Acoustic Profiling of the Guqin Zither

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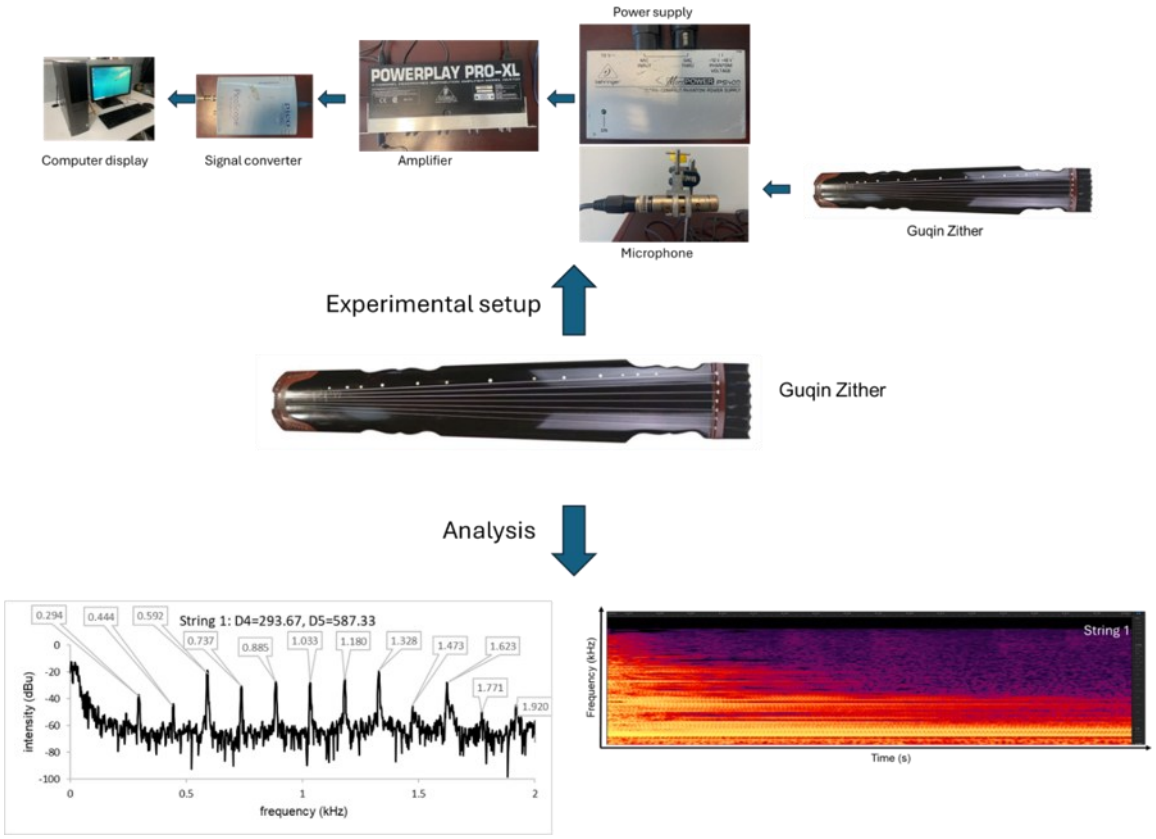
GRAPHICAL ABSTRACT



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This study's main goal was to investigate the guqin's frequency spectrum and the time frequency analysis. Its non-fret-based pitch system yields measurable polynomial connections which may reflect systematic patterns in the instrument's acoustics, though further theoretical justification is required to confirm their significance. The tuning and harmonic content changes across the strings, which provides fresh perspectives on the instrument's acoustic character and artistic versatility. Although the sounds of the lowest to the highest pitch were perceived as: C2, D2, F2, G2, A2, C3, and D3, the results from the PicoScope showed: C3, D3, F3, G3, A3, C3, and D4. The 1st harmonic on the open 7th string occurred at C3. The 2nd, 3rd, 4th, 5th, 6th and 8th harmonic occurred at half the string length, *i.e.*, hui 7 is C4, at one and two third the string length, *i.e.*, hui 5 and hui 9 are G3, at one and three fourth the string length, *i.e.*, hui 4 and hui 10 are C4, at one and four fifth the string length, *i.e.*, hui 3, 6, 8 and 11 are E4, at one and five sixth the string length, *i.e.*, hui 2 and hui 12 are G4, and one and seven eight the string length *i.e.*, hui 1 and 13 are C5.

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Keywords: Guqin; Time Frequency Analysis (TFA); Fast Fourier Transform (FFT)

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INTRODUCTION

The Chinese guqin, one of the world's oldest plucked instruments, has deep cultural and historical significance. Chinese music is heavily reliant on this seven-stringed zither. Zhao and Li (2024) examine the guqin's acoustical profile, and the aesthetic concepts and artistic qualities of guqin music. The building of the guqin is full of symbolism, and its history is entwined with philosophy and mythology. The guqin, an instrument of high culture, was once connected to the Imperial elite (Waltham *et al.* 2016). It is played with horizontal strings. At the back are two sound holes. To date, there seems to be no documented acoustical analysis of the guqin. Tian and Ng (2024) describe and quantify guqin's timbre by analyzing its sounds using a number of time- and frequency- domain parameters including frequency, amplitude, perturbation, spectral contents, *etc*. The study highlights the guqin's distinctive acoustic characteristics in order to deepen our understanding of sound produced with this ancient Chinese musical instrument.

Although FFT-based spectral analysis is well-established, this study applies it to a carefully selected dataset of guqin recordings, covering the intensity. This allows for controlled comparison across frequency, examining time-frequency evolution in ways that

previous studies did not, and combining FFT with other representations (spectrogram-derived features-the time frequency analysis (TFA) from Adobe Audition). This work highlights the time-frequency evolution of guqin tones, demonstrating dynamic aspects related with spectrogram-derived features, rather than employing FFT exclusively for static spectral characterization. The physical design and tuning of the instrument were not covered in previous research, but the harmonic content variations among the strings offer new insights into the instrument's acoustic nature and creative adaptability. Its non-fret-based pitch mechanism produces observable polynomial connections that may represent regular patterns in the instrument's acoustics, but additional theoretical support is needed to validate their relevance. This is a novel interpretation of acoustical behavior.

Its elegance, serenity, and subliminal nature are enhanced by the complex playing skills of its musicians, which include sliding and plucking, that enable the creation of sounds with unique qualities. The current study analyzed the sounds of guqin music utilizing a variety of time- and frequency-domain factors, such as frequency, amplitude, and spectral contents, in an effort to objectively characterize and quantify its timbre. It sought to enhance comprehension of the sound generated by this age-old Chinese musical instrument by showcasing the guqin's unique acoustic qualities.

Yang *et al.* (2024) use qualitative data analysis, including thematic and comparative approaches, to clarify the guqin's function as a cultural icon and carrier of literary motifs and topics. Interdisciplinary methods are suggested in order to enhance comprehension of Chinese cultural heritage and its various expressions in music, art, and literature. Although both the guqin and the guzheng (Sinin *et al*. 2026) are plucked string instruments from ancient China, they differ greatly in terms of appearance, string count, method of playing, and musical function. Often referred to as the instrument of the sages, (sometimes referred to by the Chinese as the father of Chinese music), the guqin is a long, narrow instrument with seven strings that has a quiet, reflective sound and has long been connected to academic endeavors and personal development. The guzheng, another Chinese long-stringed instrument with movable bridges beneath each string but no frets, should not be confused with the guqin.

With a range of roughly four octaves, the guqin is an extremely quiet instrument with open strings tuned in the bass register. Its' lowest pitch is about two octaves below middle C (C4) *i.e*., C2 (65.40Hz), the cello's lowest note. Plucking harmonics, stopped strings, and open strings creates sounds. Its use of glissando, or sliding tones, makes it sound like a slide guitar, fretless double bass, or pizzicato cello. There are 13 'hui' (stand for various positions) in a single string (Fig.1). Various 'hui' can be pressed to produce different sounds.

Fig. 1. The 13 'Hui' (visible dots) stand for various positions in a single string. Strings can be pressed at various 'hui' to produce different sounds.

The dotted spots indicate the 91 (7 strings x 13 'hui') most frequently used harmonics that the guqin can produce. According to tradition, the guqin's five strings stood for the gong, shang, jue, zhi, and yu in the ancient Chinese musical system. However, there

have been discovered ancient guqin-like instruments with one string or more strings. Seven strings are now the standard size for the modern version. Over 3,360 pieces of guqin music from the ancient and imperial eras are known to have survived. UNESCO declared the Chinese guqin to be an Intangible World Cultural Heritage on November 7, 2003. Guqin was included in China's 2006 List of National Non-material Cultural Heritage. In the traditional Chinese number system or jianpu, this system uses numbers (1 to 7) to represent musical notes, rather than letters on a staff, and is widely used in China, Taiwan, and other parts of East Asia. The most frequent tuning, zheng diao (meaning original tuning or standard tuning, refers to the standard tuning system used for the guqin), is pentatonic from the lowest to the highest pitch, 5 6 1 2 3 5 6 (which can also be performed as 1 2 4 5 6 1 2). This is because 1 equal do, 2 equals re, and so on. Since the guqin was not historically tuned to absolute pitch, this should be regarded as 'sol la do re mi sol la', even if it is commonly understood today to imply C D F G A c d (from the lowest to the highest pitch). The tuning pegs at the head end are used to change the string tension and produce other tunings. Thus, ruibin diao (raised fifth string) yields 1 2 4 5 7 1 2, which is translated to 2 3 5 6 1 2 3, and manjiao diao (slackened third string) gives 1 2 3 5 6 1 2. Table 1 displays the note range of a guqin.

Table 1. The Note Range of a Qin for Open String and Hui 1 to 13 (https://www.wikiwand.com/en/articles/Guqin)

	open	1	2	3	4	5	6	7	8	9	10	11	12	13
String7	C	C#	G#	E	C	G	E	C	A	G	F	E	A#	A
String6	D	D#	A#	F#	D	A	F#	D	B	A	G	F#	C	B
String5	F	F#	C#	A	F	C	A	F	D	C	A#	A	D#	D
String4	G	G#	D#	B	G	D	B	G	E	D	C	B	F	E
String3	A	A#	F	C#	A	E	C#	A	F#	E	D	C#	G	F#
String2	C	C#	G#	E	C	G	E	C	A	G	F	E	A#	A
String1	D	D#	A#	F#	D	A	F#	D	B	A	G	F#	C	B

Although there are other tunings, the most popular one creates an anhemitonic pentatonic scale with the notes C2-D2-F2-G2-A2-C3-D3. In this conventional tuning, a low C (C2) is the lowest note played on the thickest string that is farthest away from the musician. C6 is the highest note that may be reached. It's crucial to remember that note names frequently correspond to tuning, with the lowest note functioning as 'do' or C. Seven strings of various thicknesses make up the qin. To alter the pitch, the thumb and index finger of the left hand press the strings on the instrument's soundboard. The instrument's tonal capabilities are further enhanced by inlaid dots on the soundboard, which indicate locations on the strings where light touches might produce harmonics. Western letter notation was used to translate guqin notes. Open string notes are indicated by the letters on the left column (see Table 1), and the 'hui' 1 through 13 are represented by the numbers on top. To fully convey the guqin's expressive capabilities, musicians may employ a range of techniques during a performance. This paper thoroughly examines the Fast Fourier Transform (FFT) and the Time Frequency Analysis (TFA). The fundamental sound emission of the guqin is revealed by the FFT and TFA, which are described in this work.

Three distinctive sounds can be used to classify guqin tones. Unfettered sound is the literal meaning of the first category, 'san yin'. It is the basic frequency that is produced when the right hand's fingers pluck a free string. The second type, known as 'fan yin' (floating sound) or overtone harmonics (the equivalent technique in Western music is the

string harmonic), is produced by plucking a string with the right hand and lightly tapping specific note positions on the string with the left hand. Thirteen glossy white spots made of mica or seashell inset on the quqin's front surface indicate important scale notes, known as hui, which occur at integer divisions of the string length. Tapping the strings at this hui is the only way to evoke the crystal concordant (perfectly harmonic) overtones. Another name for this type is 'shi yin' (full sound) or 'zou yin' (changing sound). The third form is a 'yin' (pressed sound). The majority of guqin works have these as their main cadences. A 'yin' is played by stopping a string on the board surface at a particular pitch with the thumb, middle, or ring finger of the left hand, striking the string with the right hand, and then sliding the left hand up and down to change the note. Playing a slide guitar across the player's lap is comparable to this method. Guqin manipulation, on the other hand, is significantly more varied than guitar manipulation, which only has about three or four primary techniques. The book 'Cunjian Guqin Zhifa Puzi Jilan' states that there are around 1,070 distinct finger techniques for the guqin. Therefore, among the Chinese and Western instrument families, the guqin may have the most playing techniques. About 50 of the guqin's techniques are still used in contemporary performances, although the majority are no longer in use. A violin bow can occasionally be used to play the guqin. It sounds like a cello, but with a raspier tone.

The 13 inlaid dots (studs) along the soundboard of a guqin, known as hui, are composed of materials such as pearl or jade and act as visual cues for the left hand of the player to locate particular pitches, particularly while producing harmonics. In order to guide finger placement and generate desirable tones and noises, the instrument's notation refers to the hui, which are not evenly spaced but rather positioned in accordance with the harmonic structure of the instrument. The hui's main job is to direct the left hand of the musician to certain spots on the fretless strings so that particular notes may be produced. A characteristic of guqin playing is the pure, airy harmonic sound produced by lightly touching a string in a specific position and plucking it. The hui positions are essential to guqin notation, which, as demonstrated in simplified notation, uses characters and pictures to show the finger placements needed to play particular notes and produce particular sounds. Instead of representing equal spacing, the hui's placement is determined by the natural overtone series and indicates particular harmonic places for the fundamental tone. To find the pitch, the player places their left-hand finger on or close to a hui dot. The note is produced by the right hand plucking or strumming the string after placing the finger. In order to produce a bell-like tone when the string is plucked, the left-hand finger lightly touches the string at the desired position without applying pressure. In the picture below, the first hui is the dot on the right, and the thirteenth hui is the dot on the left. At first glance, the location appears somewhat arbitrary. The huis are not equally spaced, and it is not as though they are separated by a great distance before becoming closer or vice versa. Their symmetry is the sole discernible pattern. Performers frequently get some proprioceptive and haptic familiarity with the instrument during practice, which enables them to locate locations using both touch and sight. Given repeated experience and the stable spatial layout of the hui, there is no obvious physical reason why tactile localization cannot take place. However, because the hui is usually not raised or textured in a way that significantly emphasizes tactile feedback, visual guidance probably takes center stage, especially when it comes to exact positioning or for less experienced players. Therefore, a truer explanation would be that localization may require a combination of tactile and visual methods, with their relative relevance depending on performer experience and context, even though our description focused on visual cues.

A staff with an unseen treble clef is shown in Fig. 2, along with waves that have been split in half, thirds, fourths, etc. For the sake of simplicity, a string that is tuned to C in each of these cases is used. There is only one node (the twist) in the exact center of the upper wave (2nd harmonic). Therefore, the player will receive a C' if they barely touch the guqin's very center, which is the 7th hui. Going to the third harmonic, a G' note if the player positions their finger where the twists are (1/3 and 2/3) along the string. The 13 guqin hui is reached by taking all of the twists in the solid color waves above, which include the 2nd, 3rd, 4th, 5th, 6th, and 8th harmonics. Once more, there is an undetectable treble clef on the staff because the huis would become a little too packed. It is not meaningful to add two more although we would still be able to play those notes and obtain the harmonics without any problems.

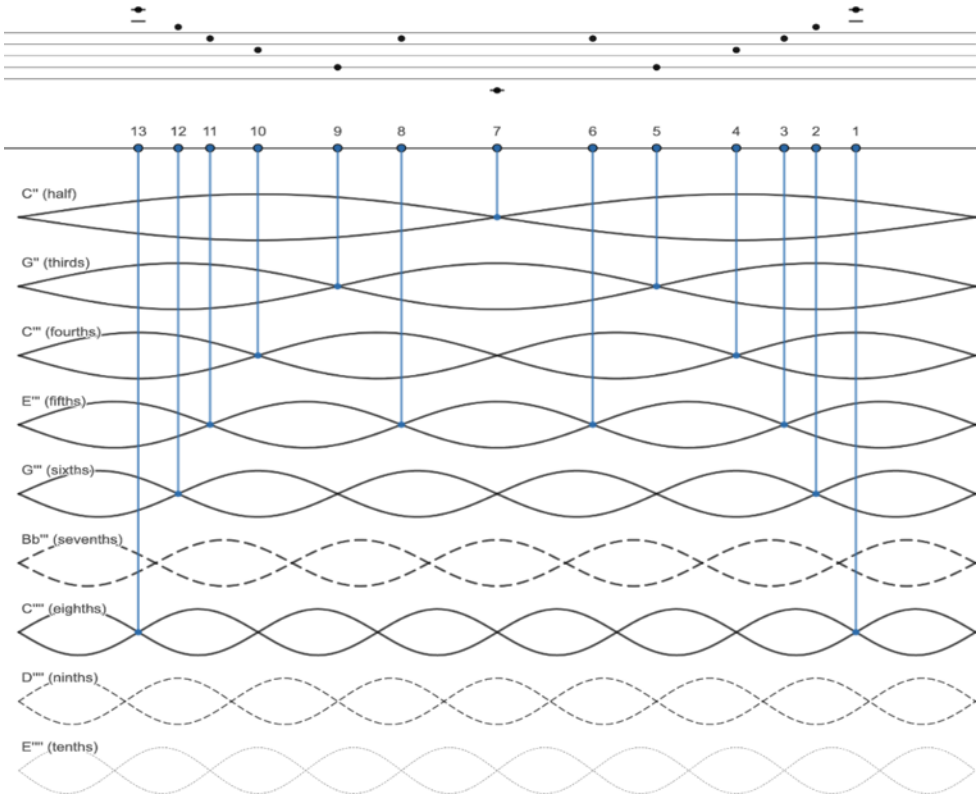


Fig. 2. The 13 guqin hui are reached by taking all of the twists in the solid color waves above, which include the 2nd, 3rd, 4th, 5th, 6th, and 8th harmonics.

EXPERIMENTAL

Another name for the guqin is the seven-stringed qin. The body is a wood sound box that is long and narrow. In general, it measures 130 cm in length, 20 cm in width, and 5 cm in thickness. Seven strings are strung along the surface, which is often composed of China fir or paulownia wood. The sound box is created in two parts. The back is a flat plate of catalpa (a catalpa is a tree of the genus *Catalpa*, known for its large leaves, showy trumpet-shaped white flowers, and long, slender seed pods. It is also known as an Indian bean or bean tree), while the front is typically carved out of paulownia (Waltham *et al.* 2016). *Paulownia elongata* is the main wood used in modern soundboards. Around 1965, large amounts of this fast-growing tree were planted in Lankao County, Henan province,

to protect agricultural fields, act as a windbreak, and reduce dust. When someone realized that the dust control technique could be used to produce high-quality lumber for musical instruments, it suddenly became profitable. Báihuā pāotóng, another name for *Paulownia fortunei*, was a common instrument wood before 1965. It is in the same genus as *Paulownia elongata* and is still sold as the wood used in the guqin. Figure 3 shows the guqin use in this study.

Fig. 3. The guqin used in this study

To remove outside sound reflections, all recordings were made in an anechoic room. To record the emitted sound, an omnidirectional polar pattern microphone was placed 20 cm in front of the guqin. In order to simulate normal playing settings and provide the best possible sound resonance, it was plucked in a traditional sitting position. A PicoScope 3000 series oscilloscope and related data recorder (Pico Technology, Eaton Socon, UK) were used to record the sound signals in real time. Waveform viewing, spectrum visualization, Fast Fourier Transform (FFT) analysis, and voltage-based triggering were all made possible by the PicoScope software. Figure 4 shows the equipment utilized in the experimental setting.

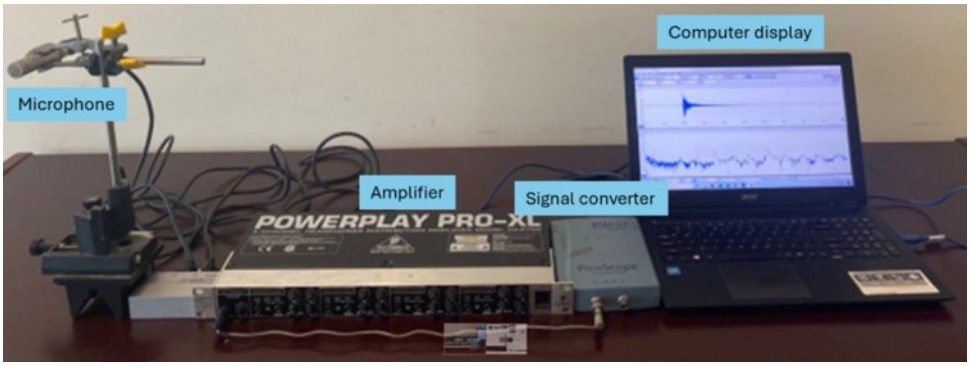


Fig. 4. The apparatus used in the experimental setup

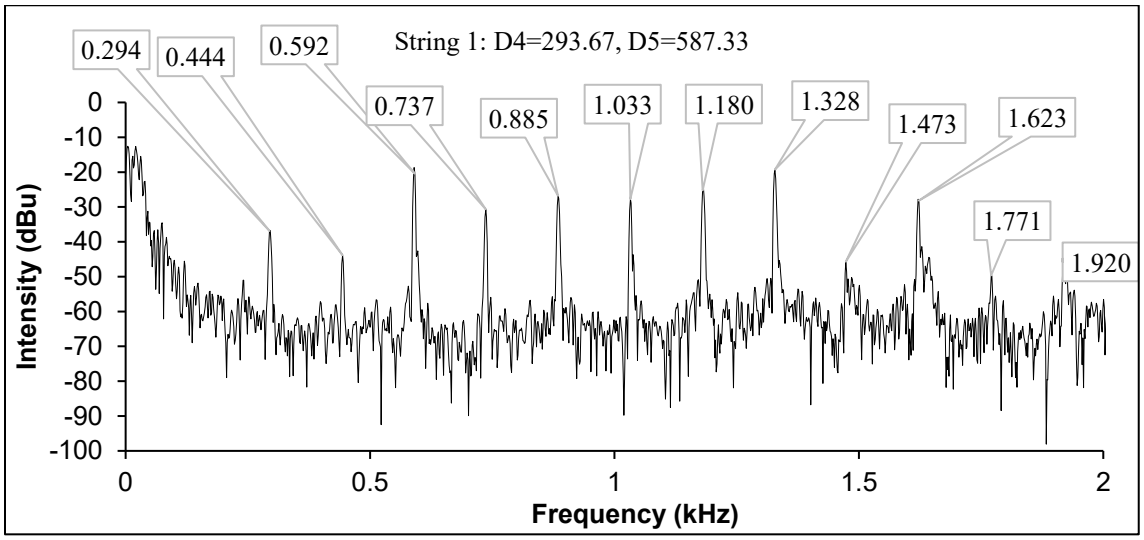
The guqin was recorded in the same way, with a fixed microphone position and orientation, to avoid distortion or bias. Prior to being processed by the PicoScope, the signal was amplified using a Behringer Powerplay Pro XL amplifier (Zhongshan, Guangdong, China). Adobe Audition was used to examine the obtained sound spectra, extracting dominant frequencies and assessing tonal characteristics through the use of FFT analysis. Finding the fundamentals, harmonics, and subharmonics in the recorded waveforms was made possible by the Fourier Transform technique. During several trials, sound data from the guqin was gathered. The same settings were used to record each iteration, and the waveforms that were produced were averaged to minimize noise and variability. An accurate and significant acoustic comparison was guaranteed by this method. A clear, accurate, and scientifically reliable comparison of the guqin's acoustic performance is ensured by the methodology, which uses controlled plucking, constant recording

parameters, and numerous rounds of measurement with averaged results. The guqin's plucking was done by a proficient musician to guarantee precise and consistent sound production. Using the same method and force on every try, consistency was guaranteed. To reduce human error and improve the accuracy of the sound comparison, the player practiced the exact movements several times before recording.

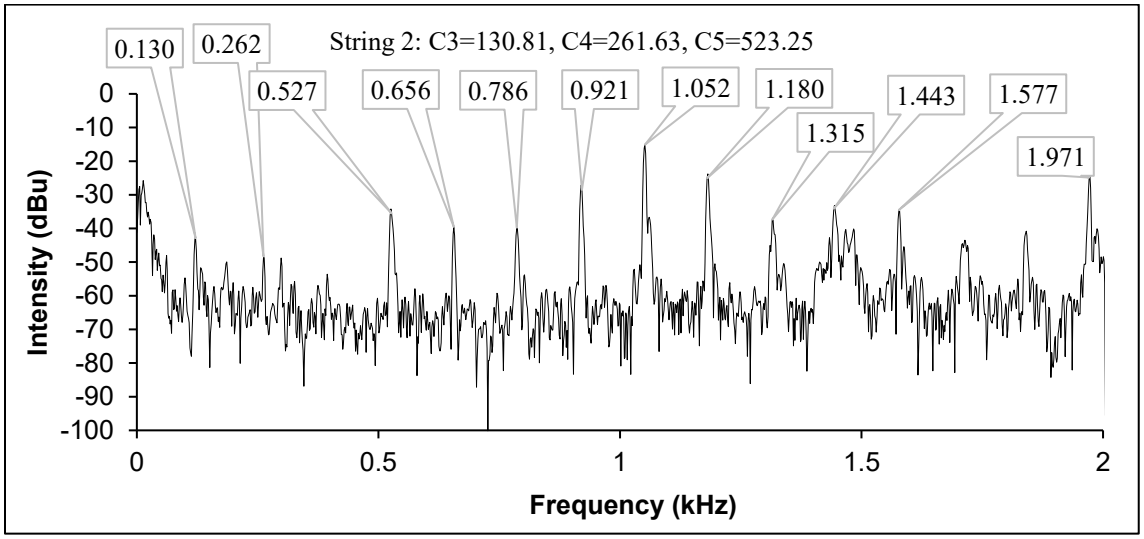
Quqin playing sessions were recorded in monophonic format at a sample rate of 48 kHz and a resolution of 24 bits. A Hann window to minimize spectral leakage and a Fast Fourier Transform (FFT) with a window length of 4096 samples were used for spectral analysis. This arrangement produces a frequency resolution of about 11.72 Hz ($\Delta f = f_s/N$), which is adequate to resolve the guqin tones' fundamental frequencies and harmonic structure across their usual range. In this equation, f_s represents the sampling frequency (48 kHz) and N denotes the FFT window length (4,096 samples). This resolution is suitable for examining the fundamental frequencies and harmonic structures of the guqin tones across their usual range. Analysis of frequency components up to 24 kHz is made possible by the 48 kHz sampling rate, which guarantees the preservation of timbral features and higher-order harmonics. The chosen FFT size strikes a balance between frequency and temporal resolution, allowing harmonic content to be clearly identified while retaining sufficient temporal precision to monitor pitch changes and expressive methods like vibrato and sliding tones. However, very fast transients may be slightly smeared because of the limiting window length, which reflects the intrinsic trade-off in time-frequency analysis.

RESULTS AND DISCUSSION

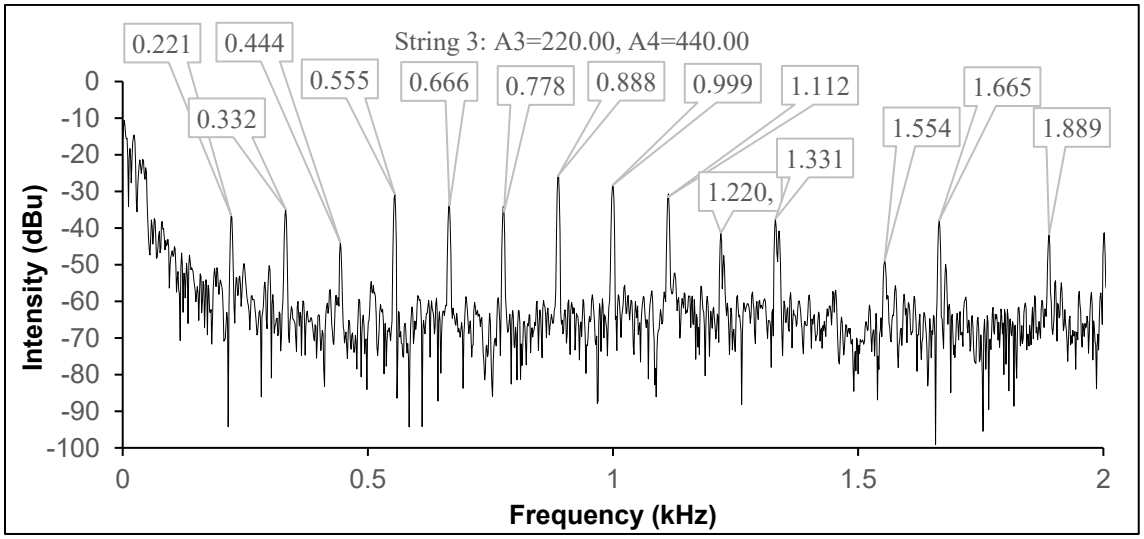
Figure 5 shows the FFT spectra for string 1 to 7 from the PicoScope. Although the sound of the lowest to the highest pitch was perceived as: C2 (65.40), D2 (73.41), F2 (87.30), G2 (97.99), A2 (110.00), C3 (130.81), and D3 (146.83), the results from the PicoScope showed the sound from the lowest to the highest pitch as: C3(130.81), D3 (146.83), F3(174.61), G3(196.00), A3 (220.00), C3 (130.81), and D4 (293.67). Only string 2 showed the fundamental frequency similar with the perceived sound whereas other stings displayed the fundamental frequency one octave higher than the perceived sound. The PicoScope recorded a frequency that corresponded to C3, although the listener believed the note was C2. This anomaly can be explained by octave perception mistakes, harmonic confusion, or psychoacoustic effects. Even when the basic pitch is not physically present, human ears can occasionally detect it. The brain may interpret C2 as the fundamental if the sound has strong C2 harmonics (such as C3 and C4). The ear interprets or identifies the pattern, and the PicoScope displays the real frequencies. For instance, if harmonics that belong to C2 (65.40 Hz) are present on string 7 along with C3 (130.81 Hz) as a high peak, the listener may perceive C2. Sometimes, especially with low-frequency notes, people misinterpret a tone's octave. Because there are no reference pitches and the listener are used to instruments that accent lower fundamentals, a C3 note could be wrongly perceived as a C2. Strong overtones produced by certain instruments have the potential to obscure the fundamental. Even though the lower pitch is not acoustically dominant, a listener may detect it if C3 is dominant and C2 is weak or implied.



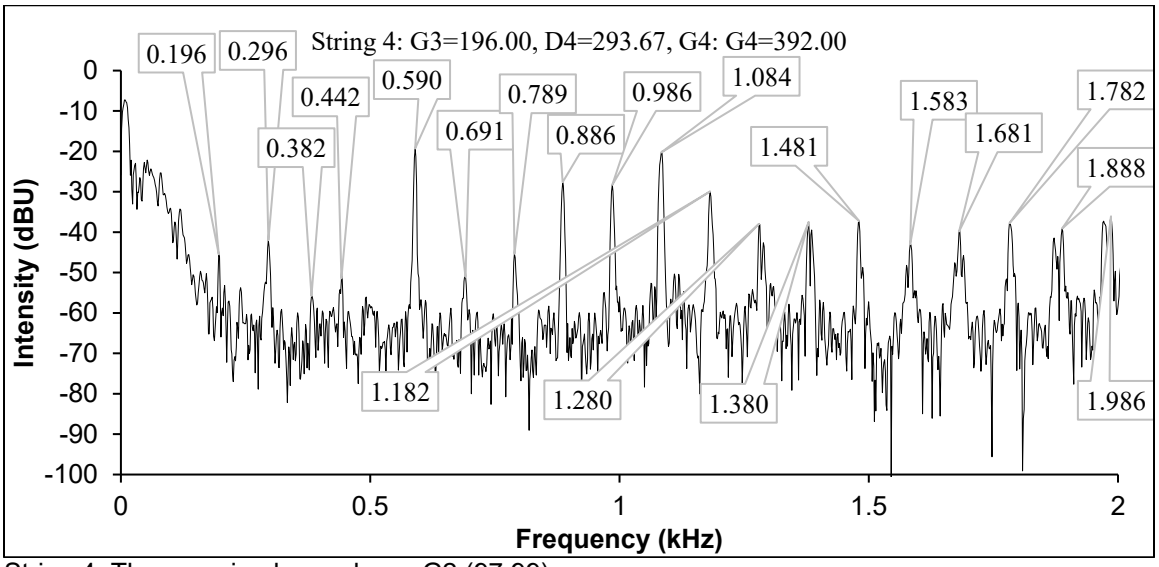
String 1: The perceived sound was D3 (146.83)



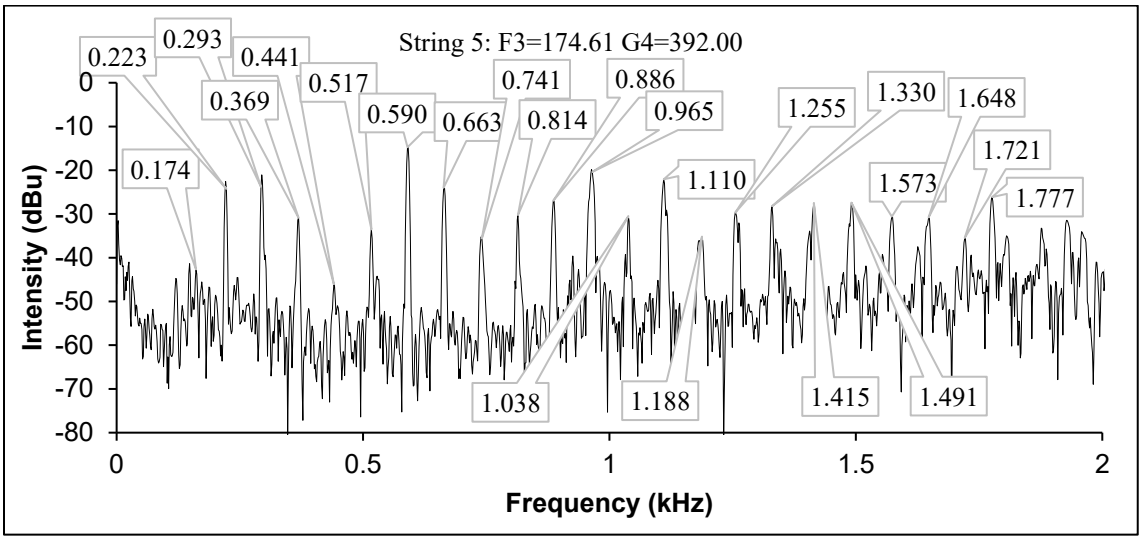
String 2: The perceived sound was C3 (130.81)



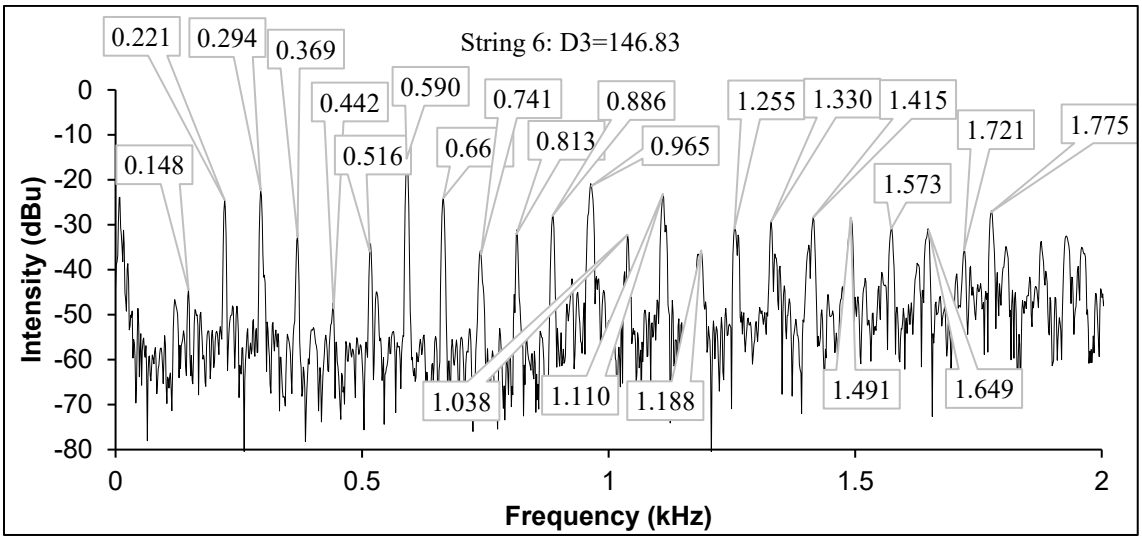
String 3: The perceived sound was A2 (110.00)



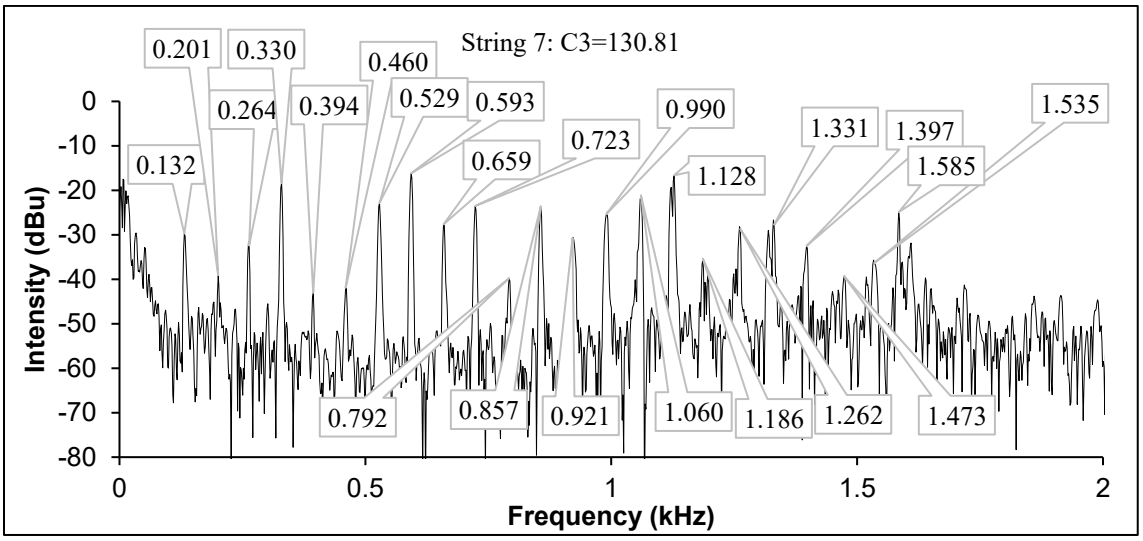
String 4: The perceived sound was G2 (97.99)



String 5: The perceived sound was F2 (87.30)



String 6: The perceived sound was D2 (73.41)



String 7: The perceived sound was C2 (65.40)

Fig. 5. The Fast Fourier Transform (FFT) spectra for string 1 to 7 from the PicoScope

The current observations are in line with the theoretical predictions of psychoacoustics, despite the fact that the missing fundamental phenomenon is well established. There was no discernible fundamental frequency in the spectra of strings 1, 3, 4, 5, 6, and 7, which is consistent with the hypothesis that listeners deduce the fundamental from the harmonic series. Additionally, some instrument-specific details are provided by the results. Specifically, the selective lack of the fundamental throughout these strings indicates that the relative suppression of the fundamental component may be influenced by factors like resonance characteristics, excitation technique, or string structure. This illustrates how the missing fundamental effect appears in this particular physical system and may help develop more thorough models of sound production and radiation in comparable instruments, even though it does not contradict current theories.

From Fig. 5, the tunings are in the tonal relationships for the seven strings as shown in Table 2, which displays the fundamental and higher partial frequencies for string 1 to 7. From Table 2, Fig. 6 was plotted to show the changes in partial frequencies *versus* the harmonic number (harmonic number =1 is for fundamental frequency).

Table 2. The Fundamental f_1 and Higher Partial Frequencies f_n for string 1 to 7

Harmonic Number (f_n /f_1)	String1	String2	String3	String4	String5	String6	String7
1	294	130	221	196	174	148	132
2	592	262	444	382	369	294	264
3	885	-	666	590	517	442	394
4	1180	527	888	-	741	590	529
5	1473	656	1112	986	886	741	659
6	1771	786	1331	1182	1038	813	723
7	-	921	1554	1380	1188	886	792
8	-	1052	-	1583	1415	965	857
9	-	1180	-	1782	1573	1038	921
10	-	1315	-	1966	1721	1110	990

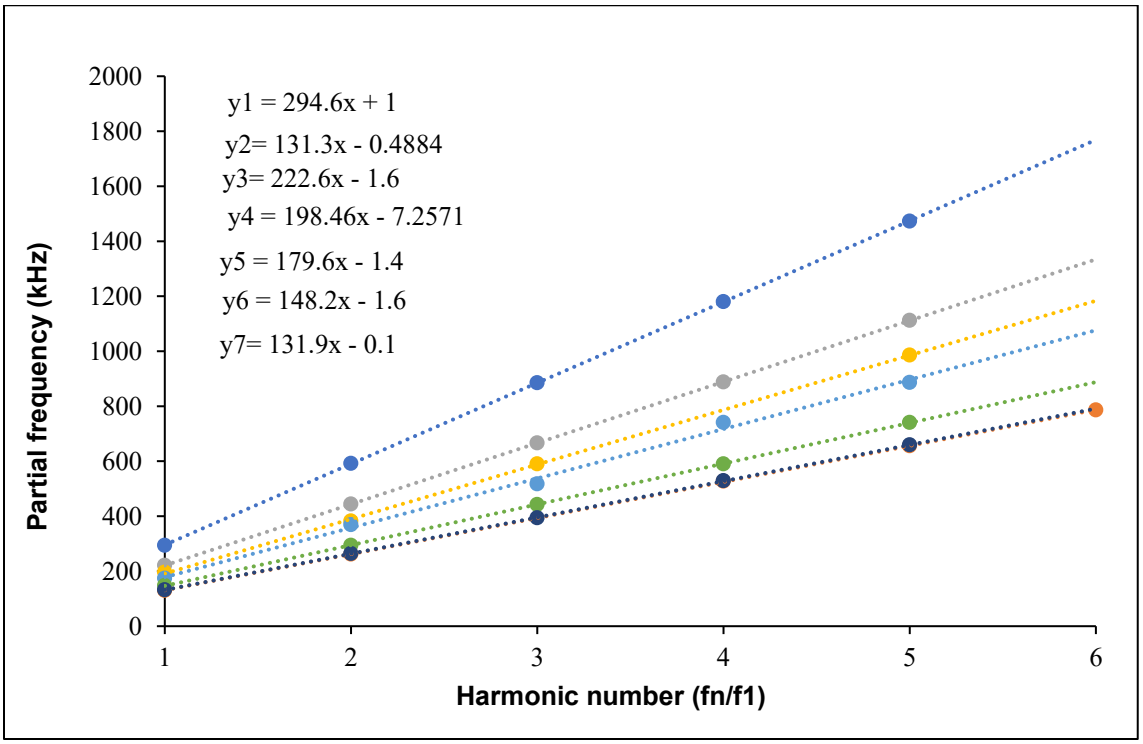
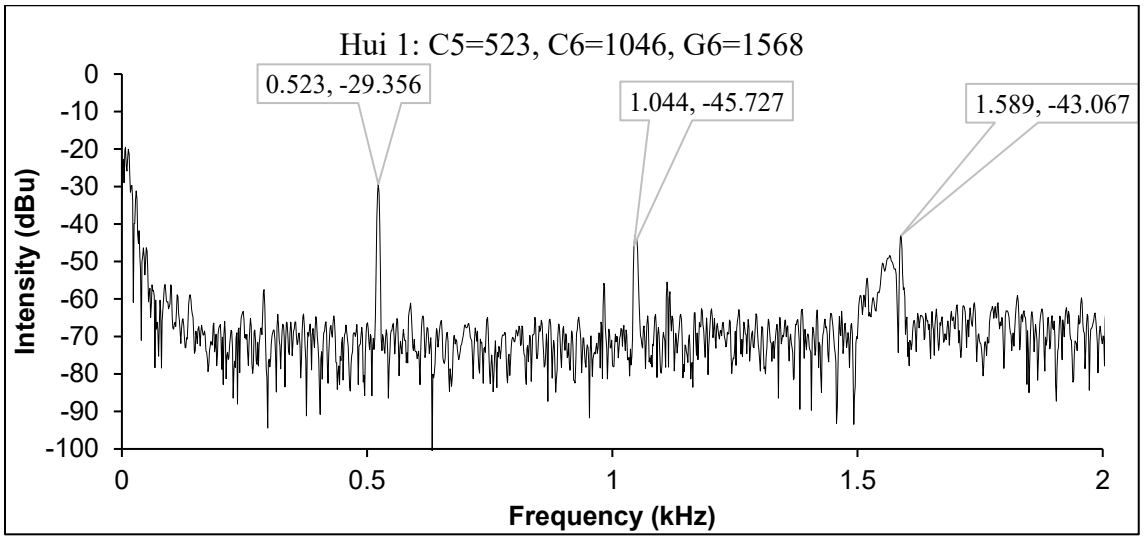


Fig. 6. The partial frequency (Hz) *versus* the harmonic number (f_n /f_1) for string 1 to 7 (harmonic number = 1 is for fundamental frequency.

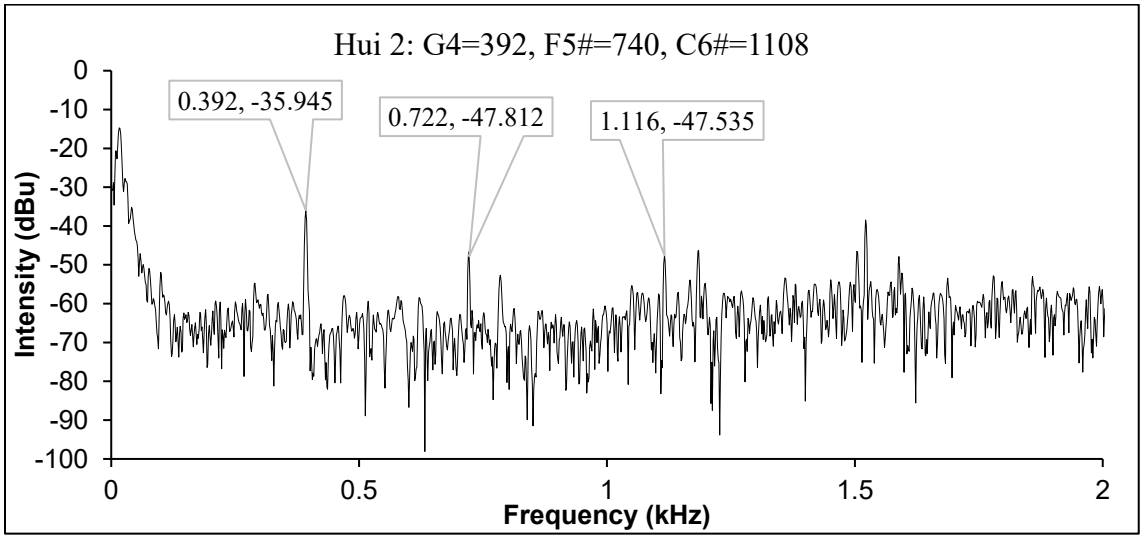
The linear equation (eq. y1 to y7 from Fig. 6) for the partial frequency (kHz) *versus* the harmonic number (f_n /f_1) from string 1 to 7 is given as follows (the number in the bracket is the fundamental frequency f_1 of the strings):

y1 = 294.6x + 1 eq.1 (f_1=294)
y2 = 131.3x - 0.5 eq.2 (f_2=130)
y3 = 222.6x - 1.6 eq.3 (f_3=221)
y4 = 198.46x - 7.3 eq.4 (f_4=196)
y5 = 179.6x - 1.4 eq.5 (f_5=174)
y6 = 148.2x - 1.6 eq.6 (f_6=148)
y7 = 131.9x - 0.1 eq.7 (f_7=132)

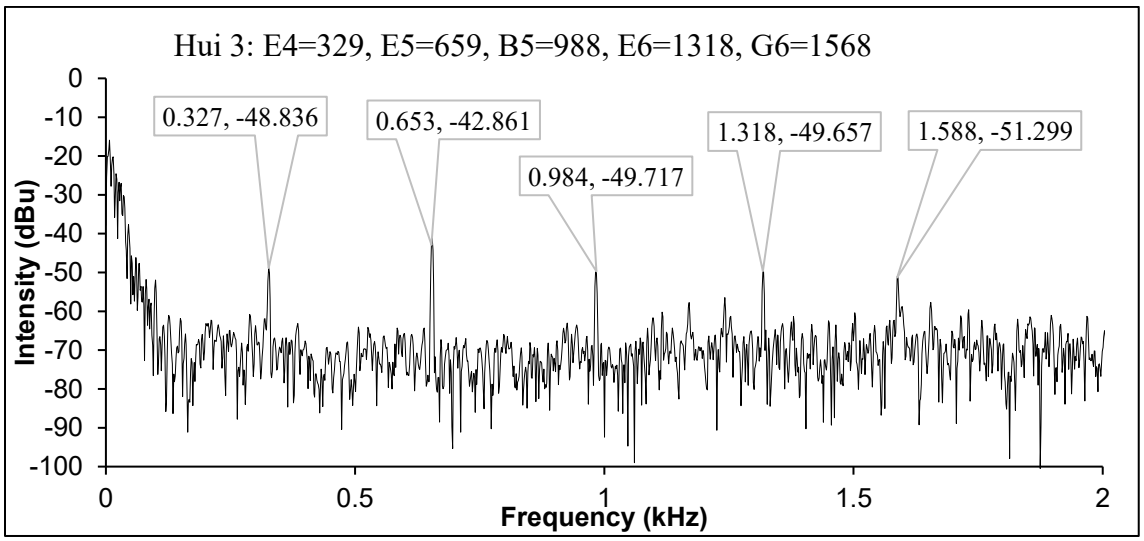
The linear relationship between the partial frequency (kHz) *versus* the harmonic number (f_n /f_1) demonstrated that the gradient of the equation is similar to the fundamental frequency of all the seven open strings. Figure 7 shows the FFT spectra for hui 1 to 13 from string 7.



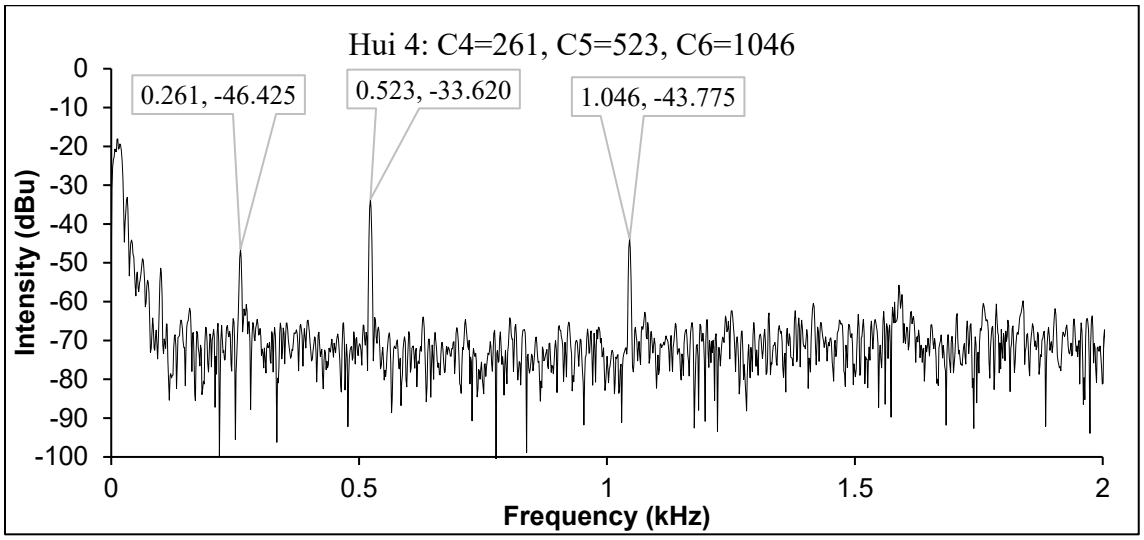
Hui 1: 523 (C5=523), 1044 (C6=1046), 1589 (G6=1568)



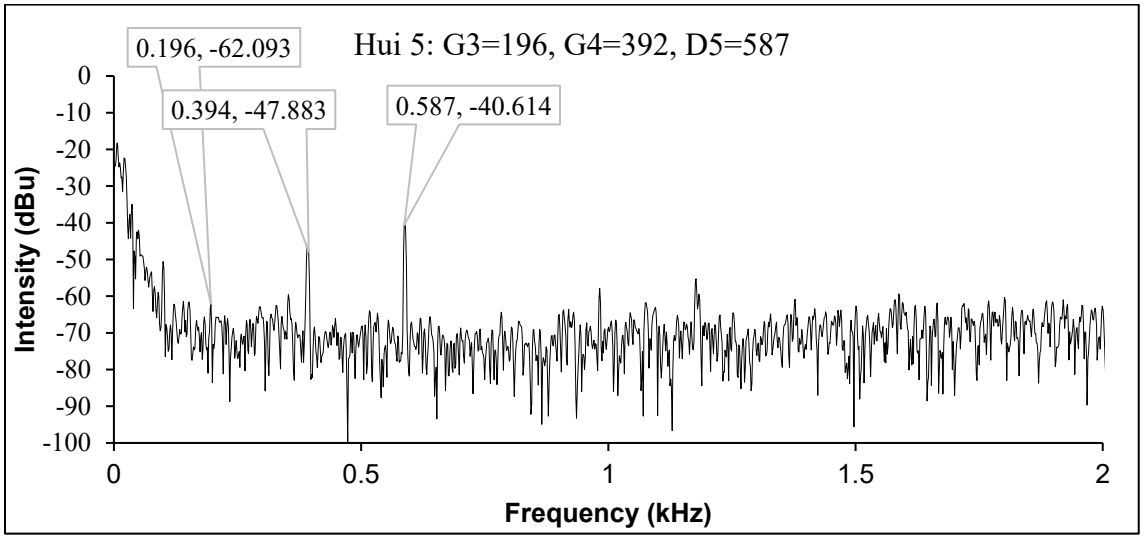
Hui 2: 392 (G4=392), 722 (F5#=740),1116 (C6#=1108)



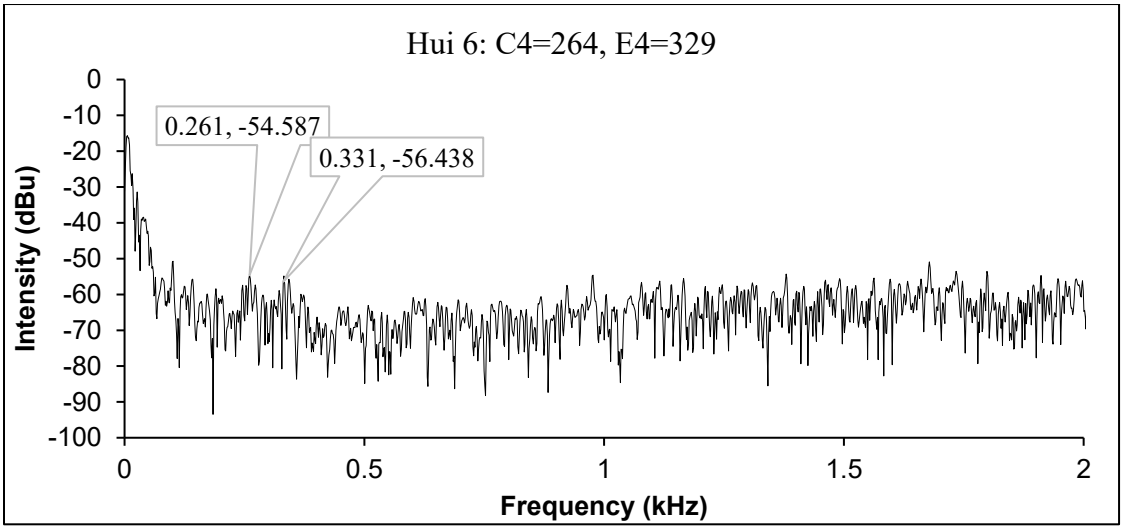
Hui 3: 327 (E4=329), 653 (E5=659), 984 (B5=988),1318 (E6=1318),1588 (G6=1568)



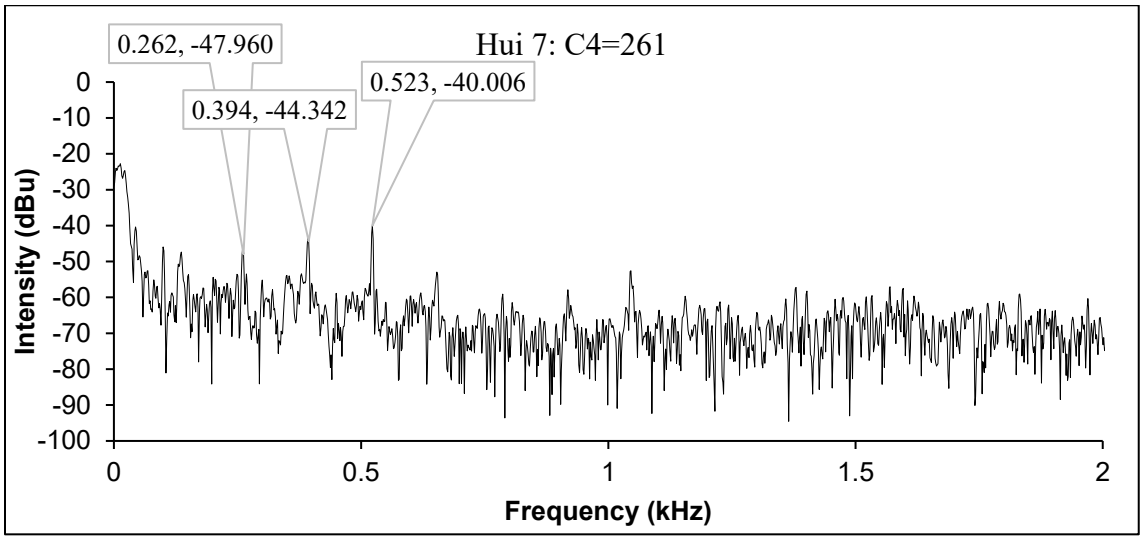
Hui 4: 261 (C4=261), 523 (C5=523),1046 (C6=1046)



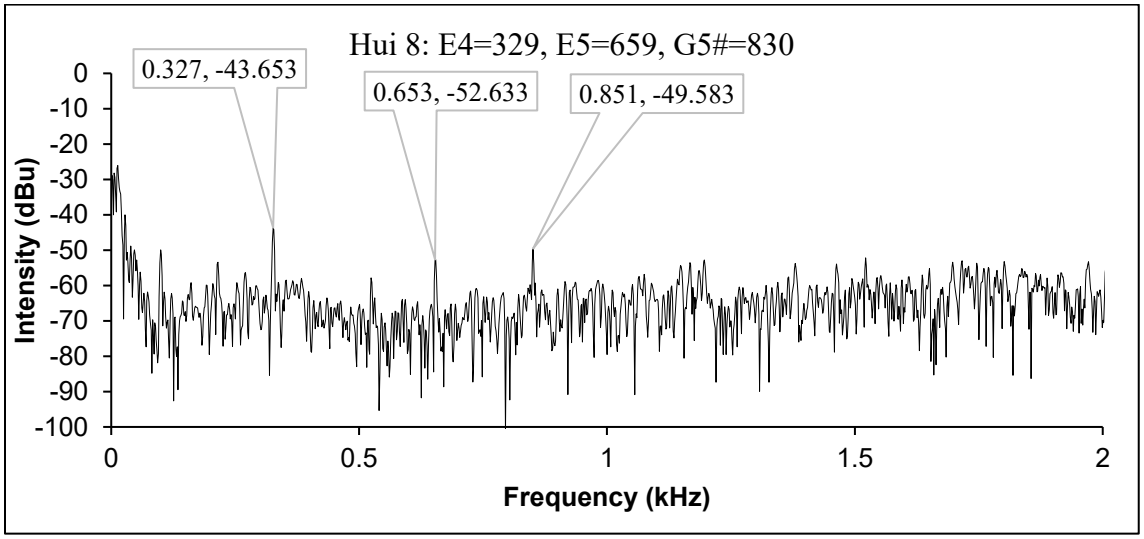
Hui 5: 196 (G3=196), 394 (G4=392), 587 (D5=587)



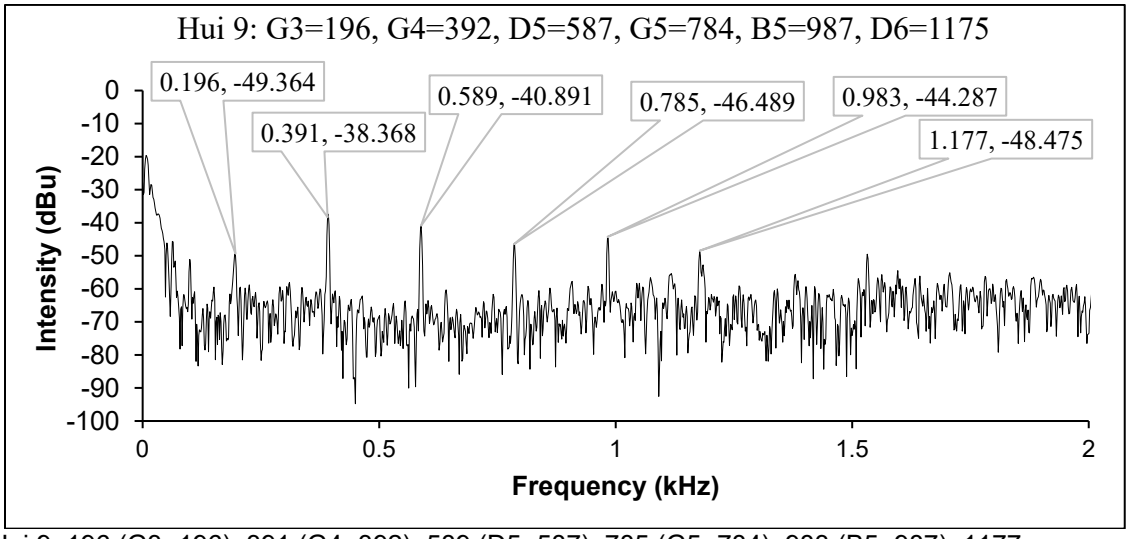
Hui 6: 261 (C4=264), 331 (E4=329)



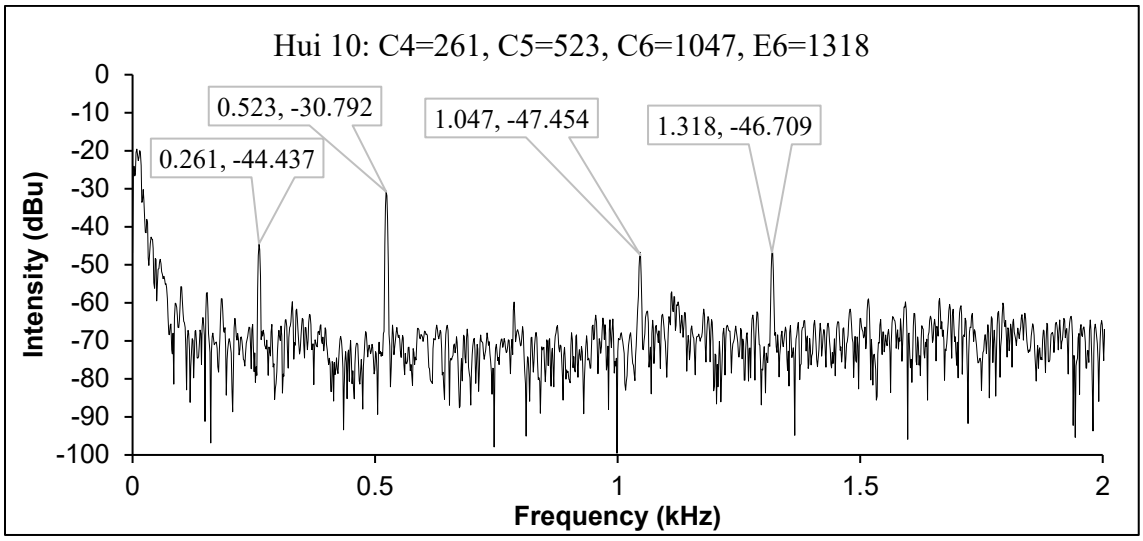
Hui 7: 262 (C4=261), 394 (G4=392), 523 (C5=523)



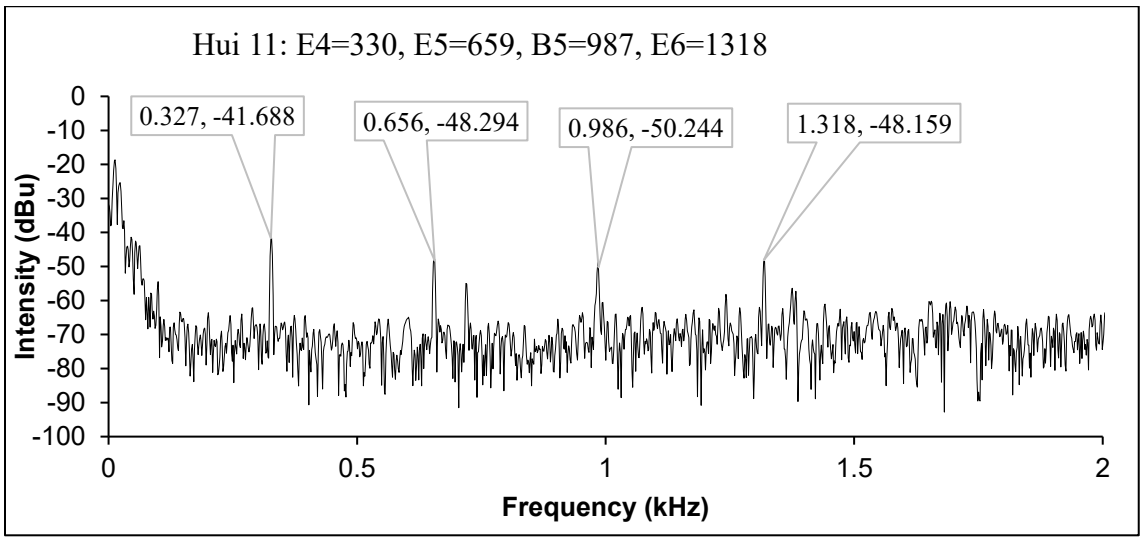
Hui 8: 327 (E4=329), 653 (E5=659), 851 (G5#=830)



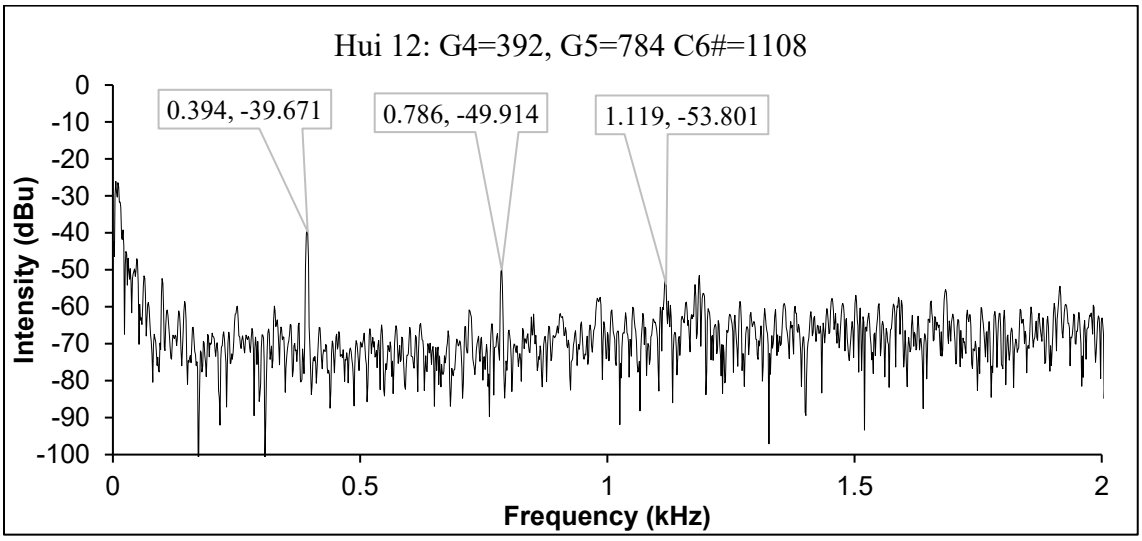
Hui 9: 196 (G3=196), 391 (G4=392), 589 (D5=587), 785 (G5=784), 983 (B5=987), 1177 (D6=1175)



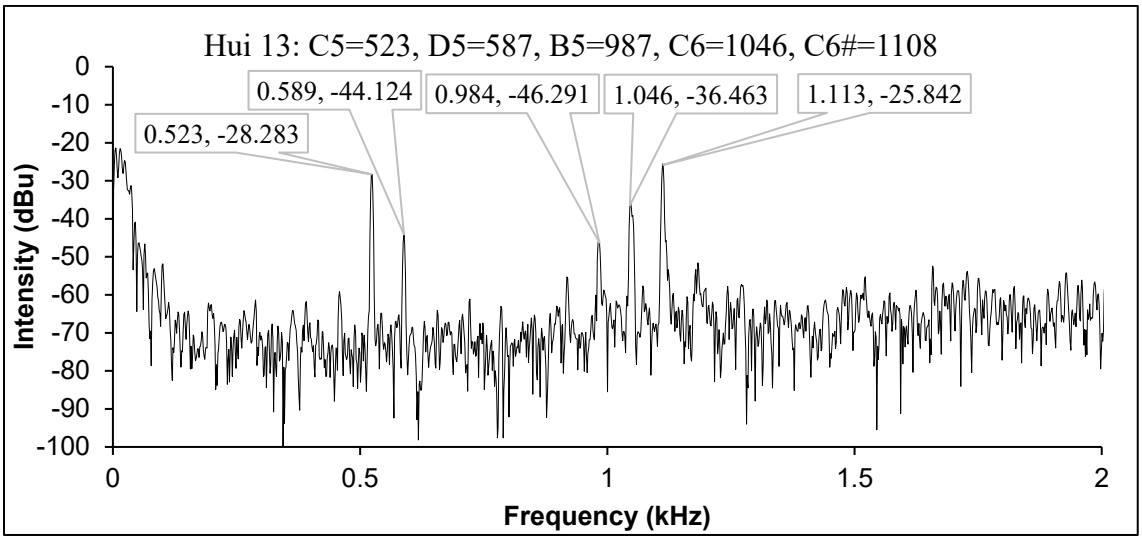
Hui 10: 261 (C4=261), 523 (C5=523),1047 (C6=1047),1318 (E6=1318)



Hui 11: 327 (E4=330), 656 (E5=659), 986 (B5=987), 1318 (E6=1318)



Hui 12: 394 (G4=392), 786 (G5=784),1119 (C6#=1108)



Hui 13: 523 (C5=523), 589 (D5=587), 984 (B5=987), 1046 (C6=1046), 1113 (C6#=1108)

Fig. 7. The Fast Fourier Transform (FFT) spectra for the 13 Hui from string 7

The 1st harmonic is obtained from the open string (Fig. 5). From Fig. 2 (a staff with an unseen treble clef along with waves that have been split in half, thirds, fourths, etc.) the 2nd, 3rd, 4th, 5th, 6th and 8th harmonics are obtained from hui 7, (hui 5 and 9), (hui 4 and 10), (hui 3, 6, 8 and 11), (hui 2 and 12) and (hui 1 and 13) positions.

From Fig. 7 the fundamental frequency (and note) at the hui position for 7th string is shown in Table 3. Their symmetry pattern as seen in Fig. 2, along with waves that have been split in half, thirds, fourths, *etc.*, is discernible in Table 3 with the exact center (2nd harmonic) as C4 at the 7th hui.

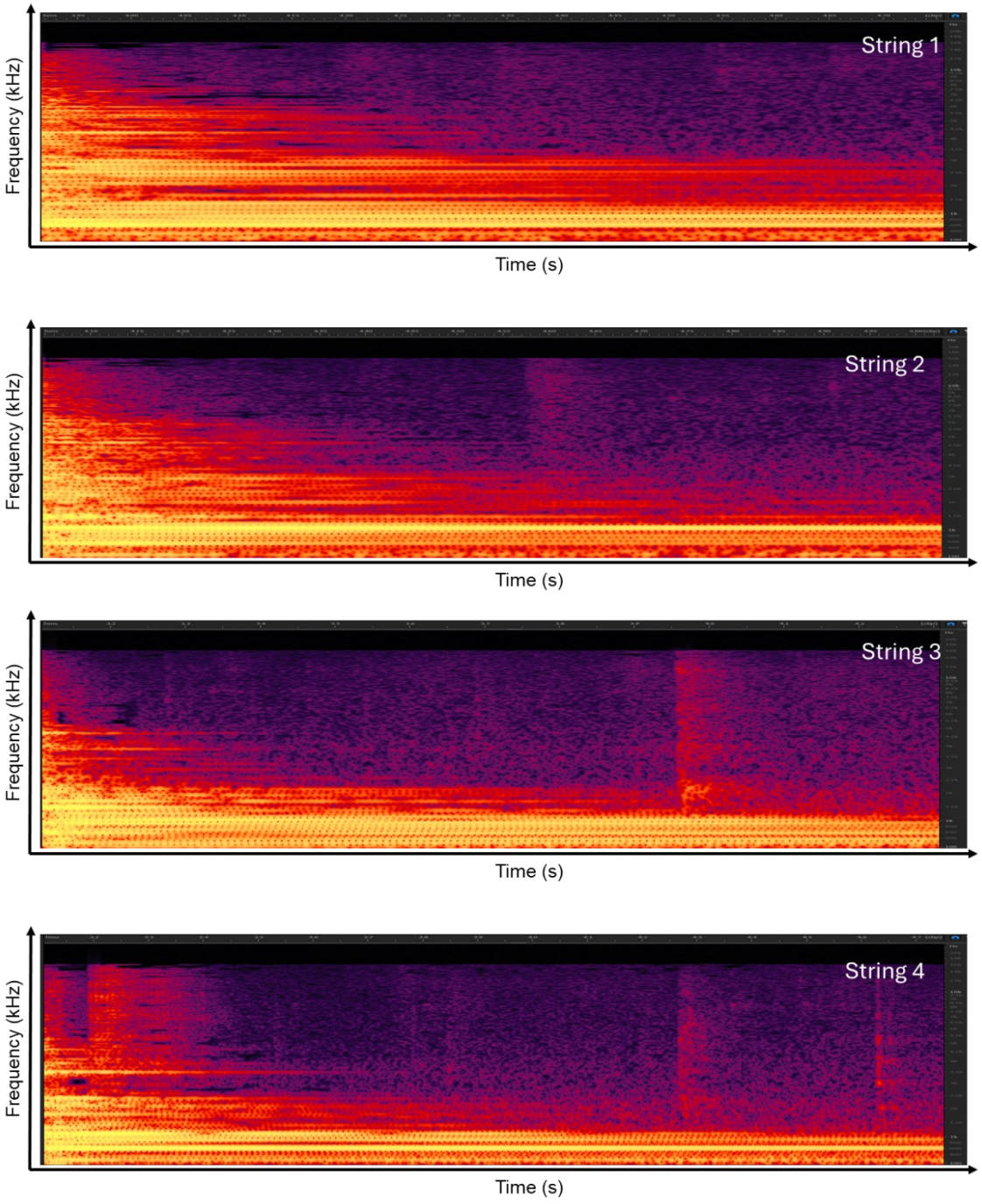
Table 3. The 1st, 2nd, 3rd, 4th, 5th, 6th and 8th Harmonics Fundamental Frequency (Hz) Obtained from the Open 7th String and the 13 Hui

Harmonic	Hui	Frequency (note)	Perceived
1st	open string	132(C3)	C2
2nd	7	262(C4)	C4
3rd	5 & 9	196(G3)	G3
4th	4 & 10	261(C4)	C4
5th	3, 6, 8, 11	327(E4)	E4
6th	2, 12	392(G4)	G4
8th	1, 13	523(C5)	C5

The 1st harmonic as perceived on the open string 7th occurred at 65.4Hz (C2), whereas the PicoScope recorded 132Hz (C3=130.81). The 2nd harmonic, which occurred at 1/2 the string length, *i.e.*, hui 7, occurred at 262 (C4=261), 394 (G4=392), and 523 (C5=523.24). The 3rd harmonic at 1/3 and 2/3 the string length, *i.e.*, hui 5 and hui 9, occurred at 196 (G3=196), 394 (G4=392), 587 (D5=587) and 196 (G3=196), 391 (G4=392), 589 (D5=587), 785 (G5=784), 983 (B5=987), and 1177 (D6=1175), respectively. The 4th harmonic which occurred at 1/4 and 3/4 the string length, *i.e.*, hui 4 and hui 10, occurred at 261 (C4=261), 523 (C5=523), 1046 (C6=1046) and 261 (C4=261),

523 (C5=523),1047 (C6=1047), and 1318 (E6=1318) respectively. The 5th harmonic, which occurred at 1/5 and 4/5 the string length, *i.e*., hui 3, 6, 8, and 11, occurred at 327 (E4=329), 653 (E5=659), 984 (B5=988), 1318 (E6=1318), 1588 (G6=1568), and 261 (C4=264), 331 (E4=329), and 327 (E4=329), 653 (E5=659), 851 (G5#=830), and 327 (E4=330), 656 (E5=659), 986 (B5=987), and 1318 (E6=1318) respectively. The 6th harmonic, which occurred at 1/6 and 5/6 the string length, *i.e.*, hui 2 and 12, occurred at 392 (G4=392), 722 (F5#=740), 1116 (C6#=1108) and 394 (G4=392), 786 (G5=784), and 1119 (C6#=1108) respectively. The 8th harmonic, which occurred at 1/8 and 7/8 the string length, *i.e.*, hui 1 and 13, occurred at 523 (C5=523), 1044 (C6=1046), 1589 (G6=1568) and 523 (C5=523), 589 (D5=587), 984 (B5=987), 1046 (C6=1046), and 113 (C6#=1108), respectively.

Gaining an understanding of the guqin's sound, structure, technique, and cultural background enables one to set out on a journey that promises to be fruitful in exploring sound and culture. The guqin is a remarkable instrument that can provide insights into China's vast musical history. The guqin entices with its deep historical significance and profound tranquility, making it an ideal medium for quiet reflection and introspection. It was hypothesized in this study that the guqin's non-fret-based pitch system yields measurable polynomial relationships between the partial frequency and the harmonic number across all seven strings, and that the instrument's tonal and acoustic qualities can be systematically examined using frequency and time-frequency methods. Furthermore, it was proposed that the physical structure and tuning of the instrument are reflected in the harmonic content changes between the strings, providing fresh perspectives on the instrument's acoustic character and artistic versatility. The results' relationship to acoustics became more evident as a result of the sound analysis process, namely how the partial frequencies, harmonic content, and polynomial fitting of pitch frequencies of each string aid in understanding of the instrument's tonal structure and intonation behavior. The time frequency analysis (TFA) from Adobe Audition is displayed in Fig. 8. String 1 with the highest pitch displayed very bright yellow color compared to string 7 with the lowest pitch with less bright yellow color.


String 1
Frequency (kHz)
Time (s)
String 2
Frequency (kHz)
Time (s)
String 3
Frequency (kHz)
Time (s)
String 4
Frequency (kHz)
Time (s)

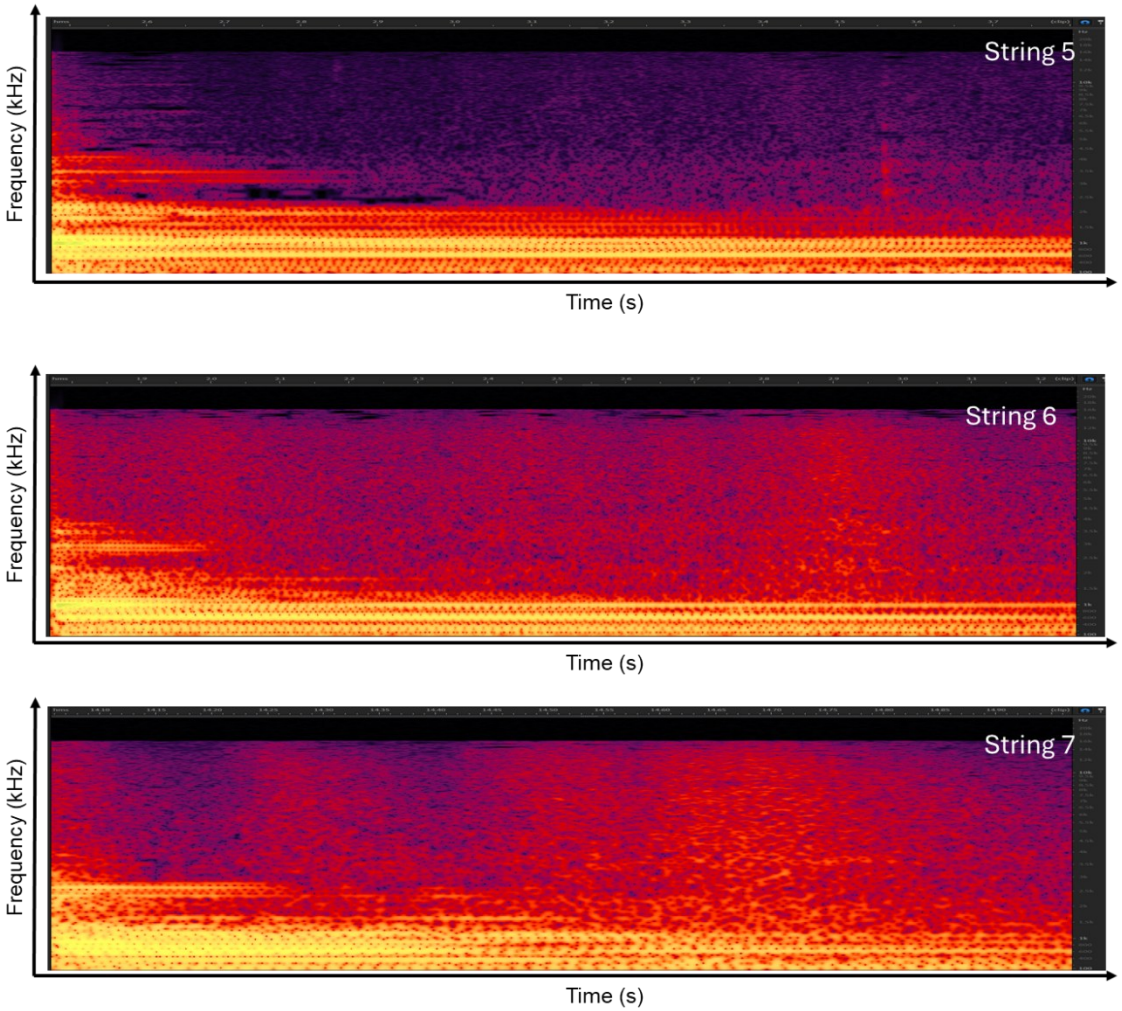


Fig. 8. The time frequency analysis (TFA) from Adobe Audition

CONCLUSIONS

1. This study used frequency-domain (FFT) and time-frequency analyses to investigate the guqin's acoustic properties. The findings demonstrate that the measured spectra for the majority of open strings lack a significant fundamental component, yet the perceived pitch is associated with a lower frequency. This finding is in line with the well-known missing fundamental phenomena in psychoacoustics, which states that even in cases when the fundamental frequency is not physically dominant, the auditory system deduces it from the harmonic series. Therefore, rather than being an abnormality, the difference between the PicoScope readings and perceived pitch validates established auditory processing systems.

2. The overtones follow an almost harmonic sequence, with gradients closely matching the observed fundamental (first noticeable spectral component), according to the linear connections found between partial frequency and harmonic number over all seven strings. This validates the hypothesis that the guqin generates well-structured harmonic content controlled by string vibration physics in spite of its fretless construction. The little variations in intercepts are probably the result of measurement errors or inharmonicity brought on by the characteristics of the strings and playing style.
3. Predictable harmonic behavior is further shown by analysis of the hui positions, with nodes at fractional string lengths (such as 1/2, 1/3, and 1/4) generating the anticipated overtone series. The symmetry of these locations and the frequencies that correspond to them supports established string vibration theory and validates the physical foundation of harmonic production on the instrument.
4. Time-frequency analysis also reveals differences in the spectral energy distribution between strings, with larger high-frequency components found in higher-pitched strings. This draws attention to variations in timbral brightness that add to the expressive range of the guqin.
5. Overall, the results do not point to essentially novel occurrences and are in line with accepted acoustic theory. Nonetheless, they offer a methodical description of how well-known concepts, such as the behavior of harmonic series and the absence of the basic effect-appear in the guqin. By placing the findings into the larger framework of musical acoustics rather than presenting them as new discoveries, this advances our understanding of the instrument's tonal structure and supports both acoustical analysis and performance practice.

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