IJTK, Vol 5(4)-October 2006 -pp 439-444

Spectral analysis of *GamakaSwaras* of Indian music

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Received 6 April 2005; revised 24 April 2006

In Indian classical music, there are a huge number of modes (*Ragas*). There arealso pieces (*Ragamala* or Ragamalika) in which modulations are employed. In both Hindustani & *Carnatic*(Karnataka) music, songs are usually preceded by an improvised unmeasured prelude (*Alap*), which is sometimes extensive. Individual pieces are shorter in *Carnatic*music, so recitals are constructed by selecting items in contrasting ragas. *Gamaka Swaras*, the subtle decorations of musical notes, usually referred to as the shaking of notes or vibration of *Swaras* come in various forms. *Gamaka*plays a very essential role in Indian music. Spectral analysis of the seven notes of Indian music has been reported. The work reported in the paper is a continuation of that work, extending it to *GamakaSwaras*. Report of the preliminary study giving a glimpse into spectralintricacies of *Arohana Gamaka* has also been discussed.

Keywords: Gamaka Swaras, Indian music, Karnataka music, Spectral analysis

IPCInt. Cl.[8]: G06F17/20, G10G3/00,G10L19/02

Gamaka Swaras are subtle decorations of musical notes, usually referred to as the shaking of notes or vibration of Swaras. They come in various forms and are incorporated into *Ragas*, giving each note a unique characteristic and delicate beauty. *Gamaka* plays a very essential role in Indian music, whether Hindustani or Karnataka, classical or otherwise. It is even considered the very essence of music, without which music tends to become flat, pale and unaesthetic. Recently, the Spectral analysis of the seven notes of Indian Music has been reported.[1] The workreported in the paper is a continuation of the earlier work, extending it to Gamaka Swaras. There are various types of *Gamakas* in use.[2] Gamaka Swaras of the ascending scale of the *Raga Mayamalavagowla*, which uses the seven notes in a sequence and is the basis for the commencement of training in Karnataka music of southern India, has been discussed. Indian music owes its origin to the Samaveda[2-4]. The evolution of Music from the *Samaveda* has been the subject of study by many holars and a good number of literatures are available on this subject. Some of them give a bird's eye view of the development of music down the ages until it reached its current [4].

Indian music is one of the oldest musical traditions in the world and its origin go back to *Vedas*(ancient Indian scripts). Many different legends have grown up concerning the origin and development of Indian classical music. Indian music has developed within a very complex interaction between different peoples of different racesand cultures. The basis for Indian music is *Sangeet*. *Sangeet* is a combination of three art forms: vocal, instrumental and dance. Although these three art forms were originally derived from the single field of stagecraft, today these three forms have differentiated into complex and highly refined individual art forms. Indian music is based upon: Rag and *Tal*. *Rag* is the melodicform while *Tal* is the rhythmic. Rag may be roughly equated with the Western term mode or scale. There is a system of seven notes, which are arranged in a means not unlike Western scales. *Tal* (rhythmic form) is also very complex. Many common rhythmic patterns exist. They revolve around repeating patterns of beats. All of this makes up the complex and exciting field of Indian classical music. Its understanding easily consumes an entire lifetime.

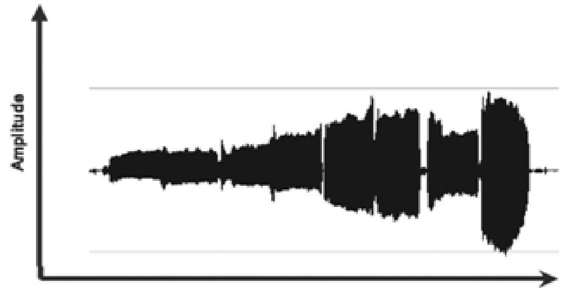
Speech and sound analysis, on the other hand, is of recent origin. The impetus for this came from the famous work of Fourier, leading to the study of sound patterns by splitting them into sinusoidal and co-sinusoidal components, now called Fourier analysis or spectral analysis. However, the analysis of human voice itself commenced only about half-a-century ago, with the invention of the Sound Spectrograph in 1946. Today, it has become a highly developed technical domain.[5]

The analysis of sound patterns is usually done either in the frequency domain or in the time domain. The former gives information about the distribution of the energy of sound over a range of frequencies. For human voices, the range is 20-20,000 Hz. However, the contribution above 8,000 Hz. is usually negligible. In the case of slow speech, the shape of the vocal tract remains steady up to about 200 millisec. Hence, itis the usual practice to do time domain studies in the range of 30-100 millisec. Frequency domain analysis leads to the energy spectrum, where theinitial waveform is Fourier-analysed. This has the handicap of losing information about variations with time. Therefore, it is the usual practice to supplement the spectrum by a Spectrogram, which is a plot of frequency as a function of time. The spectrogram consists of a set of horizontal lines of varying thickness and intensity, which are an index of the energy level. In this sense, the spectrogram is a parametric representation, with the energy asthe parameter. Between them, the energy spectrum and the corresponding spectrogram provide enough information for the analysis of the sound pattern.[5,6]

Methodology

The experimental procedure consisted of the following steps: (1) recording the *Gamaka Swaras* with a sensitive microphone in a quiet ambience, (2) digitizing the waveforms using a sampling rate of 44100 per sec, (3) analyzing the digitized data to extract the energy-frequency and frequency-time spectra, and (4)identifying the predominant frequencies through spectrograms. The procedure for recording was essentially the same as described earlier[7]. Even though the human voice normally does not use frequencies higher than 8000 Hz.,it was still decided to digitize the signals with a sampling rate of 44100 per second for the sake of fidelity. Trials showed that with a threshold level of 7500 Hz., the spectrograms showed very clear lines, easy for analysis. Using a higher threshold made the lines too thin and difficult to analyze.

The recording was done for a total of 5 male voices and 5 female voices, choosing the ascending scale of the raga Mayamalavagowla of Karnataka music and was supervised and checked for fidelity by the first author, a trained singer of Karnataka classical music. The seven notes were sung in the ascending order, giving long runs to each note. Three criteria were used for selecting the best recordings - steadiness of the pitch, perfection of the notes and breath control of the reciter leading to the steadiness of the voice. Based onthese criteria, three male and three female recordings were selected for further study. The most important segment of the recording is the exact location in the waveform of the *GamakaSwaras*. The identification was done as follows: The signal was expanded in the time scale and the cursor was moved from one end of the waveform to the other, using the play icon in the Sound Forge software. The musical notes were scanned with the help of a headphone. Wherever the *Gamaka* note was heard, the cursor was stopped to note down the precise location in the waveform. This position was highlighted and that portion of the waveform was used for further analysis. In this manner, the position before the *Gamaka*, during the *Gamaka*,after the *Gamaka* and the transitionfrom one note to the next were identified.



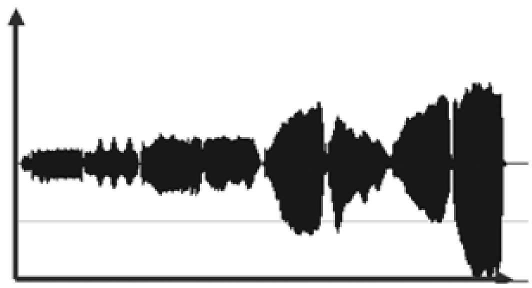
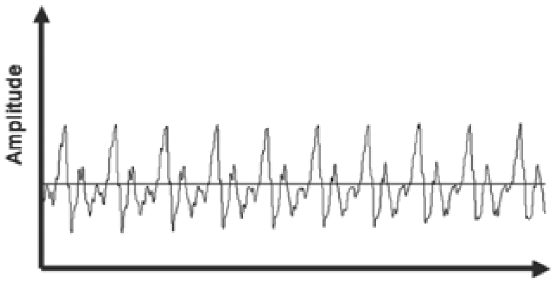


Fig. 1 Female voice waveform

Fig. 2 Male voice waveform



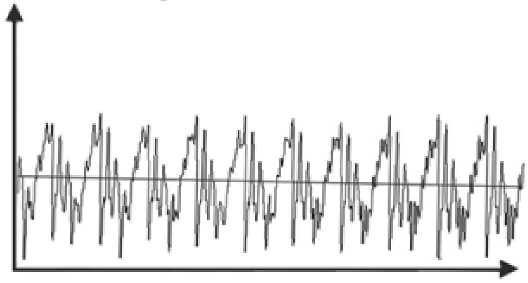
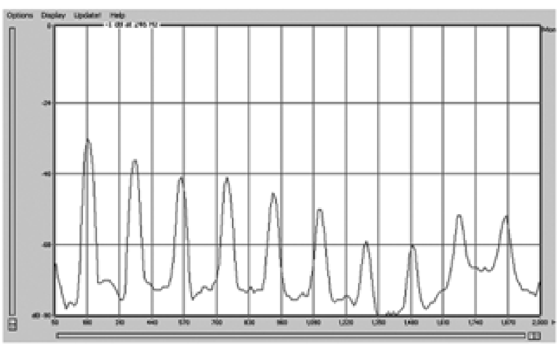


Fig. 3 Short-time window pattern for female voice

Fig. 4 Short-time window pattern for male voice



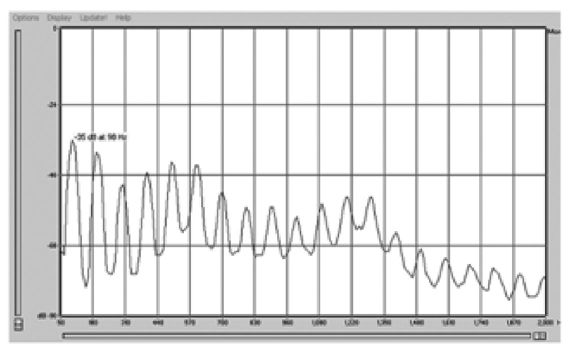
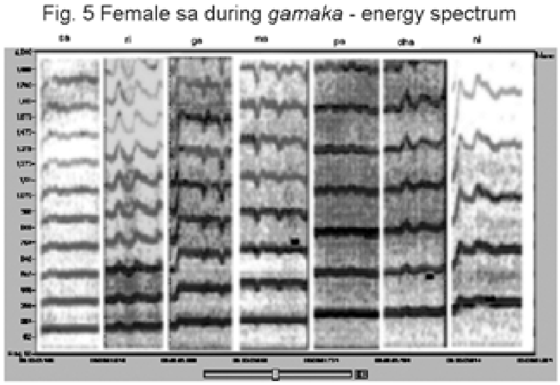


Fig. 5 Female sa during *gamaka* - energy spectrum

Fig. 6 Male sa during *gamaka* – energy spectrum



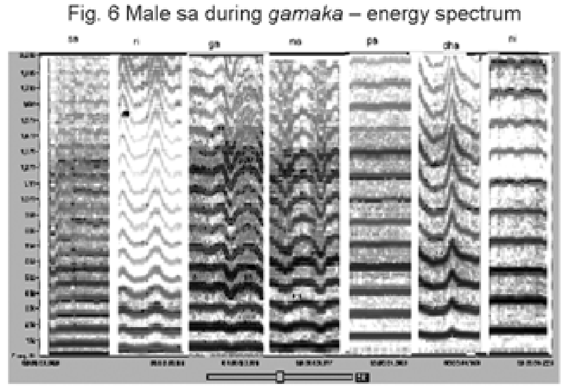


Fig. 7 Sonogram for all the seven notes: female voice

Fig. 8 Sonogram for all the seven notes: male voice

The results are presented in theform of sample waveforms, short-time window patterns, sample energy-frequencyspectra and sonograms of the seven notes as well as of the transitions. The waveformof the seven notes with *Gamaka* for afemale voice (Fig. 1) and that for a male voice (Fig. 2) has been presented. The analysisreported is based on all waveforms recorded, but only two of them are displayedto give an idea as to what the waveforms look like. A short-time window patternfor a female voice (Fig. 3) and that for a male voice (Fig. 4) have beendisplayed. These patterns demonstrate the periodic nature of the signals, indicating that no random analysis isneeded. Sample energy-frequency spectra are shown in figs 5 & 6. Fig. 5shows the spectrum for the note *Sa* ofa female voice during *Gamaka*. Thesame spectrum for a male voice is displayed in Fig. 6. A sample set ofsonograms has been displayed (Figs 7-14). The sonogram for all seven notes fora female voice (Fig. 7) and that for a male voice (Fig. 8) have been displayed.There are in all seven transitions between the notes and the sonogram of thesetransitions for the female voice (Fig. 9) and that for the male voice (Fig. 10). Lastly,

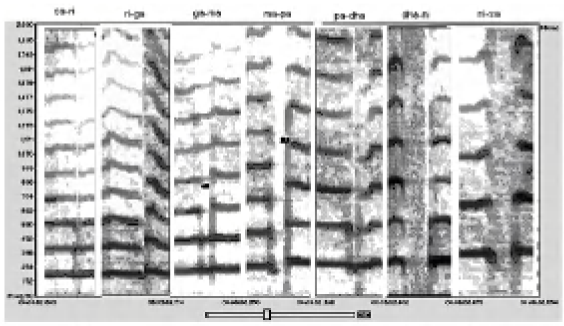


Fig 9 Sonogram for the seven transitions: female

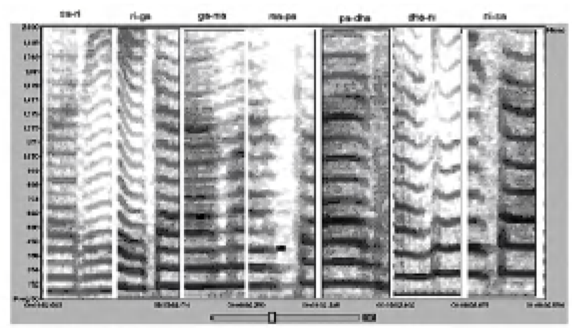


Fig 10 Sonogram for the seven transitions: male

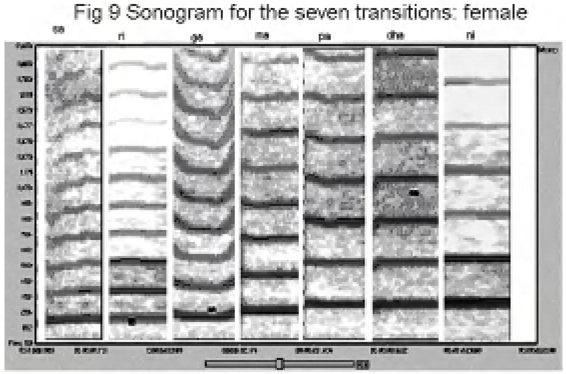


Fig 11 Seven notes before gamaka: female voice

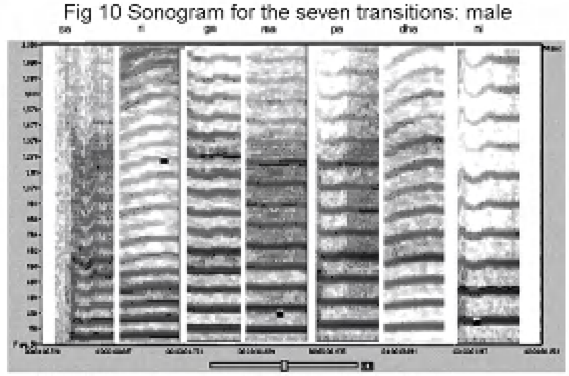


Fig 12 Seven notes before gamaka: male voice

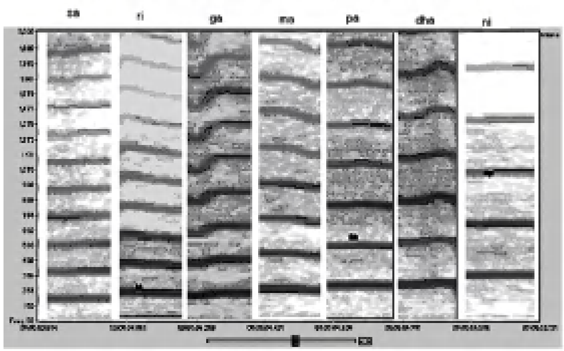


Fig 13 Seven notes after gamaka: female voice

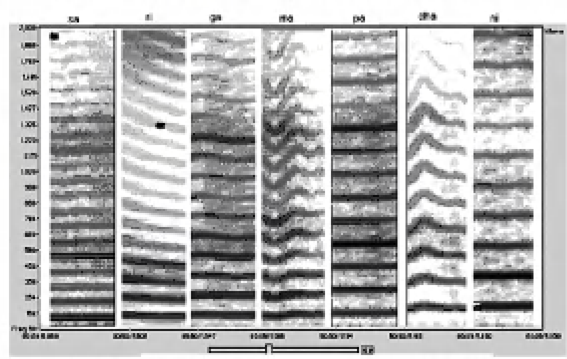


Fig 14 Seven notes after gamaka: male voice

the sonograms for the seven notes before Gamaka for the female voice in (Fig. 11)and the male voice in (Fig. 12) and the corresponding sonograms for the seven notes after *Gamaka* (Figs 13-14) have also been displayed. Of the total 390 figures, only sample figures to illustrate the kind of data analysis, which has been used to draw the conclusions, have been presented.[4]

Discussion

Musical notes are periodic in natureand differ from noise, which is non-periodical. It is the periodic nature of the musical notes, which makes them so pleasant to hear even for long periods of time. Noise, on the other hand, creates mental disturbances leading to discomfort. This is a common experience. The advantage of musical notes is their periodicity, which makes working with them and their analysis much simpler. Therefore, before working on any musical waveform for its periodicity, not only to ensure its fidelity but also to see that there is no intrusion by external or internal noise is checked. With this end in view, all recorded waveforms (Figs 1-2), were checked for periodicity by taking several 100 millisec windows. It is said that the human voice finds it difficult to bestable beyond a time period of 200 millisec. But during the study, all the singers were well trained and could hold their voice steady. Nevertheless, windows of 100 millisec were used to ensure that all the waveforms were periodic.

The signals can be analyzed by the energy-frequency spectrum and the frequency-time sonogram. The former gives a static picture and the latter gives a dynamic picture. Both the representations are equally useful if the spectra are independent of time. But where the energy spectra vary with time, the sonogram representation is more useful, since it gives information about variations with time, which tend to get masked in theenergy spectra. In the current study, the focus of attention was the Gamaka, which represents minute variations in the voice resorted to by musicians to bring out emotions more effectively. Therefore, sonograms were considered to be more appropriate medium for the study and hence they have been used primarily for drawing the conclusions. While studying the sonograms, the abscissa represents time and theordinate the frequency, with the energy level serving as a parameter. The lowest line represents the fundamental frequency and successive lines are harmonics. Shades of grey serve to identify the level of energy. The darker the line, the higher the energy. It is also seen that there is hardly any energy between the lines, since the signal is periodic and composed of harmonicfrequencies, which are integral multiples of the fundamental. Black and white sonograms have been used rather than coloured ones, since they highlight the variations more clearly.

The frequency of the signal is a function of time and hence the sonogram lines are expected to be bent and not straight, which would be the case if the frequency is independent of time. The time variation of the frequency was clearly seen (Figs 7-14) contrasted with sonograms for the notes without *Gamaka.*In the *Gamaka* way of singing, there is a transition from one note to another, which is expected to be smooth (Figs 9-14). The largest time variation was to be found within the window of the signal at the point of *Gamaka* itself (Figs 9-10). The magnitude of these variations depends upon the way the singer introduces *Gamaka* into the singing of the notes, which varies among the various schools or *Gharanas* (according to the North Indian style of classical music). The male voice is usually richer in timbre than the female voice and thus displays a larger number of harmonics or lines in the sonograms. This is borne out by comparing Figs 7, 9, 11 and 13, respectively with Figs 8, 10, 12 and 14. Certain striking features of the signals were observed. Some of them are common to both the male and the female voices. There are seven transitions involved inthe signal, namely *sa* to *ri, ri* to *ga, ga* to *ma, ma* to pa, pa to *dha, dha* to *ni* andfinally *ni* to *sa*. The *Gamaka* for the first and the last transitions are usually not emphasized by singers. Gamaka usually starts with *ri*. It is alsomild for *ga* and emphatic for ma. Similar is the case for pa and *dha*, the latter being vibrated more predominantly. The note ni is also sung with mild Gamaka.

A study of the spectrograms in theirtotality revealed that in all cases the spectrograms for *sa* and *pa* are almostflat, whereas those for the other notes showed predominant time variation. Itappears as if the notes form a staircase, alternate notes representing the riseand the tread. In this sense, the word *Arohana*,meaning ascent, is indeed appropriate.

Conclusion

Male voices have a richer timbre, which many a time, plays the same role as *Gamaka*.Hence, there is no need for the male voice to use or emphasize Gamaka. The female voice on the other hand, with a shallower timbre, needs to emphasize *Gamaka* more, to bring out the same effect. This has been noticed in the recitation of *Mantras* also. In the case of any flat note, the fundamental frequency remains unchanging with time. However, it is also a function of the pitch. When the human voice moves over the ascending scale of notes, the fundamental frequency gradually increases. This is irrespective of whether the voice is male or female. The notes with *Gamaka* appear to form a staircase, with the alternate notes representing a rise or the step, thus justifying the use of the technical word *Arohana*.This is a preliminary study giving a glimpse into the spectral intricacies of Arohana Gamaka. A more detailed studywould have to take into account the actual variations in the frequency during Gamaka, the peak frequency reached and its relation to the transition between the notes. The study has been undertaken and the results will be reported later.

Acknowledgement

Authors thank Sri Natesh Babu and Sri Heisnam Bison Singh for their help in the use of the Sound Forge Software. Authors are grateful to all those who leant their voices for the *Gamaka* recordings.

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