Content Based Music Information Retrieval: Concepts And Techniques

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***Abstract*—Due to digitization of musical objects large music repositories are maintained to cater to the needs of listeners, learners and composers as per their query. Music listeners make use of MIRs to retrieve music objects of their choice for listening purpose. The music composers also use MIRs for accessing music and analyzing the music objects for assessing their quality and originality. The MIR systems were built to respond to metadata based queries by specifying annotational details like name of the composer, singer, title etc. Modern MIR systems maintain content based indexes in order to respond to query by humming based on the musical phrases requested for. In this paper the general characteristics of music different ways of representation, indexing, matching and responding to the query are discussed.**

Keywords—CBMIR, QBH, MIDI.

1. Introduction

Music has always been an integral part of human living, both individually and socially, through the cultural, professional, leisure or religious aspects of life. Music is a way by which composers express their innermost feelings [9], [17]. A musical tone is characterized by its duration, pitch, intensity (or loudness), and timbre (or quality). The notes used in music can be more specific than musical tones, as they may also include temporal aspects, such as attack transients, vibrato, and envelope modulation. Music contains symbolic or structural relationships existing within and between various dimensions namely pitch, time, timbre, harmony, tempo, rhythm, phrasing and articulation. These elements combine to make music representation a rich field of study. Only during the recent decade that large scale computer-based storage of sound and music is taking place. Additionally, the increasing ease of distribution of music in computer files over the Internet gave further impulse to the development of digitized music databases as well as to new methods for Music Information Retrieval (MIR) from these collections.

Every popular music object is digitized and hence is available anywhere and anytime. Due to the huge volume of available music objects retrieval of a specific object based on the user request is becoming more and more complex. In addition to this, the researchers are challenged by the demand to retrieve music in response to query given in terms of content rather than Meta data. Accordingly modern MIRs have to adopt intelligent pattern extraction and matching techniques in support of content based MIRs [1].

1.1 Classification of Music objects

Music objects are classified into three groups depending on the number of participating streams and their roles. Monophonic music object involves only one musical note sequence resulted from playing one and only one note or the same note duplicated at the octave at a time stamp [8]. Rhythmic textures are generally added to the monophonic music objects to enhance style and atmosphere and the resulting music object is classified as homophonic. Both monophonic and homophonic music objects are created with a single melody layer representing the note sequence. On the other hand a polyphonic music object [10] is created with two or more simultaneous lines of independent melodies and hence a polyphonic music object contains a series of multiple notes plays simultaneously in time order. This research work concentrates on handling monophonic and homophonic music objects.

2. Representation of Music Objects

The music objects are represented in three formats:

1. *Conventional Music Notation (CMN):*

Represents music objects with symbols and time signature and it does not support automated processing as it is only human readable but not machine readable.

2. *Audio file format:*

Represents general songs digital form which can be played by CD players and iPods. These files are available in original format as *.wav* file and in compressed format as *.mp3* file.

3. *Musical Instrument Digital Interface (MIDI) file format:*

Provides event messages about the pitch and intensity, control signals for parameters such as volume, vibrato and panning, cues and clock signals to set the tempo [2]. Fig[1] depicts representation of music files in three formats.

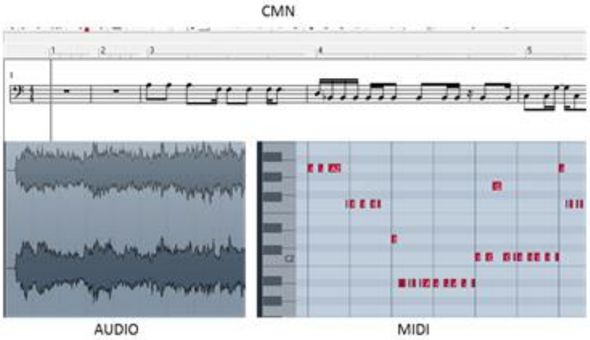

Fig [1] Representation of music files

The main melody of music object is often captured by the pitch/frequency which is represented in terms of MIDI note number which intern represents a semitone in an octave.

The musical frequencies are divided into 11 octaves numbered from '-1' to '9' each containing 12 semitones named 'C C# D D# E F F# G G# A A# B'. The range frequencies encompassed by an octave doubles as you go for higher octaves successively [18]. The name of the note reflects the semitone and the octave like 'A4' represents semitone 'A' in 4[th] octave and it has a distinct MIDI note number '60' as shown Fig[2] and Fig[3].

The MIDI note number is determined by the following formula that transforms hummed notes into the representation of MIDI values (semitones):

$$\text{MIDI value} = 69 + \left[12 \times \log_2 \left(\frac{\text{freq}}{440} \right) \right].$$

where *freq* is the frequency of hummed note and the operator '[ ]' calculates the nearest integer value, 12 leads to the classic dodecaphonic musical scale, and 69 is the MIDI note number that corresponds to central A with pitch equal to 440 Hz. By convention middle C (MIDI note Number 60) is C4. A MIDI note number of 69 is used for A440 tuning, that is the note A above middle C.

Note: C
Octave Number: 4
MIDI Number: 60

Octave	MIDI Note Numbers											
Number	C	C#	D	D#	E	F	F#	G	G#	A	A#	B
-1	0	1	2	3	4	5	6	7	8	9	10	11
0	12	13	14	15	16	17	18	19	20	21	22	23
1	24	25	26	27	28	29	30	31	32	33	34	35
2	36	37	38	39	40	41	42	43	44	45	46	47
3	48	49	50	51	52	53	54	55	56	57	58	59
4	60	61	62	63	64	65	66	67	68	69	70	71
5	72	73	74	75	76	77	78	79	80	81	82	83
6	84	85	86	87	88	89	90	91	92	93	94	95
7	96	97	98	99	100	101	102	103	104	105	106	107
8	108	109	110	111	112	113	114	115	116	117	118	119
9	120	121	122	123	124	125	126	127				

Fig [2] MIDI note numbers

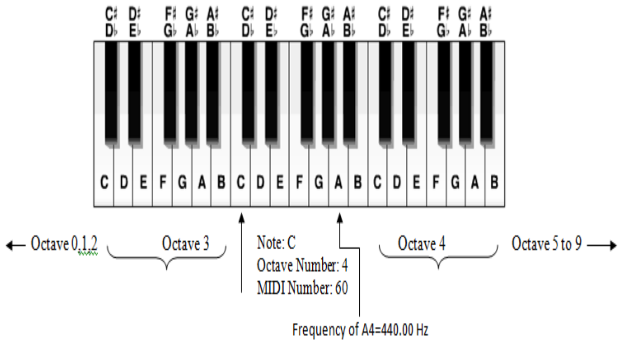

Fig [3] Frequency for A4 in 4[th] Octave

3. Music Characterization

Music is an inevitable part of human civilization and has a lot of diversity in the musical notations practiced by people of different regions worldwide. However a piece of music entertains any person irrespective of culture and region which imply there is some commonality in the fundamental concepts of all musical systems. For example the same set of semitones constitutes Indian as well as Western music.

3.1 Indian Music

The Indian Music is often composed with raga orientation. A raga is based on a scale with a given set of notes, a typical order in which they appear in melodies, and characteristic musical motifs. All compositions and artiste's improvisations that we hear in concert platforms are all raga based. The basic components of a raga can be written down in the form of a scale differing in ascent and descent referred to as arohanam and avarohanam. By using only these notes, by emphasizing certain degrees of the scale, and by going from note to note in ways characteristic to the raga, the performer sets out to create a mood or atmosphere that is unique to the raga in question.

There are several hundred ragas in present use, and thousands are possible in theory. The classification of ragas plays a major role in Indian music theory. In north India (Hindustani music), ragas are classified according to such characteristics as mood, season, and time, where as in south India (Carnatic music), ragas are grouped by the technical traits of their scales. There are 72 melakartha ragas and they are categorized in to 12 chakras namely *Indu, Netra, Agni, Veda, Bana, Rutu, Rishi, Vasu, Brahma, Disi, Rudra, Aditya.* The two systems may use different names for similar ragas or the same name for different ragas.

3.2 Western Music

Scale:

A western scale is any set of musical notes ordered by fundamental frequency or pitch. A scale ordered by increasing pitch is an ascending scale, while descending scales are ordered by decreasing pitch.

The major scale:

The major scale is a *diatonic* scale. The major scale is most simply described as the eight note progression consisting of the perfect and major semitones, i.e., perfect unison, major 2nd, major 3rd, perfect 4th, perfect 5th, major 6th, major 7th, and perfect octave in that order. The major scale is C D E F G A B; do re mi fa sol la ti; 1 2 3 4 5 6 7. Scales may be constructed according to their *intervals* as shown in Table [1].

The minor scale:

The minor scale is also a diatonic scale. The C minor scale is C D E♭ F G A♭ B♭; 1 2 ♭3 4 5 ♭6 ♭7. You can see that it consists of one whole tone, then a semitone (moving from D to E♭), then two more whole tones, then again a semitone (moving from G to A♭), and a final whole tone. If we add the implied C at the end of the scale, we would have eight notes: C D E♭ F G A♭ B♭ C.

Intervals:

Intervals are usually named according to the relationship of the higher note to the lower note in the major scale, though they also have alternate names depending upon the spelling of the particular notes on the page of music.

Semitones	Common Name	Alternate Names
0	perfect unison	diminished second
1	minor second	augmented unison
2	major second	diminished third
3	minor third	augmented second
4	major third	diminished fourth
5	perfect fourth	augmented third
6	tritone	augmented fourth, diminished fifth
7	perfect fifth	diminished sixth
8	minor sixth	augmented fifth
9	major sixth	diminished seventh
10	minor seventh	augmented sixth
11	major seventh	diminished octave
12	perfect octave	augmented seventh

Table [1] Construction of Scales with intervals

The different scales in western music [11] are 1. Traditional scales (major, minor scale) 2. Pentatonic and blues scales 3. The symmetric scales (chromatic, whole-tone, octatonic).

Music is universal and relies on the same musical frequencies with different naming for semitones representing a musical frequency in different conventions. The correspondence between the naming of the semitones in Western, Hindustani and Carnatic music systems is tabulated in Table [2].

Semitones	**Western Notes**	**Names of Western Notes**	**Hindustani**	**Carnatic**
C	Do	TONIC	S	S
C#/Db			r	R1
D	Re	SUPERTONIC	R	R2
D#/Eb			g	G2
E	Mi	MEDIANT	G	G3
F	Fa	SUBDOMINANT	M	M1
F#/Gb			m	M2
G	So	DOMINANT	P	P
G#/Ab			d	D1
A	La	SUBMEDIANT	D	D2
A#/Bb			n	N2
B	Ti	LEADING TONE	N	N3

Table [2]

4. Representing main melody as note sequence

The music objects represented in audio and MIDI formats are machine processable and hence becomes amicable for automated retrieval. A song or a piece of music with suitable accompaniment are generally represented as a homophonic music object containing separate tracks for various accompaniment in addition to main melody, as a MIDI file. The main melody contains most of the information pertaining to the identification of the music object and hence demands special focus while processing music objects in the context of music information retrieval. The main melody is extracted by separating the track representing it from originally homophonic music object to create a monophonic music object [7].

The theme of a song is inherently captured by the track representing main melody as it provides data regarding the sequence of notes played at various time stamps along with velocity etc. In the context of monophonic music information retrieval in response to Query by Humming (QBH) the note sequence representing the main melody is totally ordered. In other words the notes are strictly ordered because at every time stamp no more than one note is played excluding the accompaniments. Hence a music object can be treated as a string of characters and string matching techniques are applied in Content based MIR system [4].

5. Indexing Music Objects for Efficient Retrieval

Efficient retrieval of appropriate music objects is essential to deal with very large collections of music objects. Indexing the music objects support the efficient retrieval from large databases. Simple indexing suffices for Meta data based music information retrieval while pattern based indexing is essential for content based music information retrieval.

5.1 Meta data based Retrieval

Identifies a music object based on the characteristics associated with the song, such as the name of composer, performers, song title, title of the album on which it was released, year released, track number, genre, album art, lyrics, producer, language etc. hence index includes characterizing terms like name of singer, composer, title etc. as shown in Table [3]

Query contains some of the index terms enough for constraining the collection of songs that possess the characters

5.2 Content based Retrieval

Frequently repeating note sequences are identified as patterns, for each music object separately and these patterns constitutes index terms for the music object. Query is a note sequence often containing some of the repeating patterns of the song based on which matching proceeds.

6. Repeating Patterns

The primary problem of music data processing because of its complex structure is the selection of appropriate representation that can satisfy both semantic as well as efficiency requirements for content-based information retrieval.

A repeating pattern in music data is defined as a sequence of notes which appears more than once in a music object. The theme of a song is often captured by repeating pattern. The themes and other nontrivial repeating patterns are important music features which can be used for both content-based retrieval of music data and music data analysis [5]. A theme (especially in classical music) is a melody that the composer uses as a starting point for development, which may be repeated in the form of variations.

Repeating patterns constitute a useful representation of a music object focusing its theme. They comprise a compact form for indexing the original formats (e.g., raw audio, MIDI, etc.). This is because the total size of the collection of repeating patterns is much smaller than that of the music objects. Therefore, the repeating patterns meet both efficiency and thematic requirements for content-based music information retrieval. Repeating patterns have been used to index music sequences for the purposes of music data retrieval. In addition, they provide a reference point for the discovery of music themes. Finally, repeating patterns have been considered as characteristic signatures of music objects, which support the notion of a quantitative measure for music similarity.

6.1 Mining repeating patterns:

To find all repeating patterns in the melody string **S**, a naive method is to generate all substrings of **S**. Then, each substring **P** of **S** will be compared with **S** to decide the number of times that **P** appears in **S**. This method is simple but very inefficient: if the length of string **S** is **n**, the number of all substrings of the input string **S** is **n+(n-1)+…+1** . For a substring **P** of length **m**, it needs **O(m×n)** character comparisons to find the frequency that **P** appears in **S**. In the worst case, the total complexity will be $O(n^4)$. For example, for a music object consisting of 1000 notes, it will cost $O(10^{12})$ character comparisons to find all repeating patterns in the music object.

6.2 Sequential pattern mining:

Sequential pattern mining [6] is a specialized field of data mining which focuses on extracting sequential patterns from sequence data repositories. Sequential pattern mining has separate set of techniques to extract repeating pattern from long sequences [8] and frequent sequential patterns from a large collection of shorter sequences of fixed or variable length constituting a sequence data base.

6.3 Approximate pattern mining:

The authors have developed a frame work for representing the main melody of a monophonic music object as a long sequence of notes along with the time stamps and applied sequential mining techniques for extracting repeating patterns allowing tolerance for minor alterations in the notes played which is essential for dealing with real world applications [7]. Sequential patterns with tolerance are referred to as approximate sequential patterns which contain one or more exactly repeating patterns that are joinable as they co-occur close to one another frequently [3]. Hence, mining exactly repeating patterns provides seeds for formation of lengthier approximate sequential patterns with tolerance.

7. Query processing

Query by Humming (QBH) is a content-based retrieval method and an efficient way to search for a song from a large database. It is a very effective and natural way of querying a musical audio database by humming or singing the tune of a song. The advantage of QBH system is that the user needs only to hum or sing the song in a leisure way, instead of inputting the Meta data like name of the song to retrieve a song of his interest. Most of the QBH systems are realized by using frame based algorithms. Generally, these methods are more accurate than the note-based ones. However, the note-based methods are more efficient than the frame-based ones [15].

Earth Mover's Distance (EMD) is a note-based algorithm for querying music. Originally, this method is used in image retrieval. Rainer [16] proposed this method in music information retrieval (MIR). EMD is also an efficient algorithm due to the utilization of notes, because the note based algorithms need not compare the song with the humming frame-by-frame. This method mainly uses the pitch and duration information of the note, while ignoring the timing information of the music.

7.1 Segmentation of the input query

MIDI format music lacks the necessary separators that represent “lexical units” like text words and hence demands segmentation of a melody into units. In musicological literature, the segmentation of a melody into musically relevant phrases is a well-known problem. If a melody contains six segments such as AABABB, then we know that the first music segment is repeated at the second and fourth segments while the third one is repeated at the fifth and sixth segments. Melodic segmentation is very helpful for music analysis regarding music snippet or thumbnail, music summarization, and music retrieval. The basic idea of the algorithm is that the listener perceives the presence of boundaries between melodic phrases whenever there are some changes in the relationships among the notes caused by pitch intervals, note duration and rest and hence these differences are reflected in the query fragment he sung or hum for retrieving a music object of his interest.

Query segmentation proceeds by identifying a series of group boundaries between notes and assigning weights to them based on their suitability were been considered as a separator as musical phrases. Depending on type of music (western, classical, Indian) one of the following criteria may be used for segmentation.

7.1.1 Interval change weight:

Interval change weight refers to the pitch difference between adjacent semitones in a note sequence which is often represented in terms of MIDI note numbers [14]. Change weight is suitable for segmentation of music objects. The Table [4] depicts the series of segments identified from the MIDI melody shown in Fig [4].

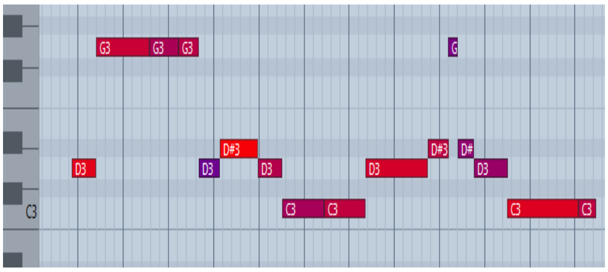

Fig [4] MIDI Melody Query

S. No.	Segments/ Patterns
1	D3
2	G3G3G3
3	D3D#3D3C3C3D3D#3
4	G3
5	D#3D3C3C3

Table [4] Segments based on the interval change weight

7.1.2 Note duration weight:

Note duration weight refers to the length of a note given by the inter onset and intervals of successive notes played. A note played for a longer duration has higher note duration weight suggesting the boundary of a musical segment as shown in Table [5].

7.1.3 Silence weight:

Silence weight refers to the difference between offset to onset time stamps of successive notes played in a melody perceivable as rest.

8. Matching

Once the query is segmented into query phrases the content based music information retrieval proceeds to match these segments with the repeating patterns used for indexing the musical objects.

whole note	longest note duration	
half note	half the duration of a whole note	
quarter note	a fourth (or a quarter) of a whole note	
eighth note	has one flag, two eighth notes occupy the same amount of time as one quarter note	
sixteenth note	has two flags, Two sixteenth notes equal the duration of an eighth note	

Table [5]: Note Duration

The normal string matching algorithms can only deal with exact matching of strings which is not suitable in this context. A musical string representing the same theme (slightly) varies depending on the person/instrument that plays it and hence the ability to match strings with tolerance for missing additional or slightly different notes is essential for matching musical phrases.

8.1 Dynamic Time Warping:

This is a segment alignment method to estimate the similarity between two symbol sequences of possibly different lengths. This method is extensively used for automatic speech recognition, bioinformatics and other time series analysis it follows dynamic programming approach to find a sequence of maximal matching symbol pairs maintaining their order from the two given symbol sequences. In the process of alignment of the given symbol sequences for maximal matching it considers insertion, deletion and replacement of a symbol in the query sequence. The matching process is illustrated in Fig. [5] and the details of DTW are discussed in [12],[13] and [15].

Let D(i,j) refer to dynamic time warping distance between two subsequences $x_1, x_2 \ldots x_i$ and $y_1, y_2 \ldots y_j$ then $D(i,j) = x_i - y_j + \min\{D(i-1,j), D(i-1, j-1), D(i, j-1)\}$

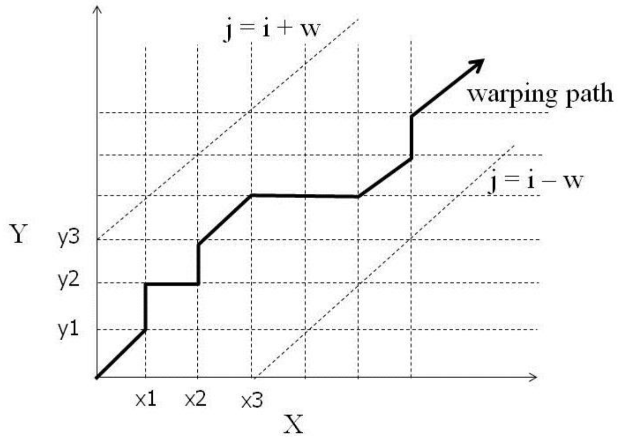

Figure [5] warping path

Algorithm:

1. Compute the distance Matrix d: $d(i, j) = d(seq_1(i), seq_2(j))$, for $(i) \in [1, n_1]$ and $(j) \in [1, n_2]$

2. Initialize the matrix D:

$D(1, 1) = d(1, 1)$

for $i \in [2, n_1]$, $D(i, 1) = D(i - 1, 1) + d(i, 1)$

for $j \in [2, n_2]$, $D(1, j) = D(1, j - 1) + d(1, j)$

3. Fill in the matrix D:

for i from 2 to n1

– for j from 2 to n_2

(a) Choose $(k, l) \in set_{(i,j)}$ so that $D(k, l)$ is minimum.

(b) $D(i, j) = D(k, l) + d(i, j)$

4. Return $D(n_1, n_2)$.

Example: Consider two note sequences.

Sequence 1: 1 1 1 3 2 2

Sequence 2: 1 1 3 1 2 2

$$\begin{pmatrix} 0 & 1 & 2 & 3 & 4 & 5 \\ 1 & 0 & 1 & 2 & 3 & 4 \\ 2 & 1 & 0 & 1 & 2 & 3 \\ 3 & 2 & 1 & 2 & 1 & 2 \\ 4 & 3 & 2 & 1 & 2 & 3 \\ 5 & 4 & 3 & 2 & 3 & 2 \end{pmatrix}$$

Fig [6] distant matrix of penalties for the given sequences using DTW

8.2 Histogram matching:

This method is often used in content based music information retrieval to identify scale of song. This method required to maintain reference histograms representing the key signatures of MIDI melody for several music objects in the database. When a query song is given it represented as a histogram of 12 bins and compared with the reference histogram of various music objects in the database. Based on the histogram of the maximum matching music object the scale of the query song is assessed.

Musical Scales with Key Signature	
Major Scales	Minor Scales
C: (no shapes)	Am:(no flats)
G:(with keys: F#)	Dm:(with keys:Bb)
D:(with keys: F#,C#)	Gm:(with keys:Bb,Eb)
A:(with keys: F#,C#,G#)	Cm:(with keys:Bb,Eb,Ab)
E:(with keys: F#,C#,G#,D#)	Fm:(with keys Bb,Eb,Ab,Db)
B:(with keys: F#,C#,G#,D#,A#)	Bbm:(with keys: Bb,Eb,Ab,Db,Gb)
F#:(with keys: F#,C#,G#,D#,A#)	Ebm:(with keys: Bb,Eb,Ab,Db,Gb)
C#:(with keys: F#,C#,G#,D#,A#)	Abm:(with keys: Bb,Eb,Ab,Db,Gb)

Table[7]: Musical Scales with Key Signature

The process of histogram based matching [14] includes construction of note histogram for the melody/query as first step followed by comparing note histogram with reference histogram to locate the root note that captures the scale. Irrespective of the range of semitones involved in the melody the histogram representation of a musical object contains 12 bins numbered from 0 to 11. Since every semitone/ MIDI note number is converted into this range by applying modulo12 representing the number of notes of a single octave as they are cyclic as shown Table [6] and Table [7]

Major Scale									**Minor Scale**							
C	D	E	F	G	A	B	C	**1**	C	D	Eb	F	G	Ab	Bb	C
C#	D#	F	F#	G#	A#	C	C#	**2**	Db	Eb	E	Gb	Ab	A	B	Db
D	E	F#	G	A	B	C#	D	**3**	D	E	F	G	A	Bb	C	D
D#	F	G	G#	A#	C	D	D#	**4**	Eb	F	Gb	Ab	Bb	B	Db	Eb
E	F#	G#	A	B	C#	D#	E	**5**	E	Gb	G	A	B	C	D	E
F	G	A	A#	C	D	E	F	**6**	F	G	Ab	Bb	C	Db	Eb	F
F#	G#	A#	B	C#	D#	F	F#	**7**	Gb	Ab	A	B	Db	D	E	Gb
G	A	B	C	D	E	F#	G	**8**	G	A	Bb	C	D	Eb	F	G
G#	A#	C	C#	D#	F	G	G#	**9**	Ab	Bb	B	Db	Eb	E	Gb	Ab
A	B	C#	D	E	F#	G#	A	**10**	A	B	C	D	E	F	G	A
A#	C	D	D#	F	G	A	A#	**11**	Bb	C	Db	Eb	F	Gb	Ab	Bb
B	C#	D#	E	F#	G#	A#	B	**12**	B	Db	D	E	Gb	G	A	B

Table [6]: The major and minor scales

9. Conclusion

This paper provides a comprehensive review of different ways of representing the music objects in particular the melody as a note sequence followed by pattern extraction from the melody and using them to identify the most relevant music object for a given query after segmenting it into query phrases. Specific technique selected at each stage of MIR system development may differ depending on the purpose or the end users of the MIR.

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S. No	Album	Music	Lyrics	Cassettes & CD’s	Song	Singers
1	Andhra Pori	Josyabhatla	Suddala Ashok Teja	Aditya Music	Ye Kaviki	Hemachandra, Pranavi
2	Daana Veera Sura Karna	Kousalya, Vandemataram Srinivas, Sabu Varghese	Chaitanya Prasad, Ganothri Viswanath	Aditya Music	Raa Raa Madhava Muralilola	Ramya Behara, Kashyap Kompella
3	Budugu	Sai Karthik	Balaji	E3 Music	Laalinche Amma	Siddarth
4	Yentha Vaadu Gaanie	Harris Jayaraj	A. M. Rathnam, Sivaganesh	Sony Music	Yentha Vaadu Gaanie	Devan Ekambaram, Mark Thomas & Abhishek

Table [3]