

An Enhanced HDR Video Quality Assessment Approach Through Luminance Clipping Detection

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Abstract—High Dynamic Range (HDR) video has high luminance range variations that are not handled effectively by existing full-reference video quality assessment (FR-VQA) models, which are designed for SDR and HD content. Existing fusion-based metrics such as the FUNQUE+ framework do not explicitly detect highlight saturation and luminance clipping, leading to inaccurate quality prediction for HDR content. In this work, we extend the FUNQUE+ framework by introducing an HDR-aware luminance clipping module based on PQ-domain brightness analysis. The proposed method detects overexposed regions at the frame level and aggregates clipping severity over time, which is then fused with conventional perceptual features for quality prediction. Experimental results on HDR datasets show improved correlation with subjective human opinion scores for sequences with strong highlight content.

Index Terms—Full-Reference Video Quality Assessment (FR-VQA), High Dynamic Range (HDR) Video, Luminance Clipping, PQ-Domain Luminance Analysis, FUNQUE+, Perceptual Quality Assessment.

I. INTRODUCTION

High Dynamic Range (HDR) video has become increasingly common in modern multimedia systems due to its ability to represent a wider range of brightness levels compared to Standard Dynamic Range (SDR) content [2]. With the growing use of HDR in streaming platforms and advanced display technologies, accurate video quality assessment has become an important requirement [3]. Objective video quality assessment models are widely used to estimate perceived quality without the need for time-consuming subjective testing [1].

Most existing full-reference video quality assessment (FR-VQA) models were originally developed for SDR or conventional high-definition (HD) video [5]. These models mainly focus on structural and texture-based distortions and have shown reliable performance for limited dynamic range content [1]. However, HDR videos introduce perceptual distortions

that are strongly related to luminance behavior, especially in very bright regions [4]. Effects such as highlight saturation and brightness clipping can lead to visible loss of detail, even when spatial structure appears preserved [6]. Since such luminance distortions are not explicitly modeled, current VQA approaches may fail to accurately reflect human perception for HDR content [3].

In this work, we address this limitation by extending the FUNQUE+ framework with an HDR-aware luminance clipping detection module [11]. The proposed approach performs PQ-domain brightness analysis to identify overexposed highlight regions and models clipping severity both at the frame and video levels [7]. These luminance-based features are then combined with conventional perceptual features within the FUNQUE+ pipeline to improve quality prediction for HDR videos [15].

II. BACKGROUND AND MOTIVATION

Subjective testing is costly and time-consuming; therefore, objective video quality assessment has been widely studied as an alternative [1]. Traditional approaches such as PSNR and SSIM mainly focus on pixel-level fidelity and structural similarity, and often show limited correlation with perceived visual quality [1]. To overcome these limitations, fusion-based models such as VMAF and FUNQUE+ combine multiple perceptual features to improve quality prediction [5]. These methods have demonstrated reliable performance for Standard Dynamic Range (SDR) and conventional high-definition (HD) video content. However, they are primarily developed under limited dynamic range assumptions and mainly target spatial and temporal distortions [3].

High Dynamic Range (HDR) video introduces perceptual characteristics that differ significantly from SDR content due to its extended luminance range [2]. In HDR sequences,

quality degradation frequently appears as brightness clipping and highlight saturation, which can cause noticeable loss of detail in bright regions [4]. Such luminance-related distortions may strongly influence perceived quality even when structural similarity remains high [6]. Since existing video quality assessment models do not explicitly model luminance-domain artifacts, their predictions may deviate from human perception in HDR scenarios [3]. This motivates the need for HDR-aware quality assessment approaches that explicitly analyze luminance clipping effects [10].

III. PROPOSED METHOD

A. System Overview

The proposed method enhances the FUNQUE+ full-reference video quality assessment framework by adding an HDR luminance clipping detection module [12]. For each pair of reference and distorted videos, FUNQUE+ extracts standard perceptual features [13]. Meanwhile, the new module examines brightness clipping in the distorted video. The extracted features are combined and mapped to subjective quality scores using support vector regression (SVR).

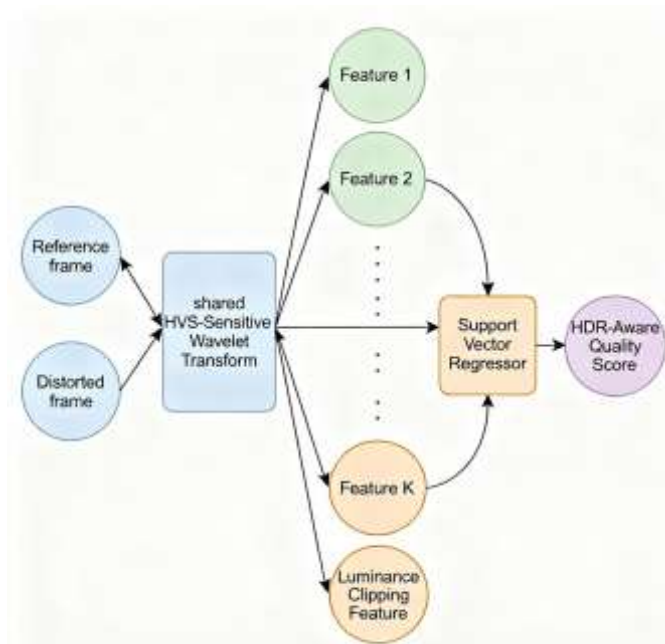


Fig. 1. Proposed HDR Video Quality Assessment Model with an Enhanced Luminance Clipping Feature

B. HDR Luminance Clipping Detection

Brightness clipping in HDR video is a distortion in the luminance domain [4]. The proposed method analyzes the PQ brightness domain [7]. The clipping detection process has five main stages, described below.

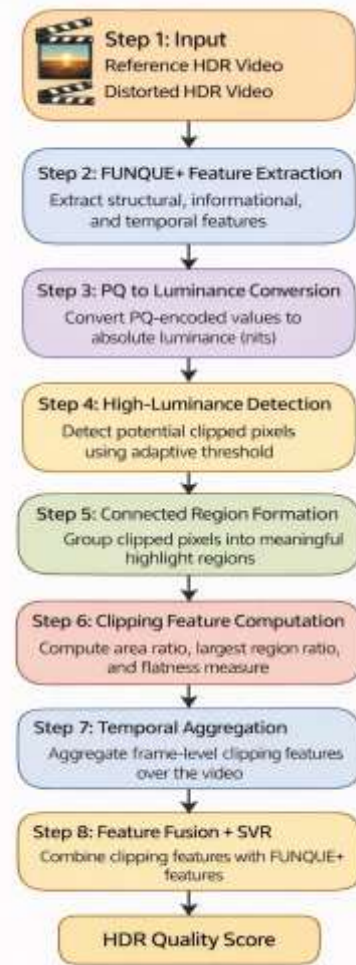


Fig. 2. Proposed HDR Video Quality Assessment Framework integrating luminance clipping detection with the FUNQUE+ model for improved perceptual quality prediction.

1) PQ-to-Luminance Conversion

HDR content is usually encoded with the Perceptual Quantizer (PQ) transfer function [7]. The PQ electro-optical transfer function (EOTF) converts normalized luma values into absolute luminance in nits:

$$L = EOTF_{PQ}(V) \quad (1)$$

where V denotes the normalized PQ-encoded luma value and L represents the corresponding absolute luminance expressed in nits.

2) High-Luminance Pixel Detection

An adaptive threshold is applied to detect pixels with very high luminance values, which are treated as potential clipped pixels [6].

3) Connected Region Formation

Connected component analysis groups nearby saturated pixels into coherent highlight regions, while small isolated compo-

nents are removed to retain perceptually meaningful clipped areas [10].

4) Clipping Feature Computation

From the detected regions, several spatial descriptors are calculated. These include the clipped area ratio, the number of clipped regions, the largest region ratio, and a flatness measure based on luminance gradients. These features reflect both the spatial extent and perceptual severity of highlight clipping [6].

$$S_f = \alpha A_f + \beta R_f + \gamma F_f \quad (2)$$

where A_f denotes the clipped area ratio, R_f represents the largest clipped region ratio, and F_f corresponds to the flatness measure. The weighting factors α , β , and γ control the contribution of each component.

5) Temporal Aggregation

Frame-level clipping features are summarized over time using statistical measures such as the mean and the 95th percentile. In addition, the proportion of frames exhibiting noticeable clipping is computed to characterize persistent luminance degradation [8].

C. Feature Integration with FUNQUE+

The combined clipping features are added to the original FUNQUE+ feature set to create an HDR-aware representation [11]. These features are then used to predict subjective mean opinion scores using support vector regression (SVR) [14]. By including luminance clipping information, the proposed approach becomes more sensitive to HDR-specific brightness distortions while maintaining the structure of the original FUNQUE+ framework [15].

IV. COMPARATIVE ANALYSIS

To study the effect of the proposed luminance clipping extension, a comparison is carried out between the original FUNQUE+ framework and the enhanced HDR-aware version. Both methods are evaluated on an HDR dataset using the same experimental setup [8].

The evaluation is performed using commonly used objective metrics, namely Pearson Linear Correlation Coefficient (PLCC), Spearman Rank-Order Correlation Coefficient (SROCC), and Root Mean Square Error (RMSE) [9]. The obtained results for the combined HDR dataset are reported in Table I.

TABLE I
QUANTITATIVE COMPARISON OF BASELINE AND PROPOSED MODELS ON HDR DATASET

Model	Median PCC ↑	Median SROCC ↑	Median RMSE ↓
FUNQUE+ (Baseline)	0.7428	0.7038	19.68
FUNQUE+ + Brightness Clipping (Proposed)	0.8637	0.8863	11.82

From the results, it can be observed that the proposed method shows improved correlation with subjective mean

opinion scores when compared to the baseline FUNQUE+ framework. A noticeable reduction in prediction error is also obtained. This improvement is mainly due to the inclusion of luminance clipping features, which allow the model to better handle brightness distortions present in HDR videos. Such distortions are especially visible in sequences containing strong highlights or overexposed regions, where conventional perceptual features alone are often insufficient.

V. RESULTS

The results indicate that incorporating luminance-aware modeling improves perceptual consistency in HDR video quality assessment. In particular, quality prediction becomes more aligned with human judgment for content containing strong brightness variations, where conventional approaches often struggle.



Fig. 3. Processing flow for luminance clipping detection: (a) original input image, (b) detected high-luminance (clipped) regions, and (c) luminance clipping highlighted on the original image.

In HDR sequences, perceptual degradation frequently occurs in highly luminous regions such as light sources, reflections, and overexposed highlights. Under such conditions, structural similarity measures may remain relatively stable, even though perceived visual quality is noticeably reduced. Since the original FUNQUE+ framework primarily relies on structural and texture-based perceptual features, it may not sufficiently capture degradations caused by extreme luminance behavior.

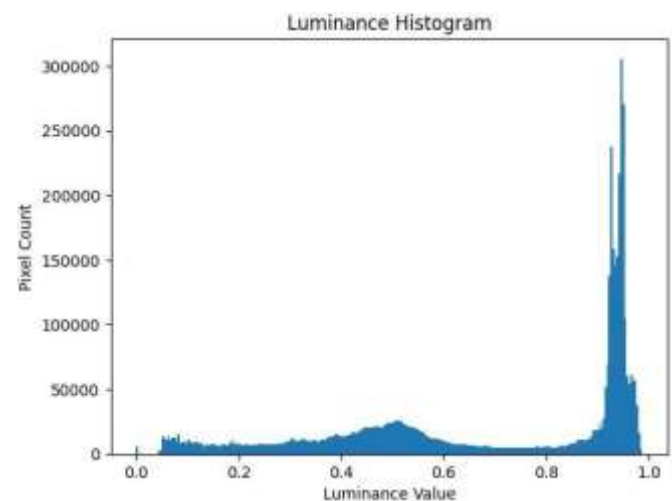


Fig. 4. Visualization of luminance clipping detection results.

By explicitly modeling luminance clipping artifacts through PQ-domain analysis, the proposed method becomes more

responsive to brightness saturation effects that are critical to HDR perception. The spatial extent and severity of clipped regions provide complementary information that enhances quality prediction reliability. Overall, these findings confirm that incorporating luminance-domain features improves the effectiveness of FUNQUE+ when applied to HDR video content.

VI. CONCLUSION

This work focused on the limitations of current full-reference video quality assessment models when applied to High Dynamic Range (HDR) content. Most traditional metrics, including fusion-based methods such as FUNQUE+, are primarily designed for Standard Dynamic Range (SDR) and High Definition (HD) video. As a result, they do not adequately account for luminance behavior and highlight distortions that are crucial for HDR perception. To address this limitation, an HDR-aware extension of the FUNQUE+ framework was proposed, incorporating a luminance clipping feature to capture brightness saturation and overexposed regions in PQ-encoded video.

Evaluation on HDR content showed consistent improvements in correlation with subjective quality scores compared to the original FUNQUE+ framework. These gains confirm that considering HDR-specific luminance distortions leads to improved perceptual alignment, particularly for sequences affected by strong highlight saturation.

In summary, the proposed HDR-extended FUNQUE+ framework provides a more reliable and perceptually meaningful approach for assessing modern high-luminance video content.

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