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ARTICLE

The Musical Descriptor Using Fast Fourier Transform (FFT): Examples in P Ramlee Songs

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Abstract

The musical descriptor can be characterize using quantitative evaluation of audio sounds. This paper evaluates the musical descriptors for P Ramlee instrumental songs utilizing the Fast Fourier Transform (FFT) from the audio sounds signal. In this study, Python programming language is used to develop a series of custom scripts to calculate the musical descriptors. The approach involved constructing musical descriptors from instrumental music through analysis and digital processing of the spectra. The signal data were first transformed using the FFT to extract frequencies and intensities, which are crucial for identifying the spectral signature of musical sounds. The FFT is particularly valuable as it uniquely represents the spectral content of any musical sound by transforming the time-domain signal into its frequency-domain components. The Affinity coefficient, A, increased from 1.43 (Jangan Tinggal Daku) to 6.67 (Dendang Perantau), 8.96 (Di Pinggiran) and 13.81 (Getaran Jiwa). The Sharpness coefficient, S for Di Pinggiran is 0.039, Getaran Jiwa is 0.040, Dendang Perantau is 0.056 and Jangan Tinggal Daku is 0.065. The Harmonicity coefficient H for Di Pinggiran showed the highest H i.e. 17.0 followed by Dendang Perantau i.e. 8.2, Jangan Tinggal Daku i.e. 7.5 and Getaran Jiwa i.e. only 5.0. Monotony coefficient M of Dendang Perantau showed the lowest M i.e. −0.0096 followed by Di Pinggiran i.e. −0.0013, Jangan Tinggal Daku i.e. 0.0198 and Getaran Jiwa i.e. 0.0638. The Mean Affinity (MA) increase from 0.1689 (Getaran Jiwa) to 0.5322 (Dendang Perantau), 0.8673 (Di Pinggiran) and 1.3877 (Jangan Tinggal Daku). The Mean Contrast (MC) increase from 0.1568 (Di Pinggiran) to 0.3160 (Dendang Perantau), 0.4430 (Jangan Tinggal Daku) and 0.4755 (Getaran Jiwa).

Keywords: Affinity, Sharpness, Harmonicity, Monotony, Mean Affinity and Mean Contrast

1. Introduction

P. Ramlee was a well-known Malay films director from the 1950s to the 1960s who act, sing and also composed songs. He started as early as 1950s in Singapore. The songs lyric highlight psychological, social, economic and physical aspects (Brunei, 2003; Md. Nor, 2003; Wan Teh, 2003). The lyrics is viewed as how life themes are applied (Logan et al., 2004; Parveen, 2017) where the use of

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one instrument produces aesthetic values in a song (Bell, 1914; Levinson, 2011; Tillman, 1969). In the social context it shows the elements attributed to real life, as found in movies directed by P. Ramlee with visual and non-visual elements (Agawu, 1991; Maeder & Reybrouck, 2015; Moore, 2016; Peirce, 1965). The pairing of the lyrics and melodies made the songs really entertaining (Ahmad, 2003; Md. Nor, 2003). The study of a song lyrics is a scientific analysis and a composite thinking of social behaviour in society. Music research gives interesting challenges to computer science particularly in Artificial Intelligence (AI). AI of music take into accounts important elements from the partial frequency and intensities of the signal giving descriptors such as affinity A, sharpness S, harmonicity H, monotony M, mean affinity MA and mean contrast MC.

In this study, AI plays a pivotal role not only in the computational analysis of musical descriptors derived from the spectral data of P. Ramlee's instrumental music but also in enhancing the development and optimization of the coding process itself. AI-assisted coding tools, such as GitHub Copilot and ChatGPT were utilized to streamline the creation of Python scripts for descriptor calculations. These tools provided intelligent code suggestions, automated routine coding tasks, and assisted in debugging and optimizing the algorithms, significantly reducing development time and improving code accuracy. The use of AI in both the analysis and the coding phases allowed for a more efficient and effective exploration of complex musical signals. By leveraging AI-driven computational techniques, key descriptors such as affinity, sharpness, harmonicity, monotony, mean affinity, and mean contrast can be extracted, providing a quantitative foundation for understanding the intricate characteristics of musical sounds. Moreover, the integration of AI-assisted coding tools facilitated a more dynamic and adaptive development environment, where algorithms could be quickly refined based on data patterns, enhancing the precision and depth of the spectral analysis. This dual application of AI not only streamlines the computational workflow but also opens new avenues for innovative approaches in music research, combining technical efficiency with creative exploration.

In this study, Python programming language is used to develop a series of custom scripts to calculate the musical descriptors. The approach involved constructing musical descriptors from instrumental music through analysis and digital processing of the spectra. The signal data were first transformed using the Fast Fourier Transform (FFT) to extract frequencies and intensities, which are crucial for identifying the spectral signature of musical sounds. The FFT is particularly valuable as it uniquely represents the spectral content of any musical sound by transforming the time-domain signal into its frequency-domain components.

The signal is presented by Fast Fourier Transform (FFT) i.e. frequencies and intensities. AI generated descriptors lacks expressiveness and gesture. Gesture is the nuances of performance (i.e. unique in conveying the personal touch of the musician), interpretive and creative. The frequencies in the FFT allow identification of spectral signature of a musical sound. The FFTs are unique for any musical sound. In a given spectrum, the partial or secondary frequencies can be counted. These partial frequencies are not necessary an integer multiple of the fundamental frequency f_o. The sound becomes more harmonically rich when its frequency value differs significantly from the multiples of the fundamental frequency, f_o. The FFT values yield different amplitudes and frequencies and are defined as the following dimensionless parameters (Gonzalez & Prati, 2022).

i. Affinity A is the fundamental frequency in relation to the average frequency,
ii. Mean Affinity MA is the frequency distribution with respect to the average frequency,
iii. Sharpness S is the amplitude of f_o with respect to the collection of amplitudes $a_{i,}$
iv. Mean Contrast MC is the average amplitude of the pulse collection,
v. Harmonicity H is the closeness of the secondary pulses are to being integer multiples of f_o,
vi. Monotony M is the envelope through the average slope in the collection of pulses.

These dimensionless coefficients are described and exemplified for the FFTs of P. Ramlee instrumental music. The centroid frequency $\bar{f}$ does not correspond to any of the partial frequencies f_i of the sounds studied. The centroid $\bar{f} \equiv \frac{\sum_{i=1}^{N} a_i f_i}{\sum_{i=1}^{N} a_i}$ is the average frequency with f_i as the partial frequencies for each spectrum. The Affinity coefficient $A = \frac{\sum_{i=1}^{N} a_i f_i}{f_0 \sum_{i=1}^{N} a_i} = \frac{\bar{f}}{f_0}$ showed the closeness of the spectrum from the ideal case, i.e., how close the maximum f_o is from the $\bar{f}$. The sharpness $S = \frac{a_0}{\sum_{i=1}^{N} a_i}$, in pure sound $S = 1$ i.e. single maximum without secondary frequencies ($S \leq 1$). The harmonicity of the partial or secondary frequencies (f_1, f_2, f_3... f_j) yield Harmonicity

H descriptor $H = \sum_{j=1}^{N}\left(\frac{f_j}{f_0} - \left|\frac{f_j}{f_0}\right|\right)$. Any frequency f_j is a harmonic of f_o if the ratio is an integer.

The Harmonicity coefficient (H) gives the number of harmonics present. Harmonicity is related to color or sonority of the sounds. Monotony $M = \frac{f_0}{N}\sum_{j=1}^{N}\left(\frac{a_{j+1}-a_j}{f_{j+1}-f_j}\right)$ yield the distribution of partial frequencies (harmonic or not). It is the average of the variations between two successive maxima. Monotony determine whether the harmonics are increasing (positive M) or decreasing (negative M) succession after f_o. The secondary or partial frequencies can be found in a distinct frequency range, with some instances where these frequencies, whether harmonic or not, are closely clustered, while in other cases, they exhibit greater spatial dispersion and separation. When the higher partials are in close proximity to each other or to f_o the sounds exhibit a denser quality, while greater spatial dispersion of the frequencies imparts a sense of transparency to f_o. This transparency is quantified as the timbral coefficient known as Mean Affinity $MA = \frac{\sum_{i=1}^{N}|f_i - \bar{f}|}{Nf_0}$ which assesses the frequency spread and the degree of separation among partial frequencies relative to the centroid.

The MA coefficient aims to assess the degree of compactness in the frequency distribution concerning the mean value ($\bar{f}$). We employ the subscript "i" instead of "j" in this sum because it encompasses f_o as well. In contrast, other coefficients exclude f_o in the summation over "j" since they pertain to secondary maxima, whether harmonic or not. Lower MA values indicate a more condensed distribution of secondary sounds in proximity to the centroid. The Mean Contrast $MC = \frac{1}{N}\sum_{j=1}^{N}|a_0 - a_j|$ coefficient quantifies the relationship between the amplitudes of the partial frequencies (referred to as tones or colors) and the fundamental frequency. MC rises with the increasing intensity of these partial frequencies.

Six functions are required to describe the monophonic musical sound characteristics in terms of normalized amplitude and frequency. The measurement of f_o against the average frequency $\bar{f}$, is called Affinity (A). The measurement of frequency dispersion against $\bar{f}$, is called Mean Affinity (MA). The measurement of amplitude a_o against the collection of amplitudes a_i is called Brightness or Sharpness (S). The measurement of the average amplitude of the pulse collection is called Mean Contrast (MC). The descriptor indicating the approximation of secondary pulses to the integer multiples of f_o is called Harmonicity (H). The descriptor for envelope through the average envelope in the pulse collection is called Monotony (M). These A, MA, S, MC, H and M will differentiate the sound characteristics of each musical sound.

This paper proposes an acoustically motivated sound characteristic descriptor. This descriptor allows for computer extraction of sound characteristic information using FFT from music recordings. Dimensionless coefficients from sound characteristics indicate descriptors in the spectrum that characterize the evaluated musical sound. Sound characteristic assessment enables us to create precise musical parameters, as well as identify, classify the sound characteristic, and assess the quality of sound recordings. The acoustic descriptor is motivated by the acoustics of the sound characteristic using spectra from FFT. Digitizing sound using computers through FFT represents a significant advancement in (i) methods for retrieving music information (Lartillot et al., 2008; Li et al., 2018), (ii) recognizing and identifying musical instruments (Nagawade & Ratnaparkhe, 2017; Chakraborty & Parekh, 2018), (iii) characterizing audio music recordings. To characterize musical sound, attributes of (i) frequency, (ii) intensity, (iii) duration, and (iv) sound characteristics are essential. The first three attributes are directly measurable quantities. The fourth attribute, sound characteristics, is multidimensional and is an attribute that allows one to distinguish between sounds that have the same frequency, intensity, and duration. Sound characteristics allow us to distinguish between sounds from different instruments even if they have the same musical notes (i.e., the same intensity and duration).

Harmonics in music refer to the frequencies of pitches that vibrate in multiples of whole integers in comparison to the fundamental frequency. The fundamental frequency is the lowest pitch possible for any given sound tube or instrument fingering. The study intends to close a gap in the literature by concentrating on P Ramlee song, a traditional music genre. This research examines the harmonic features of the P Ramlee song employing novel techniques to identify and interpret the distinct tones. In contrast to previous research, which frequently adopted a social science methodology, this study integrates scientific and cultural viewpoints.

We gain important insights regarding the differences across the musical sounds by concentrating on the P Ramlee songs. As a result, this study encourages conversation and increases understanding of the significance of creating instruments to recognize sound features in musical sounds. For example, it offers scholars, cultural enthusiasts, and musician valuable insights. The study also suggests that AI can be utilized to preserve and enhance P Ramlee songs which would significantly advance traditional music fusion with contemporary technology. Quantitative assessment of sound characteristics involves considering all three aspects: (i) fundamental frequency (f_o) and fundamental amplitude (a_o), (ii) measures of f_i or harmonic frequencies, (iii) relative intensity (measured relative to a_o). Two magnitudes (amplitude and frequency) are used for these three aspects, i.e., musical sound, value distribution shape, and minimum value for secondary sound components.

Musical frequencies form a finite and countable discrete set, comprising 12 distinct values (C, C#, D, D#, E, F, F#, G, G#, A, A#, and B) in each musical octave (for a total of 96 f_o in 8 octaves audible from 20 Hz to 20 KHz). Sound characteristics can be characterized by a limited set of dimensionless coefficients, which are quantities related to frequency and amplitude in the Fourier spectra of audio recordings. Motivated by the acoustics of music, these dimensionless coefficients serve as tone descriptors and can be explained by functions with discrete distributions of normalized frequencies and amplitudes. When the amplitudes from FFT spectra are normalized (using the ratio of amplitude a_i for each f_i to the maximum amplitude in each spectrum), we can compare normalized amplitudes. These can be aggregated into descriptors of f_o (from a musical scale consisting of 96 f_o values). The FFT values are essentially a discrete collection of pairs of different amplitudes and frequencies and can be summarized with dimensionless parameters.

2. Methodology

The acoustic spectra were obtained from the MP3 for P Ramlee songs. The audio was captured directly to the PicoScope oscilloscopes connected to PC. The PicoScope oscilloscopes display the whole frequency range displaying the time signals (which produced FFT spectrum). FFT spectrum display the fundamentals, harmonics, and subharmonics which is characterized by the intensity and harmonics/subharmonics. These characteristics determined the descriptors to distinguish the differences between the four instrumentals. In general, the sound source and particularly musical instrumentals can be identified using FFT spectrum. The instrumentals sound is characterized by the secondary frequencies (harmonics and overtones) or the partial frequencies which are not necessary an integer multiplicity of f_o. Fig. 1 illustrates the scheme for audio recordings of the MP3 for P Ramlee songs. The acoustic spectra of the song were captured from 20 Hz to 20 kHz using PicoScope oscilloscopes to investigate the fundamental and overtone frequencies. The PicoScope computer software (Pico Technology, 3000 series, Eaton Socon, UK) was used to view and analyse the time signals and data loggers for real time signal acquisition. PicoScope software enables analysis using FFT, a spectrum analyser, voltage-based triggers, and the ability to save/load waveforms to a disk. The signal produced from PicoScope oscilloscopes displayed sharp and distinct fundamental and overtone frequency peaks as shown in Fig. 2.

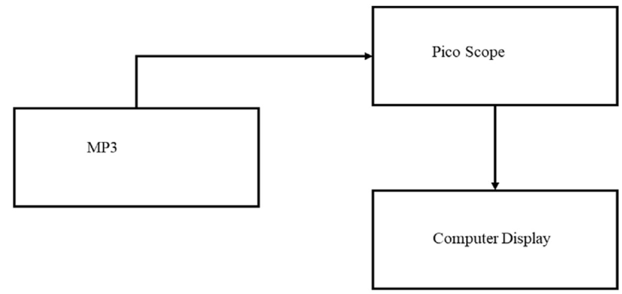

Fig. 1. Scheme diagram for audio recordings of the MP3 from P Ramlee songs.

With this FFT spectrum in Fig. 2, the amplitude a_i for each f_i can be determine as shown in Table 1. The FFT spectrum is essentially a discrete collection of N frequencies (f_i) and N amplitudes (a_i). These descriptors are calculated from the FFT spectra using the Python Programming Language. Through calculation, a frequency table (in kHz) along with normalized amplitudes (relative to the maximum amplitude) can be formed.

Once the FFT was applied to the musical signals, the descriptors were calculated through the following process: Affinity (A) was computed as the ratio of the fundamental frequency to the average frequency, providing a measure of the primary pitch's dominance. Mean Affinity (MA) captured the distribution of frequencies relative to the average, reflecting the spread of spectral components. Sharpness (S) was derived as the ratio of the fundamental frequency's amplitude to the sum of all amplitudes, indicating the prominence of the main peak. Mean Contrast (MC) assessed the variability in amplitude across the spectrum, highlighting dynamic range differences. Harmonicity (H) measured the closeness of secondary frequencies to integer multiples of the fundamental, indicating harmonic richness. Monotony (M) was calculated by analysing the slope of the envelope of the spectral peaks, providing insight into the uniformity of the signal. These descriptors were calculated using Python's

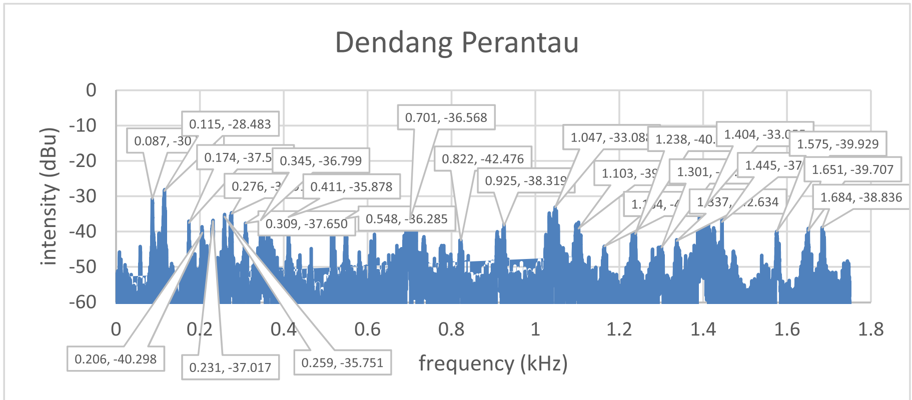

Fig. 2. The signal produced from PicoScope oscilloscopes displayed as sharp and distinct fundamental and overtone frequency.

Table 1. The amplitude a_i for each f_i determine from the signal produced from PicoScope oscilloscopes (Dendang Perantau).

frequency (kHz) f_i	Intensity (dBu) a_i
0.087	−30.79
0.115	−28.48
0.174	−37.53
0.206	−40.29
0.231	−37.07
0.259	−35.75
0.276	−34.9
0.309	−37.65
0.345	−36.79
0.411	−35.87
0.548	−36.28
0.701	−36.56
0.822	−42.47
0.925	−38.31
1.047	−33.08
1.103	−39.12
1.16	−44
1.238	−40.65
1.301	−44.45
1.337	−44.63
1.404	−33.05
1.445	−37.26
1.575	−39.93
1.651	−39.7
1.684	−38.836

numerical and scientific libraries, ensuring a comprehensive analysis of the spectral characteristics of the musical sounds.

3. Results and discussion

The spectrum of the 4 instrumentals is shown in Fig. 3. The signal from the 'Di Pinggiran', 'Getaran Jiwa', 'Jangan Tinggal Daku' and 'Dendang Perantau' instrumentals showed the frequency (kHz) in the x-axis and the intensity (dBu) in the y-axis. The identification of instrumentals can be done through the analysis of their spectrum. The spectral signature in the FFT allow their univocal identification. The 'Di Pinggiran' instrumental is in the D minor scale. D minor is a minor scale based on D, consisting of the pitches D, E, F, G, A, B♭, and C. Its key signature has one flat. The 'Getaran Jiwa' instrumental are in the Db major scale. The notes of the Db Major scale are Db, Eb, F, Gb, Ab, Bb and C. Its key signature has 5 flats. The 'Jangan Tinggal Daku' instrumental are in the C minor scale. C minor is a minor scale based on C, consisting of the pitches C, D, E♭, F, G, A♭, and B♭. Its key signature consists of 3 flats. The 'Dendang Perantau' instrumental are in the Bb natural minor scale. The notes of the Bb natural minor scale are B♭, C, D♭, E♭, F, G♭, and A♭. This scale has 5 flats.

The spectral signature in the FFT allow their identification. Through calculation, a frequency table (in kHz) along with normalized amplitudes (relative to the maximum amplitude) can be formed. The partial frequency versus the normalized intensity for 'Di Pinggiran', 'Getaran Jiwa', 'Jangan Tinggal Daku' and 'Dendang Perantau' instrumentals are shown in Fig. 4. The FFTs are not similar between any two musical sounds where the partial or secondary frequencies can be counted.

Tables 2–5 showed the partial frequency and notes from 'Di Pinggiran', 'Getaran Jiwa', 'Jangan Tinggal Daku' and 'Dendang Perantau' instrumentals. The partial frequencies (f_n) are not integer multiple to f_o. From Table 2 the harmonics from 'Di Pinggiran' are written in bold i.e. 1.98 (2), 2.95 (3), 4, 5.95 (6), 7.04 (7), 7.95 (8), 8.91 (9), 10.01 (10), 11.91 (12), 15.95 (16), 18.95 (19) and 19.97 (20). From Table 3 the harmonics from 'Getaran Jiwa' are written in bold i.e. 3, 7.2 (7), 9.2 (9), 11, 21.98 (22), 26, 29.2 (29) and 33.2 (33). From Table 4 the harmonics from 'Jangan Tinggal Daku' are written in bold i.e. 1.85 (2), 3.96 (4), 4.97 (5), 5.96 (6), 8.07 (8), 8.96 (9),

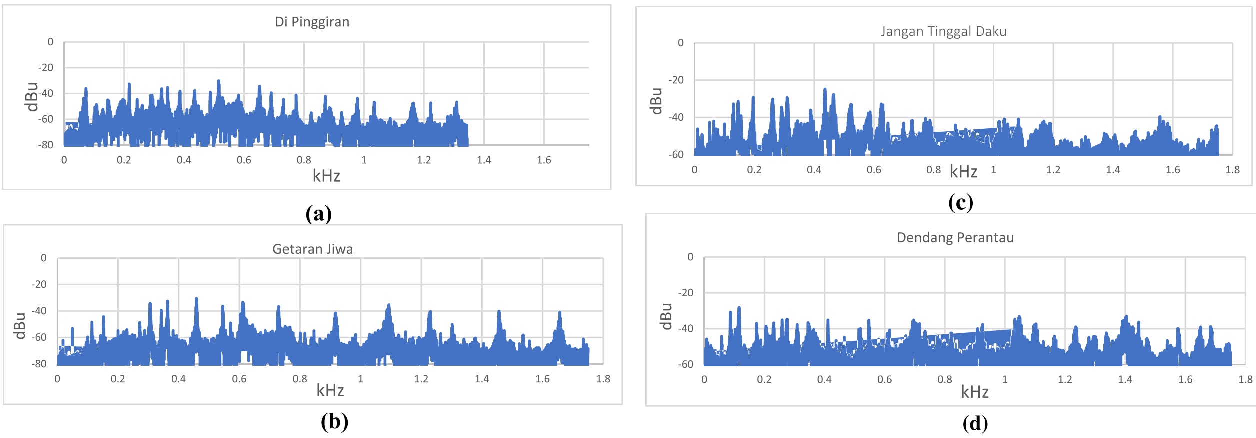

Fig. 3. (a) The signal from the 'Di Pinggiran' instrumental with the frequency (kHz) in the x-axis and the intensity (dBu) in the y-axis. (b) The signal from 'Getaran Jiwa' instrumental with the frequency (kHz) in the x-axis and the intensity (dBu) in the y-axis. (c) The signal from the 'Jangan Tinggal Daku' instrumental with the frequency (kHz) in the x-axis and the intensity (dBu) in the y-axis. (d) The signal from the 'Dendang Perantau' instrumental with the frequency (kHz) in the x-axis and the intensity (dBu) in the y-axis.

10.08 (10), 13.88 (14), 14.91 (15), 18.91 (19) and 19.96 (20). From Table 5 the harmonics from 'Dendang Perantau' are written in bold i.e. 2, 2.97 (3), 3.96 (4), 8.05 (8), 14.95 (15), 18.10 (18) and 18.97 (19). Table 6 displayed the harmonics present in the studied instrumentals.

From Table 6, 'Di Pinggiran' (with D minor scale based as D, E, F, G, A, B♭, and C) only D2, D3, A3, D4, A4, C5, D5, E5, F5#, A5, D6, F6, and F6# are having 1st, 2nd, 3rd, 4th, 6th, 7th, 8th, 9th, 10th, 12th, 16th, 19th and 20th harmonic. The 'Getaran Jiwa' (with Db Major scale as Db, Eb, F, Gb, Ab, Bb and C) only A1b, E3b, G4b, B4b, D5b, D6b, E6, G6b and A6b are having 1st, 3rd, 7th, 9th, 11th, 22nd, 26th, 30th and 33rd harmonic. The 'Jangan Tinggal Daku' (with C minor scale as C, D, E♭, F, G, A♭, and B♭) only E2b, D3, E4b, G4, B4b, E5b, F5, G5, C6, D6, G6b, and G6 are having 1st, 2nd, 4th, 5th, 6th, 8th, 9th, 10th, 14th, 15th, 19th and 20th harmonics. The 'Dendang Perantau' (with Bb natural minor scale as B♭, C, D♭, E♭, F, G♭, and A♭) only F2, F3, C4, F4, F5, C6, E6, G6, and A6b are having 1st, 2nd, 3rd, 4th, 8th, 12th, 15th, 18th and 19th harmonics.

'Getaran Jiwa' is a well-known Malay song, and it is interesting to explore the notes used in the melody. Composers and songwriters often use notes

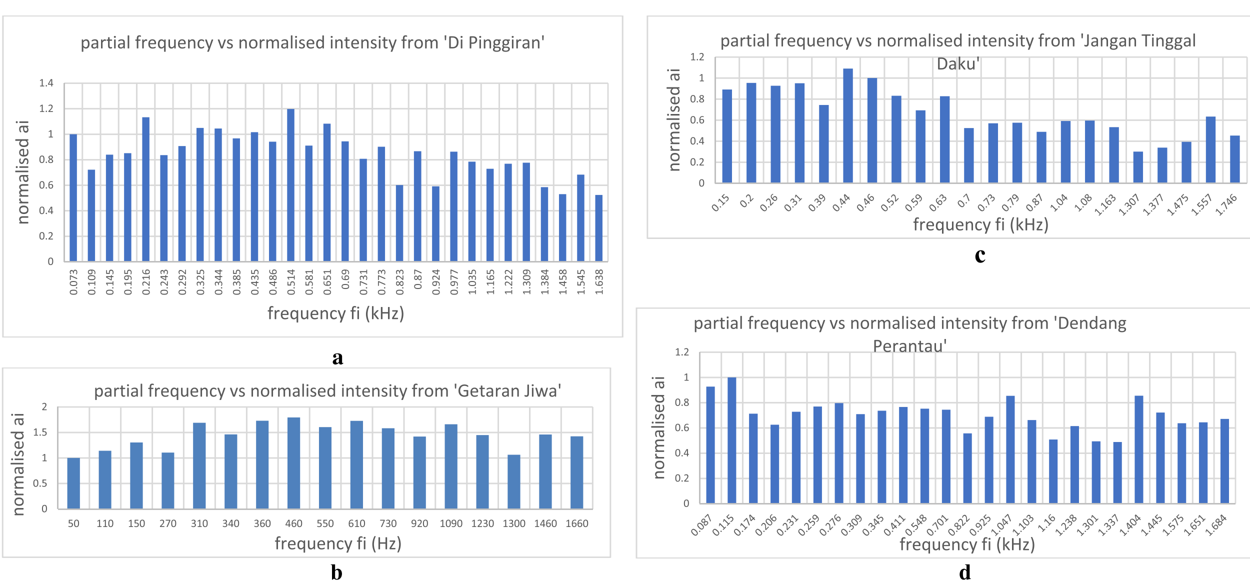

Fig. 4. (a) The partial frequency versus the normalized intensity from 'Di Pinggiran' instrumental. (b) The partial frequency versus the normalized intensity from 'Getaran Jiwa' instrumental. (c) The partial frequency versus the normalized intensity from 'Jangan Tinggal Daku' instrumental. (d) The partial frequency versus the normalized intensity from 'Dendang Perantau' instrumental.

Table 2. The partial frequency, partial frequency/f_o and notes from 'Di Pinggiran' instrumental. D minor scale consist of D, E, F, G, A, B♭, and C. The occurrence of F5#, G5#, D6#, F6# and G6# are not in the D minor scale.

Partial frequency (Hz)	Partial frequency/f_o	notes	ETS (Hz)
73	**1**	D2	73
109	1.49	A2	110
145	**1.98**	D3	146
195	2.67	G3	196
216	**2.95**	A3	220
243	3.32	B3	246
292	**4**	D4	293
325	4.45	E4	329
344	4.71	F4	349
385	5.27	G4	392
435	**5.95**	A4	440
486	6.65	B4	493
514	**7.04**	C5	523
581	**7.95**	D5	587
651	**8.91**	E5	659
690	9.45	F5	698
731	**10.01**	F5#	739
773	10.58	G5	783
823	11.27	G5#	830
870	**11.91**	A5	880
924	12.65	B5b	932
977	13.38	B5	987
1035	14.17	C6	1046
1165	**15.95**	D6	1174
1222	16.73	D6#	1244
1309	17.93	E6	1318
1384	**18.95**	F6	1396
1458	**19.97**	F6#	1480
1545	21.16	G6	1568
1638	22.43	G6#	1661

Bold indicate a number that approximate an integer value.

Table 3. The partial frequency, partial frequency/f_o and notes from 'Getaran Jiwa' instrumental. Db Major scale are Db, Eb, F, Gb, Ab, Bb and C. The occurrence of A2, D4, E4, and E6 are not in the Db major scale.

Partial frequency (Hz)	Partial frequency/f_o	notes	ETS (Hz)
50	**1**	A1b	51
110	2.2	A2	110
150	**3**	E3b	155
270	5.4	D4	277
320	6.4	E4	329
340	6.8	F4	349
360	**7.2**	G4b	369
460	**9.2**	B4b	466
550	**11**	D5b	554
610	12.2	E5b	622
730	14.6	G5b	739
920	18.4	B5b	932
1099	**21.98**	D6b	1108
1230	24.6	E6b	1244
1300	**26**	E6	1318
1460	**29.2**	G6b	1480
1660	**33.2**	A6b	1661

Bold indicate a number that approximate an integer value.

Table 4. The partial frequency, partial frequency/f_o and notes from 'Jangan Tinggal Daku' instrumental. C minor scale consist C, D, E♭, F, G, A♭, and B♭. Ab is replaced by Gb. The occurrence of A4, G5b, A5, E6, G6b and A6 are not in the C minor scale.

Partial frequency (Hz)	Partial frequency/f_o	notes	ETS
78	1	E2b	77
145	**1.85**	D3	146
196	2.51	G3	196
261	3.34	C4	261
309	**3.96**	E4b	311
388	**4.97**	G4	392
436	5.58	A4	440
465	**5.96**	B4b	466
524	6.71	C5	523
587	7.52	D5	587
630	**8.07**	E5b	622
699	**8.96**	F5	698
728	9.33	G5b	739
787	**10.08**	G5	783
872	11.17	A5	880
1036	13.28	C6	1046
1083	**13.88**	C6	1046
1163	**14.91**	D6	1174
1307	16.75	E6	1318
1377	17.65	F6	1396
1475	**18.91**	G6b	1480
1557	**19.96**	G6	1568
1746	22.38	A6	1760

Bold indicate a number that approximate an integer value.

Table 5. The partial frequency, partial frequency/f_o and notes from 'Dendang Perantau' instrumental. Bb natural minor scale consist of B♭, C, D♭, E♭, F, G♭, and A♭. The occurrence of D6, E6, and G6 are not in the Bb natural minor scale.

Partial frequency (Hz)	Partial frequency/f_o	notes	ETS (Hz)
87	1	F2	87.3
115	1.32	B2b	116.5
174	**2**	F3	174.6
206	2.36	A3b	207.6
231	2.65	B3b	233.8
259	**2.97**	C4	261.6
276	3.17	D4b	277.2
309	3.55	E4b	311.1
345	**3.96**	F4	349.2
411	4.72	A4b	415.3
548	6.29	D5b	554.3
701	**8.05**	F5	698.5
822	9.44	A5b	830.6
925	10.63	B5b	932.3
1047	**12.03**	C6	1046.5
1103	12.67	D6b	1108.7
1160	13.33	D6	1174.7
1238	14.22	E6b	1244.5
1301	**14.95**	E6	1318.5
1337	15.36	E6	1318.5
1404	16.13	F6	1396.9
1445	16.60	G6b	1480.0
1575	**18.10**	G6	1568.0
1651	**18.97**	A6b	1661.2
1684	19.35	A6b	1661.2

Bold indicate a number that approximate an integer value.

Table 6. The harmonics present in the studied instrumentals.

Pitch	Di Pinggiran	Getaran Jiwa	Jangan Tinggal Daku	Dendang perantau
A1b	–	1st	–	–
D2	1st	–	–	–
E2b	–	–	1st	–
F2	–	–	–	1st
D3	2nd	–	2nd	–
A3	3rd	–	–	–
E3b	–	3rd	–	–
F3	–	–	–	2nd
C4	–	–	–	3rd
D4	4th	–	–	–
E4b	–	–	4th	–
F4	–		–	4th
G4b	–	7th	–	–
G4	–	–	5th	–
A4	6th	–	–	–
B4b	–	9th	6th	–
C5	7th	–	–	–
D5b	–	11th	–	–
D5	8th	–	–	–
E5b	–	–	8th	–
E5	9th	–	–	–
F5	–	–	9th	8th
F5#	10th	–	–	–
G5	–	–	10th	–
A5	12th	–	–	–
C6	–	–	14th	12th
D6b	–	22nd	–	–
D6	16th	–	15th	–
E6		26th	–	15th
F6	19th	–	–	–
F6#	20th	–	–	–
G6b	–	30th	19th	–
G6	–	–	20th	18th
A6b	–	33rd	–	19th
Total number of harmonics	13	9	12	9

that are not strictly confined to a particular scale. They might introduce chromatic or non-diatonic notes to create certain emotions, add tension, or achieve a specific sound. The occurrence of A2, D4, E4, and E6 in 'Getaran Jiwa' maybe explain as the following:

i) A2: This note might be used as a passing tone or ornamentation to add a unique flavor to the melody. It could also be introduced to create a specific melodic contour or to emphasize a particular lyric.
ii) D4: While D4 is not in the Db major scale, it could be used as a chromatic passing tone or for melodic decoration. The use of non-diatonic notes can create a sense of surprise or tension, which might enhance the emotional impact of the song.
iii) E4: Similar to D4, E4 might be introduced for melodic embellishment or to add a touch of unpredictability to the melody. This note could create a subtle dissonance that resolves to a consonant note, contributing to the overall emotional expression.
iv) E6: May serve as a melodic extension or ornamentation. Its presence could contribute to a sense of musical richness and depth in the melody.

The occurrence of F5#, G5#, D6#, F6# and G6# in the D minor scale in 'Di Pinggiran', D6, E6, and G6 in the Bb natural minor scale in 'Dendang Perantau', and A4, G5b, A5, E6, G6b and A6 in the C minor scale in 'Jangan Tinggal Daku' can be explain as the occurrence of A2, D4, E4, and E6 in 'Getaran Jiwa' above. In general, all the instrumentals in P Ramlee songs might introduce chromatic or non-diatonic notes to create certain emotions, add tension, or achieve a specific sound. In summary, the instrumentals.

i) emphasize a particular lyric.
ii) create a sense of surprise or tension, which might enhance the emotional impact of the song.

iii) subtle dissonance that resolves to a consonant note, contributing to the overall emotional expression.
iv) as a melodic extension or ornamentation.

Table 7 showed the centroid ($\bar{f}$), affinity (A), sharpness (S), harmonicity (H), monotony (M), mean affinity (MA) and mean contrast (MC) from the 4 instrumentals. Fig. 5 showed the centroid ($\bar{f}$), affinity (A), sharpness (S), harmonicity (H), monotony (M), mean affinity (MA) and mean contrast (MC) from the 4 instrumentals.

The centroid $\bar{f}$ does not interpret specific acoustic. $\bar{f}$ (the average frequency for each spectrum) does not correspond to any of the partials frequencies of the sounds studied (Gonzalez & Prati, 2022). From Table 6 the $\bar{f}$ increased from 654.62 ('Di Pinggiran') followed by 667.80 ('Jangan Tinggal Daku'), 690.79 ('Getaran Jiwa') and 767.84 ('Dendang Perantau'). The Affinity A show how far f_o is from $\bar{f}$. Affinity increased from 1.43 ('Jangan Tinggal Daku) to 6.67 ('Dendang Perantau'), 8.98 ('Di Pinggiran') and 13.81 ('Getaran Jiwa'). The fundamental frequency from different musical sounds has different amplitudes. The dynamics modify the amplitude of the pitch and the amplitude ratio between f_o and its partials. The Sharpness S for 'Di Pinggiran' is 0.039, 'Getaran Jiwa' is 0.040, 'Dendang Perantau' is 0.056 and 'Jangan Tinggal Daku' is 0.065. Ideally, $S = 1$ in a pure sound that would have a single maximum without secondary frequencies. By construction, $S \leq 1$. Harmonicity evaluates how harmonic (quotient between f_j and f_o is an integer) the partial or secondary frequencies (f_1, f_2, f_3... f_j) in the FFT spectrum. H quantify the number of harmonics present for a given acoustic signal. H is related to color or sonority of the sounds. From Table 6, 'Di Pinggiran' showed the highest H i.e. 17.0 decreased to 8.2 ('Dendang Perantau') to 7.5 ('Jangan Tinggal Daku') and to only 5 ('Getaran Jiwa'). The distribution of secondary frequencies, whether harmonic or not, is quantified by monotony (M), which is the mean of the variances between two successive maxima. M determines whether the harmonics follow the fundamental frequency in an increasing (positive M) or decreasing (negative M) sequence. From Table 6, the monotony of 'Dendang Perantau' increased from −0.0096 followed by −0.0013 ('Di Pinggiran') to 0.0198 ('Jangan Tinggal Daku') and 0.0638 ('Getaran Jiwa'). The MA increase from 0.1689 ('Getaran Jiwa') to 0.5322 ('Dendang Perantau'), 0.8673 ('Di Pinggiran') and 1.3877 ('Jangan Tinggal Daku'). The MC increase from 0.1568 ('Di Pinggiran') to 0.3160 ('Dendang Perantau'), 0.4430 ('Jangan Tinggal Daku') and 0.4755 ('Getaran Jiwa').

Table 7. The centroid ($\bar{f}$), affinity (A), sharpness (S), harmonicity (H), monotony (M), mean affinity (MA) and mean contrast (MC) from the 4 instrumentals.

Instrumentals	$\bar{f}$	A	S	H	M	MA	MC
Getaran jiwa	690.79	13.81	0.040	5.0	0.0638	0.1689	0.4755
Di Pinggiran	654.62	8.96	0.039	17.0	−0.0013	0.8673	0.1568
Dendang Perantau	767.84	6.676	0.056	8.2	−0.0096	0.5322	0.3160
Jangan Tinggal Daku	667.80	1.43	0.065	7.5	0.0198	1.3877	0.4430

The measurement parameters are based on dimensionless coefficients such as the centroid as acoustic interpretations, the affinity coefficient as the mean value of centroids, and different musical sounds to determine different amplitudes, as well as harmonicity and monotony. An auxiliary note, also known as a passing note, is typically very short in duration. It is a brief, transitional note that connects two adjacent main tones in a melody. The passing note is usually played or sung quickly and does not receive as much emphasis or duration as the main tones. Its purpose is to create a smooth and fluid melodic line by adding a momentary embellishment between the primary notes. The exact duration of a passing note can vary based on the tempo of the music and the desired musical effect, but it is generally much shorter than a full beat, often lasting only a fraction of a beat.

In the key of Db major for 'Getaran Jiwa' the possible auxiliary (passing) notes that can take part in the melody which is typically shorter in duration than 1 beat, are typically the neighboring notes in the scale. In the case of Db major scale, it consists of Db, Eb, F, Gb, Ab, Bb, and C. So, the possible auxiliary notes would be the neighboring notes to the main tones of the melody, such as:

i) Db to C or Eb, its enharmonic is C# to C or D#
ii) Eb to Db or F, its enharmonic is D# to C# or F
iii) F to Eb or Gb, its enharmonic is F to D# or Gb
iv) Gb to F or Ab, its enharmonic is F# to F or G#
v) Ab to Gb or Bb, its enharmonic is G# to F# or Bb
vi) Bb to Ab or C, its enharmonic is A# to G# or C
vii) C to Bb or Db, its enharmonic is C to A# or C#
viii) These auxiliary notes are used to add movement and embellishment to the melody within the Db major scale.

In the key of D minor for 'Di Pinggiran', the possible auxiliary (passing) notes that can take part in the melody which is typically shorter in duration than 1 beat, are typically the neighboring notes in

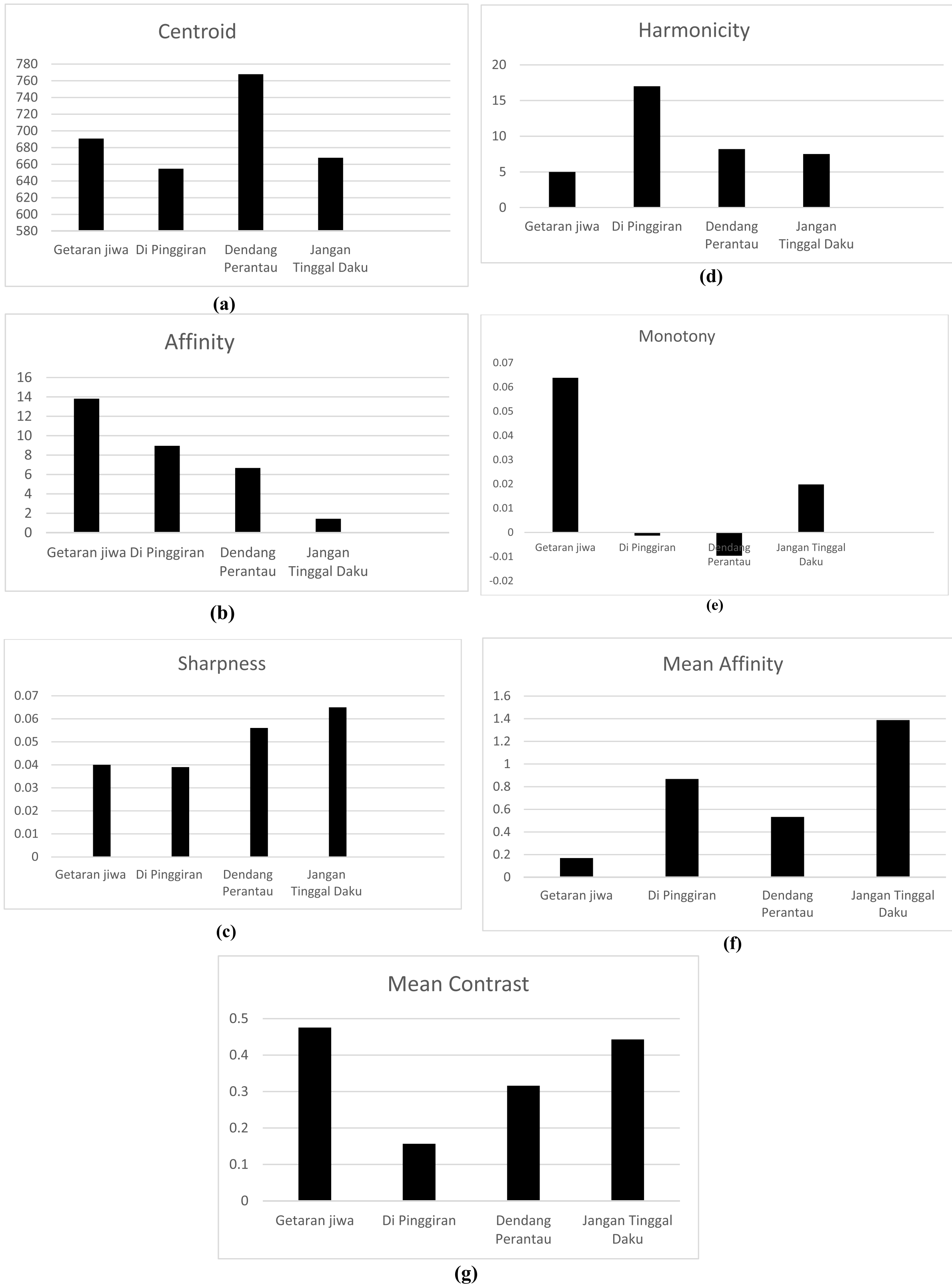

Fig. 5. (a) The centroid ($\bar{\mathbf{f}}$) from the 4 instrumentals. (b) The affinity (A) from the 4 instrumentals. (c) The sharpness (S) from the 4 instrumentals. (d) The harmonicity (H) from the 4 instrumentals. (e) The monotony (M) from the 4 instrumentals. (f) The mean affinity (MA) from the 4 instrumentals. (g) The mean contrast (MC) from the 4 instrumentals.

the scale. In the case of D minor scale, it consists of D, E, F, G, A, Bb, and C, so, the possible auxiliary notes would be the notes to the main tones of the melody, such as:

i) D to C or E, its enharmonic is D to C or E
ii) E to D or F, its enharmonic is E to D or F
iii) F to E or G, its enharmonic is F to E or G
iv) G to F or A, its enharmonic is G to F or A
v) A to G or Bb, its enharmonic is A to G or A#
vi) Bb to A or C, its enharmonic is Bb to A or C#
vii) C to Bb or D, its enharmonic is C to A# or D.

These auxiliary notes can be used to add movement and embellishment to the melody within the D minor scale.

In the key of Bb natural minor for 'Dendang Perantau', the possible auxiliary (passing) notes that can take part in the melody which is typically shorter in duration than 1 beat, are typically the neighboring notes in the scale. The Bb natural minor scale consists of Bb, C, Db, Eb, F, Gb, Ab, and Bb. So, the possible auxiliary notes would be the neighboring notes to the main tones of the melody, such as:

i) Bb to Ab or C, its enharmonic is Bb to G# or C
ii) C to Bb or Db, its enharmonic is C to A# or Db
iii) Db to C or Eb, its enharmonic is Db to C or D#
iv) Eb to Db or F, its enharmonic is Eb to C# or F
v) F to Eb or Gb, its enharmonic is F to D# or F#
vi) Gb to F or Ab, its enharmonic is Gb to F or G#
vii) Ab to Gb or Bb, its enharmonic is Ab to F# or A#

These auxiliary notes can be used to add movement and embellishment to the melody within the B natural minor scale.

In the key of C minor for the song 'Jangan Tinggal Daku', the possible auxiliary (passing) notes that can take part in the melody which is typically shorter in duration than 1 beat are usually the neighboring notes in the C minor scale. The C minor scale consists of C, D, Eb, F, G, Ab, Bb, and C. So, the possible auxiliary notes would be the neighboring notes to the main tones of the melody, such as:

i) C to Bb or D, its enharmonic is C to A# or D
ii) D to C or Eb, its enharmonic is D to C or D#
iii) Eb to D or F, its enharmonic is Eb to D or F
iv) F to Eb or G, its enharmonic is F to D# or G
v) G to F or Ab, its enharmonic is G to F or G#
vi) Ab to G or Bb, its enharmonic is Ab to G# or Bb
vii) Bb to Ab or C, its enharmonic is Bb to G# or C

These auxiliary notes can add embellishment and motion to the melody while staying within the C minor key for 'Jangan Tinggal Daku'.

In the key of Bb natural minor, the tension notes are typically note that create a sense of instability or anticipation. These notes are often used to create tension and then resolve to the stable tones of the scale. In the Bb natural minor scale (Bb, C, Db, Eb, F, Gb, Ab, and Bb), the tension notes are:

i) C (second degree): This note creates tension because it's a one step away from the root note Bb.
ii) Eb (fourth degree): The fourth degree can create tension, especially when played against the tonic (Bb), due to its unique interval relationship.
iii) Gb (sixth degree): The sixth degree can also add tension when played in certain melodic contexts.

These tension notes can be used strategically to add emotional depth and movement to the melody while maintaining the overall Bb natural minor tonality. Note that the use of tension and its resolution is a creative choice, and experimenting with different combinations can lead to interesting musical effects.

The musical names for these degrees in the context of the Bb natural minor scale are:

i) C (second degree): This is the major second interval.
ii) Eb (fourth degree): This is the perfect fourth interval.
iii) Gb (sixth degree): This is the minor sixth interval.

In the context of naming intervals beyond the octave (8th), the terms '11th' and '13th' are used to indicate the intervals above the root note. However, in the Bb natural minor scale, the 11th and 13th degrees would involve notes outside the natural minor scale itself. These degrees are often used in more complex harmony and extended chords. Tension notes add interest, emotion, and movement to a melody by creating a sense of anticipation or instability. They often lead to a resolution, which provides a satisfying musical experience. When using tension notes in a melody, it is important to consider how they fit within the overall context of the song and the intended emotional effect. Tension notes can be used to create moments of suspense, drama, or surprise, and they can contribute to the overall dynamics and narrative of the music.

4. Conclusions

The musical descriptors in the instrumental sounds of P Ramlee's compositions have been effectively characterized using six dimensionless coefficients. These coefficients, derived from Fast Fourier Transform (FFT) analysis, provide valuable insights into the distribution of harmonics, overtones, and their amplitudes in relation to the fundamental frequency, thus capturing the nuanced timbral qualities of the music. The study has applications for a broader audience in addition to advancing our understanding of musical timbre scientifically. The suggested coefficients are analytical instruments that can help academics advance the field of audio processing, learners gain a deeper grasp of musical structure, and composers replicate particular timbral properties. Through the conversion of musical subtleties into quantitative characteristics, this study provides a fresh perspective on the creative and affective depth of P Ramlee's works. The significance of these coefficients transcends mere numerical values. They serve as key parameters that enable the crafting of a comprehensive musical portrait, offering an in-depth understanding of the timbral richness and complexity inherent in the artist's works. To provide a more thorough characterization of musical characteristics, further study could expand this approach beyond the spectrum analysis by adding temporal elements, such as the assessment of note sticking time. This might improve our comprehension of musical temporal dynamics and support more comprehensive studies. By effectively translating musical nuances into quantifiable descriptors, our proposed coefficients facilitate a deeper exploration of P Ramlee's artistic realm, providing a novel lens through which to comprehend the interplay of harmonics and overtones that contribute to the emotive tapestry of his compositions. Furthermore, the insights from this study can be invaluable to audio archivists, especially in the development of deep learning systems as part of the Internet of Things (IoT) for automated music preservation and retrieval. By integrating these descriptors into deep learning frameworks, we can enhance the precision of audio classification and retrieval in large-scale archives, ensuring that culturally significant works like those of P Ramlee are preserved and accessible with high fidelity. This study's importance goes beyond P. Ramlee's direct area of expertise. The approaches and results discussed here can provide a basis for further research in a variety of musical genres, opening up new fields for the analysis and appreciation of music. The study not only pays tribute to the heritage of musicians like P Ramlee but also advances our understanding of the underlying structure and emotional resonance of music by bridging the gap between AI, signal processing, and music theory. By effectively translating musical nuances into quantifiable descriptors, our proposed coefficients facilitate a deeper exploration of P Ramlee's artistic realm, providing a novel lens through which to comprehend the interplay of harmonics and overtones that contribute to the emotive tapestry of his compositions. In the realm of music research, our findings hold potential far beyond the immediate scope of P Ramlee's work. These coefficients may serve as building blocks for future studies that seek to unravel the timbral intricacies of diverse musical genres, unlocking new avenues for music analysis and appreciation. As our investigation culminates, it is clear that the signal processing, and music analysis has unveiled a new dimension in our understanding of musical expression. This multidisciplinary approach not only pays homage to the legacy of artists like P Ramlee but also propels our understanding of music's underlying structure and emotional resonance into uncharted realms. Moving forward, our findings beckon future researchers to further refine and expand this framework, fostering a continued exploration of the dynamic relationship between artistry, technology, and cultural heritage. To sum up, this study has the potential to help researchers, composers, students, and audio archivists by equipping them with the knowledge and instruments required to investigate and comprehend the complex connections between spectral characteristics and musical expression and to promote the accessibility and long-term preservation of musical heritage.

Ethics information

None.

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Declaration of Generative AI and AI-assisted technologies in the writing process

We declare that no Artificial Intelligence (AI) technologies or AI-assisted tools were utilized in any capacity during the writing and preparation of this article.

Conflict of interest

We declare that there is no conflict of interest regarding the publication of this paper.

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