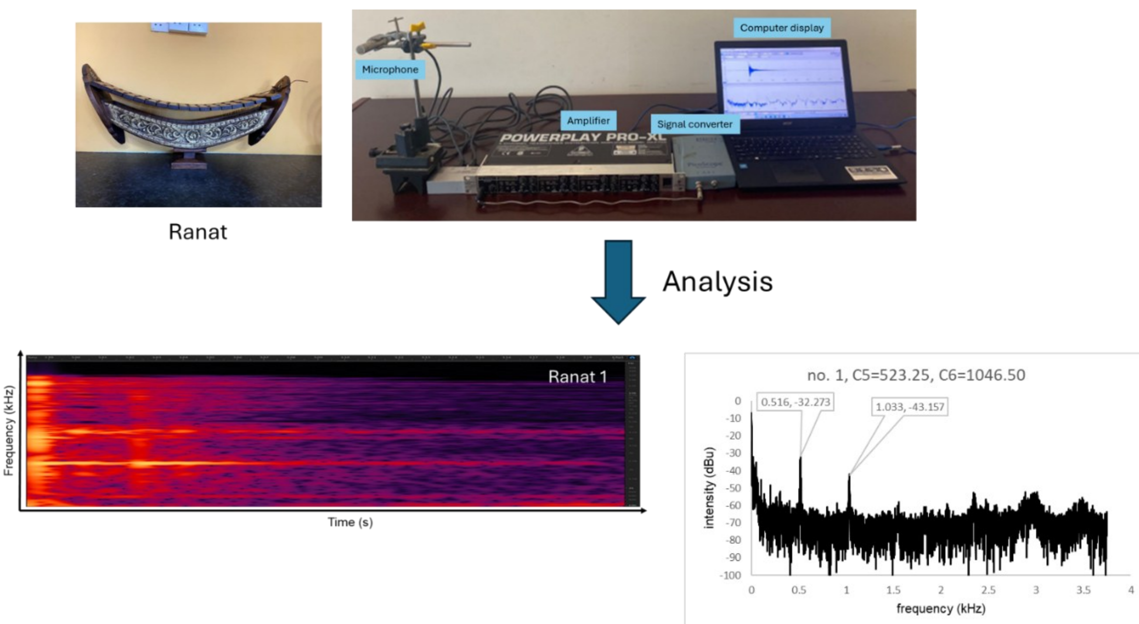
Thailand Ranat Xylophone: Analysis of the Musical Scale System

Ahmad F. Musib,[a]* Sinin Hamdan,[b] Khairul A.M. Said,[b] and Aaliyawani E. Sinin [c]

* *Corresponding author: faudzimusib@upm.edu.my*

DOI: 10.15376/biores.20.4.10838-10857

GRAPHICAL ABSTRACT



Thailand Ranat Xylophone: Analysis of the Musical Scale System

Ahmad F. Musib,[a,]* Sinin Hamdan,[b] Khairul A.M. Said,[b] and Aaliyawani E. Sinin [c]

The ranat ek belongs to the percussion family. It consists of wooden bars suspended by cords above a boat-shaped trough resonator and is played with two mallets. Serving as the principal instrument in the Thai Piphat ensemble, the ranat ek holds both musical and cultural significance in traditional Thai performance. This study examined its acoustic and tuning characteristics using modern signal analysis tools to contribute to audio preservation and future instrument design. The sound signals were recorded in real time using a PicoScope 3000. The notes identified for bars 1 to 17 ranged from C5 to E7. Grouped by octaves, octave 5 includes C5-A♯5, octave 6 includes C6-B6, and octave 7 includes C7-E7. The analysis revealed a non-tempered, heptatonic tuning system distinct from the Western equal temperament scale, reflecting the ranat ek*'s* unique cultural tuning identity. The note distribution across octaves confirmed a scale structure emphasizing natural harmonic overtones rather than fixed semitone intervals. These findings establish a scientific foundation for digital sound preservation and provide baseline data for AI-assisted sound modeling and immersive AR/VR applications in cultural heritage reconstruction. The study suggests that the collected data could inform sustainable instrument design using plant-based materials, supporting both cultural continuity and ecological innovation.

DOI: 10.15376/biores.20.4.10838-10857

Keywords: Ranat; Xylophone; Fast Fourier Transform (FFT)

Contact information: a: Faculty of Human Ecology, Universiti Putra Malaysia, 43400, Serdang, Selangor Darul Ehsan, Malaysia; b: Faculty of Engineering, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia; c: Department of Science and Technology, Faculty of Humanities, Management and Science Universiti Putra Malaysia, Sarawak, Malaysia, 97008 Bintulu, Sarawak, Malaysia; Corresponding author: faudzimusib@upm.edu.my

INTRODUCTION

This study focused on the musical scale mechanism of the traditional Thailand Ranat. The ranat ek and ranat thum are both Thai xylophones. The ranat thum is larger and has a lower pitch, while the ranat ek is smaller and sounds higher. Both are played with mallets and are important instruments in Thai classical music. Compared to the ranat ek, which commonly contains 21 or 22 wooden bars, the ranat thum typically has 17 bars. The two instruments' resonators have different shapes. The ranat thum, which is often accompanied by harmonic or contrapuntal, plays a lower range than the ranat ek and produces a deeper, more mellow tone. Both instruments are made of hardwood bars that are suspended over a resonator and have a xylophone-like appearance. Figure 1 shows the ranat ek and ranat thum (Bamrungwong and Woraratsoontorn 2016).

(a) (b)

Fig. 1. (a) Ranat ek and (b) Ranat thum (Bamrungwong and Woraratsoontorn 2016)

Xylophones first appeared in Southeast Asia and are made up of more than three sets of bars (Marcuse 1975). Xylophones were created in Thailand for the late Ayuttaya period's traditional music and are usually constructed from rosewood bars that are strung on a boat-shaped frame and supported by cords. Determining the pitch, time, and distinct sounds of every instrument included in a particular audio source would be necessary for absolute transcription (Skoki *et. al.* 2019). In the present work, the following research question was considered: How can the tuning characteristics and acoustic behavior of the ranat be scientifically documented and analyzed to support future efforts in sound preservation and digital reconstruction? The study recorded each bar's sound in an anechoic chamber using a PicoScope 3000 for precise waveform and frequency analysis. Fast Fourier Transform (FFT) was applied to identify fundamental frequencies and overtone relationships. Comparative analysis with the Western equal temperament system revealed the ranat's unique heptatonic tuning. The data form a baseline for digital preservation, suitable for AI training, AR reconstruction, and VR-based cultural exhibits.

By computing the frequency of each sound, the notes were analyzed to determine whether intervals were consonant. By comparing the vibration on various bars, the data were assessed, and mathematical techniques were used to ascertain whether or not the Thai musical scale system is consonant. This study hypothesizes that the ancient crafters of the ranat may have relied on mathematical relationships such as proportional ratios of bar length, thickness, or density rather than on purely auditory pitch intervals when determining the instrument's tuning. This hypothesis suggests that their tuning process was grounded in intuitive acoustic science, reflecting an early understanding of frequency relationships that predate formal Western acoustical theory. This hypothesis is particularly significant for modern sound preservation, as it provides a scientific foundation for recreating or modeling traditional tuning systems through digital means. By investigating whether the tuning reflects measurable mathematical proportions, the research contributes to the preservation of intangible cultural heritage while also informing future applications in audio modeling, artificial intelligence (AI), and virtual reconstruction of traditional instruments. The outcomes not only preserve traditional sonic identities but also expand the potential for sustainable design using plant-based materials and immersive AR/VR educational tools.

The frequency of the bars was determined, and the formula for measuring the Thai musical scale system was investigated based on the Western musical scale system. The equal temperament is a 12-note musical scale method used in European music that roughly corresponds to simple intervals by dividing an octave into equal steps. Since there are 100 cents (1200/12=100 cents) between two notes and the pitch is roughly the logarithm of the frequency, the ratio of the frequencies of any adjacent pair of notes is the same: C4 (261.63)/C♯4 (277.18) = C♯4 (277.18)/D4 (293.67) = 0.9438, giving an apparent step size that is comparable. In Thai music, an octave is separated into 7 equal parts. The difference between two similar notes is 171.4 cents (1200/7=171.4 cents). As a result, when someone used to Western music first hear Thai music, it may appear to be out of tune (Lin *et al.* 2023).

This musical scale technique was first put forth by Alexander J. Ellis, who introduced the idea that Thai musical scale was an equal-heptatonic scale and asserted that it was the best musical scale. He made the initial measurement of the vibration frequency of Thai musical instruments. A musical scale having seven notes or pitches per octave is called a heptatonic scale. The Greek terms hepta (seven) and tonic (tone or pitch) are the origin of the word heptatonic. The major scale, melodic minor scale, and natural minor scale are a few examples.

By definition, a heptatonic scale consists of seven distinct sounds, excluding the first note's octave recurrence. The diatonic scales, which comprise the major scale and the natural minor scale, are the most prevalent instances of heptatonic scales in Western music. Every diatonic scale contains seven modes, each of which has a distinct character and is a distinctive arrangement of the scale's notes. Despite the extensive theoretical work by Ellis and later scholars, there remains a limited understanding of the ranat ek's precise tuning behavior when analyzed using modern digital tools. Earlier studies largely relied on manual frequency measurements and lacked high-resolution spectral data, resulting in incomplete insights into its overtone structure and harmonic stability. This constitutes the research problem; the absence of empirical, waveform-based documentation of the ranat ek's acoustic properties for long-term sound preservation.

The research gap lies in the need to integrate scientific analysis with cultural preservation frameworks, ensuring that the instrument's tuning identity can be digitally archived and reconstructed for future generations. Other heptatonic scales, including the harmonic minor scale and melodic minor scale, exist in addition to the diatonic scales. A heptatonic scale's distinct sound and character are determined by the particular intervals (distances between notes) that make it up. Whole steps, half steps, or a mix of the two can be used for the intervals. A musical scale with seven pitches, or tones, per octave is called a heptatonic scale.

The shorter the bar, the faster it vibrates when we apply the same amount of force to it, thus the higher the pitch. When the bar is cut in half while keeping the strain constant, the pitch rises by one octave. When a bar starts to vibrate at half its length, an octave higher sound from A3 to A4 is produced (A3, A♯3, B3, C4, C♯4, D4, D♯4, E4, F4, F♯4, G4, G♯4, A4). When lengths are half, the pitch is 12 notes higher. Fundamental tone refers to the vibrating of the entire bar. Partial or overtone describes the various sounds that a particular vibrational segment generates. The fundamental tone (C2) is the first tone seen in Fig. 2 (Lin *et al.* 2023). The first overtone is the second tone (C3), the second overtone is the third tone, and so on. All overtones are pitches higher than the fundamental (which is a sound's lowest pitch). It is worth noting that the range as shown in Fig. 3 is a modern concept (Sumrongthong 1998). The traditional range has the lowest note a fourth lower than its neighbor, *i.e.* to play the lowest octave, the right mallet has to skip a fourth.

Fig. 2. Overtone series (Lin *et al.* 2023)

Fig. 3. The range of the ranat ek (Sumrongthong 1998)

This research was conducted to preserve the acoustic identity of the ranat ek, through scientific documentation and spectral analysis. With modernization and declining craftsmanship, original tunings and materials risk being lost. By capturing empirical frequency data and overtone behavior, this study creates a digital archive that can later support AI driven sound reconstruction and virtual learning platforms for traditional instrument preservation. This study contributes to three main areas:

1. Acoustic documentation: It provides a precise, empirical dataset of the ranat ek's tuning and harmonic structure, serving as a scientific record for preservation.
2. Digital sound preservation: The frequency and FFT data enable integration into AI sound models that can reproduce or simulate the authentic sound of traditional instruments.
3. Future instrument design: The study offers foundational data for developing sustainable, plant-based musical instruments whose resonance and tuning can be optimized using AI-assisted modeling and AR/VR immersive technologies for education and heritage dissemination.

The significant impact of this research lies in its dual contribution to both scientific understanding and cultural preservation. From a scientific standpoint, the study provides empirical acoustic data on the ranat ek, recorded through high-resolution digital instrumentation. This fills a major gap in ethnomusicological documentation, where traditional tuning systems have rarely been analyzed with the precision of modern waveform and FFT tools. The data not only reveal the ranat ek's heptatonic tuning behavior but also map its overtone patterns, serving as a benchmark for future comparative studies between Thai traditional and Western tempered systems. From a cultural and preservation perspective, the findings hold major significance for traditional music heritage. The documentation of the ranat ek's spectral characteristics ensures that the sound identity of the instrument can be digitally preserved and reconstructed in virtual environments, safeguarding it from loss due to material degradation or generational discontinuity. The results can be used to train AI-based sound modeling systems, enabling the reproduction of authentic Thai tones in AR/VR cultural simulations, digital museums, and educational applications. This creates a bridge between traditional craftsmanship and modern technology, ensuring the survival of the ranat ek's acoustic character in evolving digital contexts.

The study's results impact on traditional music by providing a scientific framework for tuning calibration, restoration, and the crafting of new instruments using sustainable, plant-based materials. This enables continuity of traditional performance practice while supporting environmental sustainability. By documenting the exact spectral and frequency profiles of each bar, traditional instrument makers can replicate or restore the ranat ek more accurately, maintaining its cultural integrity. Furthermore, digital sound libraries based on this research could enrich contemporary Thai compositions, allowing traditional timbres to coexist with modern production contexts. This reinforces the cultural relevance of traditional instruments within current creative industries and contributes to the revitalization of intangible heritage through modern means of dissemination.

A possible hypothesis arising from this study is that ancient crafters of the ranat ek may have relied on mathematical proportions or geometric ratios rather than direct pitch comparisons when setting the initial tuning. The observed frequency distribution, though not identical to the Western equal temperament, suggests a consistent proportional spacing between successive notes. This indicates a deliberate mathematical framework governing bar length, thickness, and material density, possibly reflecting an intuitive understanding of acoustical physics. The evidence collected in this study, particularly the measured frequency ratios and harmonic consistency, provides plausible support for such a hypothesis. The relatively stable cent deviation across octaves implies that the ranat ek's tuning may have been based on numeric patterns, perhaps derived from physical dimensions or the harmonic division of lengths, rather than empirical listening alone. This perspective invites further interdisciplinary research combining acoustics, historical craftsmanship, and computational modeling, potentially revealing that ancient instrument makers achieved remarkable acoustic precision through empirical geometry rather than Western notions of pitch equivalence.

Indeed, one could argue that the evidence collected in this study provides compelling support for the hypothesis that ancient ranat ek crafters employed a mathematical rather than a purely auditory approach to tuning. The frequency data obtained through FFT analysis demonstrate a consistent proportional spacing between bars, indicating a systematic tuning method rather than arbitrary adjustment by ear. The recurring frequency ratios suggest that early instrument makers may have intuitively understood geometric or arithmetic relationships between bar length, thickness, and pitch, even in the absence of modern measurement tools. This reflects a form of indigenous acoustical knowledge, where sound design was guided by experiential mathematics embedded within craftsmanship traditions. The precision observed across multiple bars supports the idea that the ranat ek's tuning was the result of deliberate calculation, possibly guided by the ratio of bar lengths or wood density rather than trial and error. In this sense, the instrument stands as both a musical and scientific artifact, embodying the intersection of art, culture, and mathematical logic long before the advent of Western acoustical theory.

EXPERIMENTAL

Rosewood (*Dalbergia oliveri*) is commonly used to make ranat ek bars. As seen in Fig. 1, there are two varieties of ranat ek mallets: hard rubber mallets and soft padded mallets. Usually utilized for rapid playing, the crisp, brilliant sound is produced by the strong mallets. For slower tunes, the mellow and gentler tone is produced by the soft mallets. Figure 4 shows the (a) ranat ek and (b) seventeen bars used in this study. The final wooden bar (right side) is shorter in length and has a different arch beneath it, while the first wooden bar (left side) has deep arches and low frequency wooden bars.

Fig. 4. (a) The ranat ek and (b) the seventeen bars

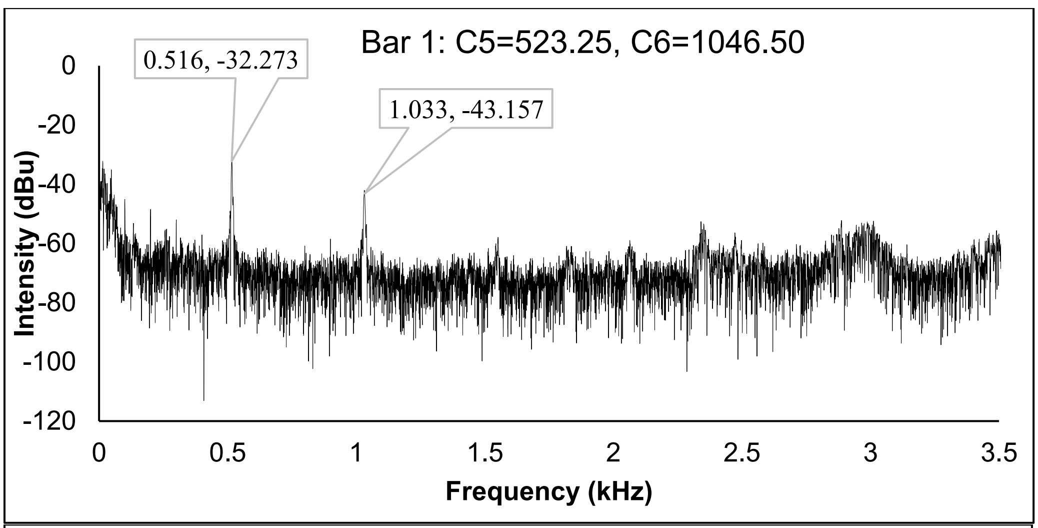
All recordings were conducted in an anechoic chamber to eliminate external sound reflections. An omnidirectional polar pattern microphone was positioned 20 cm in front the ranat to capture the radiated sound. It was hit in a conventional seated position to replicate typical playing conditions and ensure optimal sound resonance. The sound signals were captured in real time using a PicoScope 3000 series oscilloscope and accompanying data recorder (Pico Technology, Eaton Socon, UK). The PicoScope software enabled waveform viewing, FFT analysis, spectrum visualization, and voltage-based triggering. The apparatus used in the experimental setup is provided in Fig. 5.

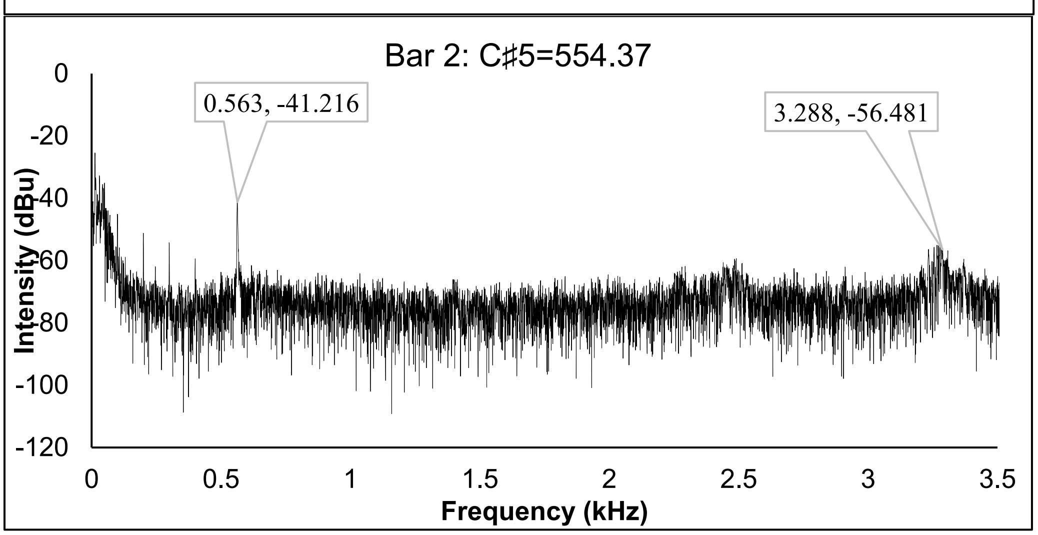
Fig. 5. The apparatus used in the experimental setup

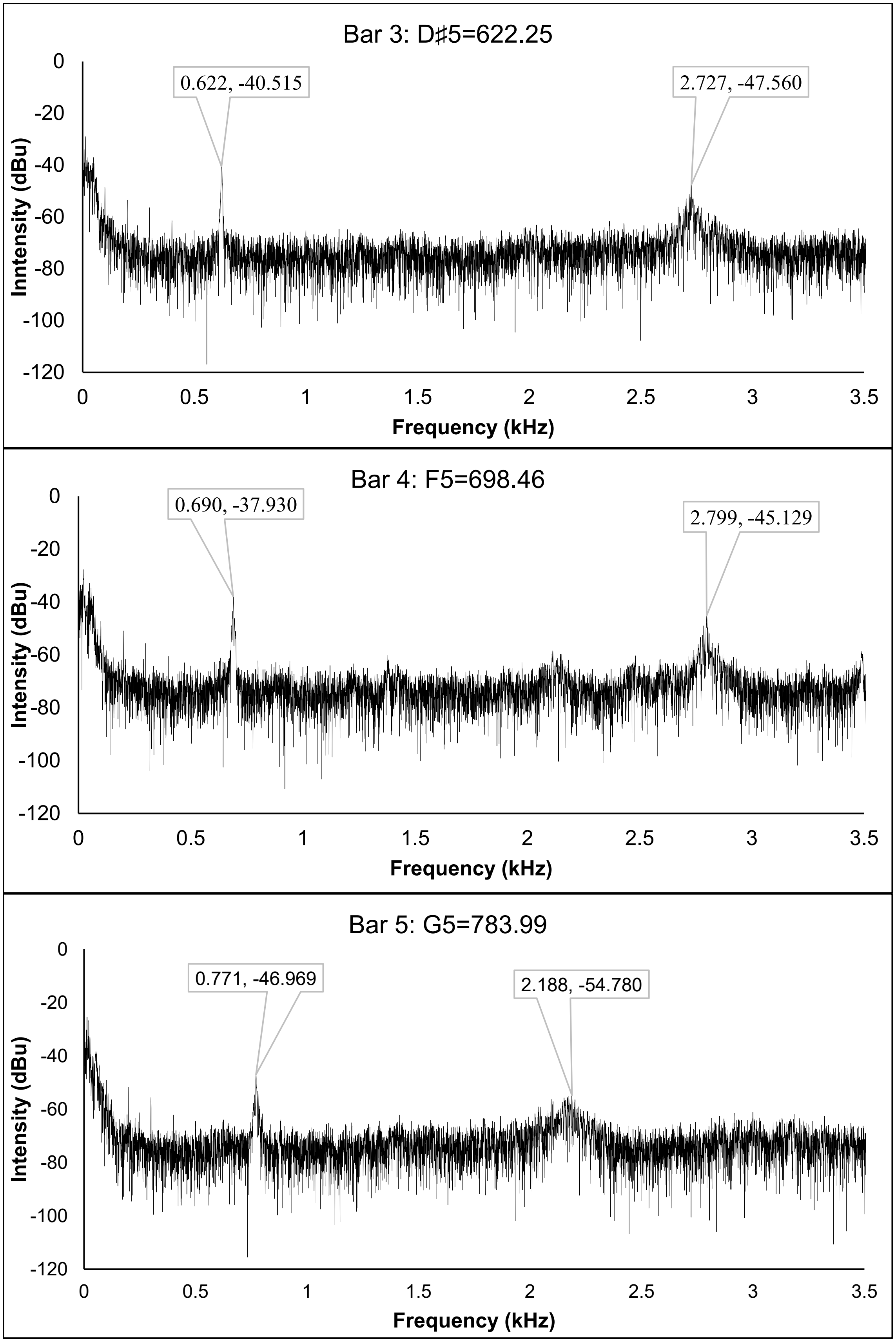
To prevent distortion or bias, the ranat was recorded under identical conditions, including fixed microphone position and orientation. The signal was amplified using a Behringer Powerplay Pro XL amplifier (Zhongshan, Guangdong, China) before being processed by the PicoScope. The resulting sound spectra were analyzed in Adobe Audition, where FFT analysis was used to extract dominant frequencies and evaluate tonal characteristics. The Fourier transform technique enabled identification of fundamentals, harmonics, and subharmonics in the recorded waveforms. Sound data from the ranat was collected in multiple trials. Each iteration was recorded under the same conditions, and the resulting waveforms were averaged to reduce variability and noise. This approach ensured a robust and meaningful acoustic comparison. By employing controlled hitting, consistent recording parameters, and multiple rounds of measurement with averaged data, the methodology ensured a clear, accurate, and scientifically valid comparison of the acoustic performance of the ranat. To ensure accurate and repeatable sound production, a skilled player performed the hitting on the ranat. Consistency was ensured by maintaining the same technique and force for each attempt. Prior to recording, the player rehearsed the precise motions multiple times to minimize human variability and enhance the reliability of the sound comparison.

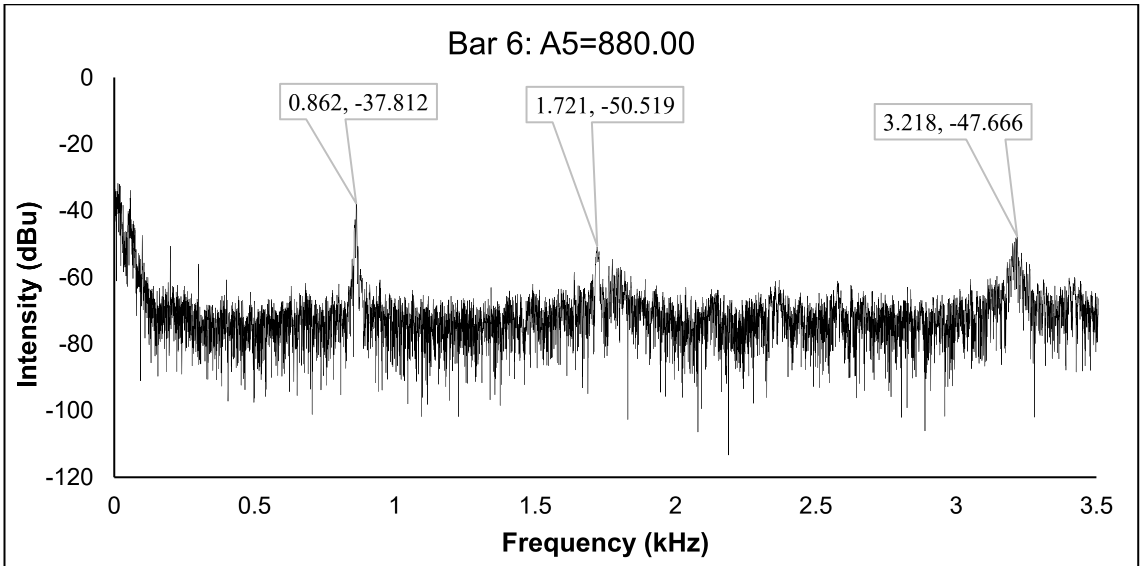
RESULTS AND DISCUSSION

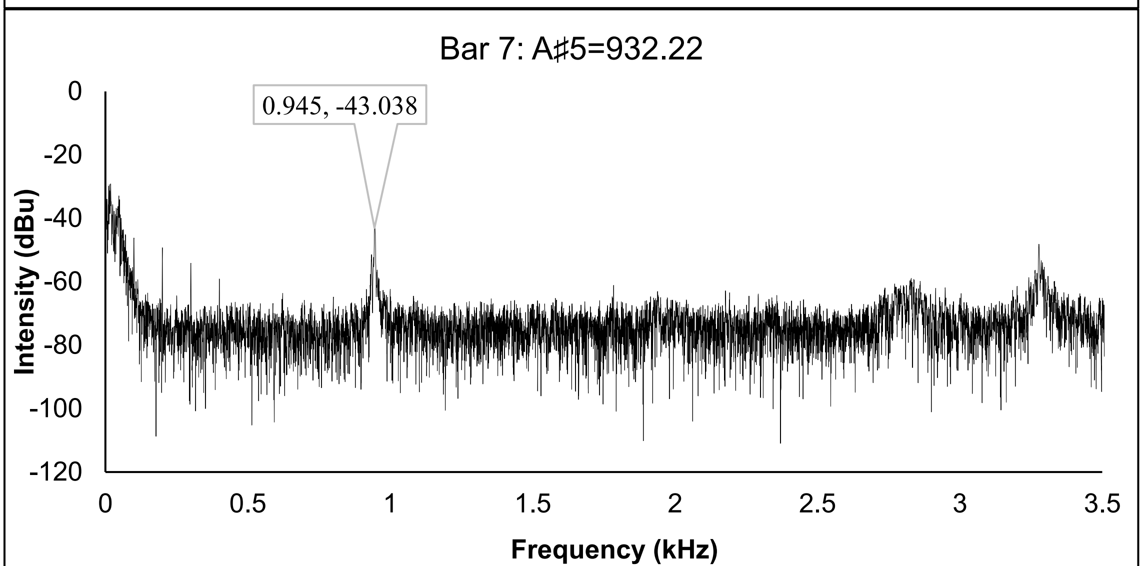
Figure 6 shows the typical signals obtained from the seventeen bars. All the bar frequencies and notes are displayed in Table 1. The frequencies for bar 1 to 17 were found to be 523, 554, 622, 698,784, 880, 932, 1046, 1108, 1318, 1396, 1568, 1760, 1975, 2093, 2489, and 2637 Hz, respectively (the notes were C5, C♯5, D♯5, F5, G5, A5, A♯5, C6, C♯6, E6, F6, G6, A6, B6, C7, D♯7 and E7). The octaves were grouped (using Western Equivalents) as follows: octave 5 includes 523, 554, 622, 698,784, 880, 932 Hz (the notes are C5, C♯5, D♯5, F5, G5, A5, and A♯5), octave 6 includes 1046, 1108, 1318, 1396, 1568, 1760, 1975 Hz (the notes are C6, C♯6, E6, F6, G6, A6, and B6), and octave 7 includes 2093, 2489, 2637 Hz (the notes are C7, D♯7, and E7).

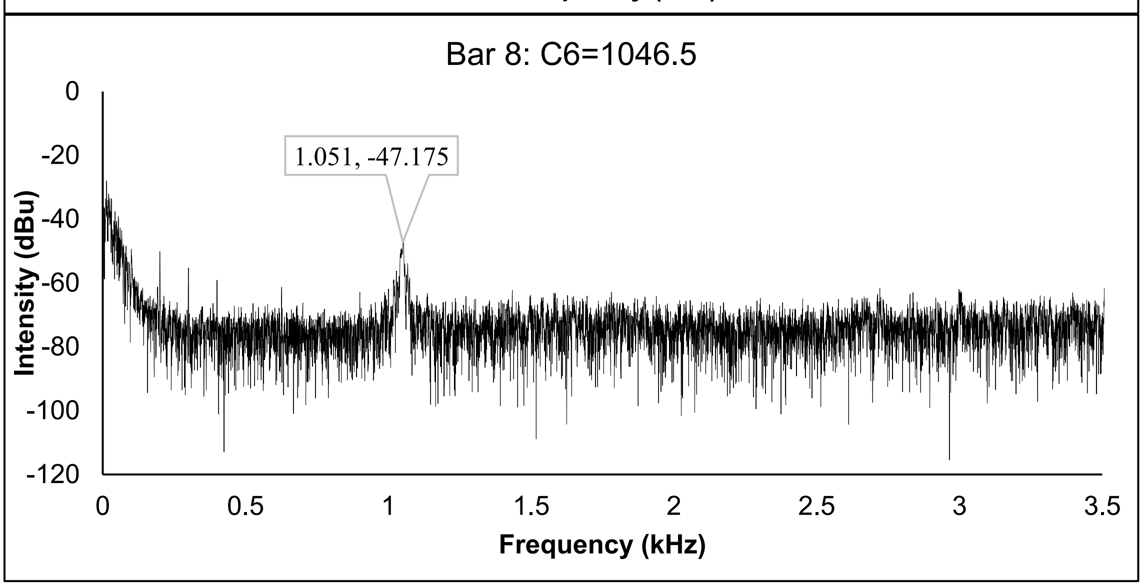


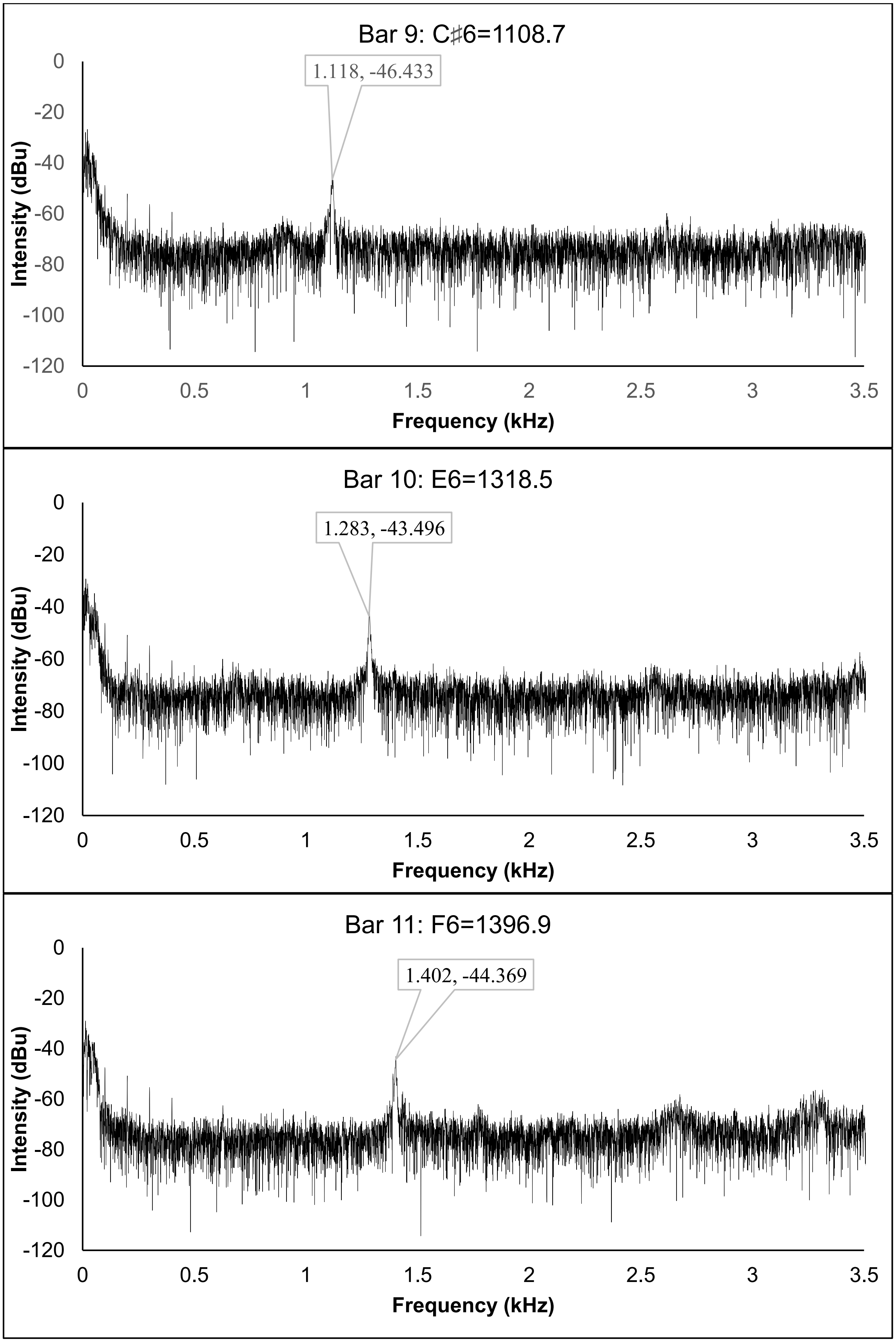


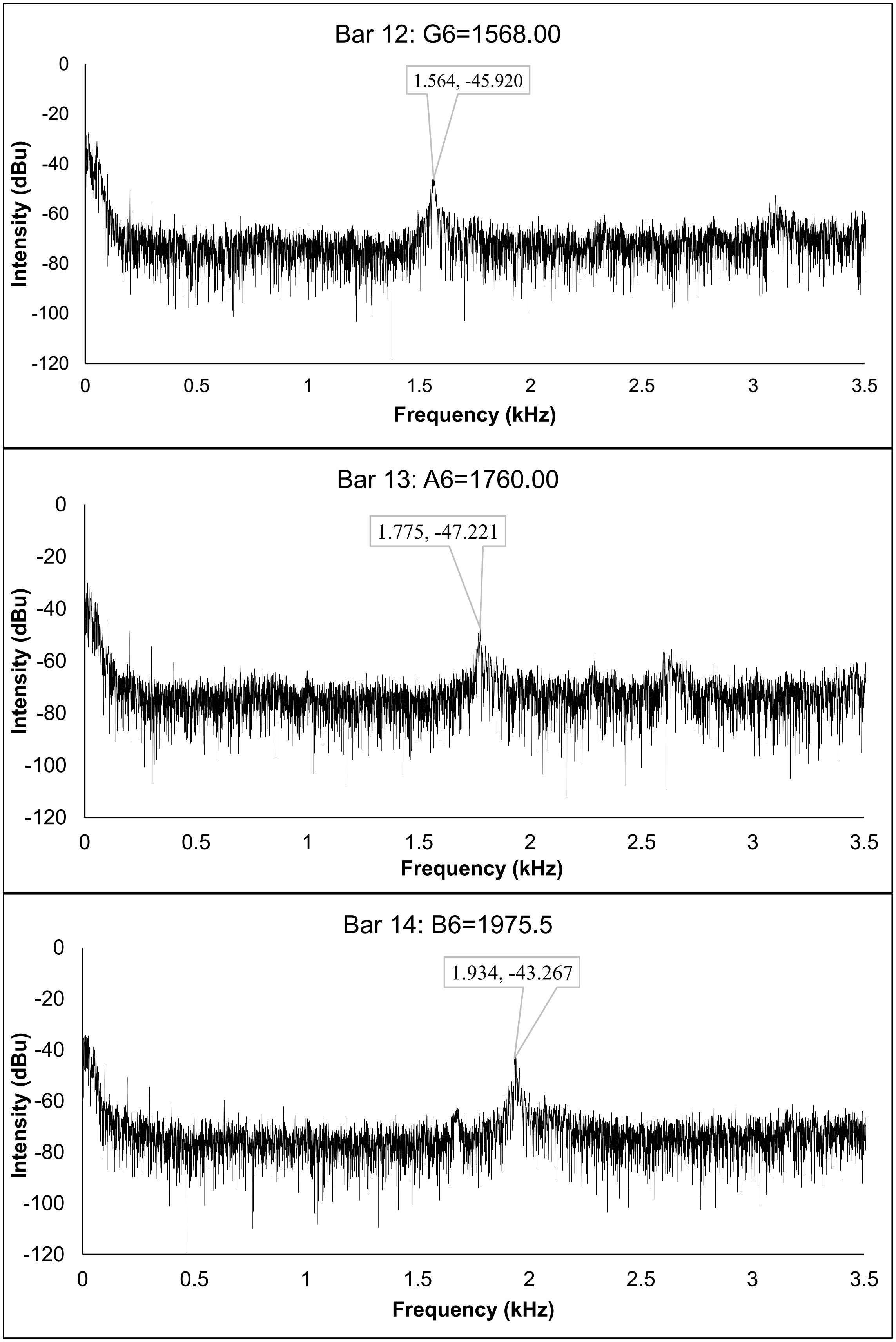

Bar 3: D♯5=622.25
0.622, -40.515
2.727, -47.560
Inntensity (dBu)
0
-20
-40
-60
-80
-100
-120
0
0.5
1
1.5
2
2.5
3
3.5
Frequency (kHz)
Bar 4: F5=698.46
0.690, -37.930
2.799, -45.129
Intensity (dBu)
Frequency (kHz)
Bar 5: G5=783.99
0.771, -46.969
2.188, -54.780
Intensity (dBu)
Frequency (kHz)


Bar 6: A5=880.00
0.862, -37.812
1.721, -50.519
3.218, -47.666
Intensity (dBu)
Frequency (kHz)


Bar 7: A♯5=932.22
0.945, -43.038
Intensity (dBu)
Frequency (kHz)


Bar 8: C6=1046.5
1.051, -47.175
Intensity (dBu)
Frequency (kHz)


Bar 9: C♯6=1108.7
1.118, -46.433
Intensity (dBu)
0
-20
-40
-60
-80
-100
-120
0
0.5
1
1.5
2
2.5
3
3.5
Frequency (kHz)
Bar 10: E6=1318.5
1.283, -43.496
Intensity (dBu)
Frequency (kHz)
Bar 11: F6=1396.9
1.402, -44.369
Intensity (dBu)
Frequency (kHz)


Bar 12: G6=1568.00
1.564, -45.920
Intensity (dBu)
Frequency (kHz)
Bar 13: A6=1760.00
1.775, -47.221
Intensity (dBu)
Frequency (kHz)
Bar 14: B6=1975.5
1.934, -43.267
Intensity (dBu)
Frequency (kHz)

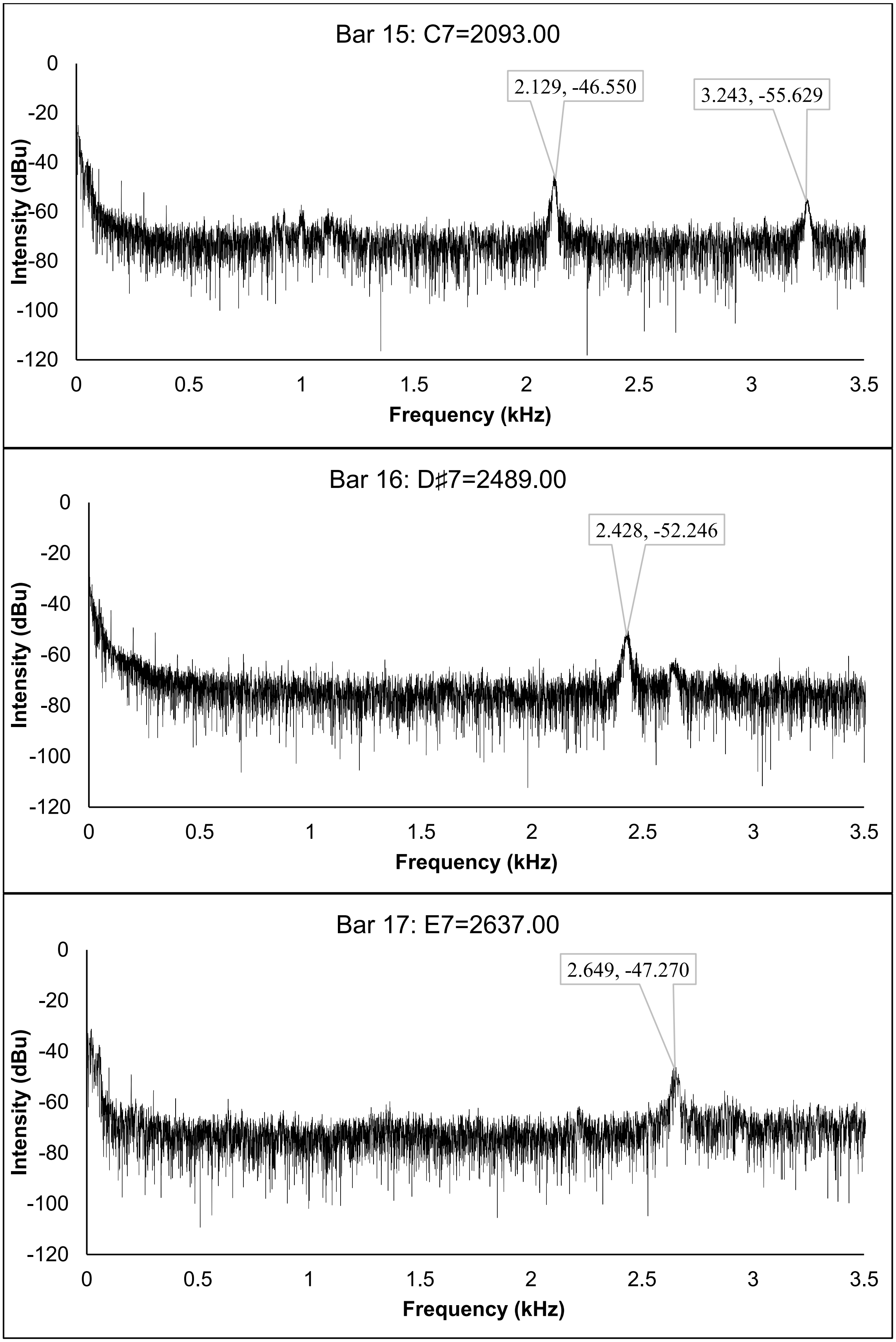


Fig. 6. The intensity (dBu) *versus* frequency (kHz) for bar 1 to bar 17

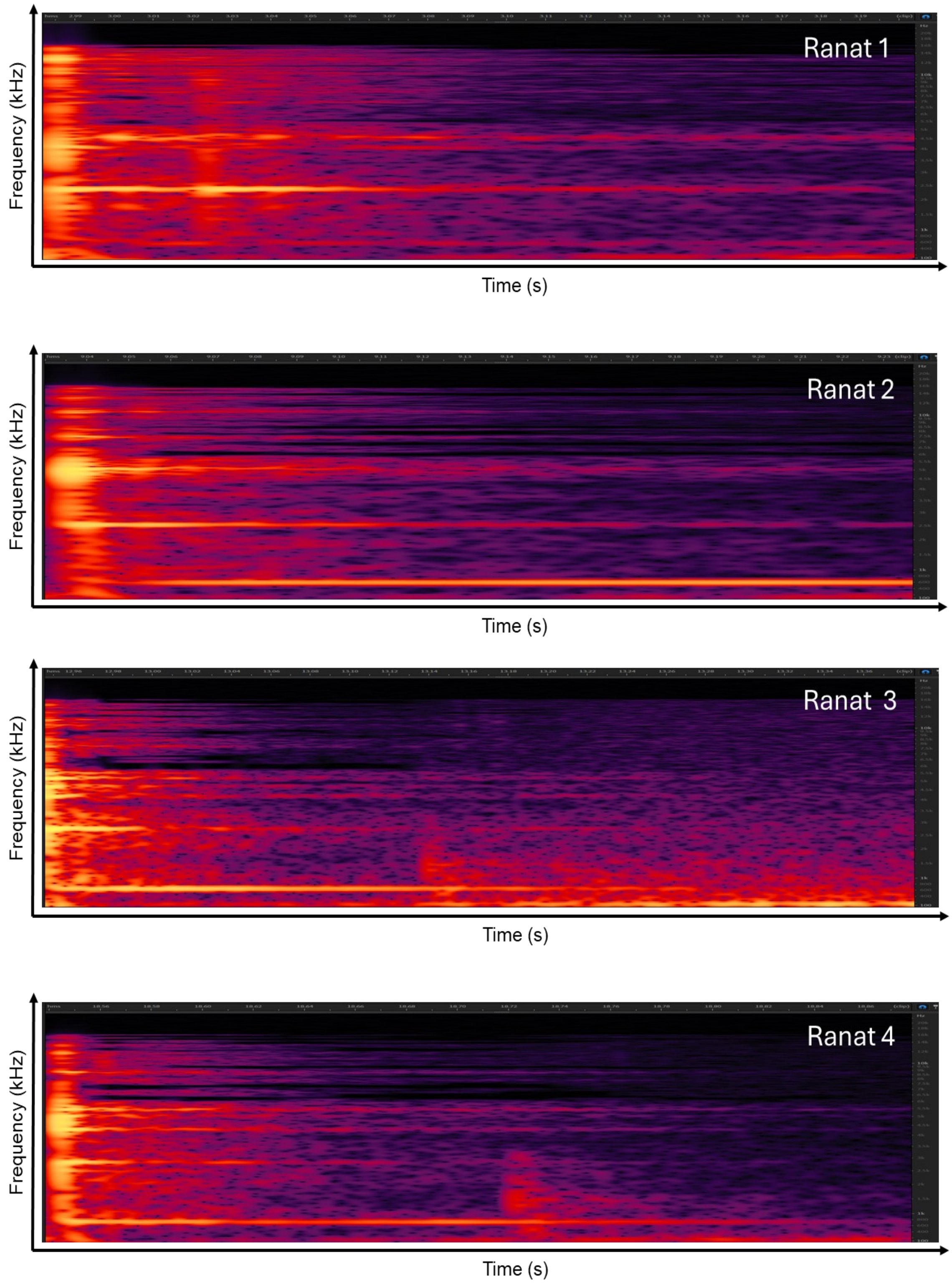
Table 1. The Frequencies and Notes from Bar 1 to Bar 17

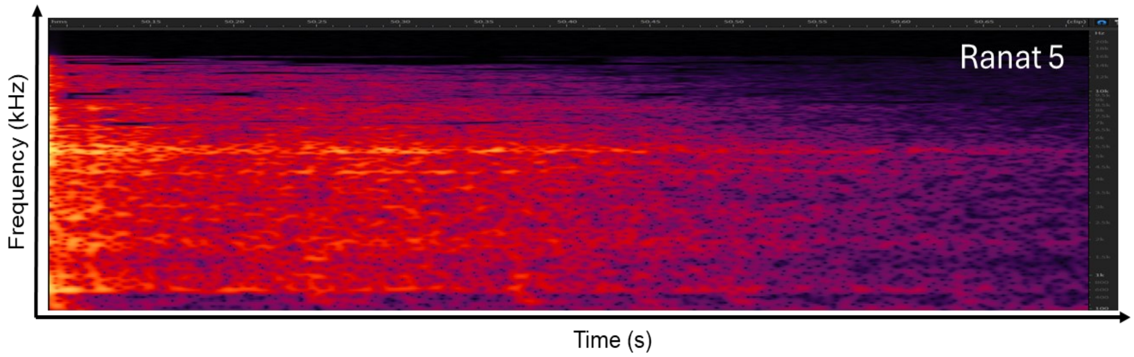
Bar no.	Frequency	Note
1	523	C5
2	554	C♯5
3	622	D♯5
4	698	F5
5	784	G5
6	880	A5
7	932	A♯5
8	1046	C6
9	1108	C♯6
10	1318	E6
11	1396	F6
12	1568	G6
13	1760	A6
14	1975	B6
15	2093	C7
16	2489	D♯7
17	2637	E7

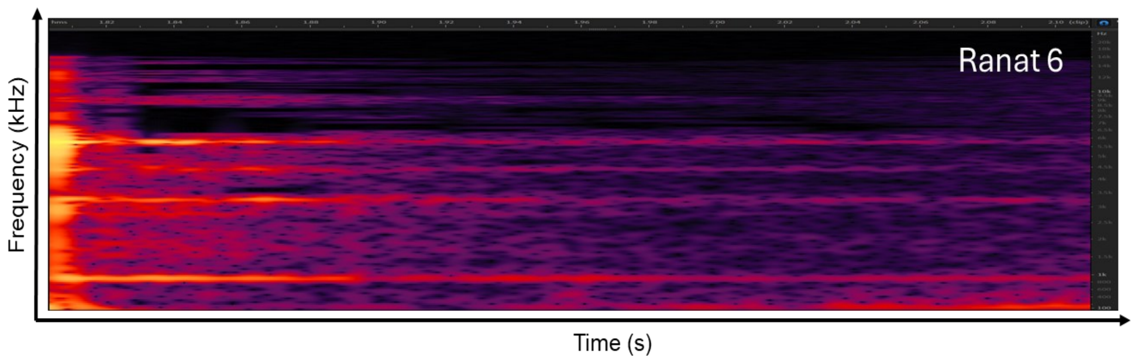
The analysis of the 17 bars of the ranat ek revealed a distinct pitch configuration that did not conform to Western equal temperament. The recorded notes C5, C♯5, D♯5, F5, G5, A5, A♯5, C6, C♯6, E6, F6, G6, A6, B6, C7, D♯7, and E7 exhibited a combination of semitone-like intervals and whole-tone steps, with some microtonal characteristics. This reflects a musical scale system that is fundamentally non-Western and culturally specific. In traditional Thai music, the octave is divided into seven equal steps of approximately 171.4 cents each, forming what is referred to as an equidistant heptatonic scale. Although Western pitch names are used here for reference and approximation, they do not fully represent the sonic logic of Thai musical scale. Instead, the ranat ek demonstrates an alternative system that places emphasis on tonal balance and modal flexibility rather than conformity to Western harmonic principles.

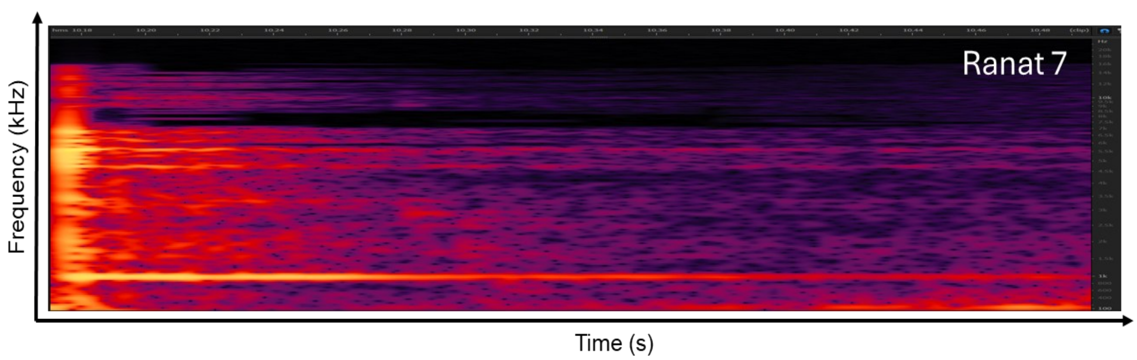
Spectral analysis using FFT of each bar's waveform revealed partial overtones that deviated from harmonic integer multiples. These inharmonic profiles are consistent with the physical properties of wooden bar instruments, where overtones are shaped by bar length, curvature, density, and the mode of excitation. Notably, the deeper arches and longer lengths in the lower-pitched bars produced broader vibration patterns and stronger fundamental tones, while higher bars displayed brighter, shorter decays. The resulting sonic fingerprint is not only unique but acoustically rich, warranting detailed preservation. These characteristics present significant implications for audio preservation. Given the ranat ek's culturally embedded and inharmonic musical scale, traditional low-resolution or compressed digital formats are inadequate to capture its full timbral detail.

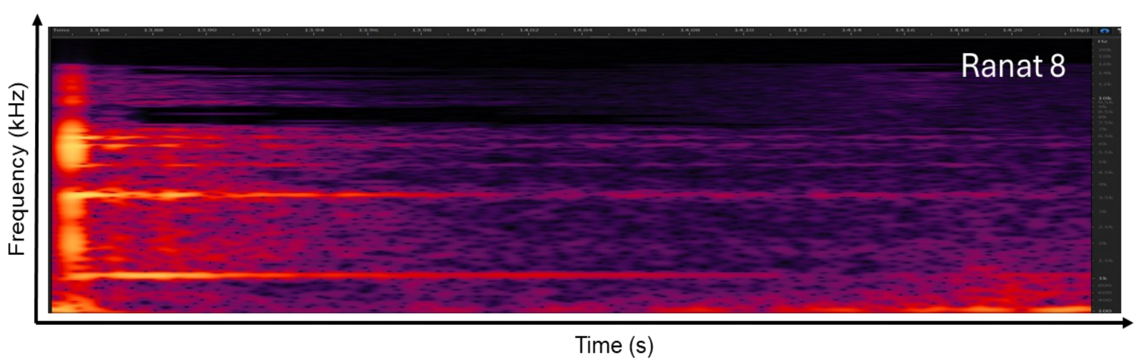
Beyond audio preservation, this research opens pathways for applications in augmented reality (AR) and virtual reality (VR) environments. The data obtained can be used to develop interactive simulations where users virtually engage with the ranat ek, hearing authentic tones derived from actual measured frequencies and experiencing playing techniques through motion capture.

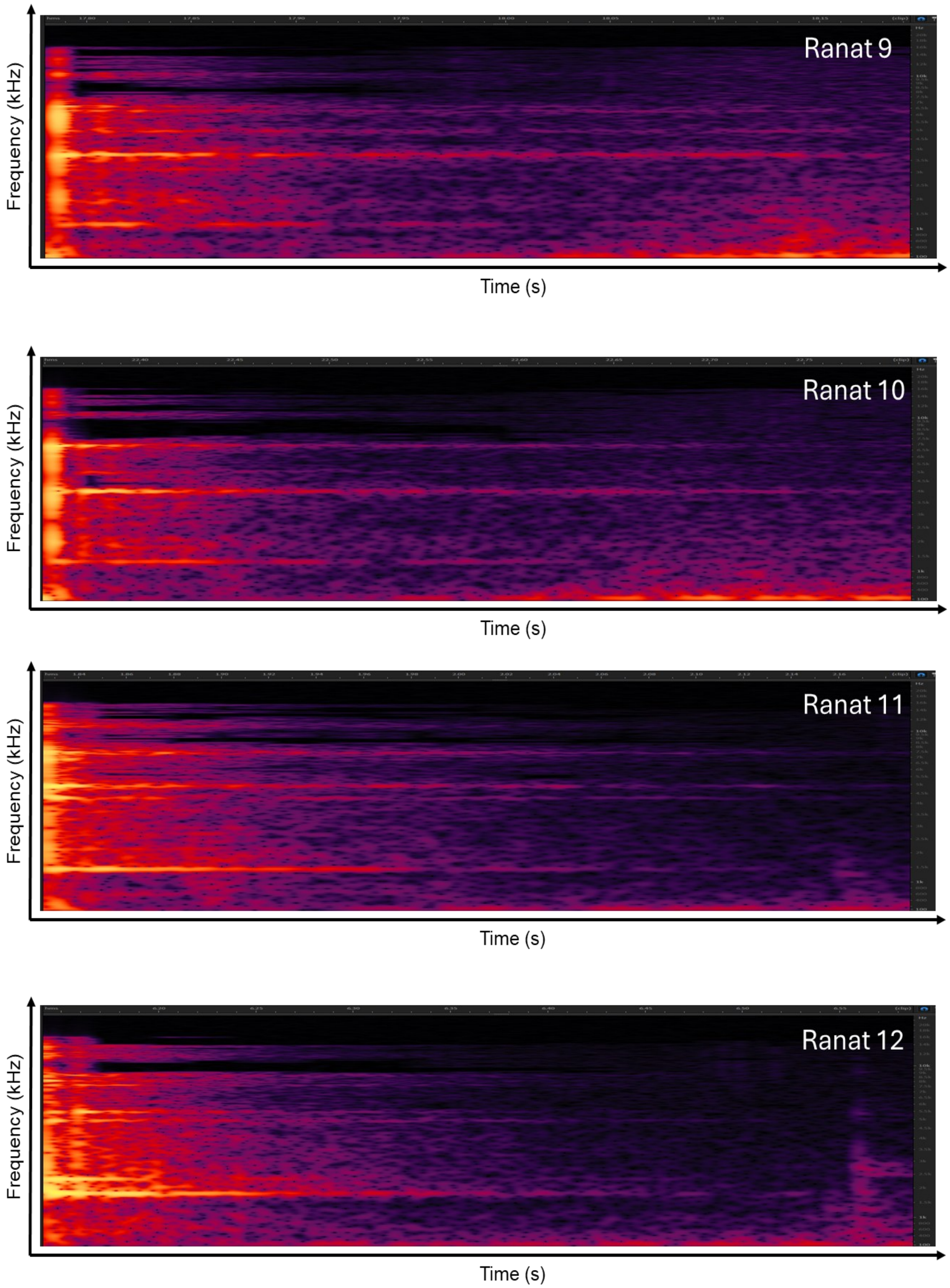

Ranat 1
Frequency (kHz)
Time (s)
Ranat 2
Frequency (kHz)
Time (s)
Ranat 3
Frequency (kHz)
Time (s)
Ranat 4
Frequency (kHz)
Time (s)

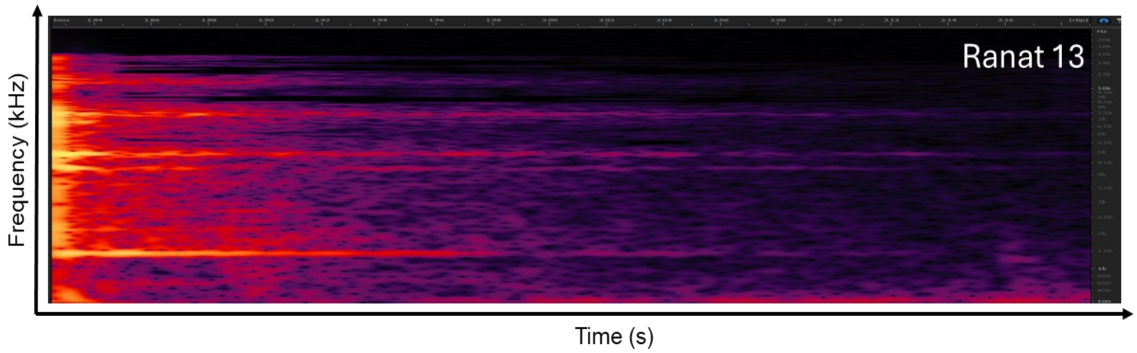

Ranat 5
Frequency (kHz)
Time (s)

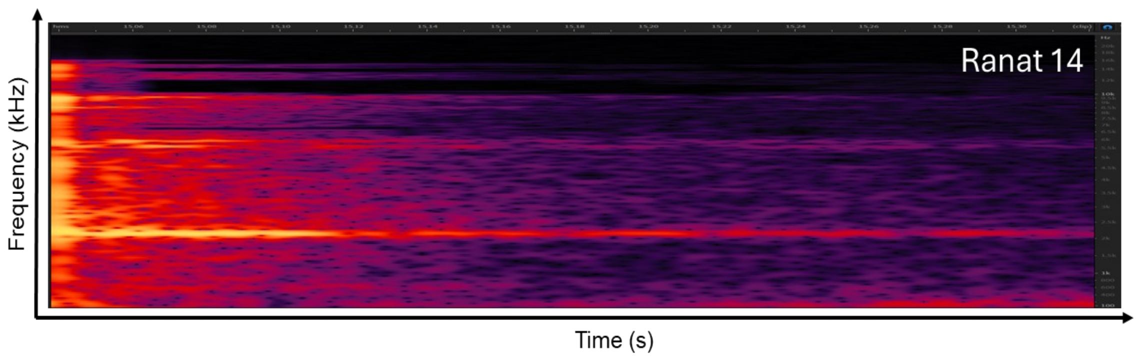

Ranat 6
Frequency (kHz)
Time (s)

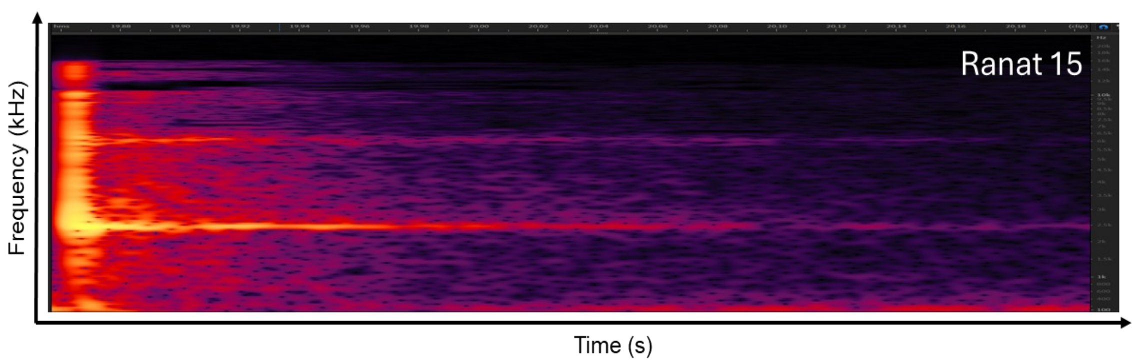

Ranat 7
Frequency (kHz)
Time (s)

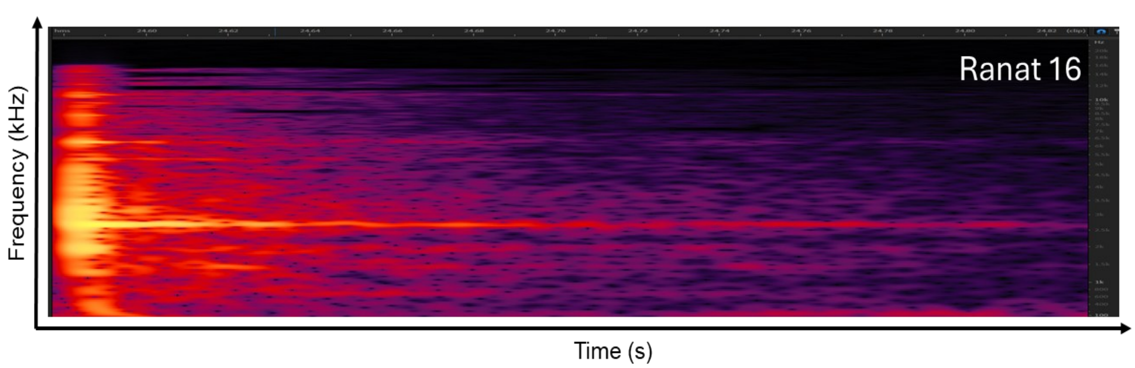

Ranat 8
Frequency (kHz)
Time (s)


Ranat 9
Frequency (kHz)
Time (s)
Ranat 10
Frequency (kHz)
Time (s)
Ranat 11
Frequency (kHz)
Time (s)
Ranat 12
Frequency (kHz)
Time (s)


Ranat 13
Frequency (kHz)
Time (s)


Ranat 14
Frequency (kHz)
Time (s)


Ranat 15
Frequency (kHz)
Time (s)


Ranat 16
Frequency (kHz)
Time (s)

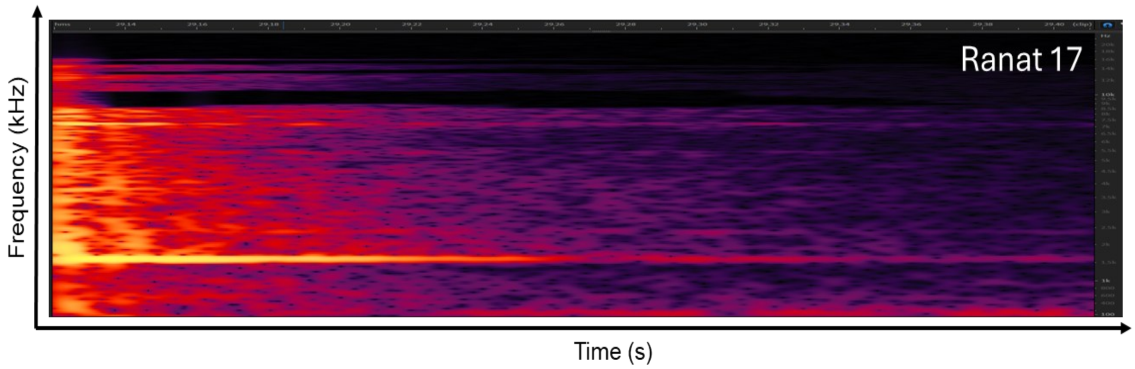


Fig. 7. The spectrogram from adobe audition for bars 1 to 17

In AR, educational apps can visualize the relationship between mallet strike and pitch generation, allowing users to learn traditional playing methods intuitively. In VR, immersive experiences could replicate historical Thai ensemble settings, presenting the ranat ek within its cultural and acoustic context. Equally significant is the potential of this study to inform sustainable instrument design. As interest grows in environmentally friendly alternatives to traditional hardwoods such as rosewood (*Dalbergia oliveri*), the spectral data gathered here can support AI-assisted simulations of acoustic outcomes using plant-based or renewable materials.

By training AI models on the vibrational characteristics of each bar, designers can predict how alternative materials such as bamboo, palm, or bio-composite wood will perform acoustically. These simulations could greatly reduce the trial-and-error process in prototyping and help produce instruments that preserve the authentic sound while advancing ecological responsibility. Furthermore, the data may be fed into generative design systems or parametric modelling platforms to fabricate bars with optimized musical scale profiles that mimic or enhance the traditional tonal qualities.

It is also important to emphasize that preservation extends beyond sound alone. The playing technique, posture, mallet type, musical scale practice, and crafting traditions are equally essential components of the ranat ek's cultural heritage. Thus, a holistic approach to preservation is recommended, *i.e.*, one that includes 3D scanning of bar shapes, motion capture of performance gestures, and detailed metadata documentation linking acoustic measurements with material and cultural descriptors. When preserved collectively, these elements can offer future generations a more complete and immersive understanding of the instrument.

Figure 7 shows the spectrogram from Adobe Audition for bar 1 to 17. All the bars display the distinct fundamental peak with the insignificant overtone. The frequency for bar 1 to 17 are 523, 554, 622, 698,784, 880, 932, 1046, 1108, 1318, 1396, 1568, 1760, 1975, 2093, 2489, and 2637 Hz, respectively. The spectrogram from the time frequency analysis *via* the Adobe Audition showed the bright yellow with a well distributed frequency spectrum on the y-axis. At the highest pitch obtained from bar 17 (the shortest bar), a sharp well define yellow frequency spectrum was very obvious due to the highest pitch from the bar 17. The time frequency analysis confirmed the result from Fig. 6, *i.e.*, for bar 17, which only displayed a single peak at 2649 Hz (E7=2637 Hz).

The acoustic and tuning characteristics of the ranat ek differ from Western equal temperament systems, showing a non-tempered, heptatonic tuning logic with unique overtone relationships. The FFT analysis demonstrated that each bar produces a distinct frequency spectrum, confirming the ranat's cultural tuning identity rather than adherence to Western tonal frameworks. These findings are significant for audio preservation, as they establish a quantitative reference for reconstructing the ranat's authentic tuning in AI assisted audio modeling, AR based instrument visualization, and VR heritage exhibitions particularly when exploring eco-material innovations such as plant-based resonators for sustainable instrument design.

CONCLUSIONS

1. The frequencies for bars 1 to 17 were found to be 523, 554, 622, 698,784, 880, 932, 1046, 1108, 1318, 1396, 1568, 1760, 1975, 2093, 2489, and 2637 Hz, respectively (the notes were C5, C♯5, D♯5, F5, G5, A5, A♯5, C6, C♯6, E6, F6, G6, A6, B6, C7, D♯7, and E7). The musical scale data collected from the Ranat ek is more than a frequency chart. Rather, it holds the cultural memory and sonic fingerprint of a centuries old practice.
2. The octaves are grouped (using Western Equivalents) as follows: octave 5 includes 523, 554, 622, 698,784, 880, 932 Hz (the notes are C5, C♯5, D♯5, F5, G5, A5, and A♯5), octave 6 includes 1046, 1108, 1318, 1396, 1568, 1760, 1975 Hz (the notes are C6, C♯6, E6, F6, G6, A6, and B6), and octave 7 includes 2093, 2489, 2637 Hz (the notes are C7, D♯7, and E7).
3. This study provides empirical documentation of the ranat ek*'s* unique tuning and acoustic characteristics, reinforcing its cultural and historical importance. The results suggest that the instrument's tuning system may have been influenced by mathematical relationships rather than fixed pitch intervals, linking ancient craftsmanship with scientific precision. By aligning this research with current technologies in AI, AR, and VR, the study not only helps preserve intangible musical heritage but also lays the groundwork for future innovations from digital twins in virtual museums to AI-assisted eco-material instrument design.

ACKNOWLEDGMENTS

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

REFERENCES CITED

Bamrungwong, J., and Woraratsoontorn, P. (2016). The Application of Inertia Relief Method in Ranat and Xylophone. *International Conference on Electrical, Mechanical and Industrial Engineering (ICEMIE 2016)* DOI: 10.2991/icemie-16.2016.54.

Lin, Z.-X, Punvaratorn, M., and Wangphanich, C. (2023). "Analysis of Thai tuning system by mathematical formula," *J. Roi Kaensarn Academi* 8(8).

Marcuse, S. (1975). *A Survey of Musical Instruments*, Harper & Row.

Skoki, A., Ljubic, S., Lerga, J., and Štajduhar, I. (2019). "Automatic music transcription for traditional woodwind instruments sopele," *Pattern Recognition Letters* 128, 340-347.

Sumrongthong, B. (1998). "The improvisation of Thai xylophone or Ranaat Eek," *Manusya, Journal of Humanities* 1(1), article 9. Available at: https://digital.car.chula.ac.th/manusya/vol1/iss1/9.

Article submitted: July 16, 2025; Peer review completed: August 9, 2025; Revised version received and accepted: October 20, 2025; Published: October 28, 2025.
DOI: 10.15376/biores.20.4.10838-10857