# NUMERICAL AND EXPERIMENTAL MODAL ANALYSIS OF THE SETAR

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## 1. INTRODUCTION

Stringed musical instruments are complex vibrating systems from both the structural and the fluid-structure coupling perspective. The direct sound of the strings is a minor component of the sound output, with most of the radiated sound generated by the body and cavity of the instrument [1]. In fact, the whole instrument acts as a filter, which converts the excitation force of the strings to sound, and radiates it [2]. In this regard, the modal properties of the body and cavity are the key feature that defines the physical properties of the instrument [3].

In this study, the Persian setar is chosen as the test case, and its numerical and experimental modal analyses are described. After a brief introduction to the setar, the creation of its finite element model is described. The results of the finite element model are then compared with the experimental findings. The excellent agreement between the numerical and experimental results verifies the validity and accuracy of the numerical model. This verified numerical model serves as a platform for future studies on the setar, such as its virtual modification.

A detailed report of this work has been submitted for publication elsewhere (Mansour, 2011).

## 2. SETAR, A LONG-NECKED LUTE

The origin of the setar can be traced to the ancient Tanbour of pre-Islamic Persia. The Setar has four strings normally tuned at C4 (262 Hz), G3 (196 Hz), C4 (262 Hz), and C3 (131 Hz), respectively. The setar is used mainly to play Persian classical music, called Dastgah. This instrument is played with the tip of the index fingernail, by strumming up and down. Its fingerboard usually has twenty-five adjustable gut frets, which provide the fundamental frequency range of 131 Hz to 831 Hz (two and a half octaves). Although each string can be played individually, melodies are usually played on the first two strings while the other strings provide drones.

## 3. APPARATUS AND METHOD

An impact hammer (LDS® model 5200-B2 with metal tip) is used to excite the body, and the resultant velocity is measured by Laser Doppler Vibrometer (Bruel & Kjaer® LDV Type 8337). The recommended operating ranges of the impulse hammer and LDV are 2.5 KHz and 22 KHz, respectively. The experimental set up, including contactless LDV and impulse hammer, guarantees there will be no disturbance on the structure. The setar was clamped by its neck in a stiff vise.

The excitation is imposed on a fixed point on the apex of the bridge, beside the notch where the first C4 string is passing, and the response is measured at 60 points all over the soundboard. The choice of the excitation point ensured that all prominent modes in the working condition of setar are properly excited. The strings were damped by three rubber bands to eliminate their sound/vibration and to keep their preload on the structure.

The PHOTON II® data acquisition unit gathered the data, and RT Photon® V.6.33 software was used to calculate the Frequency Response Functions (FRFs). Later, the FRFs were fed to ME'scope® commercial software to extract the modal properties, including the natural frequencies, dampings, and mode shapes.

A finite element model of a setar was developed in MSC/NASTRAN taking into account structural details such as orthotropic properties, direction of the grains, non-ideal joints, and the effect of strings preload. The geometry has been precisely measured by a Coordinate-Measuring Machine (CMM), imported into CATIA, and meshed in Altair Hypermesh® environment. The orthotropic material properties and thicknesses have been defined separately for different components of the instrument. For consistency, the same fixed boundary condition of our experiments is applied to the finite element model.

## 4. RESULTS

The finite element model is solved, and the results are compared with the experimental data up to 2.5 KHz, as illustrated in Figure 1. The criteria in comparing the results are natural frequencies and mode shapes. The SB($m$,$n$) system is used to name different modes, where $m$ represents the number of longitudinal half-waves on the soundboard, and $n$ stands for the number of transverse half-waves. The two last HF modes are named differently as they are more complicated and do not follow the SB($m$,$n$) form. R(2) is also a radial mode and can be considered as the high frequency version of the SB(1,1).

Damping is not considered in the numerical model; therefore, the calculated modes are all normal and real. It is noteworthy that the mode shapes are not necessarily symmetric, because the soundboard does not have the exact same thicknesses on both sides.)

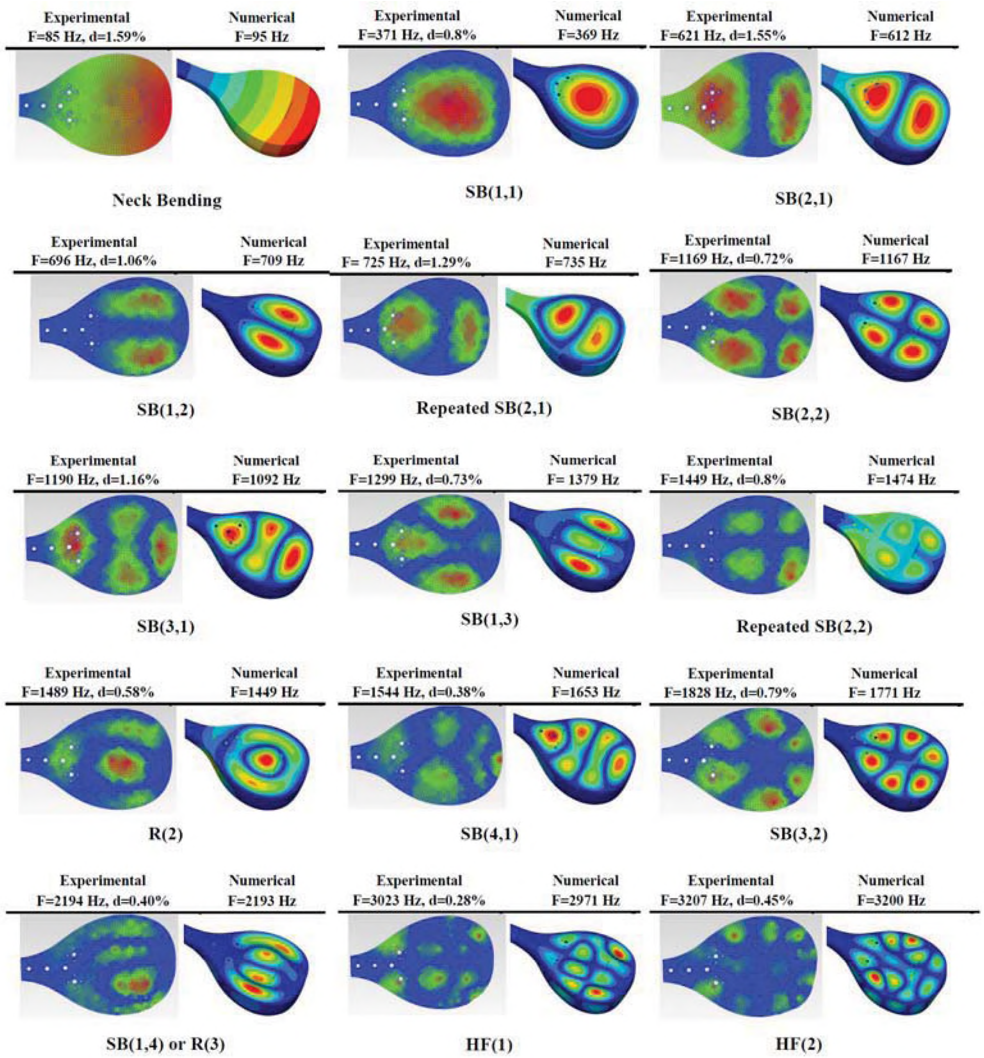


**Figure 1: Modes shapes and natural frequencies of the soundboard obtained from the experimental and numerical results, compared together. The setar was clamped by its neck**

## 5. DISCUSSION

A comparison of the first thirteen structural modes shows a good match between the numerical and experimental results. The frequency range of study is shown to be expandable to higher modes according to the results of two higher-frequency modes. The broad range of agreement between the numerical and experimental results is noticeable. The soundboard is found to be the sole resonator in all modes below 2.5 Hz, with the exception of SB(2,2) and R(2) where the bowl throat makes a minor contribution. The numerical model can be used to find the key structural parameters making the most significant effect on each mode. The results of this study can lead to more insightful structural modifications of the setar and yield better-quality instruments. In addition, the validated numerical model serves as a platform for future studies of the setar. Finally, most of the techniques used in this study can be applied to other stringed musical instruments, as well.

## REFERENCES

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