The Bundengan of Wonosobo, Indonesia

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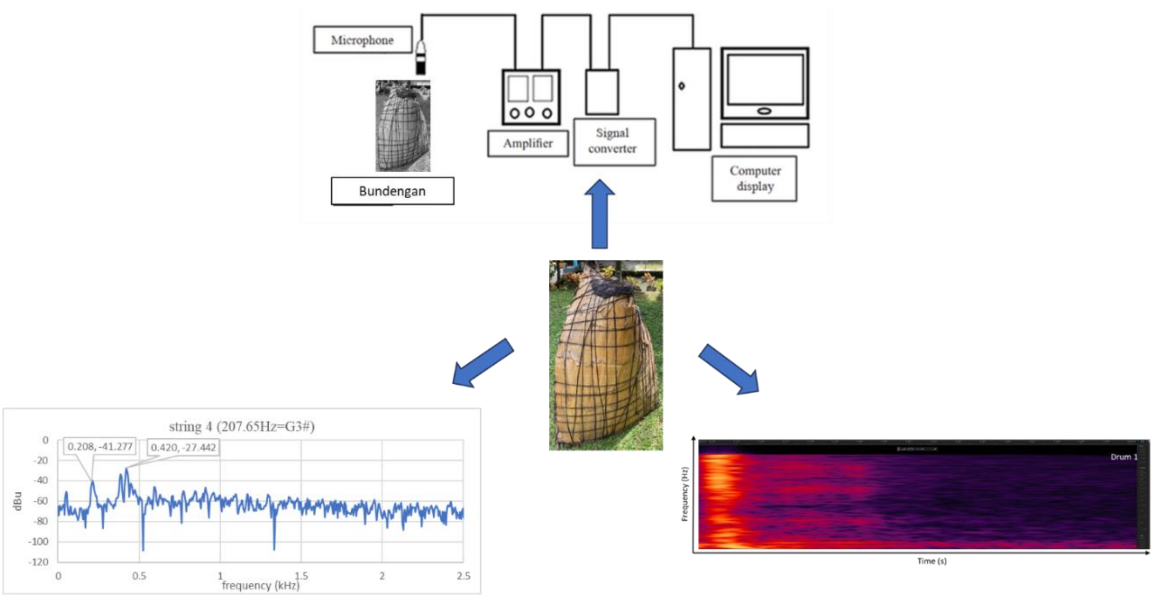
GRAPHICAL ABSTRACT



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The bundengan is a unique traditional musical instrument with plucked strings from Wonosobo, Central Java, Indonesia. It can produce sounds that imitate the gong (*i.e.*, a part of the gamelan instrument). The bundengan was initially constructed by duck herders as a means of shielding themselves from inclement weather while caring for their flocks. They also engage in musical activities and singing. The distinctive sound of the bundengan is created by plucking a set of strings fitted with tiny bamboo clips using the right hand and three elongated, slender bamboo blades with the left hand. The sound effect is produced by the bandulan, a small piece of bamboo attached to the string. The tuning of the bundengan depends on the player's instinct. This study analyzed the pitch and timbre of the bundengan strings. Using Fast Fourier Transform (FFT), the sound from a plucked string yields the frequency spectrum of the actual vibrations from the strings. The results were used to validate the frequency as heard. The results showed that the pitch from the measured frequencies is not similar to the pitch as heard. The bundengan is tuned to a pitch corresponding to the timbre rather than a specific pitch.

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Keywords: Bundengan; Bandulan; Fast Fourier Transform (FFT); Wonosobo

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INTRODUCTION

The bundengan is a rare musical instrument originating from the Wonosobo Regency in Central Java, Indonesia. It is considered endangered and is thought to have originated in the 12th century, as mentioned in the old poem *Wretta Sancaya* (Kern 1875). In Kunst's 1934 paper, it is noted that the instrument was already becoming increasingly scarce at the time. The bundengan was initially constructed by duck herders as a means of shielding themselves from inclement weather while caring for their flocks. The half-dome construction is created by interlacing bamboo splits to construct a lattice grid, then subsequently crossing the bamboo splits at the apex of the grid in a specific order to shape the curved dome. Subsequently, the dome is covered with many layers of bamboo sheaths, which are secured with sugar palm fibers to ensure their stability. The duck herders engage in musical activities and singing to occupy themselves while in the fields. The distinctive sound of the bundengan is created by plucking a set of strings fitted with tiny bamboo clips using the right hand and three elongated, slender bamboo blades with the left hand. The bundengan can replicate the sounds of gongs and drums (specifically cowhide drums) in a gamelan ensemble using clipped strings and long, thin bamboo blades. Sound recordings of the bundengan may be accessed at https://soundcloud.com/parikesitkusumaningtyas. Prior studies of the bundengan have mostly concentrated on the aesthetic aspects of the musical instrument (Cook 2016; Abdulloh 2017a). Abdulloh stated that the adjustment of the bundengan strings is achieved by moving the bamboo clips along the string to get the appropriate pitch and timbre.

The bundengan is made from kowangan, which is attached with four or five strings and three long, thin bamboo blades. To hold more aesthetic appeal, Kowangan is made from bamboo blades pursed to the top. Once the shape is formed, the outer part is covered with bamboo culm sheaths. The kowangan is then tightened with ijuk palm (*Arenga pinnata* -syn. *Arenga saccharifera*) fiber, which also acts as an ornament. Kowangan is either covered with bamboo culm sheaths from Apus (*Gigantochloa apus*) bamboo or Betong (*Dendrocalamus asper*) bamboo. There are only two luthiers from Mergalangu and Lamuk, Wonosobo regency, (in Central Java province) Indonesia. The pioneers in kowangan making are Pak Mahrumi, from Dusun Sibenda, Desa Purwojati, Kacamatan Kertek, and Pak Wahrudin, from Dusun Wonosari, Desa Mergalangu, Kacamatan Kalibawang (Mulya 2021). The authors Hamdan, Wahyono, and Sosiati visited the Yayasan Ngesti Laras in Wonosobo, Indonesia on June 23, 2024 (Fig. 1a). During their visit, the authors interviewed Mulyani Mulya, the pioneer of Bundengan in Wonosobo, Indonesia (Fig. 1b). Figure 2 displays the full and small size bundengan.

(a) (b)

Fig. 1. (a) The signage to Yayasan Ngesti Laras in Wonosobo, Indonesia, (b) Mulyani Mulya, the pioneer of Bundengan in Wonosobo, Indonesia

(a) (b)

Fig. 2. (a) The full size bundengan, (b) The small size bundengan

Materials used for kowangan manufacturing include bamboo blades, bamboo culm sheaths, and ijuk palm. After the kowangan is completed, the next step in making the bundengan is to prepare the following:

1. The strings used are from the badminton racket (originally, they were from ijuk palm).
2. Bandulans are made from bamboo branches (2 cm long) with a hole in the middle.
3. Coconut leaf stick position the bandulan at the right place along the string.
4. Three pieces of long, thin bamboo blades (26 cm, 28 cm, and 30c m long) with semi-circular cuts at the ends to produce a loud sound, which are called 'drum'. The 'drums' accompany the bundengan strings.

The 'drums' are placed between the bamboo webbing, and a ganjel is inserted to ensure the exact length between the ends of the 'drums' and the ganjel to produce a loud sound. Figure 3a shows the bundengan 'drums' attached with a ganjel. Ganjel (5 to 6 cm) is placed on the kowangan to determine the pitch of the 'drum'. The strings for the bundengan are made from badminton racket strings (the original string is from Ijuk palm). Along the string, a bandulan is fixed to determine the pitch (Fig 3b.). It is made from bamboo branches (~2cm) and cut with a 'V' shape in the middle. The bandulan is secured to the string by inserting a coconut stick inside it.

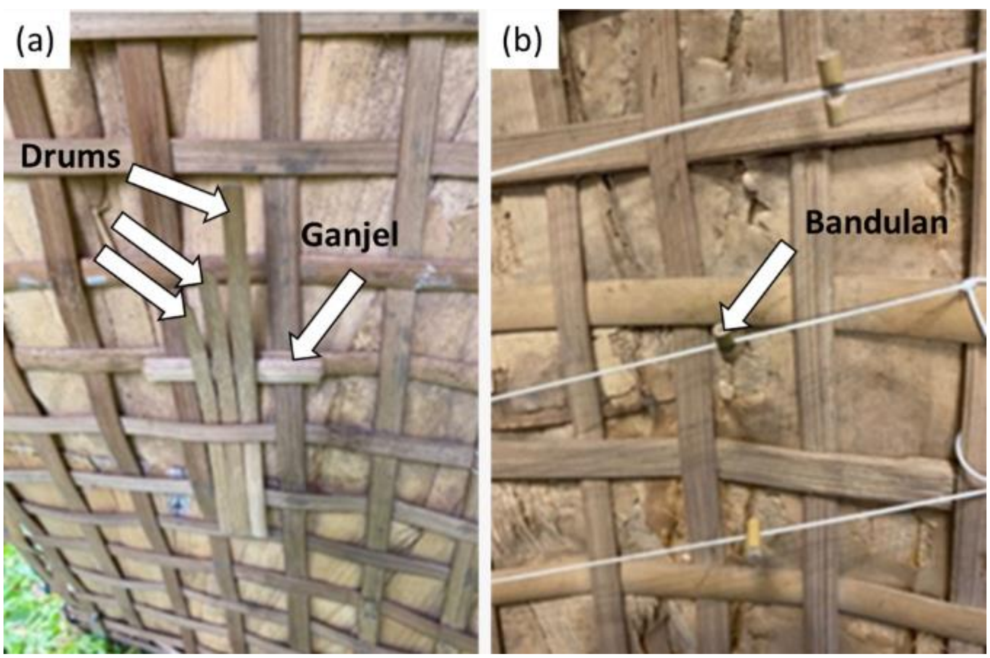


Fig. 3. (a) The bundengan 'drum' attached with a ganjel, (b) A bandulan is fixed to determine the pitch

Instead of being adjusted using a rigid mechanism like pegs, the strings are stretched over and either wedged into or connected to the bamboo lattice. The musicians do not seem to mind that this is not very precise or lasting (Keen 2017). The right hand is used for playing the strings, with the counting starting from string 1 at the bottom up to string 4 at the top. There are two versions for playing the 4-string bundengan:

Version 1: 1, 2, 1, 3, 1, 2, 1, 4, 1, 2, 1, 3, 1, 2, 1, 4

Version 2: 1, 2, 1, 3, 1, 2, 1, -, 1, 2, 1, 3, 1, 2, 1, 4

There are also 2 versions for playing the 5-string bundengan:

Version 1: 1, 2, 1, 3, 1, 2, 1, 4, 1, 2, 1, 3, 1, 2, 1, 4

Version 2: 1, 2, 1, 3, 1, 2, 1, 5, 1, 2, 1, 3, 1, 2, 1, 5

Figure 4a shows the right-hand position before plucking the bundengan strings. Figure 4b shows the left-hand position with the 2^{nd}, 3^{rd} and 4^{th} fingers resting on top of the 'drum'. Before plucking the bundengan strings, the finger is positioned on the first string for plucking.

Fig. 4. (a) The right-hand position before plucking the bundengan strings, (b) The left-hand position with the 2^{nd}, 3^{rd} and 4^{th} fingers on top of the 'drums'

The bundengan 'drum' is made to produce sound that imitates the gamelan drum. The bundengan 'drum' gives rhythm and accompanies the melody of the plucked strings. The performer sits beneath the instrument, cross-legged, to play it. He plays a set of strings with his right hand to mimic the sound of gongs. His left hand plucks a set of bamboo blades, mimicking the rhythmic sound of leather drums. Melody and rhythm are created by the left and right hands plucking together. The entire gamelan ensemble can be mimicked using just one instrument. For this reason, the bundengan is frequently referred to as a one-man gamelan (Parikesit and Kusumaningtyas 2023). When the four or five strings of the bundengan are plucked, the sound produced is similar to that of the *kethuk*, *kenong*, *kempul*, gong, and gong *penatas*. The left hand plucks the bamboo blades, and the right hand plucks the strings (Christy and Rachman 2023). To pluck the bundengan 'drums' properly, the shape of the kowangan has undergone various developments to fit its functions. In detail:

1. The big bundengan is a large kowangan with a width of 1.5 m and a height of 2 m used for bundengan wayang, where 2 kowangans serve different functions: one for the puppet screen and one for buffering and as an instrument.
2. The medium bundengan is a medium kowangan with standard measurements of 1.0 m in width and 1.25 m in height. It originally served as a replacement umbrella in the past but is now only used as a bundengan instrument.
3. The small bundengan is a small kowangan made as an imitation of the big bundengan to be played in a large group.
4. The miniature bundengan is made as a souvenir, equipped with a bundengan puppet.

Weaving split bamboo strips together forms its body, which is a semi-enclosed, resonant chamber. Usually, the instrument has strings stretched taut across its frame, which can be plucked to make sound. The Bundengan's sound originates from the vibration of these strings, which are heightened by the resonator-like bamboo body. A tiny piece of bamboo that is fastened to the strings of the bundengan musical instrument is used to set the tone; this component is known as bandulan. The bandulan is used to make the setting; it is chopped to a length of ± 2 cm and has a v-shaped incision made in the center. The strings are then locked in place by inserting a coconut stick into the bandulan (Christy and Rachman 2023). The player can modify the pitch and timbre of the sound produced by the strings by sliding these clips along the strings (Parikesit and Kusumaningtyas 2023). Instead of being adjusted using a rigid mechanism like pegs, the strings are stretched over and either wedged into or connected to the bamboo lattice. The bandulan placed spaced along the strings are used by the bundengan players to change the timbre of their instruments rather than pitch. These bandulan cause the pitch to drop by weighing the string down. Nevertheless, they also confuse the harmonics, giving the string a wavering gong-like sound. The physics behind this is complex (Keen 2017). The left hand plays the thin bamboo blade, while the right hand plays the strings in a consistent pattern. As a result, a single bundengan player can simultaneously play two patterns (Christy and Rachman, 2023). The second, third, and fourth fingers are used to pluck the three strips in a dynamic, triplet-based style that is derived from 'drum' playing, which is prevalent in local gamelan ensembles (Keen 2017). However, a general simplification of drums is covered in a few more parts that deal with bundengan 'drumming' techniques. Not all of the sound characteristics of membrane drums can be utilized, despite the fact that it sounds like an imitation of one. This makes sense given that the two instruments' physical characteristics differ. But playing technique was simplified in order to make up for these flaws (Arbi and Kapoyos 2019). The five strings being played imitate the sounding of gamelan, which involves the sense of interlocking between each string.

As mentioned above, the bundengan sound is meant to imitate the gamelan ensemble. The tuning for this bundengan is based on the Pelog Saih Pitu scale which is derived from the Phrygian Modes. The scale consists of the notes 1, b2, b3, 4, 5, b6, and b7 (Ruth 2019). However, the arrangement of the strings and tuning for the bundengan are not purposely aligned with the typical ascending or descending scale. The scales or the pentatonic tuning system known as pelog are used by the traditional bundengan musical instrument to express its melody (Arbi and Kappoyos 2019). Nonetheless, the diatonic tuning system, or scales, is used in the bundengan performance by the ensemble Akustika in Wonosobo, Indonesia (Christy and Rachman 2023). According to Keen (2017), the tuning is idiosyncratic. In this case, it has been found that the D Pelog scale tuning is neither ascending nor descending but rather represents the sound of the gamelan. The D pelog scale consists of 5 notes: D, Eb, F, G, Ab, Bb, and C. In this instrument, these 5 notes align with the D pelog scale (Pelog Slisir, Pelog Tembung, and Pelog Sunaren). Hence, bundengan musicians tune their instruments to a certain timbre rather than a specific pitch (Keen 2017). However, the vibrations produce sound waves that might affect the tuning due to the tension and position of the fingers, potentially creating a microtone sounding – a musical interval (*i.e.* the amount by which one note is higher or lower than another) that is smaller than a semitone. Table 1 shows the pitch considerations using features of traditional Bundengan 'Musik dalam Tempurung' obtained from Kabupaten Wonosobo, Indonesia (Abdulloh 2017b).

Table 1. The Pitch Consideration Using Feature of Traditional Bundengan 'Musik Dalam Tempurung' of the 5-string Bundengan

Strings	Pitch (consideration to have a microtone)
1	Between C and C# (Db)
2	-
3	-
4	Between G and G# (Ab)
5	Between C and C# (Db)

The feature of traditional Bundengan 'Musik dalam Tempurung' obtained from Kabupaten Wonosobo, Indonesia is transcribed in Fig. 5 (Abdulloh 2017b). The strings in the excerpt (a short extract from a piece of music) are in Bb3, Ab3, Gb3, and Eb3/4. The 'drum' is played in various patterns (Christy and Rachman 2023). The timbre, rather than the pitch, determines how it is played. The tuning of the bundengan indicates that the excerpt is in the tonality of Eb minor. The tuning may vary on different occasions due to the needs of the ensemble or the experience of the player. Playing the bundengan with both hands introduces various types of playing patterns and the interlocking sound of the 4 strings and the 'drum'. It is also noted that the pattern and the playing of the bundengan are related to the experience of the player, who lives in Wonosobo, Indonesia, and plays the 'music lengger' by Mistotoify (Abdulloh 2017b). The music played on this enormous, bizarre-looking instrument is relatively simple: every tune uses the same four-note rhythm (Keen 2017). The motive development of the tune employs repetition techniques, and the 'drum' playing is influenced by repetition, fragmentation (using certain motives to develop other motives), and rhythmic changes.

Fig. 5. The excerpt playing of the bundengan on the documentary written in western scale

EXPERIMENTAL

Several factors influence the sound generated, including tension and the position of the fingers. The strings were tuned by Mulyani Mulya, the pioneer of Bundengan in Wonosobo, Indonesia. To ensure a reproducible frequency is produced, the strings were plucked by consistently positioning the fingers by a skilled professional player, Mulyani Mulya, who is well-versed in these nuances. The audio signals were captured in monaural format with a 48 kHz sampling rate and a 24-bit resolution. The audio profile was saved in WAV format for later processing. The calibration process confirmed that the recording system was set up properly, ensuring that the audio signals were recorded at optimal levels. This calibration procedure was crucial to maintaining the integrity of the recorded signals and producing high-quality audio recordings free from distortions and clipping. Before the session was recorded, a calibration was done to ensure the recording settings were ideal. The following steps were included in the calibrating process:

1. Test Tone Generation: To facilitate calibration, a test tone with a sine wave frequency of 1.0 kHz was created. The European Broadcasting Union (EBU) technique for standard calibration was used to select this frequency.
2. Output Level Adjustment: The calibration ensures that the device outputs a digital recording level of 0 VU, following EBU requirements. This translates to either -18 dBFS in digital format or + 4 dBu in analog format.
3. Equipment Isolation: To avoid interfering with the signal amplitude during calibration, all nearby equipment was either switched off or isolated.
4. Recording System Configuration: The recording system was equipped with the following devices:
    a. Audio interface: Steinberg UR22mkII
    b. Microphone: Audio-Technica AT4050
    c. Amplifier: Behringer Powerplay Pro XL
    d. Cables: XLR connectors.
5. Microphone Configuration: A low-cut filter was applied to the Audio-Technica AT4050 microphone to remove undesired low-frequency noise.

The size and features of the bundengan are shown in Fig. 6. The radiated sound was measured with an omnidirectional microphone placed 20 cm in front of the bundengan and was conducted in an anechoic chamber.

Fig. 6. The bundengan with 5 strings

The time signals from PicoScope oscilloscopes and data recorders for real-time signal acquisition were viewed and analyzed using the PicoScope computer software (Pico Technology, 3000 series, Eaton Socon, UK). The PicoScope program facilitates analysis through the utilization of Fast Fourier Transform (FFT). The schematic diagram of the experimental setup is depicted in Fig. 7. The sound capture was sufficiently loud to be detected by the signal converter, facilitated by the amplifier (Behringer Powerplay Pro XL, Behringer, Zhongshan, Guangdong, China). The sound spectra were acquired through measurements conducted using PicoScope. Following the capture and recording of the sound data, the FFT analysis was performed using Adobe Audition (for time frequency analysis (TFA)) to determine the dominant frequency for each tone at specific moments. Fourier transformation is a mathematical technique used to identify fundamentals, harmonics, and subharmonics.

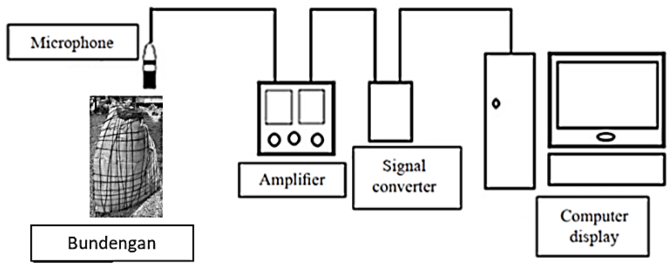
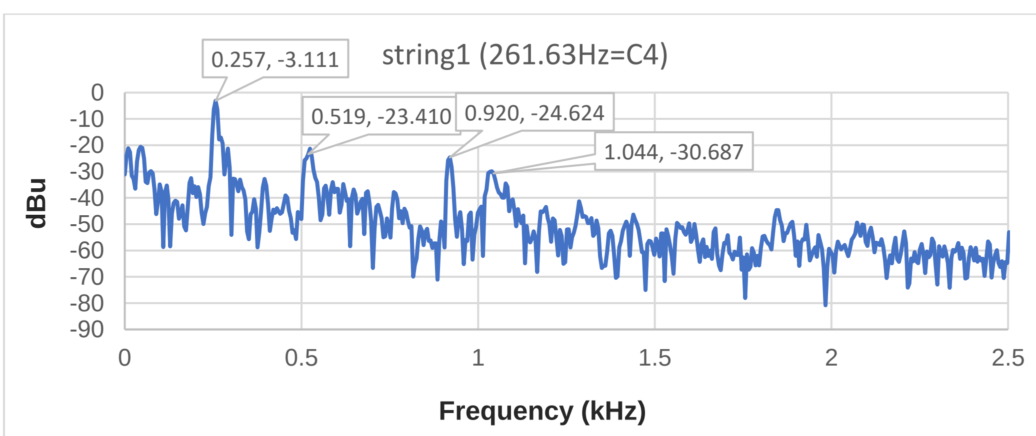


Fig. 7. Schematic diagram of the experimental setup

RESULTS AND DISCUSSION

Figures 8 and 9 show the FFT of strings 1 to 5 and ‘drums’ 1 to 3, respectively. The vibrations produce sound waves that create the notes heard in music. Several factors influence the sound generated, including tension and the position of the fingers. Table 2 shows the pitch obtained from the FFT spectrum and the pitch as heard. Table 3 shows the fundamental and partial frequencies along with the octave numbers for strings 1 to 5. Table 4 shows the pitch obtained from the FFT spectrum and the pitch as heard for ‘drums’ 1 to 3.



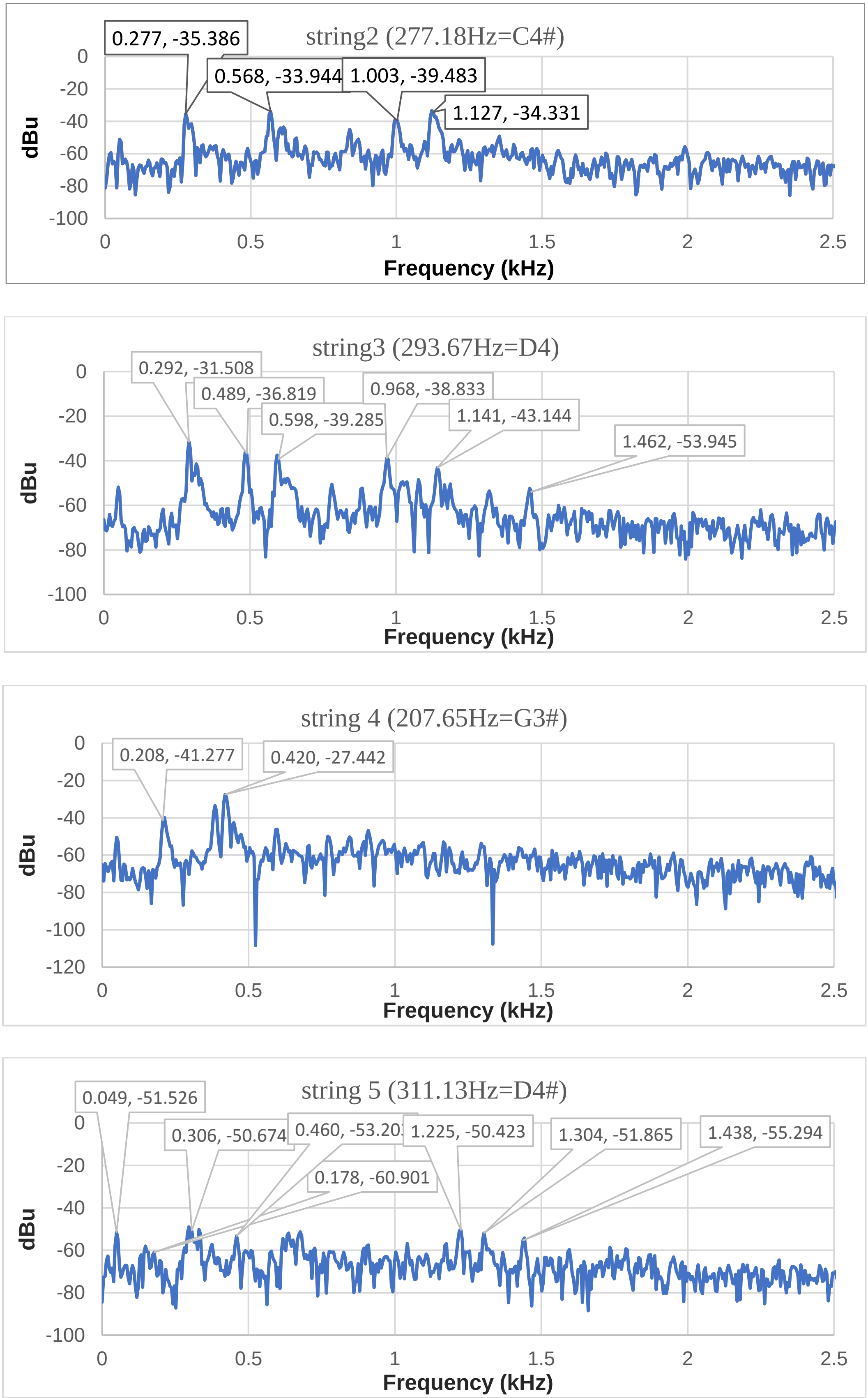
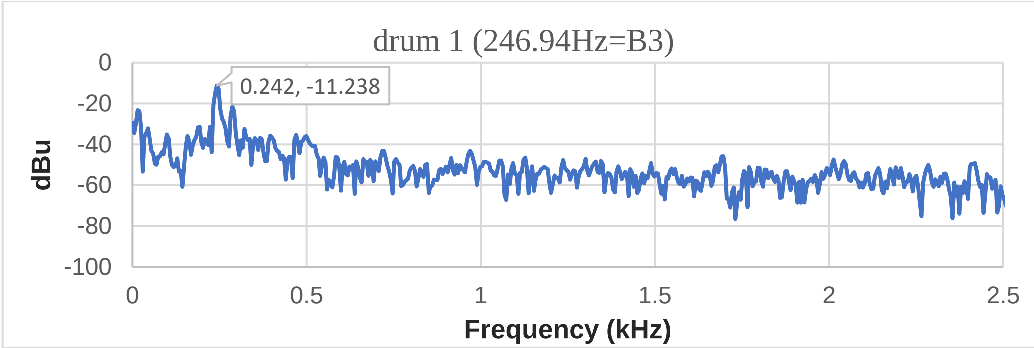
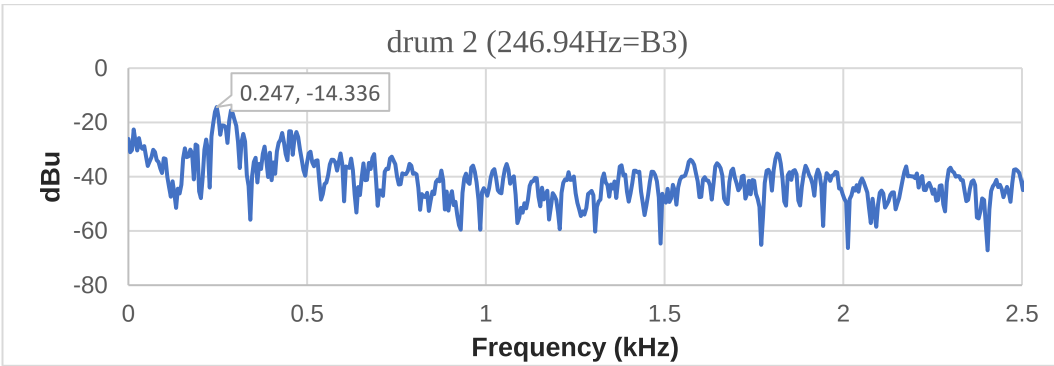


Fig. 8. The FFT of strings 1 to 5





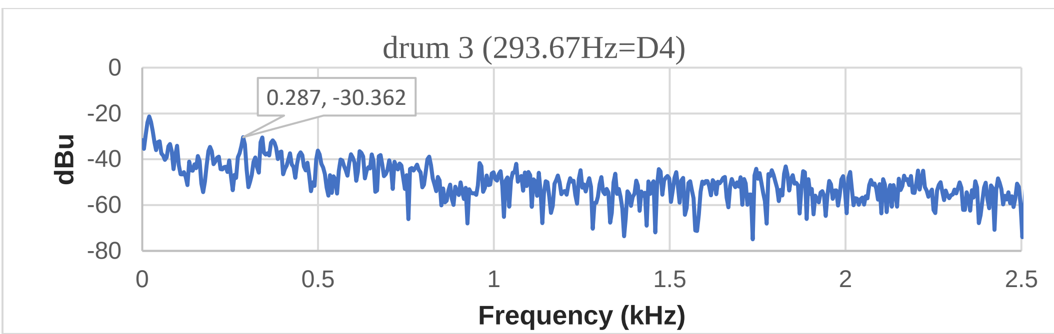


Fig. 9. The FFT of 'drums' 1 to 3

Table 2. The Pitch from the FFT Spectrum and the Pitch as Heard

Strings	Pitch from the FFT spectrum	Pitch as heard
1	257 Hz (261.63 = C4)	C3#
2	277 Hz (277.18 = C4#)	D4
3	292 Hz (293.67 = D4)	D3
4	208 Hz (207.65 = G3#)	G3
5	306 Hz (311.13 = D4#)	C#2

Table 3. The Fundamental and Partial Frequencies with the Octave Number for Strings 1 to 5

String 1		String 2		String 3		String 4		String 5	
freq	freq/fo	freq	freq/fo	freq	freq/fo	freq	freq/fo	freq	freq/fo
257	1	277	1	292	1	208	1	306	1
519	2.01	568	2.05	598	2.04	420	2.01	460	1.5
920	3.58	1003	3.62	968	3.31			1225	4.00
1044	4.06	1127	4.06	1141	3.90			1304	4.26
								1438	4.69

Table 4. The Pitch Obtained from the FFT Spectrum and the Pitch as Heard for 'Drums' 1 to 3

Drum	Pitch from the FFT spectrum	Pitch as heard	Sound
1	242 Hz (246.94 = B3)	B3	'thang'
2	247 Hz (246.94 = B3)	~F (undetermined the right pitch)	'dhet'
3	287 Hz (293.76 = D4)	~G (undetermined the right pitch)	'pung' or 'dung'

From Table 2, it was found that the bundengan was tuned to a pitch that corresponds to the timbre rather than a specific pitch (Keen 2017). From Table 3, the octave numbers of each partial are not necessarily integers. These non-harmonic frequencies resemble the non-harmonic spectra commonly found in metallic percussion instruments (Gomez *et al.* 2007). This is key to how the bundengan strings can generate gong-like sounds. From Table 4, the pitch can be determined from 'drum' 1 due to the resonance of the vibrations produced.

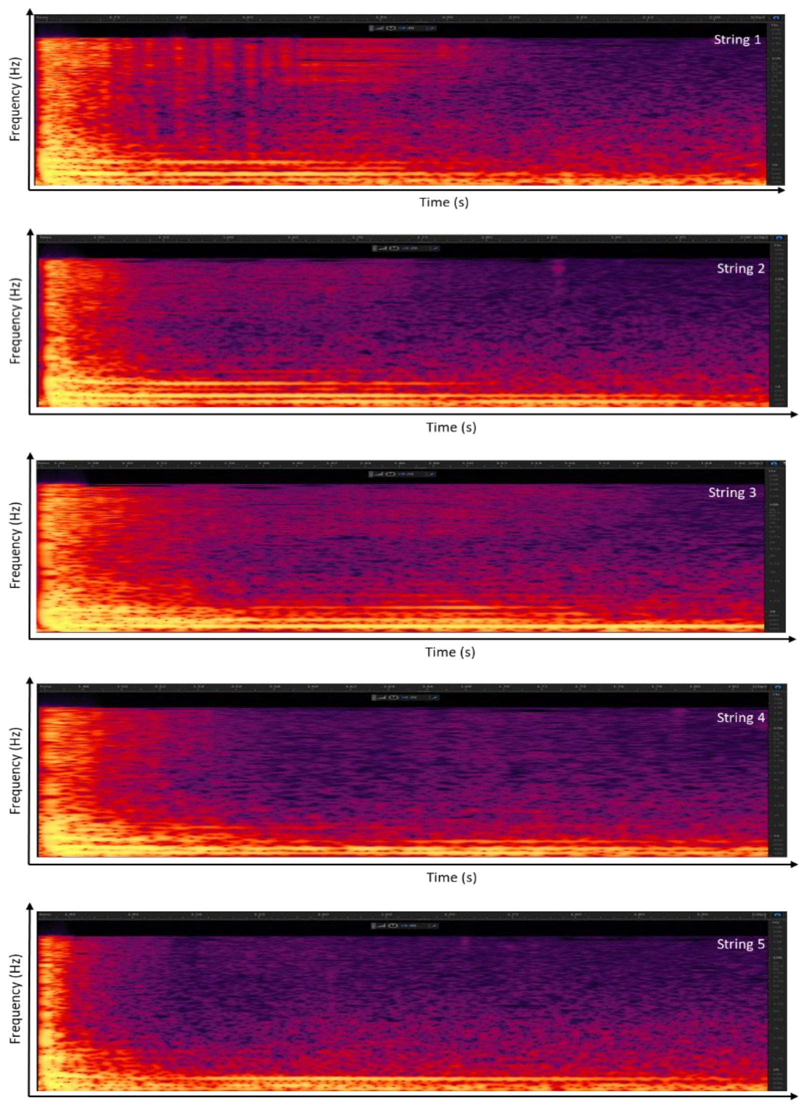


Fig. 10. The spectrogram of strings 1 to 5

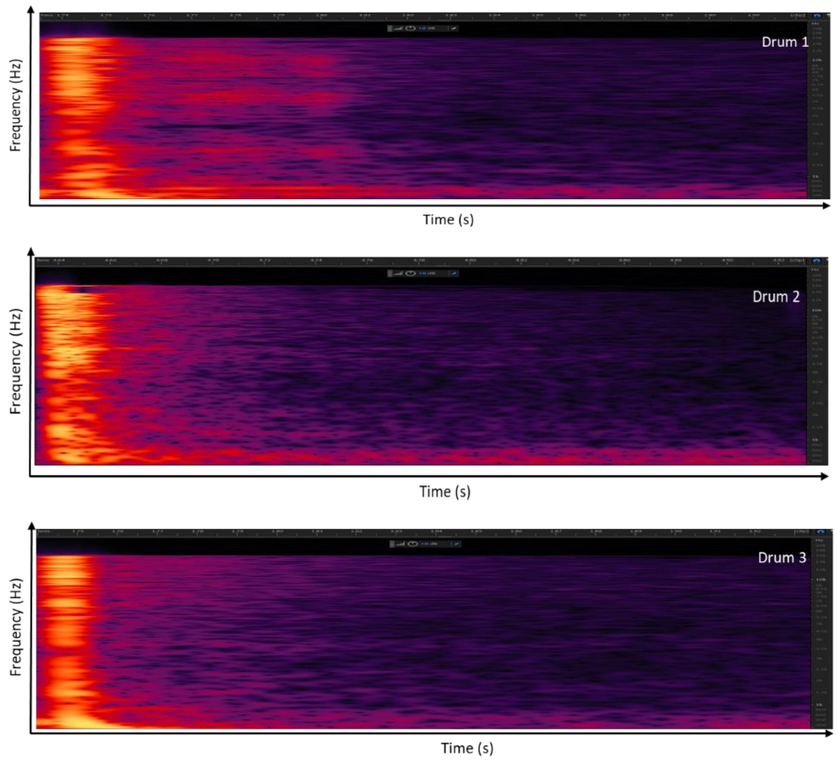


Fig. 11. The spectrogram of ‘drums’ 1 to 3

The pitch can be determined from ‘drums’ 2 and 3 but is less clear due to the lack of resonance. The pitch detected is closest to the interval of ‘drum’ 1 and the ‘drum’s’ sound. Figures 10 and 11 show the spectrogram of strings 1 to 5 and ‘drums’ 1 to 3 using Adobe Audition, respectively.

From Fig. 10, the brightness of the spectrogram corresponds to the pitch heard through the timbre rather than the specific pitch, *i.e.*, strings 1 to 5 are heard as C3#, D4, D3, G3 and C2#. The brightest spectrogram is for string 2 (D4), followed by string 4 (G3), string 3 (D3), and string 1 (C3#). It is evident that string 5 is less bright, which is heard as C2#. From Fig. 9, the FFT of ‘drums’ 1 to 3 shows frequencies of 242, 247, and 287 Hz, respectively, which correspond to B3 (246.94Hz) and D4 (293.67Hz). The spectrogram in Fig. 11 shows that ‘drum’ 1 had the highest brightness followed by ‘drum’ 2 and ‘drum’ 3. It was found that the bundengan is tuned to a pitch corresponding to the timbre rather than a specific pitch from the FFT spectra. Hence, the bundengan musicians tune their instruments to a certain timbre rather than a specific pitch (Keen 2017).

CONCLUSIONS

1. The Bundengan’s sound originates from the vibration of the strings. The effects are heightened by the resonator-like bamboo body. A tiny piece of bamboo known as bandulan is fastened to the strings to set the tone. The sound effect is produced by the bandulan.

2. The player can modify the pitch and timbre of the sound produced by the strings by sliding the bandulan along the strings. The results showed that the pitch from the measured frequencies differs from the pitch as heard.
3. The bandulan placed along the strings are used to change the timbre rather than pitch. These bandulan cause the pitch to drop by weighing the string down. It was found that the bundengan is tuned to a pitch corresponding to the timbre rather than a specific pitch.
4. The bamboo clips cause multiple vibrations of non-harmonic frequencies at different sections of the string separated by the clips, thus resembling the non-harmonic spectra commonly found in metallic percussion instruments. The non-harmonic spectra give the string a wavering gong-like sound. The five strings being played imitate the sounding of gamelan which occurred the sense of interlocking between each string.
5. The brightness of the spectrogram also corresponds to the pitch heard through the timbre rather than a specific pitch.

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