Zero_DCE

February 28, 2023

[21]:
```
import os
import random
import numpy as np
from glob import glob
from PIL import Image, ImageOps
import matplotlib.pyplot as plt
import wandb
from mpl_toolkits.axes_grid1 import ImageGrid
from wandb.keras import WandbCallback
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers, losses, optimizers, callbacks
```

[46]:
```
SEED = 10
random.seed(SEED)
tf.random.set_seed(SEED)

IMAGE_SIZE = 256
MAX_TRAIN_IMAGES = 400
BATCH_SIZE = 16
TRAIN_VAL_IMAGE_DIR = "LOL/train/low"
TEST_IMAGE_DIR = "LOL/test/low"
LEARNING_RATE = 1e-4
LOG_INTERVALS = 10
EPOCHS = 1
```

[47]:
```
train_val_image_files = glob(os.path.join(TRAIN_VAL_IMAGE_DIR, "*.png"))
test_image_files = glob(os.path.join(TEST_IMAGE_DIR, "*.png"))
train_image_files = train_val_image_files[:MAX_TRAIN_IMAGES]
val_image_files = train_val_image_files[MAX_TRAIN_IMAGES:]

print("Number of Training Images:", len(train_image_files))
print("Number of Validation Images:", len(val_image_files))
print("Number of Test Images from LOL Dataset:", len(test_image_files))
```

```
Number of Training Images: 400
Number of Validation Images: 85
Number of Test Images from LOL Dataset: 15
```

[48]:
```
AUTOTUNE = tf.data.AUTOTUNE
def load_data(image_path):
    image = tf.io.read_file(image_path)
    image = tf.image.decode_png(image, channels=3)
    image = tf.image.resize(images=image, size=[IMAGE_SIZE, IMAGE_SIZE])
    image = image / 255.0
    return image

def get_dataset(images):
    dataset = tf.data.Dataset.from_tensor_slices((images))
    dataset = dataset.map(load_data, num_parallel_calls=AUTOTUNE)
    dataset = dataset.batch(BATCH_SIZE, drop_remainder=True)
    dataset = dataset.prefetch(AUTOTUNE)

    return dataset

train_dataset = get_dataset(train_image_files)
val_dataset = get_dataset(val_image_files)
```

[49]:
```
print("Train Data Elements:", train_dataset.element_spec)
print("Validation Data Elements:", val_dataset.element_spec)
```

```
Train Data Elements: TensorSpec(shape=(16, 256, 256, 3), dtype=tf.float32,
name=None)
Validation Data Elements: TensorSpec(shape=(16, 256, 256, 3), dtype=tf.float32,
name=None)
```

[50]:
```
train_val_image_files = glob(os.path.join(TRAIN_VAL_IMAGE_DIR, "*.png"))
test_image_files = glob(os.path.join(TEST_IMAGE_DIR, "*.png"))
train_image_files = train_val_image_files[:MAX_TRAIN_IMAGES]
val_image_files = train_val_image_files[MAX_TRAIN_IMAGES:]

print("Number of Training Images:", len(train_image_files))
print("Number of Validation Images:", len(val_image_files))
print("Number of Test Images from LOL Dataset:", len(test_image_files))
```

```
Number of Training Images: 400
Number of Validation Images: 85
Number of Test Images from LOL Dataset: 15
```

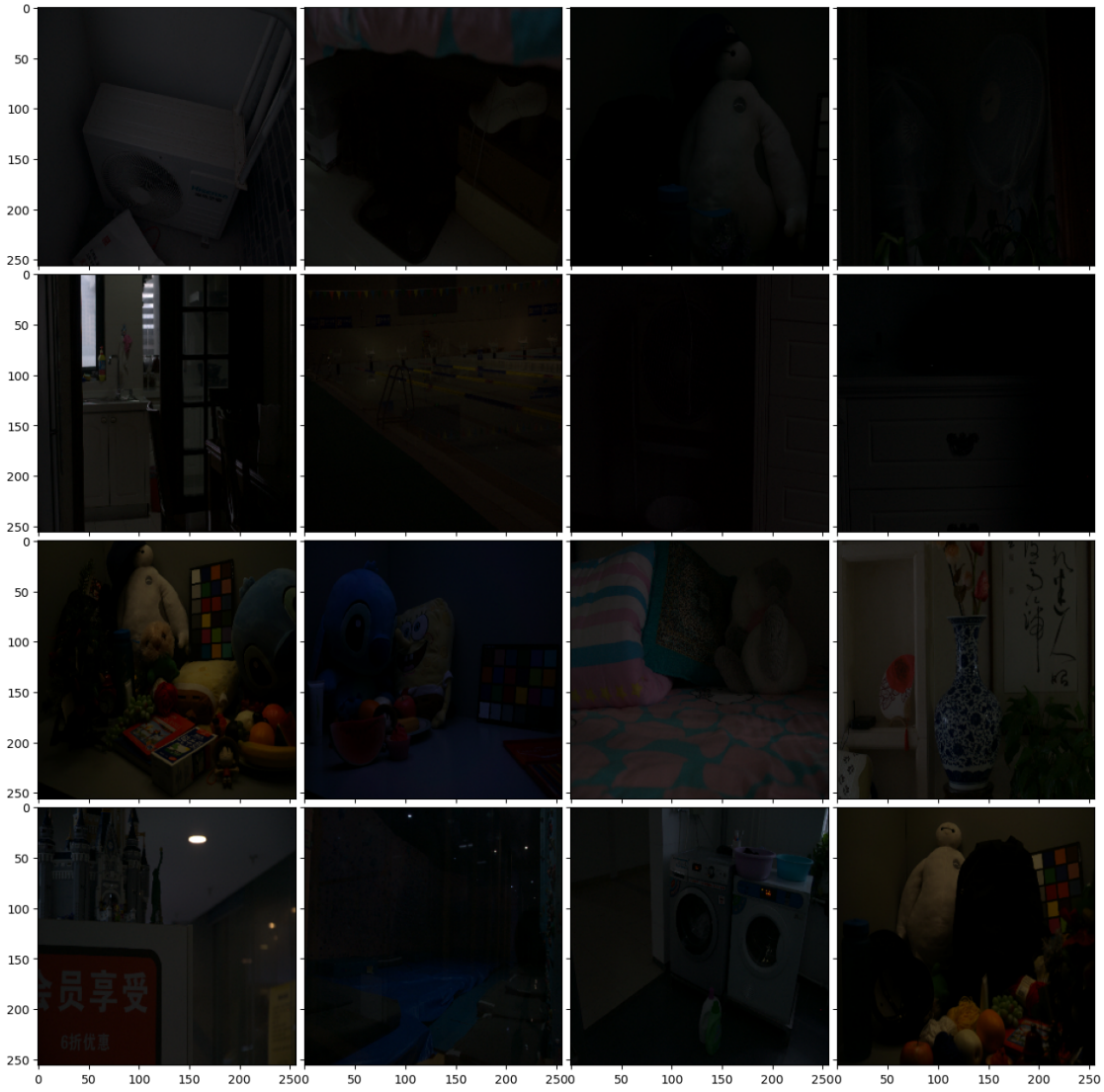
[51]:
```
def load_data(image_path):
    image = tf.io.read_file(image_path)
    image = tf.image.decode_png(image, channels=3)
    image = tf.image.resize(images=image, size=[IMAGE_SIZE, IMAGE_SIZE])
    image = image / 255.0
    return image
```

```
def get_dataset(images):
    dataset = tf.data.Dataset.from_tensor_slices((images))
    dataset = dataset.map(load_data, num_parallel_calls=AUTOTUNE)
    dataset = dataset.batch(BATCH_SIZE, drop_remainder=True)
    dataset = dataset.prefetch(AUTOTUNE)

    return dataset

train_dataset = get_dataset(train_image_files)
val_dataset = get_dataset(val_image_files)
```

[52]:
```
print("Train Data Elements:", train_dataset.element_spec)
print("Validation Data Elements:", val_dataset.element_spec)
```

```
Train Data Elements: TensorSpec(shape=(16, 256, 256, 3), dtype=tf.float32,
name=None)
Validation Data Elements: TensorSpec(shape=(16, 256, 256, 3), dtype=tf.float32,
name=None)
```

[53]:
```
images = next(iter(train_dataset)).numpy()
fig = plt.figure(figsize=(16, 16))
grid = ImageGrid(fig, 111, nrows_ncols=(4, 4), axes_pad=0.1)
random_images = images[np.random.choice(np.arange(images.shape[0]), 16)]
for ax, image in zip(grid, images):
    image = image * 255.0
    ax.imshow(image.astype(np.uint8))
plt.title("Sample Images from Tiny-NeRF Data")
plt.show()
```



[54]:
```
def build_dce_net(image_size=None) -> keras.Model:
    input_image = keras.Input(shape=[image_size, image_size, 3])
    conv1 = layers.Conv2D( 32, (3, 3), strides=(1, 1), activation="relu",␣
 ↪padding="same" )(input_image)
    conv2 = layers.Conv2D(32, (3, 3), strides=(1, 1), activation="relu",␣
 ↪padding="same" )(conv1)
    conv3 = layers.Conv2D(32, (3, 3), strides=(1, 1), activation="relu",␣
 ↪padding="same" )(conv2)
    conv4 = layers.Conv2D( 32, (3, 3), strides=(1, 1), activation="relu",␣
 ↪padding="same" )(conv3)
    int_con1 = layers.Concatenate(axis=-1)([conv4, conv3])
```

```
    conv5 = layers.Conv2D( 32, (3, 3), strides=(1, 1), activation="relu",␣
↪padding="same")(int_con1)
    int_con2 = layers.Concatenate(axis=-1)([conv5, conv2])
    conv6 = layers.Conv2D( 32, (3, 3), strides=(1, 1), activation="relu",␣
↪padding="same")(int_con2)
    int_con3 = layers.Concatenate(axis=-1)([conv6, conv1])
    x_r = layers.Conv2D(24, (3, 3), strides=(1, 1), activation="tanh",␣
↪padding="same")( int_con3)

    return keras.Model(inputs=input_image, outputs=x_r)
```

[55]:
```
def color_constancy_loss(x):
    mean_rgb = tf.reduce_mean(x, axis=(1, 2), keepdims=True)
    mean_red = mean_rgb[:, :, :, 0]
    mean_green = mean_rgb[:, :, :, 1]
    mean_blue = mean_rgb[:, :, :, 2]
    diff_red_green = tf.square(mean_red - mean_green)
    diff_red_blue = tf.square(mean_red - mean_blue)
    diff_green_blue = tf.square(mean_blue - mean_green)
    return tf.sqrt(tf.square(diff_red_green) + tf.square(diff_red_blue) + tf.
↪square(diff_green_blue))
```

[56]:
```
def exposure_loss(x, mean_val=0.6):
    x = tf.reduce_mean(x, axis=3, keepdims=True)
    mean = tf.nn.avg_pool2d(x, ksize=16, strides=16, padding="VALID")
    return tf.reduce_mean(tf.square(mean - mean_val))
```

[57]:
```
def illumination_smoothness_loss(x):

    batch_size = tf.shape(x)[0]
    height_x = tf.shape(x)[1]
    width_x = tf.shape(x)[2]
    count_height = (tf.shape(x)[2] - 1) * tf.shape(x)[3]
    count_width = tf.shape(x)[2] * (tf.shape(x)[3] - 1)
    height_total_variance = tf.reduce_sum(tf.square((x[:, 1:, :, :] - x[:, :␣
↪height_x - 1, :, :])))
    width_total_variance = tf.reduce_sum(tf.square((x[:, :, 1:, :] - x[:, :, :␣
↪width_x - 1, :])))
    batch_size = tf.cast(batch_size, dtype=tf.float32)
    count_height = tf.cast(count_height, dtype=tf.float32)
    count_width = tf.cast(count_width, dtype=tf.float32)

    return 2 * (height_total_variance / count_height + width_total_variance /␣
↪count_width) / batch_size
```

[58]:
```
class SpatialConsistencyLoss(losses.Loss):

    def __init__(self, **kwargs):
        super(SpatialConsistencyLoss, self).__init__(reduction="none")

        self.left_kernel = tf.constant( [[[[0, 0, 0]], [[-1, 1, 0]], [[0, 0,␣
↪0]]]], dtype=tf.float32)
        self.right_kernel = tf.constant([[[[0, 0, 0]], [[0, 1, -1]], [[0, 0,␣
↪0]]]], dtype=tf.float32)
        self.up_kernel = tf.constant([[[[0, -1, 0]], [[0, 1, 0]], [[0, 0,␣
↪0]]]], dtype=tf.float32)
        self.down_kernel = tf.constant([[[[0, 0, 0]], [[0, 1, 0]], [[0, -1,␣
↪0]]]], dtype=tf.float32)

    def call(self, y_true, y_pred):

        original_mean = tf.reduce_mean(y_true, 3, keepdims=True)
        enhanced_mean = tf.reduce_mean(y_pred, 3, keepdims=True)
        original_pool = tf.nn.avg_pool2d( original_mean, ksize=4, strides=4,␣
↪padding="VALID")
        enhanced_pool = tf.nn.avg_pool2d( enhanced_mean, ksize=4, strides=4,␣
↪padding="VALID")

        d_original_left = tf.nn.conv2d(original_pool, self.left_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")
        d_original_right = tf.nn.conv2d(original_pool, self.right_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")
        d_original_up = tf.nn.conv2d(original_pool, self.up_kernel, strides=[1,␣
↪1, 1, 1], padding="SAME")
        d_original_down = tf.nn.conv2d(original_pool, self.down_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")

        d_enhanced_left = tf.nn.conv2d(enhanced_pool, self.left_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")
        d_enhanced_right = tf.nn.conv2d( enhanced_pool, self.right_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")
        d_enhanced_up = tf.nn.conv2d( enhanced_pool, self.up_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")
        d_enhanced_down = tf.nn.conv2d( enhanced_pool, self.down_kernel,␣
↪strides=[1, 1, 1, 1], padding="SAME")

        d_left = tf.square(d_original_left - d_enhanced_left)
        d_right = tf.square(d_original_right - d_enhanced_right)
        d_up = tf.square(d_original_up - d_enhanced_up)
        d_down = tf.square(d_original_down - d_enhanced_down)
```

```
        return d_left + d_right + d_up + d_down
```

[59]:
```
class ZeroDCE(keras.Model):
    def __init__(self, **kwargs):
        super(ZeroDCE, self).__init__(**kwargs)
        self.dce_model = build_dce_net()

    def compile(self, learning_rate, **kwargs):
        super(ZeroDCE, self).compile(**kwargs)
        self.optimizer = optimizers.Adam(learning_rate=learning_rate)
        self.spatial_constancy_loss = SpatialConsistencyLoss(reduction="none")

    def summary(self, *args, **kwargs):
        self.dce_model.summary(*args, **kwargs)

    def get_enhanced_image(self, data, output):
        x = data
        for i in range(0, 3 * 8, 3):
            r = output[:, :, :, i: i + 3]
            x = x + r * (tf.square(x) - x)
        return x

    def call(self, data):
        dce_net_output = self.dce_model(data)
        return self.get_enhanced_image(data, dce_net_output)

    def compute_losses(self, data, output):
        enhanced_image = self.get_enhanced_image(data, output)
        loss_illumination = 200 * illumination_smoothness_loss(output)
        loss_spatial_constancy = tf.reduce_mean(
            self.spatial_constancy_loss(enhanced_image, data)
        )
        loss_color_constancy = 5 * tf.
↪reduce_mean(color_constancy_loss(enhanced_image))
        loss_exposure = 10 * tf.reduce_mean(exposure_loss(enhanced_image))
        total_loss = (
            loss_illumination
            + loss_spatial_constancy
            + loss_color_constancy
            + loss_exposure
        )
        return {
            "total_loss": total_loss,
            "illumination_smoothness_loss": loss_illumination,
            "spatial_constancy_loss": loss_spatial_constancy,
            "color_constancy_loss": loss_color_constancy,
            "exposure_loss": loss_exposure,
```

```
        }

    def train_step(self, data):
        with tf.GradientTape() as tape:
            output = self.dce_model(data)
            losses = self.compute_losses(data, output)
        gradients = tape.gradient(
            losses["total_loss"], self.dce_model.trainable_weights
        )
        self.optimizer.apply_gradients(zip(gradients, self.dce_model.
↪trainable_weights))
        return losses

    def test_step(self, data):
        output = self.dce_model(data)
        return self.compute_losses(data, output)

    def save_weights(self, filepath, overwrite=True, save_format=None,␣
↪options=None):
        self.dce_model.save_weights(
            filepath, overwrite=overwrite, save_format=save_format,␣
↪options=options
        )

    def load_weights(self, filepath, by_name=False, skip_mismatch=False,␣
↪options=None):
        self.dce_model.load_weights(
            filepath=filepath,
            by_name=by_name,
            skip_mismatch=skip_mismatch,
            options=options,
        )
```

[60]:
```
zero_dce_model = ZeroDCE()
zero_dce_model.summary()
```

```
Model: "model_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_3 (InputLayer)        [(None, None, None,  0
                              3)]

 conv2d_14 (Conv2D)          (None, None, None,    896
['input_3[0][0]']
```

```
                                32)

 conv2d_15 (Conv2D)             (None, None, None,   9248
['conv2d_14[0][0]']
                                32)

 conv2d_16 (Conv2D)             (None, None, None,   9248
['conv2d_15[0][0]']
                                32)

 conv2d_17 (Conv2D)             (None, None, None,   9248
['conv2d_16[0][0]']
                                32)

 concatenate_6 (Concatenate)    (None, None, None,   0
['conv2d_17[0][0]',
                                64)
'conv2d_16[0][0]']

 conv2d_18 (Conv2D)             (None, None, None,   18464
['concatenate_6[0][0]']
                                32)

 concatenate_7 (Concatenate)    (None, None, None,   0
['conv2d_18[0][0]',
                                64)
'conv2d_15[0][0]']

 conv2d_19 (Conv2D)             (None, None, None,   18464
['concatenate_7[0][0]']
                                32)

 concatenate_8 (Concatenate)    (None, None, None,   0
['conv2d_19[0][0]',
                                64)
'conv2d_14[0][0]']

 conv2d_20 (Conv2D)             (None, None, None,   13848
['concatenate_8[0][0]']
                                24)

==================================================================================
==================
Total params: 79,416
Trainable params: 79,416
Non-trainable params: 0
----------------------------------------------------------------------------------
------------------
```

[61]:
```
def plot_results(images, titles, figure_size=(12, 12)):
    fig = plt.figure(figsize=figure_size)
    for i in range(len(images)):
        fig.add_subplot(1, len(images), i + 1).set_title(titles[i])
        _ = plt.imshow(images[i])
        plt.axis("off")
    plt.show()

def infer(original_image):
    image = keras.preprocessing.image.img_to_array(original_image)
    image = image[:, :, :3] if image.shape[-1] > 3 else image
    image = image.astype("float32") / 255.0
    image = np.expand_dims(image, axis=0)
    output_image = zero_dce_model(image)
    output_image = tf.cast((output_image[0, :, :, :] * 255), dtype=np.uint8)
    output_image = Image.fromarray(output_image.numpy())
    return output_image
```

[62]:
```
class LogPredictionCallback(callbacks.Callback):

    def __init__(self, image_files, log_interval, *args, **kwargs):
        super().__init__(*args, **kwargs)
        self.image_files = image_files
        self.log_interval = log_interval

    def on_epoch_end(self, epoch, logs=None):
        if epoch % self.log_interval == 0:
            for image_file in self.image_files:
                original_image = Image.open(image_file)
                enhanced_image = infer(original_image)
                plot_results([original_image, enhanced_image],["Original",␣
 ↪"Enhanced_Image"], (15, 7), )
```

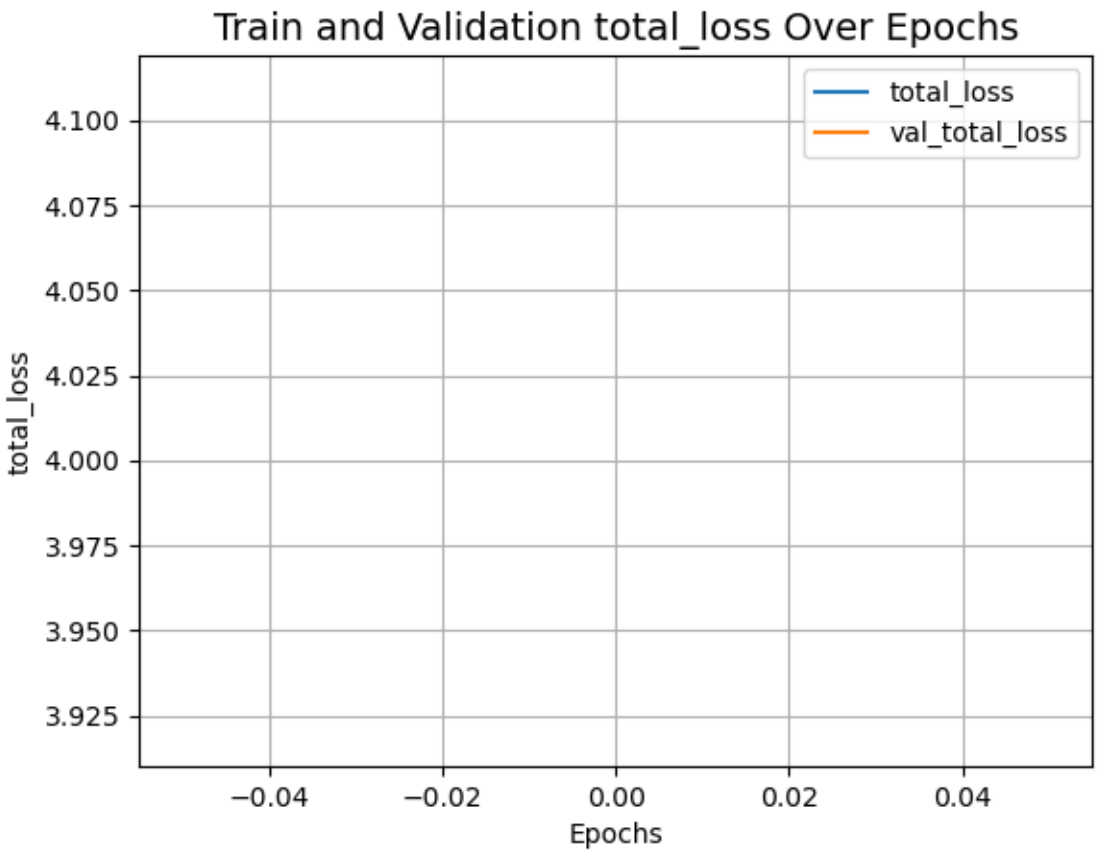
[63]:
```
zero_dce_model.compile(learning_rate=LEARNING_RATE)
history = zero_dce_model.fit(
    train_dataset,
    validation_data=val_dataset,
    epochs=EPOCHS,
    callbacks=[
        LogPredictionCallback(
            image_files=random.sample(val_image_files, 4),
            log_interval=LOG_INTERVALS
        )
    ]
)
```

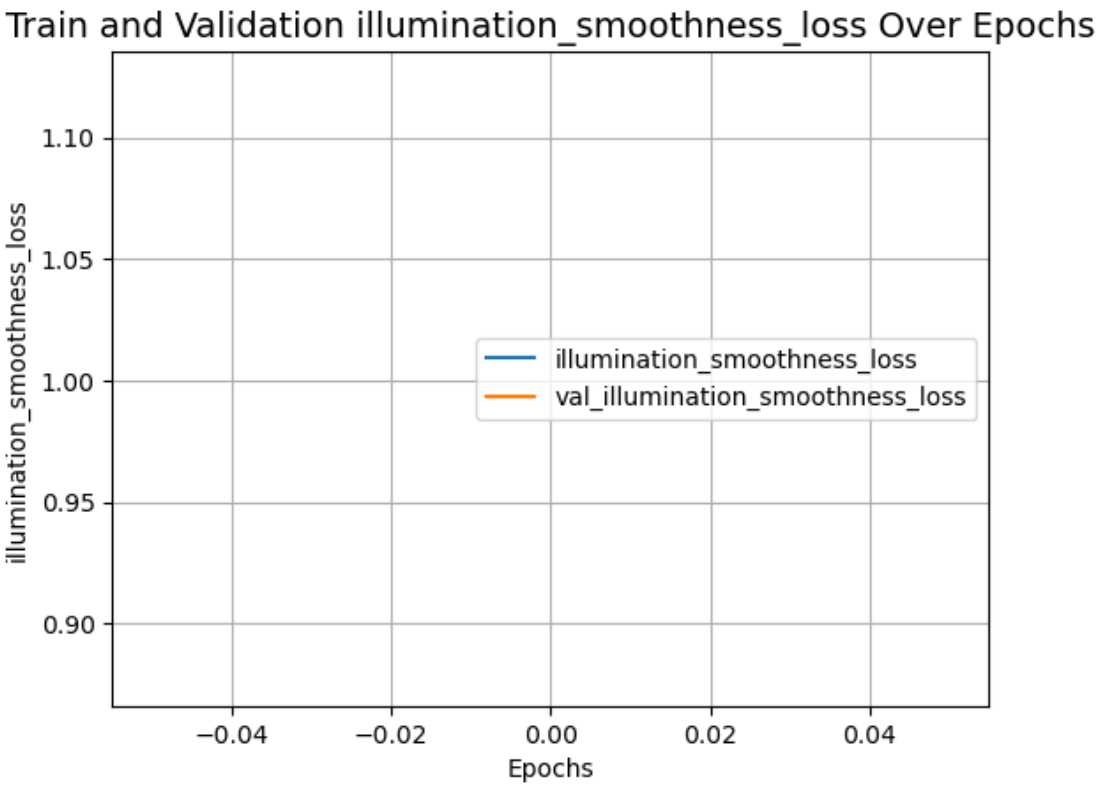
```
25/25 [==============================] - ETA: 0s - total_loss: 4.8402 -
```

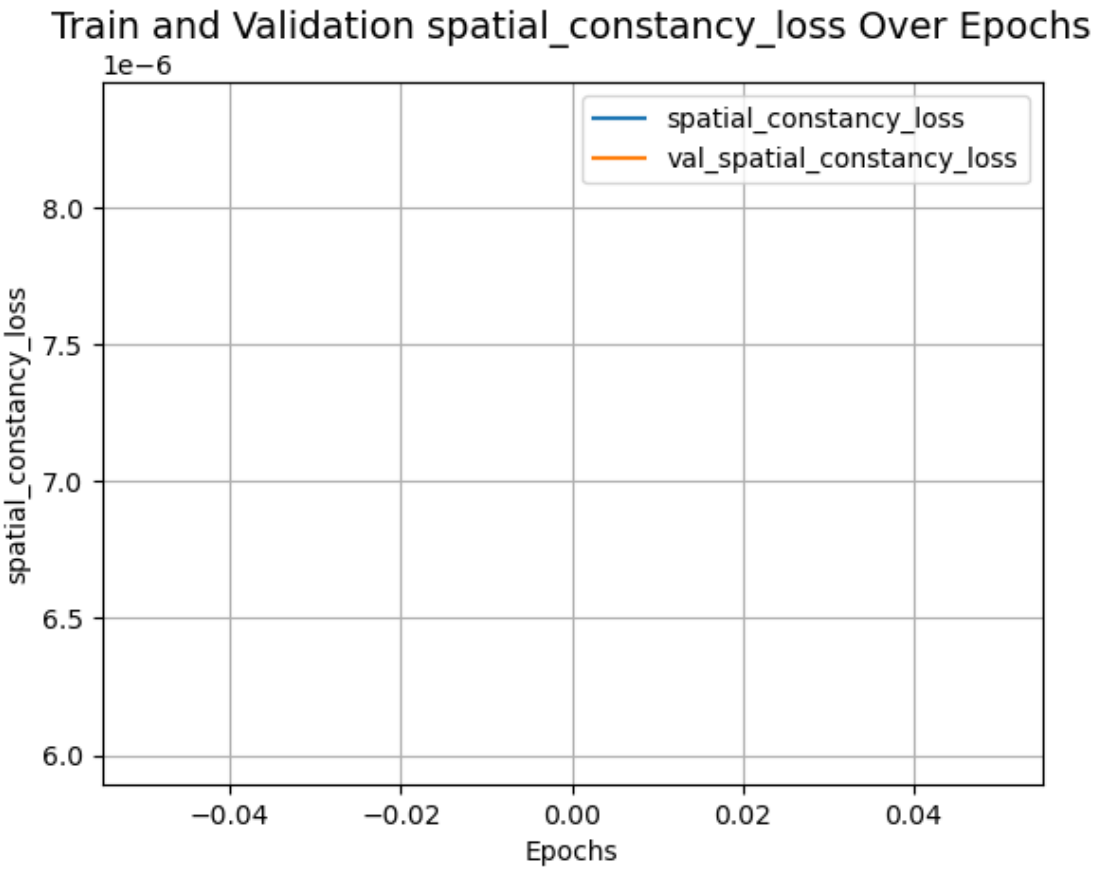
```
illumination_smoothness_loss: 1.8875 - spatial_constancy_loss: 9.8999e-06 -
color_constancy_loss: 0.0030 - exposure_loss: 2.9498
```

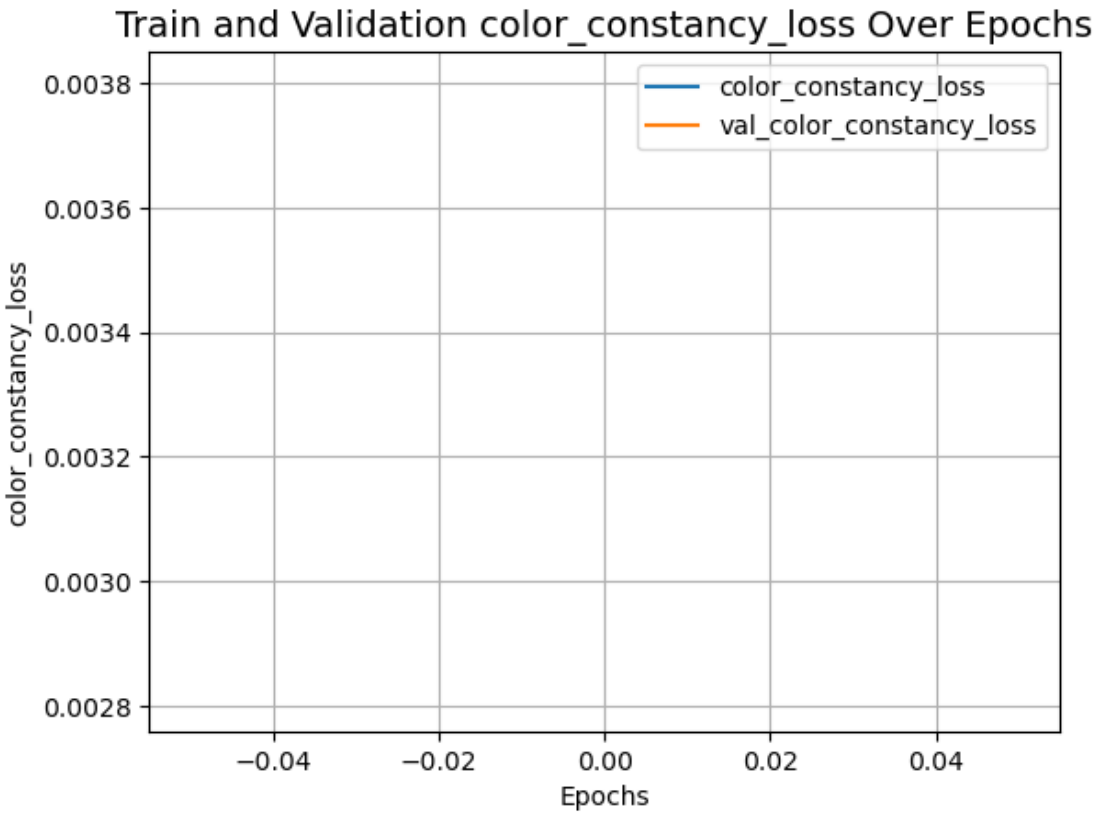

```
25/25 [==============================] - 351s 14s/step - total_loss: 4.8048 -
illumination_smoothness_loss: 1.8487 - spatial_constancy_loss: 9.7503e-06 -
color_constancy_loss: 0.0030 - exposure_loss: 2.9531 - val_total_loss: 4.1095 -
val_illumination_smoothness_loss: 1.1230 - val_spatial_constancy_loss:
8.3411e-06 - val_color_constancy_loss: 0.0028 - val_exposure_loss: 2.9836
```

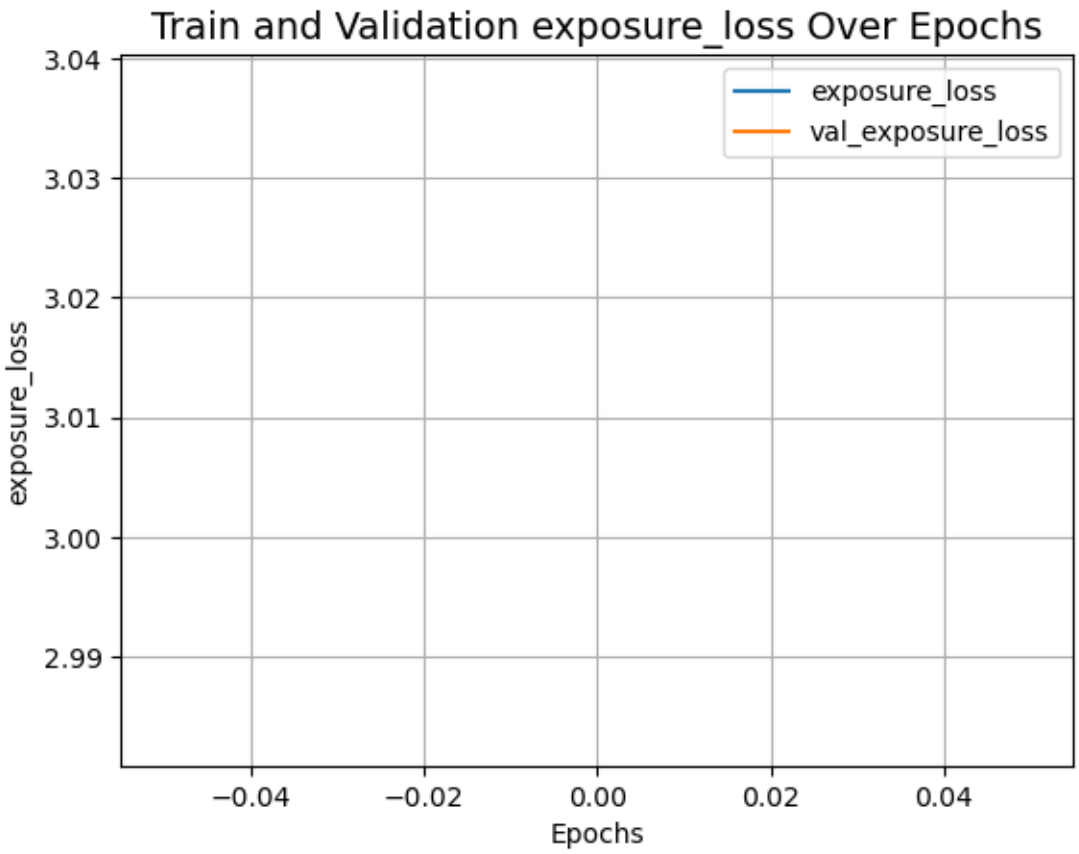
[65]:
```python
def plot_result(item):
    plt.plot(history.history[item], label=item)
    plt.plot(history.history["val_" + item], label="val_" + item)
    plt.xlabel("Epochs")
    plt.ylabel(item)
    plt.title("Train and Validation {} Over Epochs".format(item), fontsize=14)
    plt.legend()
    plt.grid()
    plt.show()


plot_result("total_loss")
plot_result("illumination_smoothness_loss")
plot_result("spatial_constancy_loss")
plot_result("color_constancy_loss")
plot_result("exposure_loss")
```


Train and Validation total_loss Over Epochs
total_loss
val_total_loss
4.100
4.075
4.050
4.025
4.000
3.975
3.950
3.925
total_loss
−0.04
−0.02
0.00
0.02
0.04
Epochs


Train and Validation illumination_smoothness_loss Over Epochs
illumination_smoothness_loss
1.10
1.05
1.00
0.95
0.90
−0.04
−0.02
0.00
0.02
0.04
Epochs
illumination_smoothness_loss
val_illumination_smoothness_loss

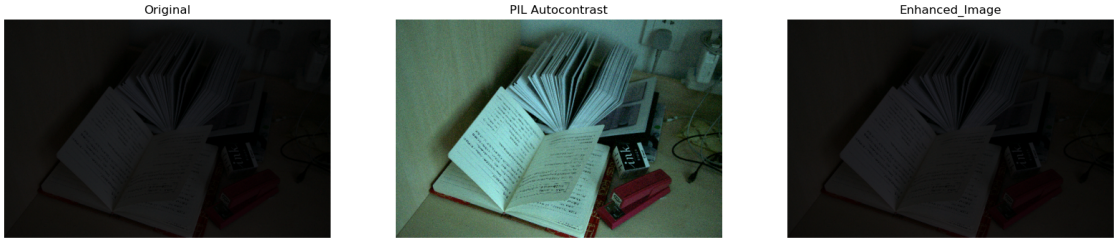

Train and Validation spatial_constancy_loss Over Epochs
1e−6
spatial_constancy_loss
val_spatial_constancy_loss
8.0
7.5
7.0
6.5
6.0
spatial_constancy_loss
−0.04
−0.02
0.00
0.02
0.04
Epochs


Train and Validation color_constancy_loss Over Epochs
color_constancy_loss
val_color_constancy_loss
0.0038
0.0036
0.0034
0.0032
0.0030
0.0028
color_constancy_loss
−0.04
−0.02
0.00
0.02
0.04
Epochs

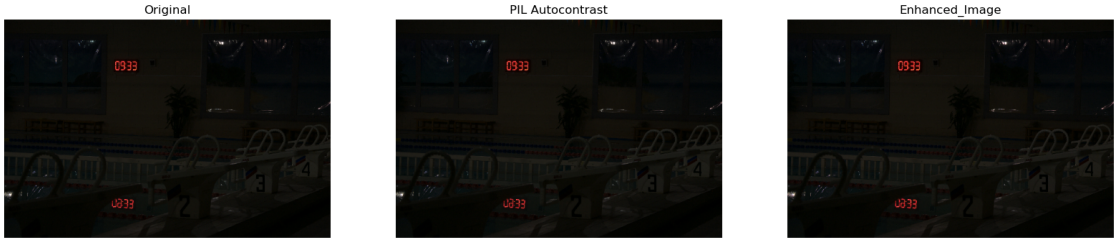


[66]:
```
for image_file in test_image_files:
    original_image = Image.open(image_file)
    enhanced_image = infer(original_image)
    plot_results(
        [original_image, ImageOps.autocontrast(original_image), enhanced_image],
        ["Original", "PIL Autocontrast", "Enhanced_Image"],
        (20, 12),
    )
```


Original
PIL Autocontrast
Enhanced_Image

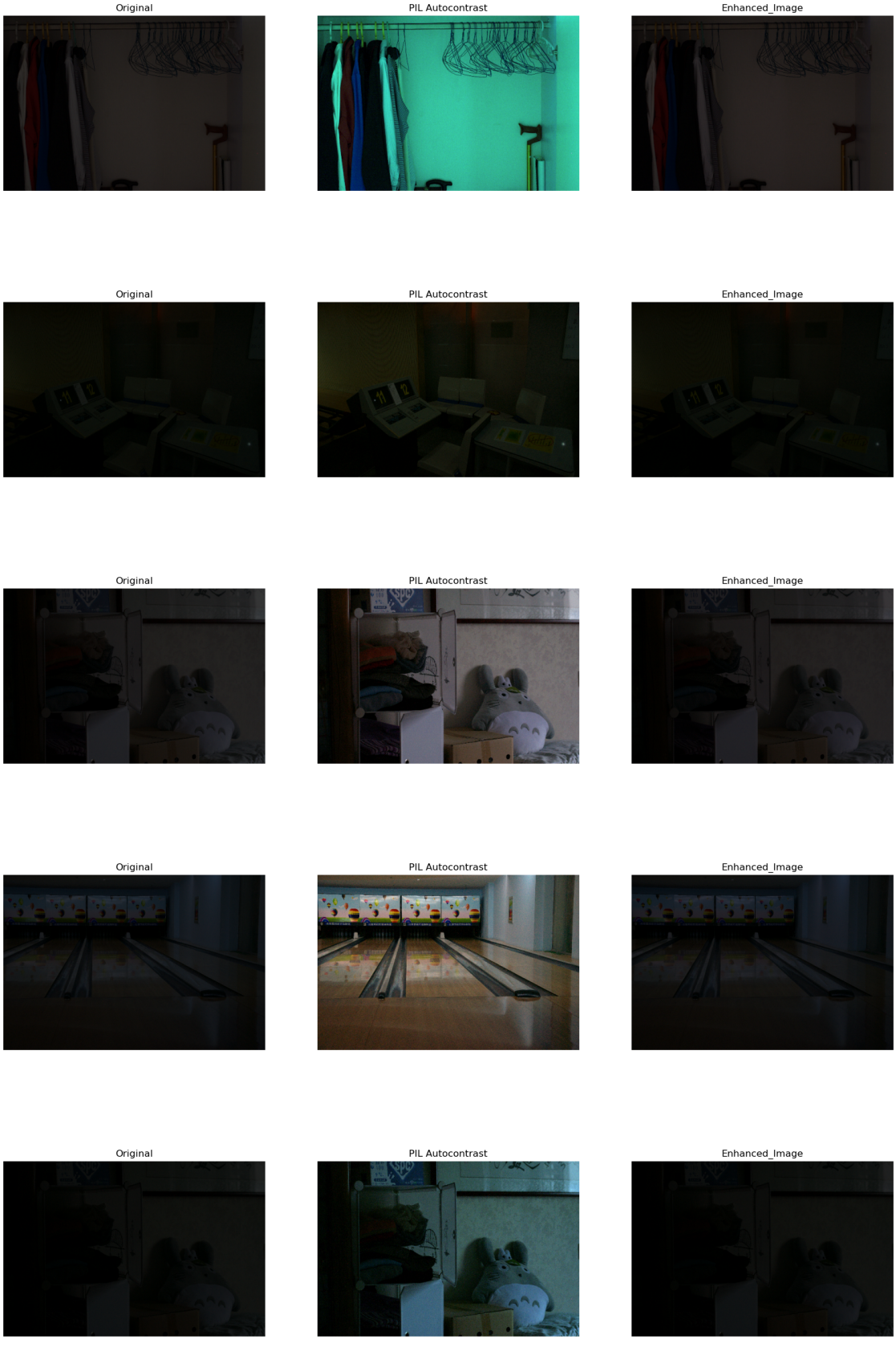

Original
PIL Autocontrast
Enhanced_Image


Original
PIL Autocontrast
Enhanced_Image

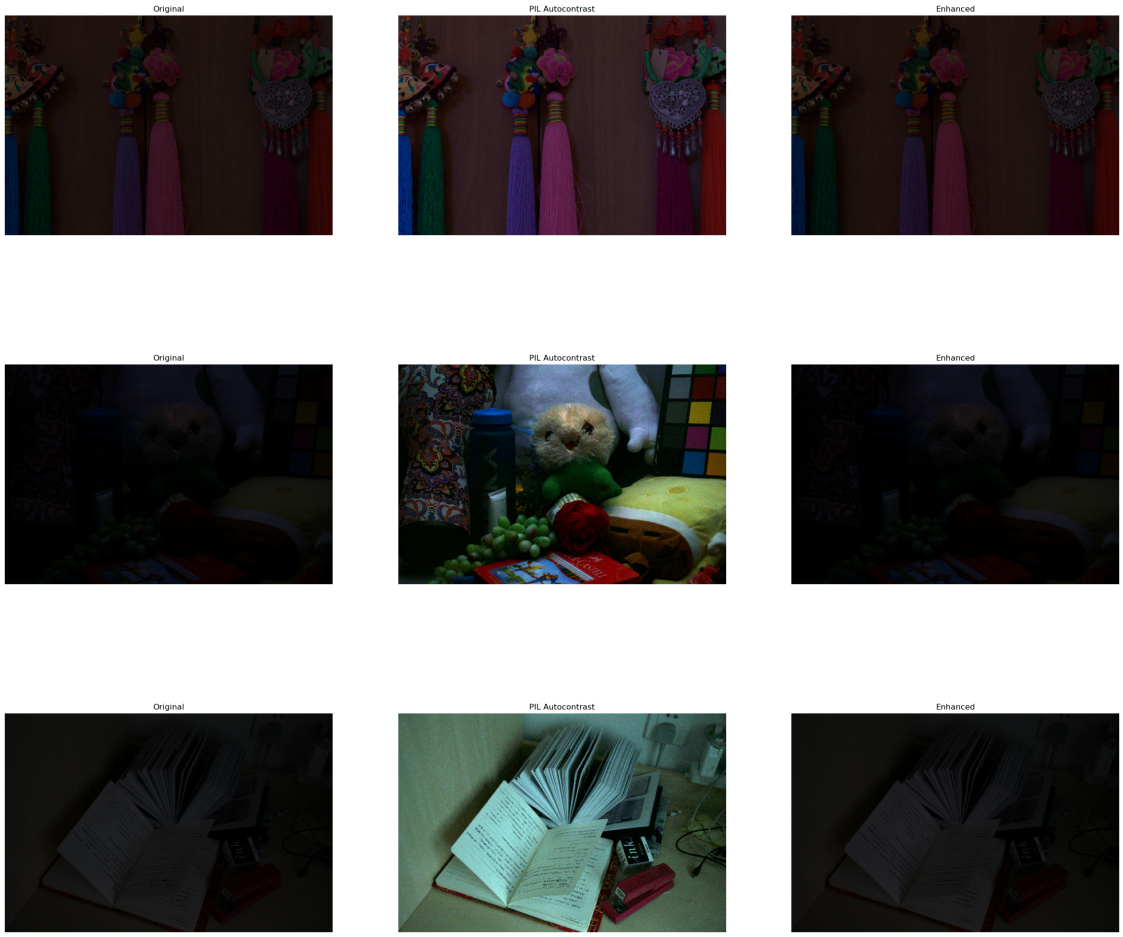

Original
PIL Autocontrast
Enhanced_Image


Original
PIL Autocontrast
Enhanced_Image


Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image


Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image
Original
PIL Autocontrast
Enhanced_Image

[67]:
```
game_of_thrones_images = glob("LOL/test/low/*.png")
for image_file in game_of_thrones_images:
    original_image = Image.open(image_file)
    enhanced_image = infer(original_image)
    plot_results(
        [original_image, ImageOps.autocontrast(Image.fromarray(np.
 ↪array(original_image)[:, :, :3])), enhanced_image],
        ["Original", "PIL Autocontrast", "Enhanced"],
        (30, 22),
    )
```




Original
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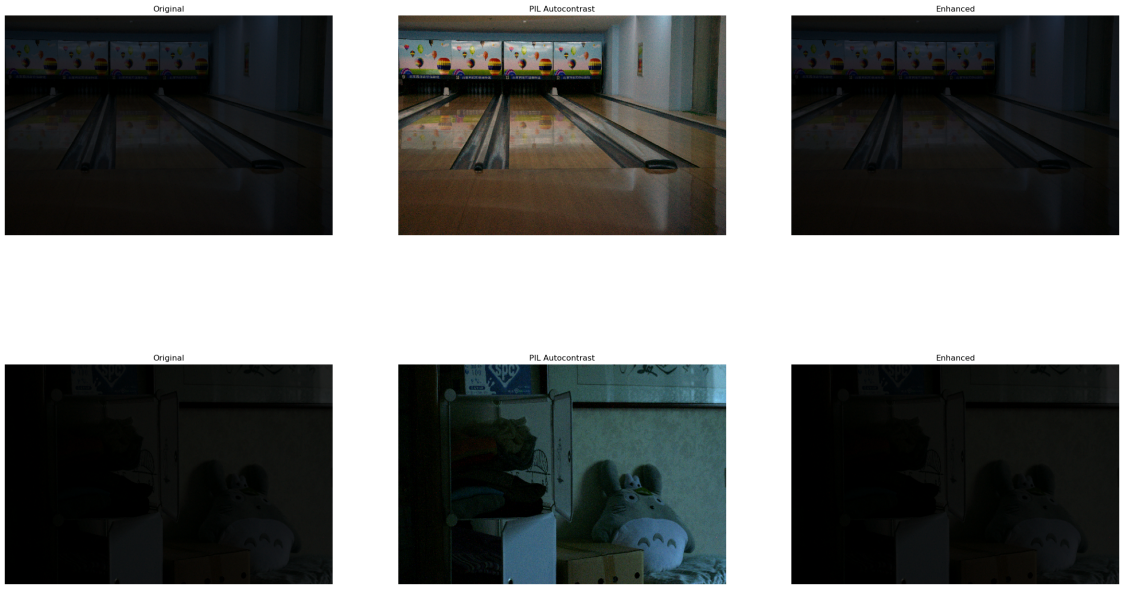
Original
PIL Autocontrast
Enhanced


Original
PIL Autocontrast
Enhanced
Original
PIL Autocontrast
Enhanced

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