

Raga classification based on pitch co-occurrence based features

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Article Info

Article history:

Received May 17, 2021

Revised Jul 31, 2021

Accepted Aug 4, 2021

Keywords:

Data mining

Instruments

Mel frequency cepstral coefficients

Music information retrieval

Raga classification

ABSTRACT

Analysis and classification of raga is the need of time especially in music industry. With the presence of abundance of multimedia data on internet, it is imperative to develop appropriate tools to classify ragas. In this work, an attempt has been made to use occurrence pattern of pitch based svara (note) for classification. Sequence of notes is an important cue in the raga classification. Pitch based svara (note) profile is formed. This pattern presents in the signal along with its statistical distribution can be characterized using co-occurrence matrix. Proposed note co-occurrence matrix summarizes this aspect. This matrix captures both tonal and temporal aspects of melody. Ragas differ in terms of distribution of spectral power. K-nearest neighbor (KNN) has been used as the classifier. Publicly available database consisting of 300 recordings of 30 Hindustani ragas consisting of 130 hours of audio recordings stored as 160 kbps mp3 files which is part of CompMusic project is used. Leave one out validation strategy is used to evaluate the performance. Experimental result indicates the effectiveness of the proposed scheme which is giving accuracy of 93.7%.

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1. INTRODUCTION

Indian music is broadly classified into North Indian Hindustani (North Indian) music, Carnatic (South Indian) [1]. The melody in Indian classical music is controlled by raga. Raga typically comprises of allowed notes or svaras of the 12-tone scale, their sequence, ascending or descending svara patterns (arohana-avarohana), gamakas (movements between notes), and by a set of characteristic catch phrases like pakad. 'Pakad' contains the melodic theme of the raga in Indian classical music [2]. In addition, they serve as the main cues for raga identification by experienced listeners [3]. Raga classification consists of techniques that identify different notes and characteristic phrases. Modeling raga classification using computational approaches can open many channels for Indian classical music. Study of documents and artifacts to examine patterns in music signal in a systematic manner can provide strong cues for melody of the song.

Music information retrieval (MIR) is the need of the time due to large availability of it on internet. MIR based applications are search and retrieval of music, similarity-based music classification, musicological studies [4], recommendation systems, in music learning, beat tracking and tempo estimation of music. Raga analysis has many computational opportunities [4]. Audio analysis of the performance recordings of eminent musicians can be used to identify the relationship of implicit musicological knowledge to contemporary practice. Computational modeling of ornaments of raga from attributes of pitch, timbral and volume dynamics can be useful in MIR. Raga analysis can be applied for identification of Gharana and raga-

specific styles of ornamentation. Most important thing in MIR is classification. It is possible to manage such huge database if recordings are categorized into different groups.

- Raga theory and concepts

Indian classical music has seven notes called as saptak or octave. There are three major saptakas or octaves in which these svaras can be played, tivra (higher octave), Madhya (middle octave) and mandra saptak (lower octave). Every svara has predefined frequency in these saptakas. Shadja, Rishabh, Gandhar, Madhyam, Pancham, Dhaivat and Nishad along with five intermediate notes as komal Rishabh, komal gandhar, tivra Madhyam, komal Dhaivat and komal Nishad [5], [6] which can easily be represented as shown in Table 1. The seven notes used are termed as svaras. Except for Sa and Pa svaras, the rest of them have two or three variants as shown in Table 1. Svaras in raga have different functions. Certain svaras are reference pitches, stable and repeated frequently and appear at important positions in musical phrases. Certain svaras are said to be more important than the rest [7]. These svaras bring out the mood of the raga. They are called the jiva svaras. The svara which occurs at the beginning of melodic phrases is referred to as graha svara. Nyasa svaras are those svaras which appear at the end of melodic phrases. Dirgha svaras are svaras that are prolonged. A svara that occurs relatively frequently is called amsa svara, and that which is sparingly used is called alpa svara, and so on. Therefore, even if two given ragas have the same set of constituent svaras, their functions can be very different. Raga can be recognized with the help of many attributes like vadi, samvadi, anuvadi, and vivadi svaras. Vadi is most frequently occurring and most important svara of raga. Next most important are samvadi and anuvadi while vivadi is varja svara which is not used in particular raga. The sequence in which the svaras are played is called aaroha and avaroha. The ascending order is called aaroha while descending is avaroha. A set of notes or phrase played by the artist repeatedly which represent the raga is called pakad. Ornaments of the raga are called gamakas.

Table 1. Table of Hindustani and Carnatic svaras

Symbol	Position	Ratio	Karnataka/Hindustani name
Sa	1	1	Sadjama
R1	2	16/15	Suddha/Komal Risabha
R2	3	9/8	Chatusrti/Tivra Risabha
G1	3	9/8	Suddha Gandhara
G2	4	6/5	Sadarana/Komal Gandhara
R3	4	6/5	Satsrti Risabha
G3	5	5/4	Antara/Tivra Gandhara
M1	6	4/3	Suddha/Komal Madhyama
M2	7	64/45	Prati/Tivra Madhyama
Pa	8	3/2	Panchama
D1	9	8/5	Suddha/Komal Daivata
D2	10	5/3	Chatusrti/Tivra Daivata
N1	10	5/3	Suddha Nisada
N2	11	16/9	Kaisiki/Komal Nisada
D3	11	16/9	Satsrti Daivata
N3	12	15/8	Kakali/Tivra Nisada

- Previous work done

There are lot of methods attempted so far considering various features of raga. Sharma and Bali [6], have used pitch as feature and defined some heuristic to identify notes and Ngram matching for ‘pakad’ with the help of ‘Praat’ software. Approaches based on pitch class distribution (PCD) based features are in [7], [8]. They make excellent use of tonal material in the signal and robust to pitch octave errors. But they ignore temporal aspects which are useful in distinguishing ragas which have same set of notes [9]. In [10], [11] have used ‘chromogram’ of ragas feature and Bayesian classifier, random forest and K-star for identification. In [12]-[19] authors have made use of arohana-avarohana pattern to capture the sequential information in the melody. Padmasundari and Murthy [20], use locally sensitive hashing to measure the similarity of ragas. However, the movement between svaras known as ‘gamakas’ are not captured which are important cues for raga classification. In this paper, an attempt is made to capture the tonal and temporal aspects using co-occurrence matrix of pitch-based notes [21]. It captures the pattern present in the signal along with its statistical distribution which we think can be useful in distinguishing ragas. Table 2 summarizes at a broad level the features used, their advantages and shortcomings and the overall progression in the work done so far.

- Proposed work

One of the major challenges was to identify features which can model both tonal and temporal characteristics of a melody and in a compact way and have musically meaningful representation. The feature should effectively capture the sequential pattern of raga providing details about melodic transitions between svaras. The feature should be robust to pitch octave errors which is the one of the most frequent errors in raga

classification. Occurrence pattern of each svara and and the characteristic melodic transitions between svarasat different time scales is captured effectively in co-occurrence matrix. As a result, it represents in its entirety both tonal and temporal characteristics of the entire melody. Each raga differs in terms of distribution of spectral power. It captures overall usage of the svaras and their short time temporal relation which are useful in distinguishing raga. Another major challenge was to choose a classifier which could distinguish large number of classes. At the same time be fast and computationally efficient with a smaller number of parameters to tune. KNN is used as a classifier as it is relatively simple to implement considering the task of distinguishing 30 ragas. It requires no training and faster to execute. In addition, there is ease of capacity control as only one parameter k required to tune.

Remainder of this paper is organised as follows. In section 2, we discuss about the proposed method describing the implementation details used for feature extraction and classification. In section 3, we discuss about results and future steps. Section 4 covers conclusion.

Table 2. Categorization of the work done so far

Features based on	Paper	Distinctive characteristics
Pitch and PCD	[6]	Using pitch as feature identify notes in raga and Ngram matching for 'pakad'.
Advantages: robust to pitch octave errors. Shortcomings: completely disregard the temporal aspects. Temporal aspects	[7], [8]	Excellent use of tonal material in the signal.
Advantages: capture the sequential information in the melody. Shortcomings: ignore the characteristic melodic transitions between svaras required for distinguishing allied ragas	[12]-[19]	Excellent use of arohana-avrohana pattern to capture sequential information. Transcribe the predominant melody in terms of a discrete svaras.

2. RESEARCH METHOD

The most important svara in Indian classical raga is the 'Sa' or the tonic frequency of the main singer. All other accompanying instruments are tuned to this svara. Therefore, first step is to carry out tonic normalization using tonic pitch which is also a part of the provided database. The normalized pitch values in Hz are then converted to cents scale for making it musically relevant as 1200 cents correspond to one octave. The normalized pitch values in cents are then mapped to 120 different bins making the resolution to 10 cents per bin which is considered as optimal pitch resolution. For each audio clip file, 120 by 120 co-occurrence matrix is constructed where an element denotes number of occurrences of a particular svara (bin) pair in two successive frames. Thus, the matrix effectively captures both tonal and temporal characteristics of the various svaras. Co-occurrence matrix is N-th order matrix used to describe the joint distribution probabilities of pitch pairs in adjacent frames where N in this case is number of bins. Time required for calculation of co-occurrence matrix is directly dependent on two major factors which are length of the audio clip and number of levels or bins. The longest audio clip in the database consists of 753766 pitch values and time required for calculations of co-occurrence matrix of this clip is 4.19 ms.

Performance of KNN classifier depends on the distance measure to be used. For KNN classifier, 3 different distance measures of Frobenius norm, Kullback-Leibler divergence (KLD) and Bhattacharya are used to compute distance between 2 audio clip files and eventually retrieve k neighbors. For 300 audio clips, it took 3.7 second for Euclidean, 40 second for Bhattacharya and 140s for KLD.

2.1. Implementation steps-co-occurrence matrix

- Figure 1 explain the steps for identifying raga. Each step is explained below.
- Read the audio clip which is then into divided into number of frames. So, each frame consists of pitch value corresponding to it.
- Read the file which contains tonic frequency for that audio clip.
- Tonic normalization and converting to cents are done as follows where $0 \leq i < N$, where N is the total number of frames, c_i is the normalized svara frequency in cents, and f_i is the predominant pitch (in Hz) in that frame ω is the tonic pitch of the lead artist and will be different for each artist. All other notes are with reference to this note. Hence tonic normalization is performed.

$$c_i = 1200 \log_2 \left(\frac{f_i}{\omega} \right) \tag{1}$$

- Binning is done as follows where $\omega = 120$ and B is an octave-wrapping integer binning operator defined by;

$$B(x) = \left\lfloor \left(\frac{\eta x}{1200} \right) \right\rfloor \text{ mod } \eta \tag{2}$$

The purpose of binning is to analyse the frequency of pitch values grouped into categories that are perceptually relevant.

- Co-occurrence matrix is constructed.

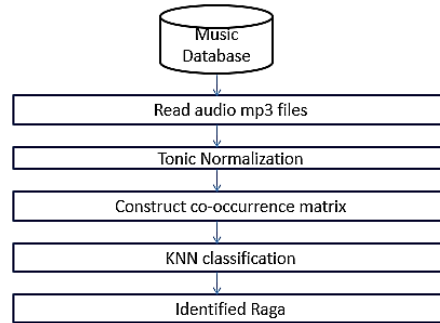


Figure 1. Raga identification steps

2.2. Implementation steps KNN

Musical signals have wide variety making classification task critical. We have chosen to use KNN as classifier [22]-[24]. Its simplicity and relatively high convergence speed make it a popular choice. It is based on the concept that examples that are near to each other will have similar characteristics. Thus, if you know the characteristic features of one of the examples, you can also predict it for its nearest neighbor. It is based on the idea that any new example can be classified by the majority vote of its 'k' neighbours, where k is a positive integer, usually a small number.

Implementation steps:

- Distance between 2 audio clips with co-occurrence matrices $S(n)$ and $S(m)$ respectively are calculated using 3 different distance measures:

a) Frobenius norm

$$D_F^{(n,m)} = \|S_n - S_m\|_2 \quad (3)$$

where S_n = feature vector of the nth mp3 file

where S_m = feature vector of the mth mp3 file

b) Kullback-Leibler divergence

$$D_{KL}^{(n,m)} = D_{KL}(S^{(n)}, S^{(m)}) + D_{KL}(S^{(m)}, S^{(n)}) \quad (5)$$

$$D_{KL}(X, Y) = \sum X \log\left(\frac{X}{Y}\right) \quad (6)$$

c) Bhattacharya

$$D_B^{(n,m)} = -\log\left(\sum \sqrt{S^{(n)} \cdot S^{(m)}}\right) \quad (7)$$

- For all the three distances, we perform element-wise operations and sum over all the elements of the resultant matrix. We tried with three values of k which are 1,3,5.

Testing has been carried out with leave one out cross validation strategy.

3. RESULTS AND DISCUSSION

We use the Hindustani music dataset (HMD) from the publicly available Indian art music raga recognition datasets from the CompMusic Corpora, assembled by the music technology group at University of Pompeu Fabra, Barcelona, Spain. [25], [26]. They contain full length mp3 audio recordings and their corresponding Raga labels. They are the most extensive and exhaustive datasets available for research in the Raga recognition field. HMD contains 130 hours of audio recordings stored as 160 kbps mp3 stereo audio files. It contains 300 recordings in 30 Ragas, with 10 recordings for each Raga. Dataset is balanced in the number of instances per class.

We have used leave-one-out validation strategy. In this, one recording is used for testing and rest of the recordings are used for training. It is observed that large number of classes makes the task of raga identification challenging. As can be seen from the Figures 2(a)-(d) (See APPENDIX), Figure 3(a)-(d) (See APPENDIX), and Figure 4(a), (b) distribution of spectral power (pitch frequencies) varies for each raga and capturing the distribution pattern in the form of a co-occurrence matrix has proven to be good cue for raga classification. The distribution is more along the diagonal. These correspond to the svaras. The noticeable elements along the diagonal correspond to the Vadi svara, i.e., it is the svara which is most frequently used or is the most stressed one. Uneven spread with respect to the diagonal is due to different set of svaras used in the arohana and avarohana of the raga. It is observed that co-occurrence matrix also effectively captures the short time temporal relation between pitches.

Confusion matrix in Figure 5 is computed over the predicted classes for accuracy purpose. Table 3 captures the accuracies for the 3 distance measures for $k=1,3,5$. Predicted class is assigned based on the majority class of its k -nearest neighbors. Random selection of the majority class is done in case of a tie. Performance is highest for Bhattacharya which is 93.7% and $k=3$. We observe that as k increases, accuracy decreases. This can be attributed to a smaller number of samples for each class in the data set.

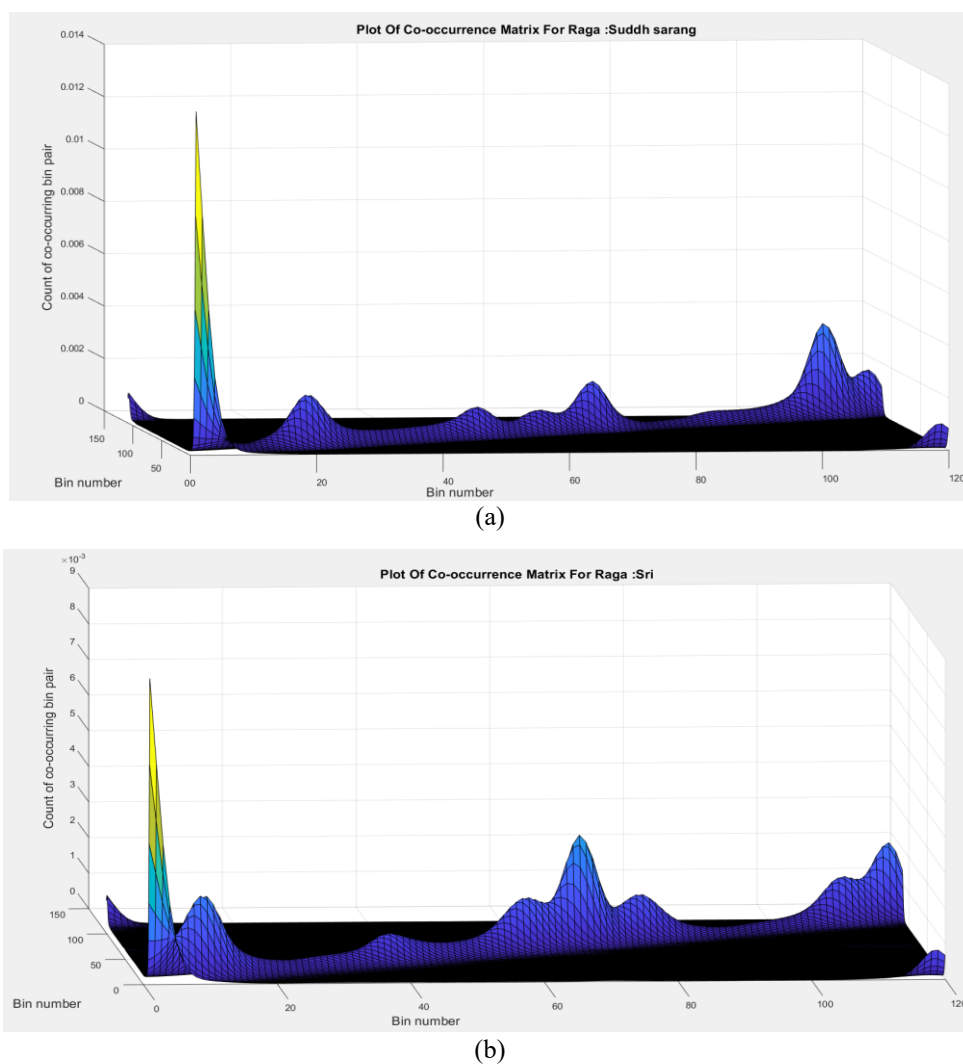


Figure 4. Plot of co-occurrence matrix for (a) Shudha Sarang and (d) Sri respectively

The two existing methods used for evaluation are the ones proposed by Chordia and Senturk [2], denoted by EPCD, and by Gulati *et al.* [26], denoted by EVSM. In Table 4, results of the proposed method with three different distances, and the existing methods using HMD data sets are shown. EPCD, uses pitch class dyad-based features computed from the entire audio recording. EVSM, uses automatically discovered

melodic phrases and vector space modeling. Kullback-Leibler and Bhattacharya give the highest accuracy of 97.7% on HMD. It is significantly higher than 91.7% obtained by *EPCD*. It is also observed that incorrectly classified ragas are the ones which have common set of svaras or phrases. Bhairavi, Mukhari are allied ragas. So are Harikambhoji, Kambhoji.

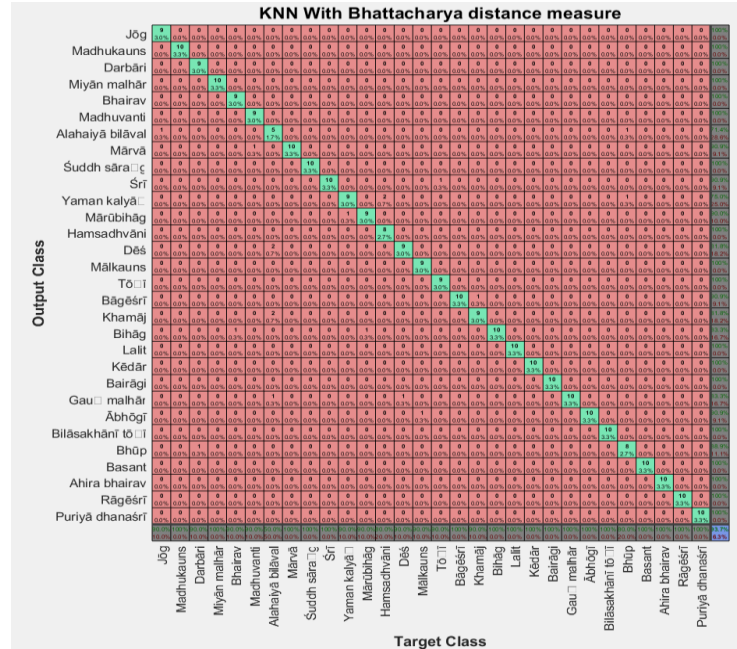


Figure 5. Confusion matrix for ragas using Bhattacharya distance on HMD

Table 3. Plot of accuracy as a function of k

K Value	Frobenius Accuracy (%)	KLD Accuracy (%)	Bhattacharya (%)
1	92	95	96.3
3	88	93	93.7
5	82	87.2	88

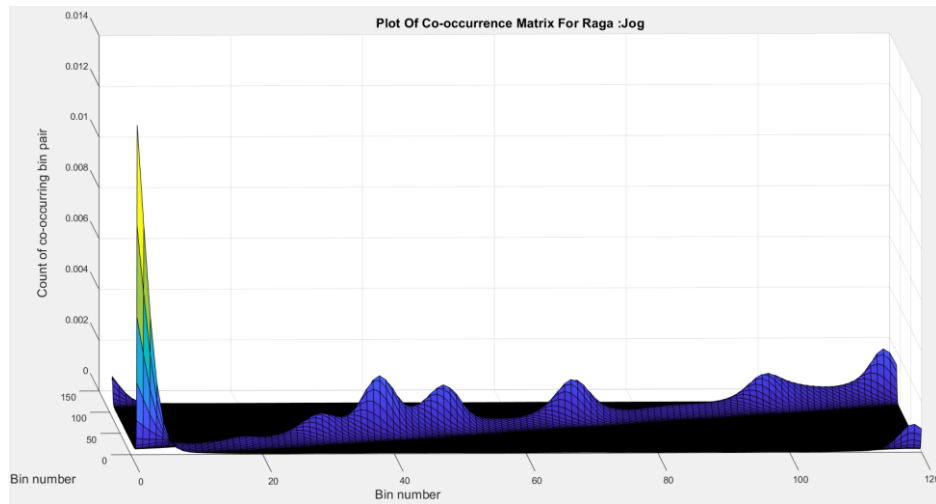
Table 4. Accuracy of the three proposed variants, and the two existing methods *EPCD* and *EVSM*

Data Set	Frobenius Accuracy (%)	KLD Accuracy (%)	Bhattacharya (%)	<i>EPCD</i> Accuracy (%)	<i>EVSM</i> Accuracy (%)
HMD	88	93	93.7	91.7	83

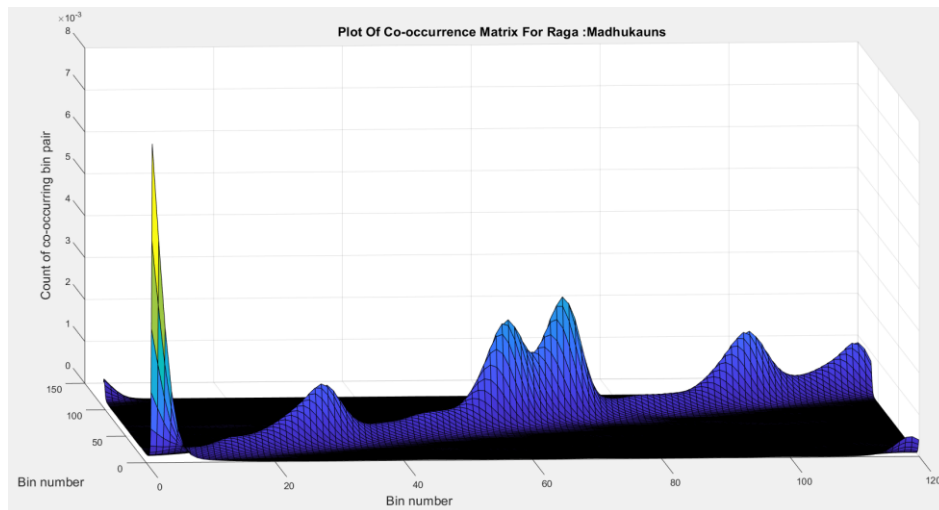
4. CONCLUSION

To summarize, the choice of features is much dependent on the type of raga classification problem to be dealt with. Use of occurrence pattern of pitch based svara (note) which captures tonal and short time temporal characteristics of melody for classification of different ragas is giving accuracy of 93.7%. This research can be tested to a more varied and complex dataset consisting of vocal and instrument tracks making use of good source separation algorithms to separate vocal part. For meaningful extraction, “beat interval” which is an important attribute giving information about scale and tempo can be considered as the frame length. This is because music is well structured and contains information about several components in an organized manner. With limited number of features, this method is performing better task of raga identification. Addition of more techniques like compression techniques to reduce the dynamic range in the co-occurrence matrix which can eventually help to separate the closely spaced frequencies to distinguish similar set ragas can be applied. Also features which can highlight the transitory melodic regions can be added to distinguish allied ragas. To conclude, raga music file can be hierarchically processed and split into subsequences and gamaka sequences. Use of recurrent neural network (RNN) in particular long short term memory networks (LSTM), which are good at processing sequential data can be explored to learn the tonal and temporal sequence patterns.

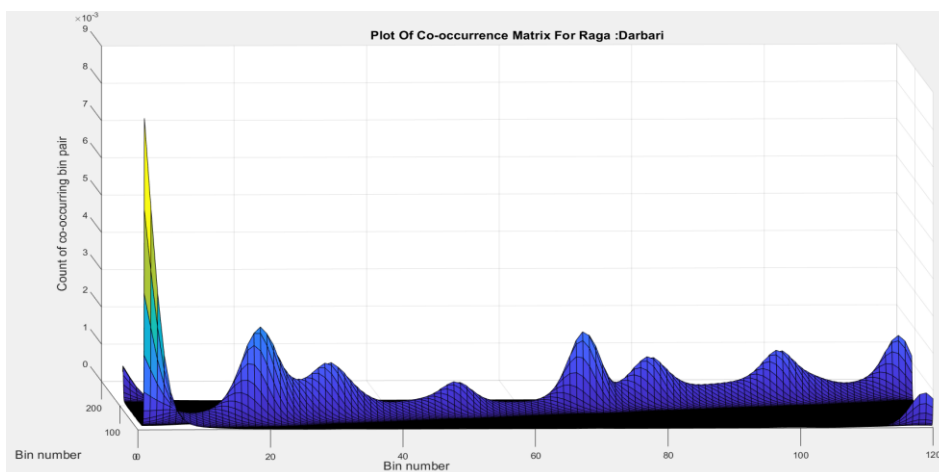
APPENDIX



(a)

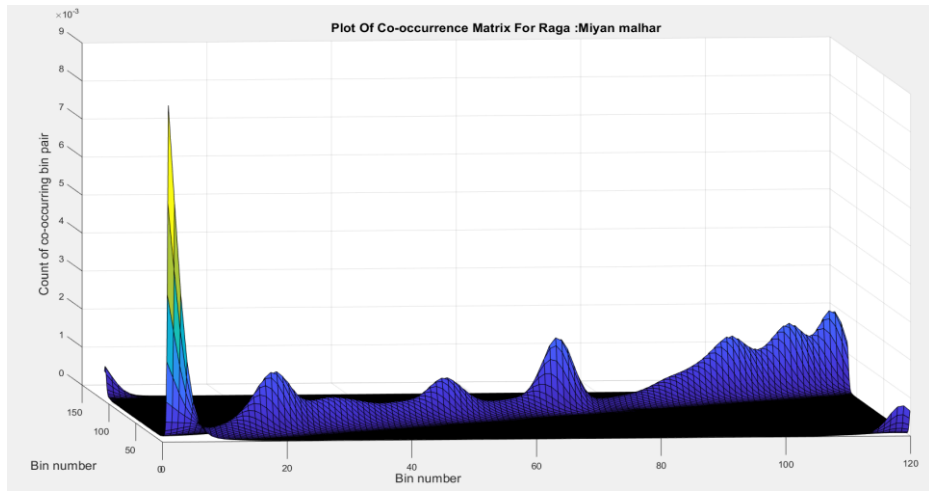


(b)



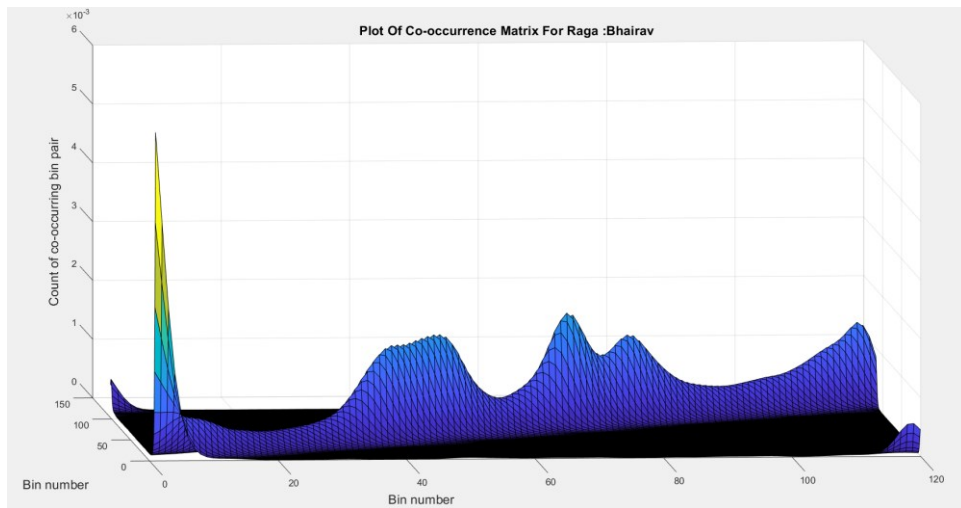
(c)

Figure 2. Plot of Co-Occurrence matrix for; Figure 2. Plot of co-occurrence matrix for (a) Jog, (b) Madhukauns ragas and (c) Darbari respectively

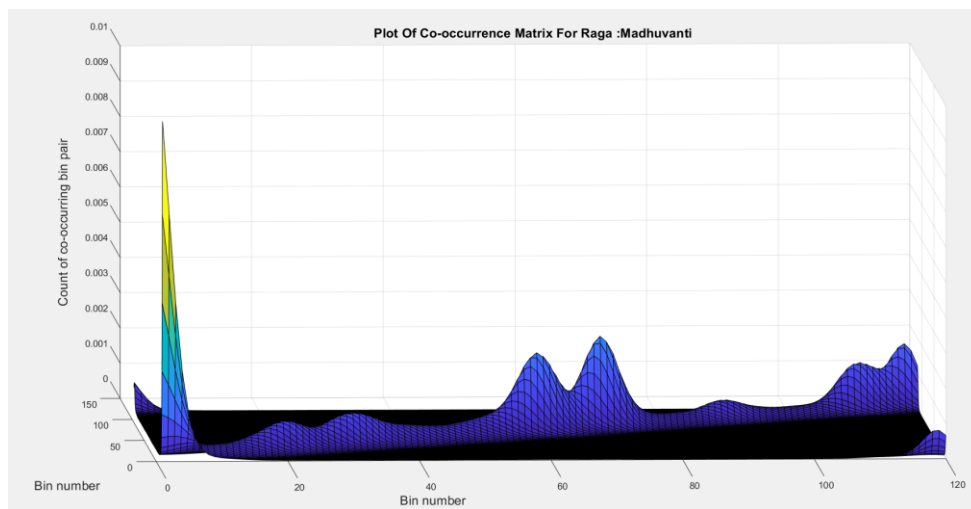


(d)

Figure 2. Plot of Co-Occurrence matrix for (d) Miyan Malhar ragas respectively (continue)

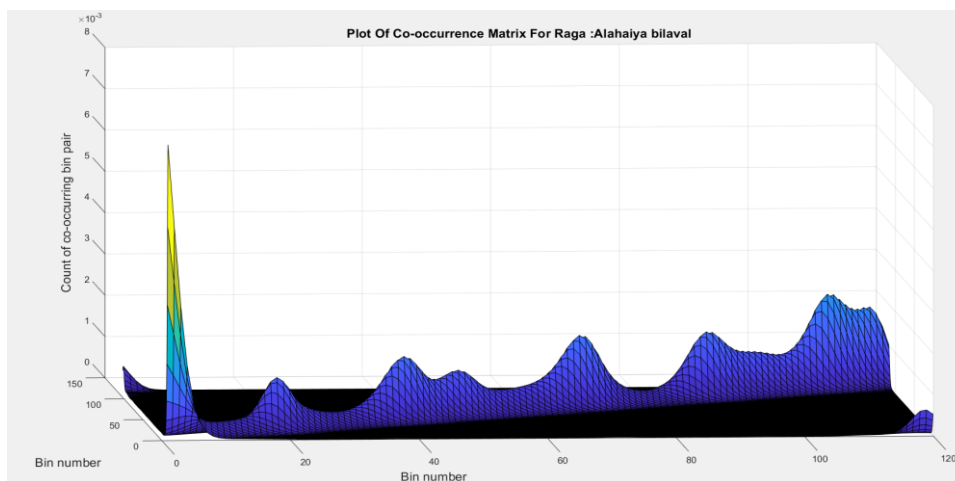


(a)

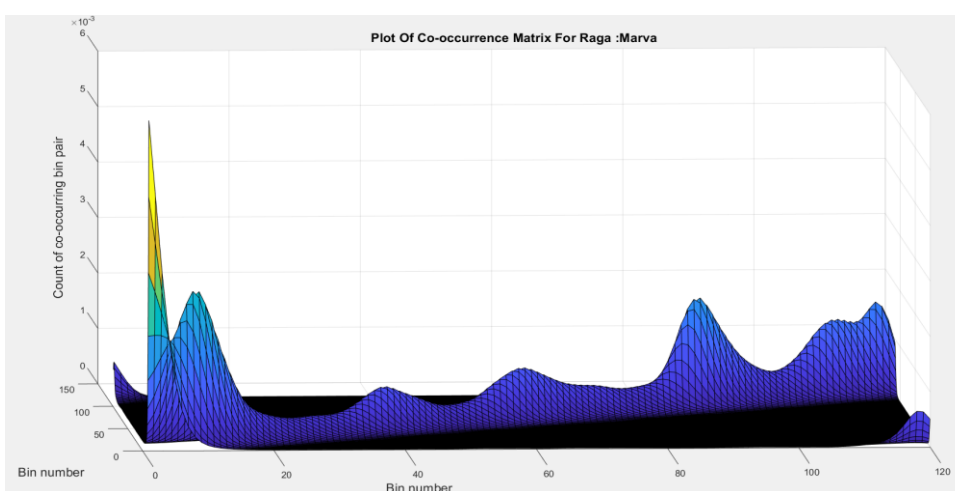


(b)

Figure 3. Plot of co-occurrence matrix for (a) Bhairav respectively and (b) Madhuvanti



(c)



(d)

Figure 3. Plot of co-occurrence matrix for (c) Alahaiya Bilaval and (d) Marva respectively (continue)

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