Experimental investigations of tānpurā acoustics

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Summary

High-speed video camera recordings are used to observe dynamics of an actual tānpurā string. The temporal evolution of the frequency spectrum is obtained by measuring the nut force during the string vibration. The characteristic sonorous sound of tānpurā is attributed to not only the presence of a large number of overtones but also to the dominance of certain harmonics over the fundamental, the latter manifesting itself as a certain cascading effect. The nature of sound is shown to be strongly dependent on the initial plucking amplitude of the string. The stability of the in-plane vertical motion of the string is also emphasised.

1 Introduction

Tānpurā (or tambūrā) is an unfretted long-necked lute, with four strings, used exclusively for providing the drone in Indian classical music. The purpose of drone is to establish a firm harmonic basis for a musical performance by constantly playing a particular note or a set of notes. The sound of a well tuned tānpurā, and hence the resulting drone, is remarkably rich in overtones and creates a pleasant "melodic background" for the performance [1, 2]. The tānpurā drone is widely recognized for enhancing the musicality of the rāga being played by constantly reinstating the notes which form the essence of the rāga [3]. The distinctiveness of tānpurā's sound is due to the unique manner in which the strings interact with the soundboard [1, 4]. The strings pass over a doubly-curved bridge of finite width before reaching the board, see Figure 1, as is the case with other Indian string instruments such as sitār and rudra vīṇā [4]. The curved bridge provides a unilateral constraint to the vibrating string and, in doing so, becomes the source for an overtone rich sound of the musical instrument [5, 6]. The characteristic feature of tānpurā is however the cotton threads, known as jīvā (meaning the "soul"), which are inserted below the strings on the bridge, see Figure 1. The correct placement of jīvā, essential for obtaining the required drone from a tānpurā, is when the string makes a grazing contact with the bridge before going over the neck of the instrument [1, 4], as shown in the bottom-most picture in the right side of Figure 1. The purpose of this brief note is to present certain experimental results which elucidate the nature of tānpurā sound while emphasizing the role of jīvā.

We use high-speed video camera recordings of the vibration of a single tānpurā string to capture the string motion close to the bridge and at the nut (see the videos provided as supplementary material). The latter is used to measure the nut force and to subsequently plot 3-dimensional spectrograms. The previous tānpurā experimental measurements were based either on the audio signals [7, 8] or the sensors placed between the string and the nut [9]. Our experimental setup provides a novel visualisation of string–jīvā–bridge interaction in an actual tānpurā and can be used to further the scientific study of the musical instrument. In the present paper, we use the nut force measurements to establish a cascading effect of energy transfer between lower and higher overtones, resulting in a strong presence of certain overtones, as

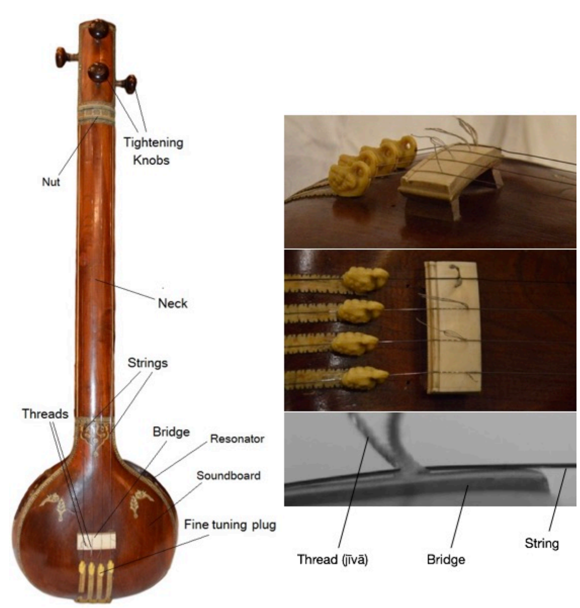


Figure 1: (Colour online) A typical mirāj style tānpurā (left); (right top to bottom) side view of the bridge with jīvā, top view, close side view of the bridge with one string and jīvā.

a distinguished feature of the tānpurā's overtone rich sound. In the absence of jīvā, the overtones decay faster, the fundamental remains the dominant frequency, and there is no cascading effect. The observed richness of overtones, their slow decay, and the energy cascade effect are in fact confirmation of the findings in previous experimental [8, 9] and numerical [10, 11, 12, 13, 14, 15] work on tānpurā.

We demonstrate the dependence of tānpurā's sound, as evident from the spectrograms, on the initial plucking amplitude of the tānpurā string. We show that the effect of jīvā in producing a desirable sound is lost for high plucking amplitudes, as is expected from the actual practise of tānpurā playing. We also establish that an arbitrary (out-of-plane) initial pluck of the string eventually stabilises into an in-plane vertical motion. None of the previous works have discussed the effect of initial plucking amplitude and the stability of the in-plane vertical motion of the string.

2 Experimental results

The experimental setup consisted of a tānpurā, with all but one string removed, two supports, to firmly hold the instrument, a high-speed camera, and DC light sources. The string was plucked at the center using the index finger as is done in actual tānpurā playing. In doing so, the string experiences an initial vertical (in-plane) displacement of around 0.5 cm and a horizontal (out-of-plane) displacement of around 0.2 cm. The tension in the string was measured by hanging a mass at the center of the string, observing the angle between the string on either side of the mass, and using the principle of static equilibrium. The string was consistently tuned to F-sharp (using an electronic tānpurā drone), having a fundamental frequency of around 92.8 Hz. The high-speed camera was triggered manually and was adjusted to capture 10000 fps. The nut force was calculated as the vertical component of the string tension at the nut using the estimated tension value and the observed slope of the string at the nut. The temporal evolution of the nut force (normalized with respect to string tension) is shown in Figure 2. One can clearly observe a high-frequency precursive wave, as reported earlier by Valette [9, 16]. The presence of precursive wave validates the role of dispersion in tānpurā string vibration and hence of incorporating bending rigidity even for small vibration amplitudes. A video capture of the string motion close to the nut is provided as a supplement (video1.gif). The data was acquired from the video experiments using MATLAB's (version 9.0, R2016) inbuilt image processing toolbox. The frequency evolution of the nut force was plotted using the `spectrogram` function, where the sampling frequency was taken to be the same as in the video experiments.

We begin by comparing the spectrograms obtained with and without the jīvā. The 3-dimensional spectrograms are shown in Figure 3. The presence of jīvā, when positioned appropriately, not only brings out a richer set of overtones but is clearly marked by a definite change in the pattern of how overtones evolve over time as well as how they interact with each other. The interaction among overtones is clearer in Figure 4 where the three important signatures of tānpurā sound are distinctively visible. First, there is a characteristic reoccurring pattern of energy transfer leading to a cascading effect with higher overtones giving way to immediately lower overtones. A cartoon of the effect is illustrated in Figure 5, where the curves in green, red, violet, and blue represent the nth, (n+1)th, (n+2)th, and (n+3)th overtones, respectively, for $n \geq 3$. Second, in the presence of jīvā,

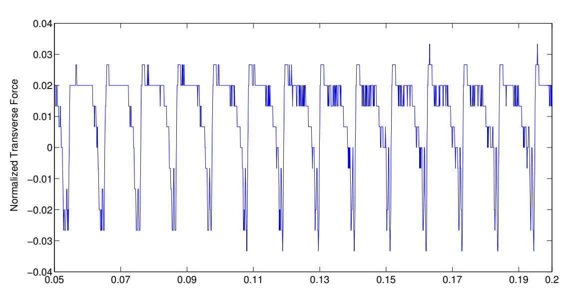
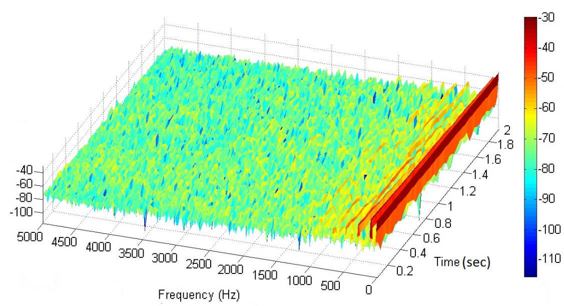
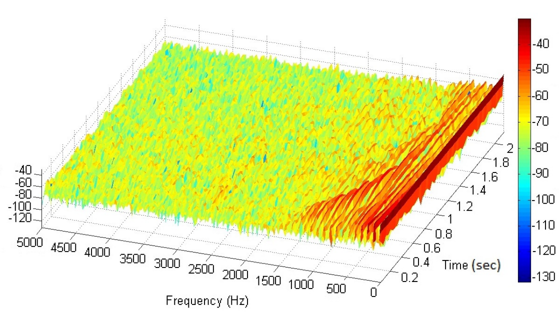


Figure 2: Evolution of nut force, normalized with respect to string tension.



(a)

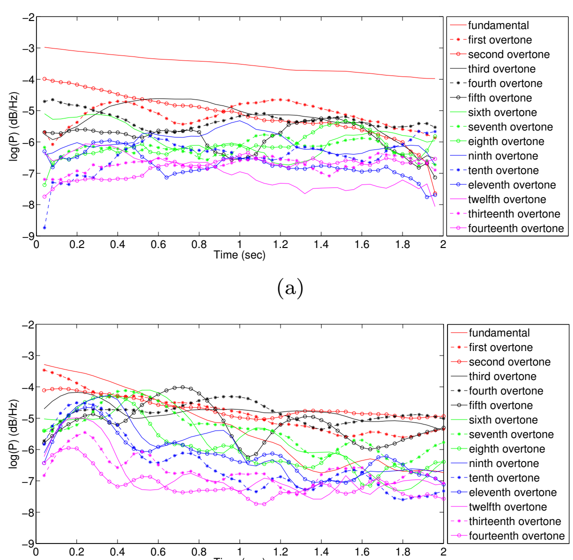


(b)

Figure 3: (Colour online) 3-dimensional nut force spectrograms (a) without and (b) with the jīvā.

the fundamental decays faster than many of the overtones so much so that it is completely overshadowed after a short initial span of time. This is in contrast to the situation without jīvā where the fundamental remains the dominant frequency and the contribution of the higher overtones remains low in comparison. The coupling of various modes, and therefore of the overtones, is also present in this case due to the wrapping/unwrapping motion of the string on the bridge [5, 6]. With jīvā, the interaction of the string with the bridge becomes more complex as it leads to a more impactful collision of the string on the bridge. This is clearly visible in the video recordings, provided as supplementary files, of the string interacting with the bridge in both the cases (see video2.gif and video3.gif). Third, the presence of jīvā clearly slows down the decay of overtones thereby adding to the richness of tānpurā sound. Finally, we report the psd evolution as obtained from the numerical simulation based on the recently proposed penalty based models [10, 11, 12, 13, 14, 15], see Figure 6 (the details of the numerical model and the choice of parameters can be found is a recent thesis [17]). The numerical model is clearly able to capture the cascading effect, the dominance over the fundamental, as well as the slow decay of the overtones.

The tānpurā drone is very sensitive to the initial plucking amplitude of the string. In fact, it is commonly said among the musicians that a tānpurā should be played such that the strings should not know that they have been plucked. To support this argument, we obtain spectrograms when the plucking amplitude is 2.5 cm (Figure 7(a)) and 1 cm (Figure 7(b)), in comparison to 0.5 cm used to generate the plot in Figure 4(b). The higher plucking ampli-



(a)

(b)

Figure 4: (Colour online) Evolution of power spectral density (psd) for various overtones in the nut force spectrogram (a) without and (b) with the jīvā.

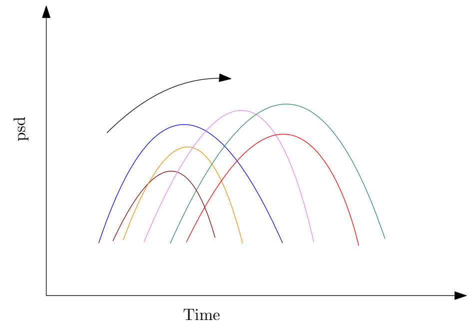


Figure 5: (Colour online) A cartoon of the reoccurring pattern in the evolution of psd for various overtones of a tānpurā string.

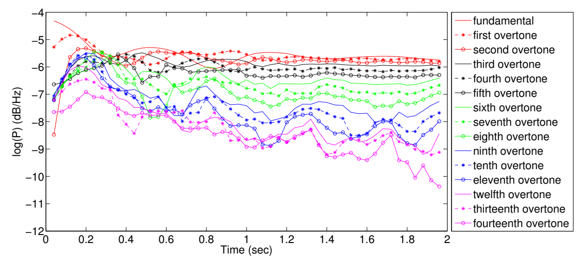
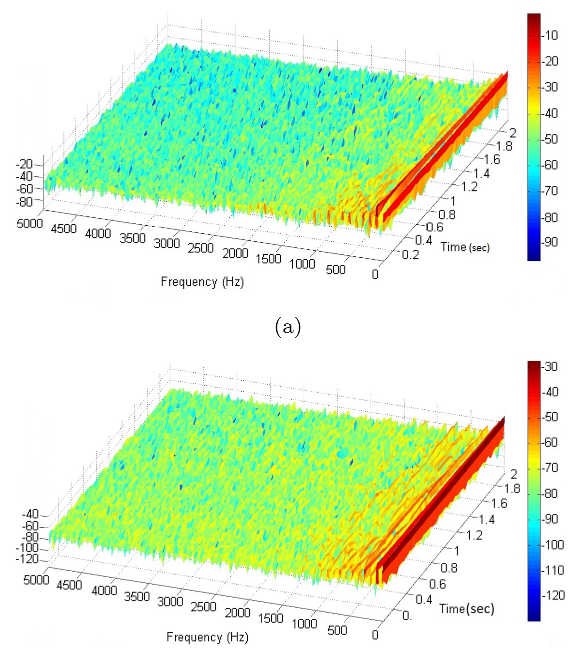


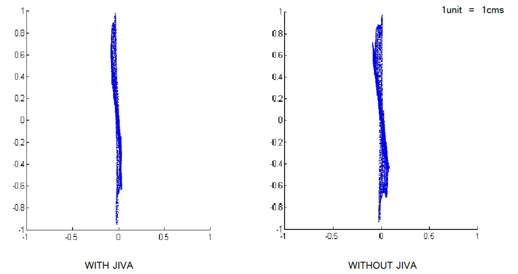
Figure 6: (Colour online) Numerical simulation of psd evolution for various overtones with the jīvā using a penalty based model.



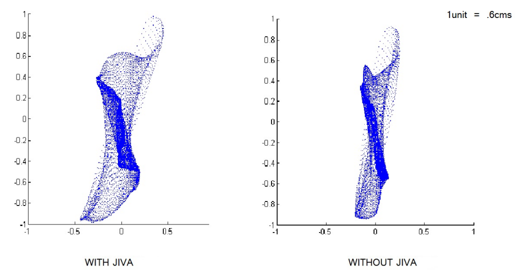
(a)

(b)

Figure 7: (Colour online) 3-dimensional nut force spectrograms with initial plucking amplitudes of (a) 2.5 cm and (b) 1 cm.



(a)



(b)

Figure 8: Out-of-plane motion of the tānpurā string, with and without jīvā, for (a) an in-plane initial plucking and (b) an out-of-plane initial plucking of the string.

tudes are given by pulling the string vertically at the center using a thread and then burning the thread. The desired pattern, and hence the desired drone, disappears as the amplitude goes above 0.5 cm. We have observed this conclusion to remain valid for different plucking positions on the string.

Finally, we present some results on the out-of-plane motion of the tānpurā string. The camera is now placed in the direction of the wire and a fixed point on the string is marked and then tracked during the vibratory motion. Figure 8(a) plots the locus of the point when the initial pluck is an in-plane triangle with a peak amplitude of 1 cm. Figure 8(b) plots the locus of the point when the initial pluck is as given in the actual playing of the instrument. In all the cases we note that the in-plane (vertical) motion of the string is stable with the point on the string eventually coming back to the vertical plane. The presence of jīvā has no noticeable effect on the stability of the string. Our conclusion remains valid even when we varied the plucking position on the string.

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Supplementary material

(i) video1.gif: string motion close to the nut.
(ii) video2.gif: string motion close to the bridge without jīvā.
(iii) video3.gif: string motion close to the bridge with jīvā.

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