

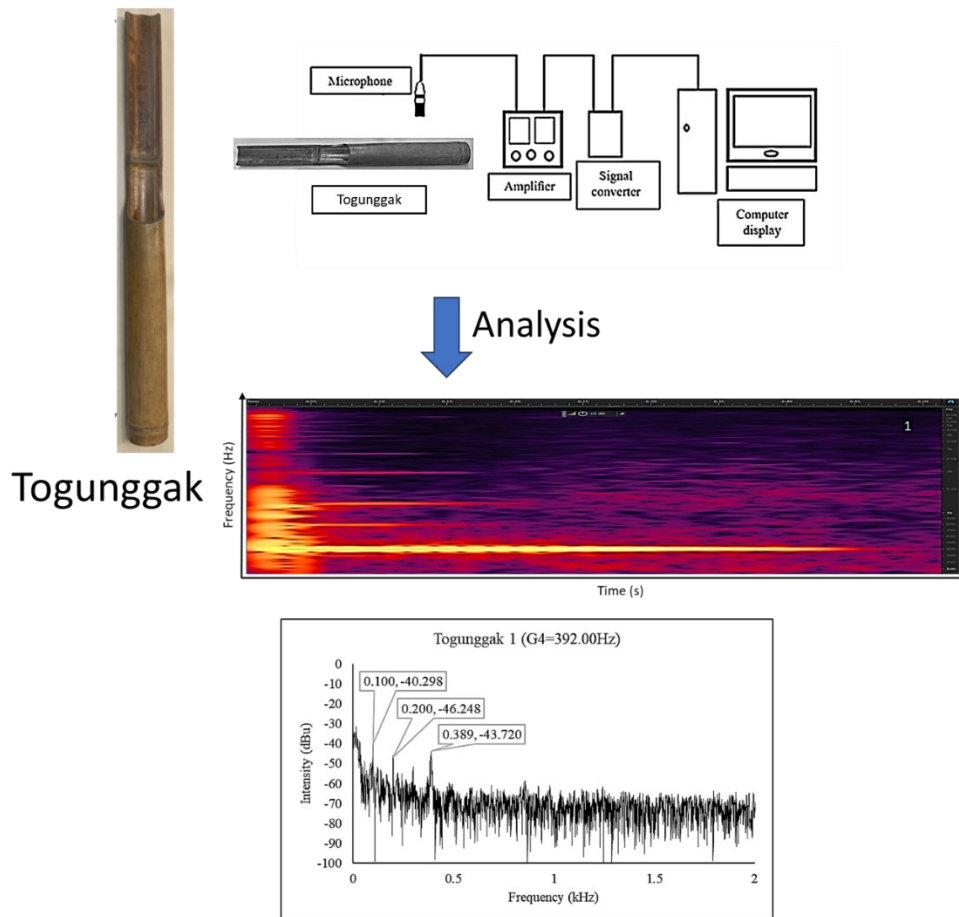
Togunggak: Traditional Music of Kadazandusun

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GRAPHICAL ABSTRACT



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The togunggak is a traditional musical instrument made of bamboo. This work observed the unique sound characteristics to define the notes using Fast Fourier Transform (FFT) *via* a picoscope. The sound characteristics are represented by the dominant frequency with the corresponding intensity. The note of the biggest (tog. 6) to the smallest (tog. 1) bamboo tube is recorded as from G3 to G4. This work reveals that tog. 2 to tog. 5 for togunggak A produce the notes E4, D4, B3, and A3, which is not similar to togunggak B, i.e., E4, D4, C4, Bb3. All bamboo tubes produced fundamental frequency with the presence of two lower partials at 100 Hz and 200 Hz and weaker overtones (except tog. 6) in their frequency spectrum. Using symbol S for semitone and T for tone (i.e. 2 semitone), the note interval of the tog. 6 to tog. 1 can be presented as TT2TT2T i.e., the G3, A3, B3, D4, E4, G4 note interval are presented by G3-A3 as T, A3-B3 as T, B3-D4 as 2T, D4-E4 as T and E4-G4 as 2T. The time frequency analysis (TFA) displays all the spectrograms with distinct prominent fundamental frequency peak.

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Keywords: Bamboo tube; Togunggak; Fast Fourier Transform (FFT); Time Frequency Analysis (TFA)

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INTRODUCTION

The togunggak is referred to as tagunggak by the Murut tribes, togunggak by the Dusun/Kadazan tribes, and togunggu in Penampang, Sabah, Malaysia. Togunggak is a bamboo idiophone musical instrument utilized to accompany dances or parades during public festivities. This instrument shares a similar shape with the angklung musical instrument (Hamdan *et al.* 2022). Maulidyawati *et al.* (2018) conducted scientific research through an anatomical approach to compare the anatomical character and sound intensity of *Gigantochloa atrovioleacea* and *Gigantochloa pseudoarundinacea*, which influences its selection as raw material of angklung Gubrag. The number of pieces in a set varies by tribe, typically ranging from six (for togunggu) to thirty (for tagunggak) pieces. The togunggak is believed to be an early precursor to the gong.

A standard togunggak ensemble comprises six to seven pieces, each constructed from bamboo sections of varying lengths and diameters to produce distinct sounds and pitches. The togunggak is typically played in synchrony with gong rhythms (Scholz 2009). In the realm of entertainment, ensembles such as the togunggak in Sabah and the pratuokng (Hamdan *et al.* 2024) in Sarawak created rhythmic beats to enhance parades and welcome guests. These ensembles are analogous to the dance music typically performed by large gong ensembles (Matusky and Beng 2012).

Each performer holds a bamboo tube and strikes it with a bat crafted from coconut fronds, treated with beeswax. Some of the beaters are made from wood and wrapped with unused motorcycle innertube. The togunggak is composed of a sequence of hollowed bamboo tubes, each differing in size similar to the various gongs. The resulting music is characterized by a hollow, rhythmic ‘tung’ sound, with each tube producing a distinct pitch, serving as an alternative to the traditional gong ensemble. To create this tube, bamboo of considerable maturity and size, specifically of the poring type (*Gigantochloa levis*) is selected. The bamboo is cut with nodes preserved at both ends. This cavity functions to enhance the frequency of the sound generated by the vibration of the resonator.

Bamboo is extensively utilized in the construction of musical instruments, including string, percussion, and wind instruments. Bamboo has been utilized for the construction of musical instruments for millennia, first likely as a percussion instrument, and subsequently for wind and string instruments. The walls of bamboo pipes are intricate, consisting of a stratified arrangement of fibers. The pipe walls display irregularities in radial structure and density, with a significant disparity between the elastic moduli aligned with and perpendicular to the bamboo fibers. The inherent hollow structure of bamboo renders it a prominent selection for several traditional instruments, such as various flutes. The mechanical characteristics of bamboo vary in three directions due to its orthotropic composition. The speed of sound perpendicular to the grain is around 20% to 30% of the longitudinal speed, since the transverse Young's modulus is about 1/20 to 1/10 of the longitudinal modulus. The air that radiates and transmits dictates the pitch of a musical instrument and the spectrum of frequencies. Bamboo has been selected for musical instruments due to its superior acoustic properties (Richter 1988; Bucur 2006; Wegst 2006).

This paper aims to explore the togunggak in depth, examining its construction, and the cultural contexts in which it is utilized. Bamboo is a non-timber forest product, which can be utilized for musical instruments (Wong 2004; Arinasa 2005). The macroscopic structure of bamboo includes external diameter, wall thickness, and length of the bamboo culm's segment. The microscopic structures include the exodermis (outer surface layer), parenchymal cells, and vascular bundles (xylem, phloem, and fibre) (Sutnaun *et al.* 2005). As described by Nuriyatin (2000), *Gigantochloa atrovioleacea* is regarded as the best species for musical instruments due to the equitable distribution of vascular density compared to other bamboo species.

The bamboo tubes, which vary in length and diameter, are played by a properly positioned musician. An ensemble of togunggak being played is shown in Fig. 1. Each tube produces a distinct pitch. Coordination and rhythm are essential, by practicing to strike the tubes in a consistent pattern that produce harmonious melodies. The togunggak is often played in an ensemble. Listening and synchronizing with other players is crucial for creating a cohesive musical performance.



Fig. 1. An ensemble of togunggak being played (National Department for Culture and Arts (JKKN), Ministry of Tourism, Arts and Culture, Malaysia)

Typically, each bamboo tube is labeled with numbers, indicating the pitch sequence that is selected based on the composition. This pitch aligns with either the gong ensemble or pentatonic scales. For instance, in Katia Tiutiunnik's composition 'Tarian Takdir' (Tiutiunnik 2015) for amplified gambus, togunggak ensemble, two gendang, and gong agung, were used (Fig. 2). The 'Malam Putih' (Tiutiunnik, 2012) used two violas and togunggak, where the togunggak were tuned differently (Fig. 3).

An ensemble consisting of seven bamboo tubes is called togunggak B (Table 1). This piece reflects influences from Arab, Jewish, and Dusun music, and it explores polymodality, polyrhythms, and variation techniques. The togunggak were labeled from Tog. 1 to Tog. 6 and a Bass Tog. where the pentatonic scales are being tuned in descending scale. This tuning is highly influenced by the Dusun flavor, where the interlocking pattern of each beat produced a motive with a polyphonic sound. When several separate, independent musical sections or voices play or sing simultaneously, each having its own melody, the sound is referred to as polyphonic. It can also refer to an instrument or device that can produce multiple tones at once, such as organ or synthesizer. A common description of the texture is 'thick' or 'densely textured' because of the way these different melodic lines interact.

The Dusun flavor is mostly being related with the excessive of pentatonic scales and intervals among the pentatonic scales. Five-note musical scales known as pentatonic scales are utilized to produce aesthetically pleasant melodies that steer clear of harsh-sounding intervals such as the semitones included in conventional seven-note diatonic scales. Major pentatonic and minor pentatonic are the two primary varieties. Although major or minor seconds and major or minor thirds make up the intervals of both scales, their precise arrangement and connection to the root note are different.

Bar 5 - 6

Togunggak 1: *f* 3

Togunggak 2: *mf* 3

Togunggak 3: *f*

Togunggak 4: *mf*

Togunggak 5: *f* 3

Togunggak 6: *f* 3

Bass Togunggak: *p* *mf* 3

Fig. 2. Excerpt score of togunggak ensemble from 'Tarian Takdir' composition (Tiutiunnik 2015)

Bar 1-3

Togunggak 1: *mf* 6

Togunggak 2: -

Togunggak 3: -

Togunggak 4: *mf* 6

Togunggak 5: -

Togunggak 6: -

Bass Togunggak: *mf*

Fig. 3. Excerpt score of togunggak ensemble from 'Malam Putih' composition (Tiutiunnik 2012)

Table 1. The Tuning Systems for Togunggak B in 'Tarian Takdir' (Tiutiunnik 2015) and 'Malam Putih' (Tiutiunnik 2012) Scores

Togunggak B	Tuning system for togunggak in 'Tarian Takdir' (2015) & 'Malam Putih' (2012)
Tog.1	G4
Tog.2	E4
Tog.3	D4
Tog.4	C4
Tog.5	Bb3
Tog.6	G3
Bass Tog.	G2

EXPERIMENTAL

In this study, 6 bamboo tube resonators were used (called togunggok A). Togunggok A was from Kampong Papar Baru, Sook, Keningau, Sabah, Malaysia. The tubes were tuned in pentatonic scales. These resonators were labelled as Tog. 1 to Tog. 6. The experiment was conducted in anechoic chamber at Department of Music, Universiti Malaysia Sarawak (UNIMAS), Malaysia. Figure 4 shows an interlocking of the beating pattern of togunggok A recorded and transcribed by Soobili (2024).



Fig. 4. The beating pattern for each bamboo tube from togunggok A (Soobili 2024)

The 6 bamboo tube resonators, 6 beaters, and the anatomy of the bamboo tube are shown in Fig. 5, Fig. 6, and Fig. 7, respectively. The bamboo tube resonators are made from a segment of a bamboo with one of its ends closed by its node. Part of the segment near the open end of the tube is removed, forming the tongue of the tube. The beater is made from wooden stick wrapped with rubber from a motorcycle innertube. The apparatus used in the experimental setup is provided in Fig. 8. The sounds for the resonators were recorded using microphone, which is positioned at 20 cm away. The recorded sounds were analyzed using Fast Fourier Transform (FFT).



Fig. 5. The bamboo tube resonators were labelled as Tog. 1 to Tog. 6



Fig. 6. The beaters made from wooden stick wrapped with rubber from motorcycle innertube

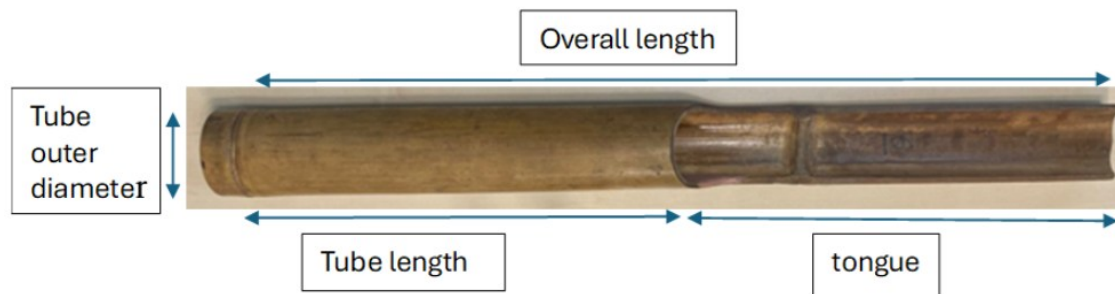


Fig. 7. The anatomy of the bamboo tube



Fig. 8. The apparatus used in the experimental setup

The frequency was measured at the studio hall of Universiti Malaysia Sarawak (UNIMAS). The audio signal was recorded in mono, at 24-bit resolution, and 48 kHz sampling rate. The signal was calibrated using a 1 kHz sine wave. The signal was recorded using the Steinberg UR22mkII (audio interface), Audio-Technica AT4050 (microphone) and XLR cable (balance). To ensure a fair comparison, the togunggak was played in the conventional seated position. In order to capture the true acoustic qualities of the sound, this posture is most indicative of normal playing settings and promotes natural sound output and resonance throughout the recording process. This arrangement guarantees that the recordings accurately capture the tonal qualities of the sound without adding bias or distortion from different microphone positions. The model of the PicoScope was

PicoScope 4224, 2 Channel, USB powered, 12-bit resolution and 20 MHz bandwidth. PicoScope software (Pico Technology, 3000 Series, Eaton Socon, UK) was utilized to visualize and analyze time signals from PicoScope oscilloscopes and data recorders for real-time signal capture. The PicoScope software facilitates analysis using Fast Fourier transform (FFT), a spectrum analyzer, voltage-based triggers, and the capability to store and load waveforms to a disk. The togunggak was positioned to record sound with little interference. The Behringer Powerplay Pro XL amplifier (Behringer, Zhongshan, Guangdong, China) guaranteed that the sound capture was sufficiently loud for detection by the signal converter. The sound spectra are derived from PicoScope readings. Subsequent to the acquisition and recording of the data sound, the FFT was evaluated utilizing Adobe Audition to ascertain the dominant frequency for each tone at designated intervals. The Fourier transformation identifies fundamentals, harmonics, and subharmonics. The experiment was conducted at 26 °C and 64% relative humidity.

Regarding environmental controls, all recordings were conducted in an anechoic chamber to eliminate reflections and external acoustic interference, ensuring that only the instrument's direct sound was captured. A fixed microphone placement (20 cm, omnidirectional polar pattern) was maintained throughout to guarantee consistency in sound capture. Furthermore, the instrument was played in a conventional seated position by a skilled player to replicate realistic performance conditions, while multiple rehearsals were carried out to standardize striking technique and force. Each trial was repeated under identical conditions, and the resulting waveforms were averaged to reduce noise and variability. Together, these steps ensured that both environmental and performance factors were tightly controlled, thereby enhancing the validity and reliability of the acoustic measurements. 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, Fast Fourier Transform (FFT) analysis, spectrum visualization, and voltage-based triggering.

Sound data from the togunggak 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 striking, consistent recording parameters, and multiple rounds of measurement with averaged data, the methodology ensures a clear, accurate, and scientifically valid comparison of the acoustic performance of the togunggak. The microphone was positioned 20 cm from the tube, as shown in Fig. 8. This 20 cm microphone position promotes natural sound generation and resonance and is most realistic of normal playing situations. To capture the authentic acoustic qualities, the microphone was positioned in front the togunggak at a constant distance and angle during the recording process to guarantee that the recordings accurately captured the acoustic qualities of the instrument without adding any bias. With this setup, distortion is avoided and the recordings are guaranteed to accurately capture the tonal qualities. The instrument was played and recorded under identical circumstances to minimize any anomalies or variations. In the present work, the data were found to be similar for every run. Therefore, the statistical variance was zero. Based on the findings, the data were always consistent regardless of how many experiments were conducted. Therefore, the mean was similar to the data with no standard deviations.

RESULTS AND DISCUSSION

The dimensions of the bamboo tube are shown in Table 2. The frequency is calculated using physical measurements of the tube where the length and diameter of the air column are used to calculate the frequency. Note that the tube is made to produce just one musical note. The frequency is then measured using the FFT method which eventually determine the pitch. Therefore, a whole ensemble of togunggak players is needed to play a specific melody. The fundamental frequency of the tube was introduced by Zainal *et al.* (2009) as $f = nv/4(L + 0.305d)$ where f is the frequency of resonator in Hz, n is the harmonic number (for fundamental frequency $n = 1$), v is the speed of sound in air (340.29 m/s), L is the length of the inner bamboo tube measured from the root of the tongue, and d is the inner diameter of the bamboo tube. The constant 0.305 in the equation is related to the shape of the tongue of the bamboo tube (Siswanto *et al.* 2012)

Two metrics are primarily used for tuning: the air resonator's length and the bamboo tubes' tongue length. The air resonator functions similarly to an amplifier by enhancing the sound frequency that corresponds to the inherent frequency of the air vibrations within the resonator. The inherent frequency of the entire bamboo tube vibration is determined by the length of the tongue. In general, the pitch of the sound produced decreases with the length of the bamboo tube. By slicing portions of the tongue, the bamboo tube can be fine-tuned. The tongue can be made shorter at the end to raise the pitch or sharpen it. By cutting away the area where the tongue and air resonator connect, the effective tongue length can be somewhat increased, which will flatten or decrease the pitch (Zainal *et al.* 2009).

Table 2. Dimensions of the Bamboo Tubes (togunggak A)

	Overall length (cm)	Air column L (cm)	Tube outer diameter (cm)	Thickness T (mm)	Tube inner diameter d (cm)	Theoretical calculation $f = nv/4(L + 0.305d)$
Tog. 1	45	19	6.0	5.0	5.50	411.42
Tog. 2	52	23	6.0	6.0	5.40	345.16
Tog. 3	59	26	7.0	6.1	6.39	304.38
Tog. 4	65	30	7.5	6.1	6.89	265.01
Tog. 5	75	35	7.5	6.3	6.87	229.33
Tog. 6	84	40	8.0	6.5	7.35	201.39

Figure 9 shows the frequency spectra of Tog. 1 to Tog. 6. All togunggak A tubes produced fundamental frequency note with the presence of two lower partials at 100 Hz and 200 Hz and weaker overtones (except Tog. 6) in their frequency spectrum.

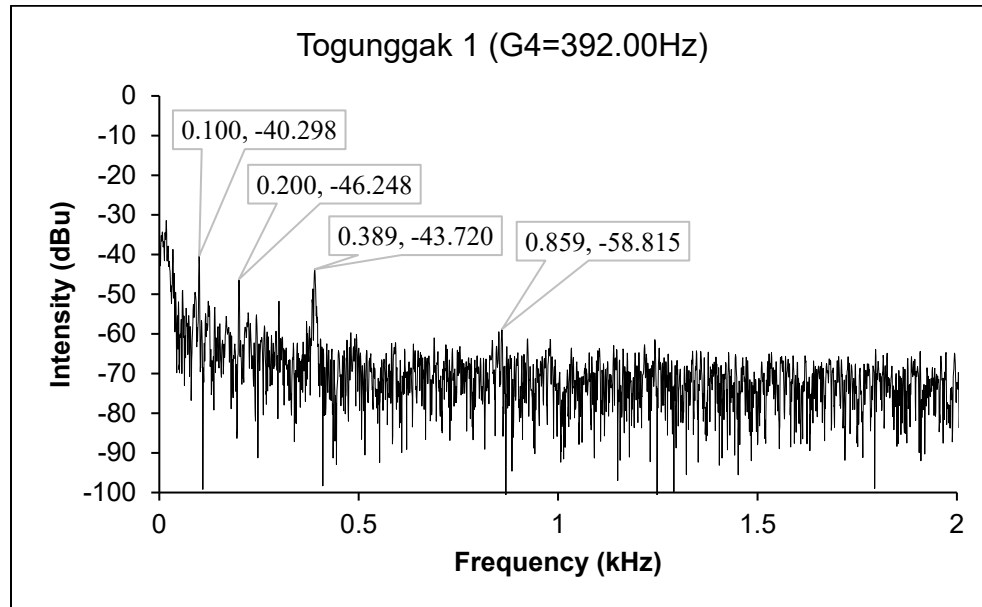
An open-ended tube's inherent property is its capacity to support odd and even harmonics with wavelengths that are integer multiples of half the tube length by forming standing waves with displacement antinodes at both ends. Different harmonic frequencies are whole-number multiples of the fundamental frequency, which is inversely proportional to the tube length. Only odd harmonics can occur in closed tubes. The harmonics are as follows if the symbol f_1 is used to represent the first harmonic, or fundamental tone:

$$f_3 = 3 f_1$$

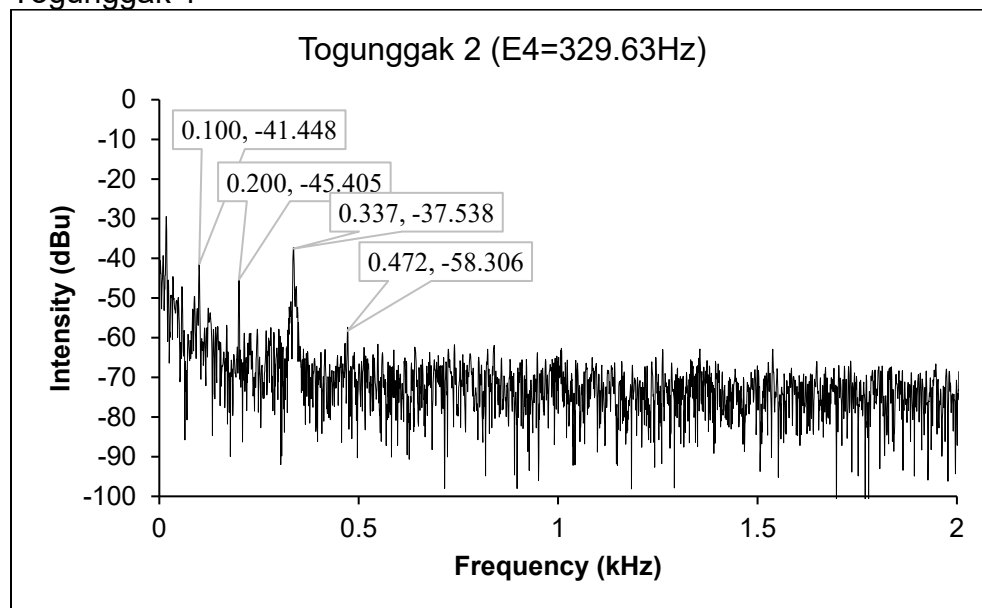
$$f_5 = 5 f_1$$

$$f_7 = 7 f_1$$

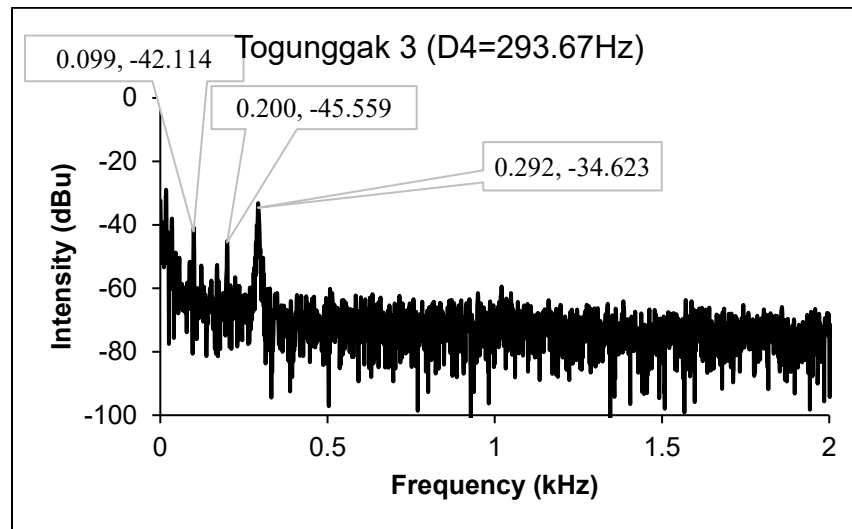
The lack of harmonics can be attributed to the physical nature of the closed tubes. Table 3 display the tuning system obtained from togunggak A (Fig. 9), together with theoretical calculation and from ‘Tarian Takdir’ (2015) and ‘Malam Putih’ (2012) score (togunggak B).



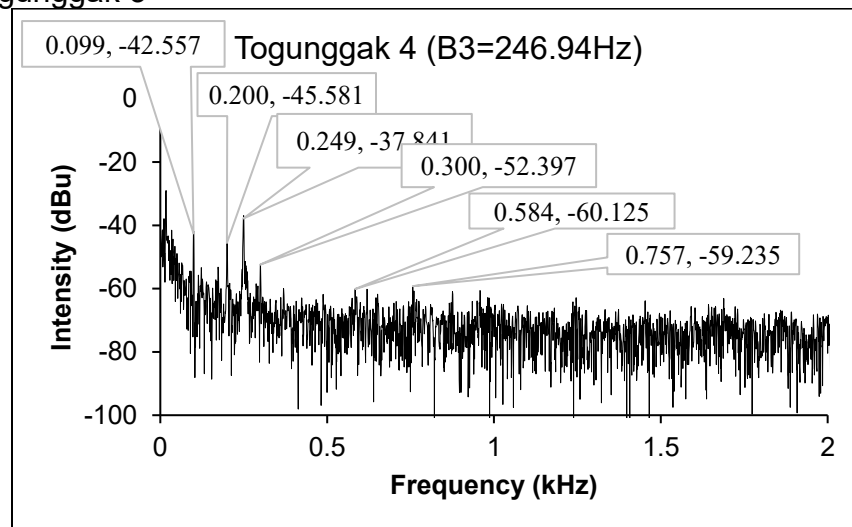
Togunggak 1



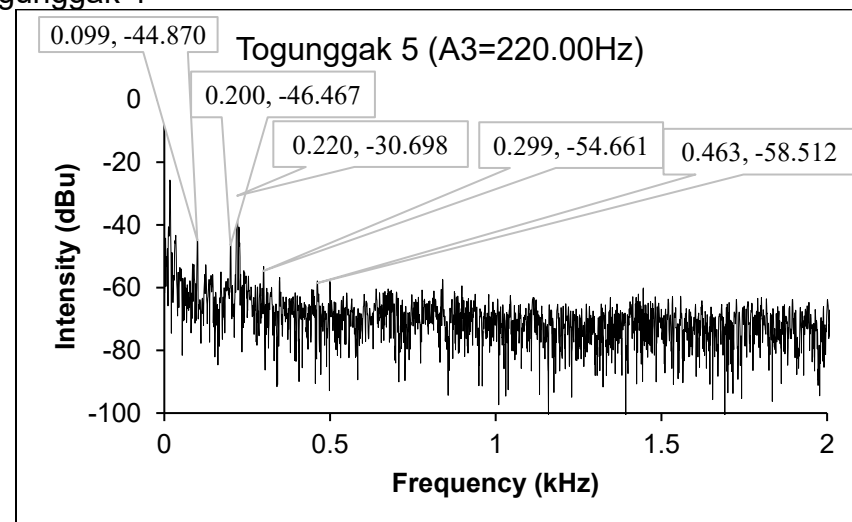
Togunggak 2



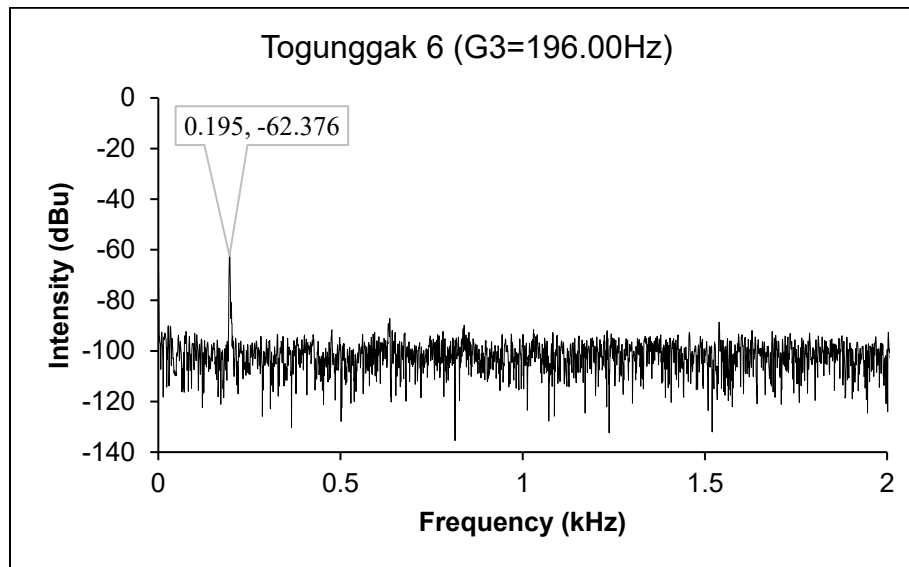
Togunggak 3



Togunggak 4



Togunggak 5



Togunggak 6

Fig. 9. The frequency spectra of Tog. 1 to Tog. 6 from togunggak A**Table 3.** Tuning System Obtained from Togunggak A (Fig. 9), Together with Theoretical Calculation ($f=nv/4(L+0.305d)$) and from 'Tarian Takdir' (2015) and 'Malam Putih' (2012) score (togunggak B)

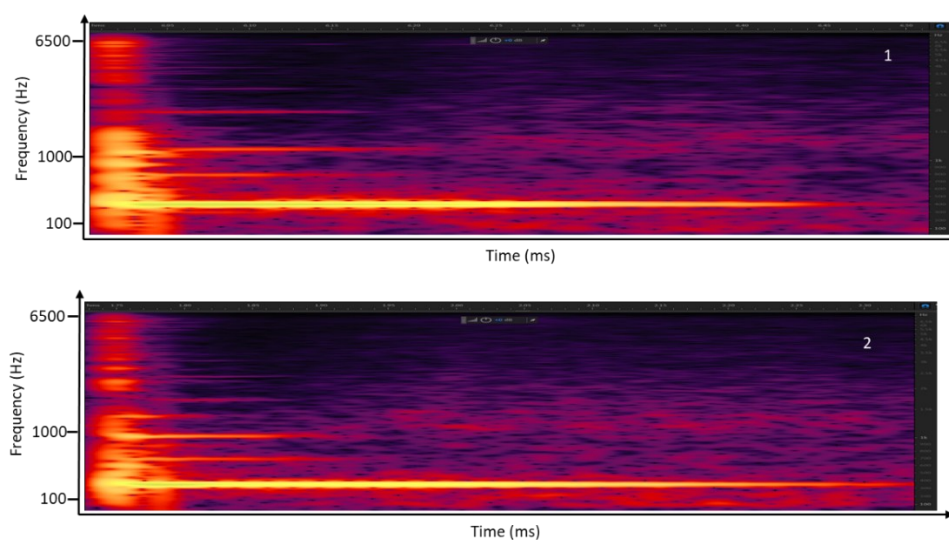
Togunggak	Theoretical calculation $f=nv/4(L+0.305d)$	Experimental frequency and tuning system from togunggak A	Difference between theory & experiment	Tuning system from togunggak B
Tog.1	411.42 (G4#=415.30)	389 Hz (G4=392)	5.76%	G4
Tog.2	345.16 (F4=349.23)	337 Hz (E4=329.63)	2.42%	E4
Tog.3	304.38 (D4#=311.13)	292 Hz (D4=293.67)	4.24%	D4
Tog.4	265.01 (C4=261.63)	249 Hz (B3=246.94)	6.43%	C4
Tog.5	229.33 (A3=220)	220 Hz (A3=220)	4.24%	Bb3
Tog.6	201.39 (G3#=207.65)	195 Hz (G3=196.00)	3.27%	G3

From Table 3, the percentage difference between theoretical calculation ($f=nv/4(L+0.305d)$) and experimental frequencies are between 2.4% (Tog. 2) and 6.4% (Tog. 4). The calculated frequencies estimate the pitch exactly due to the related theory itself, which use the effective length ($L+0.305d$) as a rough estimation. The difference between theoretical and experimental frequency may be mainly attributed to the difficulty in accurately measuring the inner radius of the tube rather any problem related to the theory itself. From Table 3, Tog. 1, Tog. 2, Tog. 3, Tog. 5, and Tog. 6 from togunggak A and B are similar, *i.e.*, G4, E4, D4, A3, and G3. Tog. 4 from togunggak A is B3, whereas Tog. 4 from togunggak B is C4. Using symbol S for semitone dan T for tone (*i.e.* 2 semitone), the note interval of the Tog. 6 to Tog. 1 from togunggak A can be presented as TT2TT2T *i.e.*, the G3, A3, B3, D4, E4, G4 note intervals are presented by G3-A3 as T, A3-B3 as T, B3-

D4 as 2T, D4-E4 as T, and E4-G4 as 2T. The note interval from togunggak B can be presented as T2TTT2T *i.e.*, the G3, Bb3, C4, D4, E4, G4 note intervals are presented by G3-Bb3 as T, Bb3-C4 as 2T, C4-D4 as T, D4-E4 as T, and E4-G4 as 2T. The intervals between the consecutive notes produced by the different togunggak are approximately equidistant where there are three equidistant intervals with T interval and two equidistant intervals with 2T interval within one octave.

The sound or the color produced depends on how the players strike the instruments. Usually, the musicians will try to obtain a ‘pung’-like sounding. Such a tone can be described as clear and rounded. The timbre and color of the tone is most likely to be in mid-to-low register compared to the brighter ‘ping’. The tone will be smooth, more dampened, and but yet punchy. The tonality can be heard once the clear tone is being produced. In this case, the tonality will be in G Major (combination of 5 pitches). Since the ensemble produced a series of pitches, the togunggak can be classed as a pitch-instrument. A sound that can be described as rounded results when struck with a beater layered with rubber from a motorcycle innertube. However, if the beater being used is not covered with rubber, then the tone will sound bright and produce a ‘tak’ sounding, which will be heard as loud and rough by the listener.

A statistical metric known as variance shows how widely distributed the numbers in a dataset are in relation to the mean or average value. It represents the dataset’s variability and is computed as the average of the squared deviations from the mean. Another definition of variance that sheds light on the distribution of data points is the square of the standard deviation. For statistical treatment, it is possible to assure that reading from the Picoscope instrument is accurate and identical across many replications (Musib *et al.* 2025). The present results show that the data were consistent across all runs. As a result, there was no statistical variance. No matter how many trials were carried out, the data remained consistent. As a result, the mean and the data without standard deviations were comparable. Meanwhile, multiple sets of instruments for comparison would require a different scope of study. Each craftsman has a different skill, and many of these instruments are fabricated/built based on requirements by the player. Figure 10 shows the time frequency analysis (TFA) of Tog. 1 to Tog. 6 from togunggak A. TFA reveal all the spectrograms display distinct prominent fundamental frequency peak only.



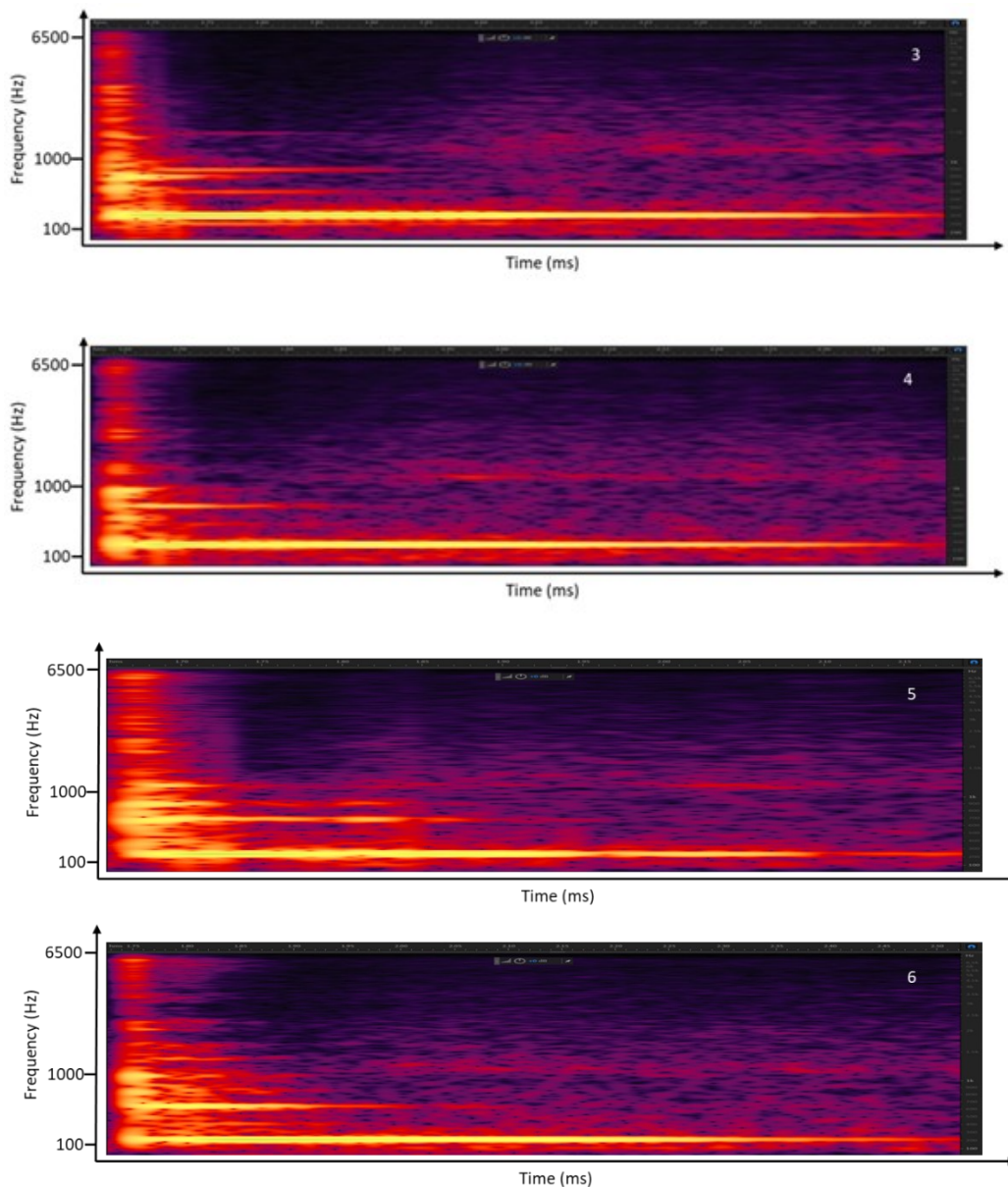


Fig. 10. The time frequency analysis TFA of Tog. 1 to Tog. 6 from togunggak A

CONCLUSIONS

1. The fundamental frequency of air resonance in the tube can be used to estimate the pitch of the bamboo tube. Exceptions to that rule can be attributed to the natural shape of bamboo that differs from the effective length and diameter of the air column to that of an ideal open cylinder.
2. Each resonance tube displayed a single prominent fundamental with very weak or no harmonic existent. The spectra of the togunggak displayed two main features. The first feature is that the sound output had three main peaks in the frequency spectrum, with the highest peak corresponding to the pitch of each tube and 2 peaks at 100 and 200

Hz. The second feature is that these two peaks were below the fundamental frequency and were inharmonic partials.

3. The interval between the consecutive notes produced by the different bamboo resonators was approximately equidistant and there were three equidistant intervals with T interval and two equidistant intervals with 2T interval within one octave. The note interval of togunggak A from Kampong Papar Baru, Sook, Keningau, Sabah, Malaysia can be presented as TT2TT2T, *i.e.*, from G3, A3, B3, D4, E4, to G4. The note interval of togunggak B from 'Tarian Takdir' (2015) and 'Malam Putih' (2012) score can be presented as T2TTT2T, *i.e.*, from G3, Bb3, C4, D4, E4, to G4.
4. Most of the bamboo tubes Tog. 1 to Tog. 5 (except Tog. 6) produced a fundamental frequency note and lower frequencies peaks at 100 and 200 Hz in their frequency spectrum, with weak overtones. By contrast, Tog. 6 only displayed a fundamental frequency peak.
5. Time frequency analysis (TFA) revealed that all the spectrograms (Tog. 1 to Tog. 6) displayed distinct prominent peaks that belonged to the fundamental frequency only.

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