HairStep: Transfer Synthetic to Real Using Strand and Depth Maps for Single-View 3D Hair Modeling

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Computer Vision and Pattern Recognition, 2023

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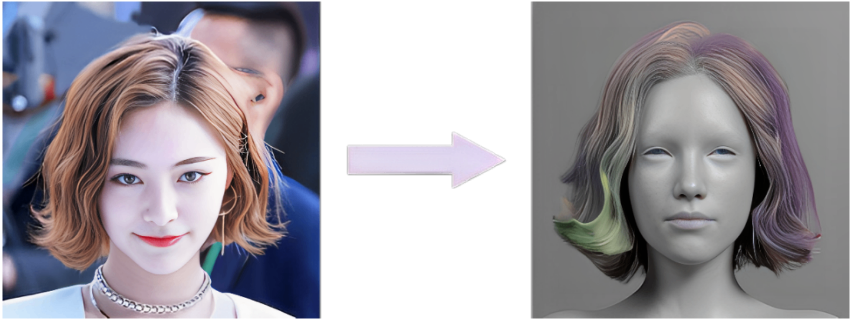
December 2024

Outline

Objective

3D Hair Reconstruction from a Single Image

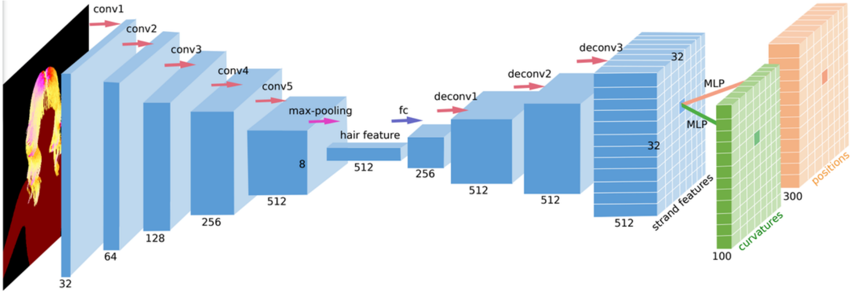


Single-view 3D Hair Modeling

Related Works

Related Works

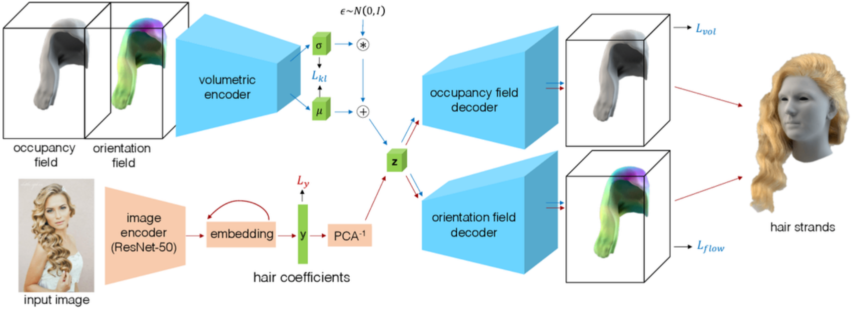
Single-View Hair Reconstruction using Convolutional Neural Networks



Zhou et al. 2018[1]

Related Works

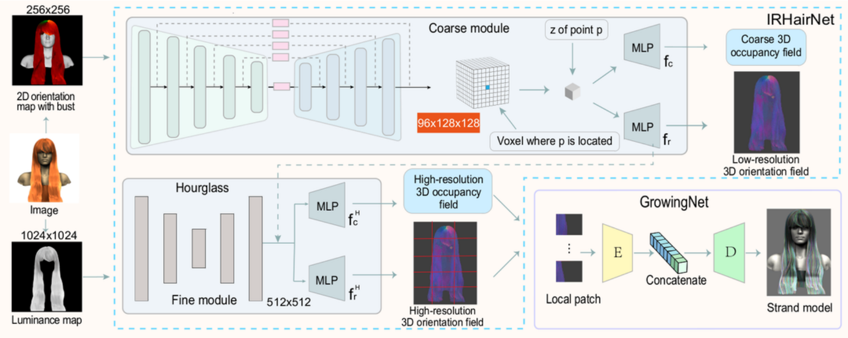
3D Hair Synthesis using Volumetric Variational Autoencoders



Saito et al. 2018[2]

Related Works

NeuralHDHair: Automatic High-fidelity Hair Modeling from a Single Image Using Implicit Neural Representations



Wu et al. 2022[3]

Motivation

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Main Challenge: Using synthetic data as a prior for real-world 3D hair modeling introduces a domain gap.

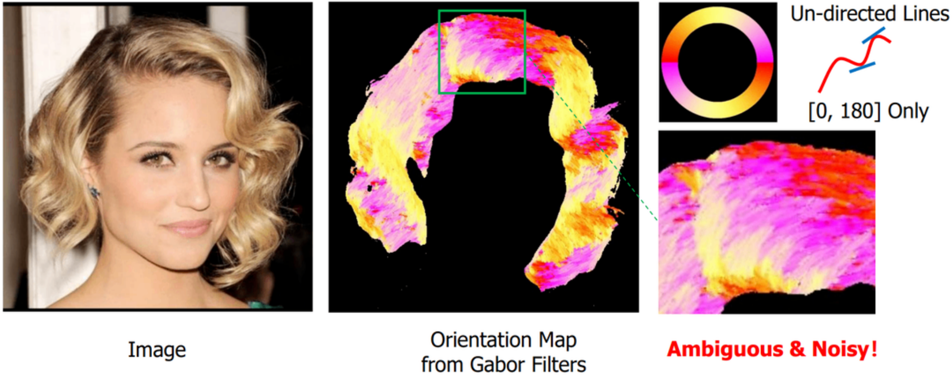
Existing Solutions:

- Utilize undirected 2D orientation maps as an intermediate representation between the input image and the 3D hair model.

Limitations:

- Ambiguous directionality: Loses 3D cues from the image.
- Reliance on image filters: Adds noise and inaccuracies.

Undirected Orientation Maps Challenges



Example of a 2D orientation map used in existing solutions.

Contribution

Contribution

- Proposed *HairStep*, a novel intermediate representation combining strand maps and depth maps for 3D hair reconstruction.
- Developed a weakly-supervised domain adaptation method for depth estimation using synthetic priors and real-world sparse annotations.
- Created *HiSa* (strand annotations) and *HiDa* (relative depth annotations) datasets for 1,250 real portrait images.
- Introduced new metrics, *HairSale* (strand alignment error) and *HairRida* (relative depth accuracy), for quantitative evaluation of 3D hair modeling.
- Achieved state-of-the-art performance in single-view 3D hair modeling.

Proposed Method

HairStep Representation

HairStep is defined as $\mathbf{H} = \{\mathbf{O}, \mathbf{D}\}$ for each input image $\mathbf{I} \in \mathbb{R}^{W \times H \times 3}$, where:

- $\mathbf{O} \in \mathbb{R}^{W \times H \times 3}$ is the **Strand Map**.
- $\mathbf{D} \in \mathbb{R}^{W \times H \times 1}$ is the **Depth Map**.

The **Strand Map** $\mathbf{O} \in \mathbb{R}^{W \times H \times 3}$ is defined at each pixel x as:

$$\mathbf{O}(x) = \left(\mathbf{M}(x), \frac{\mathbf{O}_{\mathrm{2D}}(x)}{2} + 0.5\right), \quad (1)$$

- $\mathbf{M}(x) \in \{0, 1\}$ is the hair mask indicating hair regions (1) and background (0).
- $\mathbf{O}_{\mathrm{2D}}(x) \in \mathbb{R}^2$ is the unit vector of 2D hair-growth orientation at pixel x.

The **Depth Map** $\mathbf{D} \in \mathbb{R}^{W \times H \times 1}$ defines relative depth differences among hair strands.

- Each pixel $\mathbf{D}(x) \in [0, 1]$:
  - $\mathbf{D}(x) = 0$: Farthest from the camera (background or distant strands).
  - $\mathbf{D}(x) = 1$: Closest to the camera.

Method Overview

The pipeline consists of three main components:

1. **Strand Map Extraction and Prediction**
   - Extract strand maps from real images using the *HiSa* dataset.
   - Train a network to predict strand maps from input images.
2. **Domain-Adaptive Depth Estimation**
   - Estimate relative depth from real images using the *HiDa* dataset.
   - Employ domain adaptation techniques to refine depth estimation.
3. **3D Hair Reconstruction**
   - Reconstruct 3D hair strands from the predicted strand and depth maps.
   - Utilize implicit fields for volumetric hair representation.

Conclusion

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Contributions:

- Proposed *HairStep*, a novel intermediate representation combining strand and depth maps.
- Collected new datasets *HiSa* and *HiDa* with annotated real images.
- Proposed two quantitative metrics: *HairSale* and *HairRida*.
- Achieved state-of-the-art performance in single-view 3D hair modeling.

Limitations:

- Manual annotation is time-consuming, limiting scalability.
- Generalization to unseen hairstyles and diverse real-world conditions needs further investigation.

References I

[1] Y. Zhou, L. Hu, J. Xing, *et al.*, "Single-view hair reconstruction using convolutional neural networks," in *European Conference on Computer Vision*, 2018. [Online]. Available: https://api.semanticscholar.org/CorpusID:49666680.

[2] S. Saito, L. Hu, C. Ma, H. Ibayashi, L. Luo, and H. Li, "3d hair synthesis using volumetric variational autoencoders," *ACM Transactions on Graphics (TOG)*, vol. 37, pp. 1–12, 2018. [Online]. Available: https://api.semanticscholar.org/CorpusID:54101192.

[3] K. Wu, Y. Ye, L. Yang, H. Fu, K. Zhou, and Y. Zheng, "Neuralhdhair: Automatic high-fidelity hair modeling from a single image using implicit neural representations," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2022, pp. 1526–1535.

[4] Y. Zheng, Z. Jin, M. Li, *et al.*, "Hairstep: Transfer synthetic to real using strand and depth maps for single-view 3d hair modeling," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2023, pp. 12 726–12 735.