

HIGHLIGHT SOUND EFFECTS DETECTION IN AUDIO STREAM[†]

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ABSTRACT

This paper addresses the problem of highlight sound effects detection in audio stream, which is very useful in fields of video summarization and highlight extraction. Unlike researches on audio segmentation and classification, in this domain, it just locates those highlight sound effects in audio stream. An extensible framework is proposed and in current system three sound effects are considered: laughter, applause and cheer, which are tied up with highlight events in entertainments, sports, meetings and home videos. HMMs are used to model these sound effects and a log-likelihood scores based method is used to make final decision. A sound effect attention model is also proposed to extend general audio attention model for highlight extraction and video summarization. Evaluations on a 2-hours audio database showed very encouraging results.

1. INTRODUCTION

Audio content analysis plays an important role in video content parsing. Besides visual features, audio features are widely considered in many works, such as highlights extraction [1] and video summarization [2]. In order to extract the highlight shot more accurately, Rui [1] utilized announcer's excited speech and baseball hit for TV baseball programs; Ma and Lu [2] proposed an audio attention model to measure the importance curve of an audio track. However, these works did not consider some general highlight sound effects, such as laughter, applause and cheer. These sounds are usually semantically related with highlight events in general video, such as entertainments, sports, meeting, and home videos. The audience's laughter often means a humor scene in TV shows and applause in meeting often imply wonderful presentations. Detection of these highlight sound effects in audio stream is very helpful for highlight extraction and video summarization.

Most of previous works on audio content analysis focused on general audio segmentation and classification [3][4][5], where an audio track is segmented and then each segment is classified into one of predefined classes. In comparison with these previous works, sound effects detection in audio stream must handle the following cases: (i) model more particular sound classes and (ii) recall the expected sound effects only and ignore audio segments not belonging to any predefined effect.

An ideal framework of sound effects detection should possess following characters: (i) high recall and precision: it should exactly locate the interested sound effects and ignore others; (ii) extensibility: it should be easy to add or remove sound effect models for new requirements. In this paper, an extensible framework and an efficient algorithm for highlight sound effects detection in audio stream is presented. HMM is used to model these sound effects, as suggested in Casey's sound recognition tools [7]. Based on the log-likelihood scores got from each model, the final judgment is made.

The rest of this paper is organized as follows. Audio features are discussed in Section 2. The highlight sound effects modeling and detection scheme is presented in detail in Section 3. The highlight effect attention model is illustrated in Section 4. In Section 5, experiments and evaluations of the proposed framework and algorithm are given.

2. AUDIO FEATURE SELECTION

In our experiment, all audio streams are 16-bit, mono-channel, and down-sampled to 8 KHz. Each frame is of 200 samples (25ms), with 50% overlaps. Grounded on previous work in [3][4][5], two types of features are computed for each frame: (i) perceptual features and (ii) Mel-frequency Cepstral Coefficients (MFCCs). The perceptual features are composed of short time energy, zero crossing rate, sub-band energies, brightness and bandwidth.

A. Short-Time Energy

Short-Time Energy (STE) provides a convenient representation of the amplitude variation over time. The STE is normalized as follow:

$$E_k = E_k / \max(E_i) \quad 1 \leq i \leq N \quad (1)$$

Here E_k is the k^{th} frame's STE and N is the frame amount of the input audio data.

B. Average Zero-Crossing Rate

Average Zero-Crossing Rate (ZCR) gives a rough estimate of frequency content, which is one of the most important features of audio signal.

C. Sub-band Energies

In order to model the characteristics of spectral distribution more accurately, sub-band energies are used in our method. The entire

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frequency spectrum is divided into four sub-bands at the same interval of 1 KHz. The Sub-band energy is defined as

$$E_i = \sum_{\omega=\omega_L}^{\omega_H} |F(\omega)|^2 \quad (1 \leq i \leq 4) \quad (2)$$

Here ω_{iL} and ω_{iH} are lower and upper bound of sub-band i , and then E_i is normalized as

$$E_i = E_i / \sum_i E_i \quad (1 \leq i \leq 4) \quad (3)$$

D. Brightness and Bandwidth

Brightness is defined as the frequency centroid.

$$Br = \sum_{\omega} \omega |F(\omega)|^2 / \sum_{\omega} |F(\omega)|^2 \quad (4)$$

Bandwidth is the square root of the power-weighted average of the squared difference between the spectral components and the brightness.

$$Bw = \sqrt{\sum_{\omega} [(\omega - Br)^2 |F(\omega)|^2] / \sum_{\omega} |F(\omega)|^2} \quad (5)$$

E. 8 order Mel-frequency Cepstral Coefficients (MFCCs).

Mel-scale gives a more accurate simulation of human auditory system. It's a gradually warped linear spectrum, with coarser resolution at high frequencies. MFCC is one of the Mel-frequency sub-band energy features. As suggested in [5], 8 order MFCCs are used in our experiment.

These features are then combined as a 16-dimensional feature vector for a frame. In order to describe the variance between frames, the gradient feature of adjacent frames is also considered, and is concatenated to the original vector. Thus, we get a 32-dimensional feature vector for each frame.

3. SOUND EFFECTS MODELING AND DETECTION

3.1. Sound Effect Modeling

Most sound effects can be partitioned into several statistically significant patterns. More importantly, the time evolution of these patterns is critical for sound effect modeling. While both GMM and HMM possess states which can represent such patterns, HMM also describes the time evolution between states using the transition probabilities matrix. Thus, HMM is selected to model sound effects.

A complete connected HMM is used for each sound effect, with the continuous Gaussian mixture modeling each state. The component number of Gaussian mixture for each state is selected as four, since the sound effects are relatively simple and with little variation. Using more components need more training data, but give slightly improvement to the accuracy in experiments.

The training data for each sound effect includes 100 pieces of samples segmented from audio-track. Each piece is about 3-10s long and totally about 10min training data for each class. The basic sound effect modeling process is as follows. At first, a clustering algorithm proposed in [6] is used to find a reasonable state numbers of HMM for each sound effect. In our experiment, the HMM state numbers for applause, cheer and laughter are 2, 4 and 4 respectively. And then, frame-based feature vectors are extracted for estimating the HMM parameters using the Baum-Welch method, which is widely used in the field of Automatic Speech Recognition (ASR).

3.2. Sound Effect Detection

3.2.1. Framework Overview

The system framework of sound effect detection is illustrated in Figure 1.

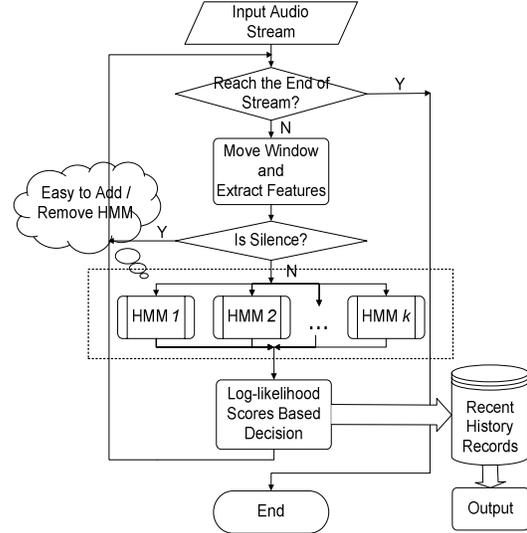


Figure 1. System Framework of sound effect detection

As the Figure 1 shows, a sliding window of t seconds moves through the input audio stream with Δt overlapping. In our experiment we choose $t=1$ and $\Delta t=0.5$ for the tradeoff of the algorithm's efficiency and accuracy. Each data window is further divided into 25ms frames with 12.5ms overlapping, from which feature is extracted. The extracted feature vectors form an input of HMM. In order to reduce the process time, silence window is skimmed before testing on HMMs. A silence window is detected base on average short time energy and average zero-crossing rate:

$$Average STE < \delta_E \ \& \ Average ZCR < \delta_Z \quad (6)$$

Here δ_E and δ_Z are thresholds of average STE and ZCR respectively.

Non-silence window is compared against each sound effect model and then k log-likelihood scores are obtained, given that there are k sound effect models. A judgment is made using decision algorithm based on these scores. In this framework, it's easy to add or remove sound effect model to adapt for new requirements.

The recent three decisions are preserved in the *Recent History Records* database for a post-processing. The decision given by the algorithm is first send to the *Records* database and the final result is obtained after post-processing. Some simple rules are used in this post-processing. For example, considered the continuity between adjacent windows, if the consecutive three decisions are "A-B-A", they are modified to "A-A-A".

3.2.2. Log-likelihood Scores Based Decision Method

The most important issue is how to do decision based on the log-likelihood scores. Unlike audio classification, we can't simply classify the sliding window into the class which has the maximum log-likelihood score. Sliding window not belonging to any predefined sound effect should be ignored.

Figure 2 illustrates the flowchart of the proposed log-likelihood based decision method. From Figure 2, each log-likelihood score is examined to see if the window data is “accepted” by the corresponding sound effect. To implement this task, an optimal decision is made by minimizing the following cost function [8], based on Bayesian decision theory,

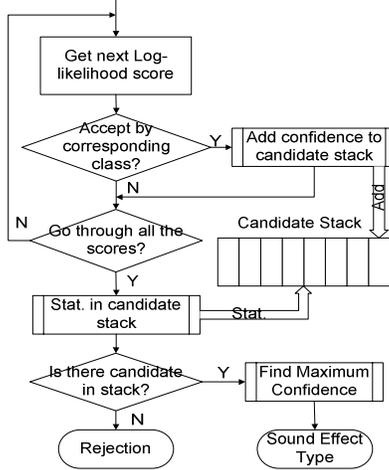


Figure 2. The flowchart of log-likelihood based decision

$$C = P(C_j)P(\bar{C}_j | C_j)C_{\bar{C}_j|C_j} + P(\bar{C}_j)P(C_j | \bar{C}_j)C_{C_j|\bar{C}_j} \quad (7)$$

where $C_{\bar{C}_j|C_j}$ and $C_{C_j|\bar{C}_j}$ denote the costs of false rejection (FR) and false acceptance (FA) respectively. The minimization of Eq. (7) leads to the Bayesian optimal decision rule [9]:

$$\frac{p(s_j | C_j)}{p(s_j | \bar{C}_j)} \geq R_j \quad (8)$$

where s_j is the log-likelihood score under HMM of sound effect C_j ; $p(s_j | C_j)$ and $p(s_j | \bar{C}_j)$ are probability distributions of log-likelihood scores of the samples within and outside C_j respectively; R_j is the Bayesian threshold:

$$R_j = \frac{C_{C_j|\bar{C}_j}}{C_{\bar{C}_j|C_j}} \times \frac{P(\bar{C}_j)}{P(C_j)} \quad (9)$$

The *priori* probabilities are estimated based on our database. The cost of FR is set larger than that of FA, given that a high recall ratio is more important for summarization and highlight extraction.

To implement Eq. (8), $p(s_j | C_j)$ and $p(s_j | \bar{C}_j)$ are both estimated from our database. Figure 3 (a) illustrates the scores distributions of samples within and outside the sound effect applause. These distributions are asymmetric since the log-likelihood scores are less or equal to zero. Considered that Gaussian distribution is symmetric, it's more reasonable to approximate these distributions' probability density function with negative Gamma distribution, as illustrated in Figure 3 (b).

$$p(s | C_j) = -\frac{1}{\beta^\alpha \Gamma(\alpha)} s^{\alpha-1} e^{-s/\beta} \quad (10)$$

where parameters α and β are estimated as:

$$\alpha = \mu^2 / \sigma^2, \quad \beta = \sigma^2 / \mu \quad (11)$$

where μ and σ are mean and standard deviation of log-likelihood scores. In order to get an accurate estimation of all these parameters, it's necessary to prune abnormal scores first. In our experiment, the abnormal score is defined as those whose distance with μ are larger than 2σ . In each iteration μ and σ are calculated firstly, and then those abnormal ones are pruned. The iteration is stopped until there is no abnormal data in score set any more.

Based on Eq. (8), each input window is examined if it is “accepted” by a sound effect. If it is accepted by a sound effect, the corresponding likelihood score, which is also considered as confidence, is added to the candidate stack, as the Figure 2 shows. After going through all the log-likelihood scores, the final decision is made as following. If the stack is empty, the input window does not belong to any registered model; otherwise, it is classified into the i^{th} sound effect with the maximum confidence,

$$i = \arg \max_j (p(s_j | C_j)) \quad (12)$$

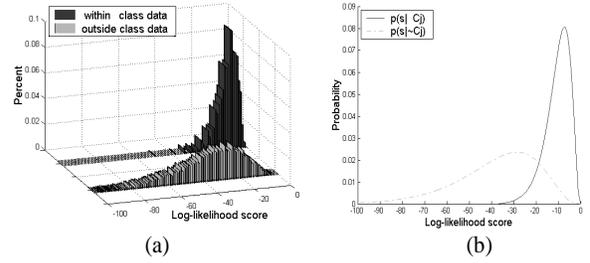


Figure 3. (a) log-likelihood scores distributions; (b) Approximate (a) with Gamma distribution

4. SOUND EFFECT ATTENTION MODEL

Based on the location of these highlight sound effects, an extended audio attention model can be established, which describe the saliency of each sound effect. It's very helpful for further highlight extraction and video summarization. In this paper, two characters are used to represent sound effect attention model. One is loudness, which can be represented by its energy; the other is the confidence in some sound effect class, which is represented by the log-likelihood score under corresponding HMM.

These two characters are normalized as:

$$\begin{aligned} \bar{E} &= E_{avr} / Max_E_{avr} \\ \bar{P}_j &= \exp(s_j - Max_s_j) \end{aligned} \quad (13)$$

where E_{avr} and s_j denote the average energy and log-likelihood score under model j of an audio segment respectively. Max_E_{avr} and Max_s_j are the maximum average energy and log-likelihood score under model j in an entire audio stream. Then the attention score for class j is defined as:

$$M_j = \bar{E} \cdot \bar{P}_j \quad (14)$$

Figure 4 illustrates the sound effect attention curves of three effects, which include laughter, applause and cheer, for 1 minute clip of the NBC's TV show “Hollywood Square”.

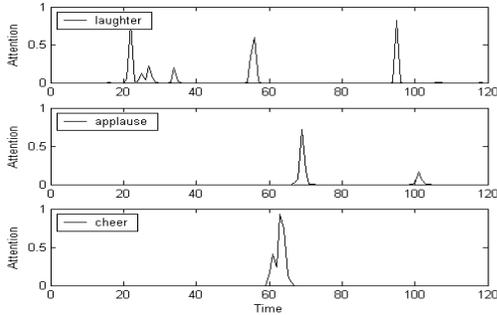


Figure 4. Sound effect attention model curves

5. EXPERIMENTS

The evaluations of the proposed algorithm are performed on our database. Three sound effects, including laughter, applause and cheer, are modeled. The training data for each sound effect includes 100 pieces of samples. Each piece is about 3-10s long and totally about 10min training data for each class. The testing database is about 2 hours videos, with different programs and different language, including NBC's TV show "Hollywood Square" (30 min), CCTV's TV show "Lucky 52" (60 min) and a live program record of table tennis championship (30 min). All the audio-tracks are first manually labeled. And then, the audio streams are segmented into 1-second windows with 0.5-second overlap, each window get a ground truth according to the labels.

In order to estimate the log-likelihood distributions in Figure 3 more accurately, two kind distribution curves, *Gaussian* and *Gamma* distribution, are compared. Recall and precision, which is always used in retrieval system evaluation, are used to measure the performance of our system. With all other parameters kept the same, the comparison results on the 30min "Hollywood Square" are showed in Table 1. From the Table, it can be seen that *Gamma* distribution performs much better than *Gaussian* distribution. Compared with *Gaussian* distribution, *Gamma* distribution increases the precision remarkably (about 9.3%) while just affects the recall ratio lightly (about 1.8%).

Table 1. Performance on different *p.d.f.* distribution

<i>p.d.f.</i>	Sound Effect	Recall	Precision
<i>Gaussian</i>	laughter	0.959	0.791
	applause	0.933	0.668
	cheer	0.907	0.906
<i>Gamma</i>	laughter	0.927	0.879
	applause	0.910	0.850
	cheer	0.907	0.916

Results of general tests on all the 2-hours data are listed in Table 2. From Table 2, it can be seen that the performance is encouraging. The average recall is about 92.95% and precision is about 86.88% respectively. The high recall can meet the requirements well for highlights extraction and summarization. However, there still exist some mis-detections. In the table tennis championship, sometimes the reporter uses brief and exciting voice for a wonderful play, which is often detected as laughter, thus makes the laughter's precision is a little low. Moreover, when sound effects are mixed with music, speech and other complicated environment sounds, it's also hard to make a

judgment, that's why the recall of TV shows are somewhat lower than that of the table tennis match, which has a relative quiet environment.

Table 2. Performance of the algorithm

Video	Sound Effect	Recall	Precision
Hollywood Square	laughter	0.927	0.879
	applause	0.910	0.850
	cheer	0.907	0.916
Lucky 52	laughter	0.956	0.813
	applause	0.894	0.826
	cheer	0.910	0.917
Table Tennis Championship	laughter	0.977	0.778
	applause	0.956	0.945
	cheer	0.957	0.946

6. CONCLUSION

In this paper, we have presented in detail our framework and algorithm for highlight sound effects detection in audio stream. Three highlight sound effects are considered in current system: laughter, applause and cheer, which are mostly semantically related with interesting events in TV shows, sports, meeting and home videos. HMMs are used to model sound effects and a log-likelihood based method is proposed to make decision. A sound effect attention model is also proposed for further highlight extraction and summarization. Experimental evaluations have shown that the algorithm can obtain very satisfying results.

7. REFERENCES

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