IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 20, Issue 1, Ver. IV (Jan.- Feb. 2018), PP 01-08
www.iosrjournals.org

Vedic Swara Recognition System: A Move towards Vedic Chanting

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Abstract: *Being one of the oldest among scriptures, Vedic scriptures are considered to be one of the richest creations of mankind. After much demolition and ruins, the Vedic Chanting techniques are still vast and tough to learn. In chanting a Vedic verse the notes used, known as the Swaras are strictly bound by rules. Mistake in implementing one Swara is considered a serious blunder in case of Vedic chanting. The motto of this work is to analyze a Vedic chant in order to get its Swaras and to check the accuracy of the chanting signals afterwards, whether their swara implementation is proper or not. Analyzing the complexity of the chanting signals, we have done the work in two phases using two separate techniques, Mel-Frequency Cepstral Coefficient and Wavelet Transformation. As Swara system is a vast field to study and analyze, this paper has only focused on the Yajurvedic verses that deals with four major swara chanting techniques. This work can be a great advancement in order to move ourselves towards the long forgotten Vedic wisdom.*

Keywords: *Vedic, Chanting, Swaras, Signals, Wavelets, Signal Processing.*

Date of Submission: 16-02-2018 Date of acceptance: 27-02-2018

I. Introduction

"History of mankind is a lie that has been honed like a weapon who suppressed the truth", said Leonardo Da Vinci once, when he was summoned by an association of four people named 'The son of Mithras', which is later got popularity in the form of 'Priory of Sion'. The history of our own country is no exception. We have been taught to believe that our ancient scriptures are the outcome of primitive ignorant and scared human minds. That led us to mistrust the ancient wisdom instead of bowing down to it. This situation gave opportunity to some people to misinterpret our scriptures and hide or to destroy them completely. History of my country has witnessed this phenomena times without number, when great libraries were burned and protectors of those wisdom were butchered by the savage invaders. It was a tradition to carry out the wisdom of the ancient scriptures through personal teachings and guidance. Selective scholars were the guardians of these scriptures once, who educated deserving young minds to grow and flourish and thus the wisdom flowed from one generation to the other. Then invasion happened, the rulers responsible for guarding the knowledge failed in their tasks and the linage got broken making the written down scripts vulnerable to misinterpretation by people who had no idea about what they were talking about. As the Sanskrit scriptures were only understandable to the properly trained ones, it was easy to misinterpret it to the common people who had absolutely no knowledge of Sanskrit. Unlike the Sultanate and the Mughal rulers, our British invaders did not stop on destroying scripts and killing the scholars. They started interpreting the scripts to their comfort. They taught us what they wanted us to be and we followed. Even today there are number of people who talk about the scriptural knowledge without knowing its source and by studying foreign authors or people who are influenced by those foreign authors. For instance here I am going to share a personal experience of mine. Once by a revered and one of the most knowledgeable person I have ever come across I was asked that if it was true that a 'Shiva-lingam'(a symbolic representation of the cosmos) is actually a comet that fell from the sky and people in order to make it cool started watering it, and thus the 'Jal-abhishek' custom emerged. When I asked him where he got the idea from, 'Internet' was the answer. It instantly cleared my vision to some extent that how people of my country think today. If such a brilliant person can nurture such ideas and can question the believed un-questionable authority i.e. the Vedas based on some article on the internet that has been clearly authored by someone who has no idea about what he is talking about, the others must be facing this same disaster. The list is really long for me as I face such questions all over and to my surprise every time I am amazed so much to see the creativity of misconceptions. They never fail to surprise me.The long introduction above is written with only one motto, to explain in brief what drove me to do this work. As we have seen that this country has lost so much of its treasure already in the hands of time and still decaying. Just like any other child I also grew up believing there is no need to be bothered about the ancient creations of my country. But at the same time I realized that it is not true for all countries. Even today, people quote and cite literatures from old and ancient times of different countries. When there is a literary meet, great poets like Shakespear and John Milton are quoted as classics, but though more relevant Kalidasa remain neglected. When there is a meet of scientists talking about big-bang or black-holes, 'Atharva Samhita' is never cited. Similarly 'Vayu Punrana' for climatology and oceanology, 'Mandukya Upanishad' for psychology are completely neglected though they have so many answers to the unsolved questions of today's stream of research. So I decided to dig a little to the ancient scriptures in original to find out if it is really that hard to ignore, or we are just blind in that specific case for our own ignorant minds. There is a misconception about Sanskrit scriptures in people's mind that whenever it is Sanskrit, it must be religious. The reason is simple, we study Sanskrit maximum for two years in school, and that education is not even sufficient to differentiate 'Laukik'(general) and Vedic Sanskrit. When I started studying, I found them not hard at all. The why we think it is hard? Because, the scriptures demand dedication of the reader. That is the place where everyone backs off. No one is ready to dedicate a little of their time to study them with a mind to explore. More I read, more I identified various problems regarding this mass Sanskrit-illiteracy. It is not that we can't, its that we won't. From those various problems I chose one that I thought could be solved using technology; Vedic swaras. Vedic verses contain information at various levels. In a one specific 'Sukta'(compilation of specific verses)it may contain theories, descriptions and poetic brilliance at the same time. But they follow certain rules while chanting. There comes the idea of Swara system. Every Vedic verse is chanted using some specific notes that can't be altered. The Vedic Sanskrit is more difficult than Laukik Sanskrit itself. And the swara system makes it more difficult. In the primitive stages a student can't properly identify the swaras and face difficulties in learning the technique. In Sanskrit language study consists of four steps i.e. 'Shravanam'(Listening), 'BhashaNam'(Speaking), 'PaThanam'(Studying), 'Lekhanam'(Writing). That narrows down the whole concept. Before studying Vedic scriptures it is needed to listen and chant them first. As I said earlier, Sanskrit study demands dedication and this is where it starts. These preliminary steps made me think to develop a system that can resolve the basic difficulties to some extent for this technique. This venture reducing some basic difficulties to some extent may make a progressive move towards Vedic scripture education, which is really so much needed today in order to reduce or stop the ongoing decaying of Vedic culture and knowledge. We all say about preserving the ancient but are we up to take a step? It begins with us. Not at any institutional level or big scale, it must begin with the individuals. We must step forward in order to preserve what is decaying, not to preserve the ancient knowledge, but to help and save ourselves from deprival from the knowledge that belongs to us. We are the ones who failed to preserve it when the decay started and now we must step forward to make things right. My effort is small, but not negligible as this ripple can touch great minds and may their mind create a turbulent stormy wall within which the Vedas will be safe for more centuries to come. This paper further discusses the background theories, both technical and domain oriented, the methods used for developing the system and the future modifications that could be made on it.

II. Background Theory

Domain Study: This part contains the domain study which is necessary for the completion of the project.

Musical Scales: In music theory, a scale is any set of musical notes ordered by fundamental frequency or pitch. A scale ordered by increasing pitch is an ascending scale, and a scale ordered by decreasing pitch is a descending scale. Some scales contain different pitches when ascending than when descending. For example, the Melodic minor scale. Often, especially in the context of the common practice period, most or all of the melody and harmony of a musical work is built using the notes of a single scale, which can be conveniently represented on a sta_ with a standard key signature. Scales are typically listed from low to high. Most scales are octave-repeating, meaning their pattern of notes is the same in every octave (the Bohlen~nPierce scale is one exception). An octave-repeating scale can be represented as a circular arrangement of pitch classes, ordered by increasing (or decreasing) pitch class. For instance, the increasing C major scale is C-D-E-F-G-A-B-[C], with the bracket indicating that the last note is an octave higher than the _rst note, and the decreasing C major scale is C-B-A-G-F-E-D-[C], with the bracket indicating an octave lower than the _rst note in the scale. Now this thing is similar to the Indian Saptak Concept as it rounds from Sa to Sa.

Scales may be described according to the intervals they contain: for example: diatonic, chromatic, whole tone or by the number of di_erent pitch classes they contain:

1. Octatonic (8 notes per octave): used in jazz and modern classical music.
2. Heptatonic (7 notes per octave): the most common modern Western scale.
3. Hexatonic (6 notes per octave): common in Western folk music.
4. Pentatonic (5 notes per octave): the anhemitonic form (lacking semitones) iscommon in folk music, especially in oriental music; also known as the "black note"scale.
5. Tetratonic (4 notes), tritonic (3 notes), and ditonic (2 notes): generally limited toprehistoric ("primitive") music.
6. Monotonic (1 note): limited use in liturgy, and for e_ect in modern art music.

The number of the notes that make up a scale as well as the quality of the intervals between successive notes of the scale help to give the music of a culture area its peculiar sound quality.The pitch distances or intervals among the notes of a scale tell us more about the sound of the music than does the mere number of tones.

Vedic Swaras: The Vedic Sanskrit, being world's first most complex language deviates a lot from the Laukik Sanskrit in its vocabulary and sentence structures. The construction of the Vedic suktas applies a completely independent grammar for its sentence constructions and Swara composition. It mainly includes the rules from the Panini Ashtadhyayi. The Vedic recitation is one of the most scientific and toughest rituals in the world along with the Mayan Fire ritual or Opus Dei practices. It needs years to develop the skills to pronounce and recite the Vedas properly. Without proper recitation the chants are considered to be foul and disgraceful. In that effect the students are suggested to take the Swara Patha before starting the Vedic chants. Generally Vedic chants are done by more than one skilled Bramhins. Each and every one chants the same Sukta at the exact accurate tones and rhythm. Not a single word or note is wrongly uttered. Thus no matter how many Bramhins are chanting it sounds like one. That's the real beauty and magnificence of the Vedic Chanting. The Rig Veda is chanted on 3 notes, the Yajur Veda on up to 5 notes and the Sāma Veda on 7 notes. The Sāma is the only chant that is considered really musical per se and as such is considered to be inferior to the other two Vedas. Because of it's 'worldly' character it is often forbidden in certain rituals. It is also prescribed that if the Sāma Veda is heard while the other two are being recited then the recitation should stop immediately and only continue after the Sāma has terminated. The Sāma veda uses 7 musical notes. Chanting of the Rik, Yajur and Atharvana Veda is done using 3 notes only.
Udātta — the raised note indicated in the text by a vertical stroke over the letter. (a̍)
Anudātta — the lowered note indicated by a line under the letter. (a̱)
Svarita — the neutral drone which is not indicated in the text (a)
Nigādha — a deviant note which is based on the udātta and is like a double udātta with the second being slight raised above the first . In the kṛṣṇa yajur veda it is usually marked by double perpendicular stokes above the letter. (a̎)
The udātta changes into a nigādha in the following situations:—

- When a mantra ends in a long udātta
- When a mantra ends in a anusvara which carries the udātta
- When the udātta is followed by a samyuktākṣara (combined letter such as kṣ, stha, tv, śr, etc).

Vedic recitation has assumed two distinct forms that evolved to preserve its immutable character: Prākṛti and Vikṛti with sub-forms. The pāda pāṭhaḥ forms the basis of a number of special recitations known as 'vikriti' or 'crooked' recitations. The text is recited backwards or forwards or the successive words are chanted in specific combinations. These were originally designed to prevent the student from forgetting even one letter of the text, however through the ages these mnemonic techniques became an end in themselves.

Technical Background: MFCC: In this project the most important thing is to extract the feature from the audio signal. The audio signal feature extraction in a categorization problem is about reducing the dimensionality of the input-vector while maintaining the discriminating power of the signal. In the feature extraction or signal processing stage, the acoustic waveform is sampled into frames (usually of 10, 15, or 20 milliseconds) which are transformed into spectral features. *Mel:* Human hearing, however, is not equally sensitive at all frequency bands. It is less sensitive at higher frequencies, roughly above 1000 Hertz. It turns out that modeling this property of human hearing during feature extraction improves speech recognition performance. The form of the model used in MFCCs is to warp the frequencies output by the DFT onto the mel scale. A mel (Stevens et al., 1937; Stevens and Volkmann, 1940) is a unit of pitch deed so that pairs of sounds whichare perceptually equidistant in pitch are separated by an equal number of mels. The mapping between frequency in Hertz and the mel scale is linear below 1000 Hz and the logarithmic above 1000 Hz.*Cepstral*: One way to think about the cepstrum is as a useful way of separating the source and filter. The speech waveform is created when a glottal source waveform of a particular fundamental frequency is passed through the vocal tract, which because of its shape has a particular filtering characteristic. But many characteristics of the glottal source (its fundamental frequency, the details of the glottal pulse, etc) are not important for distinguishing different phones. Instead, the most useful information for phone detection is the filter, i.e. the exact position of the vocal tract. If we knew the shape of the vocal tract, we would know which phone was being produced. This suggests that useful features for phone detection would and a way to deconvolve (separate) the source and filter and show us only the vocal tract filter. The cepstrum is more formally defined as the inverse DFT of the log magnitude of the DFT of a signal.

Waelets: The fundamental idea of wavelet transforms is that the transformation should allow only changes in time extension, but not shape. This is effected by choosing suitable basis functions that allow for this. Changes in the time extension are expected to conform to the corresponding analysis frequency of the basis function. Based on the uncertainty principle of signal processing,

$\Delta t \Delta \omega \geq 1/2$

where t represents time and ω angular frequency. The higher the required resolution in time, the lower the resolution in frequency has to be. The larger the extension of the analysis windows is chosen, the larger is the value of Δt .

When Δt is large,

Bad time resolution

Good frequency resolution

Low frequency, large scaling factor

When Δt is small

Good time resolution

Bad frequency resolution

High frequency, small scaling factor

In other words, the basis function Ψ can be regarded as an impulse response of a system with which the function x(t) has been filtered. The transformed signal provides information about the time and the frequency. Therefore, wavelet-transformation contains information similar to the STFT, but with additional special properties ofthewavelets, which show up at the resolution in time at higher analysis frequencies of the basis function.*Why do we need it:* As per requirement the system requires to know the exact time of a specific frequency and as the stuffs we will be working with are highly complex waveforms the STFT will be a very bad idea to adopt. For such reasons Wavelet Transform is the proposed method to get the time-frequency domain of the given signals in our system. Through wavelet transform the time-frequency matrix will be generated which will be further compared with the given test input signals. Thus the identification of the Swaras could be done.*What else we need to know about wavelets?*: Before we begin we need to know more than this about wavelets a bit. The topics include DWT & CWT, Wavelet Coherence and their Applications.Real world data or signals frequently exhibit slowly changing trends or oscillations punctuated with transients. On the other hand, images have smooth regions interrupted by edges or abrupt changes in contrast. These abrupt changes are often the most interesting parts of the data, both perceptually and in terms of the information they provide. A wavelet is a rapidly decaying, wave-like oscillation that has zero mean. Unlike sinusoids, which extend to infinity, a wavelet exists for a finite duration. Wavelets come in different sizes and shapes. Here are some of the well-known ones. The availability of a wide range of wavelets is a key strength of wavelet analysis.To choose the right wavelet, you'll need to consider the application you'll use it for. The two major transforms in wavelet analysis are Continuous and Discrete Wavelet Transforms. These transforms differ based on how the wavelets are scaled and shifted. Key applications of the continuous wavelet analysis are: time frequency analysis, and filtering of time localized frequency components. The key application for Discrete Wavelet Analysis are denoising and compression of signals and images. As I mentioned in the previous session, these two transforms differ based on how they discretize the scale and the translation parameters.We can use this transform to obtain a simultaneous time frequency analysis of a signal. Analytic wavelets are best suited for time frequency analysis as these wavelets do not have negative frequency components. This list includes some analytic wavelets that are suitable for continuous wavelet analysis. The outputs of CWT are coefficients, which are a function of scale or frequency and time. The discrete wavelet transform or DWT is ideal for denoising and compressing signals and images, as it helps represent many naturally occurring signals and images with fewer coefficients. This enables a sparser representation. The base scale in DWT is set to 2. We can obtain different scales by raising this base scale to integer values represented in this way. The translation occurs at integer multiples represented in this equation. This process is often referred to as a dyadic scaling and shifting. In the CWT, the analyzing function is a wavelet, ψ. The CWT compares the signal to shifted and compressed or stretched versions of a wavelet. Stretching or compressing a function is collectively referred to as dilation or scaling and corresponds to the physical notion of scale. By comparing the signal to the wavelet at various scales and positions, you obtain a function of two variables. The 2-D representation of a 1-D signal is redundant. If the wavelet is complex-valued, the CWT is a complex-valued function of scale and position. If the signal is real-valued, the CWT is a real-valued function of scale and position. For a scale parameter, a>0, and position, b, the CWT is:

$$C(a,b; f(t),\psi(t)) = \int_{-\infty}^{\infty} f(t)\frac{1}{a}\overline{\psi}(\frac{(t-b)}{a})dt$$

where a denotes the complex conjugate. Not only do the values of scale and position affect the CWT coefficients, the choice of wavelet also affects the values of the coefficients. The CWT can be thought of acorrelation coefficient between the data and the wavelet function. High wavelet coefficients imply a similar shape of the wavelet function with the time-series data, whereas low coefficients indicate relatively little resemblance at given time-frequency locations. Figures and show examples of CWTs applied to some of the data used in the later empirical analysis. Results for the two Morlet and Paul wavelets are plotted separately. As visible, higher and significant coefficients are coloured red and marked by black contour lines.

Wavelet Coherence: Many applications involve identifying and characterizing common patterns in two time series. In some situations, common behavior in two time series results from one time series driving or influencing the other. In other situations, the common patterns result from some unobserved mechanism influencing both time series. For jointly stationary time series, the standard techniques for characterizing correlated behavior in time or frequency are cross-correlation, the (Fourier) cross-spectrum, and coherence. However, many time series are non-stationary, meaning that their frequency content changes over time. For these time series, it is important to have a measure of correlation or coherence in the time-frequency plane. You can use wavelet coherence to detect common time-localized oscillations in non-stationary signals. In situations where it is natural to view one time series as influencing another, you can use the phase of the wavelet cross-spectrum to identify the relative lag between the two time series.
After having obtained the CWT of individual time series, one can use the transform for the investigation of co-movements among two time series. This requires the calculation of the cross-wavelet transform which is a simple multiplication of the CWT of series, with the complex conjugate of the CWT for the time series. This quantity serves as a local covariance between the two series at each time and frequency (Aguiar-Conraria and Soares 2011). Using the cross-wavelet transform, the squared wavelet coherence (WCO).
Just as one can consider the cross-wavelet transform as a covariance, the wavelet coherence acts as a correlation coefficient between the two time series in time-frequency domain.

III. Implementation of The Project

Phase I: Musical scale deduction using MFCC

This phase consists of two discrete phases namely training and testing. In the training phase the training corpus is created to form a library of two different Yajurveda verses in two different musical scales with every possible variation. In the testing phase a recorded test data of similar verse in two different musical scales, one present and one absent in the corpus is compared with the trained system to deduce the musical scale of the test chant.Used softwares to make the training corpus:
FLStudio: it is used to take the midi vamp input for a specific scale.
Adobe Audition CC2014: it has been used to record the sample training sets and make the training corpus. The steps are as follows:

1. Open a new audio file with settings of channel: mono, bit depth: 8 bits
2. Open a new multitrack composition
3. Place the required scale vamp
4. Record accordingly
5. Save as .wav file

Matlab: for the main coding of the program which has two phases namely training and testing. Two separate program codes have been written for the steps.Training : To start the classification process soundtrain.m file is executed. Matlab command window prompt for input the directory name where training file has stored. After giving input it read every file in the folder by calling a function loaddata.m. Then it call another function mfcc, mfcc function call another function "melcepst.m" which is a standard function for calculating cepstral coefficient and this program has been collected from a matlab tool box voice box. After completion mfcc store cepstral coefficient in a matlab workspace variable cepstral.m and it also store name of the corresponding file. This is the end of training phase. Testing: After completion of training phase an unknown file is taken soundtest.m file is executed. This file prompts for input sound file. After giving its proper location sound file is read. And then soundtest.m call function mfcc.m. Which calculate mel frequency cepstral coefficient by calling melcepst.m as before. Then cepstral coefficient is passed through a function distmeasure.m along with train cepstral coefficients which were stored in cepstral.mat. Distmeasure.m call function disteusq.m which is a voice box matlab function. This function calculates Euclidean or mahalanbis distance between test file and each of train file. After getting minimum distance it returns an index, this index return name of the file that is store on matlab workspace variable name.mat. By processing the filename we get corresponding match.

Phae II: the swara recognition and checking

This phase takes the classified data from previous phase and runs a wavelet analysis on the signal. This also consists of two phases.3.2.1 Phase I: wavelet analysis for the dataIn this phase the experiment datasets are undergone through a wavelet analysis. This results the signal to wavelets in time-frequency domain. This transform is done by MATLAB coding. In MATLAB we have used the function ‘iwt()’ perform the transform. The signals on which the wavelet transform was performed had following properties,

I. Different lengths,
II. Different verses
III. Different scales.

Once we have got the time-frequency representation of our signals, now they are ready to be compared with the test datasets through wavelet coherence.

Phase II: Wavelet Coherence

For applying wavelet coherence in MATLAB the in-built function that the system provides or the 'Wavelet toolbox', both were unable to render the datasets successfully to produce the desired results. So externally we have used the installation of 'grinsted-wavelet-coherence-d987ea4' toolbox that had the wavelet coherence function working and it was effectively able to render our datasets to generate the desired coherence results. In order to do this test we have made checking for various datasets to get different results. The experimenting datasets were,

I. Same verse-same length check
II. Same verse-different length check
III. Different verse-same length check
IV. Different verse-different length check

For four different cases we got four plotting for coherence datasets, which will be discussed in the following parts.

IV. Result & Discussion

Phase I: musical scale deduction:

In this step it is seen how much samples are correctly classified and thus the performance of the system is evaluated. In the testing phase, the approach discussed above was applied to two verses in two different scales namely E and Gm. There are no common sample in training set and testing set. The hit rate is percentage of times the verse was correctly identified. It was found that the proposed approach gave sufficiently good results for all of the verses. Percentage of misclassification was significantly low. Overall the result was satisfactorily good giving the total percentage of accuracy over 97. The purpose of this phase was to recognize the musical scale of a specific chant. The results show that the features used here can give good classification performance. Though the database of collection of sound is not so large but the variation of sound is so diverse that the above performances make a satisfactory result.

The sample chants that have been analyzed in this step are,

1. Ganapathi Avahanam in E Scale (5 Sample datasets)
2. Ganapathi Avahanam in G Scale (5 Sample datasets)
3. Hamsa Gayatri in E Scale(5 Sample Datasets)
4. Hamsa Gayatri in G Scale(5 Sample Datasets)

So we have got 20 chant samples as the train dataset along with five recorded sample for each category, which makes 20 record sets.

Figure 1 shows the screenshot of the program in execution.

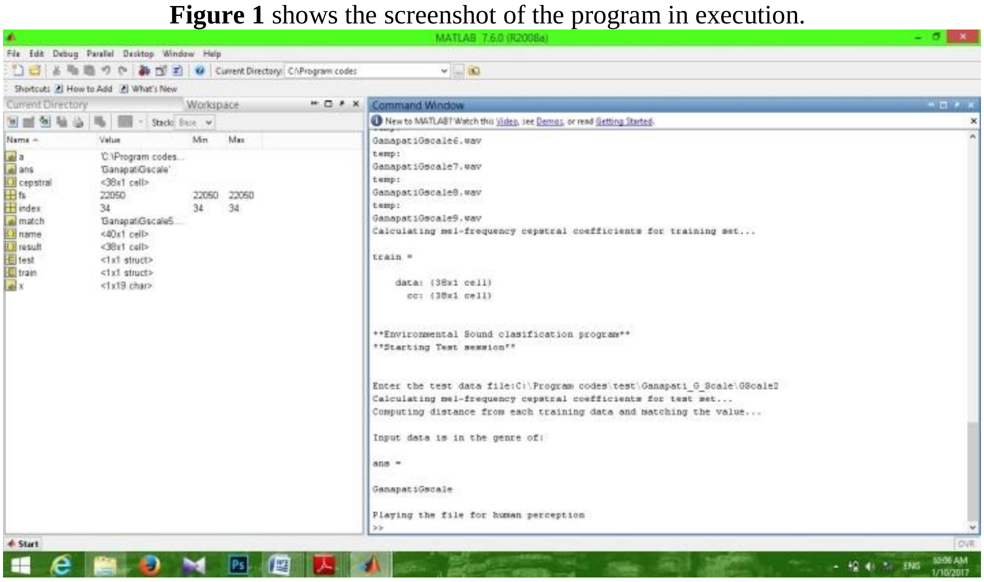

Figure 1 : Screenshot

Phase II : working with wavelets

Sub-phase I: on running wavelet transforms for the classified signals we have got their wavelet representations at time-frequency domain. Some of the examples are given below, that we used for Sub-phase II testing approach.*Sub-phase II:* Checking coherence for the above mentioned four categories we got four coherence graphs, shown below.

As we can see the results are as following

i. Same verse-same length check ::: shows perfect coherence with accuracy as both the verses have been chanted accurately in a proper scale.

ii. Same verse-different length check ::: it is also showing almost similar data as through stretching and scaling techniques embedded in wavelet both the verses are aligned accordingly and then checked for coherence.

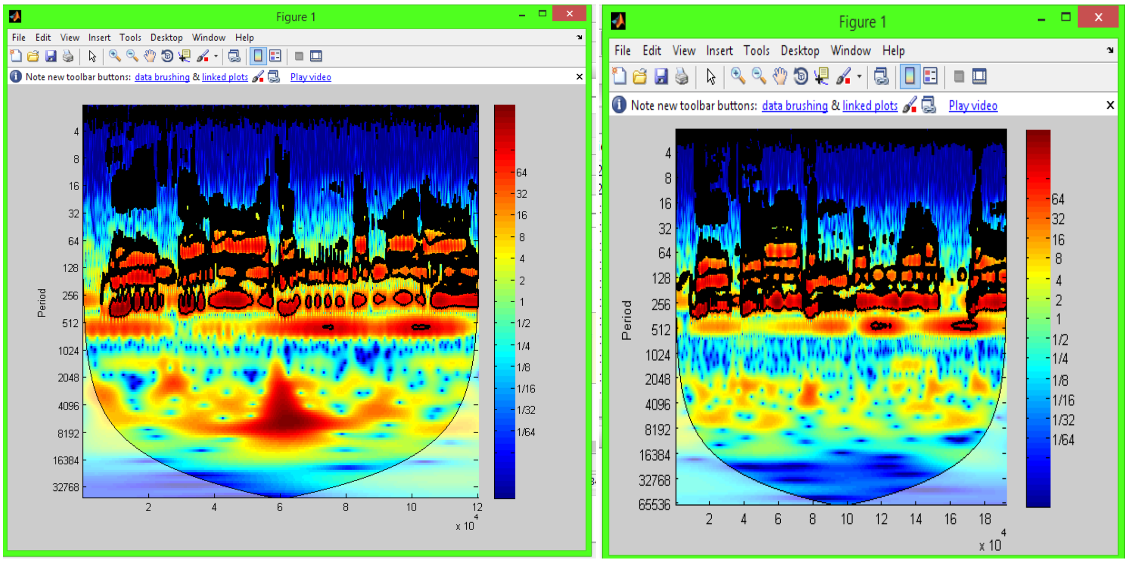

Figure 2 : Wavelet Train Samples

iii. Different verse-same length check ::: shows very less coherence due to occasional presence of Udatta and Anudatta swaras that matched somehow co-incedentally. Otherwise the graph shows the dissimilarity between the two.

iv. Different verse-different length check ::: even aligned properly the coherence plotting shows similar result for different verses showing very less coherence.

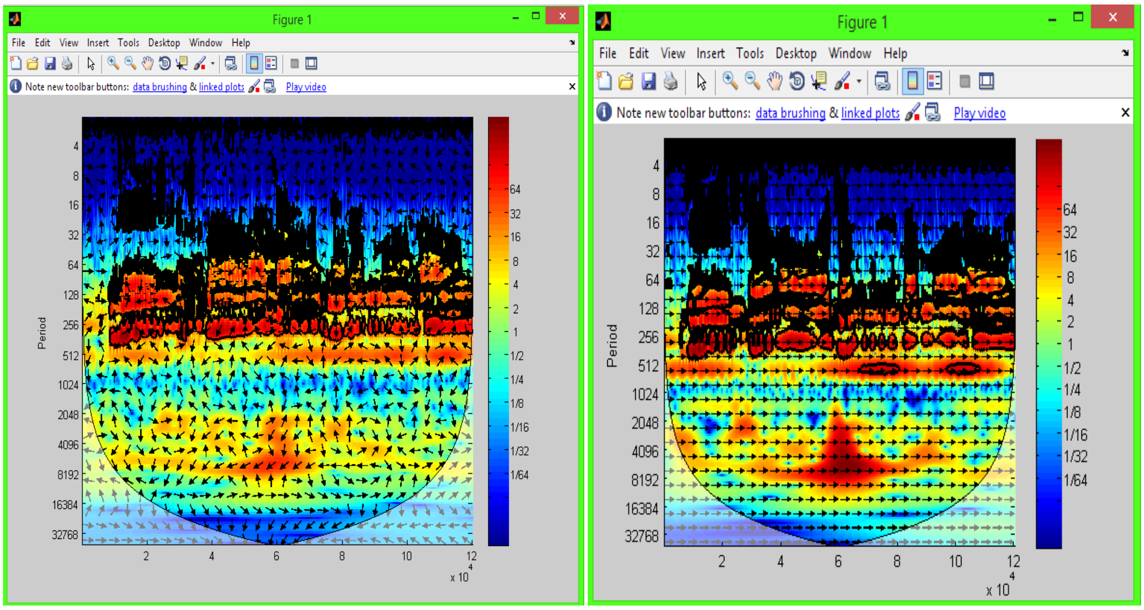

Figure 3: Coherence

As we can see in the Coherence plots first example is showing a good coherence result where other one is hardly cohering with each other being different verse with different swara.

V. Conclusion:

In this work we have successfully categorized the Chant sample into specific musical scales and created their wavelet transform that showed their Swara mapping. We have also checked whether the testing samples are in a sync with the training sets, i.e. whether their Swara mapping is okay or not.With novelty in using Wavelet coherence to check Vedic Swara this work has done a really fine job. In order to deduce the Swaras till now, a student had to undergo memorizing them or studying the vast Panini grammar to apply them into the Vedic verse. Through this work we have somehow been able to visualize the Swara positioning in the chants that is easier to memorize while learning to chant them properly.

Future Works: The future scopes of this work is high. As example,

I. It can be expanded to Saam and Rg Veda swaras, where the number of Swaras are higher than that of YajurVeda.
II. This work applies very little of Panini grammar. The complete Panini grammar can be applied to develop such a system that can completely cover whole of the Vedic grammar.

Progressing this work can unfold new horizons to Vedic studies. The Vedas have lot more to offer and we know just a little fraction of it. We hope to grow this work more and more to open up new hidden passages towards Vedic literature.

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IOSR Journal of Computer Engineering (IOSR-JCE) is UGC approved Journal with Sl. No. 5019, Journal no. 49102.

Tapas Sangiri " Vedic Swara Recognition System: A Move Towards Vedic Chanting." IOSR Journal of Computer Engineering (IOSR-JCE) 20.1 (2018): 01-08.