Gambang: The Gamelan Wooden Xylophone

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This work investigated the ironwood used to construct a gambang, which is a traditional musical instrument. A gambang is constructed from a wooden bar with a similar thickness and width but a different length. The sound and established frequencies were compared with the equal tempered scale. The peak differed from the intended pitch and the partials were not always harmonic. This gambang only classified 4 octaves. The audio classification of the gambang was based on signal processing using a Picoscope oscilloscope. This article explains how wood is transformed into musical instruments. The findings revealed that the sound aspect and sound value of the wood keyboard instruments differed from the desired pitch. The third octave notes created C5, E5, E5, G5, and A5 instead of C5, D5, E5, G5, and A5, while the fourth octave pitch produced C6, D6, E6, G6, and A6# instead of C6, D6, E6, G6, and A6. Only the third and fourth octaves exhibited nearly flawless tuning for the gambang.

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INTRODUCTION

A gambang consists of wooden bars that sit on a wooden resonator. There are two arrangements of tone, *i.e.*, slendro and pelog. Slendro is comprised of five tones, 1, 2, 3, 5, and 6, whereas the pelog tone is arranged as 1, 2, 3, 4, 5, 6, and 7 (Radèn 1984). All complete double sets of gamelan instruments contain two gambang, one for slendro and one for pelog (Gitosaprodjo 1984). In addition, the gambang has a 3 to 4 octave register pitch (Vetter 1989). The octave based on note C, starts from octave 1 (C3 to C4), goes to octave 2 (C4 to C5), and then goes to octave 3 (C5 to C6). However, in some circumstances the octave is based on note E, starting from octave 1 (E2 to E3), going to octave 2 (E3 to E4), octave 3 (E4 to E5), and octave 4 (E5 to E6). One Javanese gamelan ensemble consists of 3 sets of gambang. One set is a slendro scale, and two sets are a pelog scale. A gambang is a wooden musical instrument like a xylophone (similar to the metallic ones of a typical metallophones). It has many bars of varying lengths that correspond to different pitches and produce a diverse frequency spectrum. The bars are often constructed of teak wood, though ironwood is sometimes used because it is a dense hardwood that is difficult to rot. Teak (*Tectona grandis*) is a tropical hardwood tree species in the family Lamiaceae. It is a large, deciduous tree that occurs in mixed hardwood forests. *Tectona grandis* has small, fragrant white flowers arranged in dense clusters (panicles) at the end of the branches. Ironwood is extremely strong and heavy, and it has been classified as a heavy hardwood with an air-dry density of 835 kg/m^3 to 1185 kg/m^3 (Wegst 2008). This timber is one of the most durable types in the world. However, the heartwood is extremely resistant to preservative treatment. Ironwood (*Eusideroxylon zwageri*) is a rare timber tree native to the Brunei, Indonesia, Malaysia and Philippines region. It is known colloquially in English as Bornean ironwood, billian, or ulin. Eusideroxylon zwageri grows in lowland primary and secondary forest up to 625 m altitude. It prefers well-drained soils, sandy to clay-loam, sometimes limestone. It is commonly found along rivers and adjacent hills. It requires an average annual rainfall of 2,500 to 4,000 mm. It occurs scattered or in groups. This very important tree is one of the most durable and heaviest timbers in the world. It is now threatened by over-exploitation, lack of regeneration and difficulties in cultivation

Ironwood is a decay-resistant wood that requires no pretreatment. It has a pleasing texture, grain pattern, and colour. The acoustic properties of wood are determined by the volume, quality, and colour of the sound. Since sound is produced by vibrations in the material, these attributes are determined by the mechanical properties of the material. The density, Young's modulus, and loss coefficient all play a role in the acoustic performance of a material. These parameters govern the speed of sound, the eigen frequencies of a wooden bar, and the intensity of the sound emitted. The most essential acoustical parameters in terms of selecting materials for sound applications are the speed of sound within the material, characteristic impedance, the sound radiation coefficient, and the loss coefficient. The speed of sound is defined as the product of the root of the Young's modulus of the material (E) and its density. This study examined and explained why ironwood is the chosen material for gambang bars, as well as why tropical species are preferred. The bars were set on a resonator with a deep wooden casing.

Gambang instruments normally have 17 to 21 keys that are held in place by a hole made by drilling. A pair of long thin mallets made of water buffalo horn and topped with felt are used to strike the bar. A gambang is played in parallel octaves; however, other styles of playing are employed, *e.g.*, playing two notes separated by two keys (Amin *et al.* 2017). Since wood does not ring, dampening is not required, as it is with metal keys. The gambang is notable for its fast tempo, contrasted timbre, and greater melodic range. The gambang plays a leading role in the creation of melodic patterns (Radèn 1984).

EXPERIMENTAL

Materials and Methods

Figure 1 shows the gambang bars sitting on their holder, which acts as a resonator. It is known to be representative of this type of instrument and available in the Faculty of Applied and Create Art, University Malaysia Sarawak.

Fig. 1. Gambang bars sitting on the resonator

As illustrated in Fig. 2, the microphone was held approximately 20 cm above the top surface along the axis of symmetry. The auditory signal produced by an expert player striking the instrument was recorded in this study. The audio signal was recorded in mono at a sample rate of 48 kHz and a resolution of 24 bits. The audio signal was recorded with the aid of a digital audio interface in a .wav format. To ensure the recorded audio signal was at the optimum level, audio signal calibration for the recording system was carried out. A test tone of a 1 kHz sine wave was used for calibrating the recording system. In this study, the ‘unity’ calibration level was at +4 dBu or -10 dBV and was read by the recording device at ‘0 VU’.

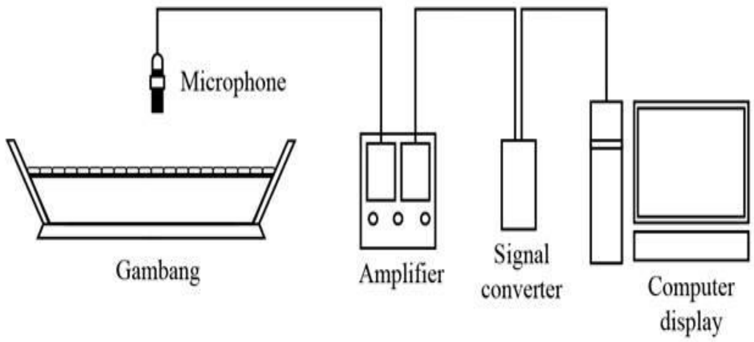

Fig. 2. Schematic diagram of the experimental setups

In this regard, the European Broadcasting Unit (EBU) recommended the digital equivalent of 0 VU. Thus, the test tone generated to the recording device of the experimentation was recorded at -18 dBFS (digital) or +4 dBu (analog), which is equivalent to 0VU. In this thorough calibration procedure, no devices were unknowingly boosted, or its amplitude attenuated in the signal chain at the time the recording was carried out. The recording apparatus was a Steinberg UR22 mkII audio interface, with an Audio-Technica AT4050 microphone, a XLR cable (balance), and a microphone position on an axis (less than 20 cm) and a microphone setting with a low cut (flat) 0 dB. PicoScope computer software (Pico Technology, 3000 series, Eaton Socon, United Kingdom) was used to view and analyze the time signals from the PicoScope oscilloscopes (Pico Technology, 3000 series, Eaton Socon, United Kingdom) and data loggers for real time signal acquisition. The PicoScope software enables analysis using Fast Fourier transform (FFT), a spectrum analyzer, voltage-based triggers, and the ability to save/load waveforms to a disk. The amplifier (Behringer Powerplay Pro XL, Behringer, China) ensured that the sound capture was loud enough to be detected by the signal converter. The resonance frequency in hertz of the wood bar was calculated using the length and width of the bar.

RESULTS AND DISCUSSION

The arrangement of the bars, consisting of the first, second, third and fourth octave, are as follows: C3, D3, E3, G3, and A3; C4, D4, E4, G4, and A4; C5, D5, E5, G5, and A5; and C6, D6, E6, G6, and A6, respectively. Figure 3 through Fig. 6 showed the spectrum of the first, second, third and fourth octave, respectively.

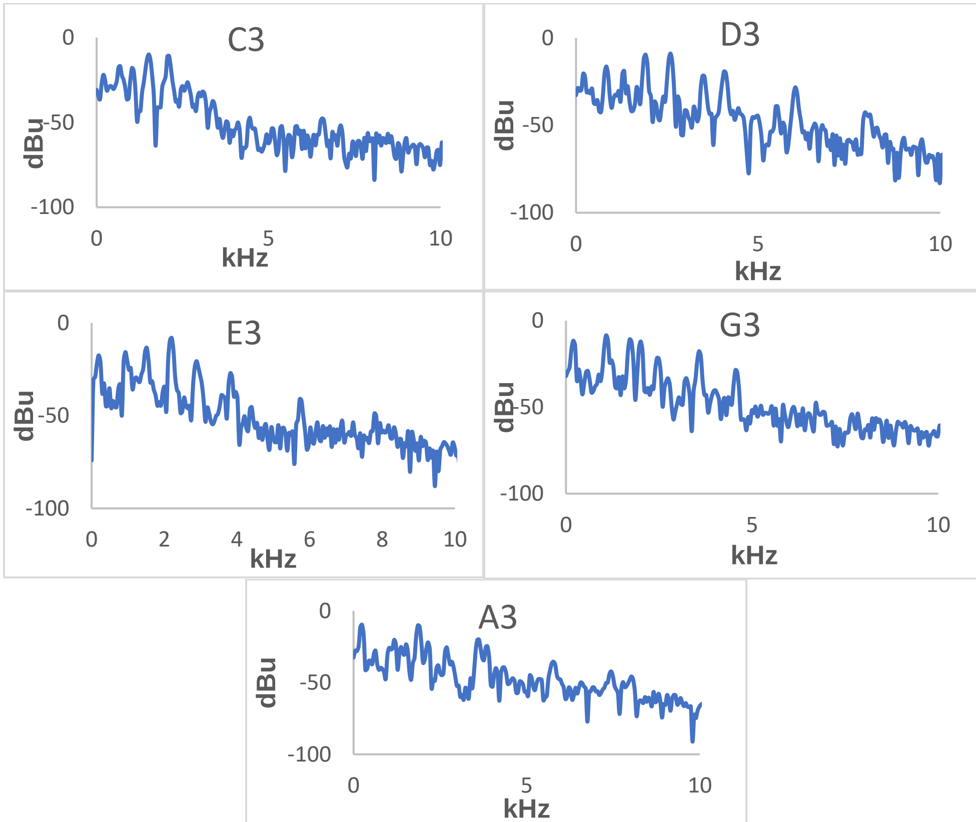

Fig. 3. Frequency spectrum of the first octave set (C3, D3, E3, G3, and A3)

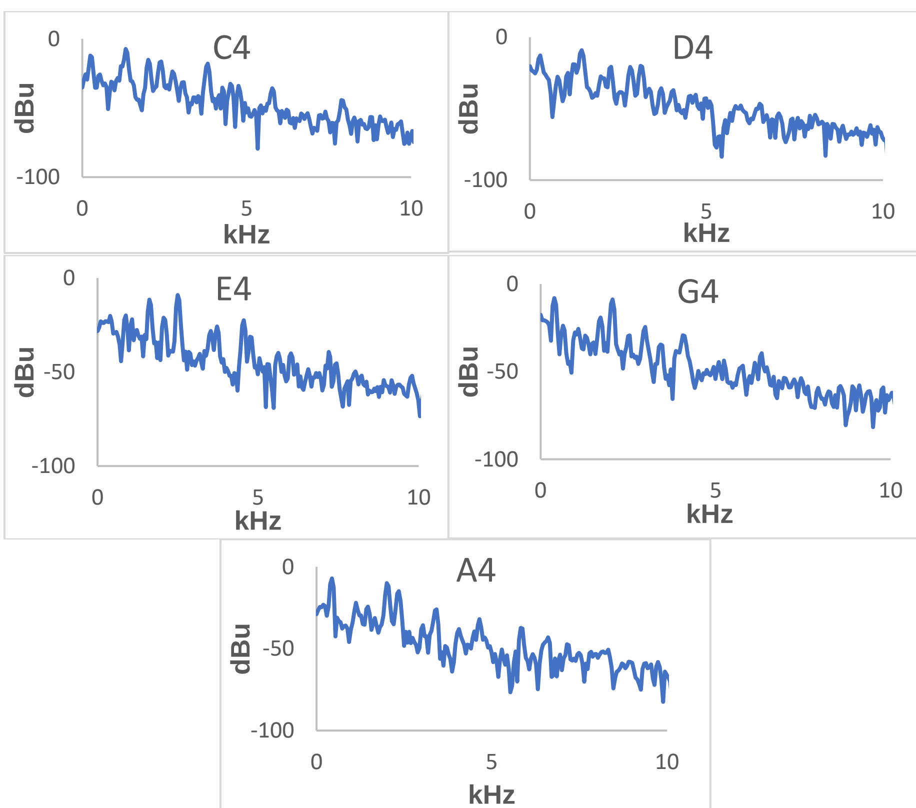

Fig. 4. Frequency spectrum of the second octave set (C4, D4, E4, G4, and A4)

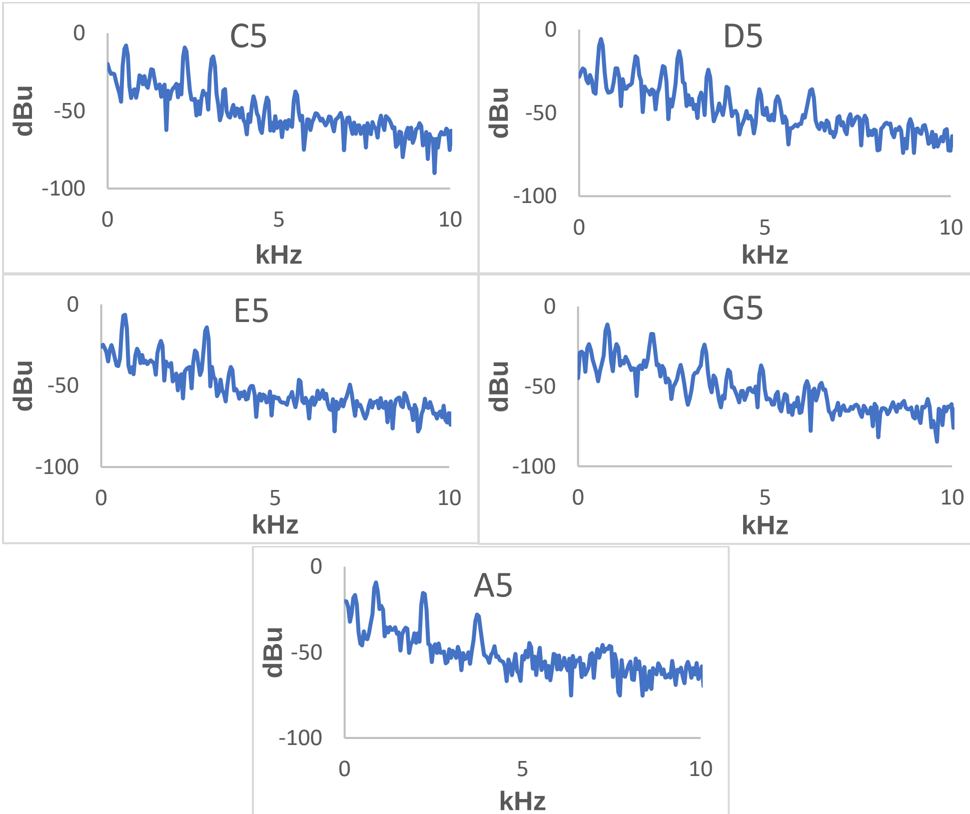

Fig. 5. Frequency spectrum of the third octave set (C5, D5, E5, G5, and A5)

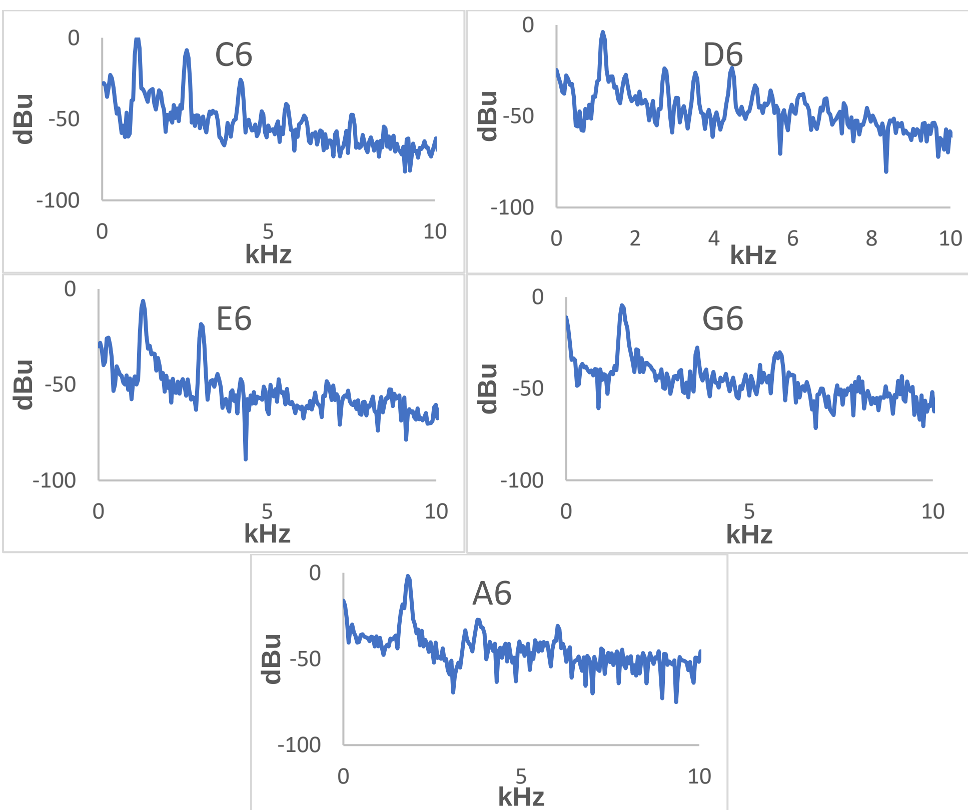

Fig. 6. Frequency spectrum of the fourth octave set (C6, D6, E6, G6, and A6)

The bar was trapezoidal in shape, with 'a' being the longer side and 'b' being the shorter side, 'c' being the width, and 'd' being the thickness. The node position was defined as the distance (e) between the holes made by with the nail. The spacing between the node positions determined the pitch of each note. Table 1 showed the arrangement of the bars from C3 to A6, the length (a and b) of the trapezoid, the width (c), thickness (d), distance (e) between the nail, and the frequency obtained from all the bars. The equal tempered scale (ETS) note beside the bar frequency is written as the equivalent pitch of the frequency obtained from the bar.

Table 1. Length (a and b), Width (c), Thickness (d), Distance (e) Between the Nail, and Frequency of All the Bars

Note (key)	*a* (mm)	*b* (mm)	*c* (mm)	*d* (mm)	*e* (mm)	Frequency (Hz) ETS Note
C3	57.70	55.80	7.10	0.92	30.8	196 G3
D3	55.80	54.20	7.02	1.05	30.2	244 B3
E3	54.20	52.50	6.82	1.10	29.5	146 D3
G3	52.30	50.70	6.78	1.16	28.9	244 B3
A3	50.80	49.20	6.72	1.52	28.2	299D4
C4	48.90	47.80	6.4	1.59	27.4	293 D4
D4	47.60	46.20	6.36	1.78	26.6	342 F4
E4	46.10	44.60	6.21	1.66	26.3	440 A4
G4	44.60	43.10	6.00	1.43	25.6	440A4
A4	43.10	41.60	5.75	1.57	24.7	440A4
C5	41.50	40.50	5.51	1.94	24.0	585 C5
D5	40.20	39.00	5.29	2.01	23.6	636 E5
E5	38.70	37.70	5.16	2.58	22.7	636 E5
G5	37.50	36.40	5.08	2.93	22.0	832 G5
A5	36.30	35.40	4.99	3.47	22.0	881 A5
C6	34.90	33.80	4.92	3.52	21.8	1026 C6
D6	33.70	32.60	4.78	3.86	21.7	1175 D6
E6	32.50	31.70	4.52	4.02	21.0	1322 E6
G6	32.00	31.00	4.35	4.22	20.3	1566 G6
A6	30.50	29.90	4.13	4.90	20.0	1860 A6#

As shown in Table 1, the first octave notes were G3, B3, D3, B3, and D4 instead of C3, D3, E3, G3, and A3, the second octave notes were D4, F4, A4, A4, and A4 instead of C4, D4, E4, G4, and A4, the third octave notes were C5, E5, E5, G5, and A5 instead of C5, D5, E5, G5, and A5, and the fourth octave notes were C6, D6, E6, G6, and A6#, instead of C6, D6, E6, G6, and A6. Since the fundamental frequencies obtained were not similar to the expected pitch of the bar, Table 2 was constructed to show the partials from every bar. Figure 7 through Fig. 10 showed the fundamental frequency and their partials from the first, second, third, and fourth octave set, respectively.

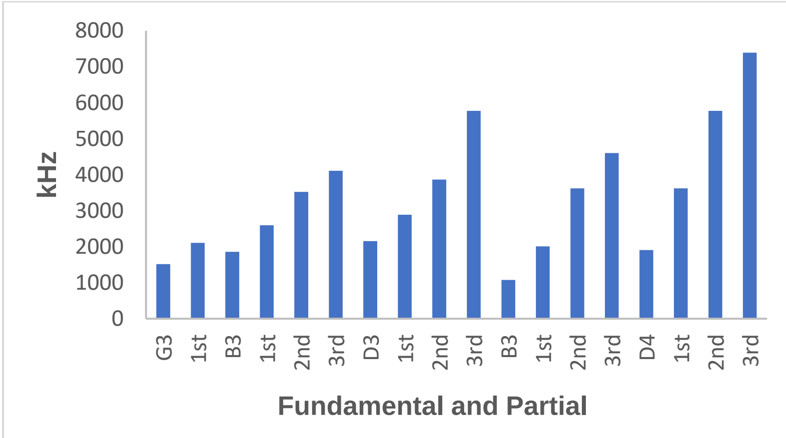

Fig. 7. The fundamental frequencies of the first octave set (G3, B3, D3, B3, and D4) and their partials (1st, 2nd, and 3rd harmonic)

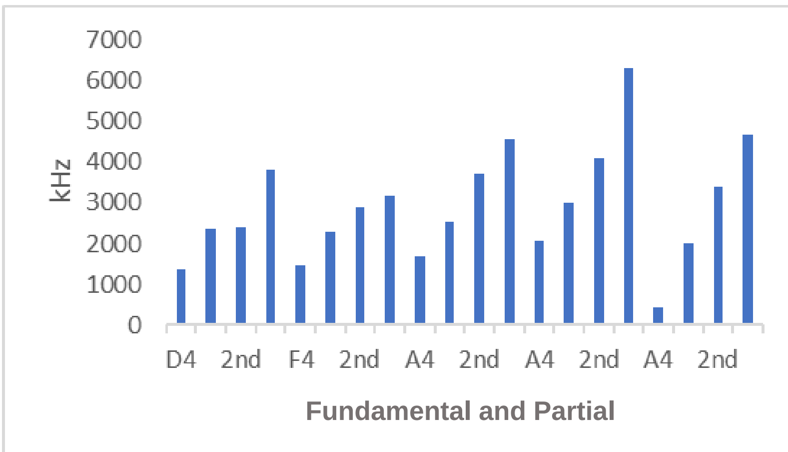

Fig. 8. The fundamental frequencies of the second octave set (D4, F4, A4, A4, and A4) and their partials (1st, 2nd, and 3rd harmonic)

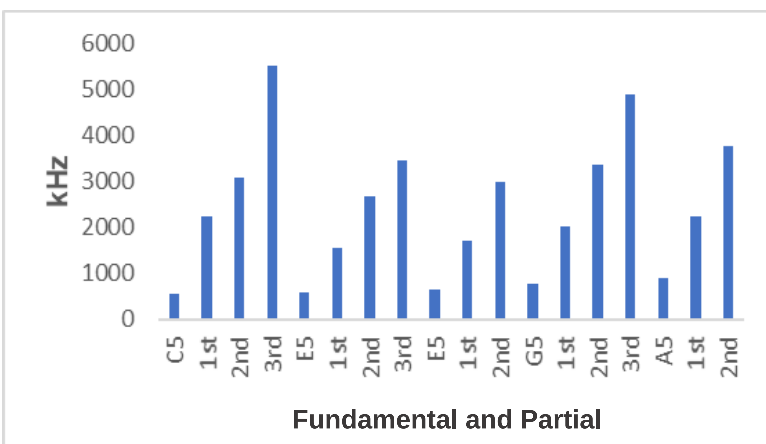

Fig. 9. The fundamental frequencies of the third octave set (C5, E5, E5, G5, and A5) and their partials (1st, 2nd, and 3rd harmonic)

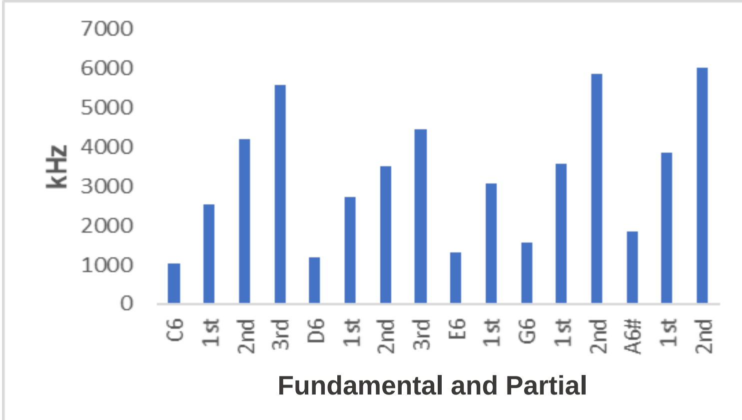

Fig. 10. The fundamental frequencies of the fourth octave set (C6, D6, E6, G6, and A6#) and their partials (1^{st}, 2^{nd}, and 3^{rd} harmonic)

Table 2. The Fundamental and Partial Frequencies (Hz) From the First, Second, Third and Fourth Octave Set

	First Octave	Second Octave	Third Octave	Fourth Octave
Fundamental (C3, C4, C5, C6)	196 G3	293 D4	538 C5	1028 C6
First harmonic	1517	1371	2252	2545
Second harmonic	2105	2349	3083	4209
Third harmonic	-	2398	5531	5580
Fourth harmonic	-	3818	-	1028
Fundamental (D3, D4, D5, D6)	244 B3	342 F4	636 E5	1175 D6
First harmonic	1860 A6#	1468	-	2741
Second harmonic	2594	2300	1566	3524
Third harmonic	3524	2888	2692	4454
Fourth harmonic	4111	3181	3475	1175
Fundamental (E3, E4, E5, E6)	146 D3	440 A4	636 E5	1322 E6
First harmonic	2154	1664	1713	3084
Second harmonic	2888	2545	2985	-
Third harmonic	3867	3720	-	-
Fourth harmonic	5776	4552	-	-
Fundamental (G3, G4, G5, G6)	244 B3	440 A4	832 G5	1566 G6
First harmonic	1076	2056		3573
Second harmonic	2007	2986	2007	5874
Third harmonic	3622	4111	3377	-
Fourth harmonic	4601	6315	4895	-
Fundamental (A3, A4, A5, 6A)	299 D4	440 A4	881 A5	1860 A6#
First harmonic	1909	2007	2252	3867
Second harmonic	3622	3377	3769	6021
Third harmonic	5776	4650	-	-
Fourth harmonic	7391	-	-	-

Although the first octave notes were G3, B3, D3, B3, and D4 instead of C3, D3, E3, G3, and A3 (as shown in Table 1), Table 2 showed that for the 1st bar there was a strong partial at 1517 Hz, *i.e.*, G6 1568 Hz. The first bar was meant to produce C3, but it turned out that the sound produced was G6. The second bar was meant to be D3, but a strong partial appeared at 1860 Hz, *i.e.*, A6# 1958 Hz. The third bar was meant to be E3, but a strong partial appeared at 2154 Hz, *i.e.*, C7 2093Hz. The fourth bar was meant to be G3, but a strong partial appeared at 1076 Hz, *i.e.*, C6 1046 Hz. The fifth bar was meant to be A3, but a strong partial appeared at 299 Hz, *i.e.*, D4 293 Hz. The notes of the first octave bars, *i.e.*, G3, B3, D3, B3, and D4, were sharper than the intended pitch, *i.e.*, C3, D3, E3, G3, and A3, where the first bar starts with G3 instead of C3.

The second octave notes were D4, F4, A4, A4, and A4 instead of C4, D4, E4, G4, and A4. As shown in Table 2, the strong partial that appeared at the first bar was 1371 Hz, *i.e.*, F6 1397 Hz, the second bar was 1468 Hz, *i.e.*, F6# 1480 Hz, the third bar was 1664, *i.e.*, G6# 1661 Hz, the fourth bar was 2056 Hz, *i.e.*, C7 2093 Hz, and the fifth bar was 440 Hz, *i.e.*, A4 440 Hz. The notes of the second octave bars, *i.e.*, D4, F4, A4, A4, and A4, were sharper than the intended pitch, *i.e.*, C4, D4, E4, G4, and A4, where the first bar starts with D4 instead of C4.

The third octave notes were C5, E5, E5, G5, and A5 instead of C5, D5, E5, G5, and A5. As shown in Table 2, the strong partial that appeared at the first bar was 538 Hz, *i.e.*, C5 523 Hz, the second bar was 636 Hz, *i.e.*, E5 659 Hz, the third bar was 636 Hz, *i.e.*,.E5 659 Hz, the fourth bar was 832 Hz, *i.e.*, G5 784 Hz, and the fifth bar was 881 Hz, *i.e.*, A5 880 Hz. The notes of the third octave bars, *i.e.*, C5, E5, E5, G5, and A5, were almost like the intended pitch, *i.e.*, C5, D5, E5, G5, and A5, except for the second bar, which was E5 instead of D5.

The fourth octave notes were C6, D6, E6, G6, and A6# instead of C6, D6, E6, G6, and A6. As shown in Table 2 the strong partial that appeared at the first bar was 1028 Hz, *i.e.*, C6 1047 Hz, the second bar was 1175 Hz, *i.e.*, D6 1175 Hz, the third bar was 1322 Hz, *i.e.*, E6 1319 Hz, the fourth bar was 1566 Hz, *i.e.*, G6 1568 Hz, and the fifth bar was 1860 Hz, *i.e.*, A6# 1865 Hz. The notes of the fourth octave bars, *i.e.*, C6, D6, E6, G6, and A6#, were like the intended pitch, *i.e.*, C6, D6, E6, G6, and A6, except for the fifth bar, which was A6# (one semitone higher) instead of A6.

Table 3 documents the difference in tone between the assigned note and the note measured during the studies. The first bar of the first, second, and third octave sets shown in Table 3 was 7, 2, and 5 semitones higher than the assigned pitch, respectively. The second bar of the first, second, and third octave sets was 9, 3, and 2 semitones higher than the intended pitch, respectively. The third bar in the first, second, and third octave sets was 2, 5, and 4 semitones higher than the intended pitch, respectively.

The fourth bar from the first and second octave set was 4 and 2 semitones higher than the intended pitch. The fifth bar from the first and fourth octave set was 5 and 1 semitones higher than the intended pitch. The observed notes that is the dominant vibrations were not true harmonics with partials.

Table 3. The Assigned Note, Measured Note, and the Tone Different Between the Intended Note and the Measured Note

Bar		1	2	3	4	5
First Octave	Assigned Note	C3	D3	E3	G3	A3
	Measured note	G3	B3	D3	B3	D4
	Tone difference	7s	9s	2s	4s	5s
Second Octave	Assigned Note	C4	D4	E4	G4	A4
	Measured note	D4	F4	A4	A4	A4
	Tone difference	2s	3s	5s	2s	-
Third Octave	Assigned Note	C5	D5	E5	G5	A5
	Measured note	E5	C5	C5	G5	A5
	Tone difference	5s	2s	4s	-	-
Fourth Octave	Assigned Note	C6	D6	E6	G6	A6
	Measured note	C6	D6	E6	G6	A6#
	Tone difference	-	-	-	-	1s

CONCLUSIONS

1. The gambang should register 3 to 4 octave pitches. The octave based on note C starts at octave 1 (C3 to C4), then goes to octave 2 (C4 to C5), and octave 3 (C5 to C6), whereas the octave based on note E starts from octave 1 (E2 to E3), then goes to octave 2 (E3 to E4), octave 3 (E4 to E5), and octave 4 (E5 to E6).
2. The gambang used in this study registered the first octave notes as G3, B3, D3, B3, and D4 instead of C3, D3, E3, G3, and A3. The second octave notes were D4, F4, A4, A4, and A4 instead of C4, D4, E4, G4, and A4. The third octave notes were C5, E5, E5, G5, and A5) instead of C5, D5, E5, G5, and A5. The fourth octave notes were C6, D6, E6, G6, and A6# instead of C6, D6, E6, G6, and A6.
3. For the first octave notes, the strong partials that appear at the first, second, third, fourth, and fifth bars were F6, F6#, G6#, C7, and A4, respectively.
4. For the second octave notes, the strong partials that appear at the first, second, third, fourth, and fifth bars were F6, F6#, G6#, C7, and A4, respectively.
5. For the third octave notes, the strong partials that appear at the first, second, third, fourth, and fifth bars were C5, E5, E5, G5, and A5 instead of C5, D5, E5, G5, and A5, respectively.
6. For the fourth octave notes, the strong partials that appear at the first, second, third, fourth, and fifth bars were C6, D6, E6, G6, and A6# instead of C6, D6, E6, G6, and A6, respectively.
7. Only the third and fourth octave showed almost perfect tuning for the gambang
8. From Table 2 the partial does not reflect true harmonic and overtones present from the sound produce d from the gambang

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