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UNDERSTANDING THE PITCH AND OVERTONE OF SLENTHEM (INDONESIAN METALLOPHONE IN JAVANESE GAMELAN ORCHESTRA) USING AUDIO-BASED APPROACHES THROUGH FAST FOURIER TRANSFORM (FFT)

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Abstract

This paper discusses the fundamental and overtone frequencies of slenthem (Indonesian metallophone in Javanese gamelan orchestra) using audio-based approach through Fast Fourier Transform (FFT). The fundamental and overtone frequencies for-each plate enables the determination of the key in the slenthem. The finding indicates that the plates 1, 2, 3, 5, 6, and 1' for slenthem from the Faculty of Applied and Creative Art (FACA) of Universiti Malaysia Sarawak (UNIMAS) are A2#, D3#, F3, G3, A3#, and C4#, respectively, while slenthem from the Badan Budaya Unimas (BAYU) is B2, C3, D3#, F3, G3, and A3 respectively. The plate has an individual tube resonator with various opening sizes and air column depths. The effects of the opening and air column were studied by changing the tube resonator of each plate. The plate determines the frequency of the slenthem, not the opening sizes or the length of the air column inside the tube resonator. The sound produced by the plate with and without a tube resonator were carried out to check the effect of the air column inside the tube resonator. The PicoScope determine the frequency using FFT and Adobe Audition analysing the frequency that leads to time-frequency analysis (TFA).

Keywords: Adobe audition, Fast Fourier transform, Fundamental frequency, Overtones frequency, Slenthem, Time-frequency analysis (TFA).

1. Introduction

An Indonesian Javanese gamelan orchestra plays the Slenthem metallophone. It is a member of the gender family and is made up of bronze plates that make up an octave. The pelog scale has seven tones, while the slendro scale has five. Above each tube resonator, all the plates are suspended from a leather cord. The slenthem is played by striking the plates with a mallet. With another hand, the plates are dampened. The mallet has a short handle, and a thin, cloth-wrapped wooden disc. Slenthem only played the main melody in composition and produced low-pitched, softer sounds. It is therefore preferred in more subtle gamelan ensembles. A metal bar that is unregulated at both ends is not subject to any restrictions.

As a result, the movement is entirely caused by the bending modes, which also control the vibration of the bar. Figure 1 depicts an ideal metal bar's first three bending modes and spectrum [1]. When a metal bar is hit, it makes sound through bending and vibrations of the bar. Figure 2 shows the waveform (for 0.75 second) from the metal bar after striking with the corresponding spectrum (in Hz) which shows four prominent partials [1].

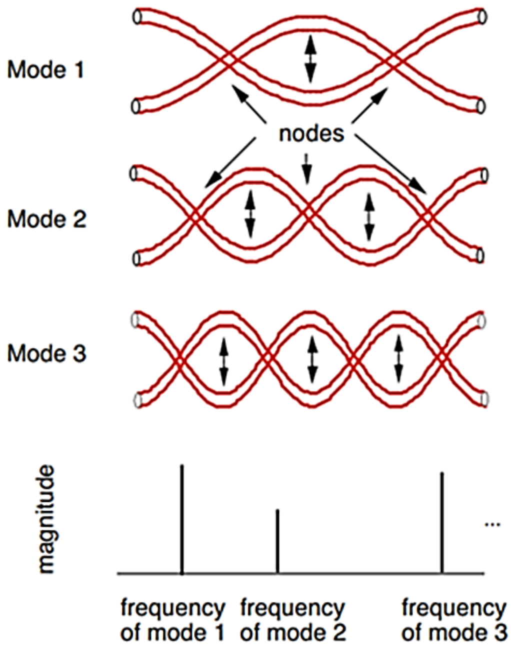


Fig. 1. The first three bending modes of an ideal metal bar and its spectrum [1].

The spectrum reveals that the sound has four distinct partials at 526, 1413, 2689, and 4267 Hz. Taking the fundamental 526Hz as the first partial f, the four prominent partials at f, 2.68f, 5.11f, and 8.11f are not harmonically related [1]. The frequencies are not integer multiples of the fundamental frequency. The relationship between the frequencies of the partials remains (roughly) the same. If the fundamental frequency of an ideal metal bar is f, the second partial will be at 2.76f, the third at 5.4f, and the fourth at 8.93f [2]. This is close to the experimental spectrum in Fig. 2 where the first partial occurs at f, the second partial at 2.68f, the third at 5.11f, and the fourth at 8.11f.

The differences are likely due to nonuniformities in the bar or to deviations in the bar height or width. The shape of the slenthem bars is not exactly like the ideal metal bar. This structure is called ‘wilah blimbingan’ which is not having a flat top surface. Considering this non-uniformity in the shape, it is very interesting to note that the keys are similarly produce like the ideal metal bar.

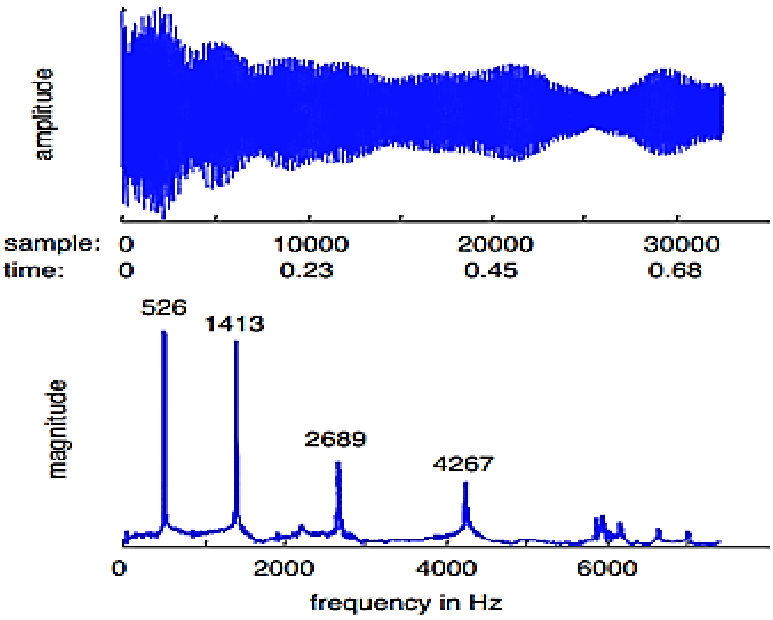


Fig. 2. The waveform (for 0.75 second) from the metal bar after striking with the corresponding spectrum (in Hz) which shows four prominent partials [1].

The theory of gamelan tuning is relatively easy to grasp but practically not simple due to in-harmonic character [3]. In Java, there is no uniformity of pitch or intervallic structure. The crafter tunes after consulting with the consumer. The gamelan is tuned to either the pelog (i.e., seven-tone) or slendro (i.e., five-tone) scales, which are not diatonic (i.e., twelve-tone. The tunings are not necessary in the 2:1 octave which can be larger or smaller significantly. On average all the slendro gamelans tuning is 0, 231, 474, 717, 955, 1208 (in cents), with a pseudo-octave stretched by 8 cents. This tuning is close to 5-tet. Some gamelans may deviate from this.

All pelog gamelan tuning is 0, 120, 258, 539, 675, 785, 943, 1206, which stretched by 6 cents. The Pelog scale and the Slendro scale are the two basic tuning systems that influence the tonal context of Javanese gamelan music. The heptatonic scale of the Pelog system acknowledged as the oldest of the two, has seven notes that are not equally spaced apart for each octave.

Slendro system is formed from the Pelog scale by choosing five tones, namely 1, 2, 3, 5, and 6. This historical realization emphasizes how the two systems are interrelated and emphasizes the importance of Pelog as the original tuning principle.

Gamelan instruments are known for following the seven-tone Pelog scale or the five-tone Slendro scale. The earlier Slendro scale (notes numbered 1, 2, 3, 5, and 6) is paired with the heptatonic Pelog scale (notes numbered 1, 2, 3, 4, 5, 6, and 7). A subtle departure from Western tuning conventions is introduced with adding a "pseudo-octave stretched by 8 cents".

With slightly altered note-to-note intervals, this adjustment highlights the music's microtonal complexities and gives the auditory experience a delicate yet unique character. Together, these three components serve as the foundation for Javanese gamelan tuning, showcasing a sophisticated and deeply ingrained method of musical expression.

This study determines the sound produced from two sets of slenthems by creating scales and all aspects of sonic as research data. The audio signal retrieval from the slenthem set is intended to stimulate and widen the approach with a range of ways in acquiring harmonic partials of metallophones.

This work is based on a deep interest in recognizing a slenthem tunings and scales through a sound recording using technological approaches. The luthier had tuned the slenthem based on their mother nature hearing. This work tried to relate their tuning through research finding using FFT.

Slenthem is made up of six plates that are supported over various tube resonators by a wooden frame. In essence, the Slenthem's tube resonators are essentially closed-end tube resonator. The slenthem was strike by the player from Badan Budaya Unimas (BAYU).

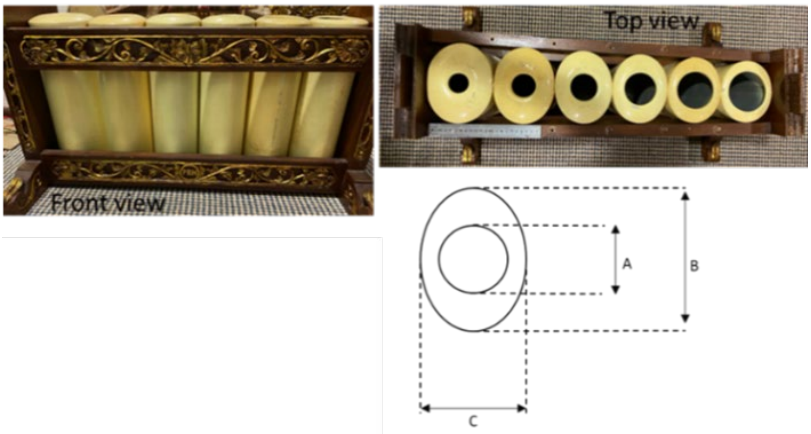
2. Material and methods

Figure 3 shows a typical slenthem with the dimension from FACA. Table 1 showed the dimension of the plate and depth of tube resonator 1, 2, 3, 5, 6, and 1'. The number 1, 2, 3, 5, 6 and 1' refer to the slendro scale as 'do', 're', 'mi', 'so', 'la' and 'do' pitches. Number 4 and 7 is not considered because the slendro scale does not have the 'fa' and 'ti' pitches. The plates and tube resonators are made of bronze and iron respectively.

The height of the tube resonator is similar but the depth of the air column in the tube resonator are different. The dimension of the plate varies from the biggest plate 1 (10cmx36.8cm) to the smallest plate 1'(8.6cmx33.4cm).

The tube resonator 1, 2, 3, 5, 6 and 1' had an oval top with the major axis (B) as 16, 15.5, 15, 14, 13.5 and 13 cm respectively and the minor axis (C) as 13, 12, 12, 11.5, 11 and 11 cm respectively. Tube Resonator 1 had the smallest circle opening (A), i.e., 4 cm diameter whereas tube resonator 1' had the biggest circle opening (A), i.e., 8.5 cm diameter. Tube Resonator 1 had the highest air column 34.5cm to the lowest air column 25.2 in tube resonator 1'.

(a)



(b)

Fig. 3. (a) The slenthem metallic key and the slenthem without tube resonator from FACA (b) The front and top view of the slenthem tube resonator with the dimension.

The microphone technique was depicted in Fig. 4. The microphone was held 20 cm straight above the vertical axis of the slenthem. The audio signal was produced by a professional player from Badan Budaya Unimas (BAYU) striking the plate.

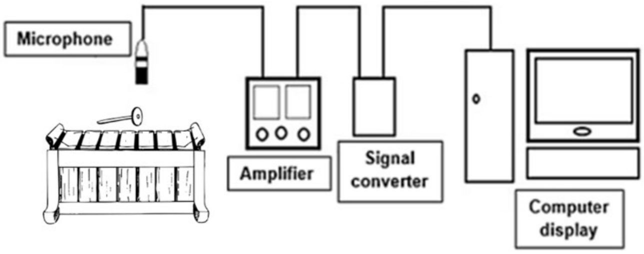


Fig. 4. Schematic diagram of the experimental setups for the microphone method.

Table 1. The dimension of plate and depth of tube resonator 1, 2, 3, 5, 6, and 1' from FACA.

Plate/Tube Resonator	Plate width (cm)	Plate length (cm)	Tube Resonator air column depth (cm)	Tube Resonator Dimension (cm)		
				A, Circle opening	B, Major axis	C, Minor axis
1	10	36.8	34.5	4	16	13
2	9.7	36.5	35.2	5	15.5	12
3	9.5	35.8	34.5	6	15	12
5	9.1	35	31.5	7	14	11.5
6	9.0	34.2	29.4	8	13.5	11
1'	8.6	33.4	25.2	8.5	13	11

The PicoScope computer software (Pico Technology, 3000 series, Eaton Socon, UK) was used to view and analyse the time signals from PicoScope oscilloscopes (Pico Technology, 3000 series, Eaton Socon, UK) and data loggers for real time signal acquisition. PicoScope software enables analysis using FFT, a spectrum analyser, voltage-based triggers, and the ability to save/load waveforms to a disk. The slenthem was placed to where the sound could be captured with minimum interference. The signal produced from PicoScope displayed sharp and distinct fundamental and overtone frequencies peak compared to the low signal level from the background noise. The amplifier (Behringer Powerplay Pro XL, Behringer, China) ensured the sound capture was loud enough to be detected by the signal converter.

In conducting this study, the audio signal derived from the striking of the slenthem played by an expert slenthem player was recorded. The audio signal was recorded in mono, at 24-bit resolution, 48 kHz sampling rate. The audio signal was recorded with the aid of a digital audio interface in a .wav format. To ensure the recorded audio signal of the slenthem was at the optimum level, audio signal calibration of the recording system was carried out. A test tone of 1 kHz sine wave was used in calibrating the recording system.

Here the 'unity' calibration level was at +4dBu or -10dBV and was read by the recording device at '0 VU'. In this regard the EBU recommended the digital equivalent of 0VU is that the test tone generated to the recording device of the experimentation is recorded at -18 dBFS (Digital) or +4dBu (Analog) which is equivalent to 0VU. In this thorough procedure of calibration, no devices are unknowingly boosting or attenuating its amplitude in the signal chain at the time of the recording is carried out.

The recording apparatus was the Steinberg UR22 mkII audio interface, Audio-Technica AT4050 microphone, XLR cable (balance), with microphone position on axis (<20cm), microphone setting with low cut (flat) 0dB. The study's calibration units, +4dBu or -10dBV, establish a consistent reference point for audio signal recording. Selected because of their widespread industry acceptability, these components provide uniformity and interoperability throughout audio systems. Their immediate influence may be seen in how the recording device interprets 0 VU, which aligns with recommendations from the European Broadcasting Union (EBU). The accuracy of recorded audio is improved by complying with standards.

Furthermore, the chosen units avoid inadvertent amplitude changes when recording, essential for preserving data integrity. Basically, +4dBu or -10dBV is an essential part that gives the experimental setup precision, compliance with standards, and reliability [4]. In this work the Steinberg UR22 mkII audio interface, Audio-Technica AT4050 microphone, XLR cable (balance) was used for recording apparatus. Adobe Audition was used for analysing the frequency that leads to time-frequency analysis (TFA). The recorded sound was amplified using the Behringer Powerplay Pro XL (Behringer, China) to a volume the signal converter could detect. The amplification level was carefully adjusted to maximize sound capture. As is customary in audio recording, the signal was never allowed to peak at a level higher than -6 dB on the peak meter since this will cause audio distortion.

Moreover, Adobe Audition was used to analyse the frequency and generate a time-frequency analysis (TFA). These specific conditions offer transparency and clarity, mitigating potential sources of bias and facilitating experiment replication. The experiment was carried out in the Music Department of Universiti Malaysia Sarawak (UNIMAS) in an anechoic chamber. The PicoScope signal is captured at 40 mV/div with the time at 5 ms/div. The frequency from the FFT is up to 7Khz. Figure 5 shows a typical signal from plate 1.

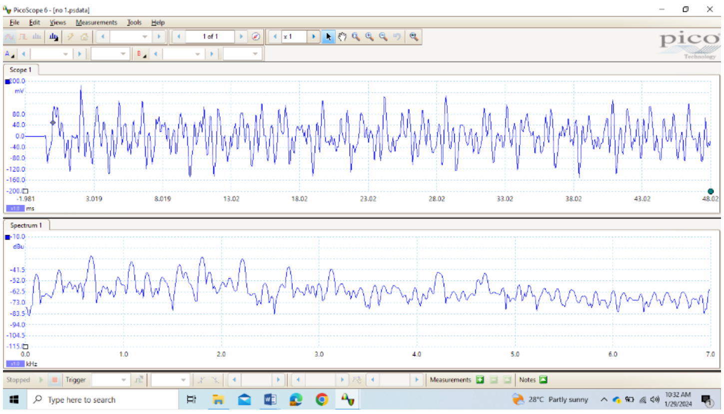


Fig. 5. A typical signal from plate 1.

The TFA explains its intensity at the frequency range on the vertical axis. The vertical scale on this figure is a frequency scale (in Hz), and the horizontal scale is a time scale (in second). Figure 5 provides a description of the sound in the time frequency plane. The TFA obviously showed distinct peaks at the fundamental and overtone frequencies. The larger values of these spectra are displayed in bright yellow colour. The spectra for the individual frequency are clearly separated in the y-axis and clearly divided into line segments, lying above each frequency and corresponding to the fundamentals and overtones in each note.

TFA illustrates a uniform scale of frequencies in the Adobe spectrogram. In this spectrogram there is a number of spectral line segments crowded together at the lower end of the frequency scale. The frequency identifies the pitch of the sound by the high pixel intensity. There are clear differences between the attack and decay of the spectral line segments for the frequency obtained from slenthem.

These differences are visible where a very prominent attack due to the striking by the mallet which is shown in the yellow regions in its spectrogram near the beginning of the fundamental and first overtone line segments for each frequency. These regions can be termed non-harmonic spectra, if they are non-integral multiples of the fundamental. These regions arise from transient, non-linear effects during the attack of each note. There is also a longer decay due to the slow damping down of the slenthem vibrations which is evident in the overlapping of the yellow region for each note line segment. TFA exhibits a much gentler attack and rapid decay for some slenthem. It is well known that, in addition to the harmonic structure of fundamentals and overtones, the precise features of attack and decay in notes are important factors in human perception of musical quality.

This comparison of slenthem plates illustrates how all of these features of musical notes can be quantitatively captured in the TFA provided by spectrograms. The fundamental and overtones frequencies correspond to the pitch of the sound. These line segments correspond to the fundamental and higher frequency peaks in the Fourier spectrum for the sound in Fig. 5 above.

3. Results and Discussion

Figures 6 and 7 showed the amplitude (dBu) versus frequency (kHz) for slenthem 1, 2, 3, 5, 6, and 1' from BAYU and FACA respectively. For an ideal metal bar, if the fundamental occurs at frequency f, the second partial will be at 2.76f, the third at 5.4f, and the fourth at 8.93f [2]. Table 2 and 3 showed the frequency of the fundamental f at the first partial and the octave of the higher partial (up to ten partials) for BAYU and FACA slenthem respectively. The fundamental frequency f (i.e., the first octave) represented the note of the plate.

The note for plate 1, 2, 3, 5, 6 and 1' for BAYU slenthem are B2, C3, D3#, F3, G3 and A3 respectively. The note for plate 1, 2, 3, 5, 6 and 1' for FACA slenthem are A2#, D3#, F3, G3, A3# and C4# respectively. The peaks from slenthem are non-harmonic spectra since they are non-integral multiples of the fundamental except for plate 1' from FACA slenthem (which is approximately like the ideal metal bar mode). A harmonic spectrum should have the second, third, fourth partial at 2f, 3f and 4f. The second partial for an ideal metal bar (fundamental frequency f) will be at 2.76f, the third at 5.4f, and the fourth at 8.93f.

Whereas from Tables 2 and 3 the second partial for plate 1, 2, 3, 5, 6 and 1 from BAYU slenthem are 2.88f, 5.62f, 5.37f, 5.69f, 5.61f and 3.10f respectively and the second partial for plate 1, 2, 3, 5, 6 and 1 from FACA slenthem are 5.8f, 5.13f, 5.02f, 5.20f 2.50f and 2.64 respectively. The potential reasons for these deviations and discrepancies in observed frequencies from theoretical expectations is the shape of the slenthem bar which is not having a flat top surface. The slenthem structure is called 'wilah blimbingan'.

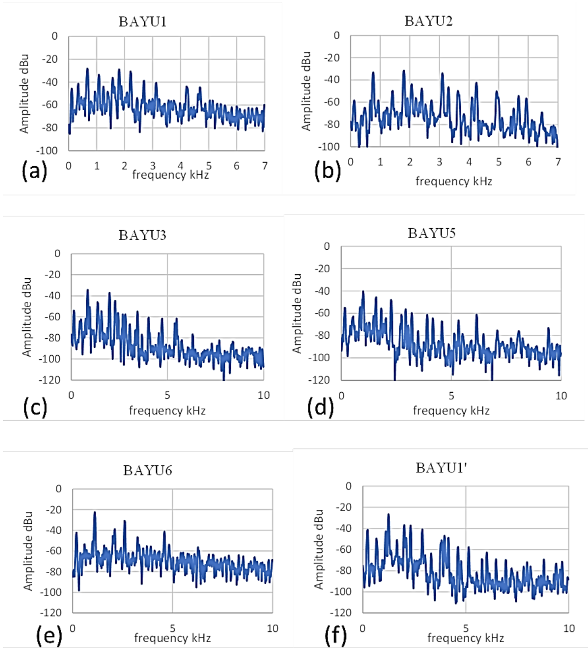


Fig. 6. Amplitude (dBu) versus frequency (kHz) for slenthem (a) 1, (b) 2, (c) 3, (d) 5, (e) 6, and (f) 1' from BAYU.

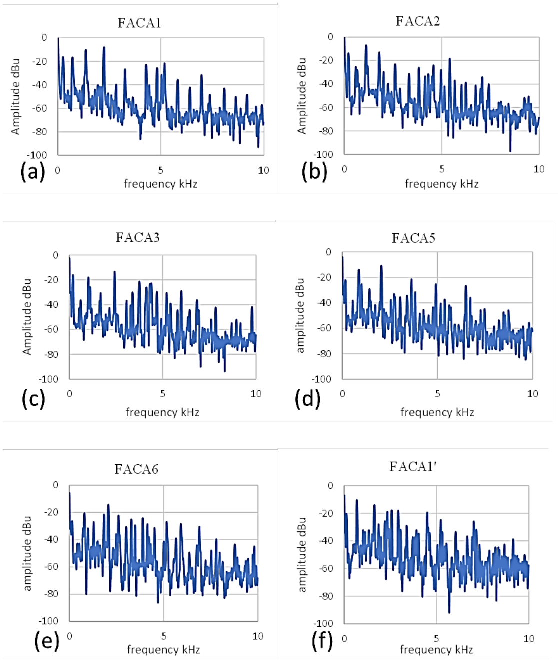


Fig. 7. Amplitude (dBu) versus frequency (kHz) for slenthem (a) 1, (b) 2, (c) 3, (d) 5, (e) 6, and (f) 1' from FACA.

Table 2. The frequency of plate 1, 2, 3, 5, 6 and 1'for BAYU slenthem with the note B2, C3, D3#, F3, G3, and A3.

	Plate 1 (123Hz B2)		Plate 2 (130Hz C3)		Plate 3 (156Hz D3#)		Plate 5 (175Hz F3)		Plate 6 (196Hz G3)		Plate 1' (220Hz A3)	
PARTIAL	Freq	Octave	Freq	Octave	Freq	Octave	Freq	Octave	Freq	Octave	Freq	Octave
First	123	1	136	1	156	1	175	1	195	1	214	1
Second	355	2.88	765	5.62	839	5.37	996	5.69	1094	5.61	664	3.10
Third	683	5.55	1817	13.36	1386	8.88	1562	8.92	2109	10.81	1250	5.84
Fourth	1093	8.88	3116	22.91	1972	12.64	2285	13.05	2617	13.42	2011	9.39
Fifth	1804	14.66	3321	24.41	2265	14.51	2929	16.73	3261	16.72	2324	10.85
Sixth	2227	18.10	3635	26.72	3457	22.16	3222	18.41	4589	23.53	2890	13.50
Seventh	2692	21.88	4250	31.25	4003	25.66	3906	22.32		-	3964	18.52
Eighth	3129	25.43	4947	36.37	4726	30.29	4179	23.88		-	4628	21.62
Ninth	4250	34.55	5685	41.80	5488	35.17		-		-	5136	24
Tenth	4701	38.21	5932	43.61				-		-	6035	28.20

From Table 5 the first partial displayed the fundamental frequency and is called the first octave. For an ideal metal bar, if the fundamental occurs at frequency f, the second partial will be at 2.76f, the third at 5.4f, and the fourth at 8.93f [2]. This is true for the second partial, i.e., 2.88f and 3.10f from plate 1 and 1' respectively from BAYU, and 2.50f and 2.64f from plate 6 and 1' respectively from FACA (theoretical second partial for an ideal bar is at 2.76f).

For the third partial once again, bar 1 and 1' from BAYU showed 5.55f and 5.84f respectively whereas bar 6 and 1' from FACA showed 4.84f and 5.03f respectively (theoretical third partial for an ideal bar is at 5.4f).

For the fourth partial, bar 1 and 1' from BAYU showed 8.88f and 9.39f respectively whereas bar 6 and 1' from FACA showed 7.59f and 8.22f respectively (theoretical fourth partial for an ideal bar is at 8.93f).

The discrepancies are likely caused by small nonuniformities in the composition of the bar or to small deviations in the height or width of the bar. Other bars do not show the trend like an ideal bar. The potential reasons for these deviations and discrepancies in observed frequencies from theoretical expectations is the shape of the slenthem bar which is not having a flat top surface. This structure is called wilah blimbingan.

The number of octaves from the BAYU and FACA slenthem were displayed against the number of partials (x-axis) in Figs. 8 and 9 respectively, using data from Table 5. The plot for the ideal plate is shown in Fig. 10. Table 6 shows the fitting equation for number of octave (y-axis) versus the number of peak (x-axis) obtained from Figs. 8 and 9 for BAYU and FACA slenthem.

Table 3. The frequency of plate 1, 2, 3, 5, 6 and 1' for FACA slenthem with the note A2#, D3#, F3, G3, A3# and C4#.

	Plate 1: 117Hz (116.5HzA2#)		Plate 2:156Hz (155.5HzD3#)		Plate 3: 175Hz (174.6HzF3)		Plate 5: 195Hz (196HzG3)		Plate 6: 234Hz (233HzA3#)		Plate 1':273Hz (277HzC4#)	
PARTIAL	Freq	Octave	Freq	Octave	Freq	Octave	Freq	Octave	Freq	Octave	Freq	Octave
First	117	1	156	1	175	1	195	1	234	1	273	1
Second	683	5.8	800	5.13	878	5.02	1015	5.20	586	2.50	722	2.64
Third	1132	9.67	1289	8.26	1425	8.14	2441	12.52	1132	4.84	1374	5.03
Fourth	1640	14.0	2070	13.27	2050	11.71	3750	19.23	1777	7.59	2246	8.22
Fifth	2558	21.86	2597	16.65	2773	15.84	4394	22.53	2617	11.18	2832	10.37
Sixth	2929	25.03	3300	21.15	3632	20.75	4687	24.03	3320	14.18	3261	11.94
Seventh	3398	29.04	3906	25.03	4902	28.01	5214	26.74	3828	16.36	4277	15.66
Eighth	4492	38.39	5175	33.17	5390	30.8	5976	30.64	4570	19.52	4824	17.67
Ninth	5312	45.40	5917	37.92	6503	37.16	6835	35.05	4960	21.19	5175	18.95
Tenth	6152	52.58	7792	49.94	6719	38.39	7832	40.16	5410	23.11	5820	21.32

Table 4. The fundamental frequency (Hertz) with the note for every plate compared with previous worker [5].

Plate	BAYU (slendro scale)		FACA (slendro scale)		Agung et al. (pelog scale)	
1	123	B2	117	A2#	145.6	D3
2	136	C3	156	D3#	160.2	E3
3	156	D3#	175	F3	171.6	F3
5	175	F3	195	G3	202.0	G3
6	195	G3	234	A3#	215.5	A3
1'	214	A3	273	C4#	233.0	A3#
7	-		-		255.2	B3

Table 5. The octave (first to tenth partial) of plate 1, 2, 3, 5, 6 and 1'for BAYU and FACA slenthem. The octave for the ideal bar is given in the last column.

PARTIAL	Plate number (BAYU)						Plate number (FACA)						Ideal bar
	1	2	3	5	6	1'	1	2	3	5	6	1'	
First	1	1	1	1	1	1	1	1	1	1	1	1	1
Second	2.88	5.62	5.37	5.69	5.61	3.10	5.8	5.13	5.02	5.20	2.50	2.64	2.76
Third	5.55	13.36	8.88	8.92	10.81	5.84	9.67	8.26	8.14	12.52	4.84	5.03	5.40
Fourth	8.88	22.91	12.64	13.05	13.42	9.39	14.0	13.27	11.71	19.23	7.59	8.22	8.93
Fifth	14.66	24.41	14.51	16.73	16.72	10.85	21.86	16.65	15.84	22.53	11.18	10.37	
Sixth	18.10	26.72	22.16	18.41	23.53	13.50	25.03	21.15	20.75	24.03	14.18	11.94	
Seventh	21.88	31.25	25.66	22.32	-	18.52	29.04	25.03	28.01	26.74	16.36	15.66	
Eighth	25.43	36.37	30.29	23.88	-	21.62	38.39	33.17	30.8	30.64	19.52	17.67	
Ninth	34.55	41.80	35.17	-	-	24	45.40	37.92	37.16	35.05	21.19	18.95	
Tenth	38.21	43.61	-	-	-	28.20	52.58	49.94	38.39	40.16	23.11	21.32	

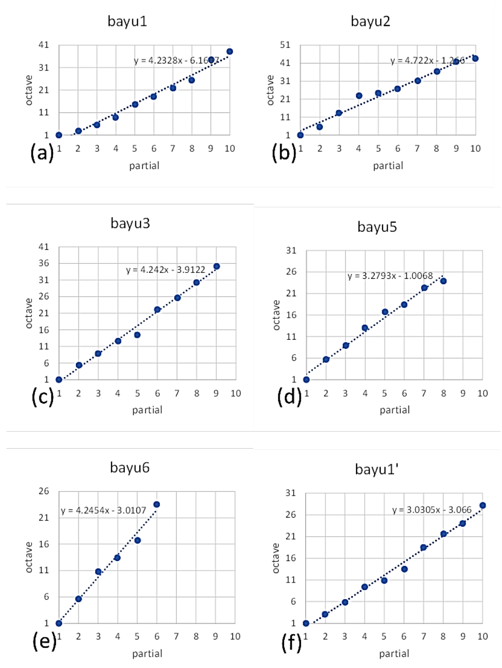


Fig. 8. The number of octave (y-axis) versus the number of partials (x-axis) from BAYU slenthem.

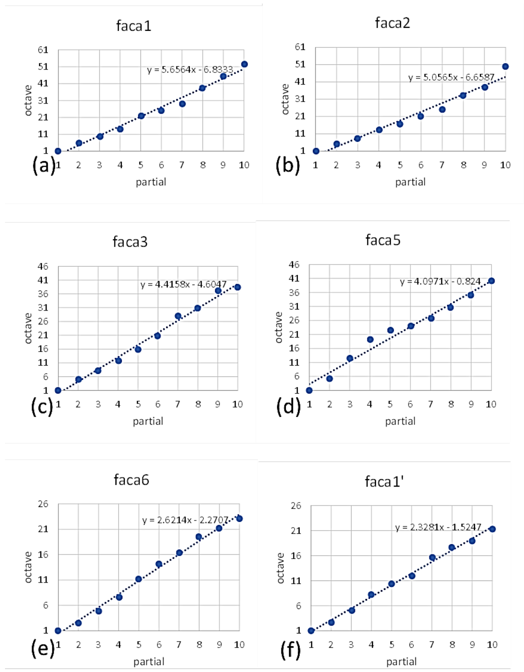


Fig. 9. The number of octave (y-axis) versus the number of partials (x-axis) from FACA slenthem.

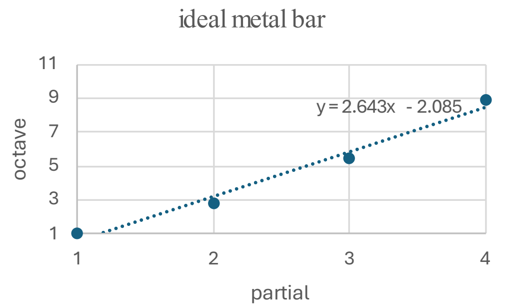


Fig. 10. The number of octave (y-axis) vs. the number of partials (x-axis) from ideal metal bar.

Table 6. The fitting equation for number of octave (y-axis) vs. the number of peak (x-axis) obtained from Figs. 7 and 8 for BAYU and FACA slenthem.

Plate No.	Equation for BAYU	Equation for FACA
1	y = 4.2328x – 6.1667	y = 5.6564x – 6.8333
2	y = 4.722x - 1.266	y = 5.0565x -6.6587
3	y = 4.242x – 3.9122	y = 4.4158x-4.6047
5	y = 3.2793x -1.0068	y = 4.0971x-0.824
6	y = 4.2454x -3.0107	y = 2.6214x + 2.2707
1'	y = 3.0305x -3.066	y = 2.3281x -1.5247
Ideal metal bar	y = 2.643x-2.085	y = 2.643x-2.085

The fitting equation for the number of octaves (y-axis) versus the number of partials (x-axis) is generally shown in Table 6 (obtained from Figs. 8 and 9 for the BAYU and FACA slenthems, respectively and Fig. 10 for the ideal metal bar). Plate 1' from BAYU, which also has the largest circle opening (8.5cm), comes in second with an equation y=3.0305x -3.066. Plate 1' from FACA has the largest circle opening (8.5cm) and has an equation y=2.3281x-1.5247, which is roughly the ideal metal bar value equation y=2.643x-2.085. The equations start deviating from the ideal metal bar values as the circle opening become smaller.

The plate act as an ideal bar when the circle opening is large. The effects of the opening were studied by changing the tube resonator of each plate. Figure 11 showed the spectrum for plate 5 with the tube resonator 1, 2, 3, 5, 6, and 1'. The spectrum for plate 5 without tube resonator is for comparison purposes. Table 7 shows the first, second, third and fourth partial (hertz) from plate 5 without tube resonator and with tube resonator 1, 2, 3, 5, 6, and 1'

Table 7. The first, second, third and fourth partial (hertz) from plate 5 without tube resonator and with tube resonator 1, 2, 3, 5, 6, and 1'.

PARTIAL	With out tube reson ator	Tube Resonat or 1	Tube Resonat or 2	Tube Resonat or 3	Tube Resonat or 5	Tube Resonat or 6	Tube Resonat or 1'
First	528	528	528	528	528	528	528
Second	1017	1017	1017	1017	1017	1017	1017
Third	1662	1525	1662	1662	1662	1662	1662
Fourth	2424	2424	2424	2424	2424	2424	2424

From Table 7 the frequency of the slenthem is only determined by the plate and not by the length of the air column inside the tube resonator. Further tests were carried out to check the effect of the air column inside the tube resonator. The test involves the decay signal of the plate without and with tube resonator as shown in Fig 12. Figure 12 showed that the tube resonator function to sustain the sound because without the tube resonator the sound decay drastically. From Fig. 12, although the pitches are not affected by the tube resonator (as shown in Table 7), the amplitude of the signal are amplified significantly.

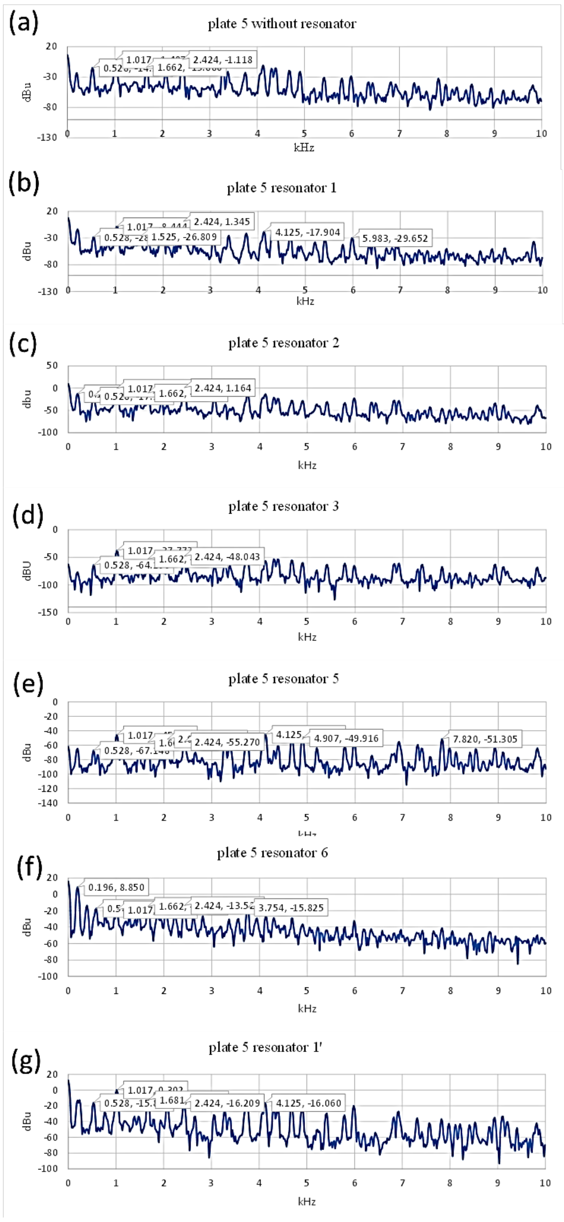


Fig. 11. The spectrum for plate 5 without tube resonator and with the tube resonator 1, 2, 3, 5, 6, and 1'.

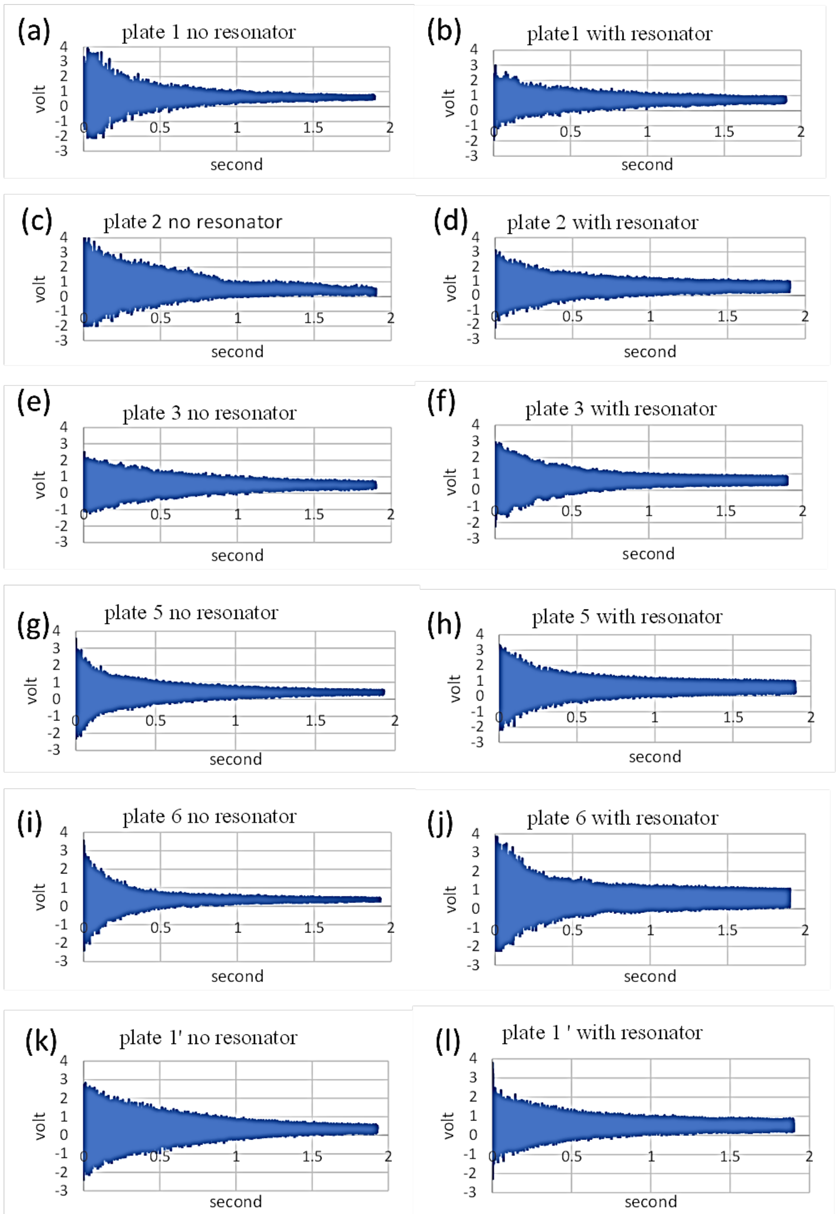


Fig. 12. The decay signal of the plate without and with tube resonator.

All the plates with tube resonator confirmed that the signal decay gradually compared with the plates without tube resonator which decay drastically. The tube resonator sustained the sound longer. Further tests were carried out to check the effect of the air column inside the tube resonator using spectrogram from Adobe Audition analysing the frequency that leads to time frequency analysis (TFA). Figure 13 shows the TFA of plate 1, 2, 3, 5, 6, and 1’ without and with tube resonator obtained from Adobe Audition. With tube resonators the frequencies (y axis) are sustained longer as shown by the time (x axis).

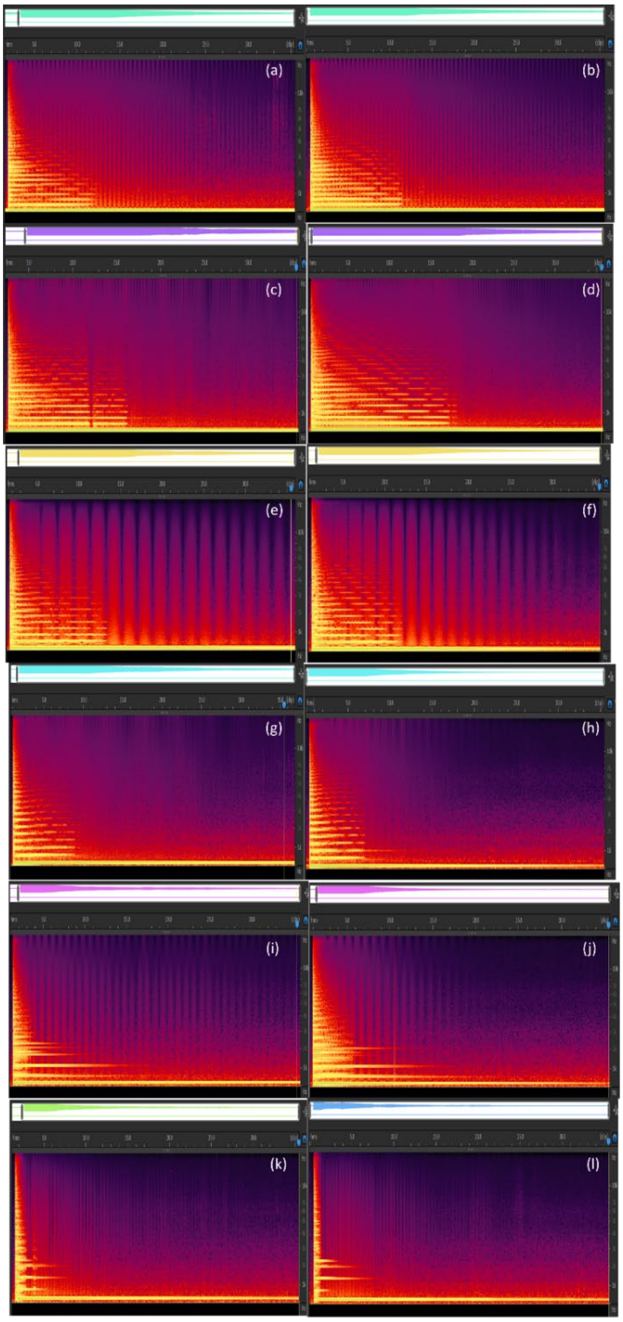


Fig. 13. TFA of plate 1 (a) without and (b) with tube resonator, TFA of plate 2 (c) without and (d) with tube resonator, TFA of plate 3 (e) without and (f) with tube resonator, TFA of plate 5 (g) without

and (h) with tube resonator, TFA of plate 6 (i) without and (j) with tube resonator and TFA of plate 1’ (k) without and (l) with tube resonator

Figure 13 obviously shows distinct peaks at the fundamental and overtone frequencies. The larger values of these spectra are displayed in bright yellow colour. The spectra for the individual frequency are clearly separated in the y-axis and clearly divided into line segments, lying above each frequency and corresponding to the fundamentals and overtones in each note.

In this spectrogram there is a number of spectral line segments crowded together at the lower end of the frequency scale. The differences are visible where a very prominent attack due to the striking by the mallet which is showed in the yellow regions in its spectrogram near the beginning of the fundamental and first overtone line segments for each frequency.

It is well known that, in addition to the harmonic structure of fundamentals and overtones, the precise features of attack and decay in notes are important factors in human perception of musical quality. This comparison of slenthem plates illustrates how all of these features of musical notes can be quantitatively captured in the TFA provided by spectrograms.

4. Conclusions

The main objective of our research is to compare the acoustic characteristics of slenthem plates, with particular attention paid to their timbral attributes. The peaks from slenthem are non-harmonic spectra since they are non-integral multiples of the fundamental except for plate 1’ from FACA slenthem (which is approximately like the ideal metal bar mode). A harmonic spectrum should have the second, third, fourth partial at 2f, 3f and 4f. The tone of the slendro slenthem sets is B2, C3, D3#, F3, G3 and A3 (Slenthem BAYU) and is A2#, D3#, F3, G3, A3# and C4# (slenthem FACA) whereas the pelog slenthem from Agung *et al.* is in D3, E3, F3, G3, A3, A3# and B3. The tube resonator function to sustain the sound because without the tube resonator the sound decay drastically. Although the pitches are not affected by the tube resonator, the amplitude of the signal are amplified significantly.

TFA investigate the dynamic characteristics of the slenthem in the frequency domain. TFA obviously showed distinct peaks at the fundamental and overtone frequencies. This comparison of slenthem plates illustrates how all of these features of musical notes can be quantitatively captured in the TFA provided by spectrograms. The slenthem bars were made manually and tune manually by grinding. The luthier was only concern about the fundamental frequency which determine the pitch of the bars. As such the plate 1’ from FACA approximates the ideal metal bar mode was purely a coincident (not on purpose). The harmonic patterns vary across plates because of the nature of the manual manufacturing and tuning.

The differences in intonation, tone, and feel between the gamelan ensembles reflect the manual nature of manufacturing and tuning by grinding. The transmission of the tuner onto the tuning of the gamelan set can be demonstrated on the aspects of intonation, tone, and feels, according to this study's PicoScope analysis of the tuning. According to this study PicoScope analysis proved that the tuning of the luthier was according to the intended pitch expected for the BAYU and FACA slendro slenthem. Only plate 1' of the FACA slenthem has fundamental frequencies and harmonic frequencies that resemble the ideal metal bar mode. The harmonics are not successive, and the number of harmonics on each plate varies.

This work had proved that all the plate except plate 1' of FACA coincidently resembling the ideal metal bar mode. Since the luthier are not concern on the higher partials, plate differs from others and its implications for the overall sound quality showed that only fundamental frequency is taken into consideration as the pitch of the slenthem bars.

In summary, the study investigates the acoustic complexities of slenthem plates, emphasizing their timbre characteristics. The results showed that most slenthem plates had non-harmonic spectra, underscoring the necessity of resolving experimental setup flaws for a more transparent and trustworthy interpretation of the study's findings. A noteworthy constraint relates to the performer's variability. The credibility of the performer creates a possible source of inaccuracy since novice strikes could cause accidental changes that affect the recorded audio signal's loudness and tone quality.

Over modulation is a problem that can occur, mainly when inexperienced users use too much force. The problem can cause vibrational distortions that affect the recording fidelity. In addition, the experimental configuration is subject to technological limitations. Microscopic distortion may result from slenthem plates being struck forcefully, particularly by unskilled individuals. The deliberate omission of ribbon microphones from the selection improves this risk. Since air movement easily damages ribbon microphones, they were left out to avoid breaking during dynamic striking.

It is important to remember that since ribbon microphones are renowned for their sensitivity and capacity to pick up on minute details, leaving them out could impact the accuracy of the captured data. In addition, the Audio-Technica AT4050 microphone is an excellent choice because of its versatility, providing three options for pickup patterns. In particular, the cardioid pickup pattern was selected on purpose in preference to the other two. This choice was made to reduce background noise and focus the microphone more narrowly, which helped to capture the acoustic qualities of the slenthem better.

It is important to remember that the intentional pickup pattern selection affects how we record and analyse the audio signal. In conclusion, research on the acoustic properties of slenthem plates has provided important information about their timbral qualities. Future research involving professional musicians with varying playing techniques may investigate the influence of performer expertise on recorded acoustic features to further understand and improve the reliability of the study. It is also advised to investigate how striking force and technique affect non-harmonic spectra.

There are also opportunities in virtual instruments for MIDI protocol-based music production, where knowledge of tuning sets other than musical characteristics could be useful in creating realistic virtual slenthem instruments. Integrating sophisticated recording techniques and spatial audio processing in acoustic and sonic investigations could offer a more precise portrayal of slenthem's acoustic attributes, enhancing the auditory experience in recorded and live contexts.

These recommendations are meant to serve as a roadmap for upcoming scholars and enthusiasts, encouraging the improvement of experimental methods and broadening the scope of slenthem research.

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Nomenclatures

dBu	Amplitude of sound
f	First partial
Abbreviations	
BAYU	Badan Budaya UNIMAS
FACA	Faculty of Applied and Creative Arts
FFT	Fast Fourier transform
TFA	Time-frequency analysis

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