TIMBRE SPACE MODEL OF CLASSICAL INDIAN MUSIC

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***Abstract*—We are trying to study classical Indian music by computational analysis of mutual dependences of all sounds in the hearing range as well as voice range. To understand mutual dependence we develop a concept of timbre which is at once perceptual as well as material. We give derivation of 22 shrutis (microtones) of classical Indian music as invariances of mutuality of sounds. We have constructed an atlas of consonance among these invariances and shown consonances of known ragas and even report unknown ragas. We also show plausibility of relating consonance of instrumental timbre with these invariances.**

***Index Terms*— Timbre, Consonance, Indian Classical Music, Dissonance, Rāga.**

I.INTRODUCTION

The concept of *rāga* (melodic ensemble) is fundamental to Indian Classical Music. Each *rāga* is unique in the way melody is formulated and performed. The various attributes of notes in a *rāga* include *vādi* (sonant), *samvādi* (consonant), *anuvādi* (assonant), *vivādi* (dissonant), *āroha* (ascent sequence), *avaroha* (descent sequence), *pakada* (grip sequence), *calana* (stylized path sequence) and *saragama* (composition) [2].

Rāga-s as units are interestingly associated with the particular time of the day, the season and other ambient properties. We take this association of melodic *rāga* with ambient timbres very seriously. Melodic consonance of sounds varies in the context of ambient sounds. Melodic reality of classical Indian music thus is based on timbre. We develop below a theory of timbre and evolve a framework of consonance measures of sounds to derive atlas of possible r*āga-s*.

There are many *rāga*-s and it is well known that new *rāga-s* are often enunciated. There is no proper method to find how many *rāga-s* exist or are possible. We propose such a method through the study of mutuality of sounds. Historically, in North Indian music, Pandit Vishnu Narayan Bhatkhande's set of six books *Rāga Malika* [6] are considered as the greatest treasure source for knowing about *rāga*-s and their various attributes. About 163 *rāga-s* are documented by Bhatkhande in his encyclopedic books. We use this data to validate our theory and evaluate hitherto unknown consonant formations.

Several experiments are carried out with the proposed framework by defining measures of consonance, assonance etc. Using these measures we (1) found new 22 *śruti* (microtonal) scale, (2) made atlas of traditional and new *rāga-s*, (3) extended our timbre model of mutuality of sounds to instruments such as the flute. Thus, we propose a new consonance based *rāga* paradigm for Indian classical music. The consonance atlas of classical music is offered.

In the paper, Section II deals with the idea of timbre and how timbre is analyzed. Section III deals with our new proposed model for timbre of sounds without distinction between musical and non-musical sounds. Section IV deals with the timbre and musical sounds, which is the key emphasis of the paper. Section V deals with several experimental results and analysis, followed by conclusion in Section VI.

II. WHAT IS TIMBRE

Timbre is defined as the tone-color or quality which gives an identity to the sound. It is that feature which distinguishes one source of sound from the other. The sounds can be natural sounds, artificially produced sounds, musical sounds or non-musical sounds. Timbre is that multi-dimensional entity which separates two sounds having the same pitch, intensity, length etc. There is no unique way by which one can quantify timbre. There have been several attempts to computationally analyze the concept of timbre. Few studies have been done on what timbre is [1][8][9]. Several scholars attributed it to the spectral envelope of sound. Few of them quantified timbre as a multi-dimensional entity which is a mixture of both spectral and amplitude envelopes taken together. Others have formulated timbre as the perceptual feature. In this way, various claims of what exactly timbre is, has been discussed since a long time and a lot of research has been done to build timbre models.

Timbre of an instrument strongly affects what tuning and scale sound best on that instrument [3][4]. There is an interesting relationship between the timbre of a sound and a family of intervals (a scale) in which the sound will appear more consonant [3]. Our proposal of the concepts of timbre is material cum perceptual which is covered in the next section.

In the paper, an attempt is made to come up with new timbres and scales specific to Indian classical music. A proposal thereby which one can create new harmonic melodies have been experimented and the results are discussed.

III. PROPOSED TIMBRE MODEL

The traditional conception of *Nād* (sound) is that it pervades the entire universe. Between the pervading sound and the differentiated sound of things there is a structure which we have attempted to articulate. Sound is inhered in every 'thing'. Timbre distinguishes various sources of sound from one another. We categorize timbre of sound as follows.

1) ideal timbre (perceptual)
2) actual timbre (material)

Nād is a conceptualization of that mysterious phenomenon which is the superposition of ideal and actual timbre [11]. Fig 1 shows our proposed timbre model.

The interaction between two things produce sound. There is hearing range and voice range of human spectrum. It is the voice range which gives the music. Ideal timbre is like the human voice range and the hearing range is for all things which are sources of sounds. Human spectrum composes of various intervals which are perceived by us in the audible range. Intervals get double in amplitude over an octave and as a result several intervals are perceived with more amplitude than the other. The ideal timbre is the potential sound that object makes with every other object in a hearing range. The actual timbre is the sounds we actually here. Ideal timbre is the potential timbre of the object where as actual timbre is materially realized timbre. The interactions between things gives rise to ideal timbre. Every thing in the world is the reflection of this ideal timbre. Actual timbre is the material sound that we hear. In the paper we made an attempt to come up with actual timbres and tried to validate ideal timbres that are perceived across various musical intervals.

We have proposed a timbre model for Indian classical music which recognizes various timbres and generates many new timbres and also validates those currently existing in Indian classical music traditions.

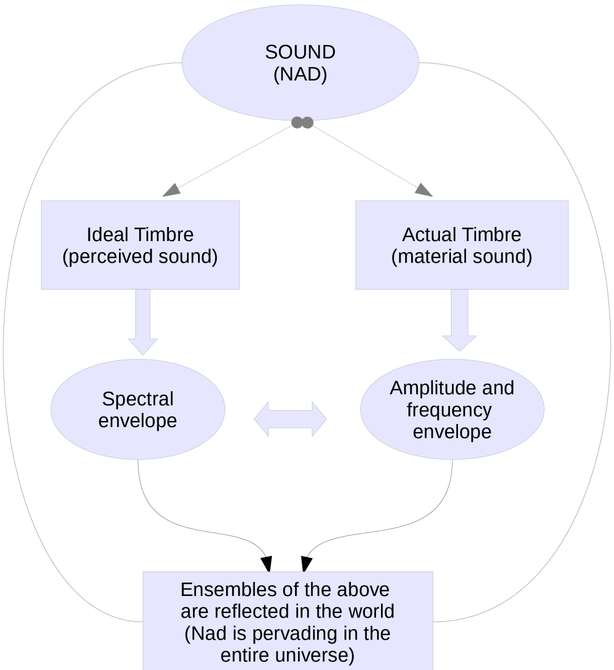

Fig I. Timbre Model

In the paper, several experiments based on timbres of musical sounds have been carried out and the details are provided in the next sections.

IV. TIMBRE AND MUSIC

Every musical sound has a unique timbre which distinguishes it from another musical sound. Consider two sounds being played with same pitch and loudness. Even though the pitch and loudness of the two sounds are same, but the spectra generated by them are different. This difference in spectra is seen because the timbres of source of the sound are not same. A consonance based model has been arrived at from the Plompt Levelt Theory of Dissonance. According to this theory, the dissonance curves can be conveniently parameterized by a model of the form [3]

$$d(x) = e^{-ax} - e^{-bx}$$

where x represents the difference in frequency between two sinusoids, and a,b determine the rates at which the function rises and falls. The dissonance function d(x) can be conveniently scaled so that the curves with different amplitudes and frequencies are represented conveniently. The dissonance function between two sinusoids at frequencies f1 and f2 with amplitudes v1 and v2 respectively (for f1<f2) [3] is given by

$$d(f1\ f2\ v1\ v2) = v_{12}(e^{-as\,(f1-f2)} - e^{-bs\,(f1-f2)})$$

and s= d*/(s1*f1+ s2) where d* is the point of maximum dissonance and $v_{12} = v_1 v_2$, where a=3.5, b=5.75, d*=0.24, s1=0.021 and s2=19 are determined by least square fitting [7].

The above model is modified such that Indian classical music can be accommodated. The above constants are retained in the experiment and sets of normalized frequencies of prevalent scales used today are taking as the frequency values. We have used MATLAB to compute this measure. The following are the steps by which musical consonance is measured:

1. normalized frequencies are taken as input to the program [2].
2. dissonance curves have been generated taking various frequency combinations.
3. depth of the dissonance curve, height of the dissonance curve, number of local minima, area of the dissonance curve and width of the dissonance curve are calculated.
4. consonance measure (C_i) ($\Sigma^{d}_{i=1}$ (depth * width) / ($\Sigma^{p}_{i=1}$ (height * width) + $\Sigma^{d}_{i=1}$ (depth *width)) where 'p' denotes the total number of peaks and 'd' denotes the total number of dips and which are calculated.
5. inverse transform of dissonance curves is calculated and the results of consonance measure have been formulated.
6. from this consonance measure, assonance measure ($A_{i)}$ ~ $\Sigma_{ni}^{=1}(C_i)$, where 'n' denotes the total number of the intervals is calculated taken in various combinations of five, six and seven notes.

The design of the experiments and the results are provided in the next section.

V. EXPERIMENTS AND RESULTS

A. *Consonance Measure*

In the Bhatkhande's six books [6], there are 16 pairs of vadi-samvadi which are listed. Taking all those vadi-samvadi pairs of frequencies as input, the consonance measure taken in pairs of two is calculated and ordered from low to high. Now all other pairs of possible frequencies are considered and consonance curves are generated as stated step by step in the previous section. [2] Table I gives the details of the analysis.

TABLE I : VADI-SAMVADI ANALYSIS

Vadi-samvadi pairs listed by Bhatkhande	Vadi-samvadi pairs which are consonant and not listed in Bhatkhande
S-m, m-S, S-P, D-G, P-S, d-g, G-D, d-r, R-P, d-G, G-N, P-R, g-n, r-D, m-n, r-P	m-g, M-G, G-M, D-n, P-D, P-g, m-P, P-N, n-d, d-n, S-n, d-M, M-d, M-g, g-M, N-S, D-N, D-R, m-R, D-M, M-D, N-D, d-N, d-m, m-d, P-G, G-P, g-P, M-R, R-M, r-n, r-m, D-m, m-D, S-g, n-P, P-m, D-P, S-D, N-g, N-P, N-R, R-d, d-R, n-R, S-G, G-d

Fig II below displays the consonance measure of the notes taken in combination of pairs of two. These pairs are used further to create assonant structures in tuples of five, six and seven so that *āroha* and *avaroha* sequences are worked out.

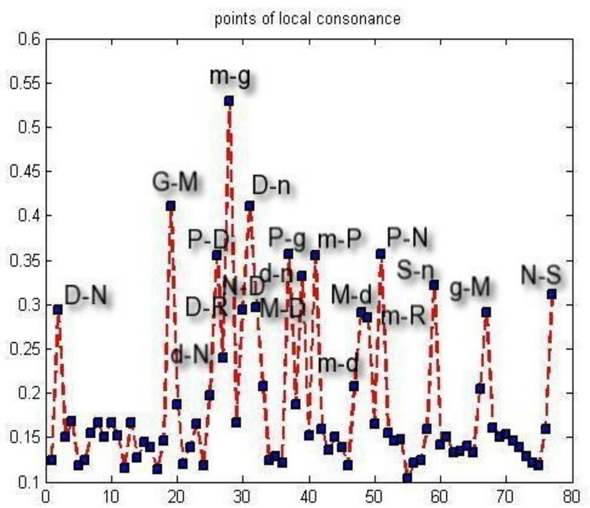

Fig. I1. Points of Consonance
(X-axis : Frequency interval range, Y-axis : Consonance)

B. Assonance Measure

Now with the consonant pairs derived from the above analysis, several combinations in the tuples of five, six and seven are taken and consonance analysis has been carried out. By this several such structures prevalent in current Indian music traditions have been derived and many more other note combinations which are not in use prominently are also arrived. Based on the consonance measure arrived above, the highly consonant pairs are considered and then in combinations of five, six and seven notes, the assonant tuples are arrived. Table II gives list of few tuples which appeared to be most consonant using the assonance measure and also those tuples which match current existing ragas in Indian classical music. Fig III shows an example of how peaks of notes are identified and assonant analysis is made. Based on the criteria mentioned in the previous section, the local dips and peaks are identified. In the Figure, an example of analysis is displayed and the corresponding notes which are analyzed are marked. In the similar way assonant tuples of *rāga* sequences are generated. The results are compared with the existing set of *rāga*-s listed by Bhatkhande and the new ones which are not stated and appear to be highly consonant are noted.

In figure III, N S G m P n S (Bhimpalasi), N r G M d N (Poorvi) and S G m D N S (Hindol) are shown. The marked points on the curve correspond to various consonant notes by which they are formed. In the similar way, various permutations and combinations of notes are tried.

Figure IV, displays various combinations of vadi-samvadi-anuvadi tuples generated out of vadi-samvadi pairs.

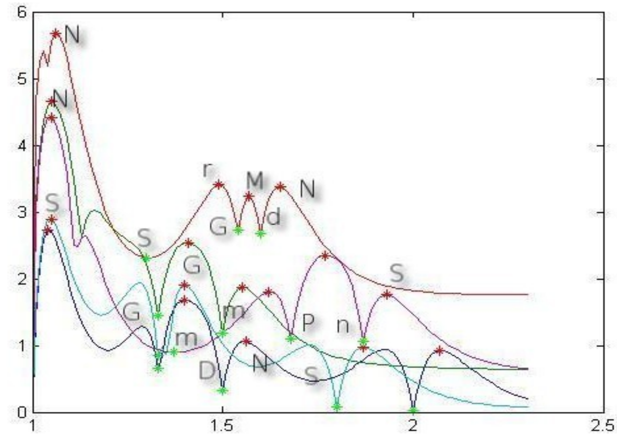

Fig. III. Dips and Peaks of assonant notes.
(X-axis : Frequency interval range, Y-axis : Consonance)

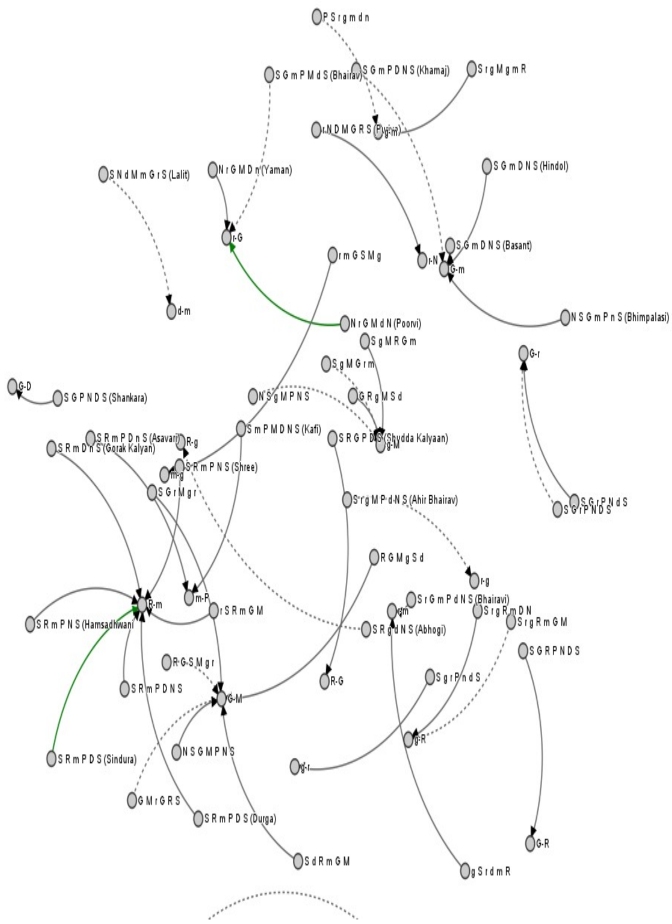

Fig IV. Tuple relation of anuvadi pairs

The table below gives a summary of highly consonant tuples. The two columns below give tuple sequences which are used (known *rāga*-s which are sung currently) and not used(unknown *rāga*-s which are not sung) in practice today.

TABLE II : VADI-SAMVADI-ANUVADI ANALYSIS

Vadi-samvadi-anuvadi analysis (Tuples that match *rāga*-s used in current day practice)	Vadi-samvadi-anuvadi analysis(Tuples that do not match *rāga*-s used in current day practice)
N r G M d N (Poorvi)	N S G M P N S
S R m P D S (Sindura)	S g M R G m
N r G M D n (Yaman)	S g M G r m
r N D M G R S (Puriya)	S G r M g r
S G m P M d S (Bhairav)	S d R m G M
S r G m P d N S (Bhairavi)	r S R m G M
N S G m P n S (Bhimpalasi)	r m G S M g
S R m P D S (Durga)	R G M g S d
S R m D n S (Gorak Kalyan)	R G S M g r
S R m P N S (Hamsadhwani)	g S r d m R
S G m D N S (Hindol)	G R g M S d
S m P M D N S (Kafi)	G M r G R S
S R g d N S (Abhogi)	P S r g m d n
S r g M P d N S (Ahir Bhairav)	N S g M P N S
S R m P D n S (Asavari)	S R m P D N S
S G m D N S (Basant)	S g r P n d S
S G m P D N S (Khamaj)	S G r P N d S
S N d M m G r S (Lalit)	S G R P N D S
S N D m P R S (Marva)	S G r P N D S
S R G P D S (Shudda Kalyaan)	S r g R m D N
S R m P N S (Shree)	S r g R m G M
S G P N D S (Shankara)	S r g M g m R

C. Shruti Scale

In another experiment, consonance amongst the twenty two notes used as shruti is analyzed. The octave is divided into 2200 cents and points of local consonance among them are noted by performing similar analysis like the above. In those 2200 intervals it is seen that there is exactly one scale in each interval, which more or less corresponds to the already existing shruti scale being followed in Indian classical music. The points of local consonance achieved across these intervals is listed in Table III. Below Table III is Figure V which gives an account of peaks noted in the experiment. The highly consonant peaks are noted.

TABLE III : SHRUTI SCALE

Note name	Frequency value at which consonance occurred
S	0
r1	144
r2	186
R1	204
R2	222
g1	336
g2	423
G1	540
G2	592
m1	636
m2	723
M1	874
M2	960
P	1105
d1	1242
d2	1324
D1	1430
D2	1553
n1	1783
n2	1805
N1	1986
N2	2134
S	2200

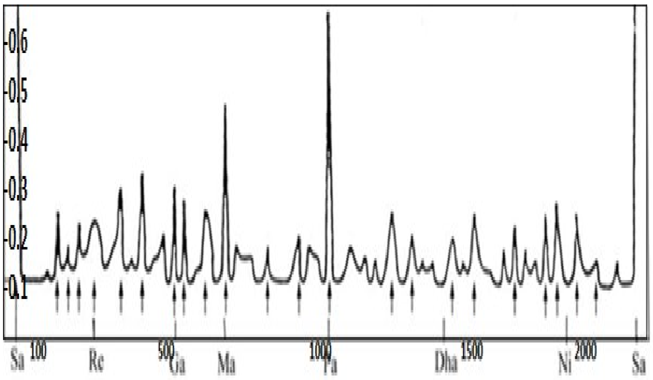

Fig V : Consonance measure of 2200 intervals: X-axis is intervals (freq) & Y-axis is their Consonance coefficient

D. Instrumental Consonance

Now with the results of the consonance analysis of ragas in north Indian classical music, an attempt is made to study consonance of instrumental music prevalent in the Indian musical culture and arrive at the consonantly pleasing timbres in them. For the above raga consonance analysis, frequencies are provided as an input by considering the frequencies of notes in the octave. Now an experiment has been done to visualize consonant timbres in an instrument. Various instrumental sounds are recorded and collected and similar experiment is run and the results are noted. The audio sample is analyzed using Audacity and the corresponding spectrum and frequency of the sound is noted and passed as the input for arriving consonance measure. An experiment done on several flute samples in an octave gives the following results.

E. Flute Note Consonance

In Figure VI, consonance among various flute notes in an octave is given. The result shows that each notes in an octave have possibilities to become the tonic while tuning the instrument. Based on the higher values of consonance, the notes below can be used to tune the instrument for generating consonant music. This experiment is carried across the range of middle octave. The consonance among flute notes taken in the octave are stated in the diagram below.

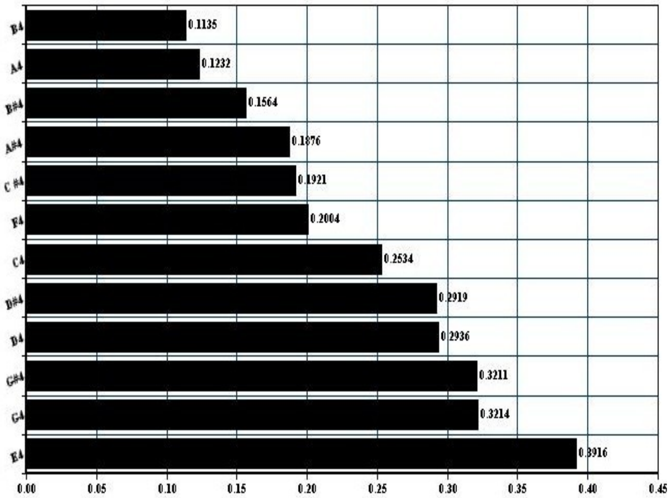

Fig. VI. Consonant flute notes in an octave

These are the possible fundamental frequencies which flute notes can have. An ordering among them is created and various new timbres based on these measures are achieved.

VI. CONCLUSIONS

We have proposed theory of timbre and found various consonant features. Classical Indian music was interpreted and the verification of the insights are done with prevalent Indian musical culture. Several new claims have been made in terms of consonances and assonances. The atlas of assonances have been made as a resource. Through the analysis, a proposal for consonant timbres of Indian classical music has been put forward and with the experiments performed, several characteristics of Indian music have been studied and verified and a new timbre based understanding of music is enunciated.

In the future, the model can be made more adaptable and expanded to other complex attributes of the Indian Classical music and thereby a formal criteria for arriving at consonance notes can be made. Also, consonance based analysis specific to instruments can be carried out in much detail and instrument based timbre classification can be achieved.

The interesting possibility of sound art involving ambient sounds as well as musical sounds opens with our model.

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