SignAvatar: Sign Language 3D Motion Reconstruction and Generation

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Project Page

Motivation

- **Background:** Achieving expressive 3D motion reconstruction and automatic generation for isolated sign words involves three main challenges:
  - Lack of 3D sign-word data.
  - Complex nuances of signing motions.
  - Cross-modal understanding of sign language semantics.
- **Solution:** Introduce a framework, SignAvatar, that is capable of both word-level sign language reconstruction and generation.
  - Utilizes a transformer-based Conditional Variational Autoencoder (CVAE) architecture, leveraging Contrastive Language-Image Pre-training (CLIP) for conditioning.
  - Incorporates a curriculum learning strategy to enhance robustness.
  - Contributes the ASL3DWord dataset and evaluates the proposed framework through extensive experiments.

Semantic: drink

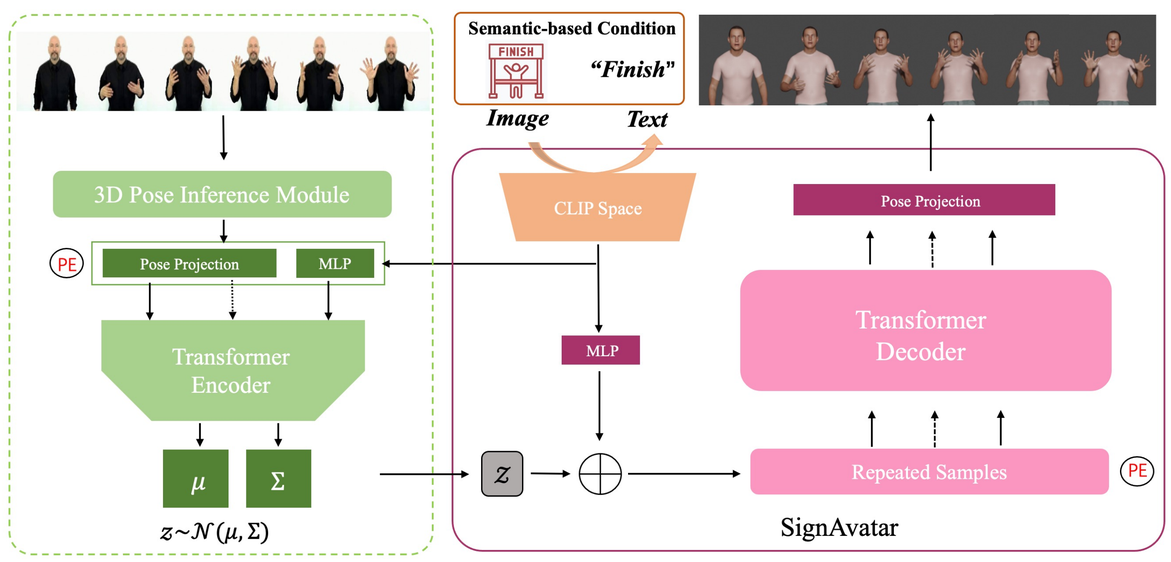
SignAvatar Overview

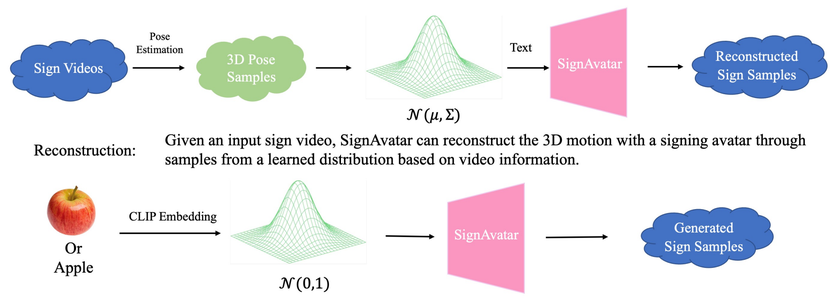
- **Problem Formulation:** Given the input video frames, we reconstruct 3D motion, M_n= [p_1, ...p_T], Meanwhile, given a label Y or an image reflecting that label, we generate the corresponding motion M_n.
- **Conditional VAE with CLIP latent space**
  - ***Encoder:*** The CVAE encoder takes the pose sequence and word-level text projections as input, using a transformer architecture to calculate Gaussian distribution parameters, μ and Σ.
  - ***Decoder:*** Given a latent vector z, with a a conditional bias that integrate categorical information, the decoder generates pose sequence in the SMPL-X parameter format.
  - ***Learning Objectives***

$$\mathcal{L}_{\text{rec}} = \frac{1}{T}\sum_{t=1}^{T}\|\boldsymbol{p}_t - \hat{\boldsymbol{p}}_t\|_2^2 \qquad \mathcal{L}_{\text{CVAE}} = \mathcal{L}_{\text{rec}} + \omega_{\text{KL}}\mathcal{L}_{\text{KL}}$$

- **Curriculum Learning Strategy:** This work employs a curriculum learning strategy by progressively increasing the mask ratio during training through $g(ep)$.

$$g(ep) = min\left\{0.1 * \left\lfloor \frac{ep}{500} \right\rfloor, 0.6\right\}, ep \in [0, 5000)$$





Experiments

- **Dataset:** To quantitatively evaluate the performance of SignAvatar, we constructed the ASL3DWord dataset from the WLASL video dataset. However, the distribution of videos for each word is unbalanced and contains a considerable number of noisy samples.
  - Quality Control
  - Pose Feature Extraction
- **Evaluation Metrics:**
  - Recognition Accuracy (Acc.)
  - Fréchet Inception Distance (FID)
  - Diversity (Div.)

$$Diversity = \frac{1}{S_d}\sum_{i=1}^{D_d}\left\|m_i - m_i^{'}\right\|_2$$

  - Multimoldality (Multi.)

$$Multimodality = \frac{1}{C \times S_l}\sum_{c=1}^{C}\sum_{i=1}^{S_l}\left\|m_{c,i} - m_{c,i}^{'}\right\|_2$$

- **Quantitative Results**

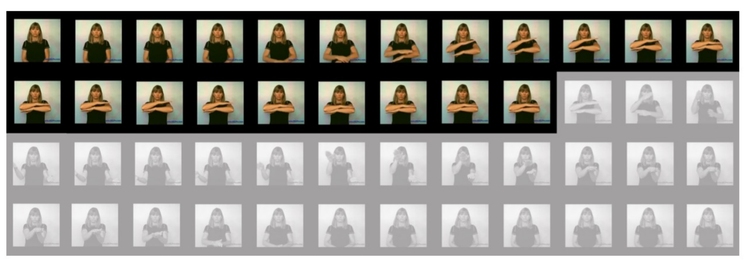
TABLE I: Quantitative results comparison on Raw Poses (*Raw*), Reconstructed Poses (*Rec*), and Generated Poses (*Gen*). → indicates results are better if they are closer to the extracted Raw pose.

ASL3DWord Subset	Acc. ↑	FID ↓	Div.→	Multi.→	ASL3DWord	Acc.↑	FID↓	Div.→	Multi.→
Raw_{train}	1.0	0	30.001	9.921	Raw_{train}	1.0	0	34.565	13.256
Raw_{test}	0.897	0	26.252	11.180	Raw_{test}	0.818	0	30.599	12.289
w/o Curriculum Learning					**w/o Curriculum Learning**				
Rec_{train}	1.0	4.566	28.981	10.160	Rec_{train}	1.0	3.395	33.566	13.803
Rec_{test}	0.962	32.583	29.495	9.095	Rec_{test}	0.906	29.184	31.356	10.249
Gen_{train}	0.884	75.243	24.566	8.250	Gen_{train}	0.515	126.830	25.732	16.500
Gen_{test}	0.890	65.285	24.187	6.600	Gen_{test}	0.5111	100.147	25.393	12.289
w/ Curriculum Learning					**w/ Curriculum Learning**				
Rec_{train}	0.997	7.195	29.340	9.993	Rec_{train}	0.999	6.112	33.583	13.347
Rec_{test}	0.976	32.973	29.165	7.362	Rec_{test}	0.952	40.637	32.561	8.486
Gen_{train}	0.946	44.469	27.115	7.160	Gen_{train}	0.729	85.025	27.973	14.700
Gen_{test}	0.941	46.435	27.097	5.916	Gen_{test}	0.733	71.809	27.811	10.483

TABLE II: Ablation Study for Quality Control

Data	w/o Quality Control		w/ Quality Control	
ASL3DWord Subset	**Acc. ↑**	**FID ↓**	**Acc. ↑**	**FID ↓**
Raw_{train}	1.0	0	1.0	0
Raw_{test}	0.790	0	0.897	0
Rec_{train}	0.927	27.319	0.997	7.195
Rec_{test}	0.851	51.846	0.976	32.973
Gen_{train}	0.856	70.250	0.946	44.469
Gen_{test}	0.860	75.515	0.941	46.435

- **Quality Control**



- **Qualitative Results**