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Design and Assessment of a harmonic model for sound timbre of *Gmelina arborea* (Roxb) wood

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ABSTRACT

Wood is a fibrous tissues which has been known to produce sound by direct striking, and can amplify or absorb sound waves originating from another bodies. More reason it is being used as a musical instruments. Pitch, amplitude and timbre are the major characteristics of sound. Timbre forms the quality of a sound, and there can be a harmonic/inharmonic timbre. However, there is still no known scientific means to determining the harmonic of a timbre common to practitioners. This study therefore helped to proffer a solution. The objective of this study is to design and assess a model suitable for determining harmonicity of a timbre of sound of *G.arborea* wood. Three trees of G.arborea were fell and samples of 20 x 20 x 300 mm^3 were collected from the wood axially (top and base) and radially (inner and outer). It has already been identified by scholars that for a timbre to be harmonic, all natural frequencies must be in arithmetic progression with each other. Thus, it was on this assertion that the model used for this study was designed statistically, ranging from 0 (perfect harmonic) – 1 (imperfect harmonic). Wood samples were suspended after which it was hit by a hammer at one end, and each sound's natural frequencies were recorded using FFT on the other end. Hence, harmonics of sounds timbre were calculated. Top wood and outer wood had the lowest values axially (0.45) and outer wood (0.47) respectively, while mean value for harmonicity of sound of *G.arborea* wood was 0.5. Therefore, sound of *G.arborea* wood has a fair harmonic sound. This study recommends the use of this model to be tested on other wood species too so it can provide us with a standard value with which to consider a wood good harmonically. Also, it recommends this model for other musical instruments such as paino, guitar and talking drum.

Keyword: timbre, *G.arborea* wood, harmonic, model, sound, musical instrument

INTRODUCTION

Wood is a hard, fibrous tissue found in many trees, which has been used for thousands of years for both domestic and industrial purposes **(**Hickey, 2001**).** Wood can produce sound (by direct striking) and can amplify or absorb sound waves originating from other bodies. When sound waves of extrinsic origin strike wood, they are partly absorbed and partly reflected, and the wood is set in vibration. For these reasons, it is a unique material instruments and other acoustic applications. Some wood are acoustic in nature and has the ability to produce sound effect. Because of this unique property, wood in itself is used as musical instrument such as bamboo slit drum, wood block, and also in the production of a number of musical instruments such as guitar, violin, piano, xylophone and percussion.

The three major characteristics of sound are pitch, amplitude (loudness) and timbre (quality). The pitch of a sound is literally dependent on the frequency of the sound, and the amplitude of a sound depends greatly on its intensity which is a function of the sound energy and surface area (Tsoumis, 1991). Both pitch and amplitude can be measured by Fast Fourier Transform (FFT), and variation can be easily perceived by listeners.

Meanwhile, timbre is a function of the fundamental frequencies and overtones (Jeffery, 2003). As stated by Winckell, (1967) and reported by Nave, (2017), timbre is mainly determined by the harmonic content of a sound. It should be noted that all sound frequencies (both fundamental and overtones) generated by a material is known as the natural frequencies of that material. Unlike pitch and amplitude of sound which a listener can easily identify with its variation or which its measurement can be done by FFT, the harmonicity of a sound is yet to be easily ascertain by listeners, or through a scientific approach common to practitioners, thus remains a challenge. Consequently, they rely on the listening prowess and perception of supposed experts to determine whether a sound is harmonic or not thereby causing variation and disparity of results, hence, disagreement and fiasco among practitioners.

Since many music practitioners do not have a scientific approach to determining the harmonic of sound timbre generated from wood and other musical instruments, there is a need to develop a form of scientific approach such as a model, equation, formula, software application etc. that will help to reduce reliance on listening prowess of supposed experts to determine sound harmonic, and in turn put an end to fiasco among music practitioners. The objective of this research study is to design a harmonic model, and assess its potential to determining the harmonicity of timbre of the sound of *G.arborea* wood.

The wood of *Gmelina arborea* is considered as one of the most widely cultivated and distributed exotic species in Nigeria and many people have benefited from the wood. More so, social survey revealed that based on indigenous knowledge, *G. arborea* is a choice species for acoustic purpose. Thus, informing the choice of test species for this study.

MATERIALS AND METHOD

Sample Collection and Preparation

Three trees of *G. arborea* with 25 ± 2cm in diameter at breast height (DBH) were obtained from Gambari Forest Reserve. From each tree, bolts of 60cm in length were collected from top and base, from which wood samples of $20 \times 20 \times 300\, mm^3$ (R x T x L) were collected from inner and outer of the sampling height for the assessment of the timbre model.

Design of timbre model

According to Physics classroom, (2015), values of fundamental frequency and its overtones (subsequent frequency) are expected to be in an arithmetic progression with each other to give a perfect harmonic sound. Therefore, it was concluded that the more the natural frequencies in a timbre of a material/musical instrument deviates from an arithmetic progression, the more inharmonic the sound becomes. It was based on this assertions that a mathematical model was designed to take into consideration perfect/imperfect arithmetic progression of the natural frequencies of a sound timbre, thus, eq. 1. This model revealed the harmonicity of a sound timbre on the scale of 0-1 where resulting value of 0 is considered perfect harmonic and 1 considered imperfect harmonic.

$$\sum_{\substack{i=1 \\ j=2}}^{n} \left| \frac{f_j - f_i}{\sum_{\substack{i=1 \\ j=2}}^{n} \left(f_j - f_i\right)} - \frac{1}{n-1} \right| \qquad (1)$$

Where

i = 1, 2… n

j = 2, 3…n

f = natural frequency

n = number of frequency observation (≥ 4)

Assessment of the timbre model

The experiment was set up as shown in fig. 1, and it was conducted in an enclosed silent room at room temperature. This is to ensure that no external sound interferes during the course of the experiment. Having ensured a total silence, and the FFT analyzer showing no sign of sound signal, the wood samples were hit with a hammer at one end and the FFT software was used to read the natural frequencies of the sound produced at the other end. However, Nave (2007) pointed out that relative intensity of the upper harmonic (natural frequencies) present in a sound contributes to a sustained tone. Therefore, only natural frequencies with amplitude of at least 1/3 of the amplitude of resonance frequency were considered for the sound harmonic analysis. This is because frequencies with amplitude lower than 1/3 of the amplitude of the resonance frequency will not be easily perceived by listeners, and as such is insignificant.

Furthermore, number of observation (n) of the natural frequencies generated ranges from 3 to 7. Thus, analysis of variance was first done to test for significance, so as to recommend how many number of observation is best suitable for adoption in this model.

Consequently, appropriate natural frequencies and number of observations were selected, then harmonicity of the sounds timbre were done using the harmonic model, thus assessing the potentiality of the model.

The mathematical model was thus,

$$Yij = \mu + Ti + \beta j + Eij \qquad (2)$$

Yij = Observation

μ = Mean

Ti = Treatment (sampling height)

Bj = Block (radial position)

Eij = Error term

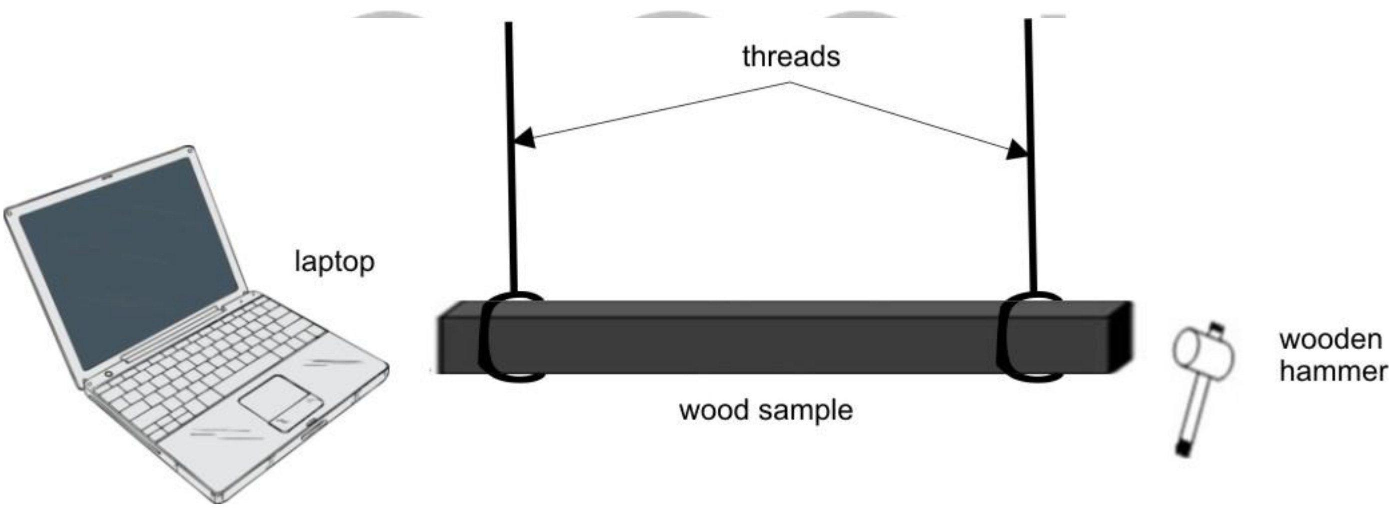

Fig. 1: The set-up of longitudinal free vibration test

RESULTS AND DISCUSSION

Table 1 and 2 shows the timbre harmonics of sound of *G.arborea* wood with respect to number of observation (n) and its analysis of variance respectively while Table 3 revealed the post-hoc test of the analysis. Notwithstanding, the trend of the harmonics with respect to number of observations was represented in Figure 1. Meanwhile, Table 4 shows the timbre harmonics of sound of *G.arborea* wood along selected axial and radial position, and Table 5 shows the analysis of variance of the samples sound harmonics.

From Table 1, harmonics of 3 observations had the least mean value of 0.13 while harmonics of 7 observations had the highest mean value of 0.65. Since the model used to determining the harmonics of the timbre of the sound measures on a scale of 0-1, 0 being perfectly harmonic and 1 being imperfectly harmonic, thus, timbre of sound of *G.arborea* wood with 3 frequencies is more harmonic than its timbre of 7 frequencies. Notwithstanding, an analysis of variance was need to affirm this statement.

In similar vein, the relatively upward trend of harmonic values with respect to number of observations done in Figure 1, and the significant difference in post-hoc test for n=3 implies that the more the number of observation of a particular *G.arborea* wood the lesser the chances of the timbre having a harmonic sound. That is, a timbre containing only 3 frequencies will be more harmonic than a timbre having 7 frequencies. However, this may not be correct for other material and musical instruments.

As highlighted by Nave (2007), numbers of natural frequencies in the timbre of a sound are contributory to a sustained tone. Also from the analysis conducted, only timbre with three frequencies was significantly separate from others, this shows that n = 3 is not in agreement with others. Therefore, though, number of observation of 3 may have had the best harmonic sound, it cannot be said to have a sustained tone. For this reason, having a timbre of sound containing only 3 frequencies is not suitable for this model. However, since harmonics of timbre with 4, 5, 6 and 7 frequencies were not significantly different from each other, then this study considered them suitable for the model, and as such $n \geq 4$ was adopted for use in this model.

Having done an assessment of this model on *G.arborea* wood, outer wood of top wood had the least value of 0.41 and inner wood of base wood had the highest value of 0.57. Therefore, the mean harmonic value for timbre of sound of *G.arborea* wood was 0.5.

Axially, sound of top wood is more harmonic than base wood, and outer wood had a better harmonic sound than inner wood owning to their closeness to 0. This implies that top wood and outer wood of *G.arborea* wood was the best suitable for musical purposes whether as a musical

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instrument such as balafon and wood block, or as a material for constructing musical instrument such as the talking drum.

With the value of harmonic of sound from *G.arborea* wood at mid-point, it cannot be concluded whether the wood species is suitable as musical instrument or not. since this study is preliminary, it thus suggest a further study into other wood species so as to enable us determine a standard value of sound harmonic with which a wood sample will certify good for acoustic purposes in relation to its timbre harmonic. Notwithstanding, other indices of acoustic is also essential if a wood is to be recommended for acoustic purposes.

Table 1: Timbre harmonics of sound of *G. arborea* wood with respect to number of observation

	Number of Observation				
	3	4	5	6	7
Replicate 1	0.12	0.49	0.42	0.53	0.8
Replicate 2	0.16	0.6	0.56	0.67	0.79
Replicate 3	0.1	0.25	0.46	0.64	0.36
MEAN	**0.13**	**0.45**	**0.48**	**0.61**	**0.65**

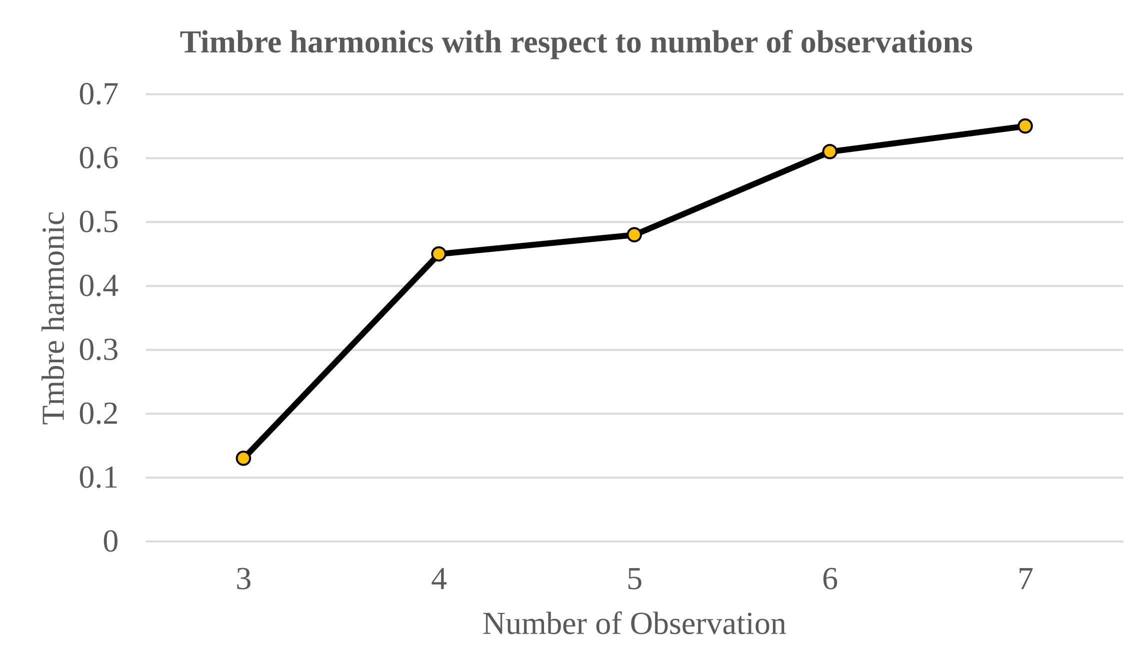

Fig 2: Trend of timbre harmonics with respect to number of observations

Table 2: Analysis of variance (ANOVA) for Number of observations of timbre harmonic

Source	Sum of Squares	df	Mean Square	F	P-Value
No. of observations	0.51	4	0.13	6.02	0.01*
Error	0.21	10	0.02		
Total	3.95	15			

***** **-** significant at $P \leq 0.05$ ns – not significant

Table 3: Post-hoc test for ANOVA for Number of observations of timbre harmonic

No. of Observation	N	Subset	
		1	**2**
3	3	0.13	
4	3		0.45
5	3		0.48
6	3		0.61
7	3		0.65
Sig.		1.000	0.14

Table 4: Timbre harmonics summary of sound of *G.arborea* wood

	Top wood	Base wood	**Mean**
Inner wood	0.49	0.57	**0.53**
Outer wood	0.41	0.53	**0.47**
Mean	**0.45**	**0.55**	**0.50**

Table 5: Analysis of Variance of timbre harmonics of sound of *G.arborea* wood

S/V	Sum of Squares	df	Mean Square	F	P-Value
axial	0.03	1	0.03	1.15	0.32 ns
radial	0.01	1	0.01	0.34	0.57 ns
axial * radial	0.00	1	0.00	0.03	0.87 ns
Error	0.22	8	0.03		
Total	3.29	12			

*** -** significant at P ≤ 0.05 ns – not significant

CONCLUSION AND RECOMMENDATION

This study has successfully design a harmonic model which was assessed on *G.arborea* wood, and it was considered suitable for determining the harmonicity of a timbre of sound. meanwhile, it was as well observed to be suitable for use for musical instruments such as piano, guitar, talking drum etc. from the afore-mentioned, this model is therefore recommended for determine harmonic of sound of wood and other musical instruments.

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