CLASSIFICATION OF INDIAN CLASSICAL VOCAL STYLES FROM MELODIC CONTOURS

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ABSTRACT

A prominent categorization of Indian classical music is the Hindustani and Carnatic traditions, the two styles having evolved under distinctly different historical and cultural influences. Both styles are grounded in the melodic and rhythmic framework of raga and tala. The styles differ along dimensions such as instrumentation, aesthetics and voice production. In particular, Carnatic music is perceived as being more ornamented. The hypothesis that style distinctions are embedded in the melodic contour is validated via subjective classification tests. Melodic features representing the distinctive characteristics are extracted from the audio. Previous work based on the extent of stable pitch regions is supported by measurements of musicians' annotations of stable notes. Further, a new feature is introduced that captures the presence of specific pitch modulations characteristic of ornamentation in Indian classical music. The combined features show high classification accuracy on a database of vocal music of prominent artistes. The misclassifications are seen to match actual listener confusions.

1. INTRODUCTION

Indian Classical Music styles span a wide range, a prominent categorization within which is Hindustani and Carnatic. The distinction is geographical with the two styles having evolved under distinctly different historical and cultural influences. Carnatic music is predominantly performed and studied in the southern states of India while Hindustani music is more widely spread in the country. Both styles are grounded in the melodic and rhythmic framework of raga and tala. While the repertoire of commonly performed ragas is different in the two styles, they share the basic scale structure, the use of raga-specific phrase motifs and ornamentation. In both styles due importance is accorded to both compositions and improvisation although the relative weighting tends to differ. The styles differ along dimensions such as structure of a performance, aesthetics, voice production and the use of decorative elements. Additionally, Hindustani and Carnatic styles differ in the musical instruments used.

There has been some past work on the computational analysis of Indian classical music related to automatic recognition of raga [1, 2, 3]. These approaches have been based on the distinctness of scale intervals, precise intonation and phraseology. With a raga being far more constrained than the Western scale, its grammar is defined by characteristic phrases rather than just the scale intervals [4]. Computational approaches have not been applied to style discrimination however. Liu et al. [5] attempted to classify audio signals according to their cultural styles as Western or non-Western by the use of characteristics like timbre, rhythm and musicology-based features. More recently, Salamon et al. [6] classified Western genres using melodic features computed from pitch contours extracted from polyphonic audio.

Hindustani and Carnatic music differ in the nature of the accompanying instrumentation and can potentially be distinguished by acoustic features relating to timbre. However, it may be noted that the two styles can also be reliably distinguished by listeners of the vocal music extracted from the alap section (i.e. the improvised component) of a concert where the accompanying instrument is restricted to the common drone (tanpura). A common perception among listeners is that the Hindustani alap unfolds "slowly" relative to the corresponding Carnatic alap which has complex pitch movements (gamakas) [7]. These observations imply that the melodic contour of the alap contains sufficient information about style differences. In this work we consider the automatic identification of the style (Hindustani or Carnatic) from the melodic contour. Since transcriptions in the form of symbolic notation are not easy to come by (apart from the absence of standard notation to represent pitch movements), we investigate style recognition from the available recorded audio of vocal performances. Such work can be useful in providing musicological insights as well as in developing tools for music retrieval.

The repertoire of commonly performed ragas differs in the two styles. However, in order to minimize any raga-specific influence on the discriminatory characteristics of the melodic contour in the present study, we choose music belonging to corresponding ragas in the two vocal styles. We examine the assumption that the style distinctions are represented in the melodic contour via listening tests. Next discriminatory features that can be computed from the detected pitch contour are presented and evaluated for automatic style identification.

2. MELODIC FEATURE EXTRACTION

In order to characterize the melody, it is necessary to first extract it from the polyphonic audio signal. The accompanying instrument in the alap section of the concert is restricted to the tanpura (drone). Melody detection involves identifying the vocal segments and tracking the pitch of the vocalist. Indian classical singing is a pitch-

continuous tradition characterized by complex melodic movements. These ornamentations (gamak) are categorized based on shape into a variety of glides and oscillatory movements. The oscillatory movements include several that are slower in rate and larger in amplitude than the Western vibrato. In this section, we present the implementation of vocal pitch detection in such a scenario followed by a discussion of melodic features that characterize the style differences.

2.1 Vocal pitch detection

We employ a predominant-f0 extraction algorithm designed for robustness in the presence of pitched accompaniment [8]. This method is based on the detection of spectral harmonics, helping to identify multiple pitch candidates in each 10 ms interval of the audio. Next pitch saliency and continuity constraints are applied to estimate the predominant melodic pitch. Although the drone is audibly prominent due mainly to its partials spreading over the frequency range up to 10 kHz, the strengths of its harmonics are low relative to the voice harmonics. Thus the singing voice dominates spectrally, and the melody can be extracted from the detected pitch of the predominant source in the 0-4 kHz range.

State-of-the-art pitch detection methods achieve no more than 80% accuracy on polyphonic audio. An important factor limiting the accuracy is the fixed choice of spectrum analysis parameters, which ideally should be matched to the characteristics of the audio such as the pitch range of the singer and the rate of variation of pitch. In the regions of rapid pitch modulation, characteristic of Indian classical singing, shorter analysis windows serve better to estimate the vocal harmonic frequencies and amplitudes. Hence for better pitch detection accuracy, it is necessary to adapt the window length to the signal characteristics. This is achieved automatically by the maximization of a signal sparsity measure computed at each analysis instance (every 10 ms) of local pitch detection [9]. Finally, it is necessary to identify the vocal regions in the overall tracked pitch. This is achieved by using the peculiar characteristics of Hindustani music where the vocal segments are easily discriminated from the instrumental pitches due to the different temporal dynamics [10].

Differences in the two melodic styles are observed by the visual comparison of the pitch contour segments of Figure 1. The detected pitches obtained at 10 ms intervals are converted to the musical cents scale. We note the presence of long held notes in the Hindustani segment versus the short and more ornamented notes of the Carnatic segment rendered in the same raga. Finely binned (2 cent bin width) pitch histograms derived from extracted pitch contours tend to show clustering about the svar locations, with the Carnatic music distributions being more diffuse compared to the relatively concentrated peaks typical of Hindustani music [2, 11].

2.2 Musically motivated features

Carnatic vocal renditions are typically replete with ornamentation as opposed to the relatively slowly varying pitches of the Hindustani vocalist. The difference is particularly prominent in the alap section which the artiste uses for raga elaboration and where the svar appear in their raga-specific intonation whether steady or ornamented with touch notes (kan) or oscillations (gamak). We explore the possibility of a musicologically motivated feature for the above difference. Hindustani musicians refer to held notes as "standing" notes or khada svar. A manual annotation of 20 minutes of audio comprising of 30 alap sections across different ragas rendered by prominent Hindustani vocalists was carried out by 2 trained musicians. The musicians labeled the onset and offset of each instance of khada svar that was perceived on listening to the audio. The duration and standard deviation of each instance was measured. Figure 3 shows scatter plots of the 241 instances of khada svar identified by the musicians. We observe that the location of the highest density is duration=700 ms and standard deviation=10 cents. Thus these may be considered as nominal values for a khada svar as obtained by this experimental investigation. In the next section, we propose a method to segment the pitch contour into steady and ornamented regions depending on the detected local temporal variation [12].
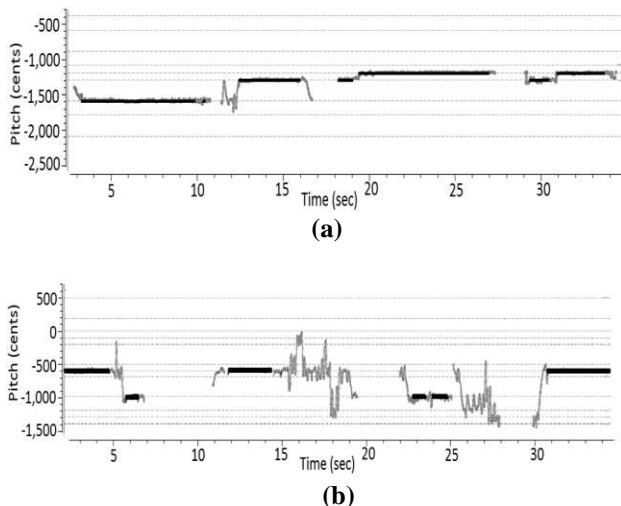
2.3 Stable note segmentation

Steady, or relatively flat, pitch regions are expected to correspond to the khada svars of the underlying raga. Based on the observations of the previous section, a stable note region is defined as a continuous segment of a specified minimum duration ("N" ms) within which the pitch values exhibit a standard deviation less than a specified threshold ("J" cents) from the computed mean of the segment.

Figure 1 depicts the detected steady note segments as dark lines superposed on the continuous pitch contours using the nominal parameters N=400 ms and J=20 cents. The gamakas, or complex pitch movements, are left untouched. We observe that the long held notes coincide with the svar locations of the raga. Traditionally, the ornamented regions too are notated to a sequence of raga notes in music teaching. However the correspondence between the complex pitch movements and sequence of notes is rarely obvious from the continuous pitch contour. It is known to depend on the raga and on the immediate melodic context and possibly on the style as well.

A visible difference between the Hindustani and Carnatic pitch contours in Figure 1 is the proportion of stable note regions in the segment. The ratio of detected steady note regions to overall vocal duration in a 70 sec clip (typically the alap section lasts for just over one minute in a concert) of each of the recordings listed in Table 1 is computed as follows.

$$Stable\ note\ measure = \frac{Duration\ of\ Steady\ Regions \geq 0.4sec}{Total\ Sung\ Duration}$$

(1)

(a)

(b)

Figure 1. Detected pitch contours of alap sections of **(a)** Hindustani vocalist Malini Rajurkar for raga Todi **(b)** Carnatic vocalist Sudha Raghunathan for raga Subhapanthuvarali. The stable note segment (black) is superimposed on continuous contour (gray).

2.4 Measure of oscillatory gamak

The relative use of specific ornamentation (gamak) differs between the two styles with the Carnatic vocalist more engaged in rapid oscillatory movements between stable note regions. The Hindustani vocalist, on the other hand, spends more time gliding between notes, or on lower frequency oscillations and isolated grace notes while approaching longer stable notes. We seek a measure to capture this distinction which appears to be evident in the rates of pitch modulation. The pitch contour segments that remain after the extraction of stable note regions are analyzed for rate of pitch modulation. The Fourier spectrum of the temporal pitch trajectory, sampled every 10 ms, shows clear peaks whenever the gamak is characterized by uniform oscillations. The presence of substantial oscillations in the 3 Hz - 7.5 Hz frequency range in the gamak regions is indicative of the Carnatic style.

The DFT spectrum of 1 sec segments of the pitch contour are computed using a sliding window with hop size of 500 ms. Each segment is characterized by its value of an energy ratio (ER) computed as the energy of oscillations in the 3 - 7.5 Hz region normalized by the energy in the 1 - 20 Hz frequency region as below.

$$ER = \frac{\sum\limits_{k=k_{3Hz}}^{k_{7.5Hz}} |Z(k)|^2}{\sum\limits_{k=k_{1Hz}}^{k_{20Hz}} |Z(k)|^2} \qquad (2)$$

where $Z(k)$ is the DFT of the mean-subtracted pitch trajectory $z(n)$ with samples at 10 ms intervals, and k_{fHz} is the frequency bin closest to f Hz.

(a)

(b)
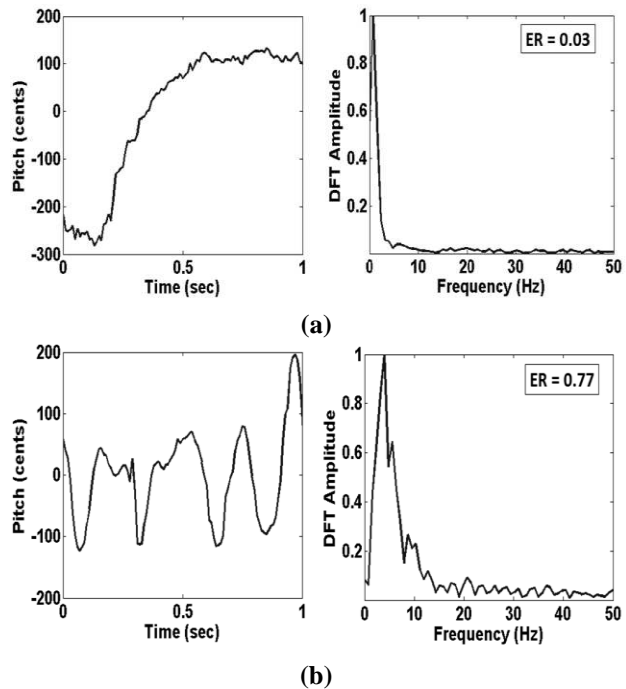
Figure 2. Mean subtracted pitch contour of a gamak region and its DFT amplitude after windowing for **(a)** raga Todi by Rashid Khan **(b)** raga Subhapanthuvarali by Sudha Raghunathan

Figure 2 shows the temporal trajectory of the pitch and the corresponding DFT amplitude spectrum for examples of Hindustani and Carnatic segments. The ER is computed at 500 ms intervals throughout the non stable-note regions of the pitch contour. The percentage of ER values so obtained that cross a specified threshold serves as an indicator of the vocal style. We get a gamak measure as below.

$$Gamak\ measure = \frac{Number\ of\ ER > x}{Total\ Number\ of\ ER} \qquad (3)$$

The threshold "x" was varied from 0.1 to 0.9 to find that x=0.3 showed good separability between oscillatory segments and relatively slowly varying segments.

3. DATABASE AND EXPERIMENTS

3.1 Database

Commercial CD concert recordings by prominent artistes of each style, as listed in Table 1, were obtained and the audio converted to 16 kHz, mono sampled at 16 bits/sample. Widely performed ragas that use the same scale intervals (relative to the chosen tonic note) in both the Hindustani and Carnatic styles are chosen for the present study. There are a total of 40 distinct concert alaps equally distributed across styles performed by renowned Hindustani and Carnatic vocalists. With alap sections of the concerts typically being of duration at least 70 sec, we segmented each concert alap into 2 non-overlapping sections each of duration between 32-40 sec with segment

boundaries selected such that continuous sung phrases are not interrupted. It was verified that all the alap sections were in the similar tempo range.

Hindustani Artistes	Carnatic Artistes
Ajoy Chakrabarty	A R Iyengar
Bhimsen Joshi	K V Narayanswamy
Fateh Ali Khan	M Balamuralikrishna
Girija Devi	M D Ramanathan
Jasraj	M L Vasanthakumari
Kaivalya Kumar	M S Subhalakshmi
Kishori Amonkar	Narayanaswamy
Kumar Gandharva	Sanjay Subramanium
Malini Rajurkar	Santanagopalan
Prabha Atre	Semmangudi S Iyer
Rashid Khan	Shankaranarayanan
Ulhas Kashalkar	Sudha Raghunathan
Veena Sahasraabuddhe	T N Seshagopalan
	T S Kalyanaraman
	T S Sathyavati
	R Vedavalli

Table 1. List of artistes covered in the alap database

Hindustani Raga (No. of clips)	Carnatic Raga (No. of clips)
Todi (12)	Subhapanthuvarali (14)
Malkauns (18)	Hindolam (12)
Jaijaiwanti (10)	Dwijavanthy (14)

Table 2. Distribution of alap clips across Ragas for automatic classification

As mentioned in the Introduction, we restrict the choice of concerts to specific raga pairs. Table 2 shows the three pairs of corresponding ragas, one in each row of the table, along with the ascending and descending scales of each [13, 14]. We use the solfege symbols **S**, **R**, **G**, **m**, **P**, **D**, **N** for notating the shuddha (natural) Sa, Re, Ga, Ma, Pa, Dha, Ni respectively. For notating komal (flat) Re, Ga, Dha, Ni we use **r**, **g**, **d**, **n** respectively and **M** for tivra (sharp) Ma. This obtains the 12 notes of an octave. Table 3 also provides the raga-specific ascending and descending forms as well as their typical phrases.

The chosen ragas represent different categories such that Todi is a diatonic scale, Jaijaiwanti uses 9 distinct semitones (both G, g and N, n are valid depending on the context) and Malkauns is pentatonic. It is observed that in the pentatonic scale ragas large pitch excursions are more.

3.2 Listening tests

We examine the assumption that the style distinctions are captured by the melodic contour via listening tests. The audio clips are processed the method of Section 2.1 to obtain the melodic contour (continuous variation of pitch in time across all vocal segments of the audio signal). The pitch is detected at 10 ms intervals throughout the sung regions of the audio track. Figure 1 depicts the extracted high-resolution continuous pitch contour of examples of

each style by gray lines. To suppress the effects of artiste identity, voice quality and pronunciation in the listeners' discrimination task, the melodic contour is resynthesized using a uniform timbre vowel-like sound before being presented to listeners. The amplitude of the resynthesized tone however follows that of the singer's voice. The amplitude is obtained by summing the energies of the vocal harmonics estimated from the detected pitch. The volume dynamics are retained together with pitch dynamics since they play a role in melody perception.

Subjective listening tests with 18 listeners were conducted. Of these, 6 listeners had had some training in one of the two traditions while the remaining were untrained. The listeners were asked to identify the style for each of up to a maximum of 60 concert clips (10 clips per raga per style) by listening to the corresponding resynthesized melodic contour over the desired duration. The clips were presented in random order within each raga set. It was found that most listeners reached their conclusion about the style within about the first 20 sec of the clip. We eventually have 600 subjective judgments spread uniformly across the ground-truth set of style and ragas.

Tables 4 and 5 show the obtained accuracies from the listening test. We observe that listeners are able to identify the style at levels well above chance. This is particularly true of Todi raga and less so in the case of Malkauns. It may be speculated that this is due to the pentatonic scale permitting larger inter-note pitch excursions in both styles. Raga Malkauns is known for its gamak such as the initial svars in the phrases **dd**SnS, **dd**mgm, **SS**ndn. A more specific discussion of common misclassifications among the audio clips is provided later.

No.	Raga	Hindustani Style		
		Total clips	Correctly identified	Accuracy
1.	Todi	100	89	89 %
2.	Malkauns	100	77	77 %
3.	Jaijaiwanti	100	87	87 %

Table 4. Listening test results for Hindustani music

| No.	Raga	Carnatic Style		
		Total clips	Correctly identified	Accuracy
1.	Subhapan-thuvarali	100	86	86 %
2.	Hindolam	100	82	82 %
3.	Dwijavanthi	100	82	82 %

Table 5. Listening test results for Carnatic music

3.3 Musical bases of parameter selection

As the parameters N, J for automatic classification was empirically set for the stable note measures in the previous work, musical concept of 'Khada Svar' is now used to have musically better grounded parameter settings.

Hindustani Raga	Carnatic Raga	Swaras in ascent (aroha)	Swaras in descent (avaroha)	Characteristic phrases
Todi	Subhapanthuvarali	S r g M d N S'	S' N d P M g r S	(.d .N S r g), (d r g- ^{M}rgr S-), (S r g- g M d P, M d N S'-)
Jaijaiwanti	Dwijavanthi	N S R G m P, G m D n S'	S' n D P m G, R g R S, ^{R}N S	(R g R S), (^{R}N S D n R S)
Malkauns	Hindolam	n S g m d n S'	S' n d m, g m g S	(g m g S), (n S g S), (g m d m), (d n d m)

Table 3. Swaras that are present in Aroha-Avaroha of Todi, Malkauns and Jaijaiwanti

Positions of the stable notes with exact boundaries were marked independently by two trained Hindustani musicians on a subset of the audio database. Duration, minimum and maximum values, mean, standard deviation of each marked 'Khada Svar's were calculated. The duration (in ms) vs. standard deviation (in cents) for Hindustani (241 tokens) and Carnatic (118 tokens) were separately plotted in 2-dimensional scatter plots to optimize the values of N, J parameters from musicians' perspective.
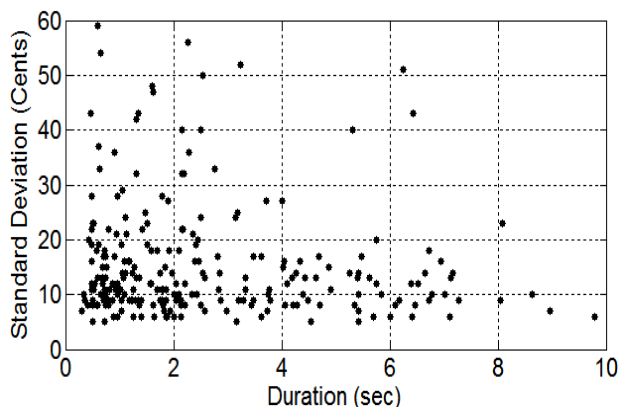
Figure 3. Distribution of Khada Svar tokens marked from clips of Hindustani style

Each of the marked 'Khada Svar' token was assigned the musical note in the corresponding Raga and the exact intonation was observed with respect to the equal-tempered scale. Minimum standard deviation was found on the tonic 'S' and the fifth note 'P', the fixed-intoned notes in an octave. It is evident from Figure 3 that average duration of Khada Svar marked is high in Hindustani clips, whereas the standard deviation is on the lower range. The optimized values of the parameters are obtained as N=700 ms, J=10 cents. The misclassified clips with this set of parameters best matches with the listeners' confused clips.

4. AUTOMATIC CLASSIFICATION

The 2-dimensional feature vector (stable note measure, gamak measure) was computed for each of the 80 alap clips across the two styles as shown in Table 2. A quadratic classifier was trained and tested for style classification in 4-fold cross-validation experiment so that in each test set there were 10 randomly picked clips from each style with the rest forming the training set. Each run of

the 4-fold cross-validation can give a slightly different overall accuracy depending on the particular randomly chosen partition. Hence, 5 entire cross-validation experiments were run to find an aggregate classification accuracy.

4.1 Classification results

Automatic classification experiments were carried out over a range of the parameters (N, J). Based on the findings from the musicians annotation of standing notes discussed in Sec. 3.3, we selected N=700 ms and computed classification accuracy over a range of values of standard deviation (J cents) in steps of 5 cents. Figure 5(a) shows the classification accuracy for a range of values of J. We observe the J=20 cents provides the best accuracy at N=700 ms. Next, we fixed J=10 cents and J=20 cents while the range of N was varied from 200 ms to 2 sec in steps of 100 ms. Figure 5(b) shows the accuracies obtained at the various parameter settings of N and J. We observe that at J=10 cents, N=700 ms provides the highest accuracy. Interestingly, this choice of parameters corresponds with the musicians' annotation criteria for Khada Svar.

However, we also note that the overall best accuracy of the settings tested is 94% as provided by J=20 cents, N=400 ms. The confusion matrices for each of the above two parameter settings viz. the musically motivated J=10 cents, N=700 ms and the data-driven J=20 cents, N=400 ms are given below. We see the confusion matrix for best case giving accuracy of 94% for N=400 ms J=20 cents in Table 6(a) while that for N=700 ms J=10 cents giving accuracy of 86% appears in Table 6(b).

	C	H
C	38	2
H	3	37
(a)		

|	C	H
C	35	5
H	6	34
(b)		

Table 6. Confusion matrix for (a) N=400ms J=20cents (b) N=700ms J=10cents

4.2 Discussion

We note that there is a significant difference in classification accuracies between the two parameter settings. This was found to be due to the increase in detection of stable

note regions with the relaxed standard deviation of J= 20 cents and reduced minimum note duration of N=400 ms.

(a)

(b)
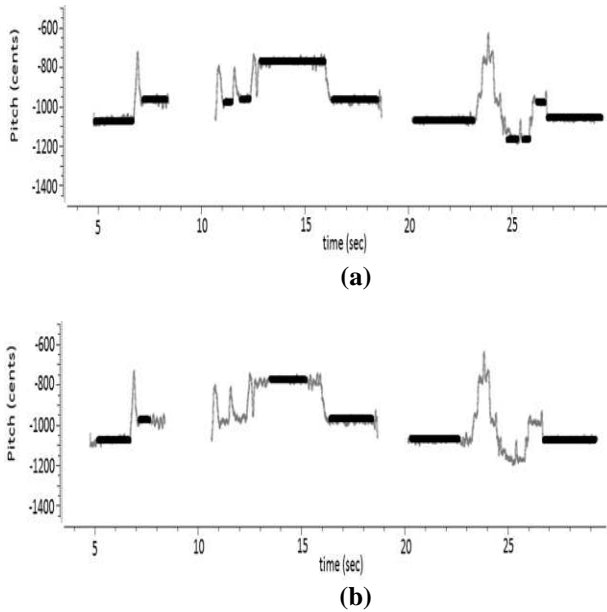
Figure 4. TPE of pitch **q**uantized steady regions (gamaka**s** untouched) in black superimposed on original TPE in grey for Prabha Atre for Raga Todi alap **(a)** N=400ms, J=20cents **(b)** with N=700ms, J=10cents

Figure 4 provides an insight into the detection performance between the two parameter settings. We see that the stable regions detected at the J=10 cents, N=700 ms settings are a better match to the perceived Khada Svar as annotated by the musicians. The more relaxed settings of J=20 cents, N=400 ms ends up marking essentially transitory segments of the pitch contour as stable regions. However this musical inconsistency seems to be leading to better accuracies in the automatic classification.

It was observed that the confusions in automatic classification at J=10 cents, N=700 ms matched better with the observed subjective confusions. Some misclassified clips in automatic classification for N=700 ms and J=10 cents are for Hindustani style: raga Malkauns by artiste Veena Sahasrabuddhe and raga Jaijaiwanti by artiste Fateh Ali Khan while for Carnatic style: raga Hindolam by artiste M S Subhalaxmi and raga Subhapanthuvarali by artiste T N Sheshagopalan. They were also confused by listeners in listening tests.

(a)

(b)
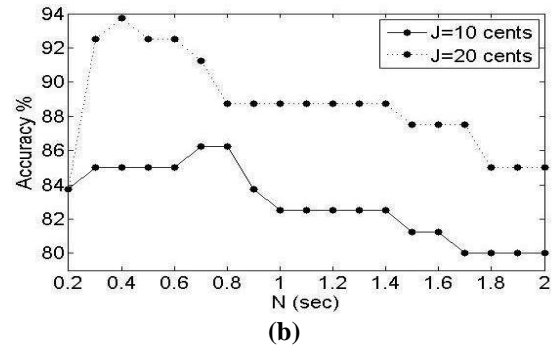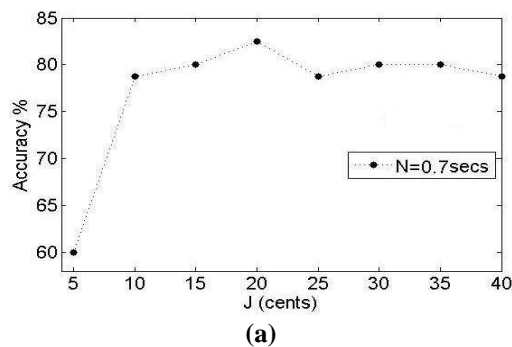
Figure 5. Percentage Accuracy **(a)** N=0.7sec with J varying **(b)** with J=10, 20cents with N varying; found by aggregating 5 confusion matrices

A discussion with the listeners of the subjective classification tests indicated that pitch interval concentration played a role in style perception. That pitch interval concentrations are distinctive, we observed the (unfolded) pitch distributions in 10 cent intervals for a number of alap audio clips in the test database. Indeed, it was observed that the Hindustani alaps are concentrated in the region near the tonic while the Carnatic alap pitch distribution is closer to the upper octave tonic. This is exemplified by the Fig. 6 for a pair of correctly classified ragas.

(a)

(b)
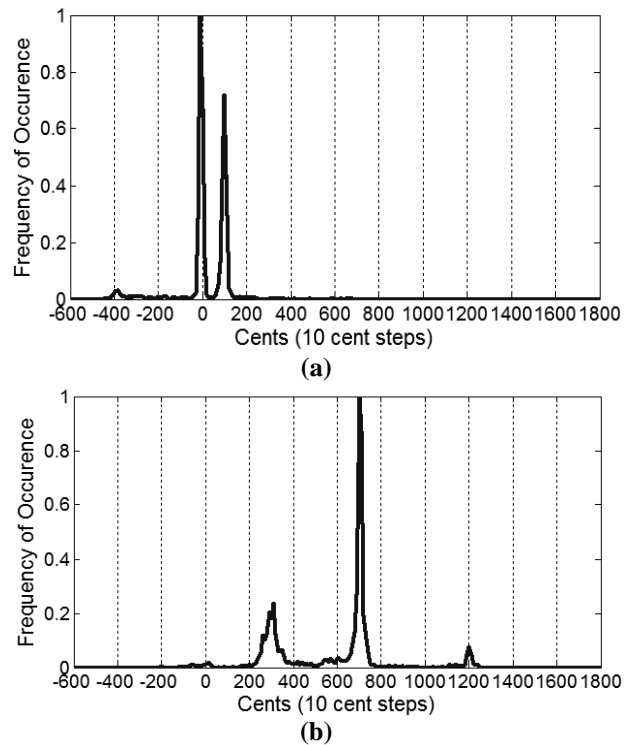
Figure 6. Distribution of Pitch Range in alap section by **(a)** Hindustani vocalist Rashid Khan for raga Todi **(b)** Carnatic vocalist Sudha Raghunathan for raga Subhapanthuvarali. Alap is centred around 'S' in Hindustani and 'P' in Carnatic style

To see whether this could act as an additional feature to disambiguate the confusions in the subjective and automatic classifications, we plot the pitch distribution of

two misclassified ragas in Figure 7. As it turns out, these clips do not follow the style norms even in the pitch distributions. However the value of the pitch interval concentration feature in the style discrimination of Hindustani and Carnatic alaps needs further investigation.
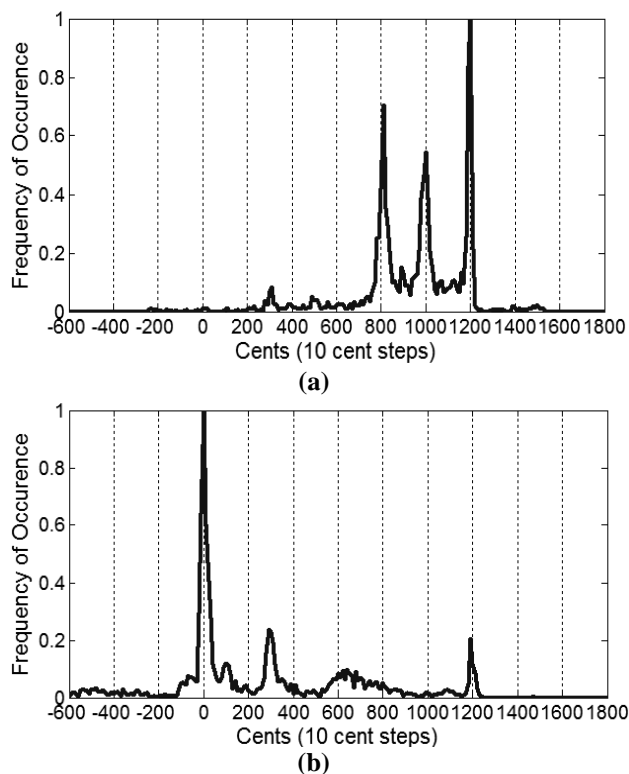
Figure 7. Distribution of Pitch Range in alap section by **(a)** Hindustani vocalist Veena Sahasrabuddhe for raga Malkauns **(b)** Carnatic vocalist T N Seshagopalan for raga Subhapanthuvarali. The commonly observed pitch range is followed by neither musicians

5. CONCLUSION

The observation that listeners can usually identify the style from vocal music corresponding to alap sections of Hindustani or Carnatic traditions provided the motivation for an investigation of melodic features for automatic style classification. Melodic contours are extracted by a predominant pitch detection method for singing voice pitch tracking in the presence of pitched accompaniment. The variety of pitch movements characteristic of Indian classical music require the adaptation of pitch analysis parameters to the underlying temporal dynamics for sufficient pitch detection accuracy. Listening tests using re-synthesized melodic contours were used to confirm that pitch variation alone provides sufficient cues to the underlying vocal style. Visual examination of the pitch contours confirms that style differences are manifested in the local stability of the pitch-continuous variation and the types of pitch modulation between stable notes. Features are derived from the melodic contour over the alap section to represent the proportion of stable note regions to pitch transition regions, and the presence of specific pitch

modulations in the transition regions. The analysis parameters used for feature estimation are linked to music knowledge via observations of musician annotated standing notes across a large database of alaps. While the parameters so selected provide for an automatic classification performance that matches subjective style identification by listeners, the data-driven optimization of classifier parameters gives higher automatic classification accuracy. Overall, the combination of extent of stable region and modulation rate in ornamental regions features separates the two styles to a large extent as seen on a database of alap sections drawn from various artistes' performances of pairs of corresponding ragas.

The present study can be extended to other sections of the concert such as the metered composition. Melodic features related to timing expressiveness could also contribute to vocal style discrimination. Comparisons of melodic phrases across the Hindustani and Carnatic styles corresponding to the characteristic phrases (motifs) of the raga can provide interesting insights into the variation of phrase level intonation with the style. Finally, the methods presented here can be extended to a study of vocal style differences across the distinct schools .

6. REFERENCES

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