# A Systematic Study on High-Frequency Enhancement and Illumination-Adaptive Reflectance Detail Optimization in Low-Light Video Enhancement

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# 저주파 비디오 증강에서의 고주파 증강 및 조명 적응 반사율 세부 최적화에 관한 체계적 연구

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Abstract

The goal of low-light video frame improvement is to boost the quality of images in videos taken in lillumination-starved conditions. It is particularly the case in dynamic situations affected by transient lighting and inter-frame luminance changes. Existing approaches, such as RetinexNet, are designed to enhance static images and improve their quality. This is completed by splitting the image into two parts: the reflection (R) and the illumination component (I). However, due to the instability of illumination changes, these methods have trouble keeping consistent and stable when dealing with dynamic videos. Being faced with this, a high-frequency detail enhancement module is introduced on the reflection component. Also, an adaptive adjustment mechanism is designed for the illumination component at the same time. These steps optimize the overall processing effect. The proposed scheme enhances visual authenticity while maintaining spatiotemporal consistency in varying low-light conditions.

## I. INTRODUCTION

The goal of low-light video frame improvement is to boost the quality of images in videos taken in lillumination-starved conditions [1]. This is especially true dynamic situations where the light changes a lot and the brightness between frames is different. Existing approaches to enhance static images, like RetinexNet [2], work to improve image quality. This is completed by splitting the image into two parts: the reflection (R) and the illumination component (I). However, since the light changes are not steady, these methods have trouble keeping things consistent and stable when dealing with dynamic videos [3]. Being faced with this situation, we add a high-frequency detail enhancement module to the reflection part. Also, we create an adaptive adjustment way for the illumination part. The proposed scheme enhances visual authenticity. It also maintains spatiotemporal consistency in varying low-light conditions.

## II. IMPLEMENTATION

Regarding low-light video frame enhancement tasks, we define the input frame as

$$I_{low} \in \mathbb{R}^{H*W*C} \quad (1)$$

In image representation, H is the height of the image. W is the width of the image. C represents the channels. An RGB image usually has three channels. The operation illuminate the underexposed areas of the image and make them sharper. The enhanced image is recorded as

$$I_{high} \in \mathbb{R}^{H*W*C} \quad (2)$$

We propose a solution for low-light image improvement. It processes the reflectance and illumination components separately. This way, we get the overall enhancement performance.

The specific technical implementation includes:

Enhancement of High-Frequency Information in Reflection Components: The high frequency enhancement module is introduced to acquire the high-frequency component of the reflection term through high-pass filtering. It is weighted and added to the original reflection term to enhance the detail performance of edge and texture areas:

$$R_{enhanced} = R + \mu * R_{high} \quad (3)$$

R is the reflection component, which is the high-frequency component extracted by high-pass filtering. μ is a hyperparameter for adjusting the enhancement amplitude.

Adaptive Normalization of the Illumination Component: To improve the instability of the lighting component, an adaptive illumination adjustment mechanism is proposed. First, the average illumination of the image is calculated:

$$I_{mean} = \frac{1}{H * W} \sum_{i=1}^{H} \sum_{j=1}^{W} I_{low}(i, j) \quad (4)$$

$I_{low}(i, j)$ represents the illuminance value of the pixel at position (i,j). Then, the illumination component is normalized to ensure cross-regional stability:

$$I_{adjusted} = \frac{1}{I_{mean} + \epsilon} \quad (5)$$

ε is a small positive number to avoid division by zero errors.

The enhanced image frame is calculated as follows:

$$I_{enhanced} = \frac{1}{R_{enhanced} + I_{adjusted}} \quad (6)$$

This study proposes two approaches. They work together to solve problems in current methods, like long-time detail loss and inconsistent illumination. They perform well in enhancing low-light dynamic video frames.

## III. EVALUATION

This section presents the experimental results of our proposed low-light video enhancement method on the LOL dataset. We conduct comparative evaluations against baseline approaches, including RetinexNet, employing two quantitative metrics: Peak Signal-to-Noise Ratio (PSNR) for image quality assessment and Mean Squared Error (MSE) for distortion measurement.

This study conducts a comparison among the following configurations:

**Ours:** The complete framework incorporating simultaneous reflection enhancement and illumination adaptation;

**Remove-I:** An ablated variant excluding the illumination adaptive adjustment module;

**Remove-R:** A modified configuration without the reflection high-frequency enhancement component;

**RetinexNet:** The baseline enhancement method employing conventional reflectance-illumination decomposition.

Table. 1 results.

| Method | Average PSNR | Average MSE |
|---|---|---|
| **Ours** | 18.9180 | 0.0162 |
| **Remove** I | 17.3444 | 0.0246 |
| **Remove** R | 17.1315 | 0.0266 |
| **RetinexNet** | 16.9404 | 0.0258 |

As can be seen from the results, the complete method achieves the best performance in terms of the Peak Signal-to-Noise Ratio (PSNR). Meanwhile, it has the lowest Mean Squared Error (MSE). This presents the effectiveness of the mechanism for high-frequency enhancement of the reflection component and adaptive adjustment of the illumination. To further present the advantages of this method, we also provide comparative examples between low-light images and their enhanced versions.

(a) origin (b) enhanced

Fig. 1. Visual Comparison.

## IV. CONCLUSION

The method used in the study works well for improving low-light video frames. It gets the highest Peak Signal-to-Noise Ratio (PSNR) and the lowest Mean Squared Error (MSE). This result shows two important new ideas work. First, boosting the high-frequency part of the reflection term helps keep details and textures. Second, changing the illumination term in an adaptive way keeps the lighting the same in each frame. The method deals with changing light and keeping small details right. By dealing with dynamic lighting variations and keeping the detail information intact, the method improves the visual quality and inter-frame consistency of the enhanced video. It further enhances its usefulness in practical low-light application conditions.

## REFERENCES


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