Bulletin of the *Transilvania* University of Brasov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 15(64) No. 2 – 2022
https://doi.org/10.31926/but.fwiafe.2022.15.64.2.7

# USE OF SCANNING LASER TECHNOLOGY TO OBTAIN THE ERHU VIBROACOUSTIC

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**Abstract:** *The aim of this research is to develop and validate an experimental model testing method of the erhu instrument. The model analysis is applied to investigate the dynamic behavior of materials, which results in the relationships between excited shape and its structure. There are three major factors which would directly affect the performance of erhu vibroacoustics: (1) the string, (2) the vibrating membrane, and (3) the wooden soundbox. However, the transducer mass effect is the significant impact factor in the membrane vibration measurement. Attention is focused on the erhu membrane vibration modes by using the scanning laser method. The method for experimental mode shapes of the erhu membrane was notable in that the equipment assembled a loudspeaker, a signal point laser, and a scanning laser vibrometer. Depending on the white noise, the mode shapes can be excited with plane acoustic waves to push on the membrane surface. The scanning laser method consists in two types of laser doppler vibrometer for various purposes. The single point laser measured the driving point vibration as the reference in the center of the membrane surface. The responses were measured by the scanning laser vibrometer with 276 measuring points on the surface. The results showed the vibroacoustics of the erhu membrane and the various mode shapes that are dependent on the frequency diversifications. The mode shapes of the erhu membrane can be classified into five vibroacoustic patterns according to various frequency ranges (20 to 5,000 Hz). Obviously, the scanning laser method is a convenient and readily reproducible setup to evaluate erhu vibroacoustic properties. As an engineering application, the proposed method can serve as a fundamental tool when predicting or even suppressing the possible excitations associated with vibration modes in the mechanical designs of instruments.*

**Key words:** *Erhu, vibroacoustics, operational modal testing, scanning laser.*

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## 1. Introduction

The erhu is a two-stringed bowed music instrument which could be used as a solo instrument as well as in small ensembles and large orchestras. The erhu has some particular features in the sound which is produced through the vibration of string, the wooden soundbox, and the python membrane. In fact, Python skin represents the anisotropy structural features with their respective mechanical properties [11] (Figure 1).


Fig. 1. *The anisotropy of python skin is graded according to species, age, location, growth conditions etc.*

The membrane transforms the string vibration into the soundbox so that its vibrations are very significant for the sound characteristics of the instrument. Therefore, the string, the wood, and the python membrane are important materials for making the vibrational characteristics of erhus. Previous research [12] on the erhu focused on the vibration properties of the wood materials. As shown in Figure 2, the main element of the erhu is a long vertical wooden stick at the top of which are two tuning pegs and a thin membrane (Python membrane) that is glued to the front end of the wooden soundbox. However, the characteristic of the membrane is that the lateral elasticity is greater than the longitudinal elasticity, and its thickness matches the frequency of the soundbox. Therefore, the tension value of the transverse film is established first, and the longitudinal tension value of the film is established to ensure that the tension value is not generated due to the elasticity of the film. Then two strings are attached from the pegs to the soundbox base, and a small loop of string is placed around the neck and strings acting as a nut pulling the strings towards the membrane, holding a small wooden bridge in the center.

Similarly to most string instruments, the vibrating string of the erhu transfers its vibrational energy to a solid structure or sounding board that radiates more efficiently than the string itself [5, 6]. The vibrational behavior of the structure is often quite complicated [9]. According to previous analysis, the accelerometer in the instrument vibration property measurements was widely used [3]. However, the transducer mass effects are a significant impact factor in the vibration measurement. Notably, there are few reports which have studied the membrane vibroacoustics of the erhu [4].


Fig. 2. *The configuration diagram of the erhu*

A modal shape represents the motion of the erhu in a normal mode of vibration. The modal testing parameter can be determined from a set of frequency response measurements between a reference point and the number of measurement points on the structure [1]. The modal frequencies, damping, and the mode shape can be found from all frequency response measurements on the structure [13]. The optical methods include holographic interferometry, speckle-pattern interferometry, and scanning laser vibrometry in musical instruments [2, 10]. In experimental modal testing, the scanning laser measures the response of the erhu membrane at the surface points to construct frequency response. The effects in the membrane parameters are based on the established growth direction, thickness, and tension indices. The length, diameter, and location of the erhu have a specific impact on the indices. Furthermore, the membrane of the erhu can be adjusted according to needs. Within the noncontact of the scanning laser method, this research has found the significant vibration model of the erhu membrane. This established method can be used for understanding the effects of the assorted parameters of the erhu on the acoustic quality and for further improving this instrument.

## 2. Materials and Methods

### 2.1. The Erhu Instrument

The erhu consists of a long vertical stick, two large tuning pegs on the top, and a hexagonal wooden resonator soundbox (L = 132mm, W = 53mm) at the bottom which is covered by python membrane (0.5-0.6mm thickness, 93.53 $cm^2$ surface area). The tension of the membrane is around 330-430 pounds. Two strings are attached from the pegs to the base, and a small loop of string is placed around the neck and strings acting as a nut pulling the strings towards the membrane, holding a small wooden bridge in the center. The dynamic range of the erhu is usually between 10 ~ 15dB. The frequency range covers three and a half octaves, from D4 up to A7 (293 to 3,520 Hz).

### 2.2. Experimental Setup

Figure 3 shows the testing system which was developed into measuring the acoustic properties of the erhu. The setup consists of the hinged and suspended instrument that was excited acoustically via loudspeaker. The excitation of the loudspeaker (Bruel & Kjær 4206) is an exponential white noise of 20-5,000 Hz and all modes and frequency could be excited. The generated wave form of the loudspeaker was plane acoustic wave so that the input force corresponded to the equal distribution on the membrane. The scanning laser vibration detector was positioned at the membrane side. The vibration of the membrane was measured using two types of lasers. One is the signal point laser (PDV-100, Polytech) which measured the vibration of the bridge as the reference point. The other is the scanning laser vibrometer (PSV-400, Polytech) which was put in front of the erhu (Figure 3).

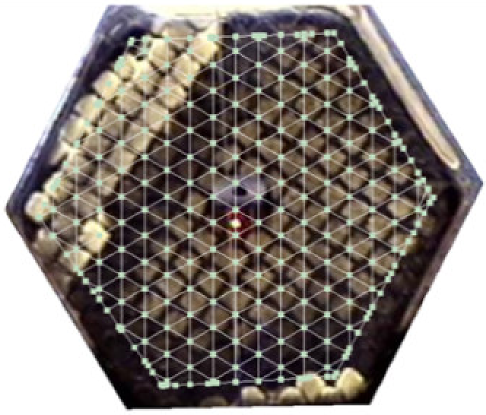


Fig. 4. *The scanning laser vibrometer measured the erhu membrane from 276 data points across the membrane surface*

The sampling frequency and sensitivity of the laser vibrometer were 12.8 kHz and 10 mm/s/V, respectively. The vibration tests selected the frequency span of each measurement to be 0-5,000 Hz. The resolution of FFT was 1.56 Hz with 3,200 FFT lines. The total duration of each measurement test setup was 30mins (10 liner average for each point). All the data was recorded with a scanning laser vibrometer from 276 data points across the resonator surface (Figure 4). The collected signals were transferred into the Polytec scanning vibrometer version 8.82 using the modal analysis.

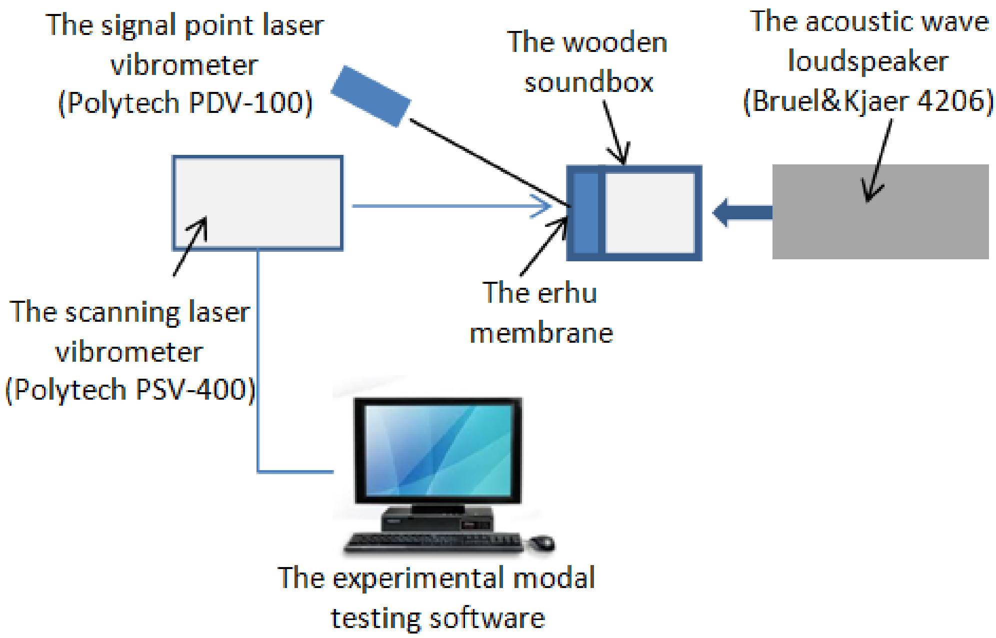



Fig. 3. *Schematic of the scanning laser system for measuring the experimental modal analysis of the erhu*

**3. Results**

The scanning laser method was built to evaluate the method and it was presented for detecting and manipulating the acoustic behavior of the erhu instrument. The experimental modal method was used to generate the perpendicular acoustic wave and measure the response vibration of the erhu membrane. The modal analysis relies on a modal parameter estimation (curve fitting) technique to obtain modal parameters from the FRF (frequency response function) (Figure 5). Selecting the FRF estimator (H – Eq. (1)) [7]:


Fig. 5. *G* represents the FRF between input *x* and output *f*

$$H = \frac{G_{XF}}{G_{XX}} \quad (1)$$

The FRF is the cross power spectrum (*G*) of the input (x) and output (*F*), where $G_{XF}$ is the average cross spectrum between response and excitation, and $G_{xx}$ is the autospectrum of the excitation.

Curve fitting is a process of matching a mathematical expression to a set of experimental points by minimizing the squared error between the analytical function and the measured data [8]. Figure 6 shows the scanning laser methods used to examine the behavior of various vibroacoustics, how the materials, structure, and process influence the acoustic behavior of the erhu.

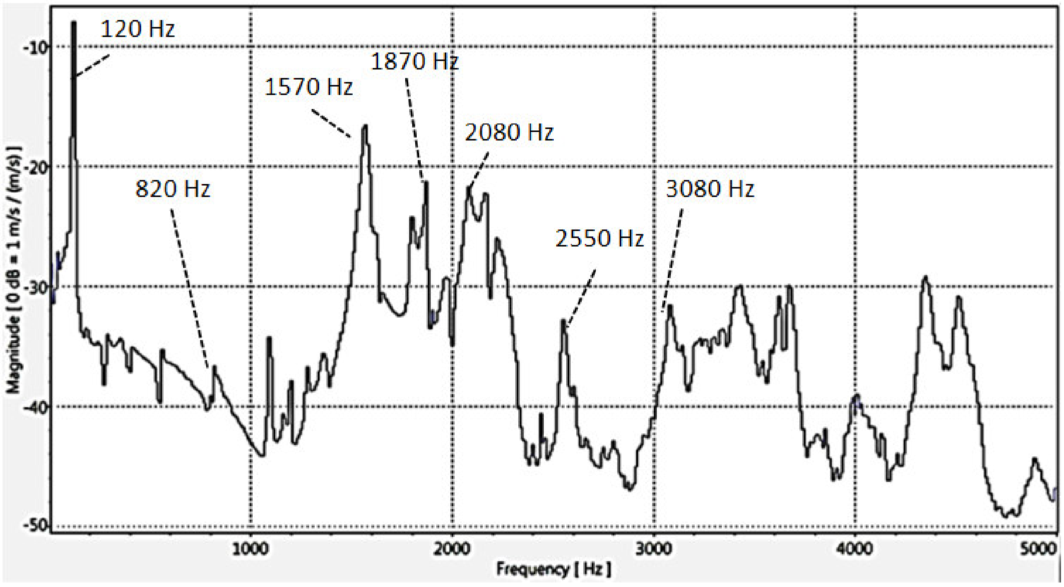
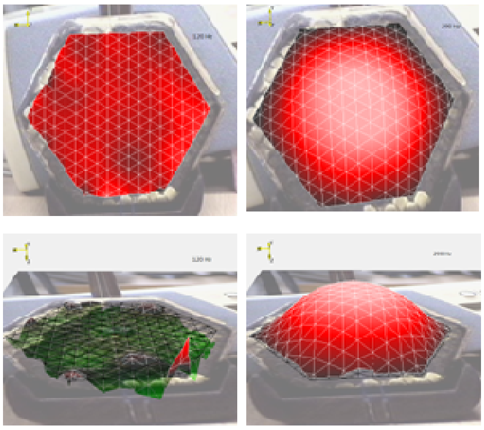



Fig. 6. *The erhu membrane vibroacoustics spectrum for a soundwave force applied perpendicular to the surface. The measureing frequency from 0 to 5,000 Hz*

The membrane in the soundbox is circular, and the first five mode patterns that could be adopted in terms of where displacement nodes and antinode are, occurred. Figure 7 shows that various frequency ranges of the erhu were related to the specific modes of the membrane. According to frequency, diversifications can be viewed as a set of individual modes of vibration, each having a characteristic resonance frequency, and the mode shape of the erhu membrane could be sorted into five vibroacoustic patterns; the first pattern in low frequency (100-1,000 Hz), the second pattern in middle frequency (1,100-1,900 Hz), the third pattern in intermediate high frequency (2,000-2,300 Hz), and the fourth pattern in the higher frequency (2,400-3,000 Hz). Furthermore, the 5$^{th}$ mode shapes became more complex in high frequency range (3,000-3,700 Hz). However, the mode shapes and frequencies of the membrane vibroacoustics depend on the exact boundary conditions (such as the thickness and tension of the membrane) and the excitation form during testing. In the first pattern, the fundamental mode (120 Hz) that occurred was the plane mode, which is the Helmholtz resonance of the soundbox (Figure 7a). Therefore, the first mode (1$^{st}$), as a bowl, occurred at 820 Hz and the node point was found at the glued edge of the membrane. The maximum displacement could be obtained from the center surface of the membrane (Figure 7b), which was similar to the results of related studies [12].

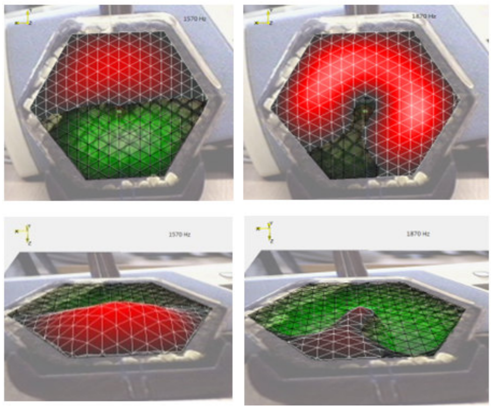


a) 120 Hz b) 820 Hz

Fig. 7. *The erhu membrane vibroacoustics spectrum for a soundwave force applied perpendicular to the surface: a) the membrane moves as plane up and down; b) vibrational 1$^{st}$ modes for a Parallelepiped in frequency 800 Hz*

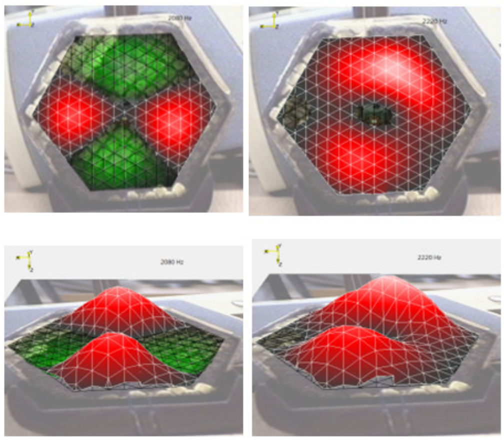
Figure 8 shows the second pattern in middle frequency range (1,100-1,900 Hz). The second mode (2$^{nd}$) occurred at 1,570 Hz and the node point was found at the center of the membrane (Figure 8a). The mode shape was obtained by the upper and lower symmetry on the center surface of the membrane. Furthermore, the mode shape that occurred was the ring phenomenon with increasing the frequencies to 1,870 Hz (Figure 8b). In fact, while the mode for both shapes is shown as 1,1 (diameter nodes, circular nodes), at 1800 Hz the shape is a rotational motion around the central position (at bridge).

Figure 9 shows the third pattern in intermediate lower frequency range (2,000-2,300 Hz). The third mode (3$^{rd}$) occurred at 2,080 Hz and the node point was still at the center of the membrane (Figure 9a). The mode shapes were turned to the 2 nodal diameter mode. Then the mode shapes were transformed to the rotation phenomenon with increasing the frequencies to 2,220 Hz (Figure 9b). However, the peaks of mode that simultaneously occurred were two in and two out of the surface. Additionally, the 2220 Hz mode shape that occurred was horizontal rotational movement in the bridge position.



a) 1,570 Hz b) 1,870 Hz

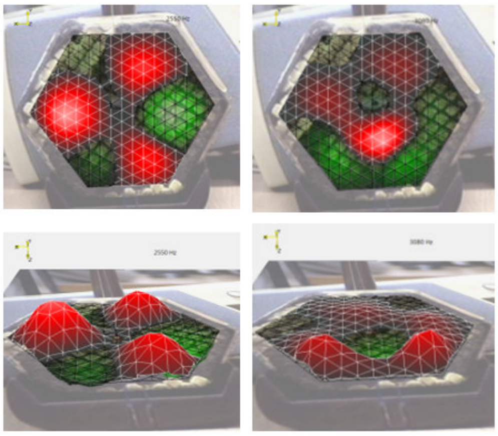
Fig. 8. *Vibrational 2$^{nd}$ modes for a Parallelepiped in frequency from 1,000 to 2,000 Hz*



a) 2,080 Hz (b) 2,220 Hz

Fig. 9. *Vibrational 3$^{rd}$ modes for a Parallelepiped in frequency from 2,000 to 2,300 Hz*

Figure 10 shows the fourth pattern in intermediate higher frequency range (2,500-3,000 Hz). The fourth mode (4$^{th}$) occurred at 2,550 Hz and turned to the 3 nodal diameter modes on the surface (Figure 10a). Then the mode shapes were transformed to the rotation phenomenon with increasing the frequencies to 3,080 Hz (Figure 10b).

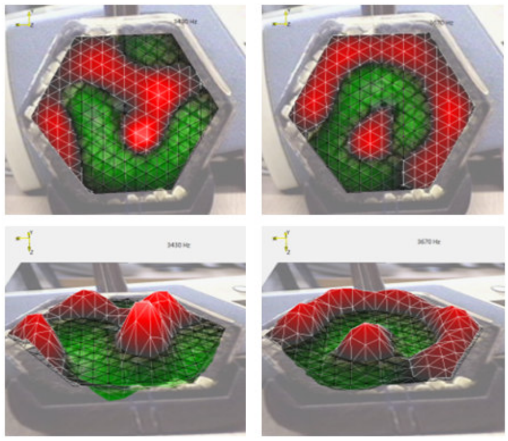


a) 2,550 Hz (b) 3,080 Hz

Fig. 10. *Vibrational 4$^{th}$ modes for a Parallelepiped in frequency from 2,500 to 3,000 Hz*

The 5$^{th}$ mode shapes became more complex in high frequency range (Figure 11). It was not only turned into the ring phenomenon, but it also increased the number of nodal diameter mode. Therefore, the anisotropic properties of snake skin and the influence of membrane technology on the dynamic patterns and high frequency vibroacoustics characteristics are more complicated.

The results showed the vibroacoustics of the membrane and the various mode shapes that are dependent on the frequency diversifications. The observed mode shapes and frequencies of the membrane vibroacoustics depend on the exact boundary conditions (such as the thickness and tension of the membrane) and the bridge excitation form during testing. Obviously, a convenient and readily reproducible setup was the scanning laser method of the erhu instrument.



a) 3,430 Hz b) 3,670 Hz

Fig. 11. *Vibrational 5$^{th}$ modes for a Parallelepiped in frequency from 3,000 to 3,700 Hz*

## 4. Conclusion

This study was conducted to examine the technical feasibility of using laser scanning technologies for obtaining the vibroacoustics of the Chinese erhu. The scanning laser method is an ideal instrument in terms of enabling designers or engineers to determine the modal parameters of a mass effect concern structure. As presented above, using the scanning laser method through the construction and testing of the erhu membrane was evaluated as appropriately measuring the vibration that introduced several prototypical mode structures. The primary purpose of the modal test was to identify the vibroacoustic modes, which was well accomplished. Overall, the behavior of the erhu appeared in various frequency ranges: as frequency increased, resonant structures diverged and differences between the acoustic properties of the erhu became more apparent. The scanning laser method was a convenient and readily reproducible setup to evaluate erhu vibroacoustic properties. Therefore, the method can provide a luthier with more accurate reference in making this instrument. A future objective is to identify other applications of this technology to understand the relationship among membrane geometry, wood species and density, bridge style and location, and processing, notably for other transportation structures.

## Acknowledgments

This work required a great deal of effort and could not have happened without the support, friendship, and help of many people, to whom we owe much. Special thanks to master Gwo-Chang Sung for providing the erhu for the experiments.

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