



## Audio Sentiment Analysis by Heterogeneous Signal Features Learned from Utterance-Based Parallel Neural Network

---

Ziqian Luo, Hua Xu and Feiyang Chen

EasyChair preprints are intended for rapid dissemination of research results and are integrated with the rest of EasyChair.

December 13, 2018

# Audio Sentiment Analysis by Heterogeneous Signal Features Learned from Utterance-Based Parallel Neural Network

Ziqian Luo, Hua Xu, Feiyang Chen

State Key Laboratory of Intelligent Technology and Systems,  
Department of Computer Science and Technology, Tsinghua University,  
Beijing 100084, China

luoziqian98@gmail.com, xuhua@tsinghua.edu.cn, chenfeiyang999@gmail.com

**Abstract.** Audio Sentiment Analysis is a popular research area which extends the text-based sentiment analysis to depend on effectiveness of acoustic features extracted from speech. However, current progress on audio sentiment analysis mainly focuses on extracting homogeneous acoustic features or doesn't fuse heterogeneous features effectively. In this paper, we propose an utterance-based deep neural network model, which has a parallel combination of CNN and LSTM based network, to obtain representative features termed Audio Sentiment Vector (ASV), that can maximally reflect sentiment information in an audio. Specifically, our model is trained by utterance-level labels and ASV can be extracted and fused creatively from two branches. In the CNN model branch, spectrum graphs produced by signals are fed as inputs while in the LSTM model branch, inputs include spectral centroid, MFCC and other recognized traditional acoustic features extracted from dependent utterances in an audio. Besides, BiLSTM with attention mechanism is used for feature fusion. Extensive experiments have been conducted to show our model can recognize audio sentiment precisely, and demonstrate our ASV are better than traditional acoustic features or vectors extracted from other deep learning models. Furthermore, experimental results indicate that the proposed model outperforms state-of-the-art approaches by 9.33% on MOSI.

**Keywords:** Audio Sentiment Analysis · Feature Fusion · Signal Processing.

## 1 Introduction

Sentiment Analysis is a well-studied research area in Natural Language Processing (NLP) (Pang B et al. 2008), which is the computational study of peoples' opinions, sentiments, appraisals, and attitudes towards entities such as products, services, organizations and so on (Liu B et al. 2015). Traditional sentiment analysis methods are mostly based on text, with the rapid development of communication technology, abundance of smartphones and the rapid rise of social

media, large amounts of data are uploaded by web users in the form of audios or videos, rather than text (S. Poria et al. 2017). Interestingly, a recent study shows that voice-only as modality seems best for humans empathic accuracy as compared to video-only or audiovisual communication (Kraus et al. 2017). In fact, audio sentiment analysis is a difficult task due to the complexity of audio signal. It is generally known that speech is the most convenient and natural medium for human communication, not only carries the implicit semantic information, but also contains rich affective information (S. Zhang et al. 2017). Therefore, audio sentiment analysis, which aims to analyze correctly the sentiment of the speaker from speech signals, has drawn a great deal of attention of researchers.

In recent years, there are three main methods for audio sentiment analysis. Firstly, utilizes automatic speech recognition (ASR) technology to convert speech into texts, following by conventional text-based sentiment detection systems (S. Ezzat et al. 2012). Secondly, adopts a generative model operating directly on the raw audio waveform (Van Den Oord A et al. 2016). Thirdly, focuses on extracting signal features from the raw audio files (Bertin et al. 2011), which well captures the tonal content of a music, and has been proved to be more effective than original audio spectrums descriptors such as Mel-frequency cepstrum coefficients(MFCC).

However, for converting speech into texts, by recognizing each word said by the person in an audio, change them into the word embedding and use some techniques in NLP, like TF-IDF and bag of words model. The result is not always accurate, because sentiment detection accuracy depends on being able to reliably detect a very focused vocabulary in the spoken comments (Kaushik L et al. 2015). Furthermore, when the voice is transferred to the text, some sentiment-related signal characteristics are also lost, resulting in a decrease in the accuracy of the sentiment classification. As for extracting from the raw audio files through human works and then being put into the support vector machine(SVM) classifier for classification, those methods require lots of human work and are heavily dependent on language types. Luckily, along with the success of deep learning in many other application domains, deep learning is also popularly used in audio sentiment analysis in recent years (Mariel W C F et al. 2018). More recently, (G. Trigeorgis et al. 2016) directly use the raw audio samples to train a convolutional recurrent neural network (CRNN) to predict continuous arousal /valence space. (Mirsamadi et al. 2017) study the use of deep learning to automatically discover emotionally relevant features from speech. They propose a novel strategy for feature pooling over time which uses local attention in order to focus on specific regions of a speech signal that are more emotionally salient. (Neumann et al. 2017) use an attentive convolutional neural network with multi-view learning objective function and achieved state-of-the-art results on the improvised speech data of IEMOCAP. (Wang et al. 2017) propose to use deep neural networks (DNN) to encode each utterance into a fixed-length vector by pooling the activations of the last hidden layer over time. The feature encoding process is designed to be jointly trained with the utterance-level classifier for better classification. (Chen et al. 2018) propose a 3-D attention-based convolutional recurrent

neural networks to learn discriminative features for speech emotion recognition, where the Mel-spectrogram with deltas and delta-deltas are creatively used as input. But most of the previous methods still either considered only one single audio feature (Chen et al. 2018) or high-dimensional vectors from one homogeneous feature (Poria et al. 2017), and did not effectively extract and fuse audio features.

We believe the information extracted from a single utterance must have dependency on its context. For example, a flash of loud expression may not indicate a person has a strong emotion since it maybe just caused by a cough while continuous loud one is far more likely to indicate the speaker has a strong emotion.

In this paper, based on a large number of experiments, we extract the features of each utterance in an audio through the Librosa toolkit, and obtain four most effective features representing sentiment information, merge them by adopting a BiLSTM with attention mechanism. Moreover, we design a novel model called Audio Feature Fusion-Attention based CNN and RNN (AFF-ACRNN) for audio sentiment analysis. Spectrum graphs and selected traditional acoustic features are fed as input in two separate branches, we can obtain a new fusion of audio feature vector before the softmax layer, which we call the Audio Sentiment Vector (ASV). Finally, the output of the softmax layer is the class of sentiment.

Major contributions of the paper are that:

- We propose an effective AFF-ACRNN model for audio sentiment analysis, through combining multiple traditional acoustic features and spectrum graphs to learn more comprehensive sentiment information in audio.
- Our model is language insensitive and pay more attention to acoustic features of the original audio rather than words recognized from the audio.
- Experimental results indicate that the proposed method outperforms the state-of-the-art methods (Poria et al. 2017) on Multimodal Corpus of Sentiment Intensity dataset(MOSI) and Multimodal Opinion Utterances Dataset (MOUD).

The rest of the paper is organized as follows. In the following section, we will review related work. In Section 3, we will exhibit more details of our methodology. In Section 4, experiments and results are presented, and conclusion follows in Section 5.

## 2 Related Work

Current state-of-the-art methods for audio sentiment analysis are mostly based on deep neural network. In this section, we briefly present the advances on audio sentiment analysis task by utilizing deep learning, and then we give a summary on the progress of extracting the audio feature representation.

### 2.1 Long Short-Term Memory (LSTM)

It has been demonstrated that LSTM (Hochreiter S et al. 1997) are well-suited to make predictions based on time series data, by utilizing a cell to remember

values over arbitrary time intervals and the three gates(input gate  $i$ , output gate  $o$ , forget gate  $f$ ) to regulate the flow of information into and out of the cell, which can be described as follows:

$$f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f)$$

$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i)$$

$$o_t = \sigma(W_o \cdot [h_{t-1}, x_t] + b_o)$$

where  $h_t = o_t * \tanh(C_t)$  is the output of the last cell and  $x_t$  is the input of current cell. Besides, the current cell state  $C_t$  can be updated by the following formula:

$$\tilde{C}_t = \tanh(W_c \cdot [h_{t-1}, x_t] + b_c)$$

$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$

where  $C_{t-1}$  stands for the previous cell state.

One of the most effective variant of LSTM is the bidirectional LSTM. Each input sequence will be fed into both the forward and backward LSTM layers and thus a hidden layer receives an input by joining forward and backward LSTM layers.

## 2.2 Convolutional Neural Network (CNN)

CNN (Y. Le Cun et al. 1990) are well-known for extracting features from a image by using convolutional kernels and pooling layers to emulate the response of an individual to visual stimuli. Moreover, CNN have been successfully used not only for computer vision, but also for speech (T. N. Sainath et al. 2015). For speech recognition, CNN is proved to be robust against noise compared to other DL models (D.Palaz et al. 2015).

## 2.3 Audio Feature Representation and Extraction

Researchers have found pitch and energy related features playing a key role in affect recognition (Poria S et al. 2017). Other features that have been used by some researchers for feature extraction include formants, MFCC, root-mean-square energy, spectral centroid and tonal centroid features. During the speech production, there are several utterances and for each utterance, the audio signal can be divided into several segments. Global features are calculated by measuring several statistics, e.g., average, mean, deviation of the local features. Global features are the most commonly used features in the literature. They are fast to compute and, as they are fewer in number compared to local features, the overall speed of computation is enhanced (El Ayadi M et al. 2011). However,

there are some drawbacks of calculating global features, as some of them are only useful to detect affect of high arousal, e.g., anger and disgust. For lower arousal, global features are not that effective, e.g., global features are less prominent to distinguish between anger and joy. Global features also lack temporal information and dependence between two segments in an utterance. In a recent study (Cummins N et al. 2017), a new acoustic feature representation, denoted as deep spectrum features, derived from feeding spectrum graphs through a very deep image classification CNN and forming a feature vector from the activation of the last fully connected layer. Librosa (McFee B et al. 2015) is an open-source python package for music and audio analysis which is able to extract all the key features as elaborated above.

### 3 Methodology

In this section, we describe the proposed AFF-ACRNN model for audio sentiment analysis in details. We firstly introduce an overview of the whole neural network architecture. After that, two separate branch of AFF-ACRNN will be explained in details. Finally, we talk about the fusion mechanism used in our model.

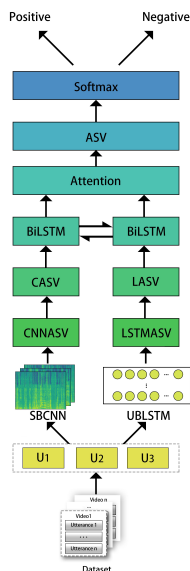
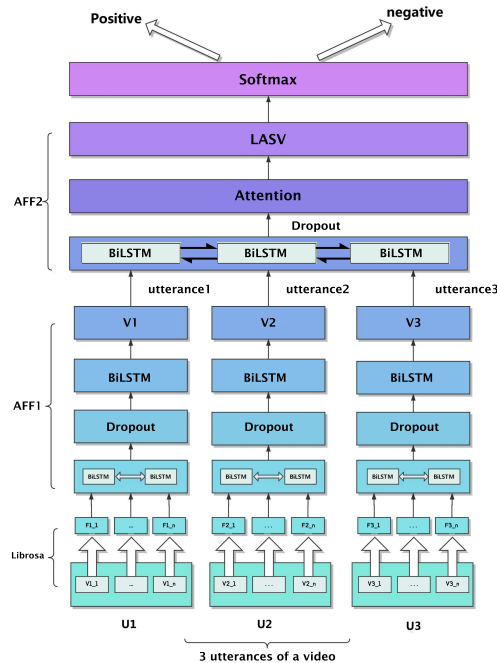


Fig. 1. Overview of AFF-ACRNN Model

### 3.1 Model—AFF-ACRNN

We concentrate on a model that has two parallel branches, the utterance based BiLSTM branch (UB-BiLSTM) and the spectrum based CNN branch (SBCNN), whose core mechanisms are based on LSTM and CNN. One branch of proposed model uses the BiLSTM to extract temporal information between adjacent utterances, another branch uses the renowned CNN based network to extract features from spectrum graph that sequence model cannot achieve. Furthermore, audio feature vector of each piece of utterance is the input of the proposed neural network that based on Audio Feature Fusion (AFF), we can obtain a new fusion audio feature vector before the softmax layer, which we call the Audio Sentiment Vector (ASV). Finally, the output of the softmax layer produces our final sentiment classification results, as shown in Figure 1.

### 3.2 Audio Sentiment Vector (ASV) from Audio Feature Fusion (AFF)



**Fig. 2.** Overview of Our UB-BiLSTM Model

**LSTM Layers** The hidden layers of LSTM have self-recurrent weights. These enable the cell in the memory block to retain previous information (Bae et al

al. 2016). Firstly, we separate the different videos and take three continuous utterances (e.g.  $u_1, u_2, u_3$ ) in one video at a time. Among them, for each utterance (e.g.  $u_1$ ), we extract its internal acoustic features through the librosa toolkit, say  $f_{1_1}, f_{1_2} \dots f_{1_n}$ , and then trained by two layers of BiLSTM in AFF1 to obtain the extracted features from the traditional acoustic feature. Therefore, three utterances are corresponding to three more efficient and representative vectors  $v_1, v_2, v_3$ , as the inputs to BiLSTM in AFF2. AFF2 effectively combines the contextual information between adjacent utterances, and then subtly acquires the utterance that has the greatest impact on the final sentiment classification through the attention mechanism. Finally, after the dropout layer, a more representative LASV extracted by our LSTM framework is obtained before the softmax layer, as shown in Figure 2. The process is described in LSTM branch procedure in Algorithm 1.

---

**Algorithm 1** Related Procedure
 

---

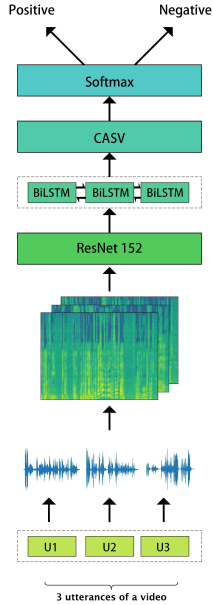
```

1: procedure LSTM BRANCH
2:   for  $i:[0,n]$  do
3:      $f_i = \text{getAudioFeature}(u_i)$ 
4:      $ASV_i = \text{getASV}(f_i)$ 
5:   end for
6:   for  $i:[0,M]$  do //M is the number of videos
7:      $input_i = \text{GetTopUtter}(v_i)$ 
8:      $u_{f_i} = \text{getUtterFeature}(input_i)$ 
9:   end for
10:   $shuffle(v)$ 
11: end procedure
12: procedure CNN BRANCH
13:   for  $i:[0,n]$  do
14:      $x_i \leftarrow \text{getSpectrogramImage}(u_i)$ 
15:      $c_i \leftarrow \text{CNNModel}(x_i)$ 
16:      $l_i \leftarrow \text{BiLSTM}(c_i)$ 
17:   end for
18: end procedure
19: procedure FIND CORRESPONDING LABEL
20:   for  $i:[0:2199]$  do
21:      $rename(u_i)$  // for better order in sorting
22:      $NameAndLabel = \text{createIndex}(u_i)$ 
23:     // A dictionary [utterance Name: Label]
24:   end for
25:    $Label_x = \text{NameAndLabel}(u_x)$ 
26: end procedure

```

---





**Fig. 3.** Overview of Our ResNet152 CNN Model

**CNN Layers** Similar to the UB-BiLSTM model proposed above, we extracted the spectrum graph of each utterance through the Librosa toolkit and use it as the input of our CNN branch. After a lot of experiments, we found that the audio feature vector learned by the ResNet152 network structure has the best effect on the final sentiment classification, so we choose the ResNet model in this branch. The convolutional layer performs 2-dimensional convolution between the spectrum graph and the predefined linear filters. To enable the network to extract complementary features and learn the characteristics of input spectrum graph, a number of filters with different functions are used. A more refined audio feature vector is obtained through deep convolutional neural network, and then put into the BiLSTM layer to learn related sentiment information between adjacent utterances. Finally, before the softmax layer, we get another effective vector CASV extracted by our CNN framework, as shown in Figure 3. The process is described in CNN branch procedure in Algorithm 1.

**Fusion Layers** Through the LSTM and CNN branches proposed above, we can extract two refined audio sentiment vectors, LASV and CASV for each utterance. We use these two kinds of vectors in parallel as the input of BiLSTM in AFF-ACRNN model. While effectively learning the relevant sentiment information of adjacent utterance, we extract the Audio Sentiment Vector (ASV) that has the greatest influence on the sentiment classification in the three utterances through the action of the attention mechanism. Finally, the final sentiment classification

result is obtained by softmax layer. In (J. Donahue et al. 2015), long-term recurrent convolution network (LRCN) model was proposed for visual recognition. LRCN is a consecutive structure of CNN and LSTM. LRCN processes the variable-length input with a CNN, whose outputs are fed into LSTM network, which finally predicts the class of the input. In (T. N. Sainath et al. 2015), a cascade structure was used for voice search. Compared to the method mentioned above, the proposed network forms a parallel structure in which LSTM and CNN accept different inputs separately. Therefore, the Audio Sentiment Vector (ASV) can be extracted more comprehensively, and a better classification result can be got.

### 3.3 Feature Fusion base on Attention Mechanism

Inspired by human visual attention, the attention mechanism is proposed by (Bahdanau et al. 2015) in machine translation, which is introduced into the Encoder-Decoder framework to select the reference words in source language for words in target language. We use the attention mechanism to preserve the intermediate output of the input sequence by retaining the LSTM encoder, and then a model is trained to selectively learn these inputs and to correlate the output sequences with the model output. Specifically, when we fuse the features, each phoneme of the output sequence is associated with some specific frames in the input speech sequence, so that the feature representation that has the greatest influence on the final sentiment classification can be obtained, and finally obtain a fused Audio Feature Vector. At the same time, attention mechanism behaves like a regulator since it can judge the importance of the contribution by adjacent relevant utterances for classifying the target utterance. Indeed, it is very hard to tell the sentiment of a single utterance if you do not concern its contextual information. However, you will also make a wrong estimation if contextual information is overly concerned. More specifically, in Figure 2, let  $A_x$  be the  $X_{th}$  attention network for utterance  $U_x$ , the corresponding attention weight vector is  $\alpha_x$  weighted hidden representation is  $R_x$ , we have:

$$\begin{aligned} P_x &= \tanh(W_h[x] \cdot H) \\ A_x &= \text{softmax}(w[x]^T \cdot P_x) \\ R_x &= H \cdot \alpha_x^T \end{aligned}$$

Final representation for  $x_t h$  utterance is:

$$h_x^* = \tanh(W_m[x] \cdot R_x + W_n[x] \cdot h_x)$$

Where  $W_m[x]$  and  $W_n[x]$  are weights to be learned while training.

## 4 Experiments

In this section, we exhibit our experimental results and the analysis of our proposed model. More specifically, our model is trained and evaluated on utterance-level audio from CMU-MOSI dataset (A. Zadeh et al. 2016) and being tested on MOUD (Prez-Rosas V et al. 2013).

#### 4.1 Experiment Setting

**Evaluation Metrics** We evaluate our performance by weighted accuracy on both 2-class, 5-class and 7-class classification.

$$\text{weighted accuracy} = \frac{\text{correct utterances}}{\text{utterances}}$$

Additionally, F-Score is used to evaluate 2-class classification.

$$F_{\beta} = (1 + \beta^2) \cdot \frac{\text{precision} \cdot \text{recall}}{(\beta^2 \cdot \text{precision}) + \text{recall}}$$

Where  $\beta$  represents the weight between precision and recall. During our evaluation process, we set  $\beta = 1$  since we regard precision and recall has the same weight thus  $F_1$ -score is adopted.

However, in 5-class and 7-class classification, we use Macro  $F_1$ -Score to evaluate the result.

$$\text{Macro } F_1 = \frac{\sum_1^n F_{1n}}{n}$$

where  $n$  represents the number of classification and  $F_{1n}$  is the  $F_1$  score on  $n$ th category.

**Dataset details** CMU-MOSI dataset is rich in sentiment expressions, consisting 2199 opinionated utterances, 93 videos by 89 speakers. The videos address a large array of topics, such as movies, books, and products. Videos were crawled from YouTube and segmented into utterances where each utterance is annotated with scores between  $-3$  (strongly negative) and  $+3$  (strongly positive) by five annotators. We took the average of these five annotations as the sentiment polarity and considered three conditions where consists of two classes (positive and negative), five classes (strong positive, positive, neutral, negative and strong negative) and seven classes (strong positive, positive, weak positive, neutral, strong negative, negative and weak negative). Our train/test splits of the dataset are completely disjoint with respect to speakers. In order to better compare with the previous work, similar to (Poria et al. 2017), we divide the data set by 7:3 approximately, 1616 and 583 utterances are used for training and testing respectively. Furthermore, in order to verify that our model will not be heavily dependent on the language category, we tested it with the Spanish dataset MOUD. MOUD contains product review videos provided by 55 persons. The reviews are in Spanish. The detailed datasets setup is depicted at Table 1.

**Network structure parameter** Our proposed architecture is implemented based on the open-source deep learning framework Keras. More specifically, for proposed UB-BiLSTM framework, after a lot of experiments, we extracted the most four representative audio features of each utterance in a video through Librosa toolkit, which are MFCC, spectral\_centroid, chroma\_stft and spectral\_contrast

Datasets	Train		Test	
	utterance	video	utterance	video
MOSI	1616	65	583	28
MOSI→MOUD	2199	93	437	79

**Table 1.** Datasets setting

respectively. In data processing, we make each utterance one-to-one correspondence with the label and rename the utterance. Accordingly, we extend each utterance to a feature matrix of  $256 * 33$  dimensions. The output dimension of the first layer of BiLSTM is 128, and the second layer is 32. The output dimension of the first layer of Dense is 200, and the second is 2.

For proposed CNN framework, the input images are warped into a fixed size of  $512 * 512$ . If the bounding box of the training samples provided, we firstly crop the images and then warp them to the fixed size. To train the feature encoder, we follow the fine-tuning training strategy.

In all experiments, our networks are trained by Adam or SGD optimizer. In the LSTM branch, we initiate the learning rate to be 0.0001, and there are 200 epochs in the training part with batch size equals to 30 in each epoch. In the CNN branch, we initiate the learning rate to be 0.001, and there are 200 epochs in training Resnet-152 with batch size equals to 20 in each epoch.

Best Feature Combination	Model	Accuracy(%)		
		2-class	5-class	7-class
Single Type	LSTM	55.12	23.64	16.99
	BiLSTM	55.98	23.75	17.24
Two Types	LSTM	62.26	28.23	21.54
	BiLSTM	63.76	29.77	22.92
Thress Types	LSTM	66.36	32.98	24.66
	BiLSTM	67.02	33.75	25.80
<b>Four Types</b>	<b>LSTM</b>	<b>68.23</b>	<b>33.15</b>	<b>26.27</b>
	<b>BiLSTM</b>	<b>68.72</b>	<b>34.27</b>	<b>26.82</b>
Five Types	LSTM	67.86	31.29	25.79
	BiLSTM	67.97	32.66	26.01
Six Types	LSTM	67.88	32.23	26.07
	BiLSTM	68.61	33.97	26.78
Seven Types	LSTM	68.01	33.06	25.99
	BiLSTM	68.67	34.18	26.12

**Table 2.** Comparison of different feature combinations

## 4.2 Performance Comparison

Methods	2-class		5-class		7-class	
	Acc(%)	F1	Acc(%)	Macro F1	Acc(%)	Macro F1
LeNet	56.75	55.62	23.67	21.87	15.63	15.12
AlexNet	58.71	57.88	26.43	23.19	19.21	18.79
VGG16	57.88	55.97	27.37	25.78	17.34	16.25
ZFNet	55.37	53.12	21.90	21.38	12.82	11.80
ResNet18	58.94	56.79	25.26	24.63	18.35	17.89
ResNet50	62.52	61.21	28.13	27.04	20.21	20.01
<b>ResNet152</b>	<b>65.42</b>	<b>64.86</b>	<b>28.78</b>	<b>28.08</b>	<b>21.56</b>	<b>20.57</b>

**Table 3.** Comparison of SBCNN with different structure

Methods	2-class		5-class		7-class	
	Acc(%)	F1	Acc(%)	Micro F1	Acc(%)	Micro F1
UB-LSTM+Res18	67.19	66.37	33.83	31.97	26.78	25.83
UB-LSTM+Res50	67.83	66.69	34.21	33.78	27.75	26.41
UB-LSTM+Res152	68.64	67.94	35.87	34.11	28.15	27.03
UB-BiLSTM+Res18	68.26	66.25	35.43	33.52	27.63	26.09
UB-BiLSTM+Res50	69.18	68.22	36.93	34.67	28.11	27.54
<b>UB-BiLSTM+Res152</b>	<b>69.64</b>	<b>68.51</b>	<b>37.71</b>	<b>35.12</b>	<b>29.26</b>	<b>28.45</b>

**Table 4.** Comparison of different combinations between SBCNN and UB-BiLSTM

**Comparison of different feature combinations.** Firstly, we have considered seven types of acoustic features that can best represent an audio, which mainly includes MFCC, root-mean-square energy, spectral and tonal features. A lot of experiments have been done in order to get the best feature combinations with different model on three types of classification. The results are listed in Table 2. What’s more, we have also compared the different performance of our LASV extracted from LSTM-based and BiLSTM-based fusion model. As the Table 2 shows, the performance of LASV that extracted from BiLSTM-based model behaves better, since the acoustic information behind may also have impact on the acoustic information previous. It can be seen that the best number of feature combination is four and those four features are MFCC, spectral\_centroid, spectral\_contrast and chroma\_stft. That means the other three features, which

are root-mean-square energy, spectral\_contrast and tonal centroid may introduce some noise or misleading in our sentiment analysis since all seven types of features do not have the best result.

**Comparison of several renowned CNN-based model.** We have compared our CASV performance extracted from the spectral map with several genres of popular models of CNN and its variants: LeNet (LeCun Y et al. 1998), AlexNet (Krizhevsky A et al. 2012), VGG16 (Simonyan K et al. 2014), ZFNet (Zeiler M D et al. 2014), ResNet (He K et al. 2016). The results are listed in Table 3. As the neural network goes deeper, more representative features can be got from the spectrum graph and that is why ResNet152 has the best performance. It is benefited from the residual unit which will guarantee the network will not degrade when the network goes deeper.

**Comparison of different combinations between SBCNN and UB-Bilstm**  
At last, we have performed fusion experiments between several best SBCNN and UB-BiLSTM and UB-LSTM. More accurately, we choose the three best SBCNN, which are ResNet18, ResNet50 and ResNet152 to combine with the two kinds of utterance dependent LSTM. The best combination is UB-BiLSTM with Res152. The final result is shown in Table 4.

**Comparison with traditional method.** Apart from training deep neural network, a bunch of traditional binary classifiers has been used for sentiment analysis. In order to demonstrate the effectiveness of our model, we firstly compare our model with those traditional methods.

[I2C2, 2017](Maghilan S et al.2017) introduced a text-based SVM and Naive Bayes model for binary sentiment classification, thus we test their model on MOUD, rather than MOSI, to make comparison with our model because MOUD has only two sentiment level and each utterance has text record in the dataset.

[BAJECE, 2018](C.bakir et al.2018) In this paper, except for SVM, the feature vectors like Mel Frequency Discrete Wavelet Coefficients (MFDWC), MFCC and LPCC extracted from original record signal are trained with classification algorithm such as Dynamic Time Warping (DTW), Hidden Markov Model (HMM) and Gauss Mixture Model (GMM).

As shown in Table 5, we use weighted accuracy (ACC) and F1-Score to evaluate our results. Especially, for the ACC on MOUD, our proposed model outperforms the best model, SVM classifier, by 11.51%.

**Comparison with the state-of-art.** (Poria et al.2017) This paper introduced a LSTM-based model to utilize the contextual information extracted from each utterance in an video. However, the input of the neural network model only has one type of feature, which is MFCC. This means all the utterance information is merely represented by one single feature. The acoustic information contained by the feature is somewhat duplicated and is bound to omit much sentiment

Model	MOUD	
	ACC(%)	F1
SVM	57.23	54.83
Naive Bayes	55.72	52.14
GMM	54.66	52.89
HMM	56.63	55.84
DTW	53.92	53.06
<b>AFF-ACRNN</b>	<b>68.74</b>	<b>66.37</b>

**Table 5.** Comparison with traditional methods on MOUD

information that might be hidden in many other useful features. What’s worse, one type of feature means the input vector should be large enough to make sure that it carries enough information before it is fed into the neural network. This will undoubtedly increase the parameters to be trained in the network and meanwhile, it is time consuming and computation costly.

Our proposed model not only extracts the feature or sentiment vector from four types of traditional recognized acoustic features, have considered utterance dependency, but also extracts the feature from the spectrum graph, which may reveal some sentiment information that acoustic features cannot reflect. The final AFF-ACRNN consists of the best combination of SBCNN and UB-BiLSTM and outperforms the state-of-the-art approach by 9.33% in binary classification on MOSI dataset and by 8.75% on MOUD. The results are shown in the Table 6.

Model	ACC(%)	
	MOSI	MOUD
State-of-the-art	60.31	47.20
<b>AFF-ACRNN</b>	<b>69.64</b>	<b>59.74</b>

**Table 6.** Comparison with state-of-art result (Poria et al.2017) . The right arrow means the model is trained and validated on the MOSI and tested on the MOUD

We have also run our model on one audio whose length is 10s for 1000 times and the average time to get the sentiment classification result from input is only 655.94ms which thanks to our concentrated ASV extracted from AFF-ACRNN.

### 4.3 Discussion

The above experimental results have already shown us that the proposed method has a great improvement in the performance of audio sentiment analysis. In order to get the best structure of our AFF-ACRNN model, we have tested two separate

branch respectively, and compare the final AFF-ACRNN with traditional or state-of-art method. Weighted accuracy and F1-Score, Macro F1-Score are used as metrics to evaluate the model’s performance. In the UB-Bilstm branch, a lot of experiments have shown that four types of heterogeneous traditional features trained by BiLSTM will have the best result, whose weighted accuracy is 68.72% on MOSI. In the SBCNN branch, we have carried out seven experiments to prove the ResNet152 used in SBCNN will have the best result, for instance, with the weighted accuracy of 65.42% on MOSI, due to its extreme depth and the helpful residual units used to prevent degradation. We selected six best combinations of SBCNN and UB-BiLSTM and find that the best is ResNet152 used in SBCNN with UB-Bilstm, whose weighted accuracy is 69.64% on MOSI and outperforms not only the traditional classifier like SVM, but also the state-of-the-art approach by 9.33% on MOSI dataset. Attention mechanism is used in both branch to subtly combine the heterogeneous acoustic features and choose the feature vectors that have the greatest impact on the sentiment classification. Furthermore, in the experiment of using MOSI as training set and verification set and MOUD as test set, it also shows that our proposed model has strong generalization ability.

## 5 Conclusion

In this paper, we propose a novel utterance-based deep neural network model termed AFF-ACRNN, which has a parallel combination of CNN and LSTM based network, to obtain representative features termed ASV, that can maximally reflect sentiment information in an utterance from an audio. We extract several traditional heterogeneous acoustic features by Librosa toolkit and choose the four most representative features through a large number of experiments, and regard them as the input of the neural network. We can get CASV and LASV from the CNN branch and the LSTM branch respectively, and finally merge the two branches to obtain the final ASV for sentiment classification of each utterance. Besides, BiLSTM with attention mechanism is used for feature fusion. The experimental results show our model can recognize audio sentiment precisely and quickly, and demonstrate our heterogeneous ASV are better than traditional acoustic features or vectors extracted from other deep learning models. Furthermore, experimental results indicate that the proposed model outperforms the state-of-the-art approach by 9.33% on MOSI dataset. We have also tested our model on MOUD to prove the model won’t heavily depend on language types. In the future, we will combine the feature engineering technologies to further discuss the fusion dimension of audio features and consider the fusion of different dimensions of different categories of features, and even apply them to multimodal sentiment analysis.



## 6 Acknowledgement

This paper is founded by National Natural Science Foundation of China (Grant No: 61673235) and National Key R&D Program Projects of China (Grant No: 2018YFC1707600).

## References

- Pang B, Lee L. Opinion mining and sentiment analysis[J]. *Foundations and Trends in Information Retrieval*, 2008, 2(12): 1-135.
- Liu B, "Sentiment analysis: mining opinions, sentiments, and emotions", The Cambridge University Press, 2015.
- S. Poria, E. Cambria, R. Bajpai, and A. Hussain, "A review of affective computing: From unimodal analysis to multimodal fusion", *Information Fusion*, vol. 37, pp. 98125, 2017.
- Kraus, "M.W. Voice-only communication enhances empathic accuracy", *American Psychologist* 72, 7 (2017), 644.
- S. Zhang, T. Huang and W. Gao, "Speech Emotion Recognition Using Deep Convolutional Neural Network and Discriminant Temporal Pyramid Matching," in *IEEE Transactions on Multimedia*, vol. PP. 99 (2017):1-1.
- S. Ezzat, N. Gayar and M.M. Ghanem, Sentiment Analysis of Call Centre Audio Conversations using Text Classification, in *International Journal of Computer Information Systems and Industrial Management Applications*, vol. 4, pp. 619-627, 2012.
- Van Den Oord A, Dieleman S, Zen H, et al. WaveNet: A generative model for raw audio[C]//SSW. 2016: 125.
- Bertin-Mahieux, T., and Ellis, D. P. 2011. Large-scale cover song recognition using hashed chroma landmarks. In *2011 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA)*, 117120. IEEE.
- Kaushik L, Sangwan A, Hansen J H L. Automatic audio sentiment extraction using keyword spotting[C]//Sixteenth Annual Conference of the International Speech Communication Association. 2015.
- Mariel W C F, Mariyah S, Pramana S. Sentiment analysis: a comparison of deep learning neural network algorithm with SVM and nave Bayes for Indonesian text[C]//Journal of Physics: Conference Series. IOP Publishing, 2018, 971(1): 012049.
- G. Trigeorgis, F. Ringeval, R. Brueckner, E. Marchi, M. A. Nicolaou, B. Schuller, and S. Zafeiriou, ADIEU Features? End-to-end Speech Emotion Recognition using A Deep Convolutional Recurrent Network, in *IEEE International Conference on Acoustics, Speech and Signal Processing*, 2016, pp. 52005204.
- Mirsamadi, Seyedmahdad, Emad Barsoum, and Cha Zhang. "Automatic speech emotion recognition using recurrent neural networks with local attention." *Acoustics, Speech and Signal Processing (ICASSP)*, 2017 IEEE International Conference on. IEEE, 2017.

- Neumann, Michael, and Ngoc Thang Vu. "Attentive convolutional neural network based speech emotion recognition: A study on the impact of input features, signal length, and acted speech." arXiv preprint arXiv:1706.00612 (2017).
- Wang, Zhong-Qiu, and Ivan Tashev. "Learning utterance-level representations for speech emotion and age/gender recognition using deep neural networks." Acoustics, Speech and Signal Processing (ICASSP), 2017 IEEE International Conference on. IEEE, 2017.
- Chen M, He X, Yang J, et al. 3-D Convolutional Recurrent Neural Networks with Attention Model for Speech Emotion Recognition[J]. IEEE Signal Processing Letters, 2018.
- Poria, Soujanya, et al. "Context-dependent sentiment analysis in user-generated videos." Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers). Vol. 1. 2017.
- Hochreiter S, Schmidhuber J. Long short-term memory[J]. Neural computation, 1997, 9(8): 1735-1780.
- Y. Le Cun, B. Boser et al., Handwritten digit recognition with a back-propagation network, in Advances in neural information processing systems, 1990.
- T. N. Sainath, O. Vinyals, A. Senior, and H. Sak, Convolutional, long short-term memory, fully connected deep neural networks, in IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE, 2015, pp. 4580-4584.
- D.Palaz,R.Collobertetal.,Analysisofcnn-based speechrecognition system using raw speech as input, in Proceedings of Interspeech, 2015.
- El Ayadi M, Kamel M S, Karray F. Survey on speech emotion recognition: Features, classification schemes, and databases[J]. Pattern Recognition, 2011, 44(3): 572-587.
- Cummins N, Amiriparian S, Hagerer G, et al. An Image-based deep spectrum feature representation for the recognition of emotional speech[C]//Proceedings of the 2017 ACM on Multimedia Conference. ACM, 2017: 478-484.
- McFee B, Raffel C, Liang D, et al. librosa: Audio and music signal analysis in python[C]//Proceedings of the 14th python in science conference. 2015: 18-25.
- Bae S H, Choi I, Kim N S. Acoustic scene classification using parallel combination of LSTM and CNN[C]//Proceedings of the Detection and Classification of Acoustic Scenes and Events 2016 Workshop (DCASE2016). 2016: 11-15.
- Prez-Rosas V, Mihalcea R, Morency L P. Utterance-level multimodal sentiment analysis[C]//Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers). 2013, 1: 973-982.
- LeCun Y, Bottou L, Bengio Y, et al. Gradient-based learning applied to document recognition[J]. Proceedings of the IEEE, 1998, 86(11): 2278-2324.
- Simonyan K, Zisserman A. Very deep convolutional networks for large-scale image recognition[J]. arXiv preprint arXiv:1409.1556, 2014.
- Zeiler M D, Fergus R. Visualizing and understanding convolutional networks[C] European conference on computer vision. Springer, Cham, 2014: 818-833.
- Dong C, Loy C C, He K, et al. Image super-resolution using deep convolutional networks[J]. IEEE transactions on pattern analysis and machine intelligence,

2016, 38(2): 295-307.

Balamurugan B, Maghilnan S, Kumar M R. Source camera identification using SPN with PRNU estimation and enhancement[C]//Intelligent Computing and Control (I2C2), 2017 International Conference on. IEEE, 2017: 1-6.

Bakir C, Jarvis D S L. Institutional entrepreneurship and policy change[J]. Policy and Society, 2018.

Zadeh A, Liang P P, Poria S, et al. Multi-attention recurrent network for human communication comprehension[J]. arXiv preprint arXiv:1802.00923, 2018.