Numerical Tension Adjustment of X-Ray Membrane to Represent Goat Skin Kompong

M Syiddiq¹, W A Siswanto²
¹,²Faculty of Mechanical Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
¹cdix91@gmail.com, ²waluyo@uthm.edu.my

Abstract. This paper presents a numerical membrane model of traditional musical instrument kompong that will be used to find the parameter of membrane tension of x-ray membrane representing the classical goat-skin membrane of kompong. In this study, the experiment towards the kompong is first conducted in an acoustical anechoic enclosure and in parallel a mathematical model of the kompong membrane is developed to simulate the vibration of the kompong membrane in polar coordinate by implementing Fourier-Bessel wave function. The wave equation in polar direction in mode 0,1 is applied to provide the corresponding natural frequencies of the circular membrane. The value of initial and boundary conditions in the function is determined from experiment to allow the correct development of numerical equation. The numerical mathematical model is coded in SMath for the accurate numerical analysis as well as the plotting tool. Two kompong membrane cases with different membrane materials, i.e. goat skin and x-ray film membranes with fixed radius of 0.1 m are used in the experiment. An alternative of kompong’s membrane made of x-ray film with the appropriate tension setting can be used to represent the sound of traditional goat-skin kompong. The tension setting of the membrane to resemble the goat-skin is 24N. An effective numerical tool has been used to help kompong maker to set the tension of x-ray membrane. In the future application, any traditional kompong with different size can be replaced by another membrane material if the tension is set to the correct tension value. The numerical tool used is useful and handy to calculate the tension of the alternative membrane material.

1. Introduction
Traditional musical instruments are unique and special which not only producing sounds but also representing the cultural value of a certain region [1]. Some research works for the traditional musical instruments have been done such as tampani [2], wadaiko [3], angklung [4], kantele [5], also gong and cymbals [6]. Those traditional musical instruments and percussions have been investigated in various aspects by researchers, some derived the mathematical models to represent the vibration characteristics. A report on related to kettledrums has been documented by [7]. For snare drums are found in [8] and [9]. There is also a report on sound reproduction of traditional musical instruments such as reproduction of kompong sound [10].

The kompong model defined in this this paper is the traditional percussion instrument found in Johor, Malaysia. There are only two interacting components: a membrane and a rigid shell for constraining the membrane (See Figure 1). The membrane of the kompong is fixed to the wood shell firmly. The incorrect placement of the membrane to the shell may cause a false sound characteristic
Kompang has various sizes, normally having a radius in between 22 cm and 35 cm. The height of the frame is in between 4 cm and 6 cm [1], while tom-toms are generally smaller [11].

A tap on kom pang can cause displacements of several millimeters along with many modes can be formed by membranes where different modes tend to give a different vibration attribute [12].

In this study, musical instrument kom pang is used to produce a numerical equation. The musical instruments are generally categorized by the musical instrument type whether string, drum or flute type, with based on its physical frameworks [6]. This is supported by [13] which stated that different type of musical instrument have distinctive characteristic which becomes its trademark thus requiring different type of physical modeling analysis. By dissecting and analyzing the component of the musical instrument, more information about that particular musical instrument styles and characteristic can be obtained for better musical instrument data and information for documentation [14].

By dissecting the components, the physical framework of the musical instrument kom pang, are found to be almost identical to the framework of the snare drum [6] and the timpani drum [15], which also build with rigid shell as main frame and attached with circular membrane. Despite exhibit the same basic framework, the sound characteristic produced will be different between these musical instruments as different musical instrument is drafted with unique properties in comparison with one another in terms of material, size and its detailed design [16]. The frequency of percussion musical instrument however, reported by [2] are mainly collaborated with the modes formed by the membrane, although other factors such as membrane density or radius may also play a role to some extent. It is also found that in percussion type of musical instrument, different modes produce different frequency where mode 1,1 tend to execute the highest membrane velocity, especially at higher membrane tension compared to any other modes.

---

Figure 1: Musical instrument kom pang with goat skin as membrane

Figure 2: Musical instrument kom pang with x-ray film as membrane
The understanding of traditional musical instrument characteristic is crucial as it represent the cultural values in some region as stated by [5] which study traditional musical instrument Kantele for Finland region, while this study focus on traditional musical instrument kompang for Malaysia region. In this paper, two types of kompang are considered; using goat skin as membrane (see Figure 1) and x-ray film as membrane (see Figure 2). The objective of this study is to use a correct mathematical model for traditional kompang and using that equation, the frequency of x-ray kompang would be similar with goat skin kompang, by altering the variable found in the numerical equation.

2. Experimental Setup

2.1. Design of Experiment
There are several equipment involved in the experiment, for measuring the weight and the thickness of the membrane, the tension of the membrane and for capturing the vibration of the membrane.

In this study, the weight and volume of sample goat skin membrane and X-ray film is measured to determine the density values. The tension of the membrane is determined by using TAMA tension watch. The measuring tools and are illustrated in Figure 3.

The capture of the membrane’s vibration is conducted by employing non-contact vibration measurement apparatus Laser Doppler Vibrometer (LDV) - Polytec PDV 100. The set-up illustration of the vibration capture is shown in Figure 4. Prior to the measurement the vibration apparatus was calibrated using Kistler Portable Shaker Accelerometer Calibrator Type 8921.

2.2. Experimental Procedure
The sample of goat skin and X-ray film is firstly carefully cut using a paper cutter with the size of 10 cm × 10 cm dimension then the thickness is measured using digital Vernier caliper. The weight is scaled by using Shimadzu AUW 220D Dual-Range Semi-Micro Balance. The density can be calculated based on the two measured parameters. The relative tension of each kompang is first measured by using TAMA tension watch as shown in Figure 3 and then the actual tension is determined using slotted weight approach. The recorded results are compiled in Table 1. These data collected will also be used for the input variables in the mathematical modelling.

![Figure 3. Measurement tools](image)
Table 1. *Kompang* parameters and their values.

| Symbol | Kompong Parameters | Goat Skin | X-ray Film |
|--------|--------------------|-----------|------------|
| 1      | Radius, $R$ (m)    | 0.1       | 0.1        |
| 2      | Tension, $T$ (N)   | 40.16     | 39.94      |
| 3      | Density, $\rho$ (kg/m$^3$) | 552.905 | 1402.56    |
| 4      | Thickness, $h$ (V) | $0.74\times10^3$ | $0.18\times10^3$ |

Figure 4 shows the experimental setup for the experiment to determine the frequency of membrane. The experimental procedure are:

1) Setting the experimental setup.
2) Boot up the computer and LDV.
3) Open up the laser cover and adjust the laser point to the smallest possible as it is at the most focus.
4) Calibrate the LDV using Kistler Portable Shaker Accelerometer Calibrator Type 8921.
5) Pointed out the laser from LDV toward the designed point on membrane.
6) With the help of Vernier height gauge, lift the mallet up to 25 cm and hit the center of membrane with mallet and record the response of membrane.
7) Determines the frequency reading of the points from the plotted graph of FFT domain.
8) Repeat the step 5 to step 7 for different kompong.
9) After finish, shut down the LDV and the result collected to be analysed.

3. Mathematical Modelling

The mathematical formula for 3D vibration simulation of circular membrane in Smath software can be found from [17]:

\[ u_{mn}(r,t,\theta) = [a_{mn} \cos(ck_{mn}t) + b_{mn}\sin(ck_{mn}t)]J_n(k_{mn}r)\cos(n\theta) \]  
\[ c = \left(\frac{T}{\rho h}\right)^{1/2} \]

With Fourier series coefficients of:

\[ a_{mn} = \frac{2}{R^2 J_1^2(\alpha_{mn})} \int_0^R r p(r) J_0 \left(\frac{\alpha_{mn}}{R} r\right) dr \]
\[ b_{mn} = \frac{2}{c\alpha_{mn} R J_1(\alpha_{mn})} \int_0^R r q(r) J_0 \left(\frac{\alpha_{mn}}{R} r\right) dr \]

where \( r \) is the radius of the point on membrane, \( T \) tension of the membrane per length, \( \rho \) is the membrane density, \( h \) is membrane thickness, \( R \) is radius of circular membrane, \( t \) is time and \( \theta \) is the angle around the axis of the membrane. For the circular membrane equation to works, the assumption for initial displacement, \( p(r) \) and initial velocity, \( q(r) \) is necessary by following [18]:

\[ p(r) = u(r,0) \text{ and } q(r) = \frac{\partial u}{\partial t}_{t=0} \]

The “\( \alpha_{mn} \)” is defined as the mth positive zeros of \( J_n(s) \), where \( m \) represent the nodal circle and \( n \) represent nodal line. The positive zeros can be calculated and determined by plotting the zero-th order Bessel function as shown in Table 2, and can be found from [19].

| \( m \) | 1   | 2   | 3   | 4   |
|-------|-----|-----|-----|-----|
| 0     | 2.4048 | 5.520 | 8.654 | 11.792 |
| 1     | 3.832 | 7.016 | 10.173 | 13.323 |
| 2     | 5.135 | 8.417 | 11.620 | 14.796 |

3.1. Natural Frequency

The equation for the frequency of the membrane is [20]:

\[ \lambda_{mn} = \frac{\alpha_{mn}}{R} \sqrt{\frac{T}{\rho h}} \]
4. Results and Discussion

![Figure 5](image)

Figure 5. Experimental result (a) Goat skin *kompong*; (b) X-ray film *Kompang*

From the experiment, the frequency reading of both type of *kompong* is recorded using LDV which running the vibration analysis software Vibsoft 3.0. The graph is plotted in FFT domain to find the highest peak of displacement which shows the natural frequency of the membrane. In the Figure 5 (a), the goat skin *kompong* shows the reading of 234.4 Hz while in Figure 5 (b), the X-ray *kompong* yield an astonishing reading peak at 294.4 Hz. This is probably due to the difference in membrane density and thickness which plays a major role in this comparison as shown in equation (6).

4.1. Numerical Modelling

![Figure 6](image)

Figure 6. Numerical result (a) Goat skin *kompong*; (b) X-ray film *Kompang*

Figure 6 shows the result from the numerical equation calculated in Smath software. The simulated 3D image is generated using equation (1) while the frequency is obtained from equation (6). It is calculated from the Figure 6 (a) that the goat skin membrane produce a result of 237.8 Hz while in Figure 6 (b), the result of 302.7 Hz is obtained. This result shows an almost similar frequency when being compared with the result from Figure 5.
The Figure 7 shows a chart as comparison between experimental and numerical calculation result. It is observed that the difference of frequency between experimental approach and calculation in Smath software is very small that from the plotted chart, the human eye can barely see the differences.

4.2. Percentage Difference
In the numerical study, it is important to know the exact error to confirm accuracy of the data collected for both from experiment and numerical calculation. The difference of the numerical simulation and the experiment results for both goat-skin and x-ray membranes are considerably very small, i.e. 1.45% and 2.82% respectively. The numerical model can be used to find the correct tension of the x-ray model to represent the goat-skin membrane.

4.3. X-Ray Membrane Tension Adjustment
In the experiment that have been conducted, the tension reading of x-ray film membrane is 39.94 N, resulting the frequency of 294.4 Hz, while the goat-skin kom pang has a fundamental frequency of 237.8 Hz. Since the tension proportionally corresponding to the frequency, it can be seen that if the tension is lowered, a frequency similar to the goat-skin membrane can be achieved.

Figure 8. Fundamental frequency of x-ray kom pang with various tension settings
Several numerical attempts are then conducted. The results of frequency of these numerical simulations for x-ray kom pang are plotted in Figure 8. By plotting line chart as shown in Figure 8, the tension parameter value of x-ray membrane to represent the goat-skin membrane should be 23.99 N (~24 N).

With the new tension setting, the sound of the traditional goat-skin membrane can be represented by an alternative x-ray membrane.

![Figure 9](image)

**Figure 9. Final result of frequency (a) goat skin kom pang frequency during experiment; (b) X-ray kom pang new frequency after altering the tension value.**

Figure 9 shows the result of kom pang fundamental frequency of goat skin and X-ray film membranes with the new tension. Both of them generates fundamental frequencies of 294.4 Hz.

5. Results and Discussion

The sound of traditional goat-skin membrane of kom pang can be replaced by x-ray film membrane. The tension for the x-ray membrane is 24 N to have similar fundamental frequency of the goat-skin kom pang.

In this research a numerical tool is used to calculate the fundamental frequency of kom pang’s membrane. The difference between the experimental and simulation is small for both x-ray and goat-skin membranes (i.e. 1.45% for goat-skin and 2.82% for x-ray film). The simulation tool is proofed to be practical and handy for the kom pang maker in determining the tension of the membrane.

The usage of the alternative x-ray film for the kom pang membrane has an advantage that the sound is stable not easily changed by the humidity. The sound also standard since the thickness is always the same.

**Acknowledgements**

The authors would like to be obliged to Universiti Tun Hussein Onn Malaysia for providing laboratory facilities and financial assistance under project Fundamental Research Grant Scheme Vot. 1206. This paper was also partly sponsored by the Centre for Graduate Studies UTHM.
References

[1] Abdullah M H 2005 Kompang: an organological and ethnomusicological study of a Malay frame drum
[2] Bertsch M 2001 Vibration patterns and sound analysis of the Viennese Timpani Proceedings ISMA
[3] Ono T, Takahashi I, Takasu Y, Miura Y & Watanabe U 2009 Acoustic characteristics of Wadaiko (traditional Japanese drum) with wood plastic shell The Journal of Acoustical Science and Technology. 30(6) 410 – 416
[4] Siswanto W A, Tam L & Kasron M Z 2012 Sound characteristics and sound prediction of the traditional musical instrument the three-rattle angklung International Journal of Acoustics and Vibration, Inst Acoustics & Vibration Auburn Univ, Mechanical Engineering Dept, 270 Ross Hall, Auburn, AL 36849 USA. 17 120-126
[5] Karjalainen M, Backman J & Polkki J 1993 Analysis, modeling, and real-time sound synthesis of the kantele, a traditional Finnish string instrument Proceedings of the 1993 IEEE International Conference on Acoustics, Speech, and Signal Processing: Plenary, Special, Audio, Underwater Acoustics, VLSI, Neural Networks. 1 229 – 232
[6] Chaigne A, Touzé C & Thomas O 2005 Nonlinear vibrations and chaos in gongs and cymbals Acoustical science and technology Acoustical Society of Japan. 26 403-409
[7] Rhaouti L, Chaigne A & Joly P 1999 Time-domain modeling and numerical simulation of a kettledrum The Journal of Acoustical Society of America. 105(6) 3545 – 3562
[8] Rossing T D, Bork I, Zhao H & Fystrom D O 1992 Acoustics of snare drums The Journal of Acoustical Society of America. 92(1) 84 – 94
[9] Avanzini F & Marogna R 2010 A modular physically based approach to the sound synthesis of membrane percussion instruments The Journal of Audio, Speech, and Language Processing, IEEE Transactions on. 18(4) 891 – 902
[10] Siswanto W A, Che Wahab W M A, Yahya M N , Ismail A E & Nawi I 2014 A platform for digital reproduction sound of traditional musical instrument Kompang Applied Mechanics and Materials. 660 823-827
[11] Fletcher N & Rossing T 2012 The physics of musical instruments Springer Science & Business Media
[12] Baricz 2010 Generalized Bessel functions of the first kind Springer
[13] Golzari S, Doraisamy S, Sulaiman M, Udzir N & Norowi N 2008 Artificial immune recognition system with nonlinear resource allocation method and application to traditional malay music genre classification. 5132 132 – 141
[14] Ferguson S 2006 Learning musical instrument skills through interactive sonification Proceedings of the 2006 conference on New interfaces for musical expression, IRCAM - Centre Pompidou. 384 – 389
[15] Bilbao S Webb C Craig J 2013 Physical modeling of timpani drums in 3D on GPGPUs,” Acoustics and Audio Group, University of Edinburgh, Edinburgh, UK. 61(10) 737-748
[16] Wieczorkowska A 1999 Rough sets as a tool for audio signal classification Proceedings of the 11th International Symposium on Foundations of Intelligent Systems. London. UK :Springer-Verlag. 1609 367 – 375
[17] Morse P M 1948 Vibration and sound McGraw-Hill New York
[18] Nguyen D M, Anton E, Allan R G & Jens G 2011 Isogeometric shape optimization of vibrating membranes Journal of Computer Methods in Applied Mechanics and Engineering. 200(13) 1343 – 1353
[19] Watson G N 1995 A treatise on the theory of Bessel Functions Cambridge University Press
[20] Kreyszig E 2011 Advanced engineering mathematics Wiley