Colorizing Image

through Regression

Presented by

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Project Overview

Objective:
To develop and evaluate a set of prediction models capable of colorizing grayscale images, transforming single-channel inputs into realistic RGB outputs.

Model:
linear regression (using gradient descent), SVR, Neural Network baseline model, and Neural Network U-net model.

Dataset:
Tiny ImageNet (64×64 image dataset containing 200 categories) (link)

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1. Linear Regression
2. SVM
3. Neural Network
4. Result Comparison

Linear Regression (Gradient Descent) : Prepare Dataset

Step 1. Dataset size

- **Training set:** 100,000
- **Test set:** 1,000
- **Validation set:** 1,000

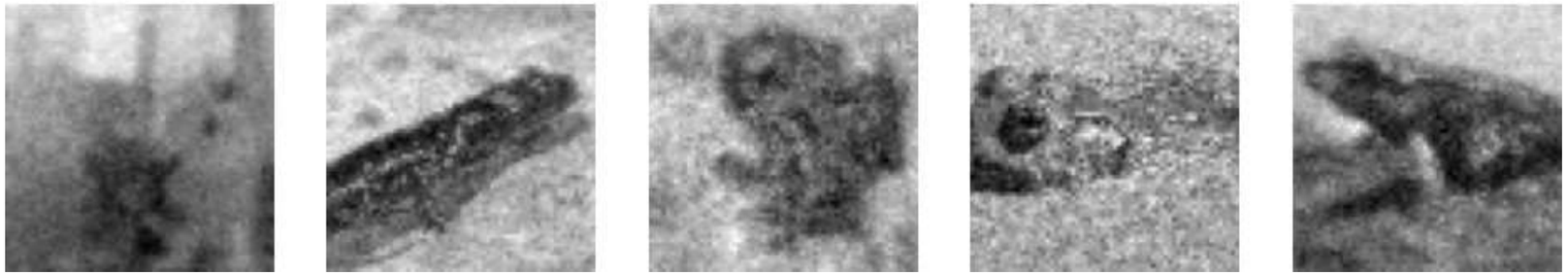
Step 2. Get L, a, b channels

- L (Black and White)
- a, b (color channels)

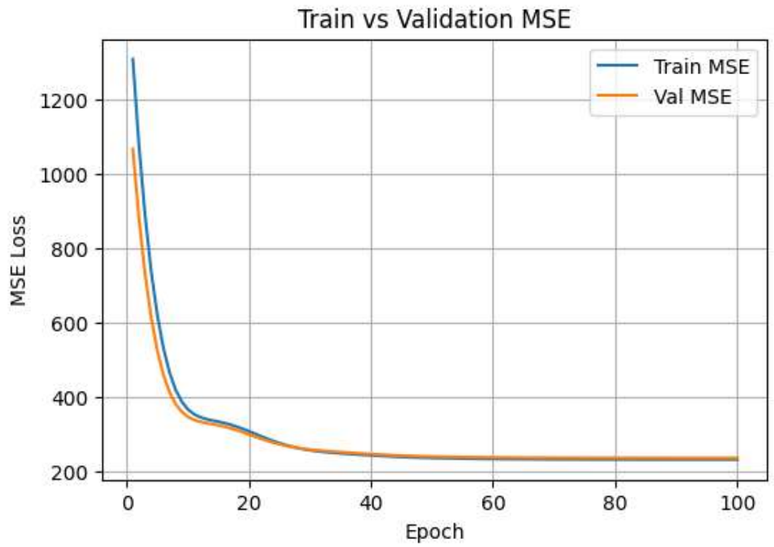
Step 3: Conduct PCA

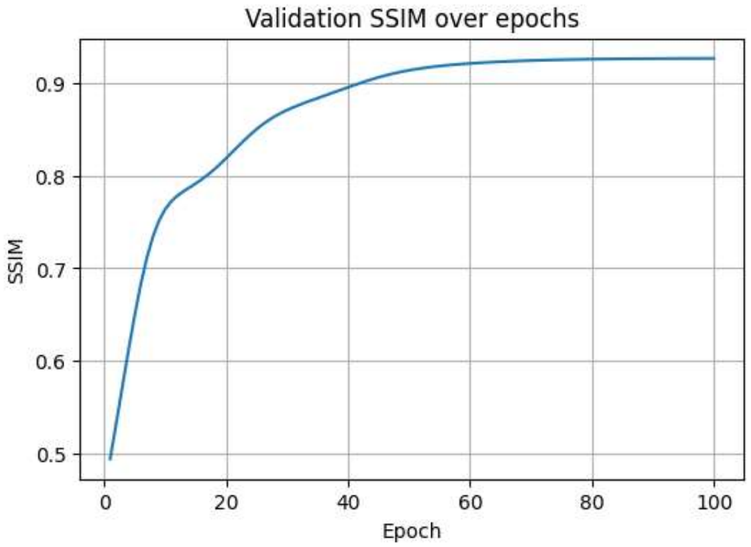
- K =600

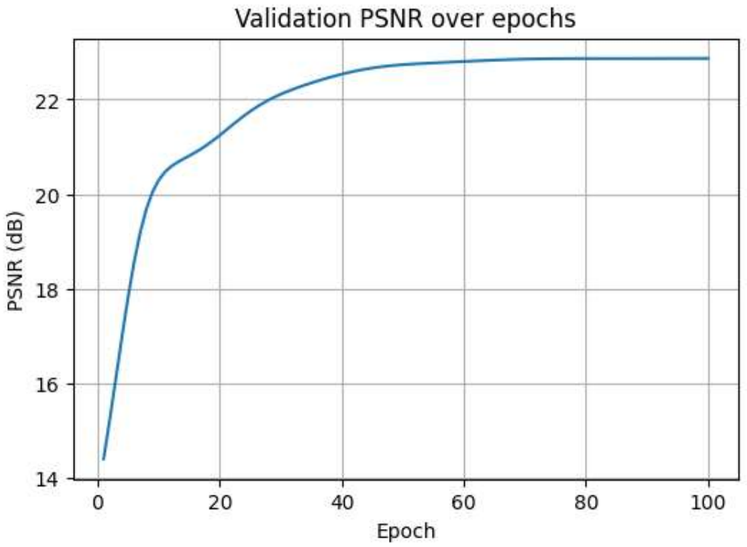
Reconstructed images from 600 PCA components



Linear Regression: Apply Model







Metrics

PSNR (Peak Signal to Noise Ratio)

- compares the difference in the pixel values of two images

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{\mathrm{MAX}^2}{\mathrm{MSE}}\right)$$

SSIM (Structural Similarity Index Measure)

- measures image similarity from three aspects: brightness, contrast, and structure.

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

$$c_1 = (k_1 L)^2$$

$$c_2 = (k_2 L)^2$$

Linear Regression: Result

SVR: Preparing Dataset

Step 1. Dataset size

- **Training set:** 2,000
- **Test set:** 1,000
- **Validation set:** 1,000

Step 2. Get L, a, b channels

- L (Black and White)
- a, b (color channels)

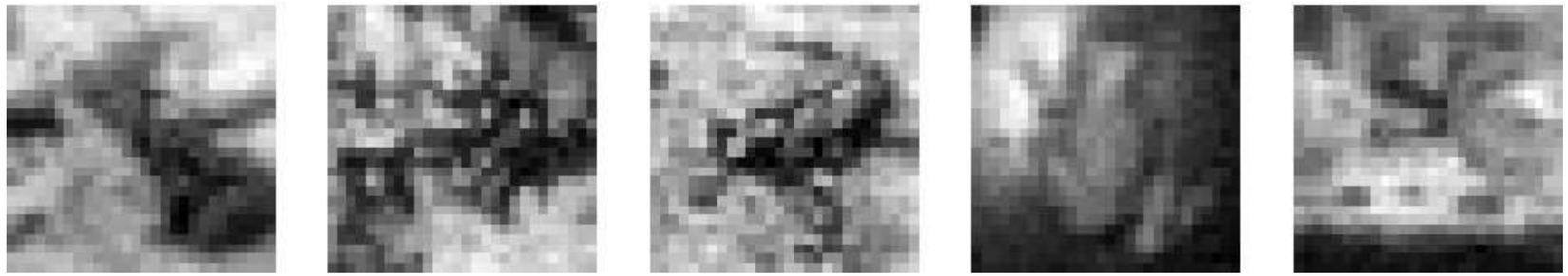
Reconstructed images from 300 PCA components

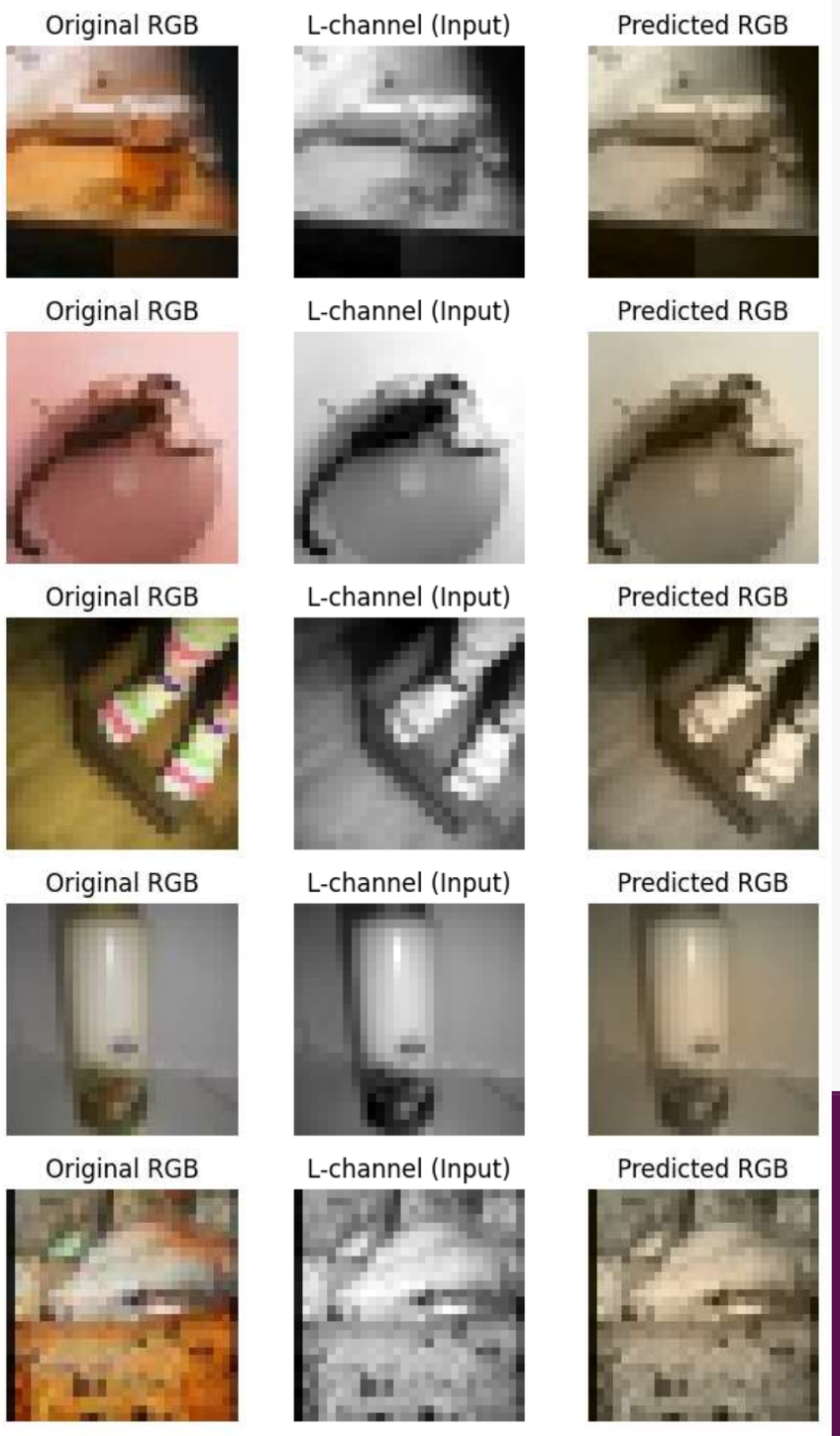
Step 3: Reduce image size

- 64*64 —28*28

Step 4: Conduct PCA

- K =300





SVR: Result

Disadvantage:
Computationally expensive and very slow

Nenural Network

Model 01: Baseline

Model 02: U-Net

Training loss

:

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2$$

- L1 Loss

$$\text{L1} = \frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}_i|$$

- Hybrid Loss =alpha *MSE +Beta * L1

Test Metrics

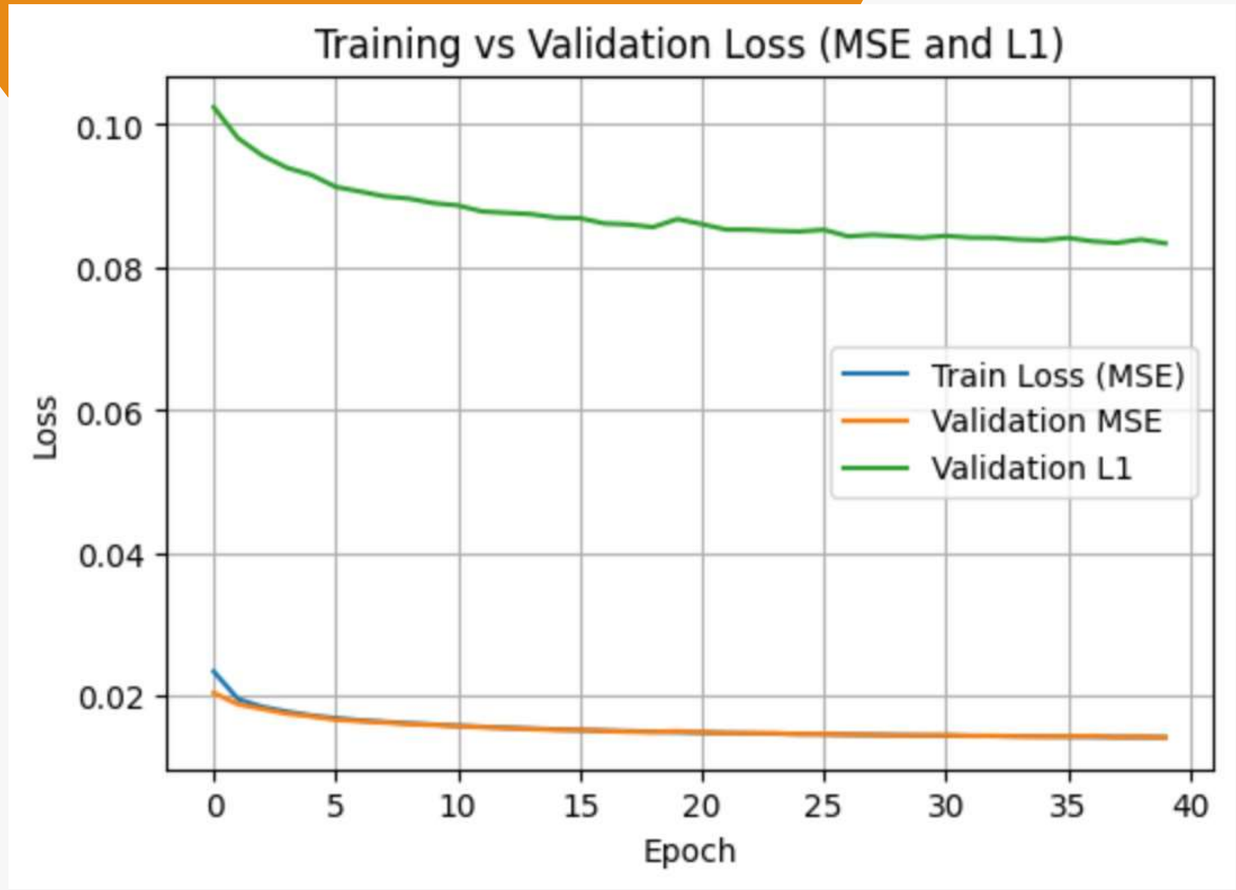
:

MSE Loss

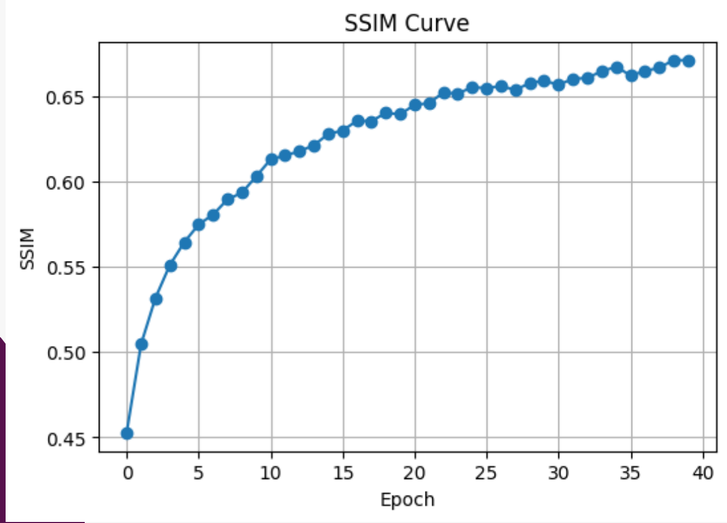
- L1 Loss
- SSIM
- PSNR

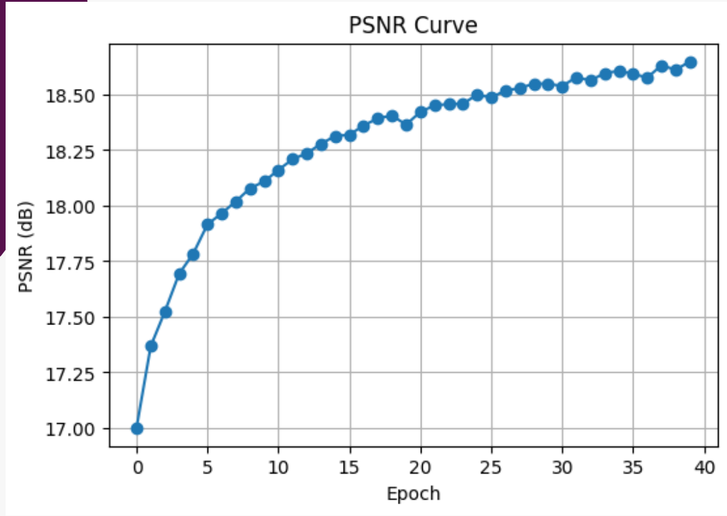
Baseline — MSE Loss

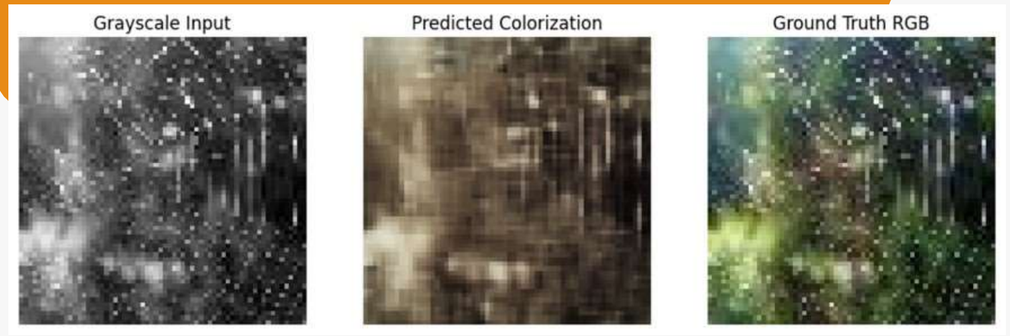
```
✓ Best model loaded!

🔹 FINAL TEST RESULTS (Best SSIM Model) 🔹
----------------------------------------
Test MSE  = 0.014489
Test L1   = 0.084472
Test SSIM = 0.6624
Test PSNR = 18.56 dB
----------------------------------------
```

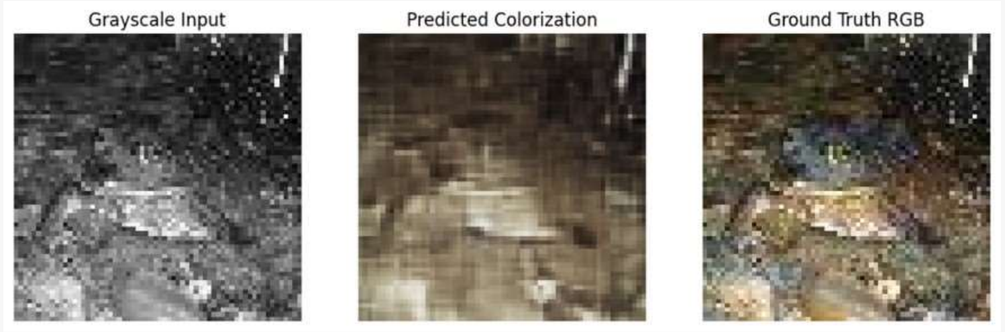


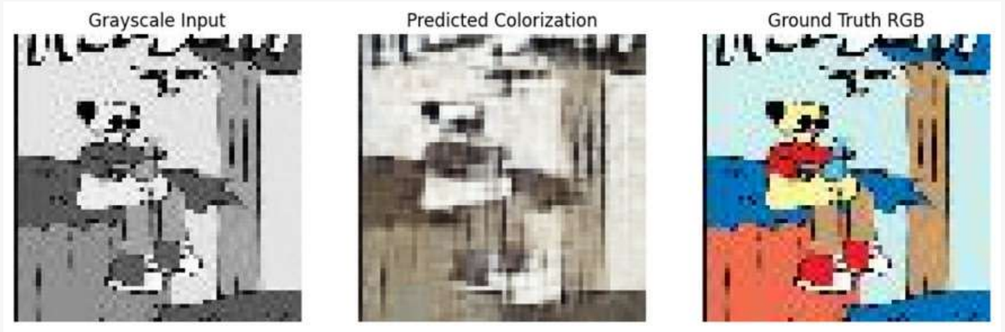
Baseline — MSE Loss





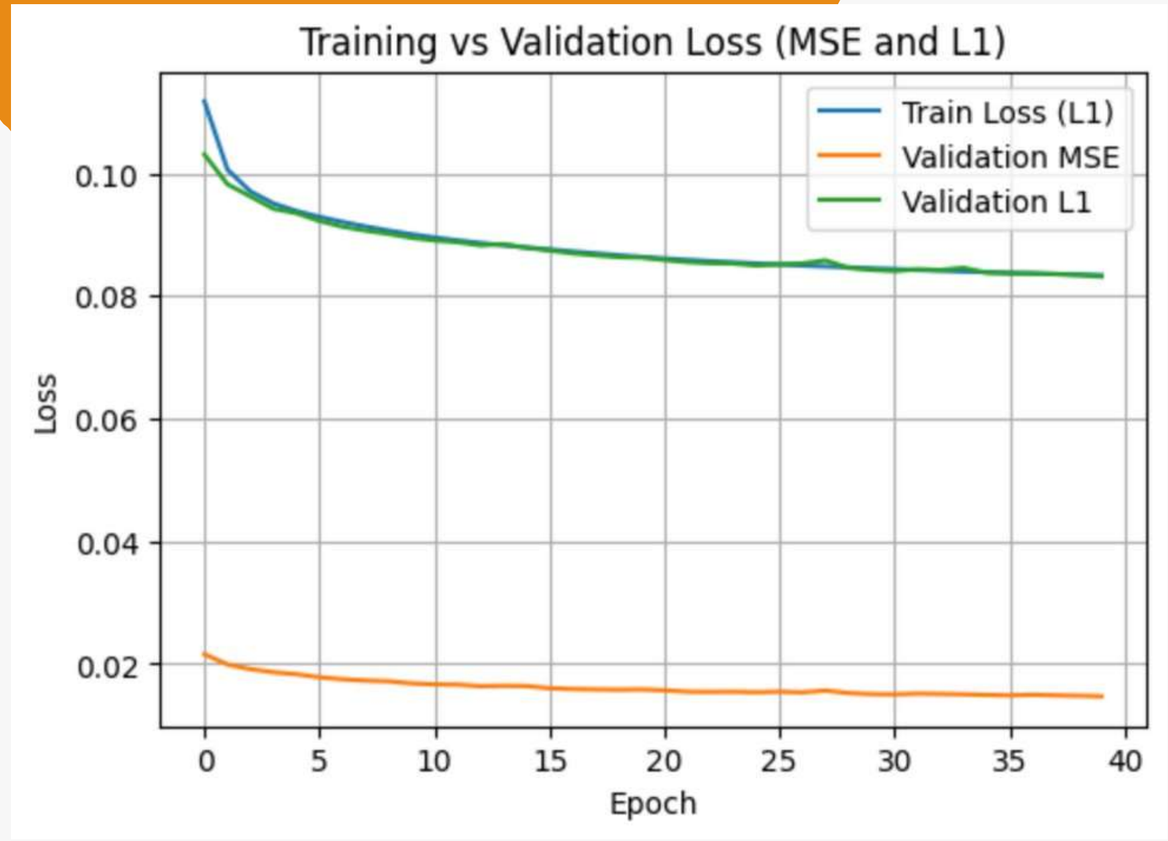




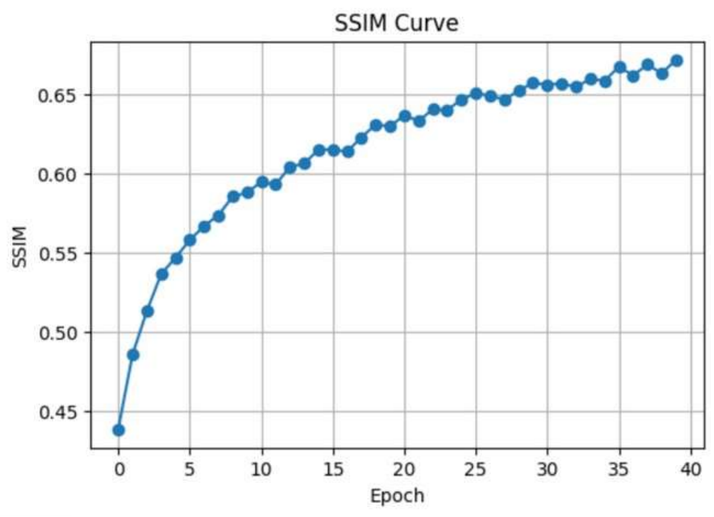


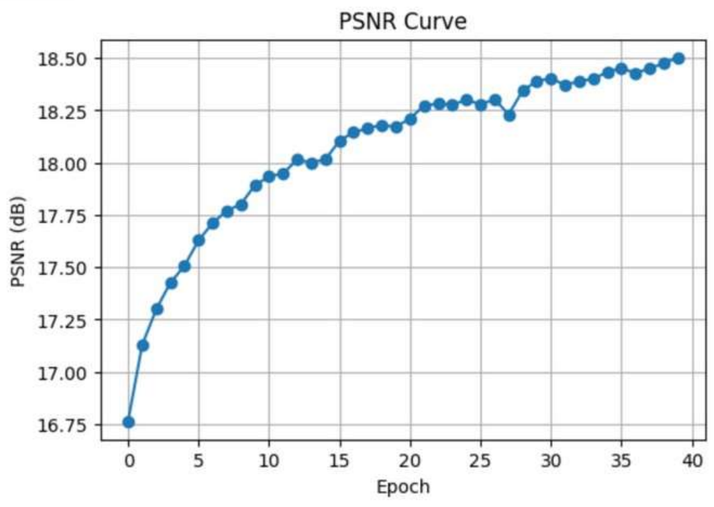
Baseline — L1 Loss

```
✓ Best SSIM model loaded for testing!

🔹 FINAL TEST RESULTS (Best SSIM Model — L1-trained) 🔹
------------------------------------------------------------
Test MSE  = 0.014991
Test L1   = 0.084288
Test SSIM = 0.6619
Test PSNR = 18.40 dB
------------------------------------------------------------
```



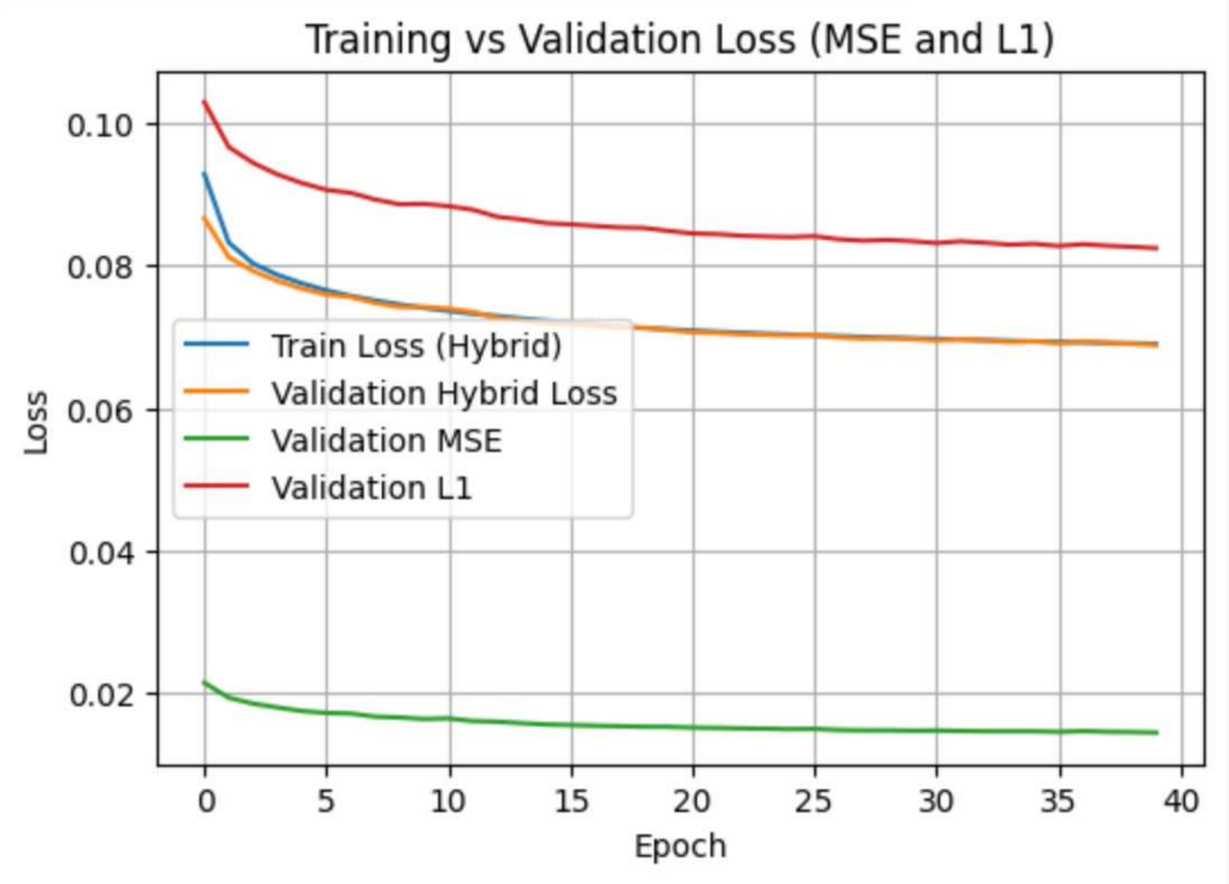
Baseline — L1 Loss



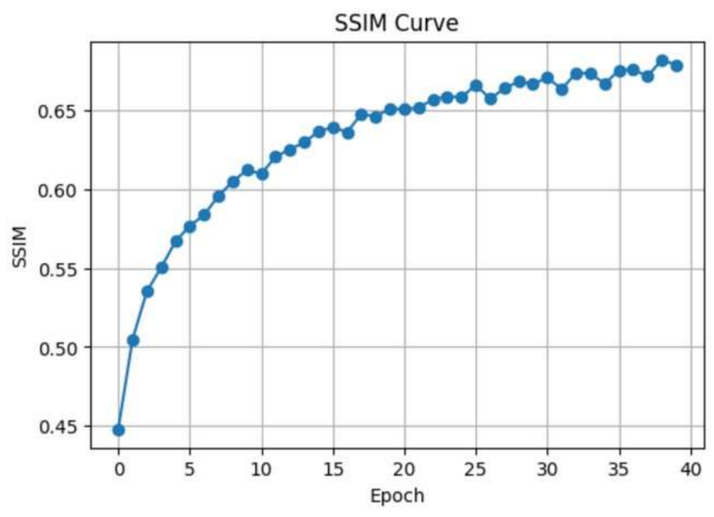


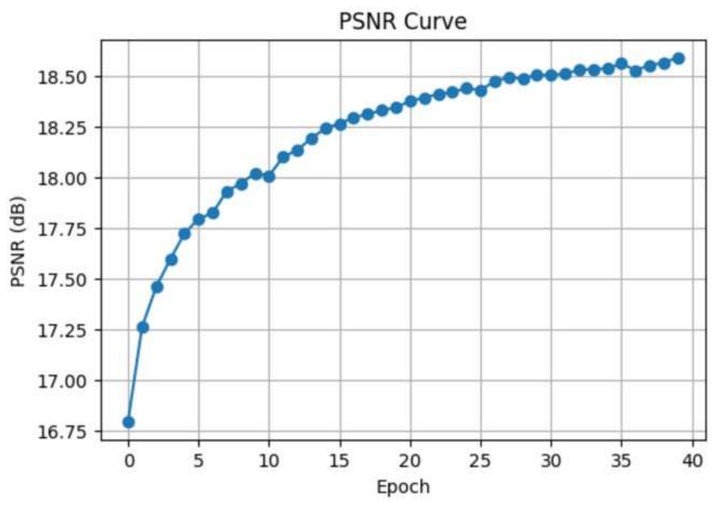
Baseline — Hybrid Loss

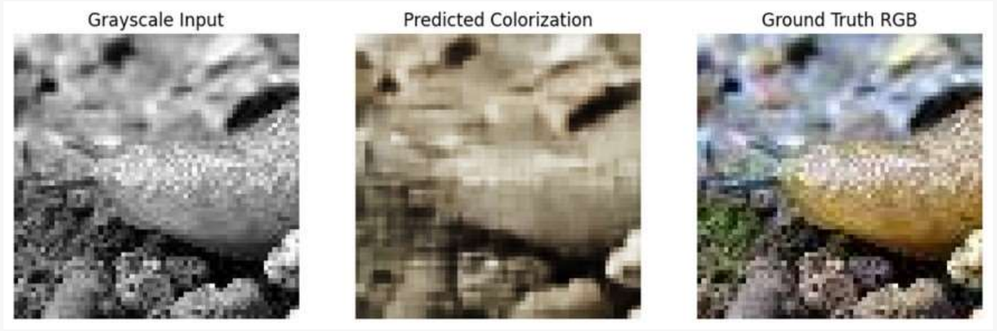
```
✓ Best SSIM Hybrid Model loaded for testing!

🔹 FINAL TEST RESULTS (Best Hybrid SSIM Model) 🔹
--------------------------------------------------
Test MSE  = 0.014803
Test L1   = 0.083720
Test SSIM = 0.6723
Test PSNR = 18.47 dB
--------------------------------------------------
```

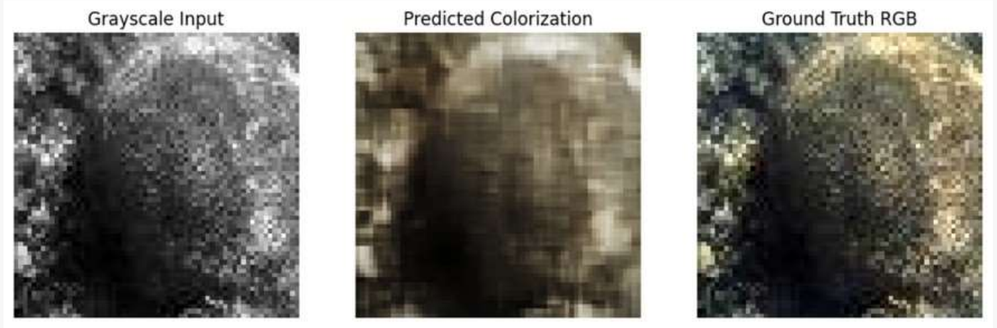


Baseline — Hybrid Loss



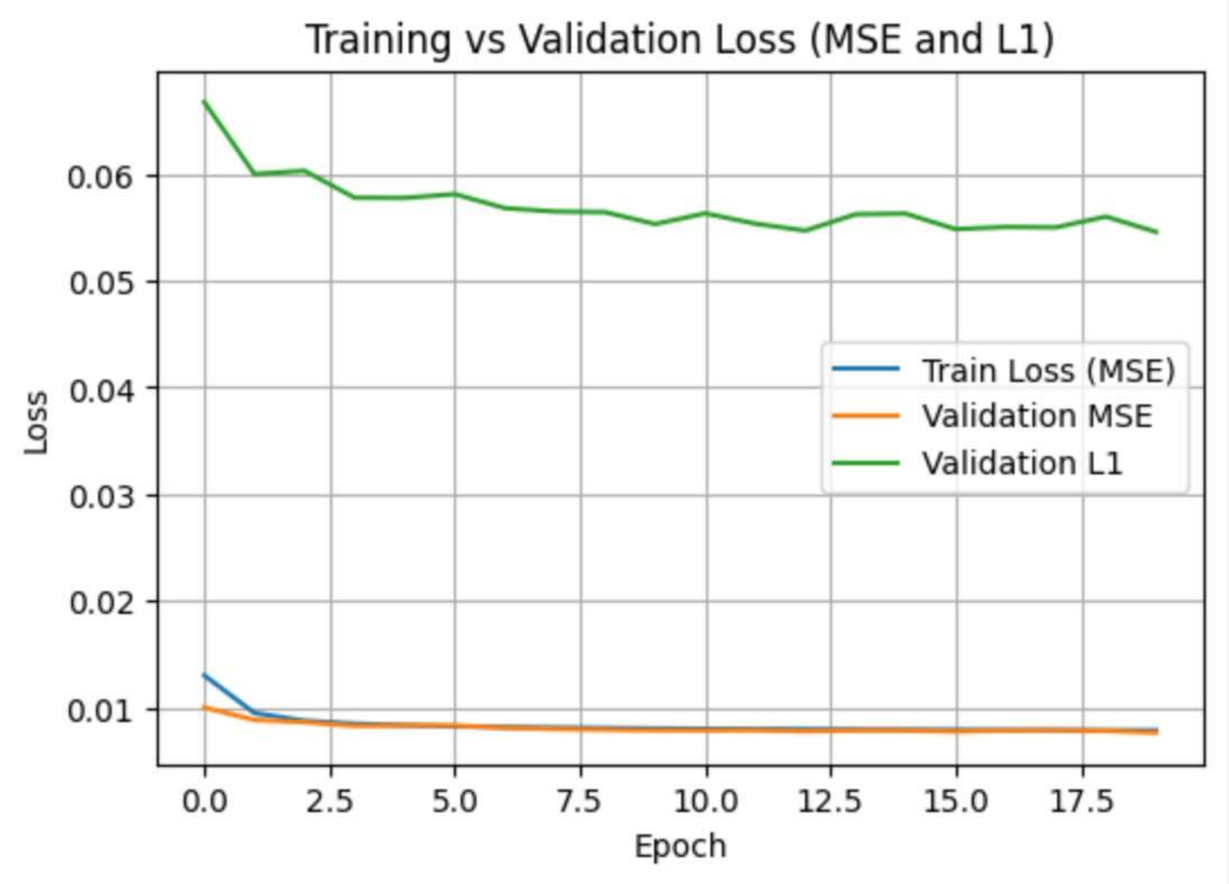




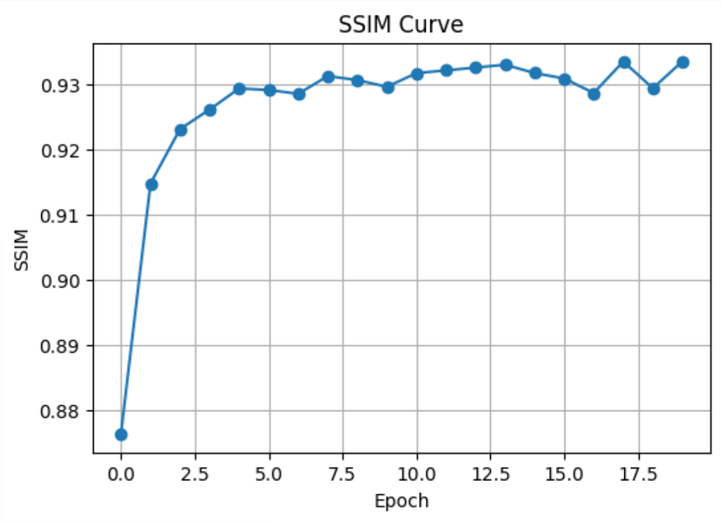


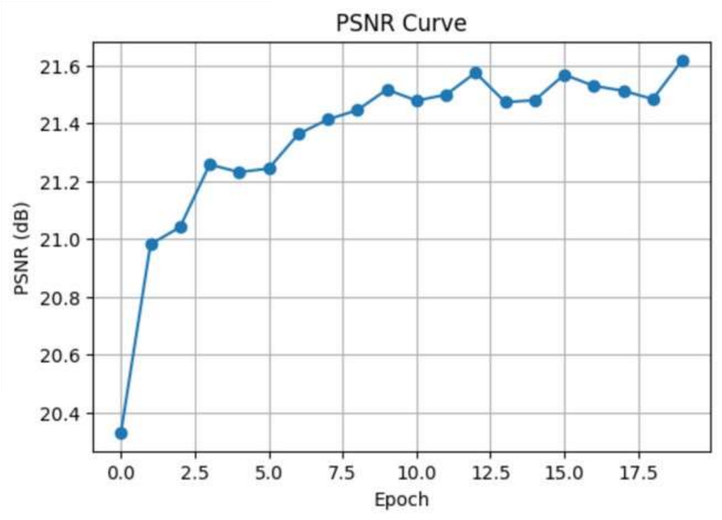
U-Net — MSE Loss

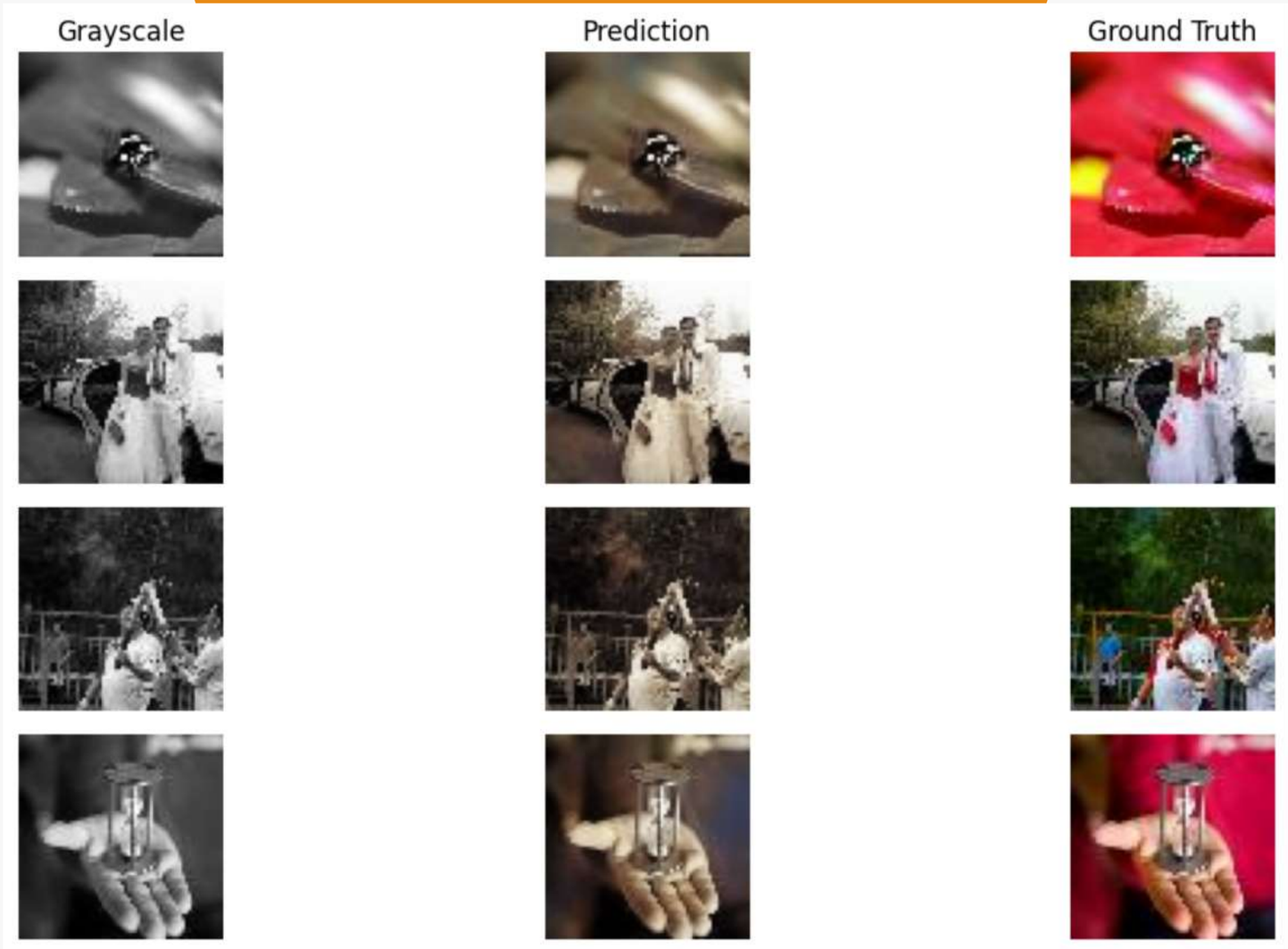
```
✓ Best SSIM MSE-trained model loaded for testing!

🔹 FINAL TEST RESULTS (Best MSE-Trained U-Net) 🔹
------------------------------------------------
Test MSE  = 0.007858
Test L1   = 0.055793
Test SSIM = 0.9320
Test PSNR = 21.51 dB
------------------------------------------------
```



U-Net — MSE Loss

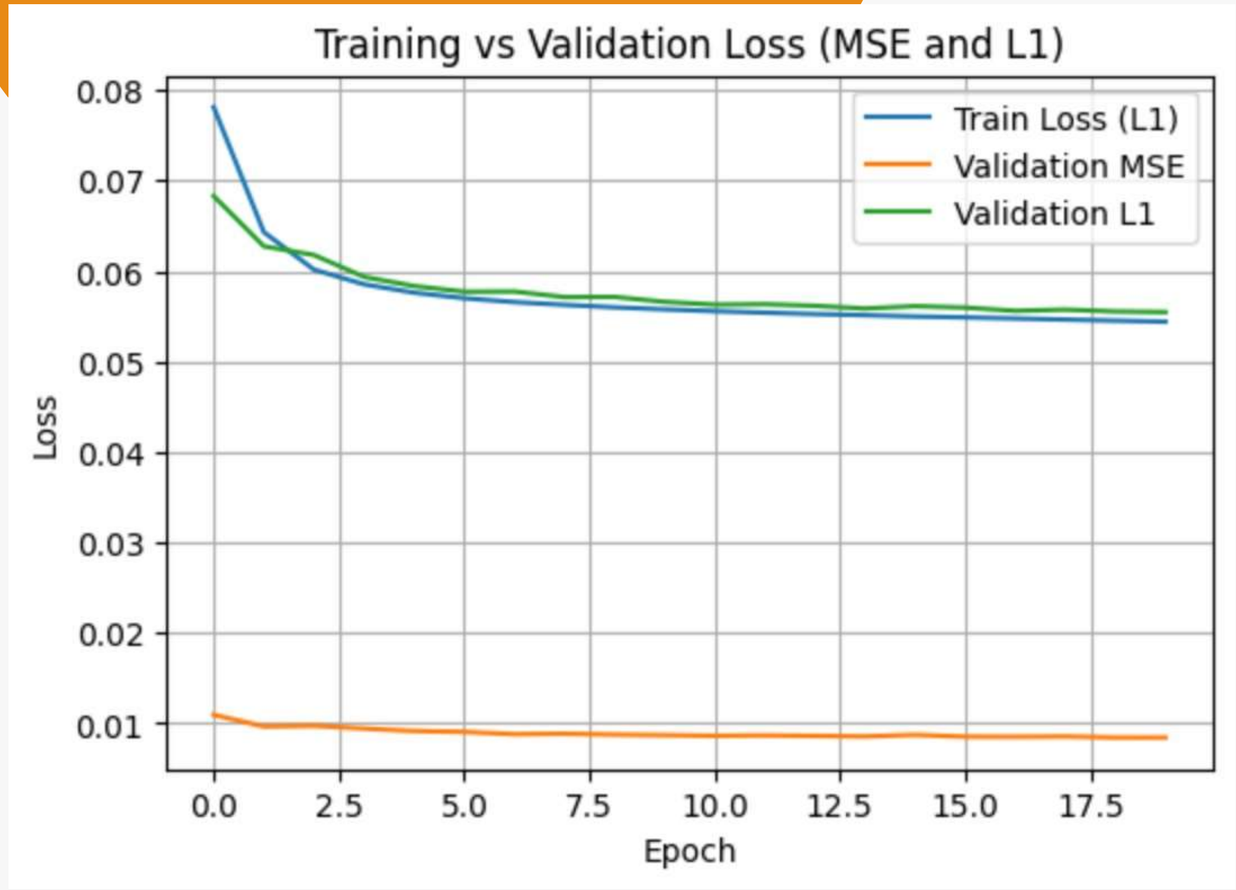




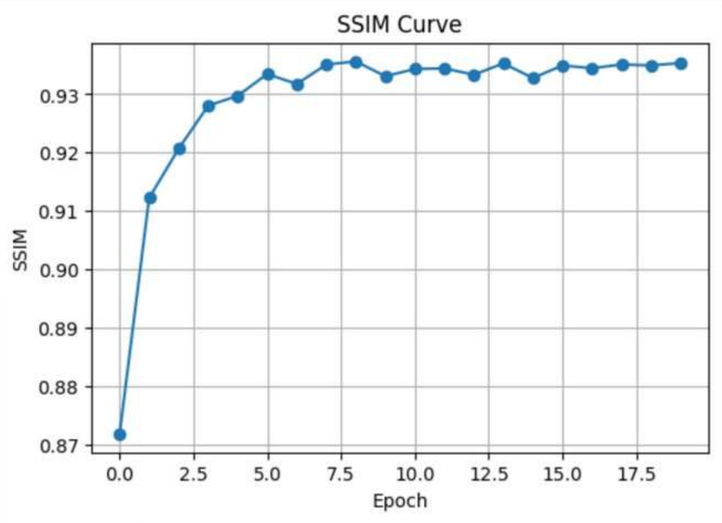


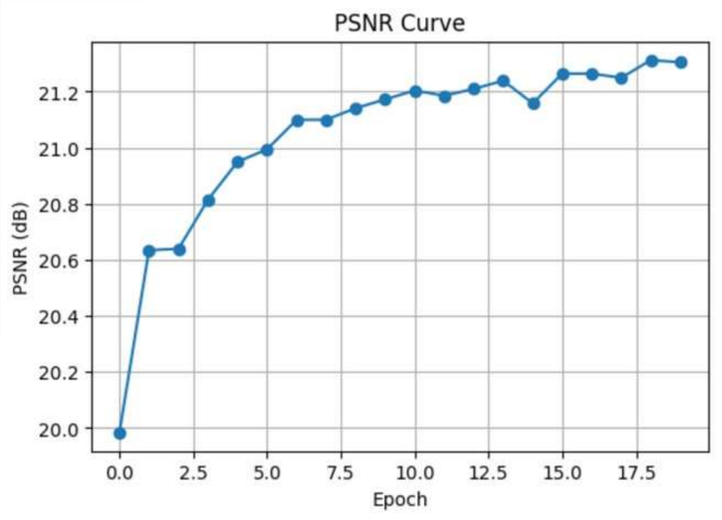
U-Net — L1 Loss

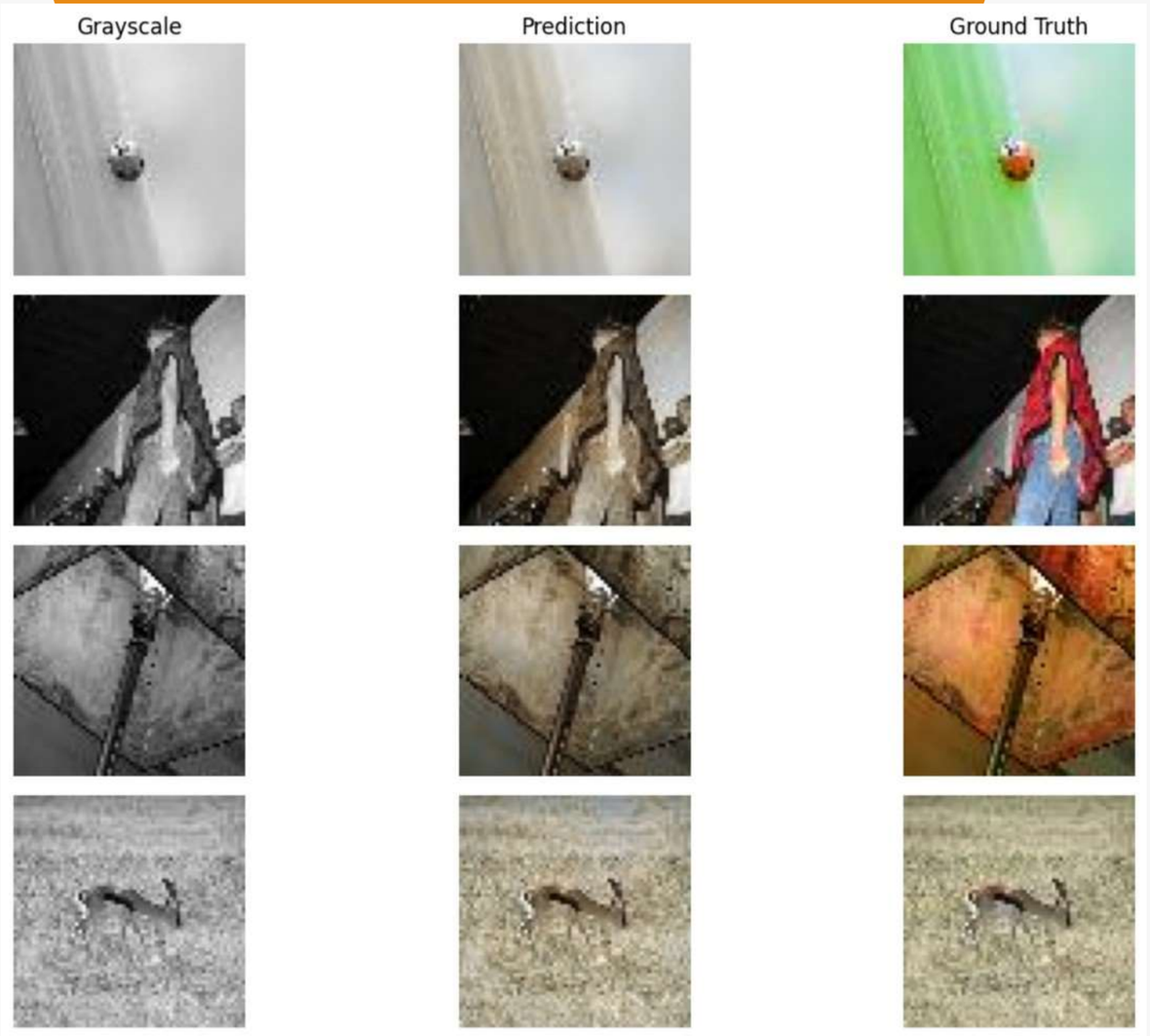
```
✓ Best SSIM L1-trained model loaded for testing!

🔹 FINAL TEST RESULTS (Best L1-Trained U-Net) 🔹
------------------------------------------------
Test L1   = 0.055431
Test MSE  = 0.008083
Test SSIM = 0.9371
Test PSNR = 21.48 dB
------------------------------------------------
```



U-Net — L1 Loss

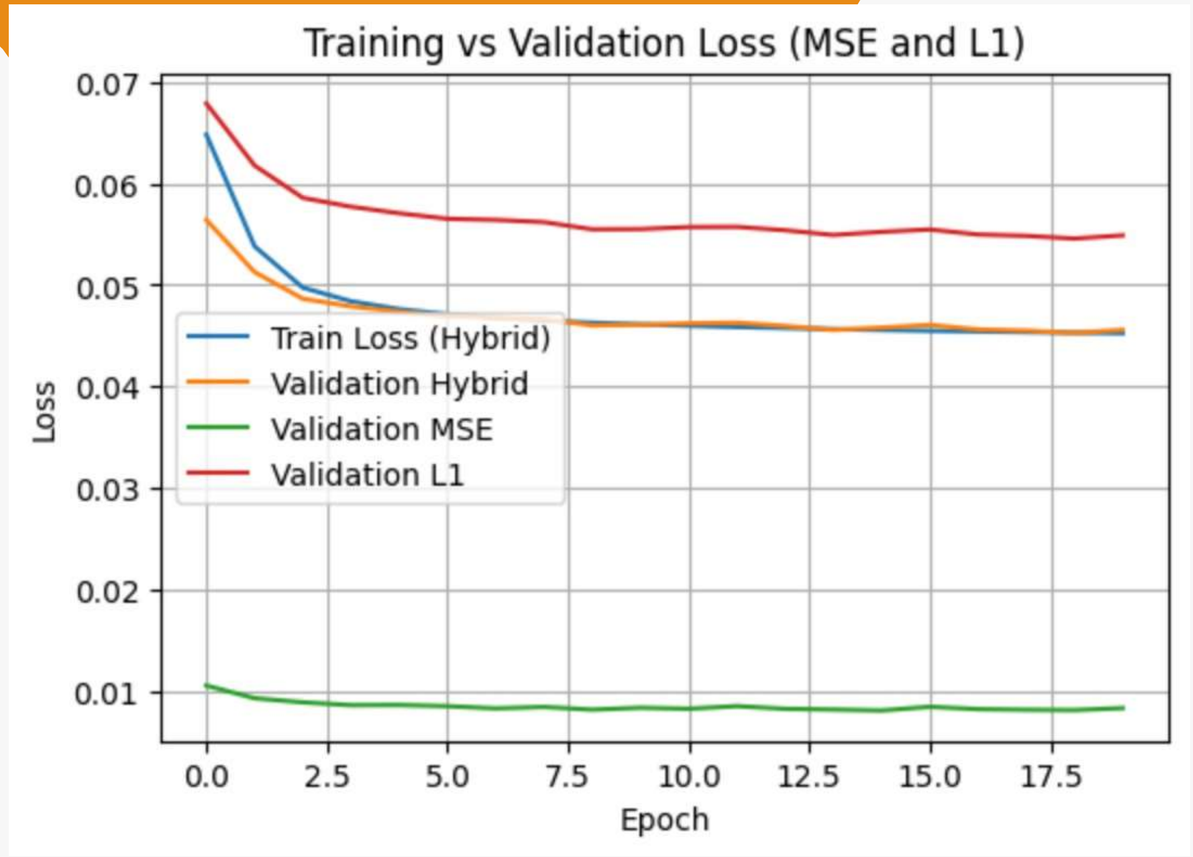

SSIM Curve
SSIM
0.93
0.92
0.91
0.90
0.89
0.88
0.87
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Epoch


PSNR Curve
PSNR (dB)
21.2
21.0
20.8
20.6
20.4
20.2
20.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Epoch

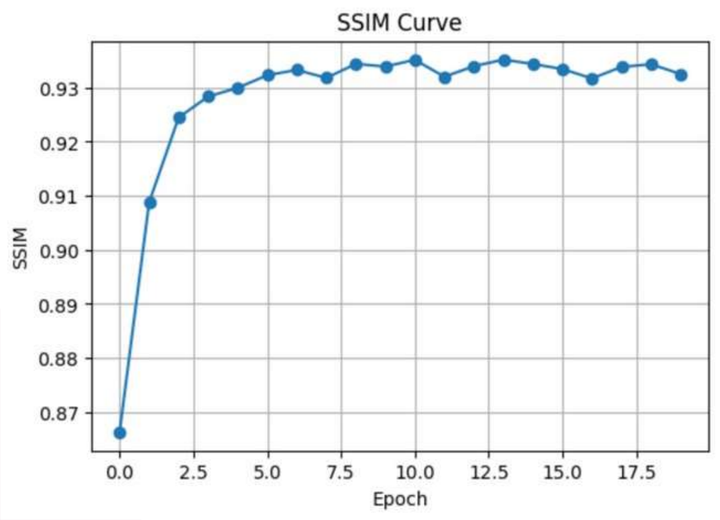

Grayscale
Prediction
Ground Truth

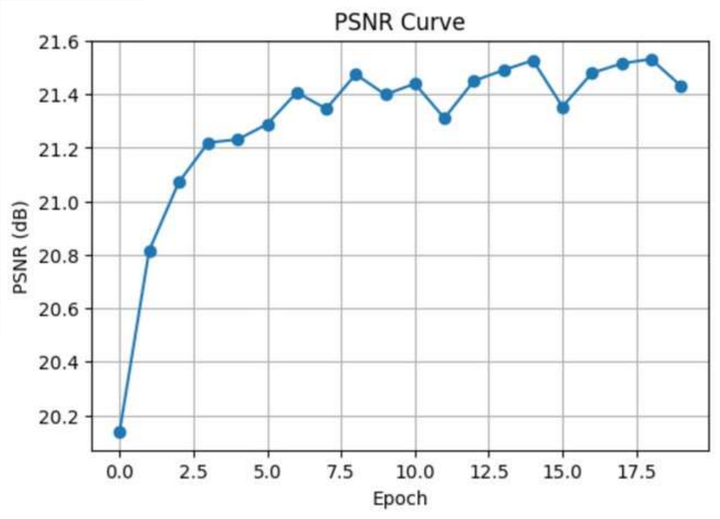
U-Net — Hybrid Loss

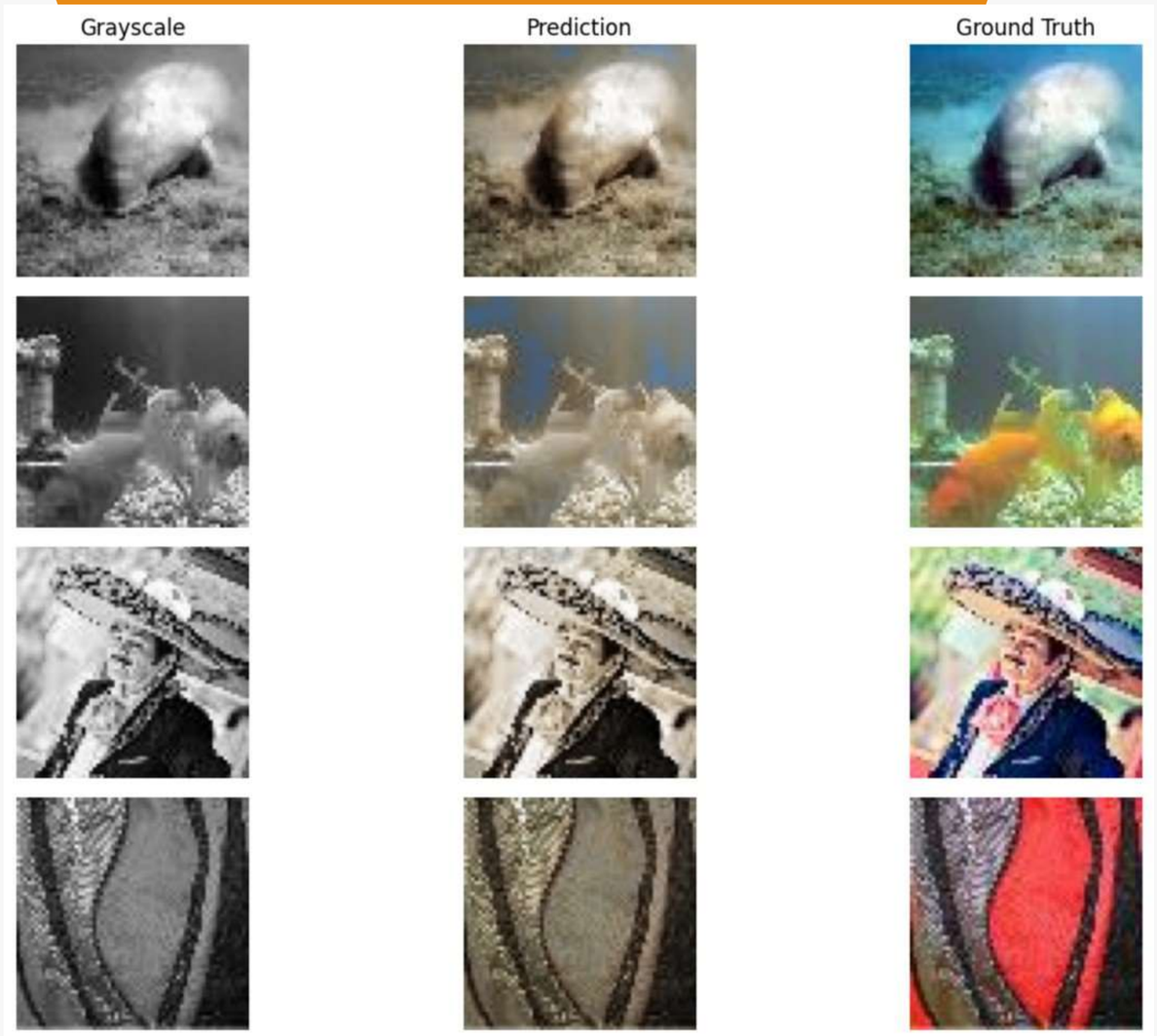
```
✓ Best hybrid SSIM-based model loaded for testing!

🔹 FINAL TEST RESULTS — Best Hybrid-trained U-Net 🔹
------------------------------------------------
Test L1   = 0.054121
Test MSE  = 0.007893
Test SSIM = 0.9387
Test PSNR = 21.59 dB
------------------------------------------------
```



U-Net — Hybrid Loss







Perfermance comparison

Metrics	R^2	MSE	L1	SSIM	PNSR
Linear Regression	-0.0367	235.9506	-	0.9287	22.08 dB
SVR	-0.051	236.69	-	0.91	22.89 dB
Baseline (MSE Loss)	-	0.0114489	0.084472	0.6624	18.56 dB
Baseline (L1 Loss)	-	0.014991	0.084288	0.6619	18.40 dB
Baseline (Hybrid Loss)	-	0.014803	0.083720	0.6723	18.47 dB
U-Net (MSE Loss)	-	0.007858	0.055793	0.9320	21.51 dB
U-Net (L1 Loss)	-	0.055431	0.008083	0.9371	21.48 dB
U-Net (Hybrid Loss)	-	0.007893	0.054121	0.9387	21.59 dB

Future Work

- Explore GAN-based colorization models (e.g., Pix2Pix, cGAN) for more realistic colors.
- Incorporate SSIM Loss into the training objective

$$\text{Hybrid Loss} = \alpha(L1) + \beta(MSE) + \gamma(1 - SSIM)$$

- Enhance the U-Net architecture with skip connections

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Thank you