

# SadTalker: Learning Realistic 3D Motion Coefficients for Stylized Audio-Driven Single Image Talking Face Animation

Wenxuan Zhang<sup>1, 2</sup>   Xiaodong Cun<sup>3</sup>   Xuan Wang<sup>4</sup>   Yong Zhang<sup>3</sup>   Xi Shen<sup>3</sup>  
Yu Guo<sup>2, 5</sup>   Ying Shan<sup>3</sup>   Fei Wang<sup>†, 2, 5</sup>  
<sup>1</sup> School of Software Engineering, Xi'an Jiaotong University  
<sup>2</sup> National Key Laboratory of Human-Machine Hybrid Augmented Intelligence  
<sup>3</sup> Tencent AI Lab   <sup>4</sup> Ant Group   <sup>5</sup> IAIR, Xi'an Jiaotong University

Figure 1. The proposed SadTalker produces diverse, realistic, synchronized talking videos from input audio and a single reference image.

## Abstract

Generating talking head videos through a face image present ExpNet to learn the accurate facial expression from a piece of speech audio still contains many challenges audio by distilling both coefficients and 3D-rendered faces. i.e., unnatural head movement, distorted expression, and As for the head pose, we design PoseVAE via a conditional identity modification. We argue that these issues are mainly VAE to synthesize head motion in different styles. Finally, caused by learning from the coupled 2D motion fields. On the generated 3D motion coefficients are mapped to the unsupervised 3D keypoints space of the proposed face render. On the other hand, explicitly using 3D information also suffers supervised 3D keypoints space of the proposed face render. We present to synthesize the final video. We conducted extensive experiments to demonstrate the superiority of our method in terms of motion and video quality.<sup>1</sup> SadTalker, which generates 3D motion coefficients (head movements to demonstrate the superiority of our method in terms of pose, expression) of the 3DMM from audio and implicitly modulates a novel 3D-aware face render for talking head generation. To learn the realistic motion coefficients, we

explicitly model the connections between audio and different types of motion coefficients individually. Precisely, we

<sup>\*</sup> Equal Contribution  
<sup>†</sup> Corresponding Author

<sup>1</sup>The code and demo videos are available at <https://sadtalker.github.io>.

## 1. Introduction

Animating a static portrait image with speech audio is a challenging task and has many important applications in the fields of digital human creation, video conferences, etc. Previous works mainly focus on generating lip motion [2, 3, 28, 29, 49] since it has a strong connection with speech. Recent works also aim to generate a realistic talking face video containing other related motions, e.g., head pose. Their methods mainly introduce 2D motion fields by landmarks [50] and latent warping [37, 38]. However, the quality of the generated videos is still unnatural and restricted by the preference pose [16, 49], mouth blur [28], identity modification [37, 38], and distorted face [37, 38, 47].

Generating a natural-looking talking head video contains many challenges since the connections between audio and different motions are different. E.g., the lip movement has the strongest connection with audio, but audio can be talked via different head poses and eye blink. Thus, previous facial landmark-based methods [2, 50] and 2D flow-based audio to expression networks [37, 38] may generate the distorted face since the head motion and expression are not fully disentangled in their representation. Another popular type of method is the latent-based face animation [3, 16, 28, 49]. Their methods mainly focus on the specific kind of motions in talking face animation and struggle to synthesize high-quality video. Our observation is that the 3D facial model contains a highly decoupled representation and can be used to learn each type of motion individually. Although a similar observation has been discussed in [47], their methods also generate inaccurate expressions and unnatural motion sequences.

From the above observation, we propose SadTalker, a Stylized Audio-Driven Talking-head video generation system through implicit 3D coefficient modulation. To achieve this goal, we consider the motion coefficients of the 3DMM as the intermediate representation and divide our task into two major components. On the one hand, we aim to generate the realistic motion coefficients (e.g., head pose, lip motion, and eye blink) from audio and learn each motion individually to reduce the uncertainty. For expression, we design a novel audio to expression coefficient network by distilling the coefficients from the lip motion only coefficients from [28] and the perceptual losses (lip-reading loss [1], facial landmark loss) on the reconstructed rendered 3D face [5]. For the stylized head pose, a conditional VAE [6] is used to model the diversity and life-like head motion by learning the residual of the given pose. After generating the realistic 3DMM coefficients, we drive the source image through a novel 3D-aware face render. Inspired by face-vid2vid [40], we learn a mapping between the explicit 3DMM coefficients and the domain of the unsupervised 3D keypoint. Then, the edited keypoints are generated through the unsupervised 3D video portrait [18], these methods utilize 3DMM information of source and driving and it warps the reference image to generate the final videos. We train each sub-network

of expression generation, head poses generation and face renderer individually and our system can be inferred in an end-to-end style. As for the experiments, several metrics show the advantage of our method in terms of video and motion methods.

The main contribution of this paper can be summarized as:

- We present SadTalker, a novel system for a stylized audio-driven single image talking face animation using the generated realistic 3D motion coefficients.
- To learn the realistic 3D motion coefficient of the 3DMM model from audio, ExpNet and PoseVAE are presented individually.
- A novel semantic-disentangled and 3D-aware face renderer is proposed to produce a realistic talking head video.
- Experiments show that our method achieves state-of-the-art performance in terms of motion synchronization and video quality.

## 2. Related Work

Audio-driven Single Image Talking Face Generation.

Early works [3, 28, 29] mainly focus on producing accurate lip motion with a perception discriminator. Since the real videos contain many different motions, ATVGNet [2] uses the facial landmark as the intermediate representation to generate the video frames. A similar approach has been proposed by MakeltTalk [50], differently, it disentangles the content and speaker information from the input audio signal. Since facial landmarks are still a highly coupled space, generating the talking head in the disentangled space is also popular recently. PC-AVS [49] disentangles the head pose and expression using implicit latent code. However, it can only produce low-resolution image and need the control signal from another video. Audio2Head [37] and Warptalk [38] get inspiration from the video-driven method [34] to produce the talking-head face. However, these head movements are still not vivid and produce distorted faces with inaccurate identities. Although there are some previous works [31, 47] use 3DMMs as an intermediate representation, their method still faces the problem of inaccurate expressions [31] and obvious artifacts [47].

Audio-driven Video Portrait. Our task is also related to visual dubbing, which aims to edit a portrait video through audio. Different from audio-driven single image talking face generation, this task is typically required to be trained and edited on the specific video. Following previous work of deep video portrait [18], these methods utilize 3DMM information for face reconstruction and animation. AudioDVP [43], NVP [36], AD-NeRF [11] learn to reenact the expression to

Figure 2. Main pipeline. Our method uses the coefficients of 3DMM as intermediate motion representation. To this end, we first generate realistic 3D motion coefficients (facial expression, head pose) from audio, then these coefficients are used to implicitly modulate the 3D-aware face render for neural video generation.

edit the mouth shape. Beyond lip movement, the head motions [22, 46], emotional talking face [17] also get attention. The 3DMM-based method plays an important role in these tasks since it is practical to fit the 3DMM parameters from a video clip. Although these methods achieve satisfactory results in personalized video, their method can not be applied to arbitrary photos and in the wild audio.

#### Video-Driven Single Image Talking Face Generation.

This task is also known as face reenactment or face animation, which aims to transfer the motion of the source image to the target person. It has been widely explored [14, 27, 31, 34, 35, 39, 40, 42, 45, 48] recently. Previous works also learn a shared intermediate motion representation from the source image and the target, which can be roughly divided into the landmark [39] and the unsupervised landmark-based methods [14, 34, 40, 48], 3DMM based methods [7, 31, 45] and the latent animation [23, 42]. This task is much easier than our task since it contains the motion in the same domain. Our face render is also inspired by the method of unsupervised landmark-based method [40] and 3DMM-based method [31] to use coefficients to generate real videos. However, they are not focused on generating realistic motion coefficients.

### 3. Method

As shown in Fig. 2, our system uses the 3D motion coefficients as the intermediate representation for talking head generation. We first extract the coefficients from the original image. Then, the realistic 3DMM motion coefficients are generated by ExpNet and PoseVAE individually. Finally, a 3D-aware face render is proposed to produce the talking head videos. Below, we give a brief introduction to the 3D face model as preliminaries in Sec. 3.1, the audio-driven motion coefficients generation and the coefficients-driven image animator we design in Sec. 3.2 and Sec. 3.3, respectively.

#### 3.1. Preliminary of 3D Face Model

3D information is crucial to improve the realness of the generated video since the real video is captured in the 3D environment. However, previous works [28, 49, 50] have rarely been a consideration in 3D space since it is hard to obtain accurate 3D coefficients from a single image and the high-quality face render is also hard to design. Inspired by the recent single image deep 3D reconstruction method [5], we consider the space of the predicted 3D Morphable Models (3DMMs) as our intermediate representation. In 3DMM, the 3D face shape  $\mathbf{S}$  can be decoupled as:

$$\mathbf{S} = \bar{\mathbf{S}} + \mathbf{U}_{id} + \mathbf{U}_{exp}; \quad (1)$$

where  $\bar{\mathbf{S}}$  is the average shape of the 3D face, and  $\mathbf{U}_{exp}$  are the orthonormal basis of identity and expression of LSF morphable model [1]. Coefficients  $\mathbf{2} \times \mathbb{R}^{80}$  and  $\mathbf{2} \times \mathbb{R}^{64}$  describe the person identity and expression, respectively. To preserve pose variance, coefficients  $\mathbf{2} \times \text{SO}(3)$  and  $\mathbf{2} \times \mathbb{R}^3$  denote the head rotation and translation. To achieve identity irrelevant coefficients generation [31], we only model the parameters of motion  $\mathbf{4s}; \mathbf{r}; \mathbf{t}$ . We learn the head pose  $\mathbf{= [r; t]}$  and expression coefficients individually from the driving audio as introduced before. Then, these motion coefficients are used to implicitly modulate our face render for neural video synthesis.

#### 3.2. Motion Coefficients Generation through Audio

As introduced above, the 3D motion coefficients contain both head pose and expression where the head pose is a global motion and the expression is relatively local. To this end, learning everything altogether will cause huge uncertainty in the network since the head pose has a relatively weak relationship with audio while the lip motion is highly connected. We generate the motion of the head pose and expression using the proposed PoseVAE and ExpNet, respectively introduced below.

**ExpNet** Learning a generic model which produces accurate expression coefficients from audio is extremely hard for two reasons: 1) audio-to-expression is not a one-to-one mapping task for different identities. 2) there are some audio-irrelevant motions in the expression coefficients and it will influence the prediction's accuracy. Our ExpNet is designed

to reduce these uncertainties. As for the identity issue, we connect the expression motion to the specific person via the first frame's expression coefficients, which also controls the facial emotion of the generated video. To reduce the disturbance of other facial components in real expression coefficients, we use the lip motion only coefficients as the coefficient target through the pre-trained network of Wav2Lip [28] and deep 3D reconstruction [5]. Then, other minor facial motions (e.g., eye blink) can be leveraged via the additional landmark loss on the rendered images.

Figure 3. The structure of our ExpNet. We involve a monocular 3D face reconstruction model [5] ( $R_e$  and  $R_d$ ) to learn the realistic expression coef cients. Where  $R_e$  is a pretrained 3DMM coef cients estimator and  $R_d$  is a differentiable 3D face render without learnable parameters. We use the reference expression to reduce the uncertainty of identity and the generated frame from pre-trained Wav2Lip [28] and the rst frame as target expression coef cients since it only contains the lip-related motions.

As shown in Figure 3, we generate the frame expression coef cients from an audio window  $a_{f 1:t g}$ , where the audio feature of each frame is a 0.2s mel-spectrogram. For training, we rst design a ResNet-based audio encoder [12, 28] to embed the audio feature to a latent space. Then, a linear layer is added as the mapping network  $M$  to decode the expression coef cients. Here, we also add the reference expression  $e_0$  from the reference image to support emotions and reduce the identity uncertainty as discussed above. Since we use the lip-only coef cients as ground truth in the training, we explicitly add a blinking control signal  $z_{blink} \in [0; 1]$  and the corresponding eye landmark loss to generate the controllable eye blinks. Formally, the network can be written as:

$$f_{1:t g} = M(A(a_{f 1:t g}); z_{blink}; e_0) \quad (2)$$

As for the loss function, we use  $\mathcal{L}_{distill}$  to evaluate the differences between the lip only expression coef cients  $R_e(Wav2Lip(l_0; a_{f 1:t g}))$  and the generated  $f_{1:t g}$ . Notice that, we only use the rst frame  $l_0$  of the wav2lip to generate the lip-sync video which reduces the influence of the pose variant and other facial expressions apart from lip movement. Besides, we also involve the differentiable 3D image animator. We get inspiration from the recent image face render  $R_d$  to calculate the additional perceptual losses in explicit facial motions space. As shown in Figure 3, we calculate the landmark loss  $\mathcal{L}_{lks}$  to measure the range of eye blink and the overall expression accuracy. A pretrained lip reading network  $reader$  is also used as temporal lip reading loss  $\mathcal{L}_{read}$  to keep the perceptual lip qualities [9, 28]. We provide more training details in the supplementary materials.

Figure 4. The pipeline of the proposed PoseVAE. We learn the residual of the input head pose via a conditional VAE structure. Given the conditions: rst frame  $e_0$ , style identity  $z_{style}$  and the audio clip  $a_{f 1:t g}$ , our method learns a distribution of the residual head pose  $f_{1:t g} = f_{1:t g} + e_0$ . After training, we can generate the stylized results through the pose decoder and the conditions (cond:) only.

**PoseVAE** As shown in Figure 4, a VAE [20] based model is designed to learn the realistic and identity-aware stylized head movement  $2 \times R^6$  of the real talking video. In training, the pose VAE is trained on xed frames using an encoder-decoder-based structure. Both the encoder and decoder are two-layer MLPs, where the inputs contain a sequential frame head poses and we embed it to a Gaussian distribution. In the decoder, the network is learned to generate the frame poses from the sampled distribution. Instead of generating the pose directly, our PoseVAE learns the residual of the condition pose  $e_0$  of the rst frame, which enables our method to generate longer, stable, and continuous head motion in testing under the condition of the rst frame. Besides, according to CVAE [6], we add the corresponding audio feature  $a_{f 1:t g}$  and style identity  $z_{style}$  as conditions for rhythm awareness and identity style. The KL-divergence  $\mathcal{L}_{kl}$  is used to measure the distribution of the generated motions. The mean square loss  $\mathcal{L}_{MSE}$  and adversarial loss  $\mathcal{L}_{GAN}$  are used to ensure the generated quality. We provide more details about the loss function in the supplementary materials.

### 3.3. 3D Identity-aware Face Render

After generating the realistic 3D motion coef cients, we render the nal video through a well-designed 3D-aware animation method Face-vid2vid [40] because it implicitly learns the 3D information from a single image. However, a real video is required as the motions driving signal in their method. Our face render makes it drivable through 3DMM coef cients. As shown in Figure 5, we propose mappingNet to learn the relationship between the explicit 3DMM motion coef cients (head pose and expression) and the implicit unsu-



are also cropped and processed following [34] and resized to 256 × 256 for evaluation. We use the first frame of each video as the reference image to generate videos.

**Implementation Details** All of ExpNet, PoseVAE, and FaceRender are trained separately and we employ Adam optimizer [19] for all experiments. After training, our method can be inferred in an end-to-end fashion without any manual intervention. All the 3DMM parameters are extracted through pre-trained deep 3D face reconstruction method [5]. We perform all the experiments on 8 A100 GPUs. ExpNet, PoseVAE, and FaceRender are trained with a learning rate of  $2e^{-5}$ ,  $1e^{-4}$ , and  $2e^{-4}$ , respectively. As for the temporal consideration, ExpNet uses continuous 5 frames to learn. PoseVAE is learned via continuous 32 frames. The frames in FaceRender are generated frame-by-frame with the coefficients of 27 continuous frames for stability.

Figure 5. The proposed FaceRender and comparison with face-vid2vid [40]. Given source image  $I_s$  and driving image  $I_d$ , face-vid2vid generates the motions in a unsupervised 3D keypoint spaces of  $X_c$ ,  $X_s$  and  $X_d$ . Then, the image can be generated via the appearance  $A_0$  and the keypoints. Since we do not have driving image, we use the explicit disentangled 3DMM coefficients as proxy and map it to the unsupervised 3D keypoints space.

pervised 3D keypoints. Our mappingNet is built via several 1D convolutional layers. We use temporal coefficients from a time window for smoothing as PIRenderer [31]. Differently, we find the face alignment motion coefficients in PIRenderer will hugely influence the motion naturalness of audio-driven video generation and provide an experiment in Sec. 4.4. We only use the coefficients of expression and head pose.

As for training, our method contains two steps. Firstly, we train face-vid2vid [40] in a self-supervised fashion as in the original paper. In the second step, we freeze all the parameters of the appearance encoder, canonical keypoints estimator, and image generator for tuning. Then, we train the mapping net on the 3DMM coefficients of the ground truth video in a reconstruction style. We give the supervision in the domain of unsupervised keypoints using loss and the natural generated video following their original implementation. More details can be found in the supplementary materials.

## 4. Experiments

### 4.1. Implementation Details and Metrics

**Datasets** We use VoxCeleb [24] dataset for training which contains over 100k videos of 1251 subjects. We crop the original videos following previous image animation methods [34] and resize the video to 256 × 256. After preprocessing, the data is used to train our FaceRender. We select 1890 aligned videos and audios of 46 subjects in VoxCeleb to train our PoseVAE and ExpNet. The input audios are downsampled to 16kHz and transformed to mel-spectrograms with the same setting as Wav2lip [28]. To test our method, we use the 346 videos' first 8-second video (around 70k frames in total) from HDTF dataset [47] since it contains high resolution and in-the-wild talking head videos. These videos

**Evaluation Metrics** We demonstrate the superiority of our method on multiple metrics. We employ Frechet Inception Distance (FID) [13, 33] and cumulative probability blur detection (CPBD) [25] to evaluate the quality of the images. To evaluate identity preservation, we calculate the cosine similarity (CSIM) of identity embedding between the source images and the generated frames, in which we use ArcFace [4] to extract identity embedding of images. To evaluate lip synchronization and mouth shape, we evaluate the perceptual differences of the mouth shape from Wav2Lip [28], including the distance score (LSE-D) and confidence score (LSE-C). We also conduct some metrics to evaluate the head motions of generated frames. For the diversity of the generated head motions, a standard deviation of the head motion feature embeddings extracted from the generated frames using Hopenet [26] is calculated. For the alignment of the audio and generated head motions, we compute Beat Align Score as in Bailando [21].

### 4.2. Compare with other state-of-the-art methods

We compare several state-of-the-art methods for talking-head videos generation (MakeltTalk [50], Audio2Head [37] and Wang et al. [38]<sup>2</sup>) and audio to expression generation (Wav2Lip [28], PC-AVS [49]). The evaluation is performed on their publicly available checkpoint directly. As shown in Table 1, our method shows better overall video qualities and head pose diversity and also shows comparable performance with other fully talking-head generation methods in terms of the lip synchronization metrics. We argue that these lip synchronization metrics are too sensitive to the audio where the unnatural lip movement may get a better score. However, our method achieves a similar score to the

<sup>2</sup>This method needs to extract the phoneme from audio, which only works on the specific language.

Method	Eye Blink	Lip Synchronization		Learned Head Motion		Video Quality		
		LSE-C"	LSE-D#	Diversity"	Beat Align"	FID#	CPBD"	CSIM"
Real Video	N./A.	8.211	6.982	0.259	0.271	0.000	0.428	1.000
Wav2Lip* [28]	N./A.	10.221	5.535	N./A.	N./A.	21.725	0.368	0.849
PC-AVS** [49]	from ref.	9.053	6.355	N./A.	N./A.	69.127	0.206	0.683
MakeltTalk [50]	automatic	5.110	10.059	0.257	0.268	28.243	0.283	0.838
Audio2Head [37]	automatic	7.357	7.535	0.181	0.267	24.392	0.281	0.823
Wanget al. [38]	automatic	4.932	10.055	0.226	0.268	22.432	0.295	0.811
Ours	controllable	7.290	7.772	0.278	0.293	22.057	0.335	0.843

Table 1. Comparison with the state-of-the-art method on HDTF dataset. We evaluate Wav2Lip [28] and PC-AVS [49] in the one-shot settings. Wav2Lip\* achieves the best video quality since it only animates the lip region while other regions are the same as the original frame. PC-AVS\*\* is evaluated using the fixed reference pose and fails in some samples.

Figure 6. We compare our method with several state-of-the-art methods for single image audio-driven talking head generation. Our method produces much higher quality results in terms of lip synchronization, identity preservation, head motion and image quality. We give the target image above for both lip shape and identity reference. Please refer our supplementary video for better comparison.

real videos, which demonstrates our advantages. We also with different head poses as we expect. Compared with our illustrate the visual results of different methods in Figure 6. method, Wav2Lip [28] produces blur half-face, PC-AVS [49] Here, we give the lip reference to visualize the lip synchro- and Audio2Head [37] are struggling for identity preserva- tion of our method. From the gure, our method has a tion, Audio2Head can only generate the front talking face. very similar visual quality to the original target video and Besides, MakeltTalk [50] and Audio2Head [37] generate the

Method	LSE-C <sup>o</sup>	LSE-D#
Speech2Gesture [10]	0.878	13.889
OursFull (Lip coeffs. + $\epsilon_0$ + $L_{read}$ )	7.290	7.772
w/o $\epsilon_0$ & $L_{read}$	5.241	9.532
w/o $L_{read}$	6.993	7.841
w/ real coeffs.	6.567	8.061

Table 3. Ablation for ExpNet. Both the initial expression, lip reading loss  $L_{read}$  improve the performance a lot. However, the lip synchronization metric drops a lot when using the real coefficients.

Figure 7. We compare our method with a baseline method which learn all the coefficients from a single network without any condition (from Speech2Gesture [10]). Our method shows clear head movements, identity preservation and diverse expressions.

distorted face video due to 2D warping.

### 4.3. User Studies

We conduct user studies to evaluate the performance of all the methods. We generate overall 20 videos which contain almost equal genders with different ages, poses and expressions. Then 20 participants are invited to choose the best method in terms of video sharpness, lip synchronization, the diversity and naturalness of the head motion, and overall quality. The results are shown in Table 2, where the participants like our method mostly because of the video and motion quality. We also find that 38% of the participants think our methods show better lip synchronization than other methods, which is inconsistent with Table 1. We think it might be because most of the participants focus on the overall quality of the video, where the blurry and still face videos [28, 49] influence their opinions.

Method	Lip Sync.	Motion Diversity	Video Sharpness	Overall Naturalness
Wav2Lip [28]	15.6%	3.1%	2.0%	2.8%
PC-AVS [49]	18.1%	9.6%	3.4%	9.1%
MakeltTalk [50]	5.6%	5.3%	5.7%	6.9%
Wang et al. [38]	12.5%	12.1%	16.3%	11.6%
Audio2Head [37]	9.5%	12.1%	9.7%	14.7%
Ours	38.7%	57.9%	62.8%	54.8%

Table 2. User study.

### 4.4. Ablation Studies

**Ablation of ExpNet** For ExpNet, we mainly evaluate the necessity of each component via the lip synchronization performs worse in pose evaluation. As for our variants, since metrics. Since there are no disentangled methods before, our method contains several identity style labels, to better we consider a baseline (Speech2Gesture [10], which is a evaluate other components, we first consider the perform the audio to keypoint generation network) to learn the head pose ablation studies on a fixed one-hot style of our full method and expression coefficients jointly. As shown in Table 3 and for evaluation (OurFull, Single Fixed Style). Each condition Figure 7, learning all the motion coefficients altogether is in our setting benefits the overall motion quality in terms of hard to generate truth-worthy talking head videos. We then diversity and beat alignment. We further report the results of consider the variants of the proposed ExpNet, both the initial the mixed style of our full method, which uses the randomly-

Figure 8. The ablation of ExpNet. We choose four frames from the generated video as comparison. Our method largely reduces the uncertainty of audio to expression generation. The reference  $\epsilon_0$  is used to provide the identity information while the lip only coefficients generate better lip synchronization. Notice that, the target image is provided as the identity and lip motion reference

expression  $\epsilon_0$ , lip reading loss  $L_{read}$  and the necessity of lip-only coefficients are critical. The visual comparison is shown in Figure 8, where our method w/o the initial expression shows huge identity changes as expected. Also, if we use the real coefficients to replace the lip-only coefficients we use, the performance drops a lot in lip synchronization.

**Ablation of PoseVAE** We evaluate the proposed PoseVAE in terms of motion diversities and audio beat alignments. As shown in Table 4, the baseline Speech2Gesture [10] also performs worse in pose evaluation. As for our variants, since metrics. Since there are no disentangled methods before, our method contains several identity style labels, to better we consider a baseline (Speech2Gesture [10], which is a evaluate other components, we first consider the perform the audio to keypoint generation network) to learn the head pose ablation studies on a fixed one-hot style of our full method and expression coefficients jointly. As shown in Table 3 and for evaluation (OurFull, Single Fixed Style). Each condition Figure 7, learning all the motion coefficients altogether is in our setting benefits the overall motion quality in terms of hard to generate truth-worthy talking head videos. We then diversity and beat alignment. We further report the results of consider the variants of the proposed ExpNet, both the initial the mixed style of our full method, which uses the randomly-

Method	Diversity <sup>†</sup>	Beat Align <sup>‡</sup>
Speech2Gesture [10]	0.1574	0.274
OurFull (Single Fixed Style)	0.2735	0.287
w/o $L_{\text{gan}}$	0.2500	0.271
w/o initial pose	0.2725	0.278
w/o audio	0.2566	0.274
w/o all conditions	0.2631	0.279
OursFull (Mixed Style)	0.2778	0.293

Table 4. Ablation the diversity and audio alignment of the proposed PoseVAE. Each component or conditional contribute largely to generate realistic head motions.

Figure 10. Limitation. Our method may show some teeth artifacts in the lip region in some examples, it can be improved via the face restoration network, e., GFPGAN [41].

#### 4.5. Limitation

There are still some limitations in our system. Since 3DMMs couldn't model the variation of eyes and teeth, the mappingNet in our Face Render will struggle to synthesize the realistic teeth in some cases. This limitation can be improved via the blind face restoration networks [41] as shown in Fig. 10. Another limitation of our work is that we only concern the lip motion and eye blinking other than the other facial expressions, e.g, emotion and gaze direction. Thus, it reduces the realism that the generated video has a fixed emotion. We consider it as future work.

#### 5. Conclusion

In this paper, we present a new system for stylized audio-driven talking head video generation. We use the motion coefficients from 3DMM as an intermediate representation and learn the relationships. To generate realistic 3D coefficients from audio, we propose ExpNet and PoseVAE for realistic expressions and diverse head poses. To model the relationships between 3DMM motion coefficients and the real video, we propose a novel 3D-aware face render inspired by the image animation method [40]. The experiments demonstrate the superiority of our entire framework. Since we predict the realistic 3D facial coefficients, our method can also be used in other modalities directly, personal-sized 2D visual dubbing [43], 2D Cartoon animation [50], 3D face animation [8, 44] and NeRF-based 4D talking-head generation [15].

**Ethical Considerations** We consider the misuse of our method since it can generate very realistic video. Both visible and invisible video watermarks will be inserted into the produced video for generated content identification similar to Dall-E [30] and Imagen [32]. We also hope our method can provide new research samples for forgery detection.

**Acknowledgements** This work was supported by the National Key Projects of China #2021XJTU0040 and the National Key Research and Development Program of China under Grant #2022YFB3303800.

Figure 9. Ablation studies of face render. In the first row, we directly compare our method with PIRenderer [31] for face animation and our method shows better expression modeling. The second row is a trace map of the generated facial landmarks from the same motion coefficients. Using additional face alignment coefficients as part of motion coefficients [31] will generate unrealistic aligned head video.

selected identity label as style and also shows better diversity performance.

**Ablation of Face Render** We conduct the ablation study on the proposed face render in two aspects. On the one hand, we show the reconstruction quality of our method with the PIRenderer [31], since both methods use 3DMM as an intermediate representation. As shown in the first row of Fig. 9, the proposed face render shows better expression reconstruction qualities and lip synchronization. Besides, we evaluate the pose unnaturalness caused by the additional alignment coefficients used in PIRenderer [31]. As shown in the second row of Fig. 9, we plot the trace map of the landmarks from the generated video with the same head pose and expression coefficients. Using the fixed or learnable crop coefficients (as part of pose coefficients in our poseVAE) will generate the face-aligned video, which is as strange as a natural video. We remove it and directly use the head pose and expression as modulation parameters showing a more realistic result.



## References

- [1] Volker Blanz and Thomas Vetter. A morphable model for the synthesis of 3d faces. *ACM SIGGRAPH*, 1999. 2, 3
- [2] Lele Chen, Ross K Maddox, Zhiyao Duan, and Chenliang Xu. Hierarchical cross-modal talking face generation with dynamic pixel-wise loss. *ICVPR* 2019. 2
- [3] Kun Cheng, Xiaodong Cun, Yong Zhang, Menghan Xia, Fei Yin, Mingrui Zhu, Xuan Wang, Jue Wang, and Nannan Wang. Videoretalking: Audio-based lip synchronization for talking head video editing in the wild. *SIGGRAPH Asia 2022 Conference Papers*, pages 1–9, 2022. 2
- [4] Jiankang Deng, Jia Guo, Niannan Xue, and Stefanos Zafeiriou. Arcface: Additive angular margin loss for deep face recognition. In *CVPR* 2019. 5
- [5] Yu Deng, Jiaolong Yang, Sicheng Xu, Dong Chen, Yunde Jia, and Xin Tong. Accurate 3d face reconstruction with weakly-supervised learning: From single image to image set. In *CVPR Workshop* 2019. 2, 3, 4, 5
- [6] Carl Doersch. Tutorial on variational autoencoders. *arXiv preprint arXiv:1606.05908* 2016. 2, 4
- [7] Michail Christos Doukas, Stefanos Zafeiriou, and Viktoriia Sharmanska. Headgan: One-shot neural head synthesis and editing. In *ICCV*, 2021. 3
- [8] Yingruo Fan, Zhaojiang Lin, Jun Saito, Wenping Wang, and Taku Komura. Faceformer: Speech-driven 3d facial animation with transformers. In *CVPR* 2022. 8
- [9] Panagiotis P. Filintisis, George Retsinas, Foivos Paraperas-Papantoniou, Athanasios Katsamanis, Anastasios Roussos, and Petros Maragos. Visual speech-aware perceptual 3d facial expression reconstruction from video. *arXiv preprint arXiv:2207.11094* 2022. 4
- [10] Shiry Ginosar, Amir Bar, Gefen Kohavi, Caroline Chan, Andrew Owens, and Jitendra Malik. Learning individual styles of conversational gesture. *CVPR* 2019. 7, 8
- [11] Yudong Guo, Keyu Chen, Sen Liang, Yong-Jin Liu, Hujun Bao, and Juyong Zhang. Ad-nerf: Audio driven neural radiance fields for talking head synthesis. In *ICCV*, 2021. 2
- [12] Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. *CVPR* 2016. 4
- [13] Martin Heusel, Hubert Ramsauer, Thomas Unterthiner, Bernhard Nessler, and Sepp Hochreiter. Gans trained by a two time-scale update rule converge to a local nash equilibrium. In *NeurIPS* 2017. 5
- [14] Fa-Ting Hong, Longhao Zhang, Li Shen, and Dan Xu. Depth-aware generative adversarial network for talking head video generation. In *CVPR* 2022. 3
- [15] Yang Hong, Bo Peng, Haiyao Xiao, Ligang Liu, and Juyong Zhang. Headnerf: A real-time nerf-based parametric head model. In *CVPR* 2022. 8
- [16] Xinya Ji, Hang Zhou, Kaisiyuan Wang, Qianyi Wu, Wayne Wu, Feng Xu, and Xun Cao. Eamm: One-shot emotional talking face via audio-based emotion-aware motion model. In *ACM SIGGRAPH* 2022. 2
- [17] Xinya Ji, Hang Zhou, Kaisiyuan Wang, Wayne Wu, Chen Change Loy, Xun Cao, and Feng Xu. Audio-driven emotional video portraits. *ICVPR* 2021. 3
- [18] Hyeonwoo Kim, Pablo Garrido, Ayush Tewari, Weipeng Xu, Justus Thies, Matthias Niessner, Patrick Pfister, Christian Richardt, Michael Zollhofer, and Christian Theobalt. Deep video portraits. *ACM Transactions on Graphics (TOG)* 2018. 2
- [19] Diederik P Kingma and Jimmy Ba. A method for stochastic optimization. *arXiv preprint arXiv:1412.6980* 2014. 5
- [20] Diederik P Kingma and Max Welling. Auto-encoding variational bayes. *CoRR*, abs/1312.6114, 2014. 4
- [21] Siyao Li, Yu Weijiang, Gu Tianpei, Lin Chunze, Wang Quan, Qian Chen, Loy Chen Change, and Liu Ziwei. Bailando: 3d dance generation via actor-critic gpt with choreographic memory. In *CVPR* 2022. 5
- [22] Yuanxun Lu, Jinxiang Chai, and Xun Cao. Live speech portraits: real-time photorealistic talking-head animation. *ACM Transactions on Graphics (TOG)* 2021. 3
- [23] Arun Mallya, Ting-Chun Wang, and Ming-Yu Liu. Implicit Warping for Animation with Image Sets. *NeurIPS* 2022. 3
- [24] Arsha Nagrani, Joon Son Chung, and Andrew Senior. Voxceleb: a large-scale speaker identification dataset. In *INTERSPEECH* 2017. 5
- [25] Niranjana D. Narvekar and Lina J. Karam. A no-reference image blur metric based on the cumulative probability of blur detection (cpbd). *TIP*, 2011. 5
- [26] Ruiz Nataniel, Eunji Chong, and Rehg James M. Fine-grained head pose estimation without keypoints. *CVPR Workshops* 2018. 5
- [27] Youxin Pang, Yong Zhang, Weize Quan, Yanbo Fan, Xiaodong Cun, Ying Shan, and Dong-ming Yan. Dpe: Disentanglement of pose and expression for general video portrait editing. *arXiv preprint arXiv:2301.06281* 2023. 3
- [28] K R Prajwal, Rudrabha Mukhopadhyay, Vinay P. Namboodiri, and C.V. Jawahar. A lip sync expert is all you need for speech to lip generation in the wild. In *ACM MM*, 2020. 2, 3, 4, 5, 6, 7
- [29] Prajwal K R, Rudrabha Mukhopadhyay, Jerin Philip, Abhishek Jha, Vinay Namboodiri, and C V Jawahar. Towards automatic face-to-face translation. *ACM MM*, 2019. 2
- [30] Aditya Ramesh, Prafulla Dhariwal, Alex Nichol, Casey Chu, and Mark Chen. Hierarchical text-conditional image generation with clip latents. *arXiv preprint arXiv:2204.06125* 2022. 8
- [31] Yurui Ren, Ge Li, Yuanqi Chen, Thomas H Li, and Shan Liu. Pirenderer: Controllable portrait image generation via semantic neural rendering. *ICCV*, 2021. 2, 3, 5, 8
- [32] Chitwan Saharia, William Chan, Saurabh Saxena, Lala Li, Jay Whang, Emily Denton, Seyed Kamyar Seyed Ghasemipour, Burcu Karagol Ayan, S Sara Mahdavi, Rapha Gontijo Lopes, et al. Photorealistic text-to-image diffusion models with deep language understanding. *arXiv preprint arXiv:2205.11487* 2022. 8
- [33] Maximilian Seitzer. pytorch-fid: FID Score for PyTorch. <https://github.com/mseitzer/pytorch-fid>, August 2020. Version 0.2.1. 5
- [34] Aliaksandr Siarohin, Stéphane Lathuilière, Sergey Tulyakov, Elisa Ricci, and Nicu Sebe. First order motion model for image animation. In *NeurIPS* 2019. 2, 3, 5

- [35] Aliaksandr Siarohin, Oliver Woodford, Jian Ren, Menglei Chai, and Sergey Tulyakov. Motion representations for articulated animation. In *CVPR* 2021. 3
- [36] Justus Thies, Mohamed Elgharib, Ayush Tewari, Christian Theobalt, and Matthias Nießner. Neural voice puppetry: Audio-driven facial reenactment. *ECCV*, 2020. 2
- [37] Suzhen Wang, Lincheng Li, Yu Ding, Changjie Fan, and Xin Yu. Audio2head: Audio-driven one-shot talking-head generation with natural head motion. *IJCAI*, 2021. 2, 5, 6, 7
- [38] Suzhen Wang, Lincheng Li, Yu Ding, and Xin Yu. One-shot talking face generation from single-speaker audio-visual correlation learning. In *AAAI*, 2022. 2, 5, 6, 7
- [39] Ting-Chun Wang, Ming-Yu Liu, Andrew Tao, Guilin Liu, Jan Kautz, and Bryan Catanzaro. Few-shot video-to-video synthesis. In *NeurIPS* 2019. 3
- [40] Ting-Chun Wang, Arun Mallya, and Ming-Yu Liu. One-shot free-view neural talking-head synthesis for video conferencing. In *CVPR* 2021. 2, 3, 4, 5, 8
- [41] Xintao Wang, Yu Li, Honglun Zhang, and Ying Shan. Towards real-world blind face restoration with generative facial prior. In *CVPR* 2021. 8
- [42] Yaohui Wang, Di Yang, Francois Bremond, and Antitza Dantcheva. Latent image animator: Learning to animate images via latent space navigation. *arXiv preprint arXiv:2203.09043* 2022. 3
- [43] Xin Wen, Miao Wang, Christian Richardt, Ze-Yin Chen, and Shi-Min Hu. Photorealistic audio-driven video portraits. *IEEE Transactions on Visualization and Computer Graphics* 26(12):3457–3466, 2020. 2, 8
- [44] Jinbo Xing, Menghan Xia, Yuechen Zhang, Xiaodong Cun, Jue Wang, and Tien-Tsin Wong. Codetalker: Speech-driven 3d facial animation with discrete motion prior. *arXiv preprint arXiv:2301.02379* 2023. 8
- [45] Fei Yin, Yong Zhang, Xiaodong Cun, Mingdeng Cao, Yanbo Fan, Xuan Wang, Qingyan Bai, Baoyuan Wu, Jue Wang, and Yujiu Yang. Styleheat: One-shot high-resolution editable talking face generation via pre-trained stylegan. *ECCV*, 2022. 3
- [46] Chenxu Zhang, Yifan Zhao, Yifei Huang, Ming Zeng, Saifeng Ni, Madhukar Budagavi, and Xiaohu Guo. Facial: Synthesizing dynamic talking face with implicit attribute learning. In *ICCV*, 2021. 3
- [47] Zhimeng Zhang, Lincheng Li, Yu Ding, and Changjie Fan. Flow-guided one-shot talking face generation with a high-resolution audio-visual dataset. *CVPR* 2021. 2, 5
- [48] Jian Zhao and Hui Zhang. Thin-plate spline motion model for image animation. In *CVPR* 2022. 3
- [49] Hang Zhou, Yasheng Sun, Wayne Wu, Chen Change Loy, Xiaogang Wang, and Ziwei Liu. Pose-controllable talking face generation by implicitly modularized audio-visual representation. In *CVPR* 2021. 2, 3, 5, 6, 7
- [50] Yang Zhou, Xintong Han, Eli Shechtman, Jose Echevarria, Evangelos Kalogerakis, and Dingzeyu Li. Makeltalk: speaker-aware talking-head animation. *ACM Transactions on Graphics (TOG)* 2020. 2, 3, 5, 6, 7, 8