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Implementation of a Ten-Tone Equal Temperament System

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Abstract

Tracing back to the ancient Greeks, humans have always been interested in the "harmony" that music creates. Throughout time, many composers like Du Fay, Monteverdi, and Schoenberg have strayed from traditional musical practices in the hope of developing a more expressive sound. In this study, a system was created that is based on ten tones instead of twelve in an attempt to make a new expressive sound.

Music has endured many changes throughout the centuries. As the world moves into the 21st century, is it possible that a new melodious sound is yet to be discovered? Music we are currently familiar with is based on an equal temperament scale composed of twelve similar intervals. Each note on a piano and its corresponding frequency can be used to represent x and y values. Using the x and y values, a graph of the frequency spectrum of a piano can be generated, from which a formula can be derived. Next, dividing the number twelve by ten and then adding the sums together yields the ten-tone system x values. By substituting the new x values into the equation of the frequency spectrum, the frequencies for the notes of the ten-tone system can be found, conforming to new system of equal tone temperament. Using a program called "Cycling '74 MAX/MSP," these new frequencies can be assigned to the notes on a keyboard, creating an instrument based on ten tones instead of twelve. The resulting sound from the ten-tone instrument is very unique and yields intervals that the ear is not conditioned to hearing, excluding the fact that the notes are produced with a sine generator.

The research involves an interesting procedure that allows for further experimentation. For example, this system can be applied to create intervals built on any other number imaginable, all of which all would be based a new equal temperament scale. This study attempts to find a new direction for music by creating a system in which the notes in each octave are spread out over ten tones instead of twelve. The limited attempts in this study were unsuccessful in creating a sound that was music to one's ears. However, with further experimentation, it is possible that this system could yield pleasing results. Though the system did not produce any satisfying results at the moment, it opened up a new procedure for the creation of a unique intervallic system.

Keywords: Music, Composition, Acoustics

1. Introduction

Viewed historically, new stylistic eras have been ushered in when composers have strayed from traditional practices in the hopes of achieving a new expressive goal. Creating a musical system that is based upon ten tones instead of twelve pushed the boundaries of common musical practices. In the creation of the new equal temperament system, elements of sound and a program called "Cycling '74 MAX MSP" were used to generate the new notes in ten-tone system, thus creating an instrument called The Decitone.

2. Straying from Common Practices

The foundation for traditional musical practice was created in the time of the Ancient Greeks. The Greek's great thinkers such as Plato believed in a philosophical theory called idealism, where true reality is beyond the world of phenomena.[1] This "true reality," could be disclosed through music, known as harmonia. Later, the connection between sound and numbers was attributed to a philosopher named Pythagoras.[2] This connection was that intervals in music could be expressed as ratios, such as an octave being 2:1.[3] Intervals were determined to be consonant or dissonant depending upon their mathematical ratios, and were labeled as consonant if they had nice compact ratios such as 4:3. As a result, the intervals such as octaves, perfect fifths, perfect fourths, and major seconds were heavily favored in music because of their ratios.

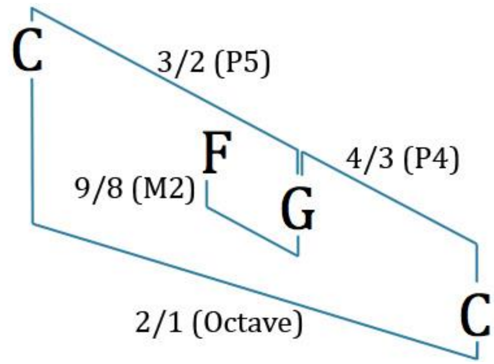

Figure 1. Perfect intervals with mathematical ratios[4]

In Plato's *Timeaus*, he said that the Pythagorean ratios produced a certain shape in the music, establishing "order."[5] This was very significant because the Greeks believed that through order, they could connect with the idealistic state. As a result, order can be found in the music of the Middle Ages, where the music was monophonic and made extensive use of these "golden intervals." There was an emphasis upon these intervals in the music because it allowed one to connect with true reality.

Individuals pushed the boundaries of music through their experimentation and unwillingness to accept the norm. During the "Renaissance," humanism placed emphasis on human perception as opposed to the ideal world of mathematical ratios.[6] Music began to focus on what is pleasing to one's ears, such as in the rise of polyphonic music; because it incorporated more notes being played at the same time. Works by Guillaume Du Fay, a composer from the 15th century, exemplified Renaissance ideals. Du Fay wrote a motet called "Nuper rosarum flores" for the consecration of the cathedral dome in Florence in 1436.[7] Du Fay employed more expressive possibilities as he made use of the intervals 3rds and 6ths, which were not favored in the Middle Ages because their ratios were not considered consonant. Therefore, Du Fay did not follow the norms; he pushed the boundaries of his time.

Later, in the Baroque period, there was a change of thought, ideas, and science from the Renaissance period. People decided to "revolt" and return to the Ancient Greek idea that music moves individuals to change their emotions. Thus came about the idea of the Doctrine of the Affections, the concept that music can affect one's emotions: such as love, hate, joy, and sorrow.[8] A composer named Monteverdi embraced this idea and revolutionized what was normally acceptable through his work "Cruda Amarilli."[9] In keeping with the idea of the Doctrine of Affections, he broke the rules specifically to express the text, which was about the sigh of love. For example, he made use of dissonance that was not prepared or resolved correctly. This type of behavior was so unacceptable that a gentleman by the name of Artusi wrote an article called the "Imperfections of Modern Music," in which he criticized Monteverdi for breaking the rules. However, Monteverdi strayed from the common practices of his time in order to achieve a new expressive effect of realizing the text.

Similarly, in the 20th century, Arnold Schoenberg developed a new musical idea called serialism, a compositional method that in which music is based off of a series of notes.[10] In serialism, one creates a line of the numbers 1-12 and then transposes that "layer." Each number can then be used to represent a note on the piano, and then the lines can be played: forward, in a retrograde, inverted, and in a retrograde inversion.[11] All 48 lines can then be implemented in the composition of the piece. Serialism created a new way to compose and thus created a new musical effect. Therefore, Schoenberg pushed the limits of music by adding a mathematical aspect to it in which a system for the arrangement of the notes is already predefined.

3. Temperament

All of these composers pushed the boundaries of their time, while adhering to a specific temperament. The Greeks followed Pythagorean temperament, Du Fay used mean-tone temperament, and Schoenberg complied with equal temperament. Temperament is a way of tuning all of the notes on a keyboard instrument so that a scale can be played and sound “in tune” in some positions.[12] For example, Pythagorean temperament, used in the Medieval Ages, is built upon a circle of pure 5ths, meaning their intervals yield perfect ratios. Consequentially, one of the fifths is a little sharp, called a Pythagorean comma, and other intervals are in odd positions.[13] Another type of temperament is the mean tone temperament. In the mean tone temperament, the interval from the notes C to E is pure, and each 5th is tuned a little flat in order to make some intervals more consonant.[14] However, the problem with this type of temperament is that as a result, the notes G# and Ab actually sound different, even though they are enharmonically the same note and should resonate the same. The standard Western equal temperament tuning solves this problem because all intervals “sound right” melodically and harmonically throughout every key, because they are constructed from a cycle of 12 modified 5ths that fit equally into the circle of 5ths.[15]

Comparison of Pythagorean and Equal Temperaments Based on C			
Notes	Pythagorean Temperament		Equal Temperament
	Fraction	Decimal	
C	1/1	1.00	1.000
D	9/8	1.125	1.12246
E	81/64	1.250	1.25992
F	4/3	1.333	1.33483
G	3/2	1.500	1.49831
A	27/16	1.667	1.68179
B	243/128	1.875	1.88775
C	2/1	2.000	2.000

Figure 2. Comparison of two types of temperament[16]

The Decitone adheres to a kind of equal temperament that has a whole new set of notes, whose intervals are consistent in every 10-tone system key.

4. The Creation of The Decitone

4.1 Acoustics

In the creation of The Decitone, fundaments of sound such as frequency and timbre were used. Any medium, such a gas, a solid, or a liquid is made up of particles. When vibrations are created by acoustical energy (such as your voice), the particles are disturbed and a waveform is created.[17] In the medium, there are areas of where the particles are condensed, and areas where the particles are spread out, creating the troughs and hills in the wave.

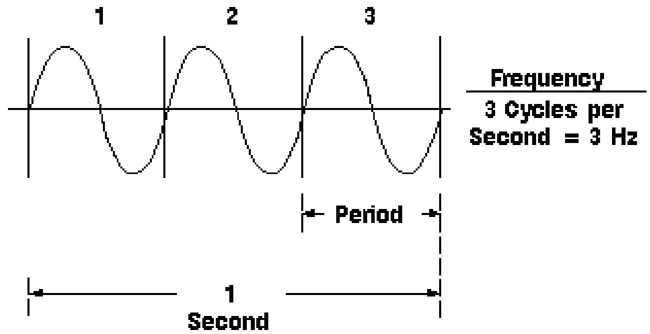

Figure 3. Completion of a 3 Hz sine wave[18]

Notice in the picture above that one completion of the wave is called a cycle, which then repeats.[19] The term frequency (perceived as pitch) is measured in cycles per second, or Hertz. The higher the frequency, the more cycles per second, so therefore the higher the pitch. Humans typically have a hearing range from 20 Hz to 20,000 Hz (or 20 kHz).[20] The wave is measured in meters per second, where the velocity (speed of the sound) is divided by the time. In order to find the time, take the inverse of the frequency. Therefore, the lower the frequency, the longer the resulting waveform will be.

The sine wave is the simplest waveform because it has only one harmonic (called the fundamental, which is the pitch you perceive it to be).[21] Harmonics are the building blocks that make up a sound. As more harmonics are added in addition to the fundamental, the waveform becomes more complex; and the timbre, which is the characteristic of the sound, changes too. For example, a piano and a clarinet may be playing the same note: however, they sound different because their complex waveforms are composed of different harmonics, resulting in different timbres. Many of these concepts were used in the creation The Decitone.

4.2 Implementation Of The Number 10

The idea of creating an equal temperament 10-tone system was inspired by the prominence of the number 10 in systems of measurement, such as in the metric system. Creating a musical system based off of 10 opens a whole new dimension of composition possibilities and connects music with the rest of the scientific world. First, a chart in Excel was created, in which all of the notes on the piano and their corresponding frequencies were mapped out. The frequencies were labeled "y" and each frequency was assigned an ascending multiple, "x." Once the coordinates were computed and a graph was assembled, the result was the frequency spectrum of an equal temperament piano. Using Excel, an equation of the graph was generated. Therefore, if any value were substituted for x in the equation, it would yield the corresponding frequency in the equal temperament system. In order to generate x values for the new 10-tone system, a new change in x would need to be created, like a semitone. A semitone is also known as a half step because it is half of a normal whole step on a keyboard.[22] If one were to strike every note on a piano in an ascending order until the first note was repeated, they would play 12 semitones. The 10-tone system does not have semitones because the actual notes are different, but it is just a point of comparison because it is still a consecutive step up. In order to create 10 "semitones" instead of the normal 12, the number 12 was divided by 10 and the result is that the new delta x (change in x), will have a space of 1.2 instead of 1. A0 was then labeled with the x value of 0 and then 1.2 was then added consecutively in order to create the new notes. Each x value was then substituted into the formula in order to generate the frequency for each 10-tone equal temperament note.

Frequencies of a Piano

Note	x (value)	y (frequency in hertz)
A3	45	220
A#3/Bb3	46	233.08
B3	47	246.94
middle C4	48	261.63
C#4/Db4	49	277.18
D4	50	293.66
D#4/Eb4	51	311.13
E4	52	329.63
F4	53	349.23
F#4/Gb4	54	369.99
G4	55	392
G#4/Ab4	56	415.3
A4	57	440
A#4/Bb4	58	466.16
B4	59	493.88
C5	60	523.25
C#5/Db5	61	554.37

Frequencies of a Decitone

Note	x (value)	y (frequency)
A4	45	220.379314
A#4	46.2	236.207396
B4	47.4	253.172282
C4	48.6	271.355621
C#4	49.8	290.844923
D4	51	311.733986
D#4	52.2	334.123343
E4	53.4	358.120748
F4	54.6	383.841695
F#4	55.8	411.409971
A5	57	440.958256
A#5	58.2	472.628758
B5	59.4	506.573899
C5	60.6	542.957047
C#5	61.8	581.953306
D5	63	623.750354
D#5	64.2	668.549349

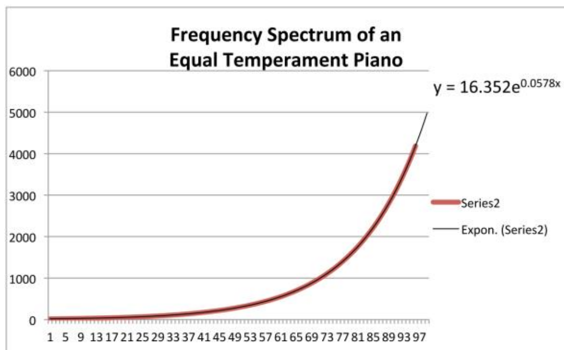

Figure 4. Frequency spectrum and examples of charts

Next, a system was needed in order to play the "notes."

4.3 Sounding The New Notes

There is a program called "MAX MSP" that allows one to perform various operations by connecting a spider web of "objects," each one having their own special functions. In the program, one can make use of a MIDI keyboard. MIDI stands for Musical Instrument Digital Interface and is a standard that allows for devices to communicate with one another by relaying a variety of performance data.[23] For example, when each note on a MIDI keyboard is triggered, they output a signal that has a numeric tag which tells the computer what note was just played. The idea of MIDI was taken a step further as these "tags" were routed so that the incoming MIDI notes will trigger the corresponding 10-tone frequency. The notes were assigned in the order of A to F#, and then back to A.

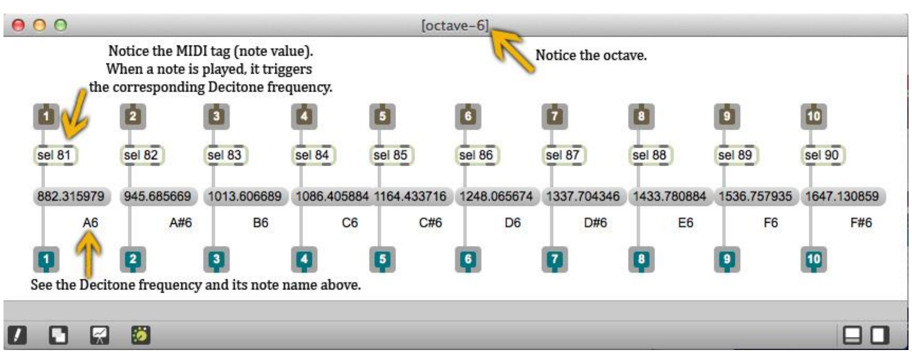

Figure 5. MIDI notes trigger their corresponding frequencies

Once the frequencies are triggered, an oscillator creates a sound at the pitch of the triggered frequency. The oscillator can create the sound for any frequency by constructing the electronic signal that one cycle of the frequency produces, and then repeating it.[24]

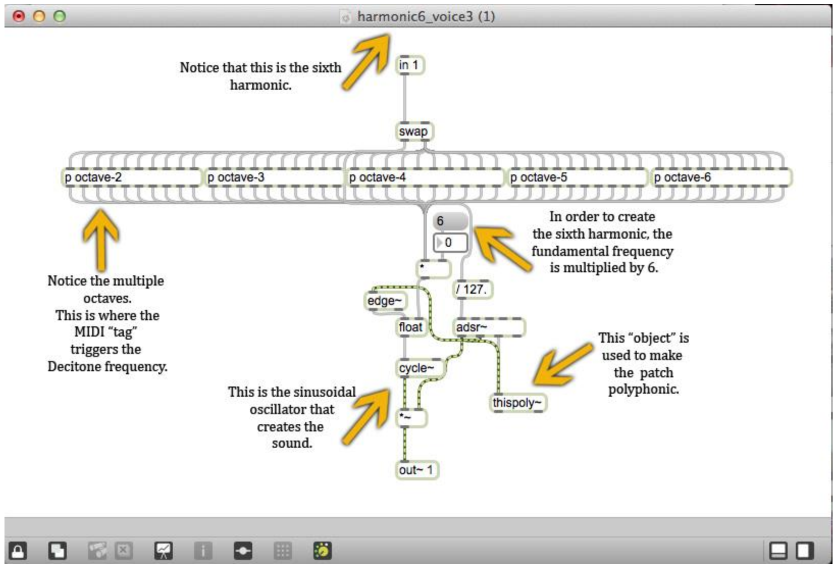

Figure 6. Sound is created through an oscillator

The sound that The Decitone creates has multiple oscillators, a technique called additive synthesis, involving the addition of harmonics. Additive synthesis is accomplished by adding numerous sine waves at different multiples of the fundamental frequency together, each at a different volume.[25] Creating a more complex sound by adding harmonics incorporates the same idea as the piano and clarinet example from earlier (4.1). Therefore, The Decitone has a unique timbre because of its harmonics.

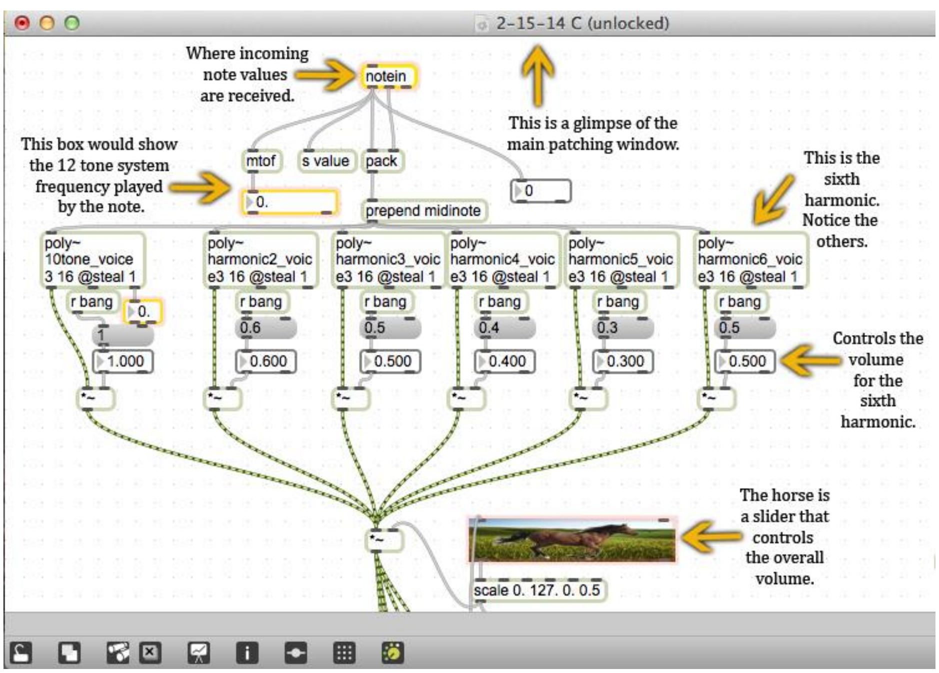

Figure 7. The complex sound is created through multiple harmonics

The patch was then made polyphonic so that multiple notes can be played at the same time. The resulting sound is very interesting, as human ears are not conditioned to the unique intervals. But, it adheres to a type of equal temperament scale.

4.4 Examples

It is important to actually hear the new system to understand the uniqueness of The Decitone. First, please copy and paste the following links into an Internet browser, then open and listen to the audio file. The first audio file is of a chromatic scale starting on A of a normal 12-tone system for reference.

http://www.ncurproceedings.org/ojs/index.php/NCUR2014/article/view/1096/609

Now, notice as the same chromatic scale is now played on The Decitone.

http://www.ncurproceedings.org/ojs/index.php/NCUR2014/article/view/1096/613

Next, the childhood song "Mary Had a Little Lamb" is played using The Decitone.

http://www.ncurproceedings.org/ojs/index.php/NCUR2014/article/view/1096/615

Notice the dramatic difference.

5. Accessibility of the System

People have created an equal temperament system based off of the numbers 31, 53, and 72. However, none were found to have been based off of the number 10.[26] These systems in the past never found practical use among composers and performers because of the difficulty involved in creating instruments that could perform the new temperament system. However, this system is extremely accessible as all one needs is a computer, the 10-tone system standalone application, and a MIDI keyboard. What is most interesting about the system is that using the procedure developed, virtually any other whole number division of the scale imaginable can be assembled.

6. Conclusion

Overtime, individuals have pushed the common practices of music in order to achieve a new expressive effect. This study strayed from the norm of a 12-tone equal temperament system and created a new equal temperament system with 10 notes. The resulting sound is very unique and interesting, but it allows for new expression in music and for music to connect with the scientific world. Who knows where music will evolve next?

Please find the downloadable version of the Decitone at: www.andrewgula.com/the-decitone

7. Acknowledgements

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