Acoustics of the Forgotten Tapi Two-strings Lute of Lun Bawang

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The Tapi two-strings lute is typically made from Pulai (*Alstonia* spp.), a light hardwood in the Apocynaceae family. This study determines the tuning retrieval of the Tapi two strings lute instrument. This work investigated the string notes using a microphone for recording the Fast Fourier Transform (FFT) of the signal to determine the fundamental and the partial frequency of Tapi two strings lute instrument. The Tapi was tuned to the E major key with F#, C#, G#, and D# note. The time frequency analysis (TFA) showed that each open string has its own timbre characteristics. The open string 1 showed only 3 important partials, whereas open string 2 showed 6 important partials. Frets 2, 4, 6, and 8 showed more partials than frets 1, 3, 5, and 7. Both fret 9 and 10 showed a similar number of partials. Frets 11, 12, 13, 14, 15, and 16 showed less partials and were evenly distributed, whereas fret 17 clearly showed only 4 partials.

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INTRODUCTION

In Malaysia, woods are generally used for building and bridge construction, furniture, musical instruments, pulp, and paper. The suitability of these woods for musical instruments is based on the experience of the luthier. Despite the availability of many wood species in Malaysia, the species selected for musical instruments are limited to *Intsia palembanica* (Merbau) and *Artocarpus champeden* Spreng (Cempedak) (Chong 2000). In this work, the suitability of Pulai (*Alstonia macrophylla*) wood for making Tapi musical instrument is determined. The mean value of quality factor Q^{-1}, dynamic Young's modulus E_D, and acoustic coefficient efficiency ACE of Pulai (*Alstonia macrophylla* with $\gamma = 0.62$) are 0.026, 8.72 GPa, and 0.718, respectively (Sedik *et al.* 2010). Studies have been conducted on Sape (Hamdan *et al.* 2023a) and Gambus instruments (Hamdan *et al.* 2023b). Historically and traditionally, the Tapi instrument is made from Pulai wood, but no data on the key, tuning of the notes, and frequency characteristics of the instrument have been published. Tapi is a Lun Bawang (Orang Ulu ethnic from Miri, Sarawak, Malaysia) musical instrument belonging to the boat lute family.

The term Orang Ulu refer to the indigenous Kayan, Kejaman, Kenyah, Kajang, Bukat, Penan, Punan, Dayeh, Ukit, Murut, Berawan, Seputan/Uheng Kereho, Aoheng/Penihing, Lun Bawang, Bahau, and Kelabit. This indigenous population resides at the upstream of Batang Rajang river that is in the Belaga district.

The Tapi is made from a single plank of Pulai wood. The Tapi was cut in the longitudinal direction with radial direction as the thickness and the tangential direction as the width. The sound analysis of the Tapi is considered important because recollection of the past is as important as conceiving the future possibility and present value sets for decision making on what is important to human life. Currently, the collections and documentations of traditional instruments are scarce. The main objective of this work is to analyze the Tapi instrument frequency spectrum *via* Fast Fourier Transform (FFT). This creates an archive of what was once heard by the community of the Orang Ulu. Archiving the sound of Tapi in the form of time frequency analysis (TFA) serves to provide the identity of the individual community. With the aid of FFT and Adobe audition, a sound analysis is able to define the fundamental and partial frequency of each note. These fundamental frequencies eventually determine the notes and the key of the instrument. The microphone method determined the fundamental and partial frequencies of the open strings and the frets accordingly. The signal was captured by Picoscope oscilloscope and saved in the time and frequency domain.

EXPERIMENTAL

The Tapi was borrowed from Mr. Rining Peter Paris (belonged to his late grandfather), who claimed that it is more than 60 years old (Fig. 1). The sounds were recorded at 48 kHz sampling rate. Figure 2 shows the schematic diagram of the microphone data acquisitions. The experiment was conducted in the anechoic room at Universiti Malaysia Sarawak (UNIMAS) Music Department. The sound was collected using a microphone. The voltage-time signal and the amplitude frequency spectrogram were recorded by PicoScope Oscilloscope. The TFA was performed with Adobe Audition, based on the distinct intensity in hertz (differentiates the strength of the partial frequencies) with magnitudes in second. Most sound analysis and re-synthesis investigate tone systems with this approach (Hamdan *et al.* 2020). The 1st to 6th partial for each string are plotted for comparison purposes. For sound recording, the microphone was arranged to be aligned with the Tapi string at a distance below 20 cm (see Fig. 2). When a lute string is plucked, it undergoes excitation and initiates vibrations. These vibrations are the source of sound waves, which in turn give birth to the musical notes we perceive. The sound generated depends on a myriad of factors, including the tension of the string, its length, and the precise plucking technique employed. Additionally, the resultant sound is profoundly influenced by a range of elements, encompassing string tension, length, plucking method, initial conditions, resonance, and the unique acoustic attributes of the instrument. To ensure uniformity in the plucking pattern and meticulous consideration of these aspects, it is common practice to engage a professional lute player with expertise in these nuances. The collective interplay of these factors coalesces to produce the rich and harmonious sounds that are emblematic of the lute.

The format for the recording of audio signals was a mono 24-bit resolution with a sampling rate of 48 kHz. The audio profile was saved in .wav format for further processing. Before recording the session, a calibration was carried out to ensure optimum setting. The method based on European Broadcasting Union (EBU) was adopted for the calibration procedure with the test tone limited to 1 kHz sine wave. According to EBU, the digital equivalent of 0 VU recorded by the device must be generated at +4 dBu or -18 dBFS in either analog or digital format. During the calibration procedure, no other device was present that may boost or attenuate the signal amplitude. The recording system setup was made of audio interfaces (Steinberg UR22mkII), a microphone (Audio-Technica AT4050), an amplifier (Behringer Powerplay Pro XL, Behringer, China), and cable (XLR) with the microphone arranged to low cut (flat). For audio processing, the signal was logged by oscilloscopes (Pico Technology, 3000 series, Eaton Socon, UK) and was analyzed by Picoscope software (ver. 6), especially on FFT, voltage-based trigger and spectrum analysis.

Fig. 1. The two strings Tapi lute of Lun Bawang

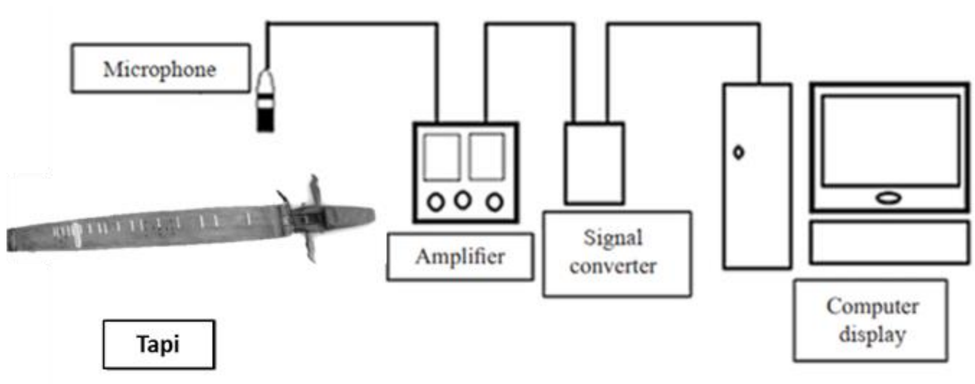


Fig. 2. Schematic diagram of the microphone data acquisitions

RESULTS AND DISCUSSION

This study identified elements in a two strings Tapi. Figure 3 shows the typical output for open string 1 from the Picoscope oscilloscope with both the time and frequency domain using the microphone data acquisitions. The fundamental frequency was at 166 Hz (E3). The Tapi was tuned to the E major key with F#, C#, G#, and D# notes. The second fret was supposed to be G3 (*i.e.*, 196 Hz), but it was slightly higher, *i.e.* A3 (214 Hz), which was only 10 Hz lower than the third fret, *i.e.* A3 (224 Hz).

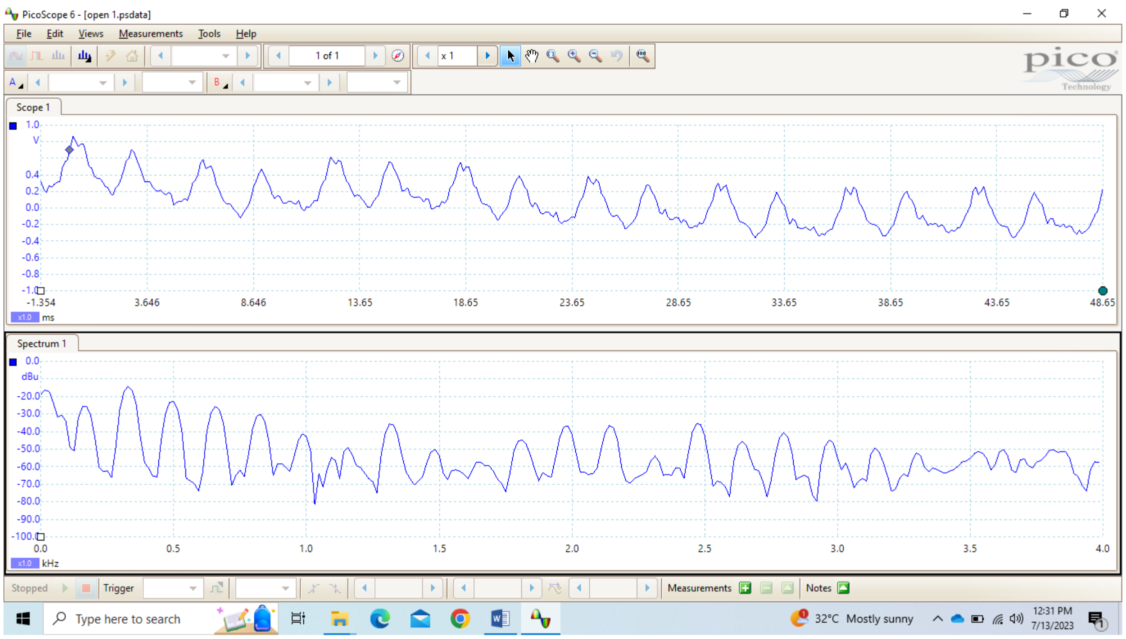


Fig. 3. The typical output for open string 1 from the Picoscope oscilloscope using the microphone data acquisitions; the fundamental frequency is at 166 Hz (E3)

The Tapi string 1 has the first two octaves in the E major scale, while the third octave is with only four notes. Because the frets are made of rattan, which was placed almost 60 years ago, the tuning of the first fret had slightly changed to a flatter note, *i.e.*, to F3 instead of F3#, and the second fret to a sharper note, *i.e.*, to A3 instead of G3#. Table 1 shows the output from the Picoscope oscilloscope with both the fundamental and partials frequencies for open string 2 and open string 1 (with the 17 frets) using the microphone method. The values in brackets indicate the note of the fundamental frequency and the harmonic numbers of the partial. The Tapi have an acoustic spectrum pattern with a constant harmonic overtone. In the authors' previous study on Sape (Hamdan *et al.* 2023a), the Sape open string 1 and frets 1 through 17 have notes F3, G3, A3, Bb3, C4, D4, E4, F4, G4, A4, Bb4, C5, D5, E5, F5, G5, A5, and C6. The Sape string 1 has the first two octaves in the F major scale, whilst the third octave has only four notes, with a jumping note between A5 and C6 in the third octave (which consists of F5, G5, A5, and C6 only). The jumping note from A5 to C6 was purposely done with the intention to ease the playing of traditional songs (Hamdan *et al.* 2023a). Table 2 shows the frequency of the open string 1 with the 17 frets for Tapi and Sape (Hamdan *et al.* 2023a). Figure 4 plots the fret number *versus* the note frequency for Tapi and Sape. The Sape is tuned one note higher than the Tapi.

The mean value of quality factor Q^{-1}, dynamic Young's Modulus E_D, and acoustic coefficient efficiency ACE of Pulai (*Alstonia macrophylla* with $\gamma = 0.62$) are approximately 0.026, 8.72GPa, and 0.718 x 10^7, respectively. Generally, wood with higher value of E/γ and lower internal friction Q^{-1} is suitable for soundboards (Matsunaga *et al.* 1996). *Alstonia pneumatophora* are preferred for making the back plate of violin (Sedik *et al.* 2010). Figure 5 shows the TFA from Adobe audition (Adobe Corporation, version Build 23.0.0.54, San Jose, CA, USA) for open string 2, open string 1 (with the 17 frets). Each string has its own timbre characteristics, *i.e.*, open string 1 is different from open string 2.

Table 1. Fundamental Frequency (Note in Bracket) and Partial Frequencies (Harmonics in Bracket) of the Open String 2 and Open String 1 (with 17 Frets)

String/ Fret	Fundamental	2nd Partial	3rd Partial	4th Partial	5th Partial	6th Partial
Open string 2	166 (E3 = 165)	333 (2.00)	495 (2.98)	667 (4.01)	830 (5.0)	992 (5.97)
Open string 1	166 (E3 = 165)	333 (2.00)	495 (2.98)	658 (3.96)	825 (4.96)	987 (5.94)
Fret 1	180 (F3 = 175)	366 (2.03)	553 (3.07)	734 (4.07)	920 (5.11)	-
Fret 2	214 (A3 = 220)	424 (1.98)	634 (2.96)	849 (3.96)	1054 (4.92)	-
Fret 3	224 (A3 = 220)	439 (1.95)	654 (2.91)	855 (3.81)	1085 (4.84)	-
Fret 4	248 (B3 = 247)	492 (1.98)	736 (2.96)	985 (3.97)	1229 (4.95)	-
Fret 5	281 (C4# = 277)	554 (1.97)	827 (2.94)	1104 (3.92)	1382 (4.91)	1650 (5.87)
Fret 6	310 (D4# = 311)	616 (1.98)	922 (2.97)	1224 (3.95)	1545 (4.98)	1846 (5.90)
Fret 7	334 (E4 = 329)	669 (2.00)	994 (2.97)	1320 (3.95)	1650 (4.94)	1980 (5.92)
Fret 8	367 (F4# = 370)	741 (2.01)	1104 (3.00)	1841 (5.01)	2220 (6.04)	-
Fret 9	415 (G4# = 415)	832 (2.00)	1238 (2.98)	1655 (3.98)	2066 (4.97)	2488 (5.99)
Fret 10	439 (A4 = 440)	894 (2.03)	1320 (3.00)	1774 (4.04)	2210 (5.03)	-
Fret 11	501 (B4 = 493)	985 (1.96)	1554 (3.10)	1975 (3.94)	2464 (4.91)	-
Fret 12	554 (C5# = 554)	1104 (1.99)	1650 (2.97)	2215 (3.99)	2765 (4.99)	3325 (6.00)
Fret 13	621 (D5# = 622)	1238 (1.99)	1846 (2.97)	2473 (3.98)	3100 (4.99)	3675 (5.91)
Fret 14	664 (E5 = 659)	1315 (1.98)	1980 (2.98)	2641 (3.97)	3392 (5.10)	3962 (5.96)
Fret 15	726 (F5# = 739)	1468 (2.02)	2196 (3.02)	2827 (3.89)	3617 (4.98)	-
Fret 16	832 (G5# = 830)	1645 (1.97)	2473 (2.97)	3062 (3.68)	-	-
Fret 17	894 (A5 = 880)	1794 (2.00)	2693 (3.01)	3574 (3.99)	-	-

Table 2. Frequency of the Open String 1 with the 17 Frets for Tapi and Sape (Hamdan *et al.* 2023a)

String/Fret	Tapi	Sape
Open string 1	166 (E3 = 165)	174 (F3 = 174)
Fret 1	180 (F3 = 175)	196 (G3 = 196)
Fret 2	214 (A3 = 220)	218 (A3 = 220)
Fret 3	224 (A3 = 220)	232 (A3# = 233)
Fret 4	248 (B3 = 247)	261 (C4 = 261)
Fret 5	281 (C4# = 277)	294 (D4 = 294)
Fret 6	310 (D4# = 311)	328 (E4 = 329)
Fret 7	334 (E4 = 329)	347 (F4 = 349)
Fret 8	367 (F4# = 370)	392 (G4 = 392)
Fret 9	415 (G4# = 415)	439 (A4 = 440)
Fret 10	439 (A4 = 440)	468 (A4# = 466)
Fret 11	501 (B4 = 493)	525 (C5 = 523)
Fret 12	554 (C5# = 554)	591 (D5 = 587)
Fret 13	621 (D5# = 622)	667 (E5 = 659)
Fret 14	664 (E5 = 659)	699 (F5 = 698)
Fret 15	726 (F5# = 739)	796 (G5 = 784)
Fret 16	832 (G5# = 830)	880 (A5 = 880)
Fret 17	894 (A5 = 880)	1046 (C6 = 1046)

Timbre on a traditional two-stringed instrument refers to the unique quality or color of its sound that distinguishes it from other instruments, even when playing the same pitch. Initially open string 2 showed 6 partials, whereas open string 1 showed only 3 important partials. String 2 act as a drone. A drone on a traditional two-stringed instrument refers to a sustained and continuous low-pitched tone that serves as a harmonic or rhythmic foundation for the melody being played. Frets 2, 4, 6, and 8 showed more partials than frets 1, 3, 5, and 7. Both fret 9 and 10 showed similar number of partials. Frets 11, 12, 13, 14, 15, and 16 showed less partial and evenly distributed, whereas fret 17 clearly showed only 4 partials.

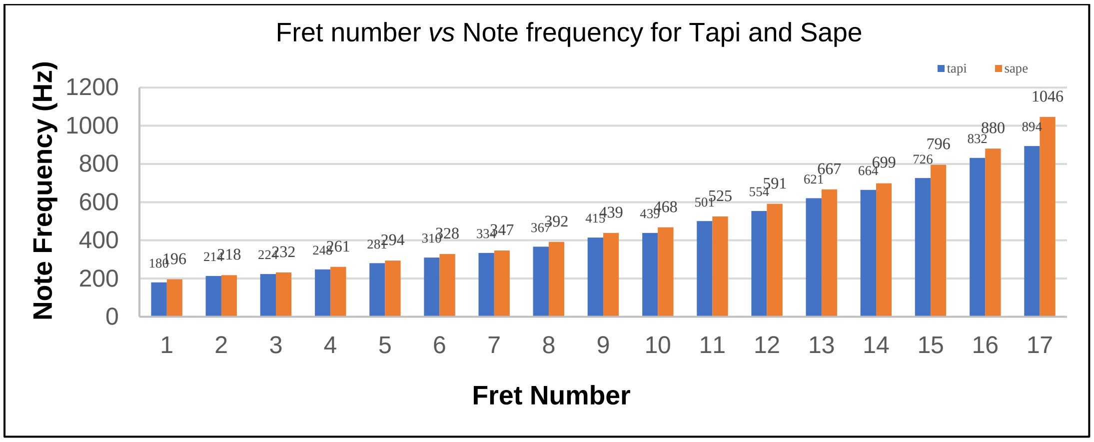
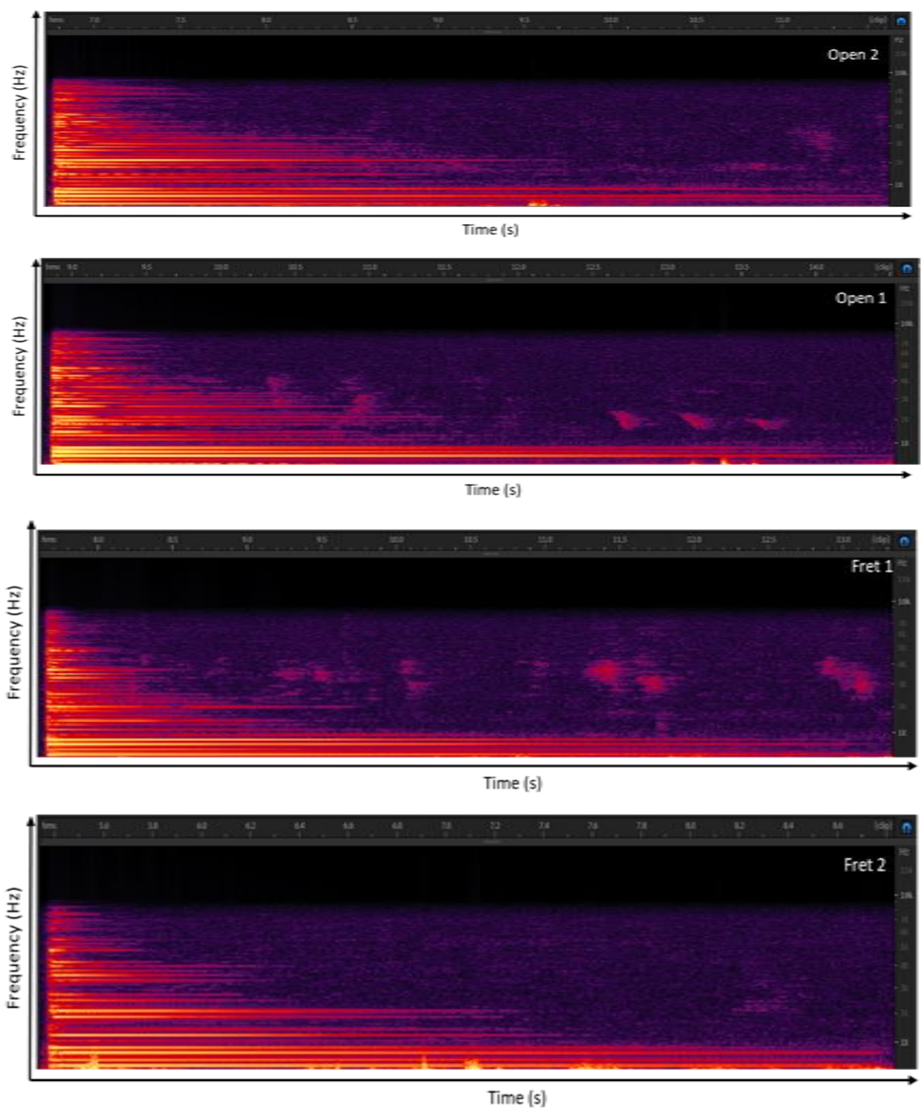
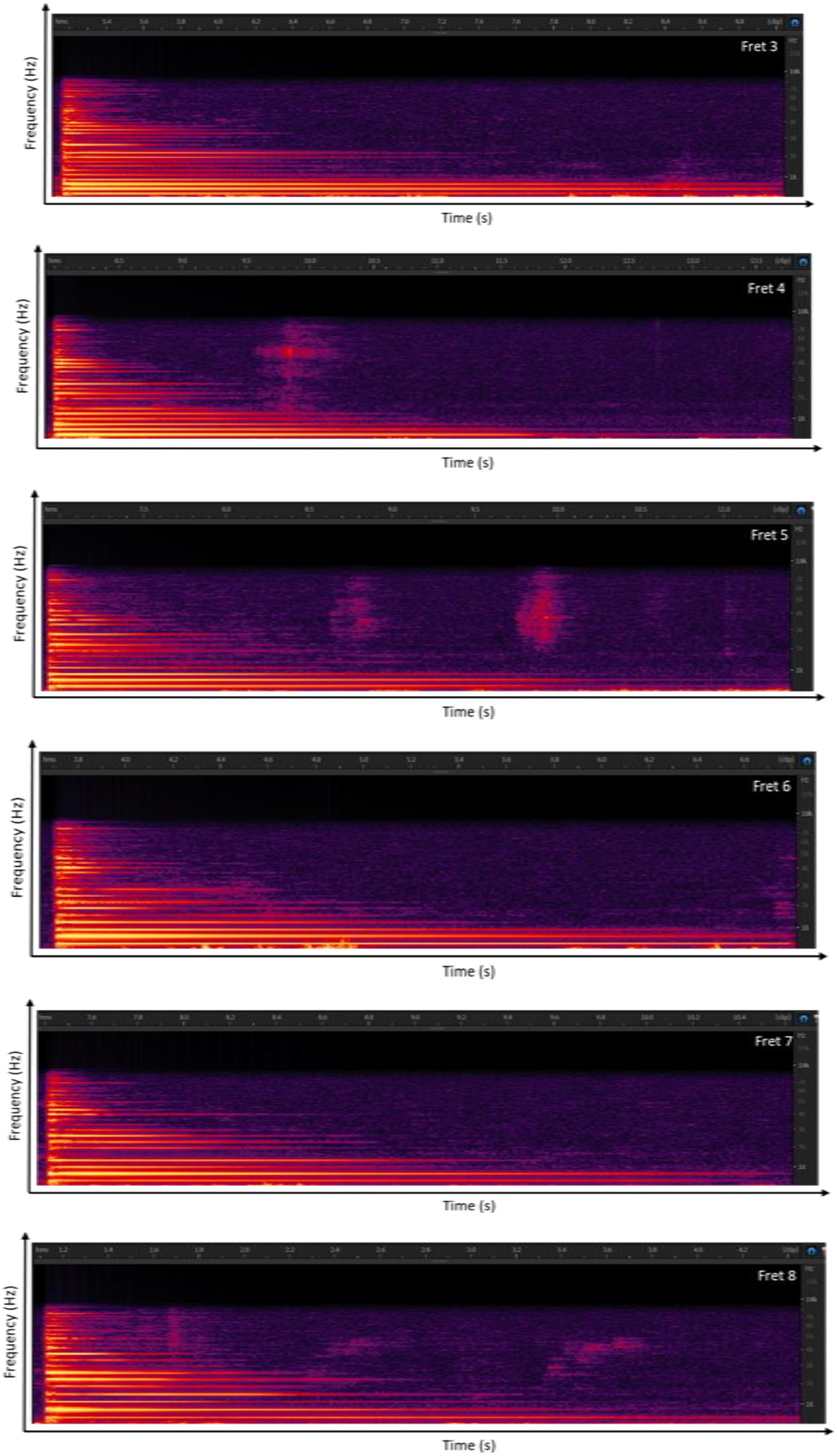
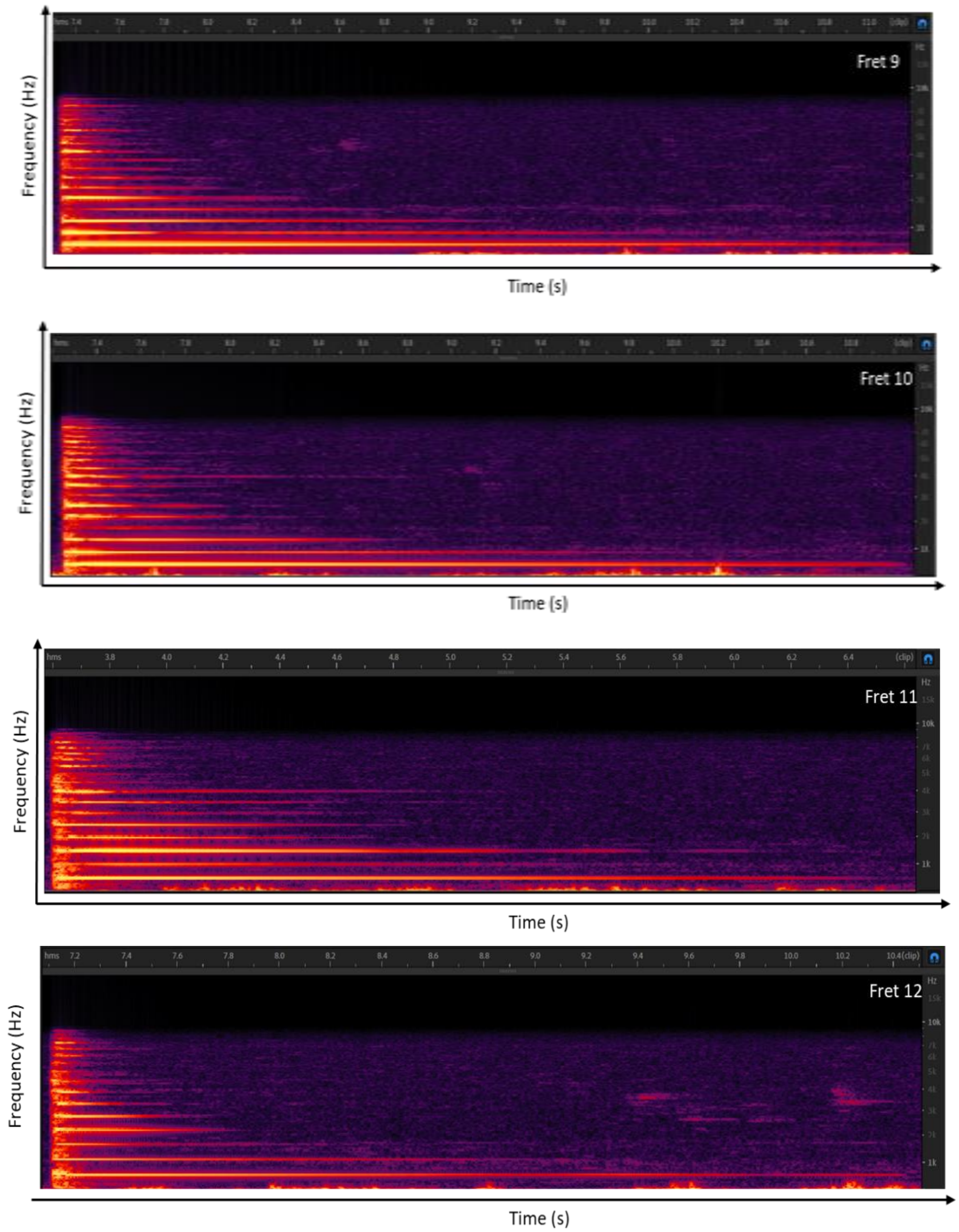


Fig. 4. The fret number *versus* frequency of the note for Tapi and Sape (Hamdan *et al.* 2023a)




Fret 3
Frequency (Hz)
Time (s)
Fret 4
Frequency (Hz)
Time (s)
Fret 5
Frequency (Hz)
Time (s)
Fret 6
Frequency (Hz)
Time (s)
Fret 7
Frequency (Hz)
Time (s)
Fret 8
Frequency (Hz)
Time (s)


Fret 9
Frequency (Hz)
Time (s)
Fret 10
Frequency (Hz)
Time (s)
Fret 11
Frequency (Hz)
Time (s)
Fret 12
Frequency (Hz)
Time (s)

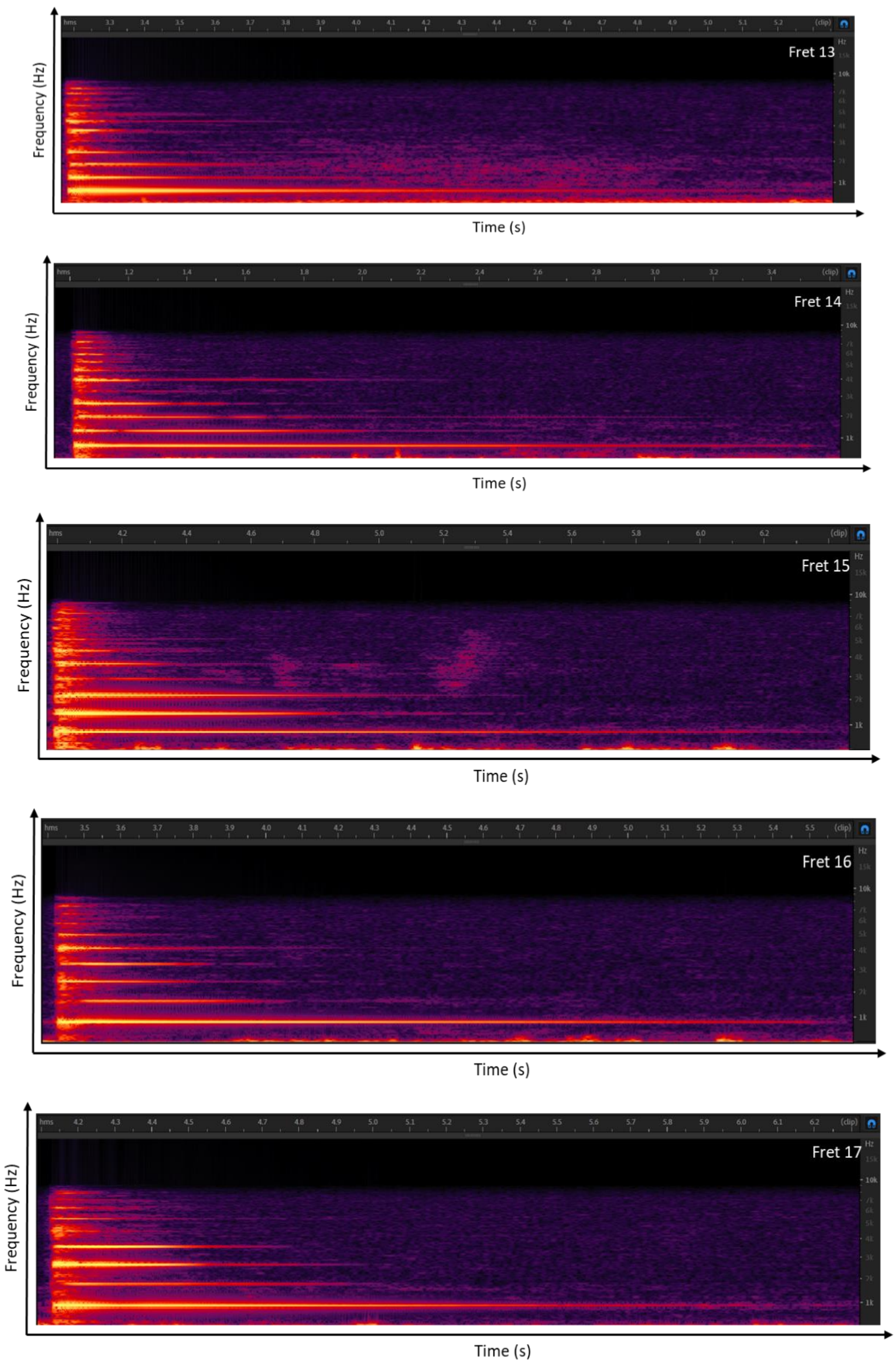


Fig. 5. The TFA from Adobe audition for open string 2 and open string 1 (with 17 frets)

CONCLUSIONS

The sound analysis of the Tapi is important as a recollection of the past, which is important as conceiving the future possibility. This creates an archive of what was once heard by the community of the Orang Ulu. The work showed that:

1. Both the open string 1 and open string 2 are tuned to E3 (166 Hz).
2. The string 1 has 17 frets with notes starting from F3 (180 Hz-fret 1), A3 (214 Hz), A3 (224 Hz), B3 (248 Hz), C4# (281 Hz), D4# (310 Hz), E4 (334 Hz), F4# (367 Hz), G4# (415 Hz), A4 (439 Hz), B4 (501 Hz), C5# (554 Hz), D5# (621 Hz), E5 (664 Hz), F5# (726 Hz), G5# (832 Hz), and A5 (894 Hz-fret 17).
3. The Tapi was tuned to the E major key with F#, C#, G#, and D# notes. The fretless open string 2 acted as a drone.
4. The TFA from the Adobe audition showed that each open string has its own timbre characteristics, *i.e.,* open string 1 is different from open string 2.

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