

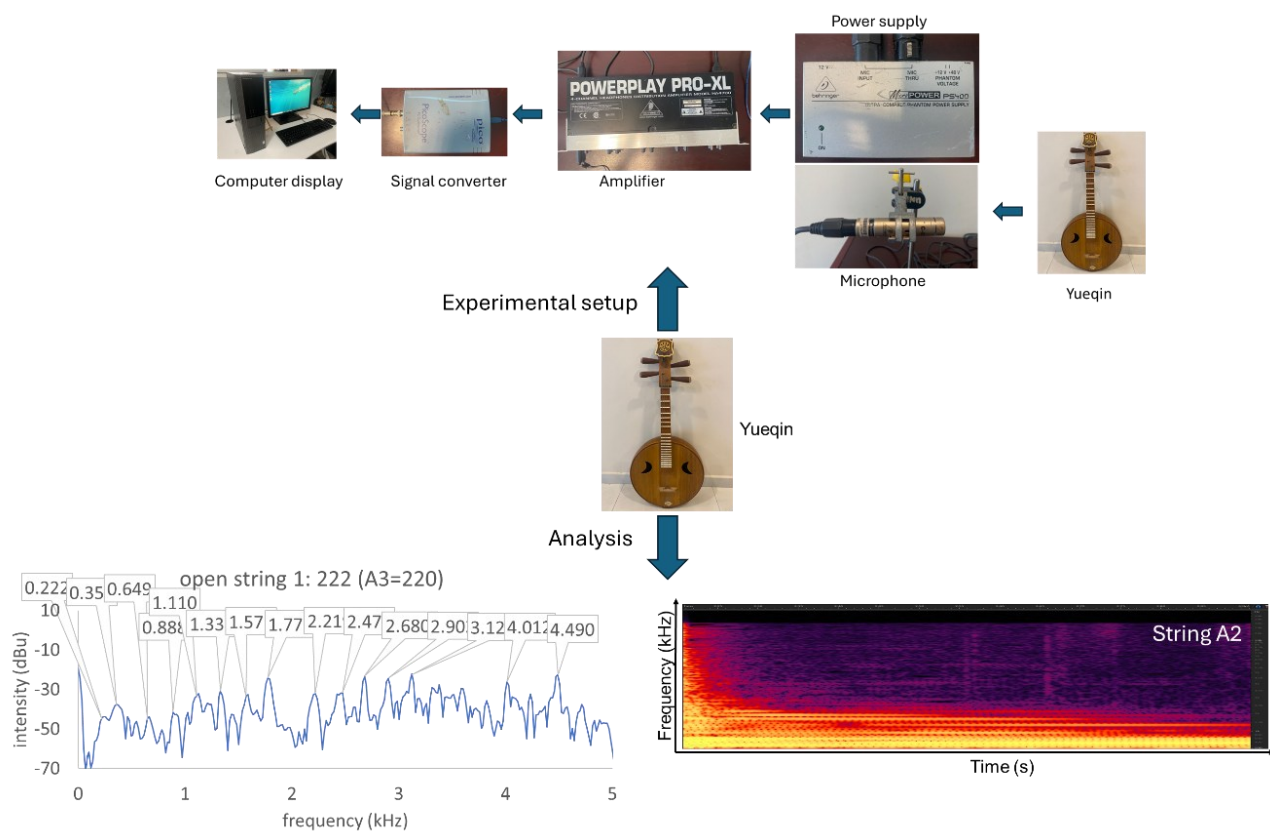
Yueqin: A Classic Chinese Plucked Guitar

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DOI: 10.15376/biores.21.3.5808-5821

GRAPHICAL ABSTRACT



Yueqin: A Classic Chinese Plucked Guitar

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The most notable characteristic of the *yueqin* is its high frets. A PicoScope oscilloscope and related data recorder were used to record the sound signals in real time. Fast Fourier Transform (FFT) analysis, and voltage-based triggering were all made possible by PicoScope software. The PicoScope recorded the fundamental frequency for open strings 1, 2, 3, and 4 as 222 Hz (A3=220), 146 Hz (D3=146), 222 Hz (A3=220), and 292 Hz (D4=294), respectively. The strings 1, 2, 3, and 4 were perceived as A3, D3, A2, and D2, respectively. The measured frequencies were not in accordance with perceived notes due to the phenomenon in which the listener claimed to recognize the note D2 when they actually heard D4. This is the well-known phenomenon of the 'missing fundamental'. The frequency between the frets follows a musical system that might change depending on the tuning and regional tradition. The running note for open string 1 is A3 and fret 1, 2, 3, 6, 7, 9, 11, 13, 14, 16, 18, 20, 22 and 23 are B3, C4, D4, E4, F4, G4, A4, B4, C5, D5, E5, F5, G5, A5 whereas fret 4, 5, 8, 10, 12, 15, 17, 19, and 21 have the notes D4[↑], D4[↓], F4[↓], G4[↑], A4[↓], C5[↑], D5[↑], F5[↓], and F5[↑] respectively.

DOI: 10.15376/biores.21.3.5808-5821

Keywords: Yueqin; Fast Fourier Transform (FFT); Lü; Equal temperament

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INTRODUCTION

The *yueqin* is a classic Chinese plucked string instrument (*qin*) that gets its name from its circular shape, which has become associated with the full moon (*yue*). It is a hollow-bodied lute with a short neck that usually has four strings tuned in pairs. The *yueqin* is renowned for its use in Beijing Opera and other regional groups, where singers are accompanied by its bright and penetrating sound. The round, hollow soundboard is its most distinguishing characteristic. Although there are regional variations with two or three strings, it typically has four strings and a short, fretted neck (Collection of stringed instruments, 2025, The Stringed Instrument Database, 2025). Large crowds can be reached by the *yueqin*'s bright, clear, and piercing tone. Players pluck the strings with a plectrum or occasionally their fingertips, using tremolo and, upward and downward strokes to provide color and sustain the tone. When playing, the instrument is held horizontally. As a lead melodic instrument, it produces clear, bright tones that fill an entire ensemble. Pairs of its four strings are tuned with five notes apart. While pressing the strings between the upper frets makes chord playing challenging, it also gives the musician more control over

intonation and timbre. The *yueqin* was a common instrument in Cantonese instrumental ensembles until 1926, but it has since lost its prominence. It does not appear to be a preferred instrument in the present Chinese music movement that is centered in performance halls and conservatories. The word *yueqin* is made of two characters, *yuè* (moon) and *qín* (stringed instrument, zither). The *yueqin* is completely round like a full moon. Circular shapes are strongly associated with the moon, wholeness, and reunion in Chinese aesthetics. Symbolic naming is frequently triggered by that alone, particularly in a society where visual metaphor is highly valued.

The two strings are tuned a fifth apart within each of the two double courses. From lowest to highest string, Liang (1985) provides the tuning as G3 and D4 for the lower course, and G4 and D5 for the upper one. Most sources concur that the *yueqin* descended from the *ruan*, a long-necked plucked lute with a history dating back to the Qin and Han periods (Yueqin 2025). In contrast to Western lutes, the *yueqin*, has high frets that protrude from the neck, giving the player more control over tone and intonation because their fingers never touch the instrument's body. Modern *yueqins* frequently use metal frets instead of the bamboo found in older models. The player's fingertips will not touch the hardwood soundboard or fingerboard. The instrument has a different sound from Western fretted instruments because of the high frets, which provide exact control over the timbre and pitch. Although this shape helps with melodic playing, it can make playing complex chords more difficult. Beyond the pentatonic scale of older, folkloristic models, modern *yueqins* can play in a wider variety of pitches and colors due to the use of metal frets. The *yueqin's* fret placement is often not based on 12-tone equal temperament (TET). Rather, the frequency between the frets follows a musical system that might change depending on the tuning and regional tradition (e.g., Northern vs. Southern styles).

The *yueqin* is not played in a set Western equal-tempered scale to attain pure intervals. Instead, especially in Chinese opera circumstances, the instrument is usually tuned once to a general pitch framework that is suitable for the ensemble and vocal range. Pitch realization happens through expressive intonation, ornamentation, and fingering rather than by methodical re-tuning (Stock 2011). The measured fretted pitches did not always line up with twelve-tone equal temperament (12-TET) pitch centers, despite the fact that the instrument's fretted structure allows for chromatic access. This can be attributed to the *yueqin's* structural and performance-related features. The use of high frets on Chinese plucked lutes permits pitch change by finger pressure and bending, leading to flexible and context-dependent intonation. Fret placement on these instruments is not precisely determined by equal-tempered semitone spacing (Li 2018; Nettl *et al.* 2015). Many traditional Chinese instruments including the *yueqin* use just intonation or other traditional Chinese tuning methods, such as the 12 *lü*, which are based on mathematical ratios. This is in contrast to guitars which use 12-TET, i.e., 12 equal semitones per octave.

Performance in all keys (with black and white keys) was made possible by equal temperament (12-TET) by the late 18th century (Ho 2025). 12-TET evolved into the norm that renders all keys equal over the 19th and 20th centuries. Only the octave is pure in 12-TET, with each semitone being 100¢ and one octave in 12-TET is 1200 ¢. The perfect fifth is $27/12 \approx 1.4983 \rightarrow 700.0\text{¢}$ ($\approx 1.96\text{¢}$ flatter than the pure $3:2 \approx 701.96\text{¢}$); the major third is $24/12 \approx 1.2599 \rightarrow 400.0\text{¢}$ ($\approx 13.69\text{¢}$ sharper than pure $5:4 \approx 386.3\text{¢}$). Powers of 2, split into 12 equal semitones, define intervals in equal temperament. The intervals no longer match small whole number ratios since these values are irrational, which is a dramatic departure from Pythagorean and just intonation systems. The ratios of 12-TET intervals are irrational and no longer correspond to straightforward small integer relationships, since they are

powers of 2 divided into 12 equal steps. As a result, partials do not exactly match the harmonic series. In contrast to pure just intonation, this results in a slight pounding in chords.

The chromatic scale's 12 fundamental pitches are represented by the 12 *lü* pitch pipes. The method used to generate the 12 *lü* is called Sānfēn sēnyì, which translates to 'three-part subtracting and adding'. It is mathematically equivalent to the cycle of fifths. Beginning with the initial *lü*, or fundamental pitch: -Deduct one third of the tube's length $\rightarrow$ length = $(2/3) \times$ original $\rightarrow$ frequency $\times (3/2) \rightarrow$ perfect fifth up. Add a third of the tube length $\rightarrow$ length = $(4/3) \times$ original $\rightarrow$ frequency $\times (3/4) \rightarrow$ perfect fourth down. Chinese theorists created a 12-note sequence by alternating these actions (up a fifth, down a fourth to stay inside an octave). This sequence is written in pipe lengths and follows the same reasoning as Pythagorean tuning. These equate to a chromatic like scale when placed in pitch order within an octave. Table 1 shows the comparison between the Chinese music concept and 12-TET music concept. Table 2 and 3 shows the frequencies of the note on one octave of the just scale from C₄ to C₅, and the 12-TET and just scale frequencies on the fourth octave on the piano keyboard respectively (Johnston 1989).

Table 1. The Chinese Music Concept Compared to 12-TET Music Concept

Concept	Chinese Music	Western Music
Pitch system	12 <i>lü</i> (Just intervals)	12-tone equal temperament (TET)
Base tuning	Mathematical (ratios)	A440 or other frequency standards
Scale basis	Pentatonic/Heptatonic from 12 <i>lü</i>	Diatonic/Chromatic from 12 tones

Table 2. The Just Scale from C₄ to C₅ (Johnston 1989)

Note	Frequencies
C ₄	264
D ₄	297
E ₄	330
F ₄	352
G ₄	396
A ₄	440
B ₄	495
C ₅	528

Table 3. The 12-TET and Just Scale Frequencies on the Fourth Octave of the Piano Keyboard (Johnston 1989)

Note	Equal Tempered Frequencies	Just Scale Frequencies
A ₄	440.00	440.00
A ₄ #	466.16	-
B ₄	493.88	495.00
C ₅	523.25	-
C ₅ #	544.37	550.00
D ₅	587.33	586.67
D ₅ #	622.25	-
E ₅	659.26	660.00
F ₅	698.46	-
F ₅ #	739.99	733.33
G ₅	783.99	-
G ₅ #	830.61	825.00
A ₅	880.00	880.00

The fret spacing does not match regular frequency ratios used by 12-TET instruments such as the 12th root of 2 (≈ 1.05946). Pure intervals such as 3:2 for a perfect fifth and 4:3 for a perfect fourth are frequently the foundation of traditional Chinese tuning. The 12 *lü* system uses ratios from the 5th (3:2) and 4th (4:3) to create a scale. Therefore, the frequency change between frets might vary according on the pitch standard utilized, the maker's placement of the frets, and the tradition it adheres to. For compatibility with other instruments, some contemporary *yueqin* models, particularly those used in Beijing opera or conservatories, may employ a 12-TET fret arrangement. The frequency between frets on these instruments may be about equivalent to semitones, and each string may have 12, 14, or more frets. The frequency ratio between each fret is $2^{1/12} \approx 1.05946$ if the *yueqin* has Western equal temperament. This indicates that the following fret, one semitone above would be $440 \times 1.05946 \approx 466.16$ Hz if one fret produced 440 Hz (A4). Unless it is a modernized rendition, traditional *yueqin* does not adhere to this strictly. Table 4 shows the musical intervals in tempered and just tuning (Rossing 1983).

Table 4. Musical Intervals in Tempered and Just Tuning (Rossing 1983)

Interval	Tempered Tuning		Just Tuning	
	ratio	ϕ	ratio	ϕ
Octave	2.000	1200	2/1	1200
Fifth	1.498	700	3/2	702
Fourth	1.335	500	4/3	498
Major third	1.260	400	5/4	386
Minor third	1.189	300	6/5	316
Major sixth	1.682	900	5/3	884
Minor sixth	1.587	800	8/5	814

Frequency ratios vary (not fixed per fret) and traditional *yueqin* fret spacing and frequency changes adhere to Chinese tuning systems rather than equal temperament. The $2^{1/12}$ per fret ratio, which represents a 5.946% frequency rise per fret, can be used to approximate equal temperament in modern/Westernized *yueqin*. The fret placements will obtain exact frequency variations between particular frets. As a traditional Chinese instrument, the *yueqin* may not necessarily employ the 12-TET seen in the West. Certain *yueqin* variations, particularly those that are older or more traditional, could employ non-standard fret spacings or alternative tuning schemes.

EXPERIMENTAL

A short neck/pegbox and a flat circular resonator are joined to create the *yueqin*, a composite lute. The resonator's soundboard and back are two thinly shaved, glued-on wooden planks, while the round hoop of wood that makes up the sidewall is approximately 5 cm deep. A securely fastened string fastener that serves as a bridge is located close to the bottom of the soundboard. Four friction pegs pierce the pegbox from either side, which is carved from the same piece of wood as the neck. A plain piece of decorative wood is used to cap it. The diameter of the sound board is 39 cm. The length of the fingerboard is also 39 cm. Figure 1 shows the *yueqin* use in this study. Twenty-three raised frets are spread across the fingerboard. Each of the four strings of the instrument has one end fastened to the wooden bridge/string fastener on the soundboard and the other end looped around a tuning peg. The strings were made of non-stainless steel wire light string. It is a set of

professional *yueqin* strings from Shanghai DunHuang Musical Instruments Co. Ltd. This string requires little or no run-in time, so it sounds clear, bright and loud and suitable for all brands of *yueqin*. With the soundboard facing outwards and the neck angled to the left at about a 45° angle to vertical, the player holds the resonator's edge in his or her lap. Liang (1985) provides the tuning as G3 and D4 for the lower course, and G4 and D5 for the upper one (from lowest to highest string). In this work the strings 4, 3, 2 and 1 (from lowest to highest string) was tuned to D2, A2, D3 and A3 respectively.

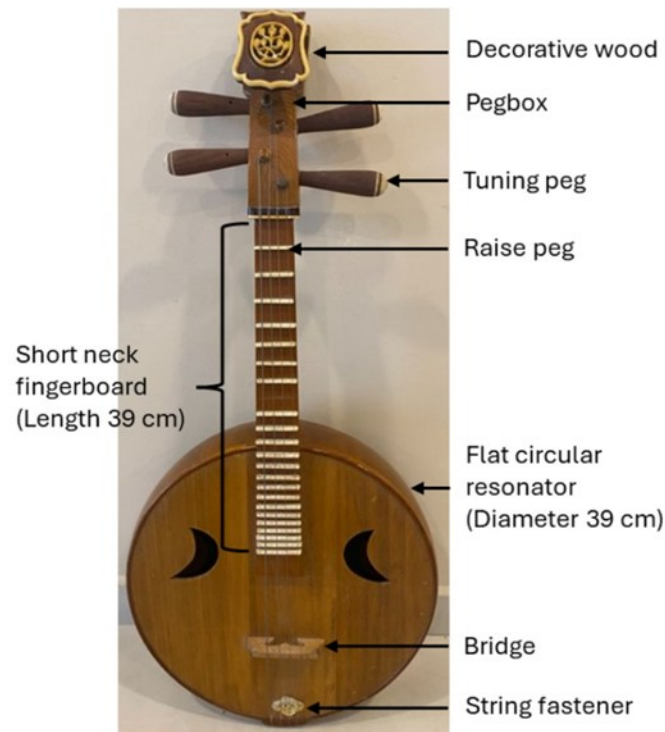


Fig. 1. The *yueqin* used in this study

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 *yueqin*. 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 2 shows the equipment utilized in the experimental setting.

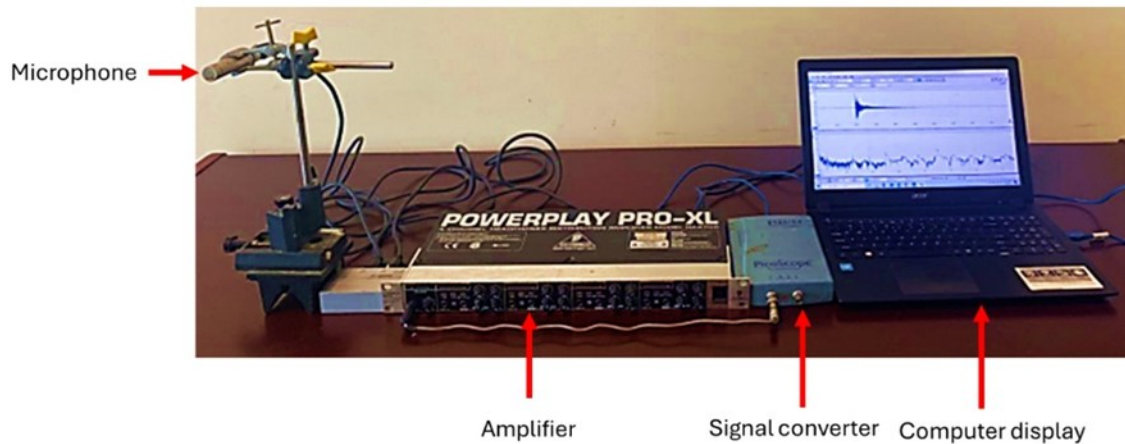


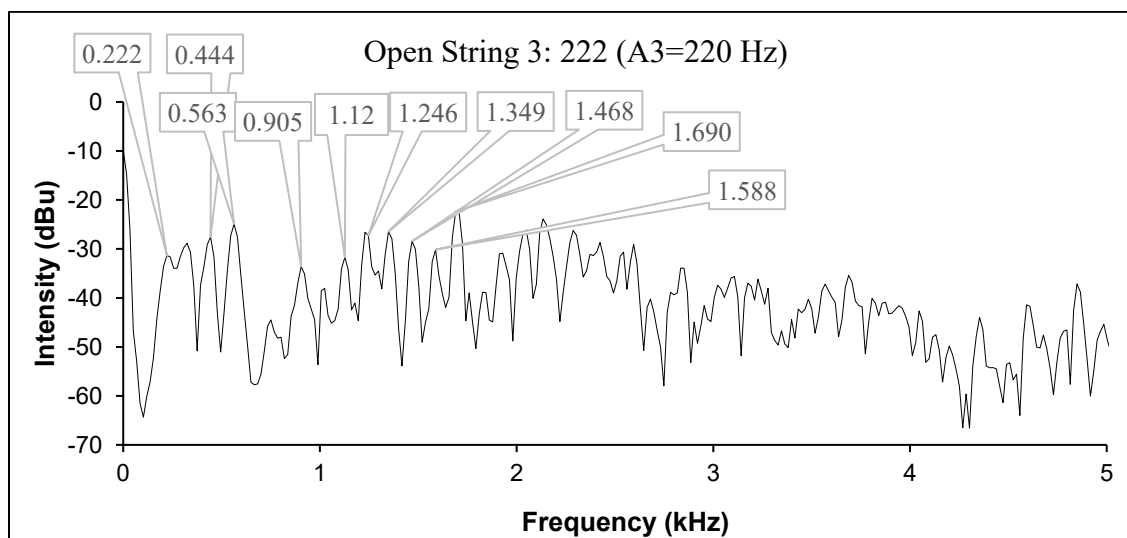
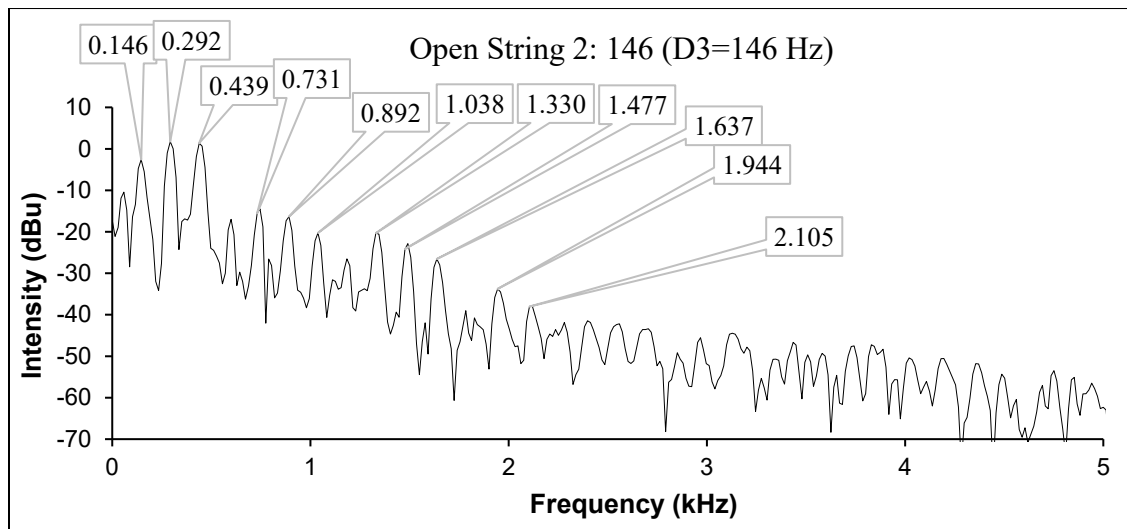
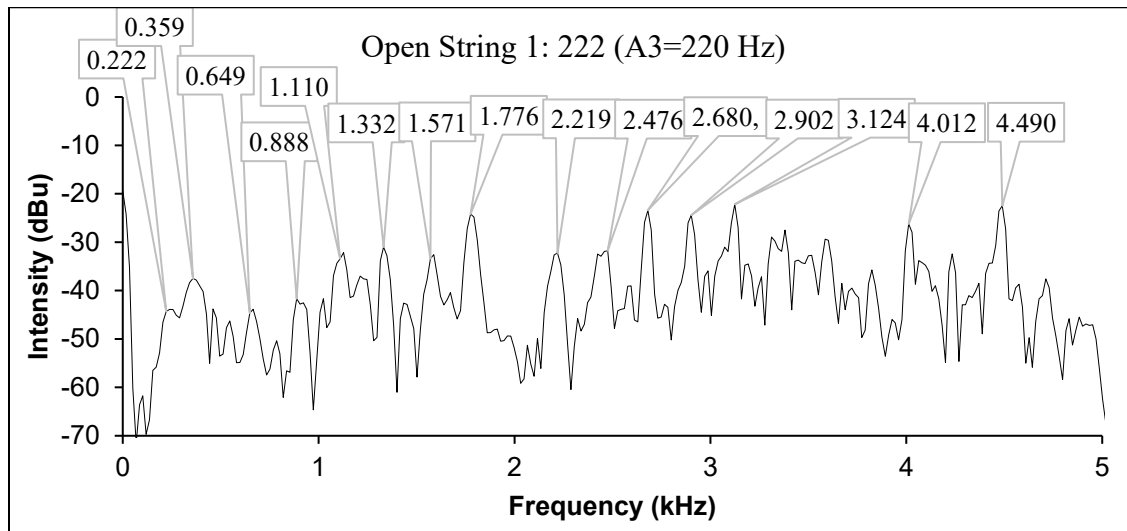
Fig. 2. The apparatus used in the experimental setup

The *yueqin* 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 *yueqin* were 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 *yueqin's* acoustic performance is ensured by the methodology, which uses controlled plucking, constant recording parameters, and numerous rounds of measurement with averaged results. The *yueqin'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.

RESULTS AND DISCUSSION

Figure 3 shows the spectra for open strings 1, 2, 3 and 4. The PicoScope recorded the fundamental frequency for open strings 1, 2, 3 and 4 as 222 Hz ($A_3=220$), 146 Hz ($D_3=146$), 222 Hz ($A_3=220$), and 292 Hz ($D_4=294$), respectively.

The strings 1, 2, 3, and 4 were perceived as A_3 , D_3 , A_2 and D_2 , respectively. The listener perceived the note for string 3 as A_2 (110 Hz), although the PicoScope recorded the frequency that matched A_3 (220 Hz). Although the listener perceived the note for string 4 as D_2 (73 Hz), the PicoScope recorded the frequency that matched D_4 (294 Hz). This discrepancy may be explained by psychoacoustic effects, harmonic confusion, or errors in octave perception. Human ears can sometimes sense the basic pitch even when it is not physically there. If there are strong A_2 harmonics in the sound (such as A_3 , A_4 , etc.), the brain might interpret A_2 as the fundamental.



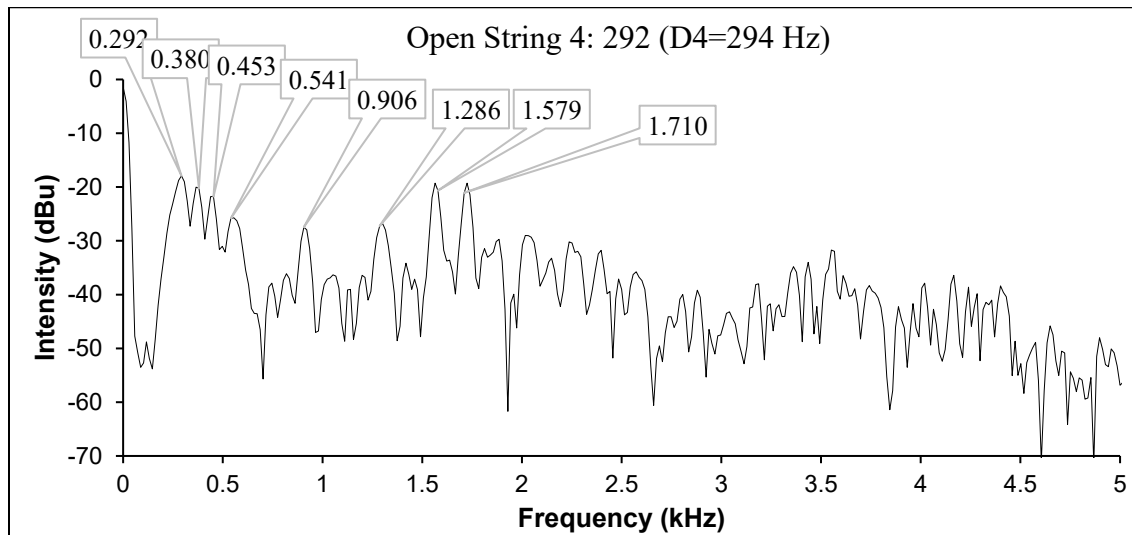


Fig. 3. The Fast Fourier Transform spectra for open string 1, 2, 3, and 4

The PicoScope shows the actual frequencies, while the ear deciphers or recognizes the pattern. For example, the listener may see A2 if string 3 has harmonics from A2 (110 Hz) in addition to A3 (220 Hz) as a high peak. People occasionally misjudge the octave of a tone, particularly when it comes to low-frequency notes. An A3 note could be mistaken for an A2 since there are no reference pitches and the listeners are accustomed to instruments that emphasize lower fundamentals. Certain instruments can produce strong overtones that can mask the fundamental. If A3 is dominant and A2 is weak or implied, the listener may pick up on the lower pitch even though it is not acoustically dominant. The phenomenon where the listener claimed to recognize the note A2 when they hear A3, is the famous phenomenon of the ‘missing fundamental’.

The missing fundamental phenomenon is the perception of pitch when the waveform’s first harmonic is absent (Howard and Angus 2017). Psychoacoustics has demonstrated that if there is a significant set of harmonics in the spectrum, the auditory system will consistently assign a pitch to a complex tone due to its innate ability to identify one tone from another (Hartmann 1996). A note with a pitch of 100 Hz, for instance, will have frequency components that are integer multiples of that value (*e.g.*, 100, 200, 300, 400, 500 Hz). This note is not a pure tone. The 100 Hz component in our example might be absent, though, because smaller loudspeakers might not be able to create low frequencies. However, a fundamental-corresponding note might still be audible.

This discrepancy can be explained by psychoacoustic mechanisms of pitch perception, particularly virtual pitch perception and the missing fundamental, whereby listeners infer a fundamental pitch from prominent harmonic components even when the fundamental frequency is weak or absent (Terhardt 1974; Moore 2012). The perceived note was determined through aural pitch identification by trained listeners rather than solely by instrumental frequency measurement. Each recorded tone was replayed under controlled listening conditions, and the listener identified the pitch perceived as most salient by matching it to the nearest equal-tempered pitch using a reference instrument tuned to A4 = 440 Hz. The perceived pitch was defined as the dominant auditory pitch, which may differ from the measured fundamental frequency when strong upper harmonic components influence pitch perception. Such perceptual differences are consistent with

established psychoacoustic phenomena including virtual pitch perception and the missing fundamental (Terhardt 1974; Moore 2012; Plack *et al.* 2005).

The partial frequency *versus* the harmonic number for strings 1, 2, 3, and 4 are plotted in Fig. 4. The gradient of the trend line is given as follows:

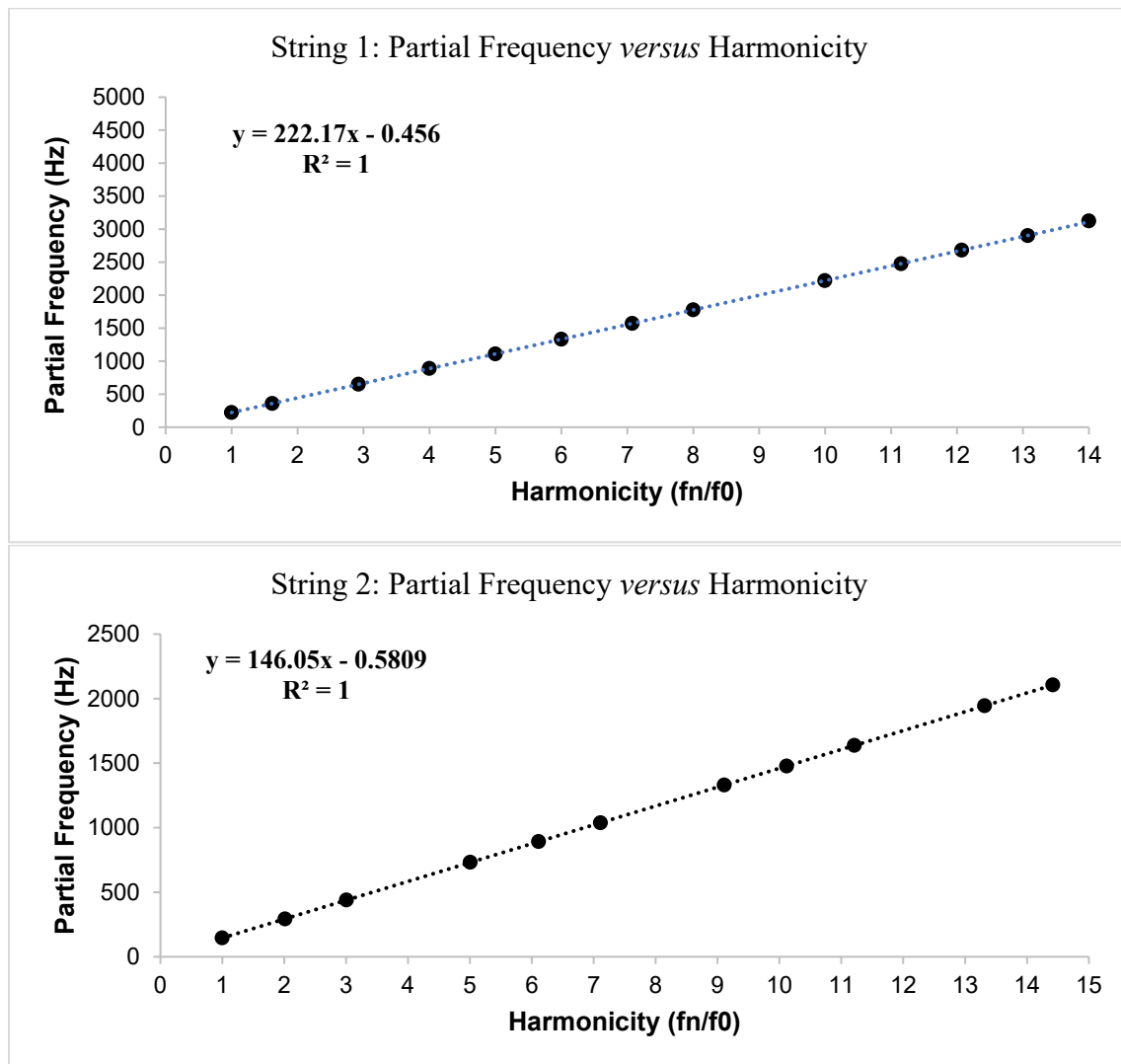
$$y_{\text{string1}} = 222x \text{ with } R^2=1$$

$$y_{\text{string2}} = 146x \text{ with } R^2=1$$

$$y_{\text{string3}} = 222x \text{ with } R^2=1$$

$$y_{\text{string4}} = 292x \text{ with } R^2=1$$

The gradient of the frequency *versus* the harmonic number for string 1, 2, 3, and 4 are exactly the fundamental frequency of the string.



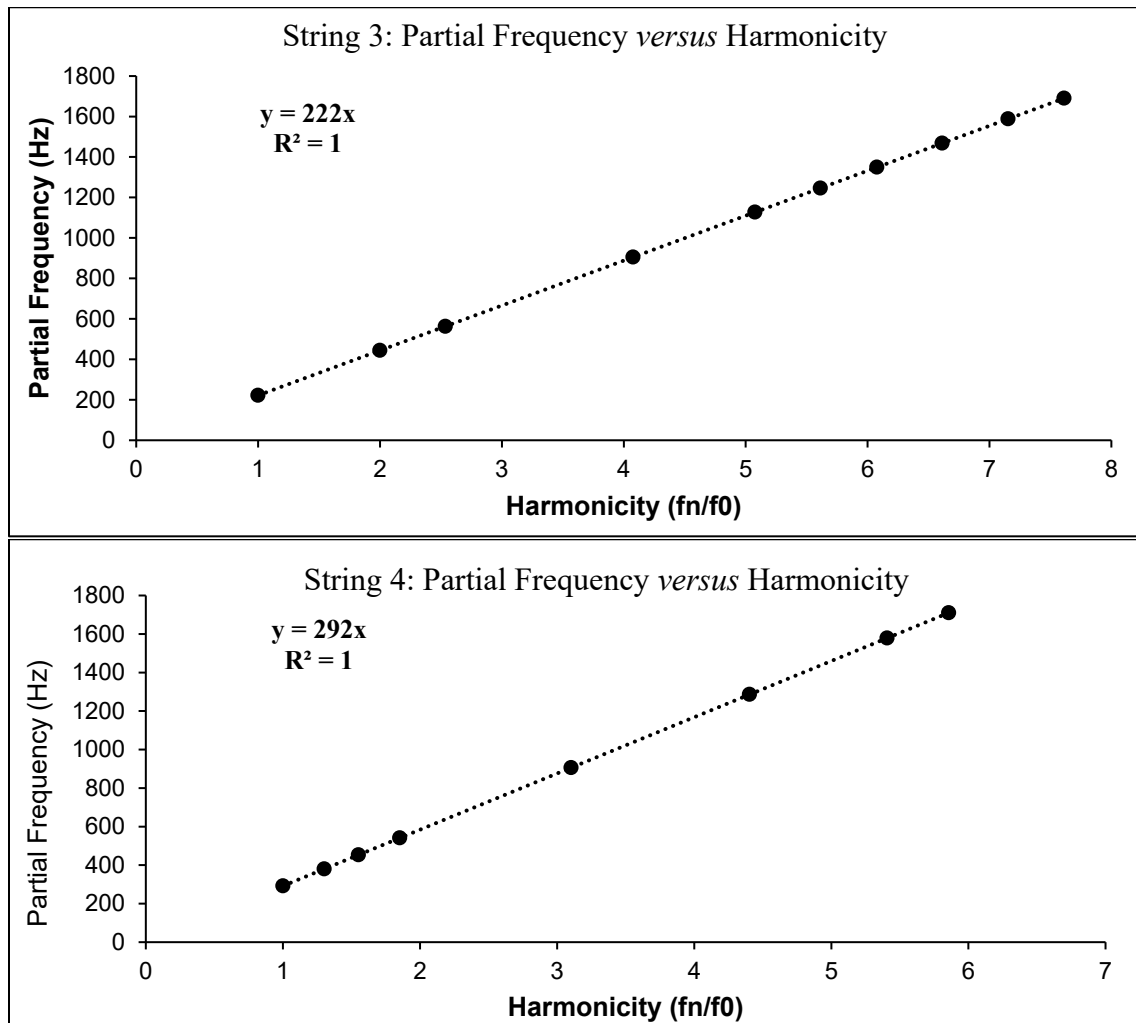


Fig. 4. The partial frequency *versus* the harmonic number for strings 1, 2, 3, and 4 ($n=0$ for fundamental frequency)

Table 5. Frequency of the Open String 1 and Fret 1 to 23

Fret No.	Recorded Frequency	Recorded Note (Just scale frequency)	Perceived Note (12-TET frequency)
Open String 1	222	A3 (220)	A3
1	249	B3 (247)	B3
2	263	C4 (264)	C4
3	292	D4 (297)	C4#
4	307	D4↑	D4 ↑
5	310	E4↓	D4#↑
6	336	E4 (330)	E4↓
7	351	F4 (352)	E4
8	365	G4↓	F4
9	409	G4 (396)	F4#
10	416	G4↑	G4
11	439	A4 (440)	G4#
12	453	B4↓	A4

13	497	B4 (495)	A4#
14	526	C5 (528)	B4
15	570	C5↑	C5
16	585	D5 (594)	C5#
17	585	D5↑	D5
18	643	E5 (660)	D5#
19	687	F5↓	E5
20	716	F5 (704)	F5
21	746	F5↑	F5#
22	775	G5 (792)	G5
23	892	A5 (880)	G5#

Note: Perceived note refers to the pitch identified through trained auditory listening and reference-based pitch matching (A4 = 440 Hz). It represents the dominant pitch perceived by the listener and may differ from the recorded frequency when harmonic components influence pitch perception.

The frequency of fret 1 to fret 23 of the 1st string was determined *via* the PicoScope. Table 5 shows the frequency of the open string 1 and fret 1 to 23. The frequency between the frets follows a musical system that might change depending on the tuning and regional tradition. The running note for open string 1 and fret 1 to 23 are as follows: A3, B3, C4, D4, E4, F4, G4, A4, B4, C5, D5, E5, F5, G5, A5 where fret 4, 5, 8, 10, 12, 15, 17, 19 and 21 has the note D4↑, D4#↓, F4#↓, G4#↑, A4#↓, C5#↑, D5↑, F5↓, and F5#↑ respectively. The frequency ratios vary (not fixed per fret) where traditional *yueqin* fret spacing and frequency changes adhere to Chinese tuning systems rather than the 12-TET.

Non-fixed interval steps such as D4↑, D4#↓, F4#↓, G4#↑, A4#↓, C5#↑, D5↑, F5↓, and F5#↑ define notes in just intonation. Although they are defined by frequency ratios (such as 3:2, 5:4, 7:4) relative to a reference note, there is not a universal sharp (#) in just intonation, where a note may be higher than another rather than a sharp or flat. When just intonation and equal temperament are compared, a just perfect fifth (3:2) is marginally higher (702¢) than the equal-tempered fifth (700¢) and a just major third (5:4) is lower (386¢) than the equal-tempered major third (400¢) (see Table 4 above). Therefore, a just intonation note may sound somewhat flat or sharp in relation to equal temperament depending on the context rather than in its own system. Musicians occasionally utilize symbols like ↑ or ↓ in extended just-intonation notation. These include options including raising the pitch by a certain percentage. The ↑ or ↓ are microtonal modifications, not sharps in the usual sense. In equal temperament the sharps are fixed pitch classes, whereas in just intonation the pitch varies depending on harmonic context. So, the same ‘note name’ in just intonation can actually have numerous alternative tunings, none of which is the sharp version.

The last column in Table 5 shows the perceived notes. The *yueqin*'s fret placement is frequently not based on 12-TET. Rather, the *yueqin* use traditional Chinese tuning procedures, such as the 12 *lü*, which are based on mathematical ratios and are not equally spaced. Pure harmonic intervals are given precedence over regular spacing because their foundation is just intonation. Figure 5 shows the fundamental frequency *versus* fret numbers. The equation for the fundamental frequency *versus* fret numbers is given by $y = 0.5534x^2 + 12.431x + 239.83$. Figure 6 shows the partial frequency *versus* harmonicity for fret 23 which shows that the gradient from the trend line ($y_{\text{fret23}} = 892x$) is exactly the fundamental frequency of the fret 23 (892 Hz).

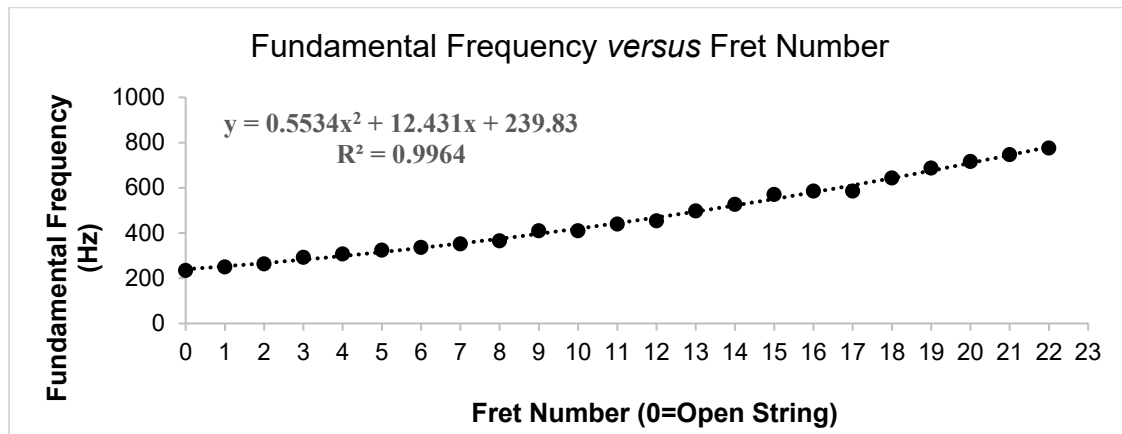


Fig. 5. Fundamental frequency *versus* fret number

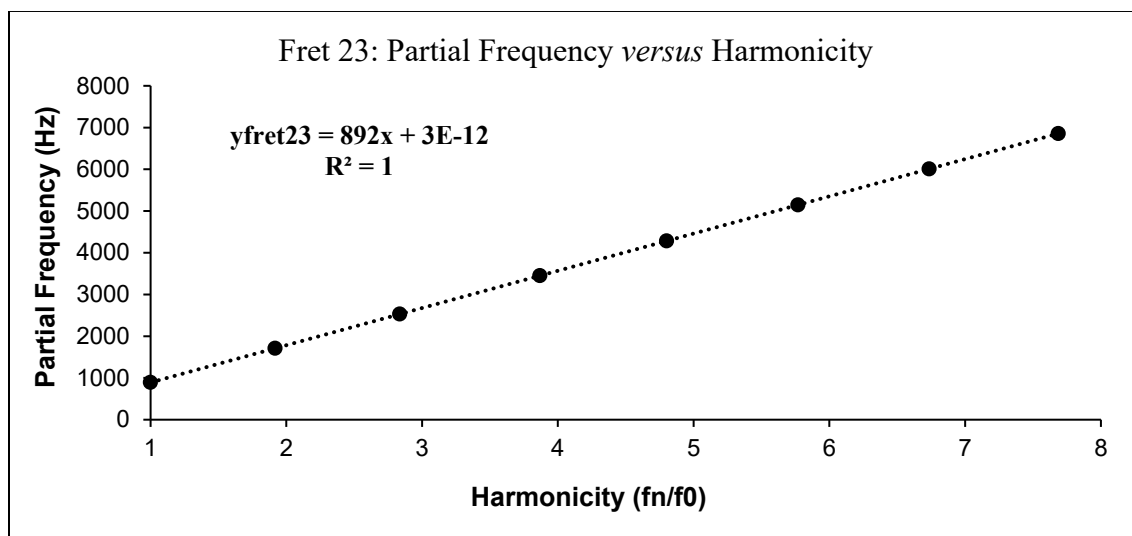


Fig. 6. Partial frequency *versus* harmonicity for fret 23

On older instruments, the frets may be arranged based on these ratios rather than equal spacing. The 12 *lü* are musically pure and widely spaced, based on pure intervals, especially perfect fifths (3:2). This serves as the foundation for Chinese music theory, and it encompasses fret and scale construction. These ratios can be seen in the frets of the *yueqin* in this study, which are not simplified in modern versions. Figure 7 shows the time frequency analysis using Adobe Audition. String 1 with the highest pitch (A3) display the brightest yellow color compared with string 4 with the lowest pitch (D2) display the least yellow color.

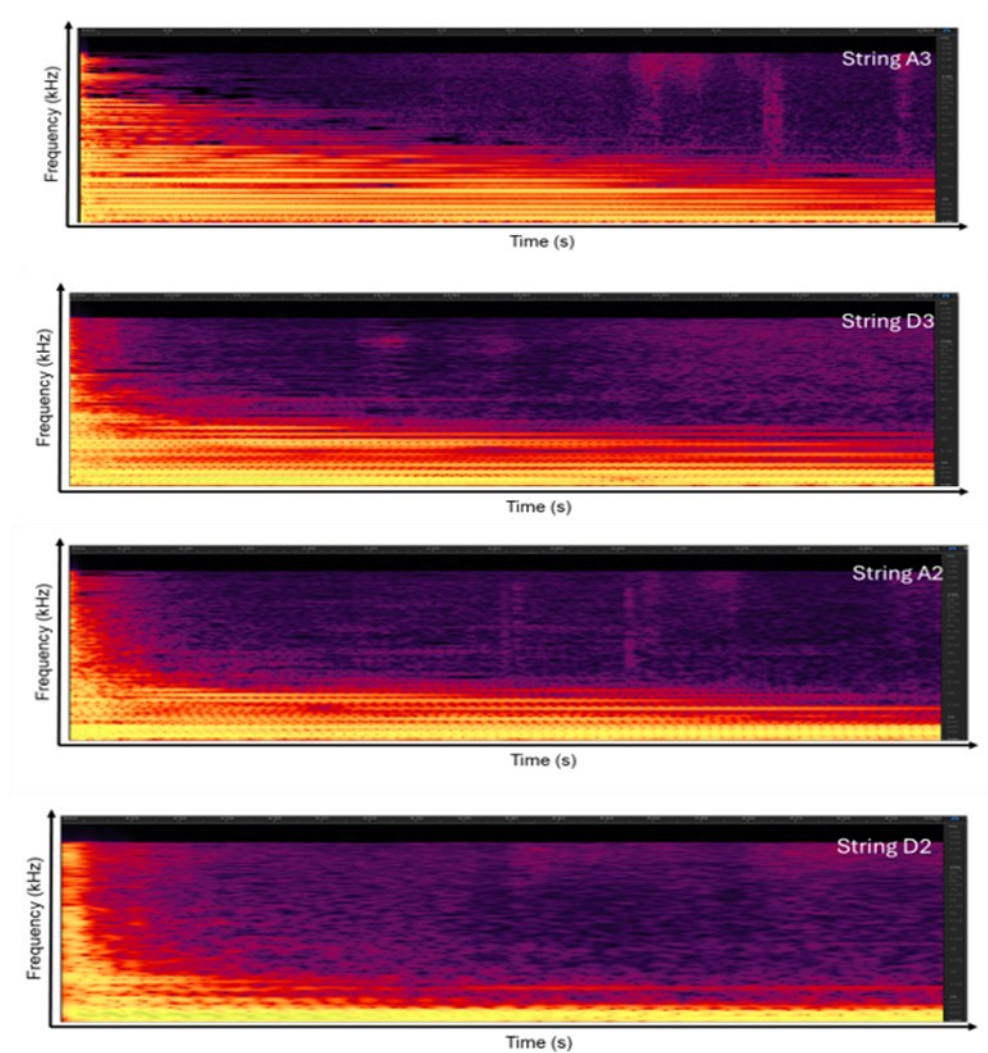


Fig. 7. The time frequency analysis using Adobe Audition for strings 1, 2, 3, and 4

CONCLUSIONS

1. The PicoScope recorded the fundamental frequency for open strings 1, 2, 3 and 4 as 222 Hz (A3=220), 146 Hz (D3=146), 222 Hz (A3=220), and 292 Hz (D4=294), respectively, whereas the perceived notes according to the 12-TET tuning were A3, D3, A2, and D2.
2. The running note for open string 1 and fret 1 to 23 were as follows: A3, B3, C4, D4, E4, F4, G4, A4, B4, C5, D5, E5, F5, G5, A5, where fret 4, 5, 8, 10, 12, 15, 17, 19 and 21 has the note D4 $\uparrow$, D4 $\#$ $\downarrow$, F4 $\#$ $\downarrow$, G4 $\#$ $\uparrow$, A4 $\#$ $\downarrow$, C5 $\#$ $\uparrow$, D5 $\uparrow$, F5 $\downarrow$, and F5 $\#$ $\uparrow$ respectively.
3. The 12 *lǚ* used in the *yueqin* are musically pure and widely spaced, based on pure intervals especially perfect fifths (3:2) which encompasses fret and scale construction.
4. These ratios of the frets note in this study are not simplified to modern *yueqin* versions.

ACKNOWLEDGMENTS

The authors would like to acknowledge Universiti Putra Malaysia Sarawak (UPMS) and Universiti Malaysia Sarawak (UNIMAS) and for the technical and financial support.

REFERENCES CITED

- Collection of stringed instruments. *Instrumap*, available at: <https://collection-of-stringed-instruments.instrumap.netlify.app> (Accessed 1 October 2025).
- Hartmann, W. (1996). "Pitch, periodicity, & auditory organization," *The Journal of the Acoustical Society of America* 100(6), 3491-3902. <https://doi.org/10.1121/1.417248>
- Ho, M. (2025). "Mathematical and scientific analysis of European and Chinese tuning systems," *American Research Journal of Physics* 11(1), 1-7. <https://doi.org/10.21694/2380-5714.25001>
- Howard, D. M., and Angus, J. A. S. (2017). *Acoustics and Psychoacoustics*, Fifth Ed., Routledge, New York., pp. 123. ISBN 9781315716879.
- Johnston, I. (1989). *Measured Tone, The Interplay of Physics and Music*, IOP Publishing Limited.
- Li, X. (2018). *Chinese Musical Instruments*, 2nd Ed., China Intercontinental Press, ISBN 978-7508539366.
- Liang, D. M. (1985). *Music of the Billion: An Introduction to Chinese Musical Culture*, Heinrichshofen, New York.
- Moore, B. C. J. (2012). *An Introduction to the Psychology of Hearing*, 6th Ed, Brill, Leiden, The Netherlands.
- Nettl, B., Stone, R. M., Porter, J., and Rice, T. (2015). *The Garland Encyclopedia of World Music: East Asia*, Routledge, Vol. 7. ISBN 978-1138989025.
- Plack, C. J., Oxenham, A. J., and Fay, R. R. (2005). *Pitch: Neural Coding and Perception*, Springer, New York.
- Rossing, T. D. (1983). *The Science of Science*, Addison-Wesley Publishing Company, Inc.
- Stock, J. P. J. (2011). "Musical theory, practice, and aesthetics," in: *The Oxford Handbook of Music in China and the Chinese Diaspora*, J. P. J. Stock (ed.), Oxford University Press, pp. 45-67). <https://doi.org/10.1093/oxfordhb/9780190661960.013.3>
- Terhardt, E. (1974). "Pitch, consonance, and harmony," *Journal of the Acoustical Society of America* 55, 106101069. <https://doi.org/10.1121/1.1914648>
- The Stringed Instrument Database: W–Z. (2025). *Stringed Instrument Database*, available at: <https://stringedinstrumentdatabase.aornis.com> (Accessed 1 October 2025).
- Yueqin (2025). "Yueqin," *Wikipedia*, available at: <https://en.wikipedia.org/wiki/Yueqin> (Accessed 1 October 2025).

Article submitted: October 19, 2025; Peer review completed: January 24, 2026;

Revisions accepted: February 11, 2026; Published: May 7, 2026.

DOI: 10.15376/biores.21.3.5808-5821