Journal of Mechanical Engineering and Sciences (JMES)
ISSN (Print): 2289-4659; e-ISSN: 2231-8380
Volume 11, Issue 1, pp. 2552-2566, March 2017

DOI: https://doi.org/10.15282/jmes.11.1.2017.13.0234

Correlation and clusterisation of traditional Malay musical instrument sound using the I-KAZ™ statistical signal analysis

M.A.F. Ahmad[1], M.Z. Nuawi[1*], A.R. Bahari[2], A.S. Kechot[3] and S.M. Saad[4]

[1]Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia,
43600 UKM Bangi, Selangor, Malaysia
[*]Email: mzn@ukm.edu.my
Phone: +60389216507; Fax: +60389259659
[2]Faculty of Mechanical Engineering Universiti Teknologi MARA Terengganu, Kampus Bukit Besi, 23200 Bukit Besi Dungun, Terengganu, Malaysia
[3]School of Malay Language, Literature and Culture Studies,
Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia,
43600 UKM Bangi, Selangor, Malaysia
[4]School of Language Studies and Linguistic,

ABSTRACT

The best feature scheme is vital in musical instrument sound clustering and classification, as it is an input and feed towards the pattern recognition technique. This paper studies the relationship of every traditional Malay musical instrument acoustic sounds by implementing a correlation and clustering method through the selected features. Two types of musical instruments are proposed, namely flutes involving key C and key G classes and *caklempong* consisting of *gereteh* and *saua.* Each of them is represented with a set of music notes. The acoustic music recording process is conducted using a developed design experiment that consists of a microphone, power module and data acquisition system. An alternative statistical analysis method, namely the Integrated Kurtosis-based Algorithm for Z-notch Filter (I-kaz™), denoted by the I-kaz coefficient, Z^{∞}, has been applied and the standard deviation is calculated from the recorded music notes signal to investigate and extract the signal's features. Correlation and clustering is done by interpreting the data through Z^{∞} and the standard deviation in the regression analysis and data mining. The results revealed that a difference wave pattern is formed for a difference instrument on the time-frequency domain but remains unclear, thus correlation and clusterisation are needed to classify them. The correlation of determination, R^2 ranging from 0.9291 to 0.9831, thus shows a high dependency and strong statistical relationship between them. The classification of flute and *caklempong* through mapping and clustering is successfully built with each of them separated with their own region area without overlapping, with statistical coefficients ranging from (2.79 x 10^{-10}, 0.002932) to (1.64 x 10^{-8}, 0.013957) for *caklempong*, while the flute measured from (2.45 x 10^{-9}, 0.013143) to (1.92 x 10^{-6}, 0.322713) in the x and y axis.

Keywords: Correlation, clustering; classification; I-kaz statistical analysis; Malay musical instrument.

INTRODUCTION

Traditional Malay musical instruments are cultural musical tools that serve as an entertainment and communication channel with a way of accompanying the performing arts in the local community through the production of a wide range of sound strains. These tools are created from the wisdom of Malay peoples by adapting their environment to the needs of life. Among all of the Malay technological performing arts instruments, *rebab*, *gambus*, *gamelan*, *serunai*, *gendang*, *rebana*, *caklempong* and *gong* are the most recognisable by the public. The instruments are mainly used to accompany traditional dance and music, such as *kuda kepang* and *mak yong*, *zapin*, *ghazal*, traditional theatre such as *wayang kulit* (shadow puppet) and for religious activities such as *Nasyid*, *Maulid Nabi* and *berzanji*[1]. Gongs, drums and flutes are commonly found in Southeast Asia. There are also some of them that have close affinities with the Islamic culture such as *rebab, rebana*, mandolin and *nafiri* [2]. These musical instruments can be classified into 4 groups, namely aerophone, membranophone, idiophone, and chordophone instruments [3]. Aerophone instruments produce sound through vibrating air such as *serunai,* flute, *bangsi* and *nafiri*. Membranophone instruments produce sound through skin stretching or a vibrating membrane where *gendang*, *rebana*, *jidur* dan *kompang* can be taken as an example. Hitting them either with the hand or a specific tool will generate vibration and energise them to produce sound [4]. *Caklempong,gong*, *kesicanang* and *gamelan* instruments are idiophone types, which produce sound through body vibration. As for chordophone instruments, they produce sound through vibrating strings such as the *rebab*, *gambus* and flute.

The basis of music is the tones arrangement produced either from musical instruments or from the voice box of a singer. The resulting tones are sound signals that have their own physical properties such as the intensity and frequency of sound. According to Bartholomiew [5], the three components that are needed to produce sound signals are devices that can vibrate, a medium for vibration transferring and the vibration receiver. The instruments are commonly recognised by local experts through the physical figure and the sound they produce when played. However, errors always occur and are present in human nature because of partial misinterpretations, an incorrect judgment of similar sounds from different types of instruments, outside interference such as noise or perceived bias [6]. Recent studies have reviewed the musical instruments sounds classification system to assist people in recognising the music of instruments. It is a systematic approach that identifies and categorises the musical sound signals. Generally, the sound classification process of musical instruments involved 4 main stages, namely pre-processing, feature extraction, feature selection and classification, where the majority of the research focuses on the feature extraction and feature analysis [7, 8]. Finding a suitable classifier is vital to improving the classification accuracy and efficiency, while the robust feature set is a major challenge in instrument classification. There is a lot of research focused on the clustering and classification of musical instruments. Previously, there were some researchers that mainly focused on the polyphonic music signal for instrument classification [9-15].Past researchers like Deng et al. [16] discussed feature analysis including the MPEG-7, statistical values of the mel frequency cepstral coefficient (MFCC), zero crossing rate (ZCR), root mean square (RMS), spectral centroid and flux using various machine learning techniques. In addition, Özbek et al. [17] worked on the time-frequency energy of wavelet ridges using the Support Vector Machine (SVM) for automatic musical instrument classification. A further study was then conducted by Souza et al. [18] by classifying drum sounds with the SVM algorithm using Line Spectral Frequencies (LSF).

All of the previous research studies above show significant redundancy within different feature schemes for the musical instrument classification. The major challenge for the musical instrument classification is finding an optimum and efficient feature set. Chandwadkar &Sutaone [19], Malheiro & Cavaco [20], Kolozali et al. [21] and Burred et al. [10] concluded that finding new features will be the future scope of research. The selection of a suitable classifier also plays a significant role in improving the classification accuracy. Furthermore, it was observed that time and frequency information would be the best choice for modelling the sound signal of musical instruments. Recent studies had developed a new alternative statistical analysis for feature extraction, namely the Integrated Kurtosis-based Algorithm for the Z-notch filter (I-kaz^{TM}). It was used in many extensive applications in engineering field studies. For example, an induction motor bearing fault detection [22] and tool wear condition monitoring on turning machining assisted by the I-kaz^{TM} statistical analysis was developed, by interpreting the raw vibration signal data from sensors [23-25]. In addition, I-kaz^{TM} was used in the development of polymer and metal material properties characterisation using the impulse excitation technique and was proven to be highly successful with minimal error [26, 27]. Additionally, Bahari et al.[28] were able to classify data signals from traditional musical instruments using a combination of I-kaz^{TM} with a novel statistical analysis technique, Mesokurtosis Zonal Nonparametric (M-Z-N).

The primary objective of this study is to develop a correlation and clustering of *caklempong* and flute traditional musical instruments music note signals using a selected feature, which is an I-kaz^{TM} statistical analysis. The tests are arranged as follows where a design of the experiment is implemented to record and process the musical instrument, consisting of a microphone, power module and data acquisition system. The atheoretical background of the I-kaz™ statistical signal analysis method is explained. The results obtained directly through the recording process of the acoustic signal are presented. Finally, a discussion on the correlation and data clustering of the acoustic signal of each instrument is presented in detail.

METHODOLOGY

This study involves two categories of traditional musical instruments, each with two types of equipment. They are traditional Malay flutes consisting of key C and key G, while *cak lempong* involves the *gereteh* and *saua* instrument. Each of the traditional Malay musical instruments is played based on fixed music notes by the musicology experts from the Academy of Arts, Culture and National Heritage (ASWARA). The sound recording is carried out in the recording room where each of the selected notes is played one by one until done. The process of recording the acoustic sound of all instruments is done using a developed experimental design, which consists of a Studio Projects B1 condenser microphone, Studio Projects VTB1 V Series power module and a National Instruments NI PXI-1031DC data acquisition device as depicted in Figure 1. Each instrument is played in a room while the recording process is initiated. Based on Figure 1, the sound of each note is converted to an electrical signal by microphone, amplified by the power module and then goes through the data acquisition system for data gathering and processing. All of the recorded signals are stored and analysed using a computer. A list of all the notes involved is shown in Table 1 with their respected instrument.

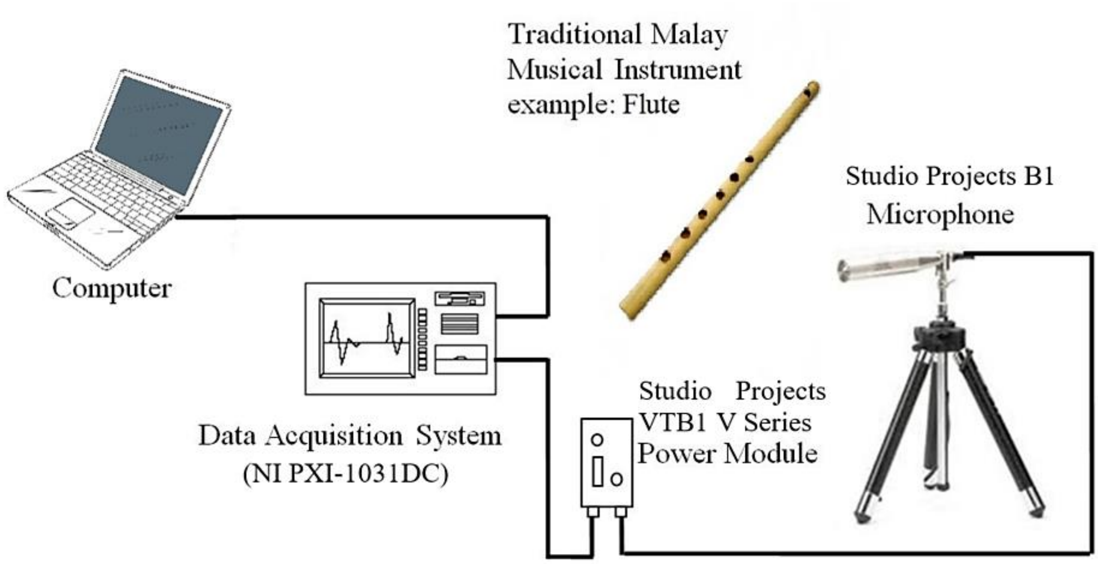


Figure 1. Schematic design of the experiment.

Table 1. List of music notes for selected traditional Malay musical instruments.

Cak Lempong	Flute
Gereteh $G^4,A^4,B^{b4},B^{4},C^5,C^{\#5},D^5,D^{\#5},E^5,F^5,F^{\#5},$ $G^5,G^{\#5},A^5,B^{b5},B^5,C^6,C^{\#6},D^6,E^6,F^6,G^6$	Key C $G^2,G^{\#2},A^2,A^{\#2},B^2,C^3,C^{\#3},D^3,D^{\#3},E^3,F^3,F^{\#3},G^3,$ $G^{\#3},A^3,A^{\#3},B^3,C^4, C^{\#4},D^4,D^{\#4},E^4, F^4, F^{\#4},G^4$
Saua B^3,C^4,D^4,E^4,F^4,G^4 $A^4,C^{\#4},D^{\#4},F^{\#4},G^{\#4}A^{\#4}$	Key G $D^2,D^{\#2},E^3,F^2,F^{\#2},G^2,G^{\#2},A^2,A^{\#2},B^2,C^3,C^{\#3},D^3,$ $D^{\#3},E^3,F^3,F^{\#3},G^3,G^{\#3},A^3,A^{\#3},B^3,C^4,C^{\#4},D^4$

The selection and extraction of acoustic signals involves the application of an alternative statistical analysis method, which is an Integrated Kurtosis-based Algorithm for the Z-notch filter (I-kaz™) and a common statistical parameter, which is standard deviation, SD. Both of them are applied using the MATLAB software. The I-kaz™ statistical analysis method is an alternative approach that was pioneered by Nuawi et al. [29]. The I-kaz™ analysis is used in this study because it is a very good method for detecting the changes of amplitude and frequency that occur in a signal. Later on, this statistical method has been optimised by Karim et al. [30] where it shows more sensitivity than the current I-kaz™ analysis and can be used for the dynamic signals analysis. The development of statistical analysis methods I-kaz ™ is based on the concept of scattering or distribution of data to its centre point called centroid. The I-kaz coefficient, Z^∞ is defined in Equation (1):

$$Z^\infty = \frac{1}{n}\sqrt{K_L SD_L{}^4 + K_H SD_H{}^4 + K_V SD_V{}^4} \tag{1}$$

where K_L, K_H and K_V is the kurtosis value of the low frequency range (L), high frequency range (H) and very high frequency range (V). On the other hand, SD_L, SD_H and SD_V are the standard deviations for the low frequency range, high frequency range and very high frequency range.

Statistical parameters, such as the standard deviation, mean value, root mean square, skewness and kurtosis are the most frequent and commonly used to classify random signals. The standard deviation, SD is a measure used to quantify the amount of variation and dispersion of how a set of data values really is. The calculation to obtain the standard deviation values is shown in Equation 2 below:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n}} \quad (2)$$

Where x represents each data value, μ is the mean and n is the number of data values.

The results of the statistical analysis obtained are obtained using the I-kaz coefficient and the parameter value of the standard deviation for the selected data. These values will be used as a resource to perform correlation, mapping and clustering based on the selected notes to distinguish the acoustic signals of each instrument. A flow chart of a whole process for the study is shown in Figure 2.

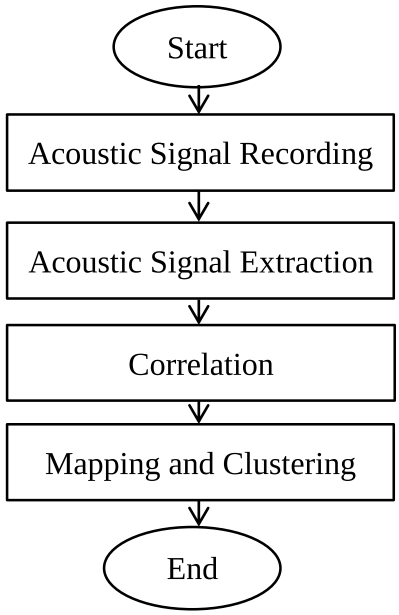


Figure2. Flow chart of the research.

RESULTS AND DISCUSSION

Acoustic Signal Recording

The recorded sound for each note is stored in a .wav format while the acoustic signals are interpreted in the time-frequency domain. Signal processing involving a time-frequency domain is done using MATLAB for each .wav data stored. Figure 3 presents the time and frequency domain of a G4 note acoustic signal for *cak lempong* that consists of *gereteh* and *saua*, while key C and key G traditional flutes are settled with the D4 note in Figure 4. The figure shows the signals, which appeared to be different for each of the instruments. It can be observed that the time domain acoustic signal of *caklempong* is in a transient shape, both *gereteh* and *saua*. When the *caklempong* is hit, the acoustic signal is generated very quickly. Once the maximum amplitude is achieved through the vibration, acoustic signals will start to decline transiently due to the damping effects of the instrument, exactly in the same pattern as described by the previous researcher [28]. For the flute instrument either on key C or key G, the time domain of the acoustic signal increases rapidly when blown. The amplitude of the acoustic wave signal is nearly constant throughout time and starts to decline rapidly and transiently when the flute is stopped from being blown. The peak magnitude happens to be on the same dominant frequency on both the *gereteh* and *saua*. Identical phenomena also occurred on both of the flutes, where the maximum magnitude took place on the same dominant frequency. However, their sound is slightly different from their counterpart because there are some residual magnitudes occurring at certain frequencies other than the dominant one. Those magnitudes occur at a different frequency location on the *caklempong* instrument, ranging from 2000 to 2600 Hz for the *gereteh* and 1500 to 2600 Hz for the *saua*on Figure 3. The same case also applies for both types of flutes in Figure 4, ranging from 3500 to 3600 Hz for Key C and 2400 to 2500 Hz for Key G. This is the main reason that led to a sound variation despite the use of the same music note [31].

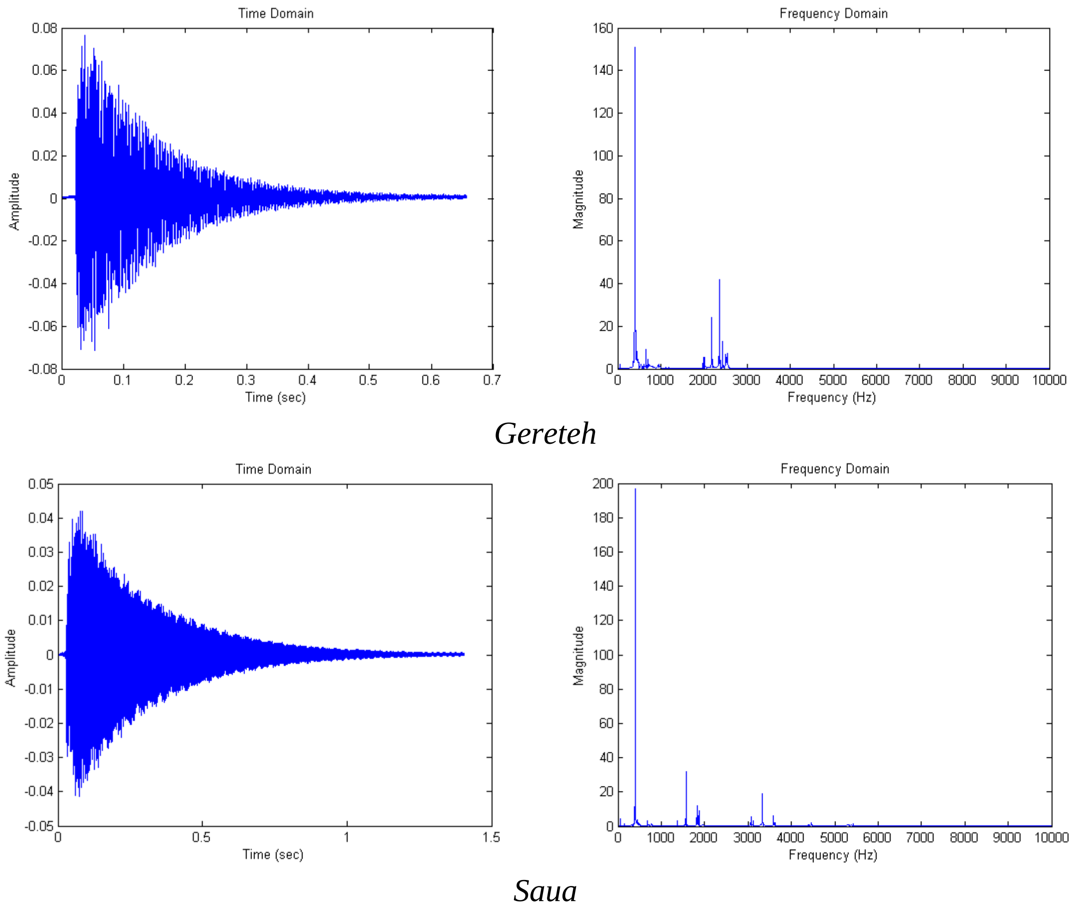


Figure 3. Time and frequency domain of *cak lempong (gereteh & saua)* on the G4 note

Acoustic Signal Extraction using the Statistical Analysis Method

Generally, the differences between the musical acoustic signals cannot be clearly identified, as shown in Figure 3 and Figure 4. Mapping and clustering of musical acoustic signals cannot be performed by using the data source of the time domain signals alone. Thus, the statistical analysis is used to assist the identification of the level of difference of the acoustic musical signal precisely. Previous researchers such as Singh & Koolagudi [32] used numerous statistical analyses to successfully classify 5 different Punjabi folk musical instruments with 91 % accuracy of recognition. Table 2 and Table 3 show the results obtained by the statistics analysis extraction for each acoustic signal involved.

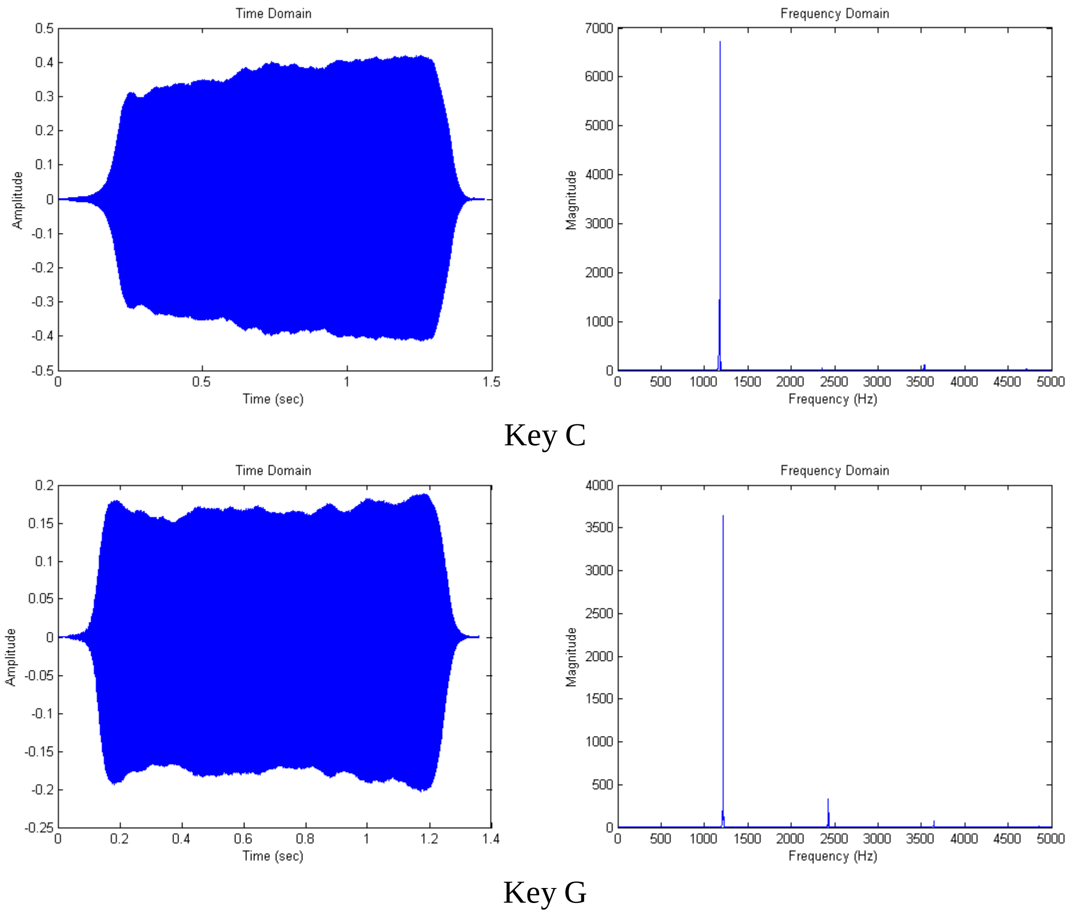


Figure 4. Time and frequency domain of the flute (key C & key G) on the D4 note

The statistical extraction method is based on the coefficient of I-kaz™ and on the standard deviation. The coefficient of I-kaz, Ƶ^{∞} is calculated using Equation 1 while the standard deviation, SD is calculated using Equation 2. Statistical analysis methods are widely used in the current research because it is simple and accurate. The process of calculating the value of the coefficients is performed using MATLAB. The values of the parameters are then plotted as shown in Figure 5 and Figure 6 so that the result criteria and their relationship can be clearly seen and observed.

Correlation of Data Using the I-kaz™ Statistical Analysis

Based on Table 2 and Table 3, data are correlated by constructing a graph of standard deviation with respect to the I-kaz coefficient values for each of the instruments. Figure 5 shows the regression line that occurs for *caklempong* (*gereteh &saua*) and Figure 6 for the flute (key C & key G) instrument. A quadratic polynomial curve fitting is used to calibrate the I-kaz coefficient. The correlation of determination, R^2 is derived from the regression analysis using Microsoft Excel and is used to measure the goodness of fit of a model.

Table 2. I-kaz™ coefficient, $Ƶ^{\infty}$ and Standard Deviation, SD for *cak lempong*

	Gereteh			*Saua*	
Notes	$Ƶ^{\infty}$	SD	Notes	$Ƶ^{\infty}$	SD
A4	9.74E-09	0.011288	A4	5.12E-10	0.003881
A5	2.05E-09	0.006345	A#4	5.41E-10	0.003777
B4	1.29E-08	0.013538	B3	1.48E-09	0.006638
B5	1.21E-09	0.005267	C4	3.86E-09	0.011774
B^{b4}	3.76E-09	0.008159	C#4	3.14E-09	0.008649
B^{b5}	7.4E-09	0.014103	D4	2.27E-09	0.008838
C5	2.81E-09	0.006914	D#4	2.79E-10	0.002932
C6	3.18E-09	0.00711	E4	7.81E-10	0.004356
C#5	1.95E-09	0.006269	F4	1.06E-09	0.005104
C#6	6.96E-09	0.010512	F#4	5.14E-10	0.003973
D5	6.31E-10	0.004224	G4	7.93E-10	0.005161
D6	5.19E-09	0.009723	G#4	7.29E-10	0.003613
D#5	2.76E-09	0.008526			
E5	7.50E-10	0.004948			
E6	4.59E-09	0.011096			
F5	1.34E-09	0.005502			
F6	5.28E-09	0.012027			
F#5	1.67E-09	0.006525			
G4	1.51E-09	0.005786			
G5	1.39E-09	0.00399			
G6	4.43E-09	0.008731			
G#5	1.64E-08	0.013957			

Table 3.I-kaz™ coefficient, $Ƶ^{\infty}$ and Standard Deviation, SD for the traditional flute

	Key C			Key G	
Notes	$Ƶ^{\infty}$	SD	Notes	$Ƶ^{\infty}$	SD
A2	4.46E-08	0.047955	A2	2.64E-08	0.039018
A3	4.89E-07	0.14567	A3	4.07E-08	0.051377
A#2	2.56E-08	0.03959	A#2	9.66E-09	0.026281
A#3	2.48E-07	0.114322	A#3	4.48E-08	0.039054
B2	1.03E-07	0.072386	B2	2.66E-08	0.042466
B3	5.38E-07	0.146012	B3	6.58E-08	0.058708
C3	8.34E-08	0.068866	C3	8.2E-09	0.022136
C4	8.57E-07	0.205069	C4	4.73E-08	0.05796
C#3	2.29E-08	0.035686	C#3	3.05E-08	0.043267
C#4	3.85E-07	0.140363	C#4	1.25E-07	0.070583
D3	4.54E-08	0.049685	D2	7.55E-09	0.01761
D4	8.05E-07	0.207682	D3	2.38E-08	0.036496
D#3	2.57E-08	0.040068	D4	1.18E-07	0.081466
D#4	2.86E-07	0.123101	D#2	2.45E-09	0.014433
E3	1.25E-07	0.074931	D#3	7.99E-09	0.024031
E4	6.35E-07	0.193431	E2	2.58E-09	0.013143
F3	1.06E-07	0.07326	E3	1.86E-08	0.037203
F4	8.99E-07	0.223448	F2	4.51E-09	0.018163
F#3	2.98E-07	0.12634	F3	9.42E-09	0.027743
F#4	1.92E-06	0.322713	F#2	1.71E-08	0.030536
G2	5.03E-08	0.0498	F#3	5.41E-08	0.052766
G3	4.06E-07	0.149085	G2	1.76E-08	0.035913
G4	6.49E-07	0.195821	G3	4.65E-08	0.052859
G#2	2.24E-08	0.03352	G#2	3.73E-09	0.015997
G#3	1.78E-07	0.095936	G#3	1.86E-08	0.034831

The significance of data was verified using the ANOVA. It was done using a one-way ANOVA to extract the p-values of each instrument. They were proven to be in a high level of precision. As shown in Figure 5 and 6, a quadratic polynomial is implemented because R^2 shows a very good value above 0.9, ranging from 0.9291 to 0.9831, thus showing a strong statistical relationship and dependency between those two statistical data. The constructed regression line is relevant and approximates the real data points. The results obtained are summarised in Table 4.

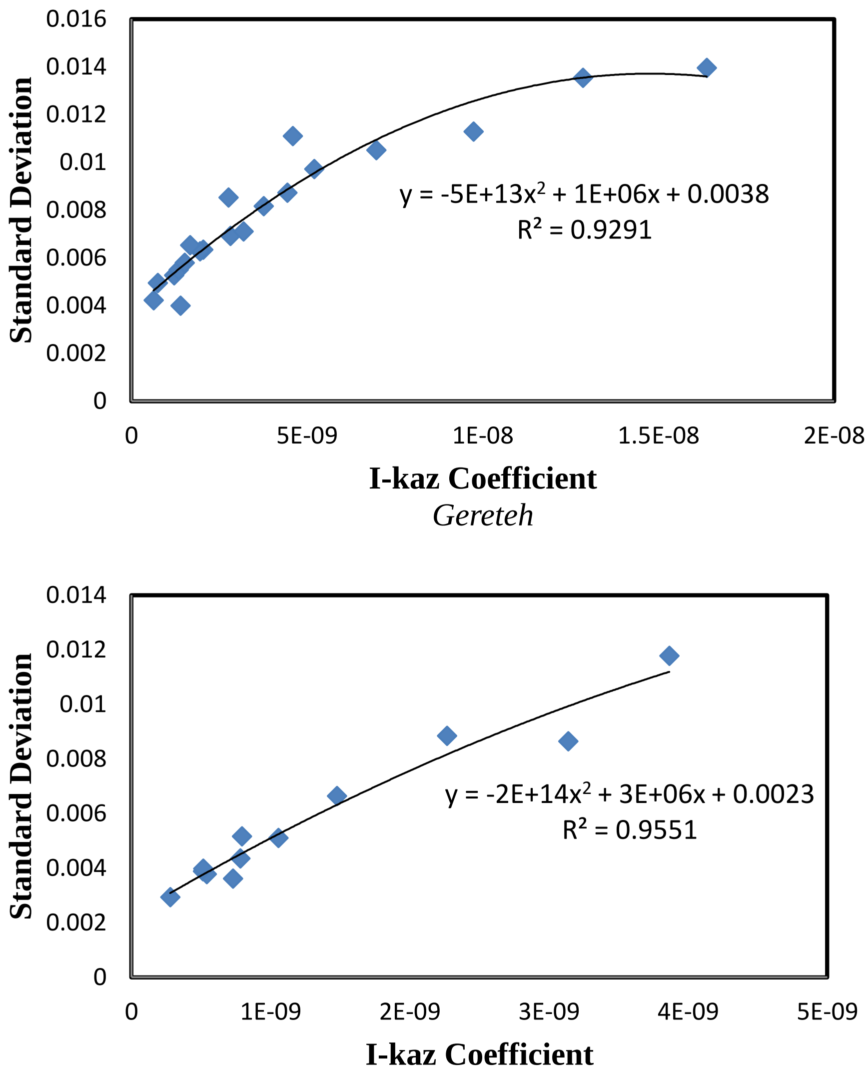
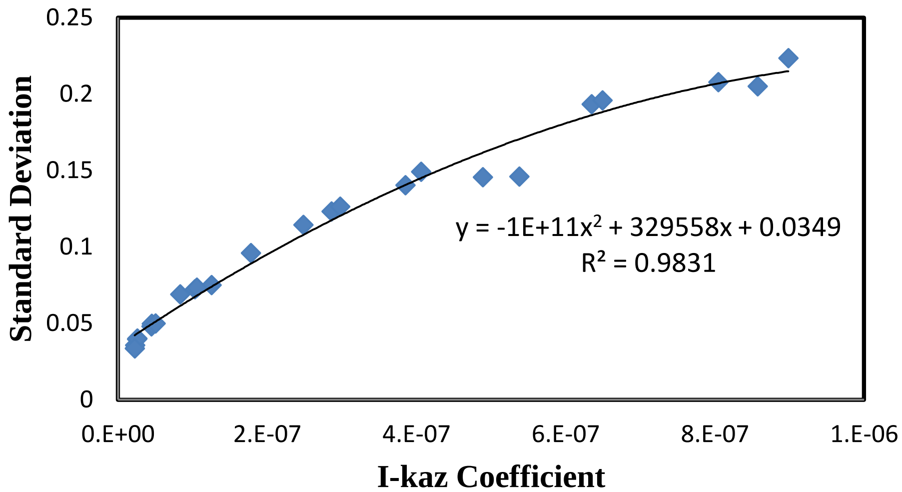
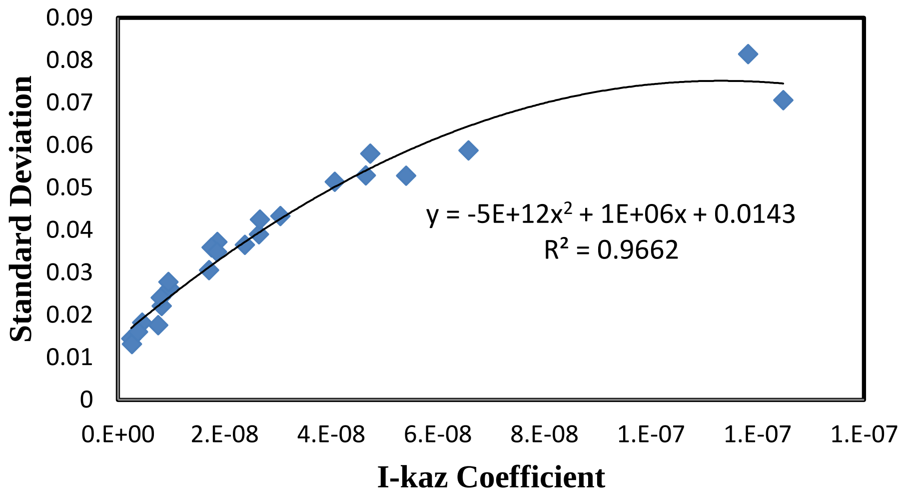


Figure 5. Correlation of *cak lempong* (*gereteh* & *saua*) using the statistical analysis

As depicted in Table 4, the polynomial equations above can be used to automatically identify musical instruments in the next future study. As the R2 are above 0.9. they need to undergo mapping and clustering before the implementation of the equations can be done. Any data that overlap in clusterisation will reduce the recognition accuracy, thus resulting in error when performing the direct and automatic musical instruments classification [7].



Key C



Key G

Figure 6. Correlation of flute (key C & key G) using the statistical analysis

Table 4. Correlation of determination, R^2 and polynomial equation for the selected musical instruments.

Category	Type	Polynomial Equation	R^2
Cak lempong	*Gereteh*	$y = -5E+13x^2 + 1E+06x + 0.0038$	0.9291
	Saua	$y = -2E+14x^2 + 3E+06x + 0.0023$	0.9551
Flute	Key C	$y = -1E+11x^2 + 329558x + 0.0349$	0.9831
	Key G	$y = -5E+12x^2 + 1E+06x + 0.0143$	0.9662

Mapping and Clustering

Based on all the data from Table 2 and Table 3, the values for the I-kaz coefficient and standard deviation for all instruments are plotted and mapped, combining the graphs from Figure 5 and Figure 6 into one to investigate a more detailed statistical result criteria. After the data are mapped, they are then clustered, representing the instruments localising area. The purpose of clustering the data values of the statistical parameter is to classify and determine the differences of the musical instruments, which are the *caklempong* and the flute based on the selected notes. The clustering graph is displayed in Figure 7 and Figure 8.

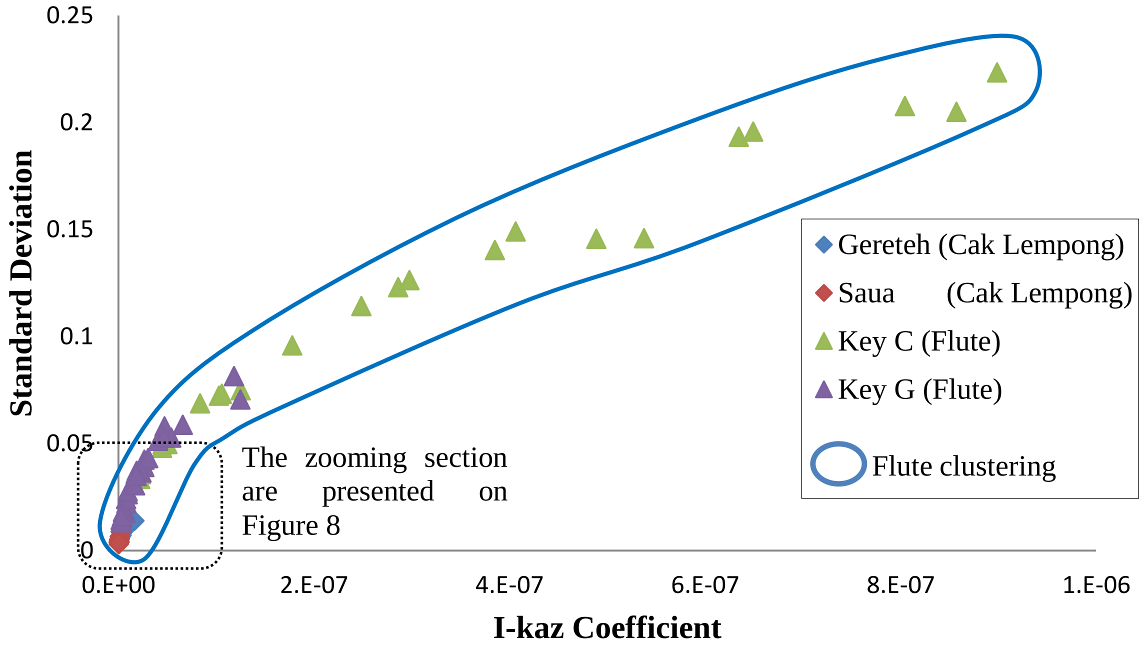


Figure 7. Data mapping and clustering of *caklempong* based on the statistical analysis

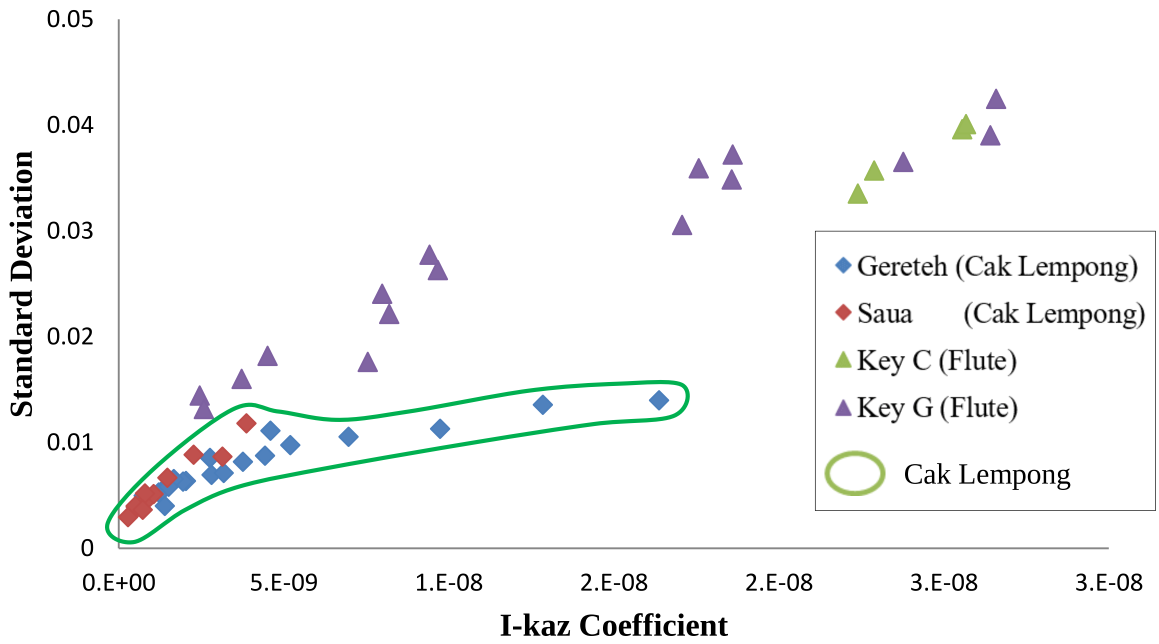


Figure 8. Data mapping and clustering of the flute instrument based on the statistical analysis

Referring to the clustering of Figure 7 and Figure 8, it can be observed that the selected notes for different musical instruments can be grouped together based on the statistical values of each of them. Figure 8 is the zooming section shown in Figure 7. The flute mapping data need to be zoomed as they cannot be seen clearly in Figure 7. The flute (key C and key G) clustering is denoted by the green line shape while *caklempong* (*gereteh* and *saua*) clustering was the green line shape. The statistical coefficient of the flute instrument has the highest range value compared with *caklempong*, ranging between (2.79×10^{-10}, 0.002932) and (1.64×10^{-8}, 0.013957) in the (x, y) axis, while the flute measured from (2.45×10^{-9}, 0.013143) to (1.92×10^{-6}, 0.322713). The previous research conducted by Bhalke et al. [7] and Shetty & Hedge [33] had employed a similar clustering method, but using the fractional fourier transform, FrFT-based MFCC feature and also the linear predictive coefficients (LPC) feature combined with MFCC for clustering. The result revealed that while most of the instruments data can be grouped together with their own kind, there are some that are overlapped with each other. Using I-kaz^{TM} as a feature for clustering, as depicted in the figures above, the caklempong and flute instrument data are not overlapping with each other, making it the ideal feature for automatic classification in a future work. However, two identical and similar instruments are somehow overlapping with themselves, for example key C and key G in the flute class, as depicted in Figure 8.

The statistical coefficients on key C have the higher value compared to key G. Whereas the range of the coefficient for *gereteh* is higher compared to *saua*. The time and frequency domain analysis as shown in Figure 3 and Figure 4 cannot clearly distinguish the acoustic signal for the two categories of instruments (*cak lempong* & flute) that cover 4 types of equipment (*gereteh*, *saua*, key C, key G). Therefore, by using the mapping and clustering method that involve the coefficient of statistical analysis, the acoustic signal with different musical instruments has been characterised in specific zones. Furthermore, the correlation method that has been discussed above can be used in a future work as a guideline for musical instrument makers to get an accurate sound when fabricating and tuning a new one especially, *caklempong* and traditional flute instruments. The statistical values of a new instrument can be compared with the original and any similarities or differences can be issued through the mapping and clustering of the I-kaz^{TM} analysis method. The correlation between the statistical parameters can be constructed and compared to distinguish their differences so that the new instrument can be fixed and tuned to meet the original specification. In addition, this research finding can be developed and extended to a further study involving the acoustic signal database for the selected traditional musical instrument by automatically identifying and recognising the musical signal using the I-kaz^{TM} statistical analysis method. This can be done by embedding the polynomial model found in the correlation section above into the programming software complete with recording equipment and directly translate the music note and type of instrument being played.

CONCLUSIONS

In this study, the correlation, mapping and clustering of acoustic signals of traditional Malay musical instruments for *cak lempong* (*gereteh* and *saua*) and flute (key C and key G) has been successfully implemented. The development of this method is based on the coefficient from statistical methods using the standard deviation value and the alternative statistical analysis, namely the kurtosis-based Integrated Algorithm for the Z-notch filter (I-kaz™). The waveforms of the time and frequency domain of the acoustic signals for the musical instruments are recorded and presented based on the music notes of the music instrument. They show a different pattern of each instrument but cannot clearly distinguish them, so a further statistical analysis is required. Thus, the correlation has been done on *caklempong* and flute using the resulting statistical values. The results showed a strong relationship between the standard deviation and coefficient of I-kaz with R^2 ranging from 0.9291 to 0.9831. Through the process of mapping and clustering, the results indicate that the acoustic signal of different musical instruments can be characterised and classified through the statistical coefficients in a specific region and do not overlap with each other. For future works, this can serve as a guide for a new automatic classification for Malay musical instruments by automatically identifying and recognising musical signals using the I-kaz™ statistical analysis method, thus distinguishing and differentiating every music note and instrument being played.

ACKNOWLEDGEMENT

The author wish to express their gratitude to Universiti Kebangsaan Malaysia and Ministry of Higher Education Malaysia, through the funds of INDUSTRI-2013-053, ERGS/1/2011/SSI/UKM/02/6 and ERGS/1/2013/TK01/UKM/02/2, for supporting this research.

REFERENCES

[1] Hassan AM. Idiosyncratic aspects of malaysian music: The roles of the compang in malay society. UNESCO Regional Expert Symposium on Arts Education in Asia, Hong Kong; 2004.

[2] Ahmad AT. Museum preservation and conservation of cultural heritage in the northern region of peninsula malaysia. SARI: Jurnal Alam dan Tamadun Melayu. 2010;28:3-34.

[3] Shriver R. Digital stereo recording of traditional malaysian musical instruments. Audio Engineering Society Convention 114: Audio Engineering Society; 2003.

[4] Ismail A, Samad SA, Hussain A, Azhari CH, Zainal MRM. Analysis of the sound of the kompang for computer music synthesis. IEEE 4th Student Conference on Research and Development; 2006. p. 95-8.

[5] Bartholomew WT. Acoustics of music: Prentice-Hall; 1942.

[6] Ferguson S. Learning musical instrument skills through interactive sonification. Proceedings of the 2006 conference on New interfaces for musical expression: IRCAM—Centre Pompidou; 2006. p. 384-9.

[7] Bhalke D, Rao CR, Bormane D. Automatic musical instrument classification using fractional fourier transform based-mfcc features and counter propagation neural network. Journal of Intelligent Information Systems. 2016;46:425-46.

[8] Senan N, Ibrahim R, Nawi NM, Mokji MM. Feature extraction for traditional malay musical instruments classification system. IEEE International Conference of Soft Computing and Pattern Recognition; 2009. p. 454-9.

[9] Barbedo JGA, Tzanetakis G. Musical instrument classification using individual partials. IEEE Transactions on Audio, Speech, and Language Processing. 2011;19:111-22.

[10] Burred JJ, Robel A, Sikora T. Dynamic spectral envelope modeling for timbre analysis of musical instrument sounds. IEEE Transactions on Audio, Speech, and Language Processing. 2010;18:663-74.

[11] Giannoulis D, Klapuri A. Musical instrument recognition in polyphonic audio using missing feature approach. IEEE Transactions on Audio, Speech, and Language Processing. 2013;21:1805-17.

[12] Jiang W, Ras ZW. Multi-label automatic indexing of music by cascade classifiers. Web Intelligence and Agent Systems: An International Journal. 2013;11:149-70.
[13] Nakamura T, Kameoka H, Yoshii K, Goto M. Timbre replacement of harmonic and drum components for music audio signals. IEEE International Conference on Acoustics, Speech and Signal Processing; 2014. p. 7470-4.
[14] Salamon J, Gómez E, Ellis DP, Richard G. Melody extraction from polyphonic music signals: Approaches, applications, and challenges. IEEE Signal Processing Magazine. 2014;31:118-34.
[15] Hu Y, Liu G. Instrument identification and pitch estimation in multi-timbre polyphonic musical signals based on probabilistic mixture model decomposition. Journal of Intelligent Information Systems. 2013;40:141-58.
[16] Deng JD, Simmermacher C, Cranefield S. A study on feature analysis for musical instrument classification. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics). 2008;38:429-38.
[17] Özbek ME, Özkurt N, Savacı FA. Wavelet ridges for musical instrument classification. Journal of Intelligent Information Systems. 2012;38:241-56.
[18] Souza VM, Batista GE, Souza-Filho NE. IEEE Automatic classification of drum sounds with indefinite pitch. International Joint Conference on Neural Networks; 2015. p. 1-8.
[19] Chandwadkar D, Sutaone M. Role of features and classifiers on accuracy of identification of musical instruments. IEEE 2nd National Conference on Computational Intelligence and Signal Processing; 2012. p. 66-70.
[20] Malheiro F, Cavaco S. Automatic musical instrument and note recognition. ISMIR; 2011.
[21] Kolozali S, Barthet M, Fazekas G, Sandler MB. Knowledge representation issues in musical instrument ontology design. ISMIR2011. p. 465-70.
[22] Othman MS, Nuawi MZ, Mohamed R. Induction motor bearing fault diagnostics using i-kaz™ and decision tree classification. International Journal of Automotive and Mechanical Engineering. 2016;13:3361-72.
[23] Ahmad M, Nuawi MZ, Abdullah S, Wahid Z, Karim Z, Dirhamsyah M. Development of tool wear machining monitoring using novel statistical analysis method, i-kaz™. Procedia Engineering. 2015;101:355-62.
[24] Othman M, Nuawi M, Mohamed R. Induction motor bearing fault diagnostics using i-kaz™ and decision tree classification. 2016.
[25] Tahir MASM, Ghani JA, Nuawi MZ, Rizal M, Haron CHC. Flank wear and i-kaz 3d correlation in ball end milling process of inconel 718. Journal of Mechanical Engineering and Sciences. 2015;9:1595-603.
[26] Ahmad MAF, Nuawi MZ, Mohamed NF, Wahid Z, Dirhamsyah M. The study of polymer material characterisation using mzn statistical analysis method. Jurnal Kejuruteraan. 2016;28:9-18.
[27] Ahmad MS, Nuawi MZ, Othman A, Ahmad F, Arif M. Metallic material characterization using acoustics signal analysis. Jurnal Teknologi. 2016;78:31-7.
[28] Bahari AR, Nuawi MZ, Hamzah FM, Saad SM. Pemetaan dan pengelompokan isyarat akustik alat muzik tradisional melayu menggunakan kaedah analisis isyarat statistik. Jurnal Kejuruteraan. 2013;25:33-8.
[29] Nuawi MZ, Nor MJM, Jamaludin N, Abdullah S, Lamin F, Nizwan C. Development of integrated kurtosis-based algorithm for z-filter technique. Journal of Applied Sciences. 2008;8:1541-7.

[30] Karim Z, Nuawi M, Ghani J, Abdullah S, Ghazali M. Optimization of integrated kurtosis-based algorithm for z-filter (i-kaztm) coefficient using multi level signal decomposition technique. World Applied Sciences Journal. 2011;14:1541-8.

[31] Alm JF, Walker JS. Time-frequency analysis of musical instruments. Siam Review. 2002;44:457-76.

[32] Singh I, Koolagudi SG. Classification of punjabi folk musical instruments based on acoustic features. Proceedings of the International Conference on Data Engineering and Communication Technology; 2017. p. 445-54.

[33] Shetty S, Hegde S. Clustering of instruments in carnatic music for content based information retrieval. IEEE 6th International Conference on Advanced Computing; 2016. p. 127-32.