Vibro-acoustic characterization of Angklung bamboo tube

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Abstract. Angklung is one of the most popular Indonesian traditional bamboo musical instruments. In this paper, bamboo tubes were harvested from West Java, which were sorted and crafted by an angklung-maker maestro. This paper is focused on finding the correlation of those bamboo tubes both in acoustic characteristic and mechanical vibration. There are three data that are measured simultaneously: force from the exciting impact hammer, normal acceleration from accelerometer, and sound pressure from a microphone. Accordingly, bamboo tubes’ mechanical admittance and acoustic sound pressure level was calculated. In terms of frequency response, it was found that the admittance and SPL of each tube are well correlated. All of the tubes have inharmonic frequency overtones with the first overtone 2.17 times higher than its fundamental frequency.

1. Introduction
Bamboo is a kind of plants that easy to find in Indonesia. It has been used in various ways including as material for traditional musical instruments. When it comes to traditional musical instrument and bamboo, Indonesians will surely mention the idiophone of angklung as this instrument is very popular. It is usually made of two bamboo tubes, which one is tuned an octave higher than the other one, bound in a bamboo frame as depicted at Figure 1. Each of the tubes has unique shape as they seem like a tube with a tongue at its opening. People play angklung mostly in a group and each member rattles their notes in turn.

Figure 1. Illustration of an angklung.

The basic acoustic and vibration properties of bamboo has been generally described and compared to other wood [1], [2]. Researchers also have determined some acoustical characteristics of angklung. From empirical experiment, Zaina [3] determined angklung’s fundamental frequency from its length.
and diameter of the air resonator with an overtone at 2.45 times of the fundamental frequency. Sudarsono and Merthayasa [4] have made remarkable findings about angklung as they made complete analysis including spectral, temporal, and spatial characteristics of angklung. In terms of overtones, their conclusion does not agree with Zainal’s as they stated $1.44\omega$, $2\omega$, $3.47\omega$, $6.31\omega$ and $7\omega$ with $\omega$ for the fundamental frequency. Despite of different overtones pattern, both researches agree that angklung has inharmonic overtones. Inharmonic is the opposite term of harmonic, which overtones are integer’s multiplication of the fundamental frequency.

This paper explains the vibration feature of angklung bamboo tube and its relation to the acoustical radiation in frequency domain. It is expected that this paper gives appropriate guidance for angklung maker in the future.

2. Methods

There were 10 angklung bamboo tubes tuned at note A4 440 Hz and 8 tubes tuned at note A5 880 Hz, an octave higher. All of these tubes were made of temen hitam bamboo (Gigantochloa Atroviolacea Widjaja), which is known as the best material for making angklung [5], from Sukabumi and Majalengka, West Java, Indonesia. Handiman Diratmasasmita, who is acknowledged as angklung maker maestro, carefully crafted all the tubes so that these could be a benchmark as favorable angklung tubes.

Each tube was hung by a rope through its hole at the tongue to imitate free-free boundary condition. The excitation was done by striking the lower edge of tube with an impact hammer. The tip of the hammer was hardened plastic to provide broadband frequency impulse. An accelerometer was glued at the other side and measured the vibration response of the tube normal to the tube surface. The measured both force and acceleration are collected by an oscilloscope with sampling frequency of 10,000 Hz. Simultaneously, a flat-response omnidirectional microphone with a distance of 1 m from the tube in the same direction of the accelerometer recorded the radiated sound pressure. The audio frequency sampling was 44,100 Hz. The experiment set, including the impact point and the position of the accelerometer, is illustrated at Figure 2. The measurement repeated 5 times for each tube. All of the measurements have been done in an anechoic chamber to avoid any acoustical distortion due to room surface reflection.

3. Results and Discussion

All of the discussions in this subtopic are in scope of spectral parameter. Thus, all of the measured data had to be transformed into frequency domain by DFT with FFT algorithm. The acceleration data were integrated into velocity and divided by the force data so that yielded mechanical admittance. The pressure data were just converted into SPL. Then, 5 data of each tube were averaged. The FFT size for both admittance and SPL was $2^{14}$ so that the frequency sensitivity is 0.6 Hz for admittance and 2.9 Hz for SPL.
Some of all the results from tubes tuned at 880 Hz can be found at Figure 3 as well as tubes tuned at 440 Hz are at Figure 4. All of the remaining results are tabulated at Table 1 for tubes tuned at 880 Hz and Table 2 for tubes tuned at 440 Hz. First to take note is admittance peak located near 4000 Hz in each graphs is occurred due to the unknown filtering effect of the impact hammer electrical instrument, and nothing to do with the tube vibration characteristic. This frequency dip of the impact hammer that took place in each measurement as can be seen in Figure 5.

Table 1. Peak frequency of angklung bamboo tube tuned at 880 Hz.

| Tube Label | f0    | f1    | f2    | f3    | f4    | f5    | f6    | f7    |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1a         | 881.8 | 81.17 | 1916  | 57.36 | 2194  | 49.59 | -     | -     | 888.3 | 0.6426 |
| 2a         | 881.8 | 70.34 | 1881  | 47.75 | 2180  | 38.16 | -     | -     | 877.3 | 0.5230 |
| 3a         | 878.9 | 75.38 | 1843  | 44.88 | 2121  | 51.27 | 2581  | 41.80 | 890.0 | 1.100  |
| 4a         | 878.9 | 74.36 | 1986  | 50.75 | -     | -     | -     | -     | 865.7 | 0.1885 |
| 5a         | 878.9 | 66.05 | -     | -     | 2051  | 45.36 | -     | -     | 884.7 | 2.532  |
| 6a         | 884.8 | 63.78 | -     | -     | 2051  | 45.36 | -     | -     | 890.8 | 0.6540 |
| 7a         | 878.9 | 71.45 | 1904  | 42.50 | 2136  | 52.80 | -     | -     | 889.5 | 1.017  |
| 8a         | 878.9 | 71.45 | -     | -     | 2083  | 42.27 | 2525  | 38.49 | 884.7 | 0.847  |

Table 2. Peak frequency of angklung bamboo tube tuned at 440 Hz.

| Tube Label | f0    | f1    | f2    | f3    | f4    | f5    | f6    | f7    |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1b         | 439.5 | 78.23 | 919.9 | 48.64 | 1148  | 58.25 | 1269  | 52.26 | 1781  | 42.94  |
| 2b         | 439.5 | 77.10 | 940.4 | 42.40 | 1128  | 49.34 | 1277  | 43.33 | 1781  | 37.06  |
| 3b         | 436.5 | 69.79 | -     | -     | 1163  | 53.85 | 1254  | 49.50 | 1875  | 36.97  |
| 4b         | 439.5 | 74.68 | -     | -     | 1189  | 55.71 | -     | -     | -     | -      |
| 5b         | 439.5 | 76.38 | 966.8 | 36.01 | 1125  | 47.83 | -     | -     | 1781  | 36.10  |
| 6b         | 439.5 | 73.16 | 960.9 | 39.66 | 1116  | 50.00 | 1271  | 50.11 | 1849  | 49.55  |
| 7b         | 442.4 | 76.01 | -     | -     | -     | -     | -     | -     | 1233  | 63.27  | 1682  | 43.81  |
| 8b         | 442.4 | 78.34 | -     | -     | -     | -     | -     | -     | 1213  | 57.17  | 1857  | 45.00  |
| 9b         | 445.3 | 78.83 | 1014  | 43.08 | -     | -     | -     | -     | 1216  | 56.15  | 1875  | 42.54  |
| 10b        | 439.5 | 77.92 | -     | -     | -     | -     | 1157  | 60.63 | 1266  | 54.85  | 1720  | 43.73  |

Table 3. Frequency (Hz)/ Admittance Peak (m/N.s).

| Tube Label | f0    | f1    | f2    | f3    | f4    | f5    |
|------------|-------|-------|-------|-------|-------|-------|
| 1b         | 440.8 | 0.7239| -     | -     | 1132  | 0.0557|
| 2b         | 440.2 | 0.6023| 933.6 | 0.0237| 1118  | 0.0735|
| 3b         | 432.0 | 1.179 | -     | -     | -     | -     |
| 4b         | 443.9 | 0.8449| -     | -     | 1185  | 0.5568|
| 5b         | 448.1 | 1.500 | -     | -     | 1120  | 0.2590|
| 6b         | 438.4 | 1.274 | -     | -     | -     | -     |
| 7b         | 444.5 | 0.8989| -     | -     | -     | 1245  | 0.2115|
| 8b         | 440.2 | 0.6696| -     | -     | -     | 1208  | 0.1477|
| 9b         | 440.2 | 0.4553| -     | -     | -     | 1225  | 0.0203|
| 10b        | 437.1 | 0.9339| -     | -     | 1146  | 0.2347|

All of the fundamentals frequencies of each tube are laid in the frequency where they were tuned for, both around the 440 Hz and the 880 Hz. In addition, all of the fundamental frequencies have the highest both SPL and admittance compared to the overtones. It indicates strong correlation between the vibration response and the radiated sound pressure in terms of frequency and magnitude.

In contrast of being able to spot on easily, the overtones were defined subjectively by the peak’s figure of merit. For example, the SPL peak around 900 Hz in tube 2b can be clearly seen so that we mark it...
as an overtone (see Figure 4); while it is hard to define the SPL peak throughout frequency area in tube 7b. The admittance graphs are a bit noisy so an overtone is marked by a small hump with less noise in its vicinity; not merely marked by a single frequency spike. SPL peaks and admittance peaks in overtones, specifically at 440 Hz tubes, also marked at similar frequency as it support the strong correlation between vibration and sound pressure.

\[ \text{Figure 3. SPL and admittance of angklung bamboo tube tuned at 880 Hz labelled as (a) 3a and (b) 7a.} \]

\[ \text{Figure 4. SPL and admittance of angklung bamboo tube tuned at 440 Hz labelled as (a) 2b and (b) 7b.} \]
Figure 5. Force magnitude frequency spectrum from the measurement of tubes tuned at (a) 880 Hz and (b) 440 Hz.

For the 880 Hz tuned tubes (see Table 1), generally there are three overtones in the SPL results while no overtones can be observed in the admittance results. Theoretically, admittance shall be obtained even if the mechanical system was excited with small force or vibrating in the slightest displacement. In reality, small force or acceleration signal could have the same magnitude with the noise thus some of the admittance peaks cannot be distinguished. Moreover, the higher the overtones’ frequency, the weaker the magnitude would be, hence only the admittance peaks of the fundamental frequency of each tube are observable. From the SPL results, the first and second overtones are quite high in the value, up to 50 dB. In the other hand, the third overtone is barely occurred with only two tubes define this overtone. Taking account these three overtones, the overtones frequency pattern is around $f_0; 2.17f_0; 2.42f_0; 2.90f_0$.

Overtones for the 440 Hz tune tubes (see Table 2) are more observable with four overtones for the SPL results and three overtones for the admittance results. It is interesting that the first overtone at around 960 Hz are barely occurred and have smaller magnitude, both SPL and admittance, compared to the second and third overtones. The second and third overtones are located respectively at around 1140 Hz and 1240 Hz. The admittance peaks of each tube at the fourth overtones are no longer recognized from the graphs while the SPL peaks are still perceivable at around 1800 Hz. The overtones frequency pattern for this 440 Hz tubes is around $f_0; 2.17f_0; 2.60f_0; 2.83f_0; 4.09f_0$.

It is interesting that the results of bamboos with two different fundamental frequencies share the same multiplication number 2.17 for the first overtone. The correlation may indicate the criteria of good angklung tube. In the other hand, the second overtones and above it have different number. Another thing to be concern about is overtones pattern found in this experiment doesn’t agree with the findings of Zainal [3] nor Sudarsono and Merthayasa [4].

4. Conclusion
In angklung bamboo tube, vibration and radiated sound have strong correlation. Both peaks from SPL and admittance are located at the similar frequency and have the same magnitude profile, with the highest at the fundamental frequency. The first inharmonic overtone of angklung tube is found at 2.17 $f_0$, with $f_0$ as the fundamental frequency. The second overtones and above are spot on different multiplication factor while still maintaining the inharmonic characteristic.

More angklung bamboo tube samples are needed so that the measured characteristic can represent angklung in general. The explanation of why tubes with same fundamentals frequency can have varying inharmonic patterns will be discussed in the future paper. The factors that affect overtones shift will be described as it will be very useful for making precise timbre of angklung bamboo tube.
5. References

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