Developing an Algorithm for Generating a Tabla Accompaniment for Hindustani Music

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***Abstract*—Indian classical music has been a key cornerstone of the Indian identity and its diasporas around the world. Hindustani music has always been played as vocal and instrumental music for festivities and cultural events. It plays a key role in all religious occasions. In many developing countries encompassing the Indian diaspora, there has been a decline in the number of skilled and amateur musicians of instruments such as the Harmonium, Sitar, Tabla and other classical Indian musical instruments. This trend can be easily noticed during religious and cultural events in which there is a lack of musical accompaniment for vocalists. To address this limitation, we have created a low cost tool that can analyze the melodies and rhythm in a song and generate a Tabla accompaniment to it in real time. This system was developed using Fast Fourier Transformation (FFT), onset analysis and autocorrelation to identify the *tempo* (BPM), *taal* (beat cycle length), and *sam* (start of song cycle) from an audio sample at the beginning of the song. A corresponding tabla accompaniment is then generated and played based on the features identified from the song. This approach only requires a mobile phone for capturing the audio and processing the data and a Bluetooth speaker for playing the Tabla accompaniment.**

***Index Terms*—Musical accompaniment, Tabla, Taal, Sam, Tempo**

I. Introduction

The definition of 'Indian classical music' denotes the musical system of the Indian subcontinent. This specific genre of music played in this region plays a vital role in the social, religious and artistic lives of society. A significant portion of the music played in these regions may be classified as vital and functional to everyday life, ranging from festivity to spirituality [1]. Indian music, similar to many other types of Asian classical music, consists predominantly of vocal, string, woodwind, and percussion instruments. All of these subclasses of instruments can be utilized to differing degrees, either as accompaniment to the voice or as an imitation or extension of it [2].

Traditionally, classical Indian music is divided into 2 subgenres: Hindustani (or north Indian) and Carnatic (or south Indian) music. While the styles and harmonic progressions of the two genres of music differ, their percussion elements are similar [3]. One of the main percussion instruments used in classical Indian music overall is the "Tabla" [4].

The tabla can produce a wide range of sounds and tones that are designed to both accompany and play original compositions and pieces. In either case, there must always be a certain "taal" when playing the tabla. Taal, which is continuously expressed through rhythm, is a crucial component of Indian music. Any composition's rhythmic structure is determined by the taal's metric beat cycles and beat subdivisions. It divides a musical piece into regular time intervals and provides a rhythmic framework for musicians to organize their performance [5].

Indian culture and music have spread and thrived among many regions and diasporas. The persistence of Indian culture is most notable in one of the oldest diasporas, the Indo-Caribbean diaspora. Indian culture plays a vital role in Caribbean society. Countless Indian festivals, cultural events and religious ceremonies are celebrated, as well as Indian culture having a strong influence in Caribbean cuisine, fashion and music [6].

In particular, Trinidad and Tobago has a strong Indian cultural heritage [7]. There are many who still compose and play both classical Hindustani music as well as fusions of Indian music, such as "chutney" and "soca" music [8]. Recently, there has been a decline in the number of skilled musicians and players of instruments such as the tabla, harmonium, sitar, dholak, and many more, which are essential sounds for these songs. This is mainly due to the lack of accessibility and affordability in these instruments as most of them are produced in India. Many times in events or performances, there is a lack of instrumental accompaniment to a singer or another instrument [9].

This study aimed to create a tool that could record a song for a brief period and generate an appropriate musical accompaniment. Due to simplicity and personal preference, the tabla was chosen as the accompanying instrument as it is a percussive instrument which is mainly focussed on timing and beat tracking. Prior works in this topic have mainly been on detection of tabla beats and notes of a sample already including a tabla signal/accompaniment. Most of the papers in this specific area use similar MIR (music information retrieval) and signal processing techniques with slight variations to each method.

The study by [5] aimed at detecting and labeling tabla signals in a song. The method involves determining the tempo of the song and then using a standard autocorrelation process and creating an onset detection system to find the beat times. Statistical Markov chain analysis was then used to find the specific notes being played [10]. While [11] used the same techniques for tempo and beat detection. However, it utilized a more advanced mathematical statistical analyses for the note detection. The study by [12] used an onset detection system for detecting tabla stroke/ beat. This system uses signaling techniques of LP (linear prediction), Hilbert envelope (HE), Fourier transforms, and spectral analysis to refine the detection algorithm. There were studies which also implemented machine learning into the beat and taal detection systems using tabla [13], [14]. [15] Employed a similar approach as utilized in the present study for implementing a drum accompaniment system. This study aimed to create a real time western drum-kit accompaniment to an input of music that is absent of percussive elements. The authors' approach to the problem is to decompose the audio signal into pitch, onset, and velocity, which would then be fed into a deep generative model and output a drum-kit overlay to the song. The objectives of the current study are:

1) to find the approximate tempo of the song;
2) to determine the beat cycle length (taal);
3) to determine the start of the beat cycle (sam);
4) to produce and overlay the corresponding tabla loop.

II. Methodology

A. *Definition of Onset envelope*

Onset detection plays a major role in signal processing. An onset represents the time at which a musical note or sound begins. It occurs just before the attack (max amplitude of sound) is heard. Onset strength measures how drastic the initial attack is. Subtle transitions between notes or sounds will exhibit low onset strengths, whereas a strong emphasis or abrupt change between notes demonstrates a high onset strength. Onset and onset strength research is still progressing and new methods of detections are still being found. The main means of onset and onset strength detection is via measuring energy changes, spectral flux, or phase differences [16]. The use of onset envelopes (graphs of onset strength of input signal) was regularly used and vital to this project as it models and relatively indicates points of emphasis in a song, which was used to estimate taal lengths and sam.

B. *Definition of Autocorrelation*

Autocorrelation is a mathematical and statistical function that measures the similarity/correlation of a signal to a delayed copy of itself. This technique is commonly used in signal processing to determine patterns and trends in a signal. It is also widely used in MIR to find musical properties such as tempo, pitch, and in our case, repeating beat cycles [17]. These two key concepts will lay out the following method of detection for each objective

C. *Tempo Detection*

In order to find the tempo of the song, we used the beat track function in the librosa Python library [18]. This function mainly implements a Fast Fourier Transform (FFT) alongside the onset envelope and an autocorrelation function to determine the average beats per minute.

D. *Taal Detection*

In order to find the taal of the song, the input recording/waveform was trimmed, and the harmonic components of the waveform were extracted and used; this will let us focus on the melodic instruments and eliminate some of the noise in the signal. The onset envelope of the signal was then extracted and auto-correlated. Since the composition would have looping melodic notes (raga - the melodic framework of Indian classical music), the corresponding taal can be detected by performing an autocorrelation and measuring at what delayed time a peak occurs.

Since the onset envelope function produces successive pulses and not a consistent waveform, the autocorrelation function will show an overall negative linear trend. To correct this, a median filter was applied to find peaks and make visualization easier. Use of the onset envelope rather than the raw form was due to it being more representative of where a tabla strike should occur, as well as allowing for faster processing time.

From the filtered autocorrelation, we graphically determine where significant peaks occur. To find the peaks, a function from the Scipy library was used. The range of peak detection was also optimized using properties of taals. Most of the commonly used taals in Hindustani music usually range from 6 to 16 beat cycles. This fact was utilised alongside the previously found tempo to make appropriate calculations for the range of peak detection. This restricted range would allow for a more efficient and accurate analysis of the sample. After various time unit conversions, the peaks found should have a beat cycle, and or multiple of the following taals:

TABLE I
Commonly used taals and their beat lengths

Types of Taal	Number of beats
Dadra Taal	4
Rupak Taal	7
Keherwa Taal	8
Jhaptaal	10
Ektaal	12
Teen Taal	16

E. *Sam Detection*

In order to find sam (start/most emphasised note of the beat cycle) we made an onset envelope of the waveform and applied a median filter to it. From this, we simply analysed when the most significant peaks occur, and checked to see the number of beats between each peak. The peak that most closely matched its corresponding taal length (or multiple of) was chosen as sam.

F. Generation of Tabla accompaniment

From all the properties found, we can now create the tabla loop. To make the tabla loop, multiple commonly played notes were recorded and sampled. With these notes (maatras) we can play preset compositions for each taal. The corresponding tabla audio to the song would begin at sam and was evenly spaced according to the calculated tempo. This tabla audio loop was then overlaid on top of the original audio, thus creating a tabla accompaniment.

III. Results and Discussion

The methods listed were implemented in Python using the libraries including librosa, scipy signal, math, matplot, numpy, and sounddevice. The input fed was approximately 40 seconds of looping Hindustani ragas (played on harmonium) for each corresponding taal in the Table I. This would facilitate easier detection due to it being a single instrument and the signals' constant rhythmic nature. All analysis of audio was done at a standard sample rate of 22050 Hz and a hop length of 512 milliseconds.

The results showed accurate detections for several taals; however, some taals had less accurate or incorrect deductions. For each raga (corresponding taal) analysed, graphs for taal detection and sam detection were made, along with tables of results.

TABLE II
Tempo and Taal detection results

Taal input	Tempo detected (BPM)	True tempo (BPM)	Taal length detected (beats)	True taal length (beats)
Dadra taal	75.9	80	7, 11, 16	6
Rupak taal	78.3	80	7. 14.	7
Keherwa taal	99.4	100	8. 16	8
Jhaptaal	86.1	80	6. 11. 15	10
Ektaal	80.7	80	12	12
Teen taal	75.9	80	8. 15.	16

From the graphs and results shown above, all of the data necessary for the tabla accompaniment (tepmo, taal, sam) were relatively accurate. The tempo extracted was at most +/- 5BPM off with the taal length detected having an error of +/- 1 beat (Table II). The sam detected was also relatively accurate with some taals (Rupak, Keherwa and Ektaal) having good accuracy while others did not have it to the same degree.

The main limitation of this method is the sam detection. Analysing peaks in the onset envelope proved to be unreliable for finding the exact sam point of a song in an efficient and

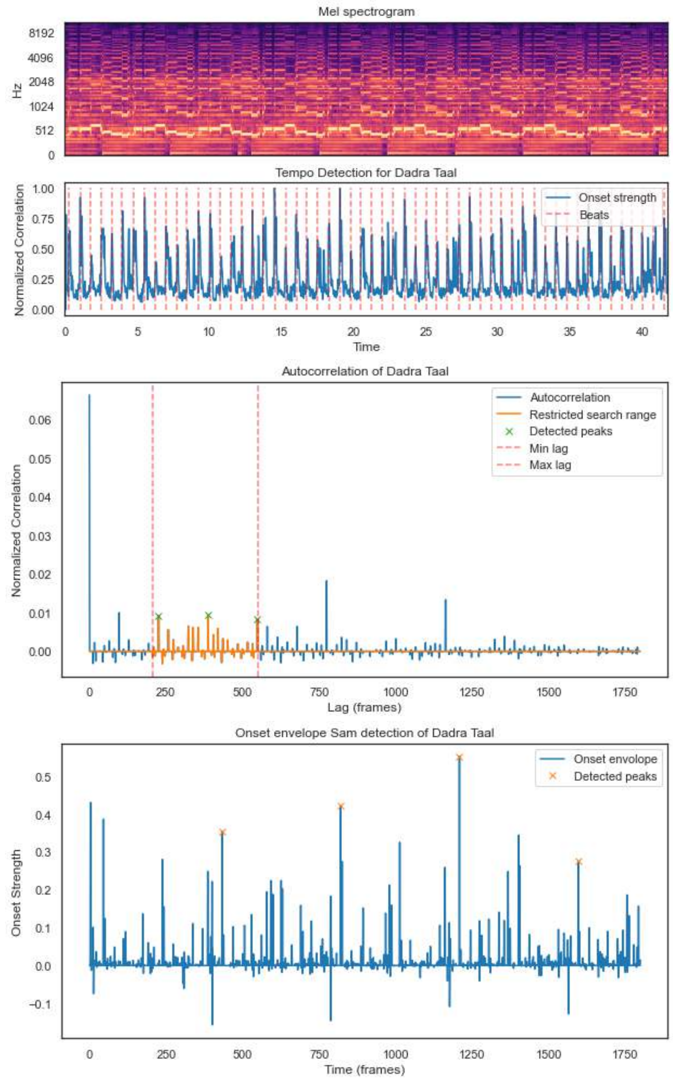

Fig. 1. Dadra Taal: Tempo Detection, Taal Detection and Sam detection

TABLE III
Sam detection results

Taal input	No. of potential Sam points detected	No. relatively accurate Sam points	Overall accuracy
Dadra taal	4	1	Inaccurate
Rupak taal	5	4	Very accurate
Keherwa taal	6	3	Accurate
Jhap taal	5	2	Inaccurate
Ektaal	5	3	Accurate
Teen taal	4	1	Inaccurate

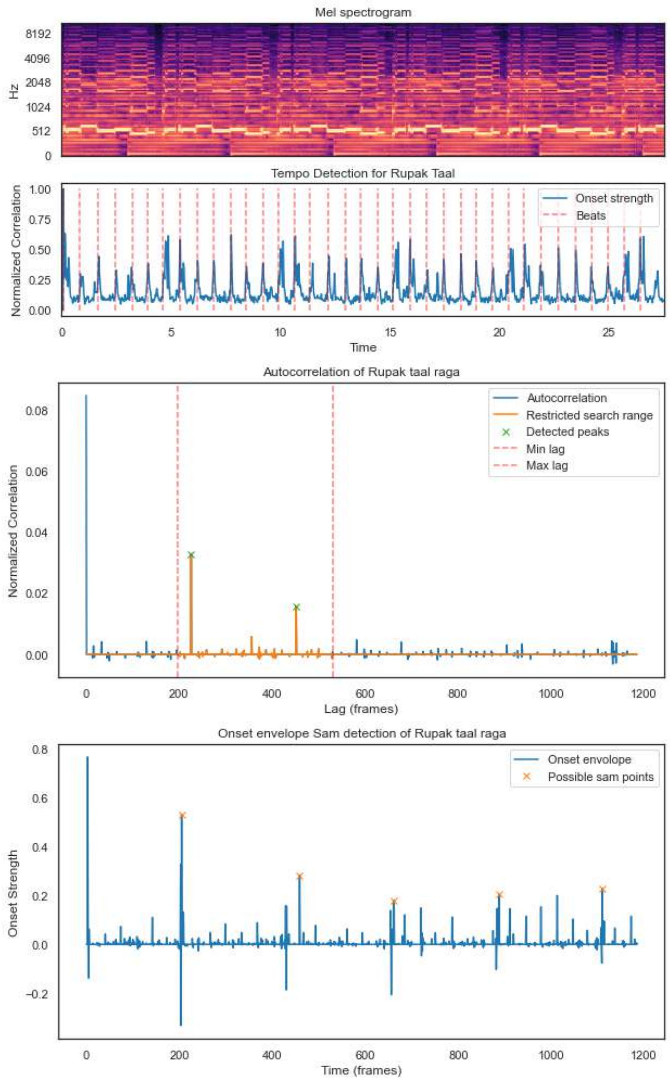

Fig. 2. Rupak Taal: Tempo Detection, Taal Detection and Sam detection

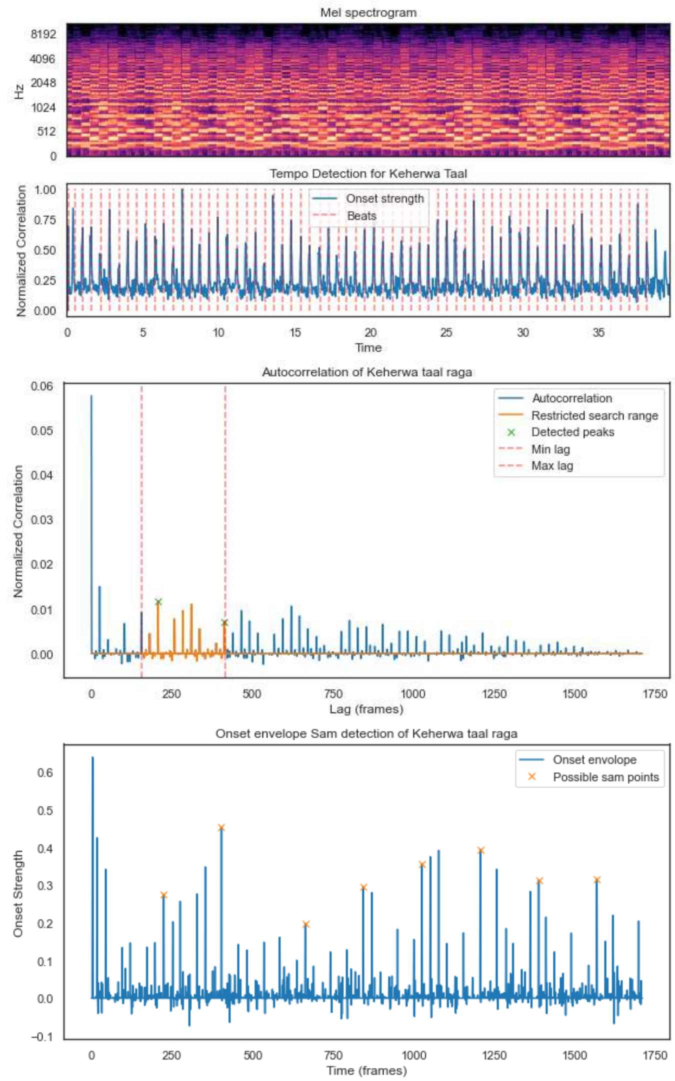

Fig. 3. Keherwa Taal: Tempo Detection, Taal Detection and Sam detection

timely manner. Out of every sam point detected in each taal, at least one of them matched up with the true sam points (Table III). However, due to this unreliability, it was very difficult to algorithmically detect which sam was most accurate rather than selecting one manually. The accurate sam points chosen all had no more than a 50 ms delay.

The main issue seen when examining the locations of the potential sam points was the detection of secondary emphasis points in the song. Every taal has a set number of subdivisions of notes (vibhag); for example, Teen taal is subdivided into 4 sets of 4 beats. In addition, there are at least 2 emphasis points (the main 2 emphasis points having a notation of 'Thali' and "Khali') in every taal, where there is a significant note change in the taal's sound.

Depending on the specific raga played, there may be more or similar emphasis on these secondary notes when compared to the raga's sam. This was the main cause of error observed in the sam points detected (especially for Jhapt and Keherwa taal). In addition to this, ragas played may not have a clear hard-emphasising note to indicate the sam, with transitions between taal loops being subtle.

Another common issue seen in the sam detection was the amount of false (non-sam) peaks present in the onset envelope. As previously mentioned, onset detection is usually used to detect the start of a note.

In the earlier research reports [5], [11]–[14], all used an input song with already included tabla waves for taal and tabla stroke analysis. When comparing the onset envolpes from these reports to ours, there are significantly more pulses and similar peaks in detection in some of our results (Fig. 1, 3, 4) . This is due to the onsets being more easily detected and having much higher peaks at more percussive elements in a signal. Since in our method, the onsets will only detect the pressing/intensity of a key, the exact sam point will have only

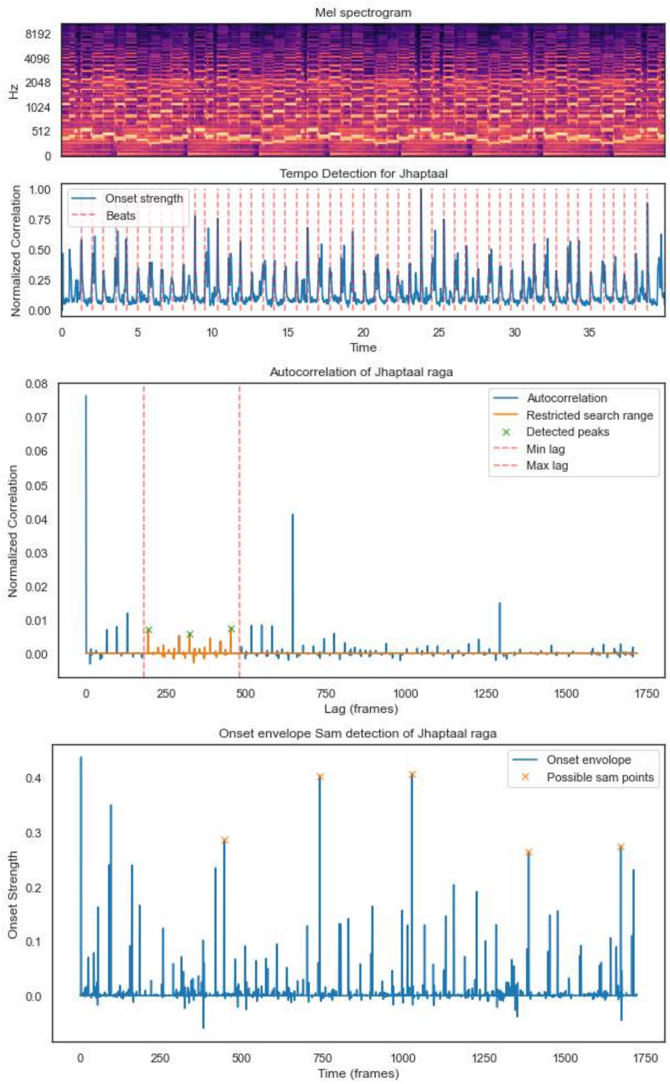

Fig. 4. Jhaptaal: Tempo Detection, Taal Detection and Sam detection

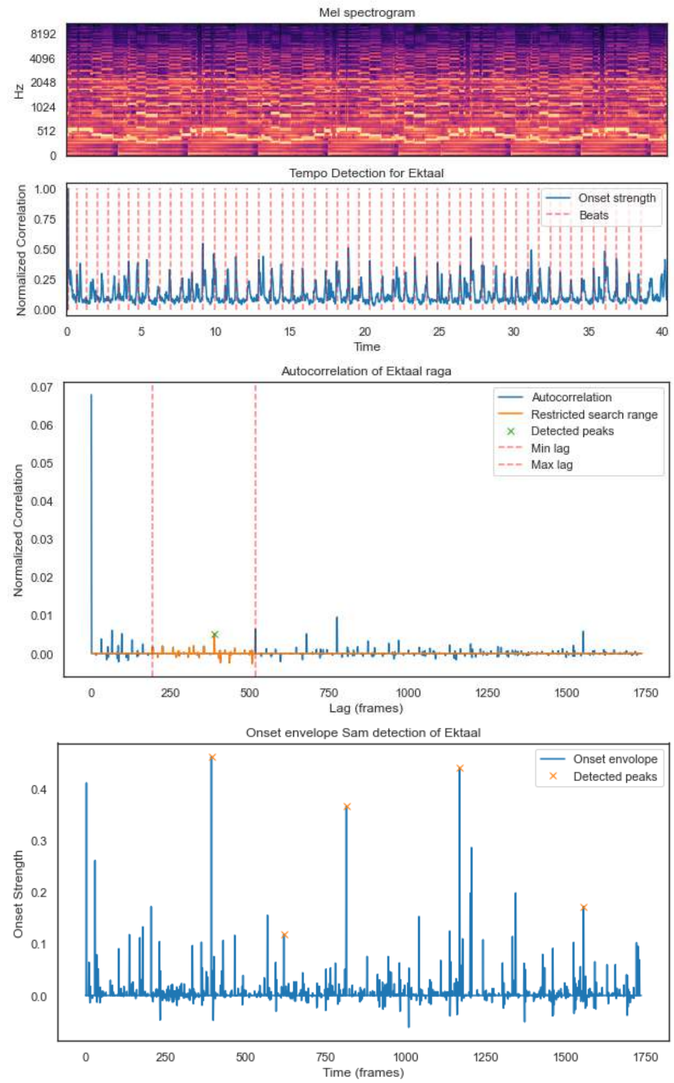

Fig. 5. Ektaal: Tempo Detection, Taal Detection and Sam detection

a slighter peak than the rest of the notes, which can lead to several false detections. To add onto this, slight variations in the raga being played can cause false sam points to be detected.

The taal and tempo detection systems were mostly very accurate. Inaccuracy in the detection system were due to limitations in accuracy for tempo detection as well as distinguishing between similar emphasis points. Since tempo is required to identify the taal being played, the observed small inconsistencies in tempo detection had a correlating effect on the taal detection.

In most cases, the taal length detected was approximately 1 beat off. For example as seen in Table II, Dadra taal was detected as 7 beats instead of 6; Jhaptaal- 11 instead of 10 beats, and Teen taal- 15 instead of 16 beats.

Depending on the raga played, emphasis points in a taal can sound similar in nature, causing a false detection in the autocorrelation. A prime candidate for this effect were Dadra, Jhap, and Teen taal. Dadra taal (Table I) has a secondary emphasis on the 3rd beat, Jhaptaal (Table I) on the 6th beat, and Teen taal (Table I) on the 9th.

The results of this can be directly seen from the data, with Dadra taal having approximately 3 and 6 beat intervals (+/- 1 beat because of tempo error) between each detected taal length. Jhaptaal has roughly a 5-beat interval between taal detections, with Teen taal having an 8-beat interval.

However, not all the taals listed had this as a major flaw. By analysing the size of peaks (such as Teen taal), we can observe that, depending on the raga played, the similar sounding emphasis points may have a lower peak when compared to the Sam point (Fig. 6, Table II). Although this cannot be said for all taals, all of the tonally similar emphasis points had relatively the same peak lengths.

Another discovery from the analysis of peaks by this method

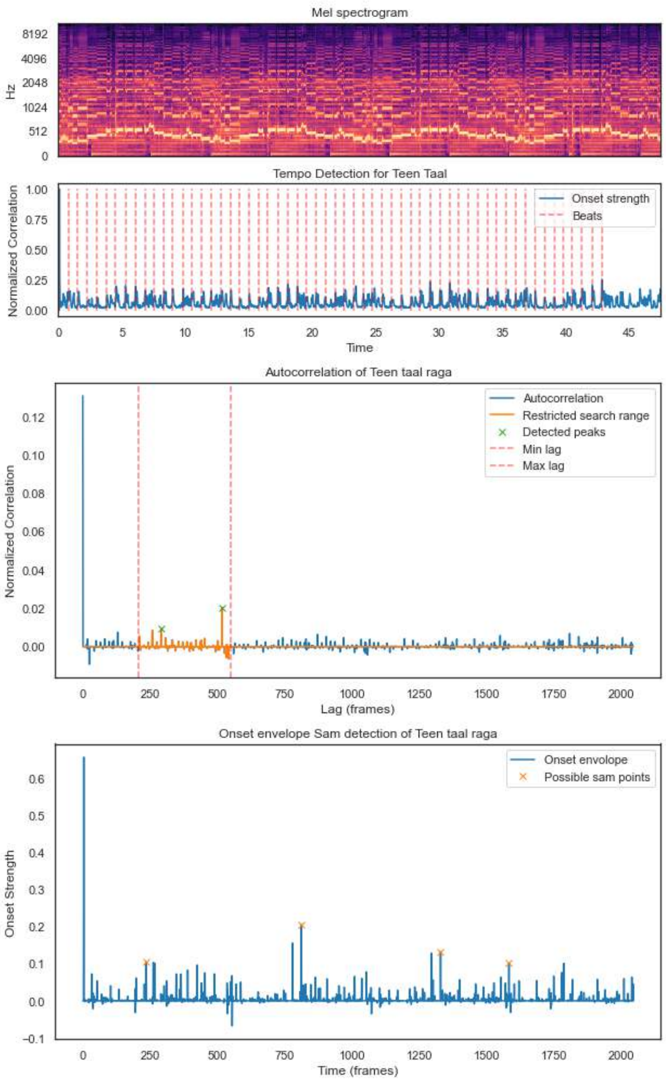

Fig. 6. Teen taal: Tempo Detection, Taal Detection and Sam detection

was that it can distinguish taals that are multiples of each other. Due to the diminishing nature of the autocorrelation of the onset envelope, multiples of the taal's length will have a minor peak. A prime example of this was the differentiation between Kaherwa taal and Teen taal. Kaherwa taal had a major peak at the 8th beat and a minor peak at the 16th beat (Fig. 3)(Table II), while Teen taal had a minor peak at the 8th beat and a major peak on the 16th beat (Fig. 6)(Table II).

IV. Conclusion

The tempo detection system used was accurate, with a minor offset in the value calculated. The autocorrelation method to detect the taal showed to be very precise and accurate at detecting taals when fed the appropriate ragas. However, the sam detection system showed to be less accurate due to the number of inaccurate readings resulting from the detection of peaks on the onset envelope. For future methods of analysis of harmonic signals and generation of a tabla accompaniment, a more advanced onset envelope and detection system (with multiple parameters) can be used. Futhermore, an entirely different element of the song can be analysed. This is especially true for the sam detection employed in this project. Overall, the use of more filters and selection of appropriate parameters should also be put in place to ensure that both the tempo and taal can be detected more easily, irrespective of the specific raga inputted. With necessary upgrades, this method could be a good accompaniment for classical Hindustani music songs and concerts under limitations including lack of musical instruments and artists. This system will serve as a tool for music analysis and research for quality components of the overall composition. The system developed can be integrated with machine learning and further signal processing for more efficient and accurate accompaniments for compositions.

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