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Editors • Arrie Kurniawardhani and Taufiq Hidayat

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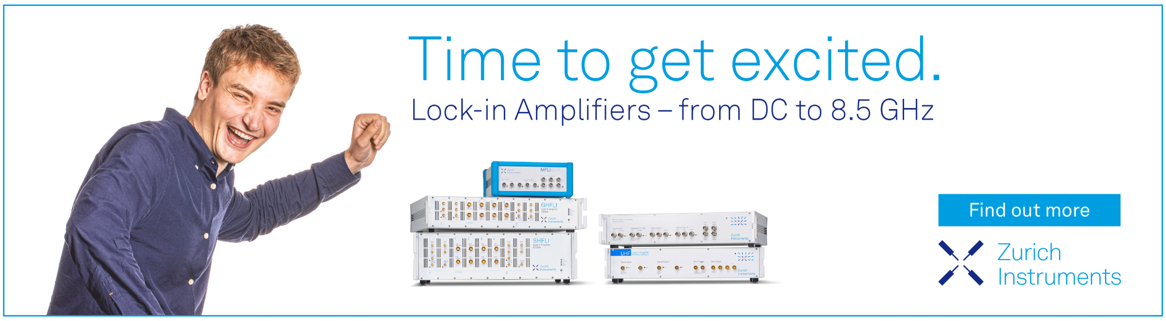

PREFACE: Proceedings of the International Conference on Information Technology and Digital Applications 2021 (ICITDA 2021)

In the name of Allah the most gracious the most merciful

Welcome to the 6th International Conference on Information Technology and Digital Applications (ICITDA), 5-6 November 2021. ICITDA is an annual international conference organized by the Department of Informatics, Faculty of Industrial Technology, Universitas Islam Indonesia, Indonesia. The first ICITDA was held in 2016, in the city of Yogyakarta, Indonesia.

This year, although we are in the second year of the Covid-19 pandemic, we still keep the spirit to continue the endeavour by holding this year's ICITDA virtually. Under the theme of the conference "Cybersecurity in Data Science Era", it is hoped ICITDA 2021 could provide an effective forum for academicians, researchers, and practitioners to exchange ideas, knowledge, and experiences on the latest development in the field of information technology and digital applications.

We would take this opportunity to thank all of the people who made this conference possible and the enthusiasm they bring to the atmosphere. This year we are happy to have 4 keynote speakers and 3 workshop speakers from 4 countries, to get valuable recommendations from reviewers from 9 countries, to receive more than 80 paper submissions (among them 42 papers from 7 countries are accepted & presented) and to admit all participants. We also thank the University and Department of Informatics for all of the support. Last but not least, I personally want to express my deep gratitude to all of my teammates of the 6th ICITDA, for the hard and sincere work.

Finally, once again thank you for joining this conference, and we are looking forward to seeing you in the next ICITDA.

Best regards,
Arrie Kurniawardhani
On behalf of the 6th ICITDA's Committee

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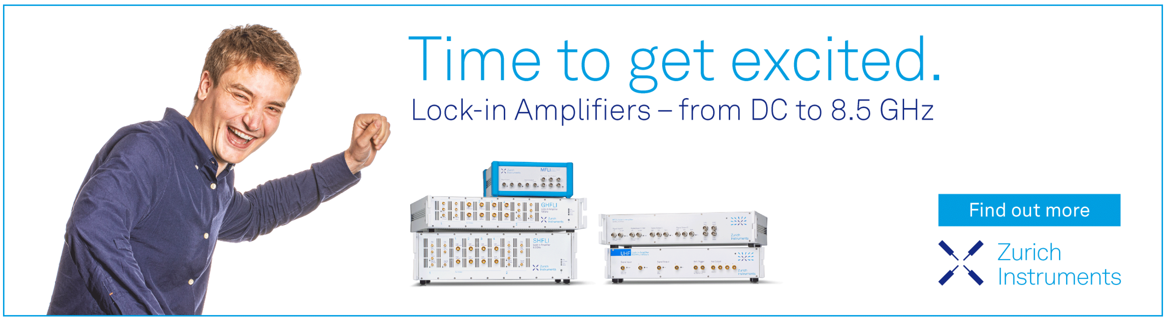

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The performance of MFCC feature extraction for guitar chord recognition

Linggo Sumarno

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The Performance of MFCC Feature Extraction for Guitar Chord Recognition

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Abstract. Previous studies on guitar chord recognition indicate that there is still a study that can be carried out to obtain a smaller number of coefficients of feature extraction. This study aims to obtain a smaller number of coefficients of feature extraction used in guitar chord recognition than previously studied. This study made use of MFCC (Mel Frequency Cepstral Coefficients) feature extraction in guitar chord recognition. By tuning the two parameters in MFCC, namely lowest mel filter frequency and number of mel filters in the mel filter bank, it could give as low as four coefficients of feature extraction. By using at least four coefficients of feature extraction, it could result in a recognition rate of up to 89.29%.

Keywords: MFCC, feature extraction, chord recognition

INTRODUCTION

Feature extraction is a method of defining a set of features that can represent meaningful information from a large amount of data. By using this set of features, there will be less data to be processed. There are two types of feature extraction in chord recognition. The first one is feature extractions that use chroma features, whereas the second one is feature extractions that do not use chroma features. PCP (Pitch Class Profile) [1] is a kind of feature extraction that uses chroma features. This PCP gives 12 coefficients of feature extraction. These coefficients of feature extraction are related to the power of a chord's fundamental frequencies. Nowadays, there a number of derivatives of the original PCP. Some of them, namely CRP (Chroma DCT-Reduced log Pitch) Enhanced PCP [2], Improved PCP [3], and Harmonic PCP [4]. These PCP derivatives also give 12 coefficients of feature extraction.

MFCC (Mel Frequency Cepstral Coefficients) [5][6] and segment averaging [7][8] are two kinds of feature extraction that do not use chroma features. Their coefficients of feature extraction are related to the spectrum shape in a chord. Traditional MFCC feature extraction only used 8-13 coefficients of feature extraction [5]. Recent studies of the MFCC feature extraction for chord recognition still use 13 coefficients of feature extractions [9][10]. Meanwhile, recent studies on segment averaging based feature extraction for chord recognition need the smallest numbers, down to eight [7] and six [8] coefficients of feature extraction respectively. As a note, by using these smallest numbers of coefficients of feature extraction, the chord recognition could reach a recognition rate of above 89%.

Based on the smallest number of coefficients of feature extraction [7][8] , there is still a study that can be carried out to obtain the smaller number of these coefficients. A smaller amount of data for data processing will benefit from the smaller number of these coefficients. Realization of chord recognition using FPGA (Field Programmable Gate Array) systems [11] [12] will benefit from using this smaller amount of data. Using this FPGA, we can create a system-on-chip that can be taped out as an application specific chip for electronic devices.

This study introduces tuning two MFCC parameters to obtain smaller than six coefficients [8] of feature extraction for chord recognition. The two MFCC parameters are the lowest mel filter frequency and the number of mel filters. As a first note, by using smaller than six coefficients of feature extraction, the chord recognition could reach a recognition rate of above 89%. As a second note, the limit value of 89% is the limit where we can see that the MFCC feature extraction in this study is better. As a third note, this study made use of guitar chords.

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RESEARCH METHODOLOGY

The developed system for chord recognition

Figure 1 shows a block diagram of the developed system for chord recognition in this study. As a note, the implementation of the developed system for chord recognition in this study made use of Octave software. To be more specific, each block in Fig. 1 is explained as follows.

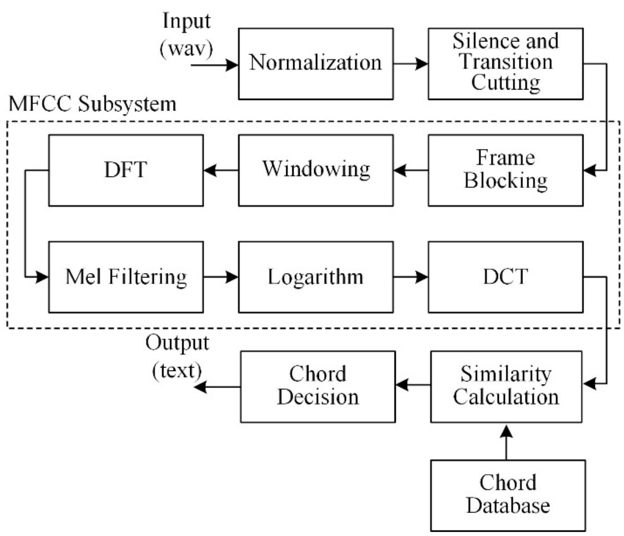

FIGURE 1. The developed system for chord recognition.

Input. The chord recognition system uses a WAV-formatted chord signal as input. This signal is a kind of an isolated signal. It was obtained by recording the chord signal from a Yamaha CPX 500-II acoustic-electric guitar. This guitar is shown in Fig. 2. Seven major chords were used in this study. They were C, D, E, F, G, A, and B [7][8]. These chords were recorded using a 5000 Hz sampling rate. This sampling rate met Shannon's sampling theorem [13] as follows.

$$f_s \geq 2f_{max} \tag{1}$$

where f_{max} and f_s are the highest frequency component in a signal and sampling rate respectively. The above-mentioned sampling rate has surpassed Shannon's sampling theorem since the highest frequency component from the above-mentioned chords is 392 Hz. This frequency comes from the tone G4 that is included in the chord G. A sampling duration of 2 s was used in this study, since by using visual observation, it was enough to acquire the steady state area in the recorded chord signal.

FIGURE 2. Yamaha CPX 500-II acoustic-electric guitar.

Normalization

Normalization sets the highest value in the array of signal data to 1 or -1. Normalization is carried out by using the following equation.

$$y_{out} = \frac{y_{in}}{(|y_{in}|)} \quad (2)$$

where y_{in} is the array of input signal data and y_{out} is the array of output signal data.

Silence and transition cutting

Silence and transition cutting removes areas of silence and transition in the array of signal data. Firstly, by using visual observation, the silence area that is on the left side of the array of signal data is removed by using a |0.5| threshold value. From the leftmost data scanned to the right, if the data was less than |0.5|, it would be removed. Secondly, by using visual observation also, the transition area that is located on the leftmost side can be removed using a duration of 200 ms.

Frame blocking

Frame blocking divides long signal data into short signal frames [14]. Previous study on MFCC used 15-25 ms signal frame length with 50% frame overlap [15]. Frame overlap is used to maintain signal continuity within frames. Based on the evaluation, this study used a 32 ms signal frame with 50% frame overlap. This evaluation was carried out by evaluating the optimal signal frame length and frame overlap that can result in the highest chord recognition rate.

Windowing.

Windowing minimizes discontinuities at the edges of the signal frame. These discontinuities will result in additional signals called harmonic signals in the magnitude spectrum. By minimizing these discontinuities, harmonic signals will be reduced. This study used the Hamming window since it is the most commonly used window in signal processing [16].

DFT (Discrete Fourier Transform)

DFT converts a windowed frame into a magnitude spectrum. Since there is a symmetry in the magnitude spectrum, this study only used half of the left part of the magnitude spectrum.

Mel Filtering

Mel filtering, as shown in Fig. 3, is filtering the magnitude spectrum frame using a number *M* mel filter in the mel filter bank followed by summing the result of each mel filter. In this mel filtering, the input is a magnitude spectrum frame, and the output is mel frequency coefficients.

A mel is a unit of measurement based on the human ear's perceived frequency. The human ear's perceived frequency does not correlate in a linear way with the tone's physical frequency. The following is an expression of mel's approximation to physical frequency.

$$f_{mel} = 1127\, ln\, ln\, \left(1 + \frac{f_{phy}}{700}\right) \quad (3)$$

where f_{phy} is physical frequency and f_{mel} is perceived frequency. In the frequency axis, the center frequencies of the mel filters in the mel filter bank are not evenly spaced. It is spaced not evenly using a nonlinear function in equation (3). The most commonly used shape for the shape of the mel filter is the triangular shape [5]. This study used this kind of shape.

As seen in Fig. 3, a magnitude spectrum frame will result in a number of mel frequency coefficients. These coefficients are stored in a 1D array. On the other hand, a magnitude spectrum frame will result in a 1D array of these coefficients. In this study, in this mel filtering step, all magnitude spectrum frames are processed, and the results are arranged in a 2D array of mel frequency coefficients.

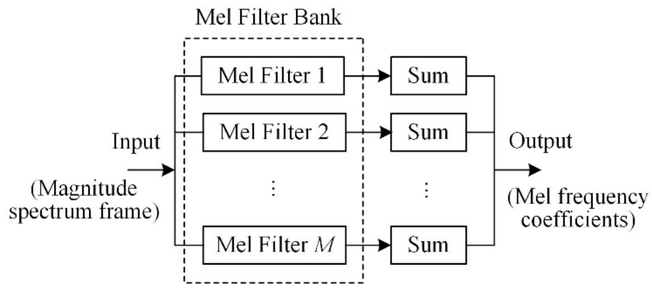

FIGURE 3. Mel filtering.

Log scale and DCT

Log scale calculates the logarithm of each element in the 2D array of mel frequency coefficients mentioned above. As a note, this logarithm operation is included in the computation of cepstral coefficients. DCT calculates the logarithm of mel frequency coefficients to produce a number of cepstral coefficients. DCT 2D is used to perform this calculation. The result of this calculation is a 2D array of cepstral coefficients. In a 2D array of cepstral coefficients, the most input signal information is located in the upper left part. This study used zigzag scanning to retrieve that information. The result of that zigzag scanning is a 1D array of cepstral coefficients. Several first numbers of that array are called the coefficients of feature extraction of the input signal. This study did not use the zeroth coefficient since it only carries a little specific information [5].

Similarity calculation and chord decision

Similarity calculation calculates a number similarity values between an array of a chord feature extraction extracted from the input signal and many arrays of chord reference feature extractions saved in a chord database. There are a total of seven similarity values in this research, since there are seven arrays of chord reference feature extractions saved in a chord database. Each array of reference feature extraction represents a C, D, E, F, G, A, or B chord. Cosine similarity was used to calculate the similarity value. It is widely used to calculate the similarity value [17][18].

Chord decision decides an output text, namely C, D, E, F, G, A, or B that relates a chord information in the input signal. The methodology for deciding the output text is described as follows.

1. Find the highest similarity value from seven similarity values mentioned above.
2. Find a chord text, namely C, D, E, F, G, A, or B that is related to the highest similarity value.
3. Set that chord text as a text output.

As a note, the similarity calculation and chord decision described above indicate that this study uses a template matching classification method [19][20][21].

Chord database

Chord database was developed by making a collection of seven reference feature extractions. These seven reference feature extractions represent all the chords, namely C, D, E, F, G, A, and B, which were used in this study. The methodology for developing the chord database is described as follows.

1. Record 10 samples for each chord, namely C, D, E, F, G, A, and B. These samples were selected by assuming that by using 10 samples, all sample variations have been acquired.
2. Compute the feature extraction of all recorded samples. This computation is carried out by using normalization up to DCT processes as shown in Fig. 1.
3. Calculate the sample average for each chord by using the following.

$$R_z = \frac{1}{10}\sum_{k=1}^{10} P_{z,k} \quad (3)$$

where z is C, D, E, F, G, A, or B that represent a chord, $\{\mathbf{P}_{z,k} \mid 1 \le k \le 10\}$ are 10 feature extraction arrays of a z chord, and $\mathbf{R}_z$ is an array of reference feature extraction of a z chord.

4. Collect each sample average, namely $\mathbf{R}_C$, $\mathbf{R}_D$, $\mathbf{R}_E$, $\mathbf{R}_F$, $\mathbf{R}_G$, $\mathbf{R}_A$, and $\mathbf{R}_B$ in a chord database.

Test Chords

Test chords were developed by recording 20 samples of C, D, E, F, G, A, and B chords. Thus, it was obtained 140 test chords.

Performance Testing and Measurement

Performance testing was carried out by using the above-mentioned test chords. Two MFCC parameters were varied during testing, namely the lowest mel filter frequency values and the number of mel filter values. As a note, the lowest mel filter frequency is the lowest center frequency of the mel bandpass filter and the number of mel filters is the number of mel filters in the mel filter bank. The lowest mel filter frequency values were varied between 40, 50, 60, and 70 Hz. The number of mel filter values were varied using 20, 25, 30, 35, and 45 filters. A number 1-8 coefficients of feature extraction were selected during performance testing.

Performance measurement was carried out by calculating the recognition rate for each selected number of coefficients of feature extraction. The recognition rate was calculated by dividing the number of chords correctly recognized by the number of chords used in performance testing. As a first note, the final results of that calculation were expressed in percent. As a second note, a total of 140 chords were used for performance testing.

TABLE 1. The performance results of the studied MFCC, for various lowest mel filter frequencies and number of mel filters. Results shown: Recognition rate (%)

Lowest mel filter frequency (Hz)	Number of mel filters	Number of coefficients of feature extraction							
		1	2	3	4	5	6	7	8
40	20	14.29	46.43	78.57	80.71	81.43	82.14	82.14	80.00
	25	14.29	49.29	82.14	81.43	82.86	84.29	84.29	86.43
	30	14.29	50.00	82.86	85.71	85.71	85.71	85.00	85.71
	35	14.29	50.00	82.14	85.71	85.71	86.43	85.71	85.71
	40	14.29	14.29	14.29	14.29	14.29	14.29	14.29	14.29
	45	14.29	14.29	14.29	14.29	14.29	14.29	14.29	14.29
50	20	14.29	45.71	80.71	82.14	82.86	83.57	83.57	83.57
	25	14.29	47.14	77.14	81.43	82.14	82.14	82.14	82.86
	30	14.29	45.00	82.14	82.86	85.71	86.43	85.71	83.57
	35	14.29	52.14	82.86	83.57	85.71	85.71	85.71	86.43
	40	14.29	45.71	86.43	88.57	90.00	90.00	90.00	**92.14**
	45	14.29	14.29	14.29	14.29	14.29	14.29	14.29	14.29
60	20	14.29	52.86	78.57	81.43	82.14	82.14	81.43	82.14
	25	14.29	47.86	75.71	81.43	82.86	83.57	84.29	82.14
	30	14.29	46.43	81.43	87.86	90.00	90.00	90.00	90.00
	35	14.29	48.57	87.14	**89.29**	89.29	89.29	89.29	90.00
	40	14.29	54.29	85.00	85.00	86.43	86.43	87.86	90.00
	45	14.29	14.29	14.29	14.29	14.29	14.29	14.29	14.29
70	20	14.29	47.86	77.86	82.14	83.57	83.57	82.86	83.57
	25	14.29	48.57	75.71	80.71	81.43	81.43	80.71	80.00
	30	14.29	52.14	83.57	84.29	85.00	85.00	86.43	85.71
	35	14.29	45.71	83.57	85.71	86.43	86.43	87.14	87.14
	40	14.29	14.29	14.29	14.29	14.29	14.29	14.29	14.29
	45	14.29	14.29	14.29	14.29	14.29	14.29	14.29	14.29

RESULTS AND DISCUSSIONS

Table 1 shows the performance results of the studied MFCC. There are two MFCC parameters that vary, namely the lowest mel filter frequency and the number of mel filters. As a note, these results are only shown for the number of coefficients of feature extraction of 1-8, since the aim of this study is to explore the number of these coefficients less than eight.

From the number of coefficients of feature extraction viewpoint, Table 1 indicates that if the number of coefficients of feature extraction gets bigger, the recognition rate gets higher. Basically, if the number of these coefficients gets bigger, it will cause the dimension of the feature extraction space to get bigger. This case will make it easier to discriminate between one and other pattern classes. This easier discrimination will eventually make the recognition rate to get higher.

From the recognition rate viewpoint, Table 1 indicates that for the studied MFCC feature extraction, for the number of coefficients of feature extraction up to 8, it can result in a recognition rate of up to 92.14%. In contrast, for other segment averaging based feature extractions [7][8], for the number of these coefficients up to 8, they can result a recognition rate of up to 100%.

From the recognition rates and also the number of coefficients of feature extraction viewpoints, Table 1 indicates that for a number of coefficients of feature extraction as low as four, it can result in a recognition rate of up to 89.29%. In contrast, for other segment averaging based feature extractions [7][8], for the number of these coefficients as low as four, they can result a recognition rate of up to 70.71% and 82.86% respectively. So, in this case, we can say that the studied MFCC feature extraction is the most efficient feature extraction method, if we consider the recognition rates of above 89%.

Comparison with Other Feature Extraction Methods for Guitar Chord Recognition

Table 2 shows the performance comparison of several feature extraction methods for guitar chord recognition. As a note, for previous methods [2][3], they always give 12 coefficients.

Table 2 indicates that the MFCC feature extraction method in this study can be considered the most efficient if we consider the recognition above 89%. It needs only four coefficients of feature extraction to result a recognition rate of up to 89.29%.

CONCLUSION AND FUTURE STUDY

This study proposes two parameters to be tuned for the MFCC feature extraction method if this feature extraction method is used in guitar chord recognition. The two parameters to be tuned are the lowest mel filter frequency and the number of mel filters. Based on the conducted experiments, by tuning these parameters, it can give as low as four coefficients of feature extraction that can result in a recognition rate of up to 89.29%. For further study, it can be explored feature extraction other than MFCC, which can give as low as four coefficients of feature extraction, but it can result in a higher recognition rate.

TABLE 2. The performance comparison of several feature extraction methods for guitar chord recognition.

Feature Extraction Methods	Number of Coefficients of Feature Extraction	Recognition Rate (%)	Test Chords
Improved PCP [3]	12	95.83	192 test chords from 192 generated guitar chords
CRP (Chroma DCT-Reduced log Pitch) Enhanced PCP [2]	12	99.96	4608 test chords from 576 generated guitar chords
Segment averaging with SHPS and logarithmic scaling [7]	8	100	140 test chords from 140 recorded guitar chords
Segment averaging and subsampling [8]	6	91.43	140 test chords from 140 recorded guitar chords
MFCC (this study)	**4**	**89.29**	140 test chords from 140 recorded guitar chords

Note: The above table only shows the smallest number of coefficients, which can result the recognition rate of above 89%.

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