly not joyful.

TEST 3.2: Play C minor with a blues bass line at Middle C for 10 seconds, changing to a F minor and asking them 10 seconds after the change should, according to contemporary notions in musical emotions, mean- melancholy or blue but certainly not joyful.

TEST 3.3: Play C minor with a blues bass line at Middle C for 10 seconds, changing to a F minor and asking them 30 seconds after the change should, according to contemporary notions in musical emotions, mean - melancholy or blue but certainly not joyful.

Table 13: Test III

Test I	% correct	% wrong to correct	% stay wrong
3.1	90.91%	100.00%	0.00%
3.2	72.73%	66.60%	33.40%
3.2	63.64%	40.00%	60.00%

TEST 4.1: Play C minor with a major bass line at Middle C for 10 seconds, changing to a E minor and asking them 2 seconds after the change should, according to contemporary notions in musical emotions, mean - melancholy or spiritual, but certainly not agitated.

TEST 4.2: Play C minor with a major bass line at Middle C for 10 seconds, changing to a E minor and asking them 10 seconds after the change should, according to contemporary notions in musical emotions, mean - melancholy or spiritual, but certainly not agitated.

TEST 4.3: Play C minor with a major bass line at Middle C for 10 seconds, changing to a E minor and asking them 30 seconds after the change should, according to contemporary notions in musical emotions, mean - melancholy or spiritual, but certainly not agitated.

Table 14: Test IV

Test I	% correct	% wrong to correct	% stay wrong
1.1	81.82%	50.00%	50.00%
1.2	72.73%	66.60%	33.40%

10 CONCLUSION

We focused on where and when subjects began to have doubts how to classify emotions perceived when listening to a passage. The results of the test show that across the board, the further we distanced the subject from that point where the dissonance of the previous chord overlayed onto the new chord, the higher was the percentage of emotional confusion.

The possibility of subjects changing their minds is untypical in previous experiments performed by Huron et al, but shows that generally subjects perceive similar emotions when close to the point where the dissonance of the previous chord overlayed onto the new chord.

Length of the passage influences emotions only where the dissonance of the previous chord being overlayed onto the new chord invokes the same changes **consistently**.

A single chord or a few chords may induce some kind of emotions, but during a longer passage emotions may change, particularly where the dissonance of the previous chord overlayed onto the new chord is **inconsistent / varying**.

Our results are that.

- The noise, dissonance from the previous influences subjects in a manner expected by Huron et al.
- The further away in time the subject is from the overlapping sequence, the more extracted the subject is to expected results.

Therefore, the only parameters necessary to induce into the Fourier Transform are those that still contain elements from the previous noise or dissonance, because as the previous noise dampens, so does the vagueness of the results. In other words, the longer a note or chord is perpetuated, the more ”neutral” or ”open” it becomes.

11 Acknowledgement

This research is supported by the National Science Foundation under grant IIS-0414815, and by the Research Center at the Polish-Japanese Institute of Information Technology, Warsaw, Poland.

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