Characterization of Traditional Thai Musical Scale

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Abstract: - This article presents an attempt to characterize the scale of traditional Thai music. The scale of interest is known as "Thang Phiang Aw" (in Thai) meaning middle pitch. The modal distribution is applied to analyze single- and multi-note sounds played by a middle-pitch Thai flute (klui phiang aw) and a Thai metal tenor xylophone. We find that the formants of Thai octave are in the range of 465-940 Hz. The pitch-intervals of Thai scale are not constant as the previous hypothesis of Morton's [1].

Key-Words: - Traditional Thai music, musical signal analysis, modal distribution, "Thang Phiang Aw", formants, pitch intervals.

1 Introduction

It has been known for a very long time that the pitch of Thai musical sound is different from that of the western. While the western musical sound contains both whole tones and semi-tones, one octave of the Thai's contains seven whole tones. The Thais regard that their musical scale possesses no semi-tone at all. Tuning of Thai musical instruments rely on the hearing capability of an experienced musician. The instruments used as reference for tuning are usually flute, and metal xylophone. About 40 years ago, Morton [1] measured and analyzed Thai musical scale played by several instruments. He proposed a hypothesis that Thai musical scale possessed a constant pitch interval of 171.43 cents (1,200 cents divided by 7).

With today's advanced signal processing techniques, and measuring instruments, reinvestigation of Thai musical scale would benefit Thai society, contemporary composers and musicians, and fans of eastern music. Previously, Iemma and Cecconi [2] studied the harmonic response of wind instruments. Also in 2003, Costantini and Casali presented their works on the recognition of musical chord notes [3]. In our work, we apply the modal distribution (MD) [4-5] to the recorded signals of the sound from a middle-pitch Thai flute (woodwind instrument), and a Thai metal tenor xylophone. The MD gives accurate formants of the scale. Moreover, we apply the method to some cases of multiple notes played by a metal tenor xylophone. The playing technique is akin to playing chord. The results obtained are useful for evaluating the performance of musicians.

Fig. 1 A middle-pitch Thai flute.

Fig. 2 A Thai metal tenor xylophone.

This article reviews the MD in section 2. Results and discussions are given in section 3, then followed by conclusion in section 4.

2 Modal Distribution

The technique of time-frequency distribution of Cohen's class [6] provides a mathematical framework for the design of kernel to analyze musical signal. In general, Cohen's class consists of linear transformations of the Wigner distribution

(WD) as given by [5]

$$C(t,\omega;\varphi) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W_s(\tau,\xi) \times \varphi(t-\tau,\omega-\xi;t,\omega)d\tau d\xi \quad (1)$$

where $C(t,\omega;\varphi)$ belongs to Cohen's class. $W_s(t,\omega)$ is the WD of signal $s(t)$ and $\varphi(\tau,\xi;t,\omega)$ is the kernel specifying the linear transformation. This kernel is formed from two different filters; one for cross-product suppression in time, $h_{LP}(\tau)$, and the other for cross-product suppression in case of frequency modulation, $G_{LP}(\xi)$:

$$\varphi_M(\tau,\xi) = h_{LP}(\tau)G_{LP}(\xi). \quad (2)$$

When we substitute $\varphi_M(\tau,\xi)$ from (2) into (1), it yields the distribution $M(t,\omega)$ [5] given by

$$M(t,\omega) = C(t,\omega;\varphi_M) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W_s(\tau,\xi) \times h_{LP}(t-\tau)G_{LP}(\omega-\xi)d\tau d\xi. \quad (3)$$

The expression in (3) is the linear transformation of the WD and is referred to as the modal distribution or modal kernel. In case of discrete sampled data, the MD is based on the discrete pseudo-Wigner distribution (DPWD) given by

$$W_s(n,k) = \sum_{\ell=-L}^{L} R_s(n,\ell)h(\ell)e^{(\frac{-j2\pi k\ell}{2L})} \quad (4)$$

where $h(\ell)$ is a function of lowpass filter and $R_s(n,\ell)$ is the discrete instantaneous autocorrelation function of the discrete data sequence $s(n)$ described by

$$R_s(n,\ell) = s(n+\ell)s^*(n-\ell). \quad (5)$$

Note that * denotes the complex conjugate. Then, we pass $R_s(n,\ell)$ through the filter window $h_{LP}(n)$ which is the inverse Fourier Transform of $h_{LP}(\tau)$ to obtain time-filtered instantaneous autocorrelation function ($R_{s,t}(n,\ell)$) using

$$R_{s,t}(n,\ell) = \sum_{p=-P}^{P} R_s(n-p,\ell)h_{LP}(p). \quad (6)$$

$R_{s,t}(n,\ell)$ in (6) is computed for some values of n (denoted by n_{step_size}) corresponding to a step size that samples at a frequency of $2\Delta\omega_{min}$. The value $\Delta\omega_{min}$ is the minimum frequency difference between the component bands in rad/s and can be approximated from the spectrogram of signal $s(n)$. The spectrogram can be obtained by computing the Short-Time Fourier Transform (STFT) of signal $s(n)$ (see Appendix). Finally, we use time smoothed instantaneous function $R_{s,t}(n,\ell)$ and substitute $h(\ell)$ with the frequency smoothing window $g_{LP}(n)$ which is inverse Fourier Transform of $G_{LP}(\xi)$ to compute the discrete modal distribution $M_s(n,k)$ of the signal $s(n)$ using [5]

$$M_s(n,k) = \sum_{\ell=-L}^{L} R_{s,t}(n,\ell)g_{LP}(\ell)e^{(\frac{-j2\pi k\ell}{2L})}. \quad (7)$$

We choose L to be a power of 2 so that $M_s(n,k)$ can be computed by using the algorithm of power-of-two fast Fourier Transform (FFT). Both $h_{LP}(n)$ and $g_{LP}(n)$ are obtained by performing autocorrelation and normalization of the Hamming window. The length of one-half of the $h_{LP}(n)$ and $g_{LP}(n)$ are N and R, respectively. The length N is calculated from the minimum distance between $\Delta\omega_{min}$ (rad/s) and the sampling rate (Hz). The total length of the DFT in (7) is 2L where L is chosen to obtain the number of bins of frequency resolution. The length R is chosen to be $L/2$. Thus, the relationship between the DFT length, the sampling rate (f_s) and the bin spacing (B) is given by

$$B = f_s / 4L. \quad (8)$$

Figure 3 shows the algorithm to compute the discrete modal distribution. The results can be plotted as a 3-D mesh plot with the magnitude of $M_s(n,k)$ in z direction. The x axis and y axis represent time and frequency spacing, respectively.

3 Results and Discussions

To record the sound of Thai flute and metal tenor xylophone in our experiment, our average room temperature is 27°C and relative humidity is approximately 72 %. The loudness of the sound is controlled to be in the range of 76-80 dB. Microphone is the electret type that has sensitivity of −52 dB and frequency response in the range of 50-18,000 Hz. We use an oscilloscope to collect the data of 2,500 points and apply filtering prior to using the STFT and MD techniques.

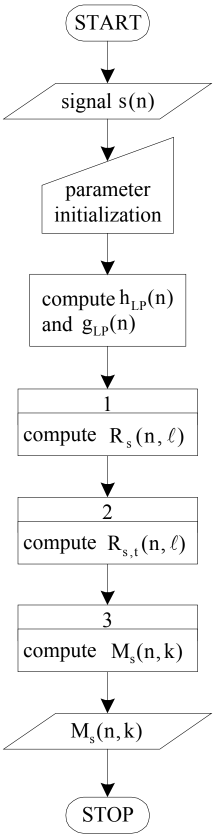

Fig. 3 Algorithm to compute the discrete modal distribution.

3.1 Case I: Single note

In case of the analysis of single note, we consider one octave of the sound (do re mi fa sol la si do′) produced by a middle-pitch Thai flute and a Thai metal tenor xylophone. For each recording, the sound for each instrument is produced constantly with the sampling frequency of 250 kHz. Then, we apply the BP Butterworth filter with cutoff frequency of 175 Hz and 25,000 Hz to reduce the effects of background noise. For the analysis using the STFT and MD techniques, we use the same set of parameters with all eight different notes of Thai flute and metal tenor xylophone.

For the STFT technique, we compute the 17,500-point DFT. The window function is the rectangular window of length 2,000. These parameters are chosen so that they give the frequency of the note “do′” twice the frequency of the note “do”. The results of the analysis show that the frequencies of some notes are integers. This is unusual for the Thai musical instruments because in the process of making them, we do not use any electronic devices for tuning the sound; just the expertise in listening to the sound of experienced musicians. From the spectrogram of the sound produced by each instrument, we can obtain the value of $\Delta\omega_{min}$ for the analysis using the MD technique.

For the MD technique, the values L, $\Delta\omega_{min}$ and n_{step_size} are 8,192 points, 183.11 Hz and 4 points, respectively. Figure 4 shows the formant for the note “sol” of a middle-pitch Thai flute.

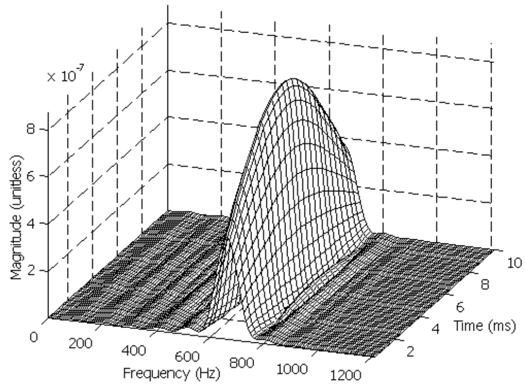

Fig. 4 Modal distribution of a middle-pitch Thai flute for the note “sol”.

Then, we compute the frequency ratio between the frequency of a note and the next consecutive one. We also compute the pitch interval using

$$\text{Pitch interval} = K\log_2(f_1 / f_2) \quad (\text{cents}) \qquad (9)$$

where $K = 1{,}200$ [7]. In theory, the pitch interval between the notes “do′” and “do” is equal to 1,200 cents. Table 1 shows the results of the frequency ratios and the pitch intervals of a middle pitch Thai flute. It can be seen that the frequency ratios are almost the same at 1.1 except the ratio between the notes “si” and “la” which is 1.14. The pitch intervals are clearly not constant.

In the analysis using a metal tenor xylophone, the formant is similar to the results using a Thai flute in Figure 4. The frequency ratios and the pitch intervals are shown in Table 2.

We can see that the pitch intervals are also not constant. Thus, these results do not follow the Morton’s hypothesis that says the pitch interval must be constant. Figure 5 compares the pitch intervals of a middle-pitch Thai flute and a Thai metal tenor xylophone with the values from

Morton’s hypothesis. We can see that the pitch intervals of the metal xylophone are closer to the ones from Morton’s hypothesis than the pitch intervals of the Thai flute are.

Table 1 Frequency ratios and pitch intervals of a middle-pitch Thai flute.

One octave of Thai musical notes	Frequency (Hz)	Frequency ratio (unitless)	Pitch interval (cent)
do	465.39	1.0984	162.44
re	511.17	1.0896	148.49
mi	556.95	1.0822	136.73
fa	602.72	1.1013	167.01
sol	663.76	1.0805	133.96
la	717.16	1.1383	224.27
si	816.35	1.0935	154.67
do′	892.64		

Table 2 Frequency ratios and pitch intervals of a Thai metal tenor xylophone.

One octave of Thai musical notes	Frequency (Hz)	Frequency ratio (unitless)	Pitch interval (cent)
do	465.39	1.1147	188.09
re	518.80	1.1029	169.61
mi	572.20	1.0933	154.49
fa	625.61	1.1097	180.28
sol	694.27	1.0989	163.29
la	762.94	1.1100	180.66
si	846.86	1.1081	177.73
do′	938.42		

When we compare the frequencies of the same notes produced by both instruments, we can see that they are not exactly the same. This is because the process of tuning for each instrument relies on the expertise in listening to the sound of experienced musicians. Thus, there might cause some error. Furthermore, the frequencies produced by Thai flute are sensitive to temperature and humidity. Thus, the change of room temperature and humidity from the environment when the instrument is tuned may cause the changes of frequency. This also explains why the pitch interval of one octave for Thai flute (1,127.57 cents) is more different from the theoretical one (1,200 cents) than the pitch interval for the metal tenor xylophone (1,214.15 cents) is.

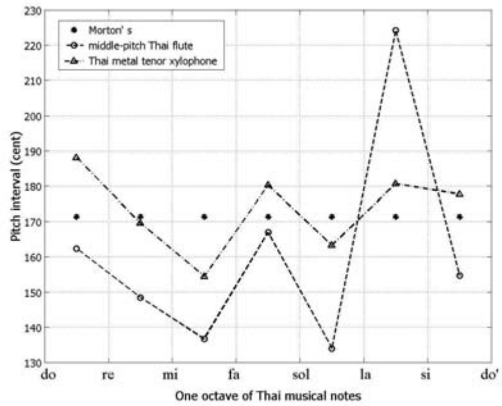

Fig. 5 Pitch intervals of a middle-pitch Thai flute, a Thai metal tenor xylophone and Morton’s.

3.2 Case II: Multi-notes

We play a Thai flute to produce sound of multi-notes. Three different ways of playing are considered: (i) making la, sol, and fa sounds by blowing the flute three times rapidly, (ii) making high-pitch mi′, re′, and do′ by blowing the flute just once, and (iii) making fa, and sol sounds alternately by blowing the flute continuously. Recording the sound used 10 kHz sampling frequency. We apply a HP Butterworth filter with 100 Hz cutoff frequency to the recorded signals. To analyze these signals needs the MD of which parameters are tabulated in Table 3.

Table 3 Parameters of MD technique for analyzing multi-notes.

Parameters / Notes	L (point)	$\Delta\omega_{min}$ * (Hz)	n_{step_size} (point)
la, sol, and fa	4,096	56.15	25
mi′, re′, and do′	4,096	56.79	25
fa, and sol	4,096	57.36	25

* determined from spectrogram of corresponding signals.

Figure 6 illustrates the magnitude spectrum plotted against time and frequency for the case (i) of blowing the flute three times rapidly. The 3-D plot is a typical display of the MD’s results. The difference in magnitudes of the plot indicates the uneven pressure of the wind blown. It might reflect that to keep the sound level evenly is very difficult with this playing technique.

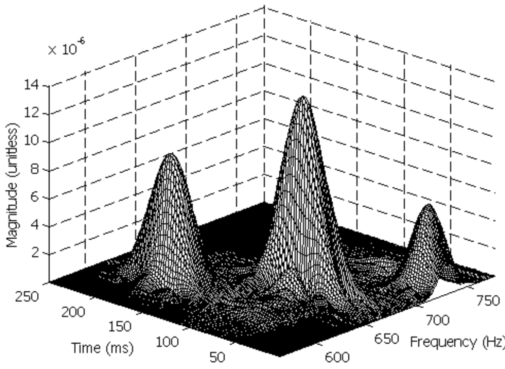

Fig. 6 Modal distribution of a middle-pitch Thai flute for the notes “la, sol, and fa”.

Figure 7 shows a typical display of MD’s results for the case (ii) mentioned above. The magnitude of the plot indicates that the loudness of the sound decreases in order. Mi′ is the loudest note played. This corresponds to the playing technique of blowing the flute only once. So, the loudness of the last note (do′) played is the least.

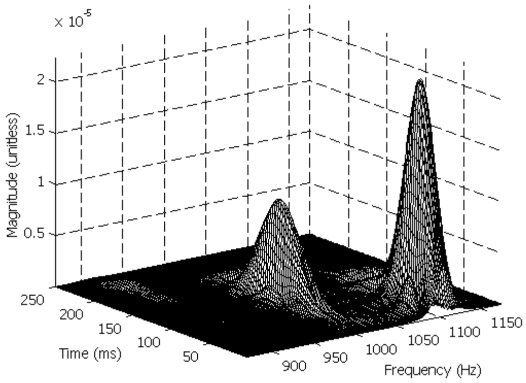

Fig. 7 Modal distribution of a middle-pitch Thai flute for the notes “mi′, re′, and do′”.

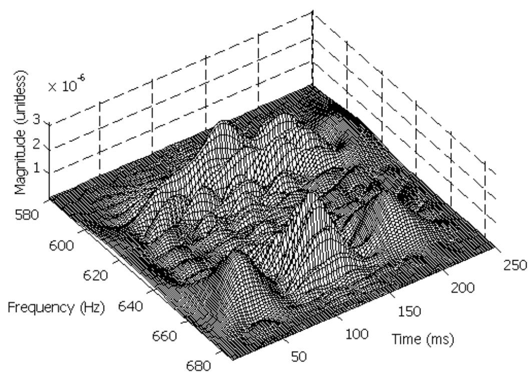

Fig. 8 Modal distribution of a middle-pitch Thai flute for the notes “fa, and sol”.

Figure 8 indicates that the sounds of fa and sol appear alternately according to the playing technique. The spectrum of the fa appears as the main while the peak spectrum of the sol appears alternately.

We also analyze the sounds of do and fa played by the metal tenor xylophone. The playing technique is called “kep”, i.e. the two playing sticks hit two different keys simultaneously. This playing technique (“kep”) is similar to playing chord. The recorded signal is sampled using 100 kHz sampling rate. The sampled signal is passed through a BP Butterworth filter having its corner frequencies of 175 Hz and 25,000 Hz. The following are MD’s parameters: L= 8,192 points, $\Delta\omega_{min}$ = 164.80 Hz and n_{step_size} = 4 points, respectively. Figure 9 shows the results obtained from the MD for this case. The spectrum of the note do is somewhat lower than that of the fa. This means that the player hit the sticks with uneven force.

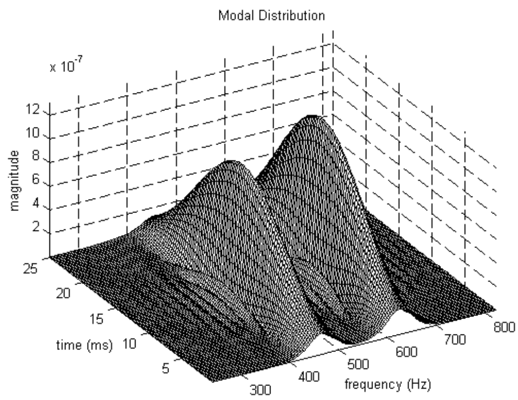

Fig. 9 Modal distribution of a Thai metal tenor xylophone for the notes “do, and fa” played by “kep” technique.

4 Conclusion

We attempt to characterize the traditional Thai musical scale via using the modal distribution (MD). Our work is elementary in that we analyze the sound played by a Thai flute and a metal tenor xylophone in order to find out the formants of the Thai octave. The middle pitch Thai octave or “thang phiang aw” has its formants in between 465-940 Hz. Tables 1 and 2 give the details. The corresponding pitch intervals are in the range of 130-230 cents. They are not constant as the previous claim made by Morton [1]. The application of the MD analysis technique to the multi-note cases is presented. The MD technique gives excellent results indicating correct appearance of each note corresponding to each different playing technique. We expect our future works extended in the areas of analyzing the special techniques played by some soloists, recognition of musical patterns, as well as, developing some devices to assist the beginners of Thai musical instruments.

5 Appendix

Spectrogram of signal $x(n)$ ($X_{STFT}(k,n)$) that can be computed by using MATLAB toolbox is defined by

$$X_{STFT}(k,n) = \sum_{m=0}^{R-1} x(n-m)w(m)e^{(\frac{-j2\pi km}{N})} \quad (10)$$

where $w(n)$ is a window sequence of length R and N is a DFT length [8].

6 Acknowledgment

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