Sound & Vibration 2026, 60(3), 4106.
doi: https://doi.org/10.59400/sv4106

Article

Timbre transfer of classical guitars using impulse response and a laser displacement sensor

Che-Hsu Yeh, Chii-Chang Chen*

Department of Optics and Photonics, National Central University, Taoyuan City 320317, Taiwan
*** Corresponding author:** Chii-Chang Chen, trich@dop.ncu.edu.tw

CITATION

Yeh CH, Chen CC. Timbre transfer of classical guitars using impulse response and a laser displacement sensor. Sound & Vibration. 2026; 60(3): 4106. https://doi.org/10.59400/sv4106

ARTICLE INFO

Received: 28 February 2026
Revised: 27 March 2026
Accepted: 1 April 2026
Available online: 14 May 2026

Abstract: Conventional characterization of musical instruments relies on microphones, whose measurements depend strongly on distance, sound radiation directionality, and the non-uniform frequency responses of microphones and preamplifiers, often introducing distortions. Laser displacement sensors, widely used for vibration and surface measurements, offer a higher maximum displacement–to–resolution ratio than laser Doppler vibrometry. Measuring instrument vibrations with such sensors enables the capture of a more intrinsic acoustic source. This study demonstrates timbre transfer from a hand-made guitar to a José Ramírez guitar using convolution with impulse responses obtained from both a laser displacement sensor and a microphone. Timbre similarity is evaluated via cross-correlation of acoustic spectra between original and transferred notes. For 33 notes (E2–C5), the laser-based method yields higher cross-correlation in 28 cases compared to the microphone-based approach. The results highlight the distinction between vibration-based and pressure-based timbre characterization. Microphone measurements capture far-field sound pressure along with environmental noise, whereas laser displacement sensing directly reflects the instrument's vibrational behavior. Consequently, laser-based impulse responses provide a more intrinsic representation of acoustic spectra and enable more accurate timbre transfer. After recording a performance, the timbre of one instrument can therefore be transferred more precisely to another using impulse responses derived from laser displacement sensors.

Keywords: classical guitars; timbre; impulse response; laser displacement sensor

1. Introduction

The guitar body acts as a resonator, amplifying certain frequencies via its normal modes (vibrational patterns of the soundboard, back, sides, and air cavity). These modes are influenced by wood properties, plate thickness, arching, bracing, and the sound hole [1]. Although the modern classical guitar largely follows the foundational design pioneered by Antonio de Torres in the mid-19th century—which established the basic body shape, scale length, and fan-bracing system that enhanced volume and tonal balance—the timbre of individual classical guitars varies significantly due to several key material (wood, strings) and structural parameters. Timbre depends on the plucking position [2] and direction (angle) as well as the nail shape and roughness [3]. Timbre allows listeners to distinguish between different instruments playing the same pitch and loudness. In digital music, it has been used for main melody extraction and the style classification of MIDI files using an improved Skyline algorithm and an optimized back propagation neural network [4]. Time-Frequency analysis was adopted to restore and enhance the timbre of guitars [5]. The recorded sound can be used for modelling realistic playing in acoustic guitar synthesis [6] and can be analyzed using wavelet methods [7]. Its significance might extend beyond identification—it affects aesthetic judgment, emotion, and expressiveness in performance.

In acoustics, the impulse response (IR) has been shown to contain all acoustic information between specific source and receiver positions [1]. Room impulse response has been used to capture and analyze the acoustic characteristics of a room or an environment including reflections, reverberation, and echoes [8–11] as well as machine learning research in acoustics [12–14]. The signature of musical instruments such as violins or guitars can be defined by impulse response [15–19]. Among different violins played in an audio recording, the impulse response can be used to identify which violin is being played [18].

The impulse response of ancient violins (Stradivarius) has been measured and analyzed [20]. The synthesis and characteristics transfer of stringed instrument sounds can be achieved using their impulse responses [21, 22]. Microphones that measure the acoustic pressure field are generally used for measuring the impulse response of musical instruments. However, microphone measurements naturally include this filtering effect, governed by radiation efficiency, along with environmental noise and interference, and are sensitive to room noise and pressure fluctuations. Traditional timbre emulation relies heavily on the data obtained by microphones, which may not fully preserve the mechanical and structural resonances of acoustic instruments. The frequency response of the microphones also depends on their type (dynamic or condenser microphones) as well as that of the pre-amplifier response. It depends on the direction and distance between the musical instruments and the microphones as well. Physical modeling synthesis, though promising, often requires precise acoustic response due to the mechanical vibration of the instruments to assess the results. An electret film pickup positioned on guitar bridge can be used to generate approximately the transfer function from the bridge vibration to the radiated sound using digital signal processing [23]. These approaches often lack the granularity needed for faithful reproduction of handcrafted instruments' subtleties. Accelerometers have also been used to measure the impulse response by exciting the guitar with a hammer [24, 25]. However, this is a contact-based method, and the results are typically reliable only up to 10 kHz due to sensor mass effects at higher modes [26].

Recently, a high-precision method, continuous-scan laser Doppler vibrometry (LDV) which measures the structural vibration, has been used to investigate the vibration properties of historic Italian violins and guitars [27–29]. This technique can be applied to record the temporal information of the vibration at a single point using a single LDV, but also the vibration mode profile of the soundboard at specific frequencies using three LDVs [30] where the laser beam scans continuously along a defined path across a structure at specifically selected scan frequencies. The vibration mode profiles of old Italian violins have been investigated. The mode profile of the classical guitar with Torres design has also been analyzed using a scanning head of the LDV system [31]. Measurements on three guitars using LDV and maximum length noise sequences for impulse responses showed strong high-frequency contributions to sound output, especially from the soundboard [24]. LDV enables displacement measurements at the picometer level. The structural-domain measurement results could preserve the raw and intrinsic acoustic data. The ratio of the maximum displacement range (2 mm) to the resolution (67.8 nm) of the commercial LDV system is around 29492.

In literature, the commercial laser displacement sensor can provide a higher ratio of the maximum displacement range (2 mm) to the resolution (30 nm) to be around 66667 [32]. The present work reports the timbre transfer using the impulse response of the classical guitars. A laser displacement sensor is used to measure the vibration of the top plate of classical guitars. The comparison of the results obtained using microphone and laser displacement sensor is performed for every note of classical guitars from E2 to C5. The results are used to transfer the timbre of any recorded guitar to that of a guitar crafted by a renowned luthier. The measurement results obtained from the laser displacement sensors can also be considered the raw data of the timbre. The timbre of a guitar crafted by a renowned luthier can be preserved after measurement.

The remainder of this article is organized as follows. First, the theoretical framework for timbre transfer using impulse response is introduced. Next, the experimental setup and measurement procedures are described, including the guitars, excitation system, and both laser displacement sensor and microphone configurations. The measured acoustic spectra and timbre transfer results are then presented and evaluated using cross-correlation. This is followed by a discussion of the physical interpretation of vibration-based versus pressure-based characterization. Finally, the main findings and implications of this work are summarized in the conclusion (**Figure 1**).

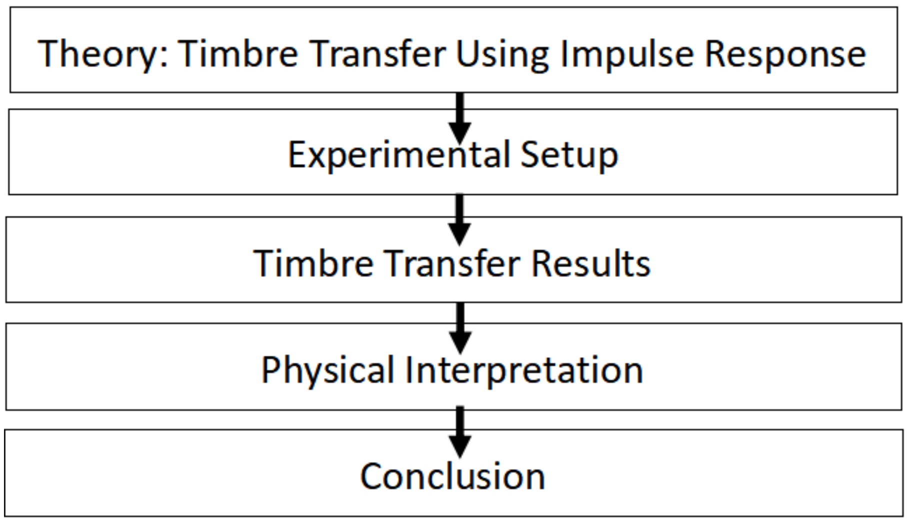


Figure 1. Structure of the article.

2. Timbre transfer using impulse response

The impulse response $h(t)$ to transfer the timbre of the guitar A to that of guitar B is an inverse Fourier transform of the transfer function $H(f)$ which can be obtained by dividing the acoustic spectrum of guitar A, $A(f)$, by that of guitar B, $B(f)$ [33]. The spectra of guitars A and B are acquired by applying the Fourier transform to the time-domain acoustic signals $A(t)$ and $B(t)$. The impulse response $h(t)$ can be expressed by:

$$h(t) = F^{-1}\left(H(f)\right) = F^{-1}\left(\frac{A(f)}{B(f)}\right) = F^{-1}\left(\frac{F\left(A(t)\right)}{F\left(B(t)\right)}\right) \tag{1}$$

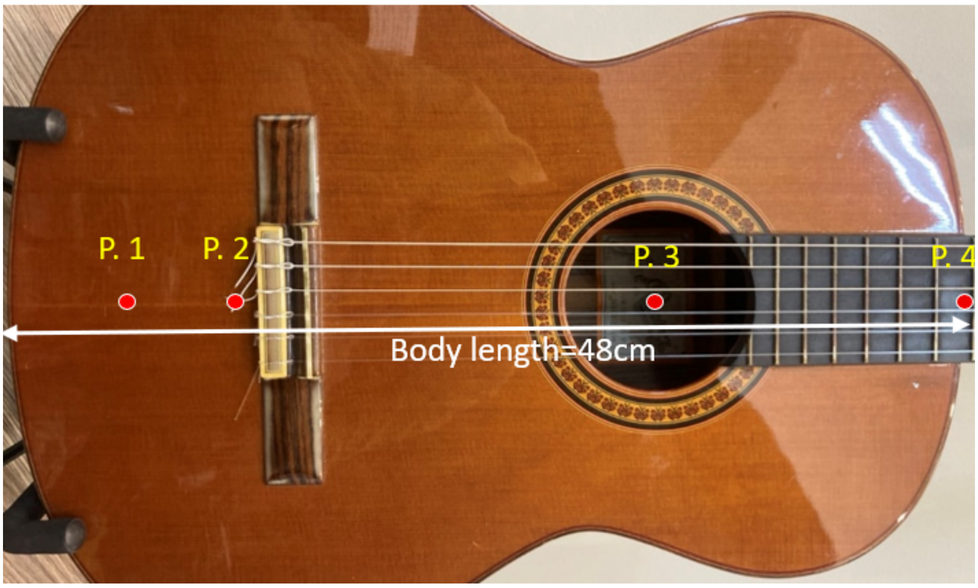
In this work, $A(t)$ and $B(t)$ are measured by plucking guitars A and B and recorded by the laser displacement sensor, respectively. The impulse response $h(t)$ can be obtained by Equation (1).

3. Experimental setup

In this study, two classical guitars are used for timbre transfer: A 1997 José Ramirez 3E guitar (body length: 48 cm, soundboard: Cedar, side and back plate: Rosewood, weight: 1,688 g, string length: 65 cm) with the dimension defined by Antonio de Torres [34] as shown in **Figure 2a** and a hand-made classical guitar in the laboratory, featuring an asymmetrical bracing structure (body length: 48 cm, soundboard: Sitka Spruce, side and back plate: Formosa Koa, weight: 1,646 g, string length: 65 cm) also with the typical dimension defined by Antonio de Torres [34] as shown in **Figure 2b**. The timbre of guitars can be influenced by their dimensions, the wood and string materials, and the bracing of the soundboard which have been studied by Lee et al. [35]. Both guitars are equipped with Hannabach 600 MT medium tension strings, tuned to standard guitar tuning and are characterized by microphone and laser displacement sensor.

The string plucking system which is built on an anti-vibration optical table as shown in **Figure 3** includes a computer-controlled motorized translation stage with a displacement resolution of 1.25 µm, a force gauge, forceps, and a current-controlled electromagnet. The tip of the forceps is used to pull the string, while the current-controlled electromagnet, connected to the forceps, silences the release of the string by deactivating the current, thereby initiating vibration of the string. A highly sensitive force gauge (1 g resolution) is positioned between the motorized translation stage and the forceps to measure the pulling force applied to the string. The computer controls both the pulling force and displacement of the string, allowing for precise calculation of the energy required to excite the string into vibration. The plucking point is set at two-sevenths of the string length (18.6 cm) from the bridge, which is above the sound hole—a typical plucking position for guitarists. This location suppresses the 7^{th}, 14^{th}, and 21^{st} overtones, among others, while allowing excitation of the fundamental note and the 2^{nd} through 6^{th} overtones. The measurement environment is enclosed with thick curtain fabric on all sides to minimize acoustic wave reflections.

The laser beam of the laser displacement sensor, with a sensitivity of displacement of 30 nm, is used to measure the displacement of the soundboard. The maximum displacement range of the sensor is 2 mm, which is adequate for capturing the vibrations of the guitar soundboard or other musical instruments. Operating at a wavelength of 405 nm, the laser's power is below 1 mW which is safe for eyes and for the lacquer on the surface of the soundboard. Measurements are conducted at the sensor's maximum sampling frequency of 49.14 kHz, exceeding the standard CD sampling rate of 44.1 kHz. The working distance between the laser displacement sensor and the soundboard is maintained at 10 mm, ensuring sufficient clearance to prevent contact or damage to the guitar during setup. All the measurements of the soundboard displacement are recorded for 20 s. The Fourier transform is performed to the temporal displacement data to obtain the acoustic spectra. The corresponding acoustic spectral resolution is 0.05 Hz.



(a)

(b)

Figure 2. **(a)** 1997 José Ramirez 3E guitar and the measurement positions P. 1, P. 2, P. 3 and P. 4, respectively; **(b)** hand-made classical guitar in the laboratory.

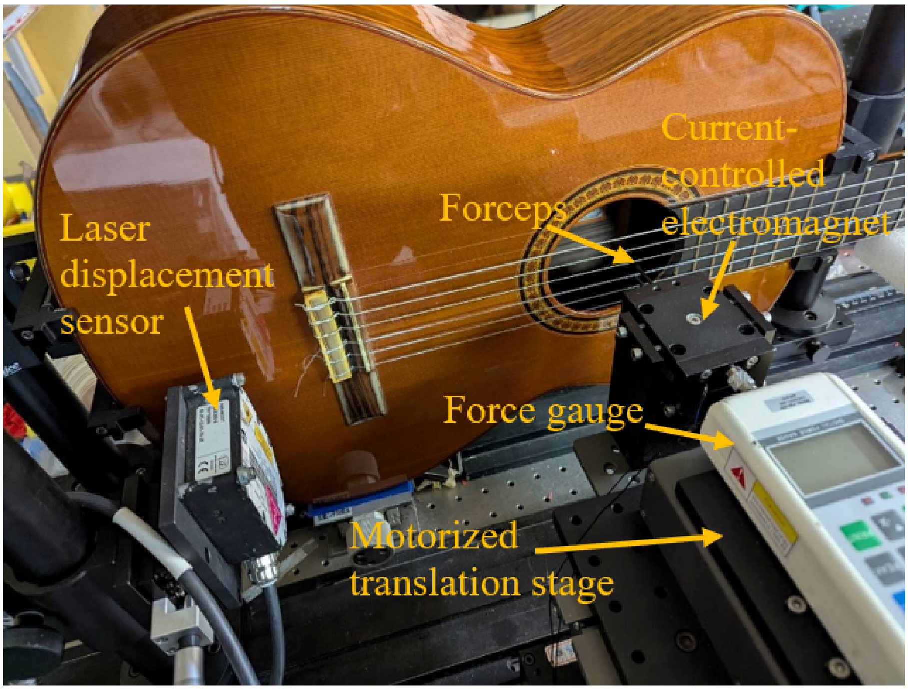
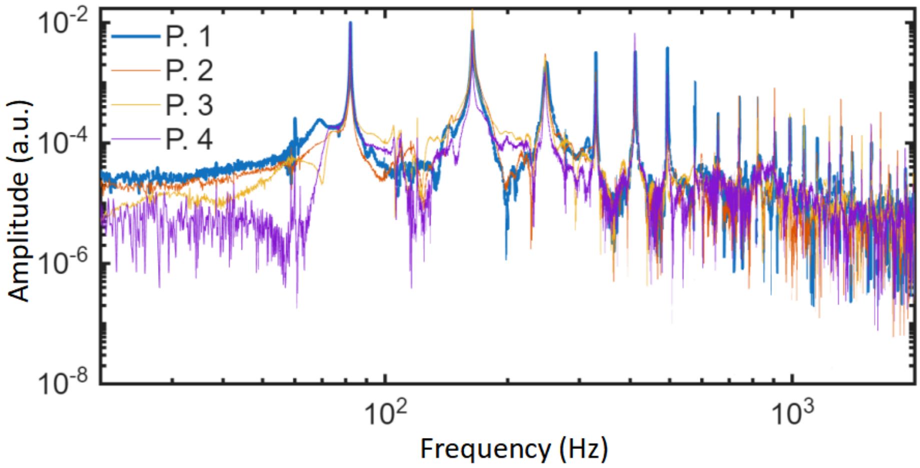


Figure 3. Laser displacement sensor and the string plucking system with forceps, a current-controlled electromagnet, a force gauge, and motorized translation stage.

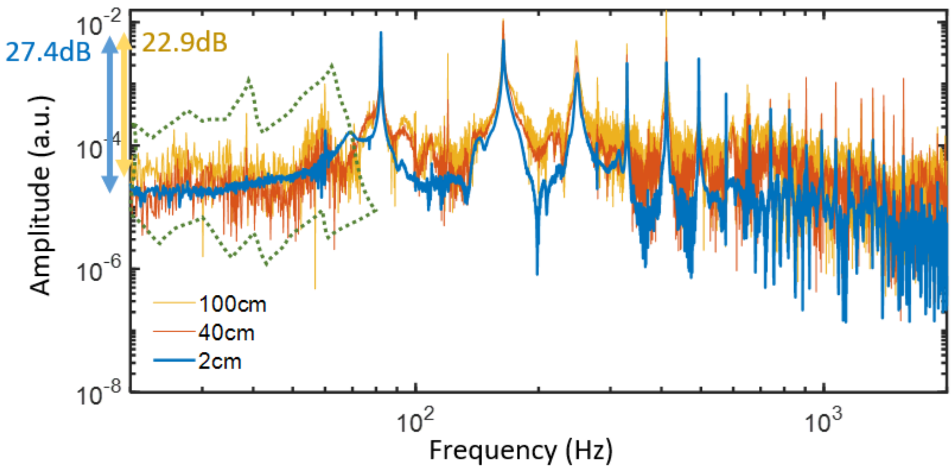
Rode model NTG1 condenser microphone with highly directional supercardioid polar pattern which can reject noises from the sides better than cardioid microphones is used to record the acoustic signals of the guitars. Focusrite Scarlett 2i2 interface operating at 44.1 kHz is adopted for analog to digital signal conversion.

4. Detection positions for microphone and laser displacement sensor

For the microphone, to excite the vibration of the guitars, the open 6th string is plucked for a displacement of 4 mm, as it more effectively excites the guitar into vibration, producing a louder sound compared to the other strings. The detection positions are P. 1, P. 2, P. 3 and P. 4 as illustrated in **Figure 2** by the red points. P. 1 is the middle position on the soundboard between the left edge of the guitar and the bridge. P. 2 is 1 cm from the left side of the bridge. P. 3 is at the center of the sound hole. P. 4 is above the 12th fret on the guitar. The acoustic spectra are shown in **Figure 4a**. The spectrum detected at P. 1 shows stronger amplitude and less noisy signals. Therefore, P. 1 is also chosen for the detection of the acoustic spectra of the guitar for microphone. **Figure 4b** illustrates the acoustic spectra of the guitar obtained from microphone for different distances (100 cm, 40 cm and 2 cm) between the soundboard and the microphone at the detection position P. 1. Relatively low noise is observed for the spectra for the distance of 2 cm. Therefore, the distance between the soundboard and the microphone at P. 1 is chosen to be 2 cm. To maintain consistency in the acquisition positions for both the microphone and the laser displacement sensor, the measurement position for the laser displacement sensor was also chosen as P1.



(a)

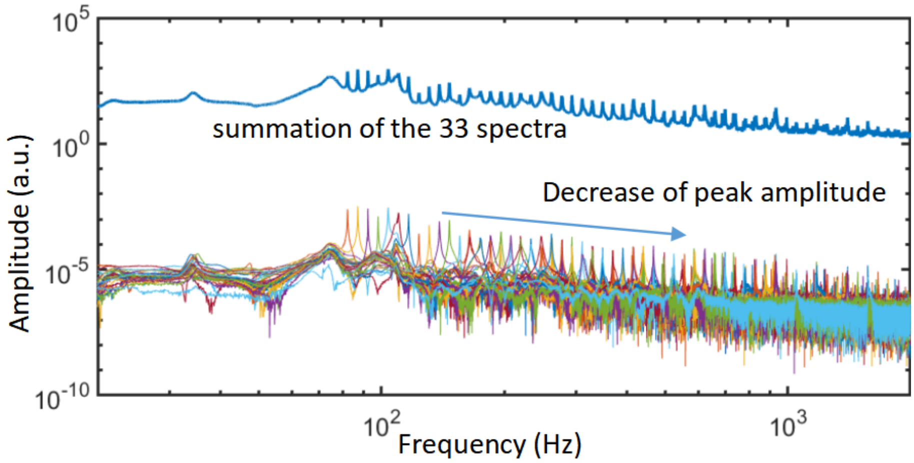


(b)

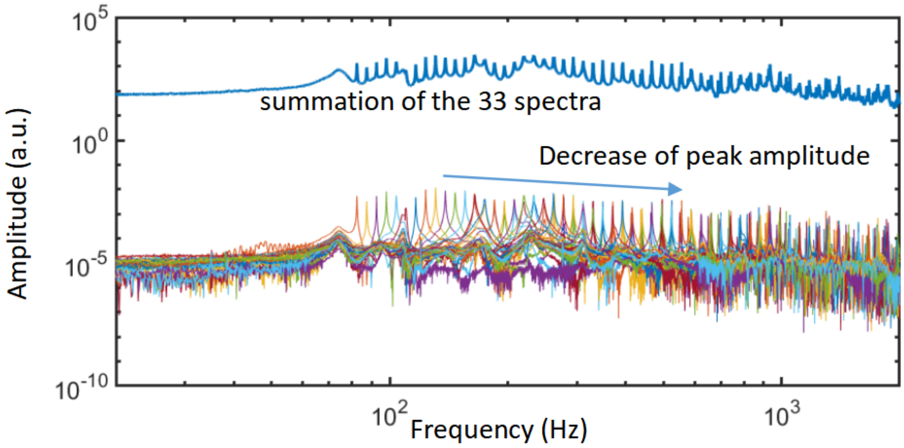
Figure 4. Acoustic spectra of José Ramirez guitar acquired by microphone **(a)** for different detection positions. The guitar is excited by plucking the open 6th string; **(b)** for the distances of 100 cm, 40 cm and 2 cm between the soundboard and microphone at the detection position P. 1.

5. Timbre transfer using impulse response

To prepare the transfer function $H(f)$ of the impulse response to transfer the timbre from hand-made guitar to that of José Ramirez guitar, the acoustic spectra for 33 notes of the José Ramirez and the hand-made guitars from E2(82.4 Hz) to C5(523.3 Hz) were measured, respectively. The work which is the product of the force to pull the string and the displacement of the string applied to each string is fixed to be 6mJ. The notes of E2–G2# are measured by plucking the 6th string. The notes of A2–C3# are measured by plucking the 5th string. The notes of D3–F3# are measured by plucking the 4th string. The notes of G3–A3# are measured by plucking the 3rd string. The notes of B3–D4# are measured by plucking the 2nd string. The notes of E4–C5 are measured by plucking the 1st string. The 33 acoustic spectra are summed for the José Ramirez and the handmade guitars, respectively. **Figure 5** shows the 33 acoustic spectra for each note of the José Ramirez guitar obtained by the laser displacement sensor and the microphone, respectively. The summed acoustic spectra are also illustrated in **Figure 5**.



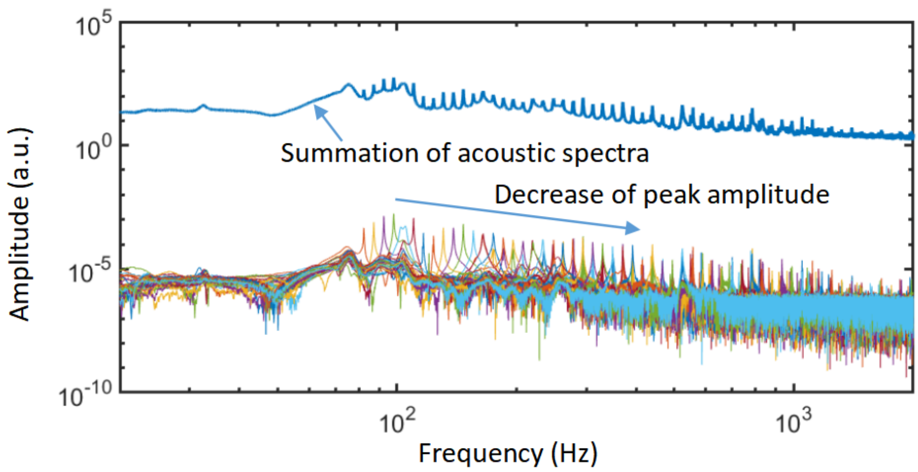
(a)



(b)

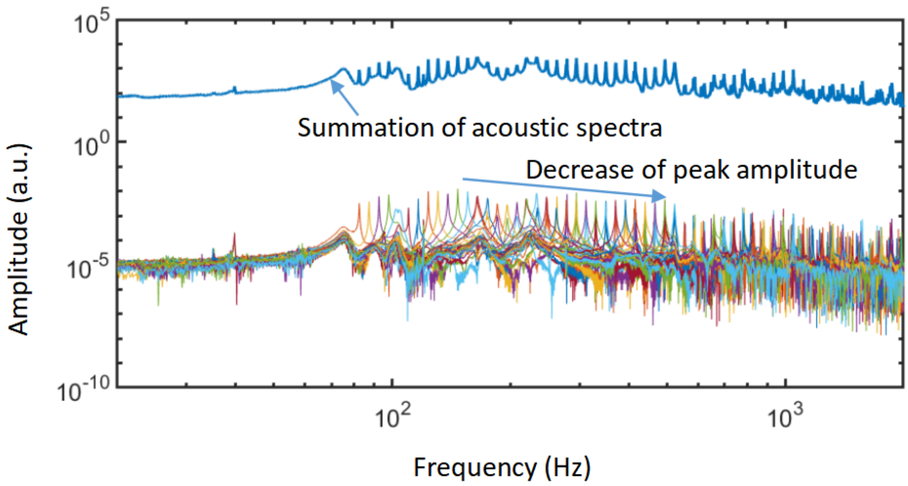
Figure 5. Spectra of 33 notes from E2(82.4 Hz) to C5(523.3 Hz) of the Ramirez guitar measured by **(a)** laser displacement sensor; **(b)** microphone as well as the summations of the 33 spectra.

Figure 6 illustrates the 33 spectra of the hand-made guitar and the summed 33 spectra for the laser displacement sensor and the microphone, respectively.



(a)

Figure 6. *Cont.*



(b)

Figure 6. Acoustic spectra for handmade guitar for 33 notes from E2(82.4 Hz) to C5(523.3 Hz) and the summations of the 33 acoustic spectra obtained by **(a)** laser displacement sensor; **(b)** microphone.

The summed 33 acoustic spectra for the José Ramirez and the hand-made guitars are utilized to obtain the transfer function $H(f)$ of the impulse response to transfer the timbre from handmade guitar to that of José Ramirez guitar. $H(f)$ is given by

$$H(f) = \frac{\sum_{i=E2}^{i=C5} A_i(f)}{\sum_{i=E2}^{i=C5} B_i(f)} \tag{2}$$

where $A_i(f)$ and $B_i(f)$ are the acoustic spectra of the José Ramirez and the handmade guitars, respectively. i indicates the note from E2 to C5.

Figure 7 illustrates the transfer functions $H(f)$ of the impulse response to transfer the timbre from handmade guitar to that of José Ramirez guitar for laser displacement sensor and microphone, respectively. It can be observed that for the laser displacement sensor, below the frequency of 70 Hz, the timbre difference between the José Ramírez guitar and the handmade guitar can be clearly observed. However, for the microphone, below the frequency of 70 Hz, the value of the transfer function is approximately unity, revealing that a few timbre differences could be transferred using the microphone. This highlights the advantage of using the laser displacement sensor for timbre transfer.

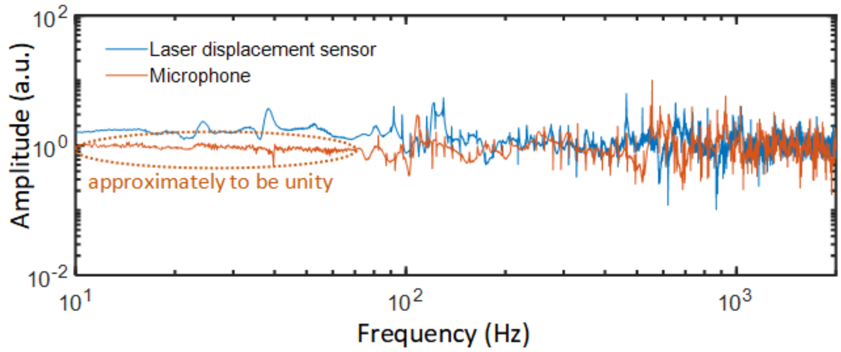


Figure 7. Transfer functions $H(f)$ of the impulse response to transfer the timbre from the hand-made guitar to that of the José Ramirez guitar for laser displacement sensor and microphone.

The timbre transfer from the note of handmade guitar to that of José Ramirez guitar is performed by multiplying the transfer function $H(f)$ by the spectra of the handmade guitar for 33 notes from E2 to C5. The acoustic spectrum $A'(f)$ of the note transferred from handmade guitar can be expressed by

$$A_i^{'}(f) = H(f) \times B_i(f) \tag{3}$$

where i is E2, E#2, F2… and C5.

The timbre transfer is applied to the acoustic spectra obtained from the laser displacement sensor and the microphone, respectively. Cross-correlation is performed for the normalized spectra of José Ramirez guitar $A_i(f)$ and the normalized spectra $A_i^{'}(f)$ obtained by timbre transfer for the notes from E2 to C5. **Figure 8** shows the cross-correlation between normalized $A_i(f)$ and normalized $A_i^{'}(f)$ for the laser displacement sensor and the microphone, respectively. All values of cross-correlation are higher than 92% revealing that for laser displacement sensor and microphone, the note can be well transferred from the hand-made guitar to the José Ramirez guitar. For laser displacement sensor, the cross-correlation is between 94% and 98%. These results surpass those reported in the study by Pradeep Atre and Apte [19], which range from 88% to 95%. This discrepancy may arise because the signals in Pradeep Atre and Apte [19] were recorded using an under-saddle pickup with a 16 kHz sampling rate and finger excitation of the strings, which may introduce variability and limit repeatability between plucks.

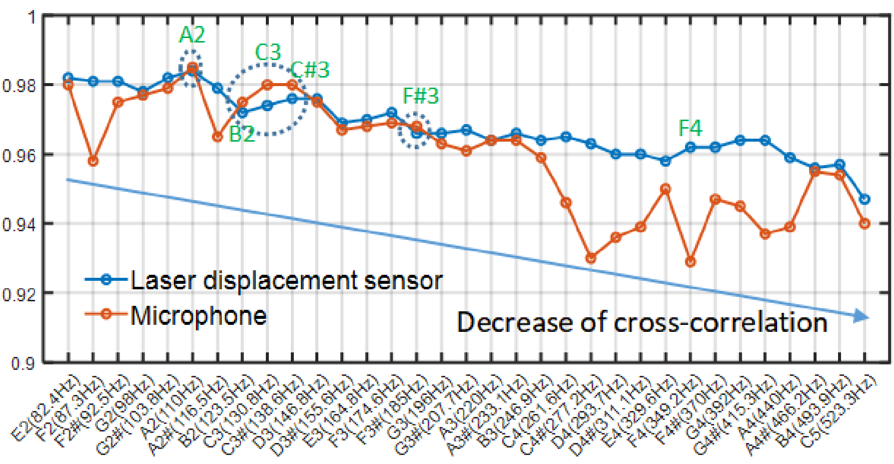


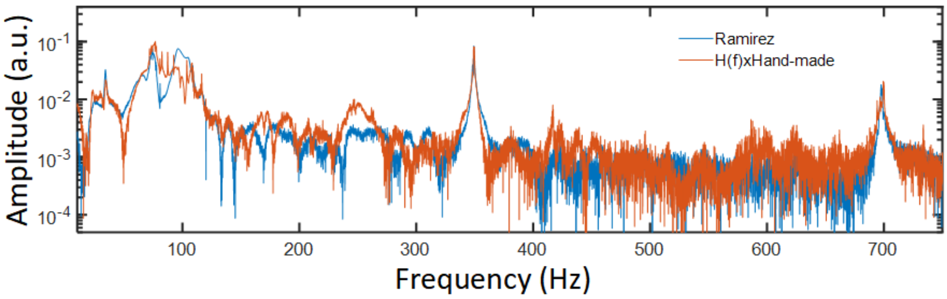
Figure 8. Cross-correlation of the acoustic spectra of José Ramirez guitar and those transferred from handmade guitar using impulse responses for the laser displacement sensor and the microphone.

In **Figure 8**, only for the notes A2, B2, C3, C#3 and F#3, the cross-correlation for laser displacement sensor is lower than that of the microphone. For the other 28 notes, the cross-correlation for laser displacement sensor is higher than that of microphone revealing that the timbre transfer performed by laser displacement sensor can provide a higher similarity to the timbre of the musical instruments.

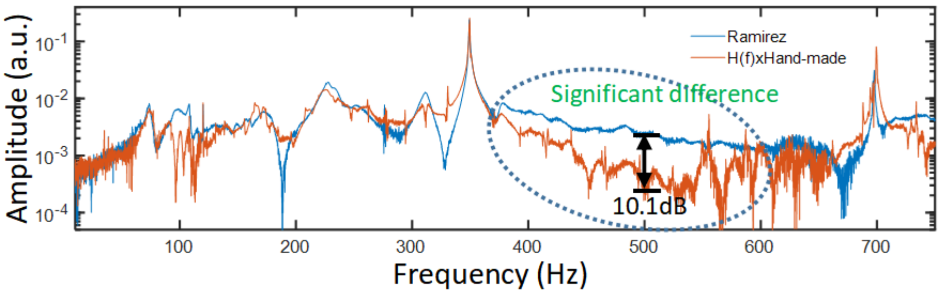
The two curves for laser displacement sensor and microphone in **Figure 8** also reveal the fact that for the notes of higher frequency, the cross-correlation is lower.

In **Figures 5** and **6**, it can be observed that for the notes of higher frequency, the peak amplitude decreases compared to the background noise in the spectra resulting in lower signal-to-noise ratio. Since the cross-correlation of the spectra depends significantly on the signal-to-noise ratio, the decrease of signal-to-noise ratio for the notes of higher frequency could result in the decrease in the value of the cross-correlation.

In **Figure 8**, it can be observed that the cross-correlation for the note F4 (349.2 Hz) for laser displacement sensor is higher than that for microphone. To understand the reason, the acoustic spectra of the note F4 (349.2 Hz) for José Ramirez guitar and that transferred from handmade guitar using impulse response for the laser displacement sensor and the microphone are shown in **Figure 9**, respectively. In **Figure 9a**, the spectra transferred using the impulse response obtained by the laser displacement sensor are quite similar to those of the José Ramirez guitar. In **Figure 9b**, a significant difference from 360 Hz to 600 Hz between the spectra is observed resulting in lower cross-correlation for microphone. At the frequency of 500 Hz, the difference is around 10.1 dB.



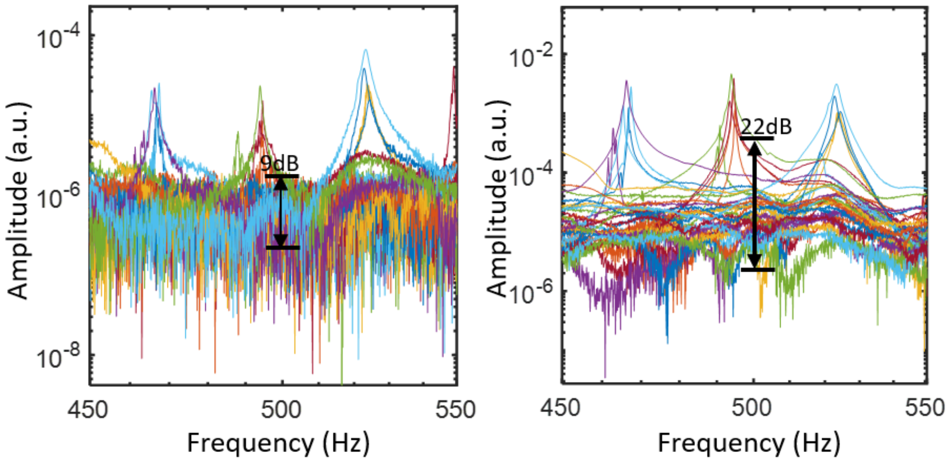
(a)



(b)

Figure 9. Acoustic spectra of José Ramirez guitar for the note F4 (349.2 Hz) and the spectra obtained by timbre transfer with impulse response from the spectra of handmade guitar for **(a)** laser displacement sensor; **(b)** microphone.

The acoustic spectra of hand-made guitar for 33 notes illustrated in **Figure 6** within the frequency range from 450 Hz to 550 Hz are shown in **Figure 10** which are characterized by laser displacement sensor and microphone, respectively. It can be observed that the amplitude variation at the frequency of 500 Hz is larger for the microphone (22 dB) than that for the laser displacement sensor (9 dB), respectively. The timbre transfer is performed using $H(f)$ and the acoustic spectra of each note for hand-made guitar according to Equation (3). Since $H(f)$ is invariant for performing the timbre transfer of the 33 notes, the amplitude difference observed in **Figure 9b** from 360 Hz to 600 Hz results from the large amplitude variation of the acoustic spectra of the 33 notes of the handmade guitar for microphone as observed in **Figure 10b**. To solve this problem, in **Figure 4**, it can be observed that the ratio between the amplitude of the note of the open 6th string and that at the frequency of 20 Hz decreases from 27.4 dB to 22.9 dB as the distance between microphone and guitar increases from 2 cm to 100 cm. However, the signals become noisy as the distance between microphone and guitar increases. The reduction of the amplitude variation in **Figure 10b** for the acoustic spectra of the different notes obtained by microphone might be achieved by increasing the distance between the microphone and guitar. The similarity of the notes after the timbre transfer could be increased at the cost of lower signal-to-noise ratio.



(a) **(b)**

Figure 10. Acoustic spectra of handmade guitar for 33 notes within the frequency range from 450 Hz to 550 Hz obtained by **(a)** laser displacement sensor; **(b)** microphone.
Note: The variation of the amplitude at 500 Hz is 9 dB and 22 dB for laser displacement and microphone, respectively.

The results obtained in this work indicate a fundamental difference between structural-domain characterization using the laser displacement sensor and acoustic-pressure measurement using the microphone. The microphone detects the radiated acoustic pressure field, which is already influenced by radiation efficiency of the soundboard, air–structure coupling, room reflections, and the frequency response of the microphone and pre-amplifier. In contrast, the laser displacement sensor directly measures the acoustic vibration of the soundboard. Since the timbre of a string instrument originates from the acoustic vibration excited by the strings and subsequently transformed into radiated sound, measuring displacement provides access to a more intrinsic representation of the instrument's vibrational characteristics. The structural response can therefore be regarded as a raw physical signature of the instrument before being filtered by acoustic radiation and environmental effects. This difference between two methods leads to the fact that the acoustic spectra obtained by the laser displacement sensor show lower background noise and reduced amplitude variation across notes compared with those obtained by the microphone.

6. Physical interpretation of vibration-based vs. Pressure-based timbre characterization

According to the Kirchhoff–Helmholtz integral equation, the measured sound pressure is generally proportional to the particle velocity of the vibrating acoustic source [1]. In structural acoustics [36], for lightly damped, baffled structures, the radiated far-field sound pressure is proportional to the spatially averaged, frequency-weighted surface velocity. Although a guitar is not a simple baffled plate, the underlying principle remains: structural vibration acts as the source, while the radiated sound represents a filtered version of that source. Microphone measurements inherently include this filtering effect (radiation efficiency) as well as environmental contamination, whereas laser-based measurements capture the source more directly. For this reason, measurement techniques such as laser Doppler vibrometry have been adopted to access the intrinsic acoustic source of violins [27,30].

Figure 11 illustrates the spectra of the José Ramirez guitar obtained from the laser displacement sensor and the microphone at P. 1 by plucking the open 6th string. The amplitude ratio between the minimum amplitude at approximately 20 Hz and that of the open 6th string note is around 33 dB for the laser displacement sensor and 22 dB for the microphone. This originates from the fact that the environmental noise detected by the microphone is not captured by the laser displacement sensor.

In **Figure 11**, it can be observed that the spectrum obtained by laser displacement sensor below the frequency of 70 Hz as indicated by green dotted line is much less noisy than that in **Figure 4b**, for the microphone, in the spectra for the detection distance of 40 cm and 100 cm as indicated by green dotted line to be quite noisy.

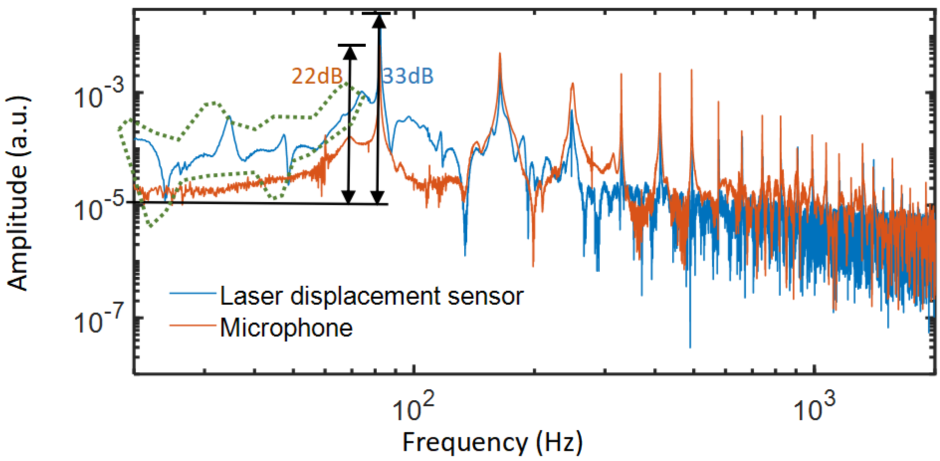


Figure 11. Acoustic spectra obtained from the laser displacement sensor and the microphone at P. 1 of the José Ramirez guitar by plucking the open 6th string.

These results highlight the advantage of laser displacement sensors, which can detect subtle signals with higher signal-to-noise ratios under the same conditions. Microphone measurements, by contrast, are sensitive to instrument-to-microphone distance and sound radiation directionality, and their non-uniform frequency responses including those of preamplifiers can introduce distortions that alter the instrument's original characteristics. Recently, a laser-based measurement technique has been reported in which light reflected from the target is reinjected into the laser cavity. This self-aligned interferometric sensing approach enables the measurement of surface vibrations without the need for an external reference arm [37]. This technique may be applied to the timbre characterization of guitars.

In this work, the detection distances between the microphone and the guitar are 2 cm, 40 cm, and 100 cm. For the first open string, the note E4 has a frequency of 329.6 Hz, corresponding to an acoustic wavelength of approximately 104 cm. Since the detection distances are comparable to or smaller than the acoustic wavelength, a significant portion of the measured signals—particularly for frequencies below E4—lies within the near field [38]. In this regime, the detected sound may include evanescent components that do not contribute to far-field radiation. Consequently, the sound recorded by the microphone may not fully represent the radiated timbre of the instrument.

7. Conclusion

This work reports the timbre transfer utilizing the impulse response from a hand-made guitar to a José Ramirez guitar by a laser displacement sensor as well as a microphone. The similarity of the timbres is presented by cross-correlation of the acoustic spectra of the note of José Ramirez's guitar and that transferred from a handmade guitar. For 33 notes from E2 to C5, the cross-correlation is higher than 92%, indicating that the timbre can be well transferred by the two methods. The amplitude difference between the minimum value near 20 Hz and the open 6^{th} string note is approximately 33 dB when measured with the laser displacement sensor, compared to about 22 dB with the microphone. This demonstrates the laser displacement sensor's superior ability to detect subtle signals due to its higher signal-to-noise ratio in the same characterization environment. The results show that for 33 notes from E2 to C5, the cross-correlation for the acoustic spectra obtained by laser displacement sensor is higher for 28 notes revealing that laser displacement sensor is the suitable tool for the acoustic spectrum measurement of musical instruments and the timbre transfer using impulse response. Handcrafted guitars by renowned luthiers are not only musical tools but cultural artifacts. Preserving their sonic identity allows future generations to study and experience their unique tonal quality, even if the physical instrument deteriorates. The proposed method provides a non-invasive approach to measure the classical guitars made by renowned luthiers with the laser displacement sensor to digitally capture as well as reproduce the timbre of the musical instruments. The digital timbre libraries could be built by preserving these timbral signatures. Luthiers could design and optimize their bracing structures by mapping the objective timbre characteristics of instruments crafted by renowned masters.

Author contributions: Conceptualization, CCC; methodology, CHY and CCC; validation, CCC; formal analysis, CHY; investigation, CHY and CCC; resources, CCC; data curation, CHY; writing—original draft preparation, CCC; writing—review and editing, CCC; visualization, CHY; supervision, CCC; project administration, CCC; funding acquisition, CCC. All authors have read and agreed to the published version of

the manuscript.

Funding: This research was funded by the National Science and Technology Council, Taiwan, grant number NSTC 113-2221-E-008-042 -MY3.

Institutional review board statement: Not applicable.

Informed consent statement: Not applicable.

Data availability statement: Data available on request from the authors.

Conflict of interest: The authors have no conflicts to disclose.

AI use statement: During the preparation of this work, the authors used ChatGPT for grammar checking. The authors subsequently reviewed and edited the content as necessary and take full responsibility for the final content of the published article.

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