Protecting Copyright Ownership via Identification of Remastered Music in Radio Broadcasts

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Abstract

Preface

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List of Acronyms

BLOB Binary Large Object

DoG Difference of Gaussians

DP Dynamic Programming

DTW Dynamic Time Warping

FN False Negative

FP False Positive

MIR Music Information Retrival

OSCA Outstanding Song Creators Association

OTI Optimal Transposition Index

PCA Principle Component Analysis

PCP Pitch Class Profiles

SIFT Scale Invariant Feature Transform

STFT Short Time Fourier Transformation

SVD Singular Value Decomposition

TN True Negative

TP True Positive

Chapter 1

Introduction

1.1 Background to the Research

According to the intellectual property act of Sri Lanka[2], royalties must be paid to the original artistes when a song is broadcast on a radio channel. Each radio channel is maintaining a playlist to keep track of the songs that were broadcast throughout the day. That playlist can later be used to pay royalties to the respective artistes. However, in order to streamline and regulate the royalty payment process, it is vital to have a method to monitor the radio broadcasts. Manual radio broadcast monitoring is infeasible and expensive due to increasing number of both radio channels and songs. In manual monitoring a person should be assigned to each channel who needs to keep record of each song in the radio broadcast of that assigned channel. Due to the increasing number of songs and the fallible nature of humans such a monitoring task is prone to errors and inaccuracies. Hence an automated radio broadcast monitoring approach must be considered as an viable alternative in the modern day radio broadcast monitoring.

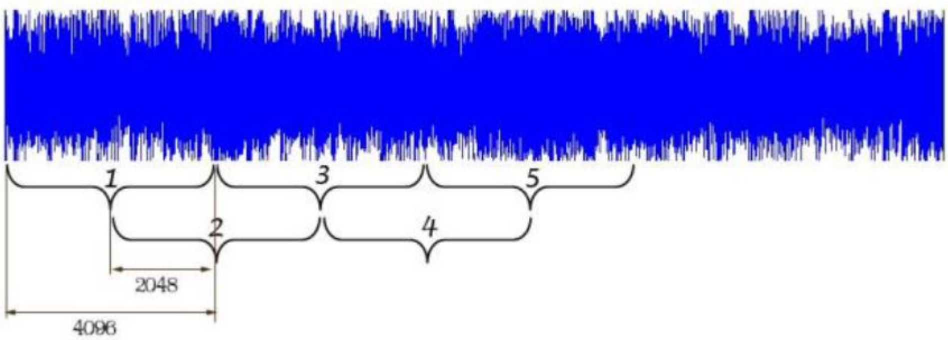

Figure 1.1: Key controlling parameters of STFT[1]

In the research "Radio Broadcast Monitoring to Ensure Copyright

Ownership"[1], researchers have implemented an automated radio broadcast monitoring system (refer the Figure 1.2 for the architecture) which has achieved 97.14% overall accuracy in identifying original songs in radio broadcasts. The researchers introduced an audio fingerprint to register and identify songs. The fingerprint was introduced as a series of hash values extracted from frequency domain audio signal. Time domain signal was converted to frequency domain by using STFT, which used 4096 bits long window and 2048 bits long overlapping area as shown in Figure 1.1. Then five peak values were extracted for each window by dividing mid frequency level into five bins and taking peak value from each bin. Extracted five peak values were used to create a hash value as depicted in Figure 1.3.

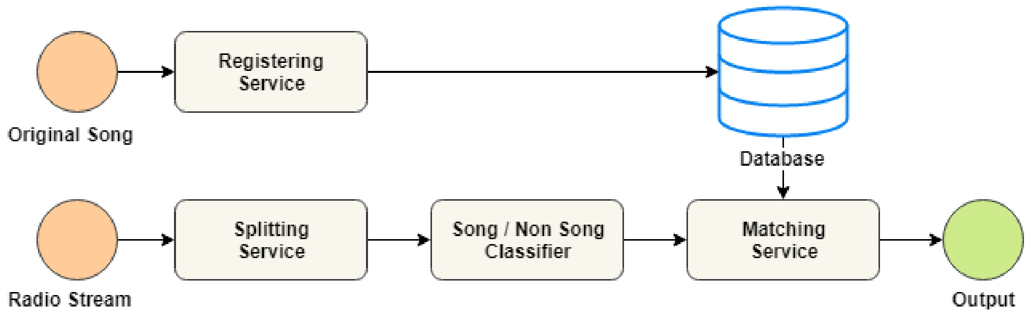

Figure 1.2: Architecture of the existing system

In contemporary radio broadcasts, channels tends to alter songs by including commercials and dialogues and by remastering the original song. Remastering can be done by adding or subtracting elements, or by changing pitch, equalization, dynamics or tempo[3]. Even though the above mentioned radio broadcast monitoring system's accuracy is not significantly affected by commercials and dialogues included in songs, the system is unable to identify a song when that song is remastered by the radio channel as changing pitch, equalization, dynamics or tempo which directly affects both time domain and frequency domain audio data.

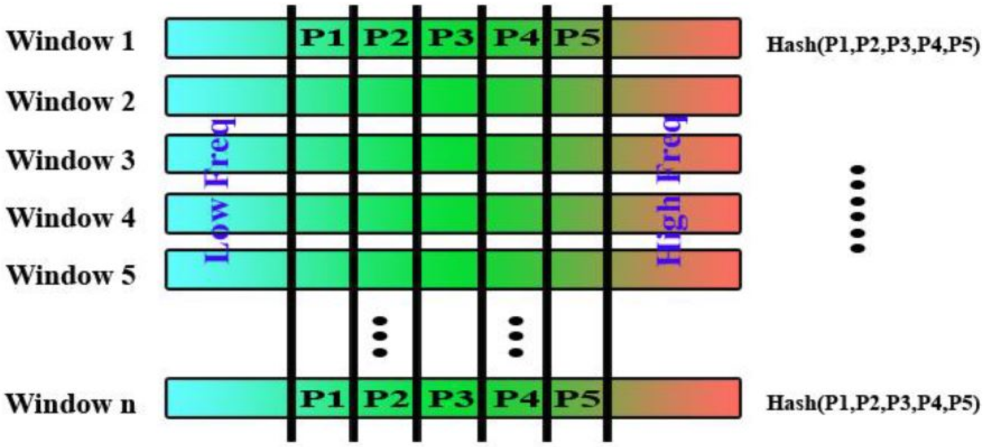

Figure 1.3: Extracting peaks and generating a hash value[1]

Timbre, tempo, timing, structure, key, harmonization and lyrics are the basic musical facets that can be identified[3].Timbre, also known as tone colour is the music facet which makes a difference of different sound productions even when they have the same pitch and loudness. Simply it is what makes a difference between a piano and a violin playing the same note at the same volume. Timbre can be changed due to the use of different sound enhancing and processing techniques or to the use of different instruments and configurations. Tempo is the speed or pace of the music which can be easily changed by playing the music in different speeds. The music facet of timing is rhythmic structure of the music which can be altered by the changes to the drum section. Structure is the arrangement of music sections, and music structure alterations can be made while remastering. Key, harmonization and lyrics are tonality, chords and words of the music which can be altered while remastering.

In order to identify remastered music in radio broadcasts, existing literature on cover song identification and music similarity measures can be used as foundation study to this research. Directly implementing a cover song identification method or a music similarity measure to identify remastered music in radio broadcasts is not possible as there is limited time to do the identification and it is not just comparing two music clips to find similarity, but comparing a radio broadcast with more than twenty thousand song database.

1.2 Research Problem and Research Questions

1.2.1 Project Aim

Aim of this research is to utilize computational theories and tools to protect copyright ownership of artistes in radio broadcasts.

1.2.2 Research Questions

Main three research questions are identified to address the challenges in music identification when remastered songs are broadcasted in radio.

1. What are forms of alterations to the basic musical facets in remastered music?
2. What are the approaches of identifying remastered music?
3. What approach can be used to identify remastered music in radio broadcasts?

1.2.3 Objectives

Answers to above research questions are obtained by accomplishing the five objectives.

1. Gather and identify the alterations made to remastered music when compared with the original music.
2. Review existing cover song identification methods and music similarity measures to implement feature extraction methods for relevant features.
3. Identify similarity descriptive features with respect to the identified forms of alterations.
4. Introduce a new music similarity descriptor using identified features.
5. Use introduced music similarity descriptor to identify remastered music in radio broadcasts.

1.3 Methodology

In the proposed method of remastered song identification, various algorithms are used to extract the audio features, create audio descriptors and match against stored descriptors. Hence we have divided our remastered song identification process in to five steps.

1. Preprocessing
2. Feature Extracting
3. Descriptor Storing (Registering)
4. Matching
5. Postprocessing

Processes of the above steps will be discussed in the following subsections.

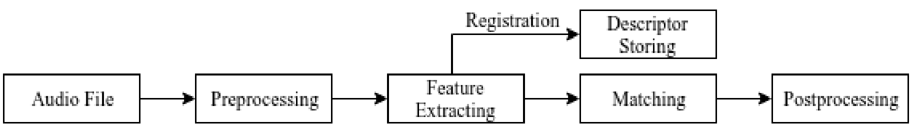

Figure 1.4: Remastered Song Identification Process

Preprocessing

In default audio data is represented in the time domain. Since even a small change in an audio changes the time domain representation drastically, using the time domain representation of the audio to extract features is not recommended. Hence time domain audio signal is converted to frequency domain signal by using STFT method. STFT is a sequence of Fourier transforms of a windowed signal[4]. 2048 bits long window with 50% overlapping was used as STFT key parameters as depicted in Figure 1.5.

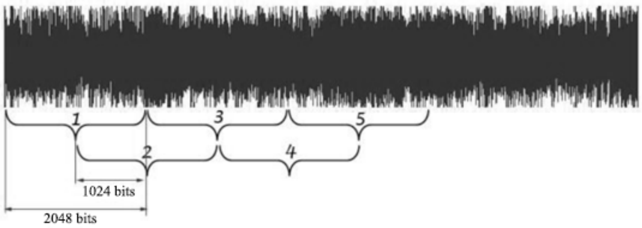

Figure 1.5: Key parameters on STFT. 2048 bits long window with 1024 bits long overlapping area.

STFT is often visualized using its spectrogram[4], which is an intensity plot of STFT magnitude over time. The generated spectrogram is converted to a color image as shown in Figure 1.6. Axis labels and ticks are removed to stop identification of them as key points in feature extracting step.

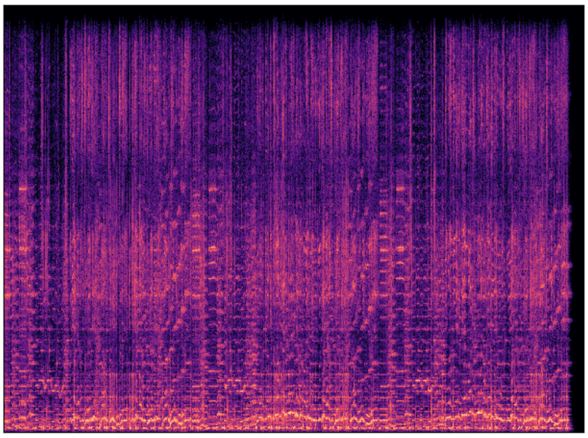

Figure 1.6: Generated colour image of spectrogram after preprocessing.

Feature Extracting

STFT spectrogram itself can be considered as an audio descriptor[5]. This method uses Scale Invariant Feature Transform (SIFT)[6] to extract the features which are robust to music remastering. In the Figure 1.7, it can be observed that when tempo is altered the spectrogram will either expand or compress with the time axis and when pitch is altered the spectrogram will either shift upwards or downwards with the frequency axis.

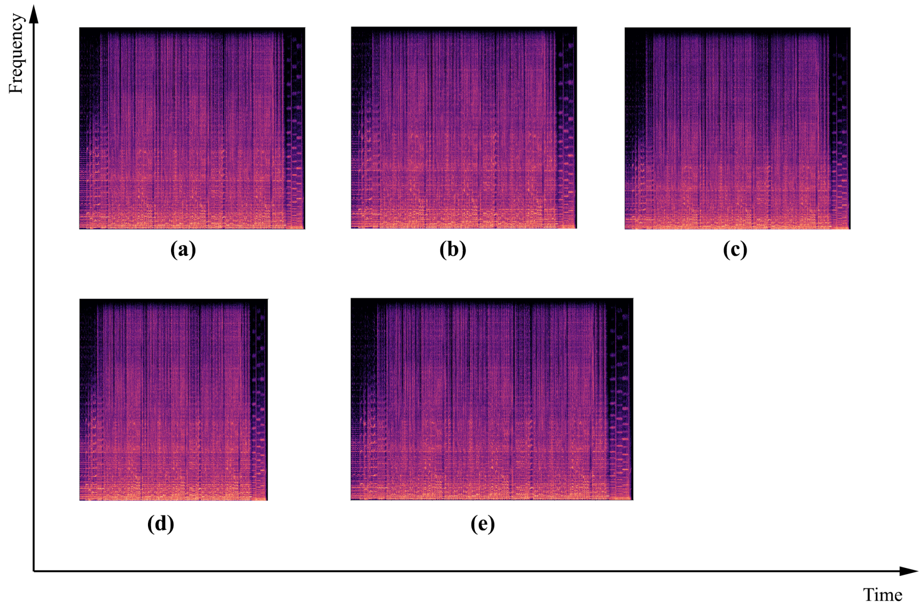

Figure 1.7: Spectrogram transformations on audio enhancements. **(a)** is the spectrogram image of a original song. **(b)** 20% pitch increase, **(c)** 20% pitch decrease, **(d)** 20% tempo increase and **(e)** 20% tempo decrease spectrogram images.

SIFT is used in computer vision to identify scale invariant features of an image. SIFT features are invariant to image rotation, scale alterations and illumination[6]. The SIFT feature extractor used in this method consists of four main steps.

1. Scale space extrema detection: Gaussian filters of different scales are applied to the image and potential key points are selected as local minima or maxima of the Difference of Gaussians (DoG) for multiple scales.

2. Keypoint localization: Keypoints that have low contrast or those that are poorly located along edges are filtered out.

3. Orientation assignment: One or more orientations are assigned to each keypoint based on local image gradient.

4. Keypoint descriptor generation: Orientation histograms are created for 4 x 4 pixel neighborhoods for each keypoint. Each histogram consists 8 bins, hence (4 x 4 x 8) 128 dimensional descriptor is generated.

A Set of extracted 128 dimensional descriptors works together in describing the input audio file. Extracted SIFT features are invariant to image stretch and translation which makes them better features to be used in audio identification algorithm which is robust to tempo alterations and pitch shifting.

Descriptor Storing (Registering)

SIFT descriptors of original songs must be stored to use them in the matching step of the remastered song identification process. Generally 3-5 minute music clip will have around 2000 key points in its STFT spectrogram. Hence a 2000×128 matrix will be generated for each original song that will be registered.

The descriptor matrix of each original song is converted to a binary string and that binary string is stored in the database as Binary Large Object (BLOB)s. Converting to binary string and storing the matrix as a BLOB will ensure fast recreation of the matrix while retrieving[7].

Matching

Flann KD Tree Matching [8].

Postprocessing

the most similar song and matched keypoint count for a given query audio clip is identified in the matching step. But it doesn't exactly mean that query audio clip contains that song. Because the number of keypoints that were matched represents how much the query song matched to the most similar song. Hence there should be a threshold keypoint count to determine whether a query audio clip contains a song in our database or not. But using just a threshold value won't work here since different query audio clips generate different number of key points to match against the database. Hence ratio based threshold is recommended as a measure to determine whether the matched song is actually a correct match. Keypoint ratio can be obtained by the below equation.

$$\text{Keypoint ratio} = \frac{\text{Matched keypoint count}}{\text{Keypoints generated for query audio clip}}$$

Based on this keypoint ratio, a threshold is used to determine the validity of the match found. In order to find this threshold value we have used 844 different audio clips with variable durations to match against 2300 original songs. Those 844 audio clips had 519 audio clips which had songs and 325 audio clips which didn't have songs from those 2300 original songs. And we calculated accuracy for 18 testcases which will be discussed in section 5.1, and took average of those 18 accuracies for variable threshold values. Then results were illustrated as shown in the Figure 1.8.

Global peak can be observed in the illustration which makes that value a clear

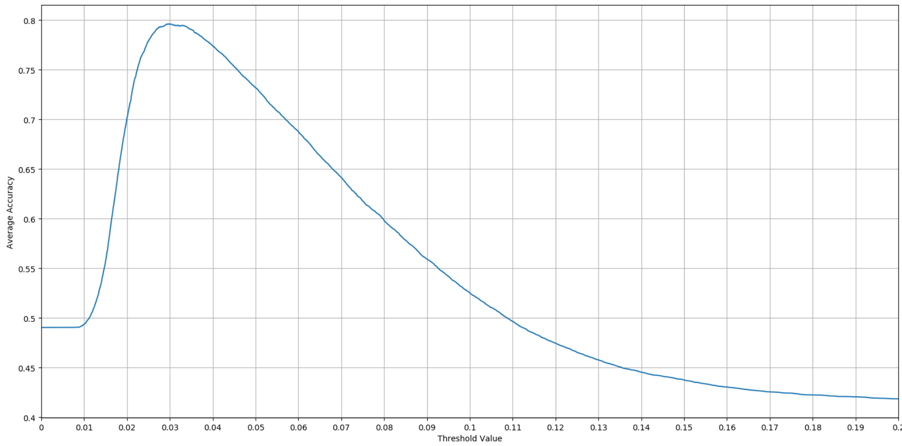

Figure 1.8: Average Accuracy Values for Different Threshold Values

threshold point. 0.0298 is the threshold value that was found. Hence if keypoint ratio of a query audio is larger than 0.0298 then it's identified as a valid match to the song that was identified in the matching step, otherwise it's identified as a invalid match. This threshold point makes this method to clearly identify whether a query audio has a song which is in a database or not.

1.4 Outline of the Dissertation

1.5 Scope and Delimitations

1.5.1 In Scope

The following areas will be covered under the research project.

- Exploration of possible remastering techniques and outcomes.
- Introduction of music similarity descriptor.
- Identification of remastered music in radio broadcasts.

1.5.2 Out Scope

The following areas will not be covered under the research project.

- Identification of instrumental, acoustic or medley covers of original music.
- Identification of quotations in music such as lyrical quotations or musical quotations.

1.6 Conclusion

Chapter 2

Literature Review

2.1 Remastered Audio Identification

Remastered song identification falls under the domain of cover song identification, which is a very active area of study in the Music Information Retrival (MIR) community [3]. Literature on cover song identification contains different approaches taken to measure and model music similarity in both symbolic and audio domains. Literature relevant to cover song identification can be divided into few areas such as query-by-humming systems, content-based music retrieval, genre classification and audio fingerprinting.

In symbolic domain of cover song identification, symbolic representations of musical content is used in content processing. Query-by-humming systems [9] falls under the symbolic domain as in query-by-humming systems music contents are stored and processed in symbolic representations. This query-by-humming method is parallel to retrieving cover songs from a song database. Even though techniques used in query-by-humming systems could be useful in future approaches of cover song identification, these systems can't achieve high accuracy on real world audio music signals [10, 3].

Audio domain cover song identification approaches focus on measuring similarity of music by exploiting music facets shared between two songs. Extracting invariant features is used to exploit shared music facets. Although such extracted descriptors are responsible to overcome majority of facet changes, special stress is given for achieving tempo, key and structure since those facets are not usually managed by the extracted descriptors themselves [3]. Hence we can look at existing literature in terms of feature extraction, tempo invariance, key invariance, structure invariance and finally similarity comparison. Furthermore, we can take approaches which falls into this general pipeline (refer Figure 2.1) to look at different techniques used for these stages and distinguish each approach from one another by those techniques.

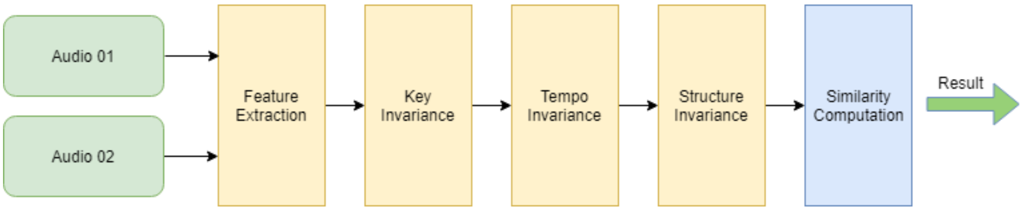

Figure 2.1: General Pipeline for Cover Song Identification

Bello's cover song identification method extracts chord sequences as the feature and uses K transpositions for the key invariance. Even though there is no technique used for structure invariance, Dynamic Programming (DP) is used for tempo invariance. Finally it uses edit distance to compute the similarity [11]. Since there is no technique used for structure invariance, that method is inefficient against the structural changes in cover songs. Egorov proposed another method which uses the same general pipeline with extracting Pitch Class Profiles (PCP) as the feature. But in this method Egorov uses Optimal Transposition Index (OTI) for key invariance and DP is used for both tempo and structural invariance. And match length is used for similarity computation [12].

Foote [13] and Izmirli [14] introduced two methods which were using Dynamic Time Warping (DTW) for similarity computation and DP for tempo invariance. Both of methods lack techniques for key invariance and structure invariance which makes those methods to perform inefficient in both key and temporal changes. The feature extracted by Foote is energy spectrum while Izmirli extracted key templates. Marlot uses same techniques for tempo invariance and similarity computation which are DP and DTW, but melody is the the extracted feature which using the key estimation for key invariance.

Related works mentioned above for audio domain can be modelled to the general pipeline for cover song identification (refer Figure 2.1) as described in Table 2.1.

Research	Feature	Key Invariance	Tempo Invariance	Structure Invariance	Similarity Computation
Bello [11]	**Chords**	**K transpositions**	**DP**		**Edit distance**
Egorov & Linetsky [12]	**PCP**	**OTI**	**DP**	**DP**	**Match length**
Foote [13]	**Energy spectral**		**DP**		**DTW**
Izmiril [14]	**Key templates**		**DP**		**DTW**
Marolt [15]	**Melody**	**Key estimation**	**DP**		**DTW**

Table 2.1: Cover song identification methods and their techniques used for each step in general pipeline

Chapter 3

Design

3.1 Architectural Design

Basic framework to identify music in radio broadcasts is proposed in "Radio Broadcast Monitoring to Ensure Copyright Ownership"[1]. And it's currently implemented and deployed in Outstanding Song Creators Association (OSCA). Hence the infrastructure to contain the basic framework of a radio monitoring system is already there. When different methods of music identification are applied to radio broadcast monitoring, only registering service, database and matching service will be changed conserving the other modules that are in the architecture as shown in the Figure 3.1.

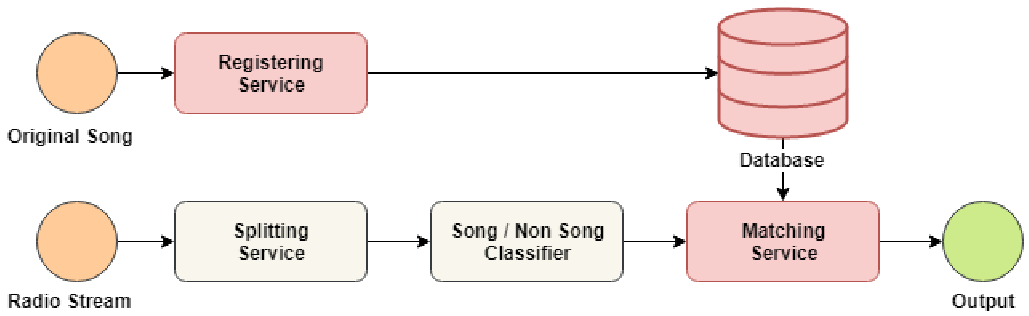

Figure 3.1: Architectural Design

Registering service takes original songs as input and generate specific descriptors to be stored in the database. Database stores the generated audio descriptors by registering service in retrieval friendly framework to help matching service to retrieve descriptors faster. Matching service takes a query audio clip and determine whether that query audio clip contains song registered before.

3.2 Principle Component Analysis (PCA)

There are many different approaches to identify music by extracting different audio features as discussed in the Chapter 2. Since there are very low number of researches conducted on sinhala music identification, finding audio features which can differentiate two sinhala songs was required to continue the research. Hence Principle Component Analysis (PCA) was conducted to find features on a 5000 song dataset extracting 27 different audio features and results were collected for different normalization techniques. Singular Value Decomposition (SVD) is used to composite multi-dimension features.

3.2.1 PCA with Raw Dataset

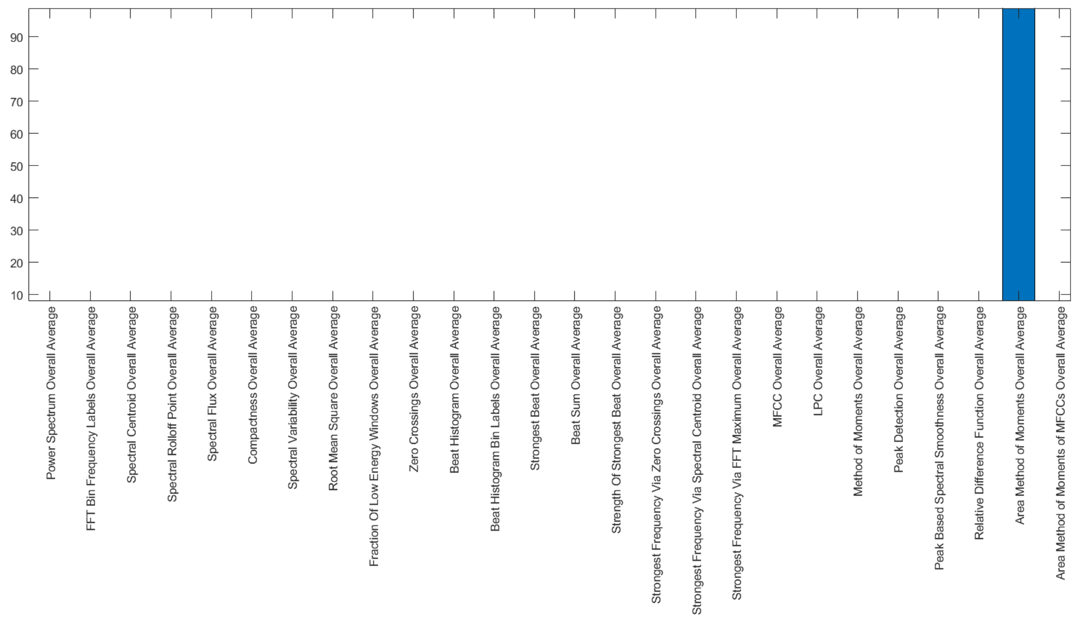

Figure 3.2: PCA coefficients weighted by eigen values

3.2.2 PCA with Dataset Normalized by Z-score

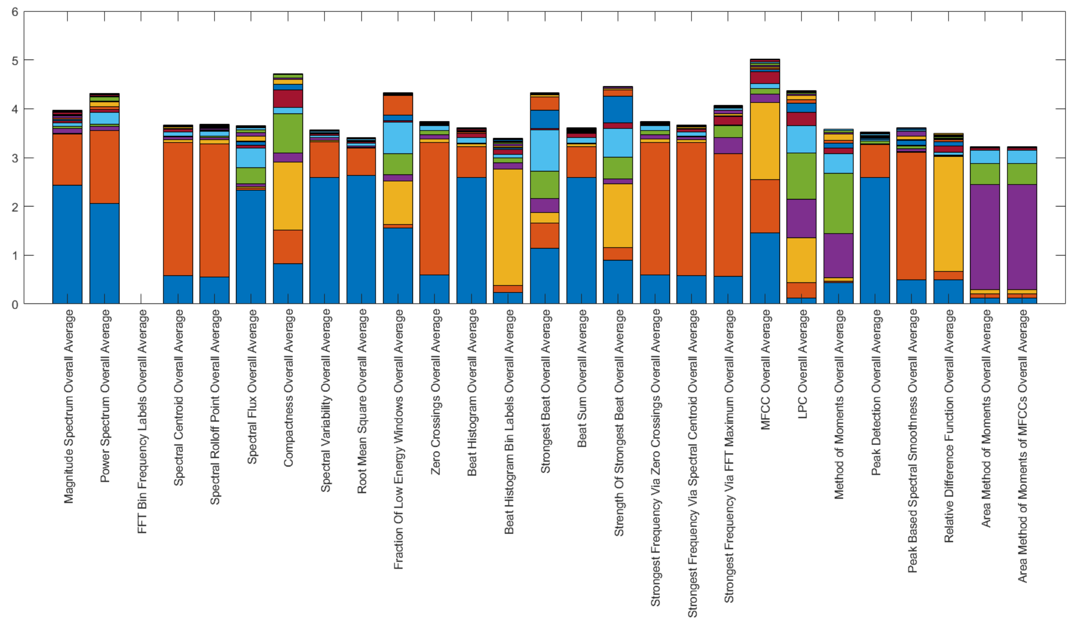

Figure 3.3: PCA coefficients weighted by eigen values (Normalized by Zscore)

3.2.3 PCA with Dataset Normalized by Rescaling

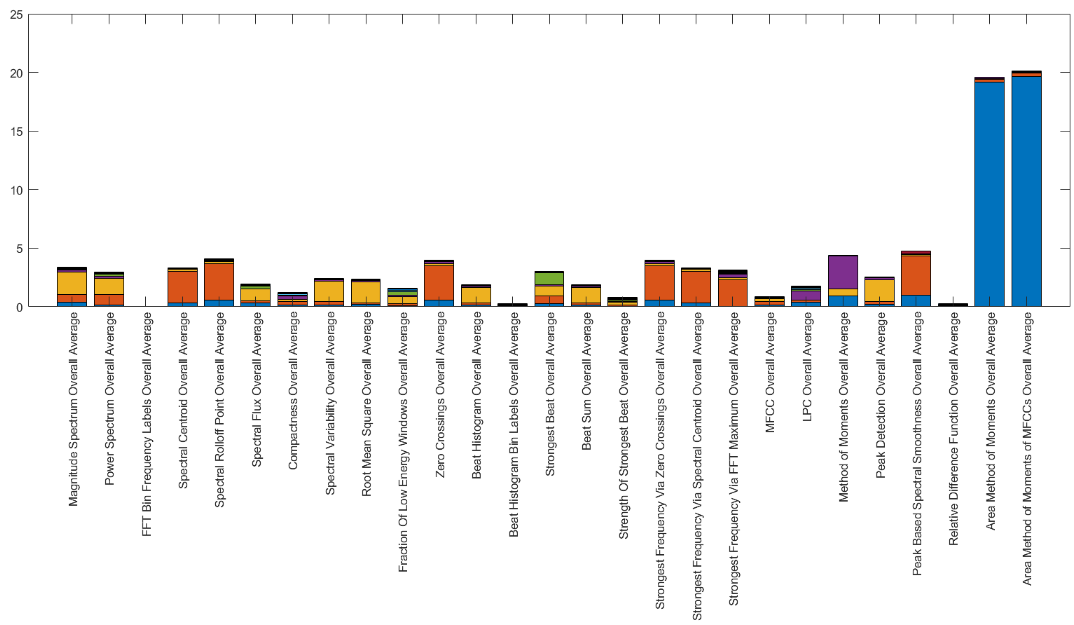

Figure 3.4: PCA coefficients weighted by eigen values (Normalized by Rescaling)

3.3 Scale Invariant Feature Transform (SIFT) Based Approach

3.3.1 Short Time Fourier Transform

3.3.2 SIFT Descriptor Extraction

3.3.3 SIFT Descriptor Matching

3.3.4 Thresholding

Chapter 4

Implementation

4.1 Principle Component Analysis (PCA)

4.2 Scale Invariant Feature Transform (SIFT) Based Approach

4.2.1 Short Time Fourier Transform

4.2.2 SIFT Descriptor Extraction

4.2.3 SIFT Descriptor Matching

4.2.4 Thresholding

Chapter 5

Results and Evaluation

5.1 Experiments

5.1.1 Song Dataset

Song dataset consisting 2300 sinhala songs were used in the registration step of the experiment. These 2300 sinhala songs were retrieved from OSCA of Sri Lanka which works as the governing organization to ensure intellectual property rights of music in Sri Lanka.

5.1.2 Query Audio Samples

Variable sized 844 query audio clips were used for the experiment to evaluate the performance of this method against different durations. 519 of the above mentioned audio clips had songs which are in the database while 325 audio clips didn't have songs from the database. Hence for each test case, sample size was 844 query audio clips with 0.61492 prevalence.

5.1.3 Test Cases

Test cases were created by doing audio distortions to the query audio samples. Performance of the method was evaluated for three main audio distortions which are tempo alteration, pitch alteration and both pitch and tempo alteration. Both increased and decreased alterations are considered for three different levels of alterations which are 10% alteration, 20% alteration and 50% alteration. Hence there are 3 audio distortions, 2 audio distortion directions and 3 audio alteration levels, 18 ($3 \times 2 \times 3$) test cases were generated to evaluate the performance.

5.2 Experiment Results

The proposed method has an exact way to identify whether a query audio clip has a matching registered song or not. Therefore this method can be considered as a classifier. A classifier can be evaluated by the confusion matrix generated for a given sample. True Positive (TP), False Positive (FP), True Negative (TN) and False Negative (FN) were calculated for each test case. Then accuracy and FP rate was calculated for each test case. Reducing FP rate is significant as same as increasing the accuracy given that this method mainly focuses on identifying music on radio broadcasts.

5.2.1 Using Keypoint Count as Threshold

Test Case	**TP**	**FP**	**TN**	**FN**	**Accuracy**	**FP Rate**
Tempo Increase 10%	509	19	306	10	0.96564	0.05846
Tempo Increase 20%	509	18	307	10	0.96682	0.05538
Tempo Increase 50%	497	10	315	22	0.96209	0.03077
Tempo Decrease 10%	515	16	309	4	0.97630	0.04923
Tempo Decrease 20%	516	19	306	3	0.97393	0.05846
Tempo Decrease 50%	517	22	303	2	0.97156	0.06769
Pitch Increase 10%	514	21	304	5	0.96919	0.06462
Pitch Increase 20%	513	11	314	6	0.97986	0.03385
Pitch Increase 50%	7	27	298	512	0.36137	0.08308
Pitch Decrease 10%	511	11	314	8	0.97749	0.03385
Pitch Decrease 20%	463	4	321	56	0.92891	0.01231
Pitch Decrease 50%	0	0	325	519	0.38507	0.00000
Tempo & Pitch Increase 10%	414	11	314	105	0.86256	0.03385
Tempo & Pitch Increase 20%	339	18	307	180	0.76540	0.05538
Tempo & Pitch Increase 50%	0	26	299	519	0.35427	0.08000
Tempo & Pitch Decrease 10%	373	5	320	146	0.82109	0.01538
Tempo & Pitch Decrease 20%	226	2	323	293	0.65047	0.00615
Tempo & Pitch Decrease 50%	0	0	325	519	0.38507	0.00000

Table 5.1: Experiment results using keypoint count as threshold

5.2.2 Using Keypoint Ratio as Threshold

Test Case	**TP**	**FP**	**TN**	**FN**	**Accuracy**	**FP Rate**
Tempo Increase 10%	512	13	312	7	0.97630	0.04000
Tempo Increase 20%	508	10	315	11	0.97512	0.03077
Tempo Increase 50%	501	9	316	18	0.96801	0.02769
Tempo Decrease 10%	515	11	314	4	0.98223	0.03385
Tempo Decrease 20%	519	10	315	0	0.98815	0.03077
Tempo Decrease 50%	519	9	316	0	0.98934	0.02769
Pitch Increase 10%	519	9	316	0	0.98934	0.02769
Pitch Increase 20%	517	9	316	2	0.98697	0.02769
Pitch Increase 50%	0	4	321	519	0.38033	0.01231
Pitch Decrease 10%	516	16	309	3	0.97749	0.04923
Pitch Decrease 20%	503	25	300	16	0.95142	0.07692
Pitch Decrease 50%	23	160	165	496	0.22275	0.49231
Tempo & Pitch Increase 10%	413	11	314	106	0.86137	0.03385
Tempo & Pitch Increase 20%	287	17	308	232	0.70498	0.05231
Tempo & Pitch Increase 50%	0	7	318	519	0.37678	0.02154
Tempo & Pitch Decrease 10%	432	28	297	87	0.86374	0.08615
Tempo & Pitch Decrease 20%	346	34	291	173	0.75474	0.10462
Tempo & Pitch Decrease 50%	6	154	171	513	0.20972	0.47385

Table 5.2: Experiment results using keypoint ratio as threshold

Chapter 6

Conclusions

6.1 Introduction

6.2 Conclusion on Research Questions

6.3 Limitations

6.4 Auxiliary Findings

6.5 Future Works

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