Paper

Study of No-Reference Video Quality Metrics for HEVC Compression

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Abstract—The paper proposes a No-Reference (NR) quality assessment measurement originally developed for H.264, used for High Efficiency Video Coding (HEVC). In particular, authors present an investigation of NR metrics to objectively estimate the perceptual quality of a set of processed video sequences. The authors take into account typical distortions introduced by the block-based coding approaches like HEVC codec. The underlying processing used for the quality assessment considers the blockiness caused by the boundaries of each coded block and the blurring as a lack of spatial details. The correlation between the NR quality metrics and the well-known and most widely used objective metric, the Video Quality Model (VQM), is performed to validate the quality prediction accuracy based on the provided scores. The Pearson correlation coefficients obtained stand for promising results for different types of videos.

Keywords—High Efficiency Video Coding, No-Reference metrics, Quality of Experience, Video Quality Assessment.

1. Introduction

In addition to traditional Quality of Service (QoS), Quality of Experience (QoE) poses a real challenge for Internet service providers, audiovisual services, broadcasters, and new Over-The-Top (OTT) services. The leading operators have to solve the problem of accurate QoE prediction since the end-user satisfaction is a real added value in the market competition. QoE tools should be proactive and provide innovative solutions that are well adapted for new audiovisual technologies. Therefore, objective audiovisual metrics are frequently dedicated to monitoring, troubleshooting, investigating, and setting benchmarks of content applications working in real-time or off-line.

To advance the field of video quality assessment, Video Quality Experts Group (VQEG) performs subjective video quality experiments, validates objective video quality models, and collaboratively develops new techniques. VQEG proposed to monitor audio visual quality by Key Performance Indicators (KPI), which are able to isolate and focus investigation, set-up algorithms, increase the monitoring period, and guarantee good prediction of video quality. It is known that, depending on the technologies used in audiovisual services, the impact of QoE can change completely. So, based on that proposed concept, it is possible to select the best algorithms and activate or switch off features in a default audiovisual perceived list. The scores are separated for each algorithm and preselected before the testing phase. Then, each artifact KPI can be analyzed by working on the spatially and/or temporally perceived axes [1].

The proposed concept is an interesting approach because it can detect the artifacts present in videos, as well as predict the quality as described by consumers. In realistic situations, when video quality decreases in audiovisual services, customers can call a helpline to describe the annoyance and visibility of the defects or degradations in order to describe the outage. In general, they are not required to provide a Mean Opinion Score (MOS). As such, the concept is completely in phase with user experience. There are many possible reasons for video disturbance, and they can arise at any point along the video chain transmission (filming stage to end-user stage).

VQEG experiments were carried out over several steps with experimental set-ups for concept verification. The impairments included in the experiments were limited to MPEG-2 and H.264. Nevertheless, in year 2013, the first version of the High Efficiency Video Coding (HEVC) standard was completed, approved, and published. HEVC is a video compression standard, a successor to H.264/MPEG-4 AVC (Advanced Video Coding), which was jointly developed by the ISO/IEC JTC 1/SC 29/WG 11 Moving Picture Experts Group (MPEG) and ITU-T SG16/Q.6 Video Coding Experts Group (VCEG) as ISO/IEC 23008-2 MPEG-H Part 2 and ITU-T H.265 [2], [3].

In this paper, the experiments carried out over several steps with an HEVC experimental set-up for the proposed concept verification are presented.

The remainder of this paper is structured as follows. Section 2 is devoted to the state-of-the-art background. Section 3 discusses NR video quality assessment. Section 4 presents objective video quality methods. Section 5 analyses results on KPI. Section 6 discusses further work and summarizes the paper.

2. Related Works

This section presents brief survey of current NR approaches for standardized models together with their limitations. Most of the models in ITU-T recommendations were validated on video databases that used one of the following hypotheses:

- frame freezes lasting up to 2 s,
- no degradation at the beginning or at the end of the video sequence; no skipped frames,
- clean video reference (no spatial or temporal distortions),
- minimum delay supported between video reference and video (sometimes with constant delay),
- up or down-scaling operations not always taken into account [4].

As mentioned earlier, most quality models are based on measuring common artifacts/KPI, such as blur, blocking, and jerkiness, for producing a prediction of the MOS. Consequently, the majority of the algorithms generating a predicted MOS show a mix of blur, blocking, and jerkiness metrics. The weighting between each KPI could be a simple mathematical function. If one of the KPIs is not correct, the global predictive score is completely wrong. Other KPIs mentioned by VQEG are usually not taken into account (exposure time distortion, noise, block loss, freezing, slicing, etc.) in predicting MOS [4]. ITU-T has been working on similar distortions for many years [5]. However, only for Full-Reference (FR) and Reduced-Reference (RR) approaches. The history of the ITU-T Recommendations for video quality metrics is shown in Table 1. Table 2 shows a synthesis of the set of standardized metrics that are based on video signals [4]. As can be noticed from both tables, there is a lack of developments for the NR approach.

Table 1
The history regarding ITU-T Recommendations

Model type	Format	Recommendation	Year
FR	SD	J.144 [6]	2004
FR	QCIF–VGA	J.247 [7]	2008
RR	QCIF–VGA	J.246 [8]	2008
FR	SD	J.144 [6]	2004
RR	SD	J.249 [9]	2010
FR	HD	J.341 [10]	2011
RR	HD	J.342 [11]	2011
Bitstream	VGA–HD	P.1202 [12]	2013
Hybrid	VGA–HD	J.343 [13]	2014

In a related research, Gustafsson *et al.* [14] addressed the problem of measuring multimedia quality in mobile networks with an objective parametric model [4]. Closely related work are ongoing standardization activities at ITU-T SG12 on models for multimedia and Internet Protocol Television (IPTV) based on bit-stream information. SG12 is currently working on models for IPTV. Q.14/12 is responsible for these projects, provisionally known as non-intrusive parametric model for assessment of performance of multimedia streaming (P.NAMS) and non-intrusive bit-stream model for assessment of performance of multimedia streaming (P.NBAMS) [4]. P.NAMS uses packet-header information (e.g., from IP through MPEG2-TS), while P.NBAMS also uses payload information, i.e., coded bit-stream [15]. However, this work focuses on the overall quality (in MOS units), while the proposed concept is focused on KPIs [4].

Table 2
Synthesis of FR, RR and NR MOS models

Resolution	Type of ITU-T model		
	FR	RR	NR
HDTV	J.341 [10]	n/a	n/a
SDTV	J.144 [6]	n/a	n/a
VGA	J.247 [7]	J.246 [8]	n/a
CIF	J.247 [7]	J.246 [8]	n/a
QCIF	J.247 [7]	J.246 [8]	n/a

Most of the recommended models are based on global quality evaluation of video sequences, as in the P.NAMS and P.NBAMS projects. The predictive score is correlated to subjective scores obtained with global evaluation methodologies (SAMVIQ, DSCQS, ACR, etc.). Generally, the duration of video sequences is limited to 10 or 15 s in order to avoid a forgiveness effect (the observer is un-enable to score the video properly after 30 s and may give more weight to artifacts occurring at the end of the sequence). When one model is deployed for monitoring video services, the global scores are provided for fixed temporal windows and without any acknowledgement of the previous scores [4].

Recently, the interest is oriented toward the HEVC standard, which has proved high efficiency compared to its predecessors. Several tools are introduced in the coding process, such as the increasing number of intra prediction modes and the frequent use of inter coded pictures within a closed Group Of Pictures (GOP). These characteristics ensure an important coding gain relative to the encoding parameters but in the other hand, the complex structure of picture division and the new configurations' models can be the source of certain artifacts. However, very limited works concern the quality assessment approaches for HEVC compression. In particular, the coding parameters and the impact of network losses on the decoder side were investigated [16]. The distortions of HEVC videos are more significant than H.264 videos. The proposed NR distortion measure exploits the spectral densities between the frames and precisely, the energy variation in the temporal domain for each coding unit.

One can bear in mind that FR measures are in general not applicable as the reference content might be not available. In the same vein, the bitstream features were selected to estimate the perceptual quality, including the different prediction modes and statistics of the motion vector [17]. In this method the measures are predicted in a NR manner.

The quality monitoring becomes primordial in communication and broadcasting environments for improving the end user's QoE [18]. A NR Peak Signal-to-Noise Ratio (PSNR) estimation was proposed for such a model [19]. Distributions of transform coefficients are considered based on the quad-tree coding structure and the distortion model was derived according to the coding unit depth level.

The concept of QoE in [20] is used for a practical recognition problem for video transmitted over a network link, where subjective satisfaction of the user is imperative. This latter requires achieving specific functionalities such as even detection and object recognition. The proposed methods measure the usefulness of degraded quality video and the solutions have been proposed to optimize the network QoS parameters.

Designing algorithms for video quality assessment requires a consistent dataset of coded video sequences. For the case of HEVC it is a key factor for an effective performance evaluation of developed metrics, to take advantage of a publicly available database, which includes several compressed versions of different sequences. In [21] Full-Reference measurements are provided with a large database of FULL-HD HEVC encoded videos based on a variety of HEVC compression characteristics.

A variety of NR quality estimation methods exist for the AVC videos but on the other side, widely used examples such pixel-based approaches are still not applied or tested for the HEVC compressed videos.

3. No-Reference Video Quality Assessment

In this section, NR measurement techniques in the spatial domain for two KPI are proposed: blur and blockiness. Assuming that we do not own a knowledge and assumptions of the original content or the distortion process of the HEVC compression. In fact, the NR pixel-based approach for measuring artifacts of the visual quality is proposed by considering a given model of degradation to investigate the performance of the mentioned metrics.

3.1. No-Reference Blockiness Metric

The same approach is used for calculating the blockiness artifact published in [22]. It is calculated locally for each coding block. Absolute differences in pixel luminance were calculated separately for intra-pairs, represented by neighboring pixels from a single coding block, and inter-pairs, represented by pixels from neighboring blocks. A ratio between the total values of intra- and inter-differences is calculated over the entire video frame. For a real time application the metric should be calculated over a time window (the number of video frames). Mean value for the window represents a blockiness level. For the purposes of the experiment the window size was equal to the sequence length (10 s). It was verified that the level of the blockiness artifact does not change significantly over time within the same video scene. Thus, any other window size or different method for temporal pooling would yield similar results.

3.2. No-Reference Blur Metric

The blurred image in compression techniques appears when high spatial frequency components of the image spectrum are truncated. For instance, possible reasons of blurring can be out-of-focus capturing or relative motion between the camera and the captured object. Besides, high compression performance can introduce blur when processing the data of images' sequence. Perceptually, the blur artifact appears along edges and textured regions. In this work, the width of the edges is measured in order to characterize smoothing blur effect [23]. First, the Sobel filter as an edge detector is applied to find the gradient of the image. It is obvious that below a certain threshold, blur remains as just noticeable and visually unperceived. According to that threshold, the pixels being the part of the edges are differentiated. Then the width of an edge is measured, depending on its growth direction (left or right). Finally, the global blur value is obtained by averaging over all edges of the whole image.

4. Objective Video Quality Methods

Huge variety of proposed works concerning the video quality measurement use the objective metrics such as the simplest and commonly used ones: the PSNR and Mean-Squared Error (MSE). But in general, it is not ensured that error visibility would always the appearance of quality artifacts for most of distortions. Assuming that the structural information is highly captured from the viewing field by the human visual system, extracting this kind of information provides a good estimation of the perceived distortion. Therefore, the Structural Similarity (SSIM) has been used recently to characterize complex structured signals [24].

However, the different types of video coding and transmission systems require a more general model that covers a wide range of quality degradations. In fact an extensive objective and subjective tests should be performed to provide an effective perceptual measurement. The Video Quality Model (VQM) was indeed proposed by the Institute for Telecommunication Science (ITS) [25] and standardized by the American National Standards Institute (ANSI). It was further included in Draft Recommendations from ITU-T SG9. The VQM has proved a good performance for measuring perceptual effects of different types of video impairments such as blurring, jerkiness and block distortion. The calculation of VQM taking as input the original and processed videos follows these main steps:

- calibrate the processed video with respect to the original sequence by estimating and correcting the spatial-temporal shifts, as well as adjusting the contrast and brightness,

- extract a set of quality features to characterize perceptual changes from particular spatial-temporal regions in the video stream; for instance, in the chrominance, temporal and spatial properties,
- compare the extracted features form the processed video with those of the original sources,
- conclude the VQM value using a linear combination of the obtained parameters.

From the described functions, it makes sense that the VQM has a high correlation with subjective scores, which makes us believe that using it as a reference metric would provide accurate testing results.

5. Experiments and Results

In order to effectively evaluate the video quality based on HEVC compressions, the dataset of the project developed by the Joint Effort Group (JEG) of Video Quality Experts Group (VQEG) is used [21]. It presents a large-scale database of HEVC coded videos for researchers involved in designing hybrid quality metrics. Different encoding parameters were performed on ten sequences representing different characteristics. Among interesting benefits of the mentioned dataset, objective quality measurements are provided at frame-level granularity. This database is exploited by applying the NR metrics of blur and blockiness. It is primordial to investigate the accuracy of these metrics for the HEVC distortions and make useful interpretations about the specificities of the target approach.

5.1. Selected Compression Parameters

The performance of the quality metrics is investigated based on a diverse set of encoding parameters. Table 3 presents the retained HEVC configurations in order to carry out tests over an increasing data compression. The distortion is intrinsically related to the following values selected from the adopted database [21].

Table 3
Encoding parameters

Parameter	Value
WIDTH	1280
GOPTYPESIZE	GOP8
RATECONTROL_QP	26, 32, 38, 46
RATECONTROL_FRAME_mbit/s	1, 2, 4, 8, 16
REFRESH	1
INTRAPERIOD	16
SLICEARGUMENT	0

The resolution of the ten original sources is 1280×720 pixels. The authors take into account all available fixed QP values as it represents a basic distortion source along with the frame rate control. The refresh number corresponds to the decoding refresh type, to apply a non-IDR clean random access point. This encoder option allows the use of an open GOP. The slicing value signifies one slice per frame. As a result, 90 processed video sequences are generated based on the above parameters. The prior-knowledge of these settings is not considered in developing the NR metrics and authors just provide it for a precise description of the compression rate and consequently the distortion strength.

5.2. Results and Analysis

Table 4 displays the results of the applied metrics on the ten processed videos. For each sequence, the Pearson correlation coefficient is used to validate the performance of the blur and blockiness measurements relative to the VQM values, offered by the JEG project for each encoded sequence according to the given parameters. From the shown results, the efficiency of the blur metric is confirmed for each source which means that the distorted edges are well predicted, providing high correlation values. It is further clear that the blockiness metric works well for the majority of the sources.

Table 4
Pearson correlation coefficients with VQM

Source	Blockiness	Blur
*src*01	–0.67	1.00
*src*02	–0.97	0.91
*src*03	–0.97	0.96
*src*04	–0.77	0.99
*src*05	–0.87	0.99
*src*06	–0.57	0.91
*src*07	–0.96	0.96
*src*08	–0.95	0.92
*src*09	–0.36	0.95
*src*10	0.69	0.99

The authors mention here that the origin of the negative scores is caused by the metric's construction, as increasing the compression rate corresponds to lower values of blockiness and vice versa. However, the correlation tends to drop for the case of src09 due to the complex nature of the motion and spatial activity in the video. Src09 consists of several combined shots separated with a black-pixels frame. Besides, the positive correlation of the src10 means that the trends of values are opposite to the expected ones.
The scatter plots in Figs. 1 and 2, representing the blockiness and blur metrics for all sequences, respectively, reveal a partial success even the measures are convincing for each source separately. The global correlation coefficient of blockiness is 0.55 whilst 0.23 for blur, which gives rise to useful interpretations for a more complete evaluation ap-

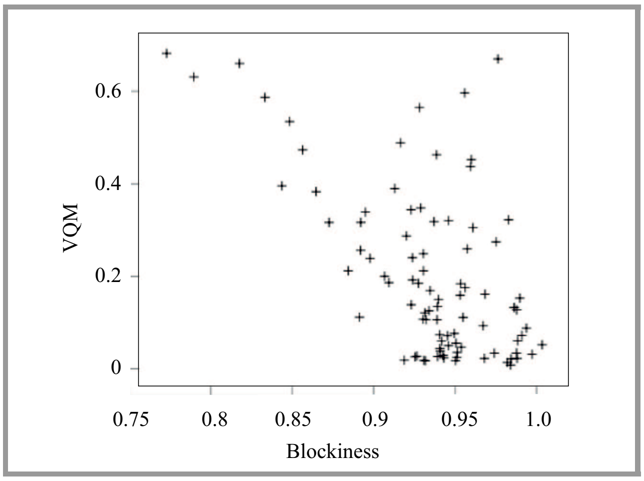

Fig. 1. Correlation with VQM for blockiness.

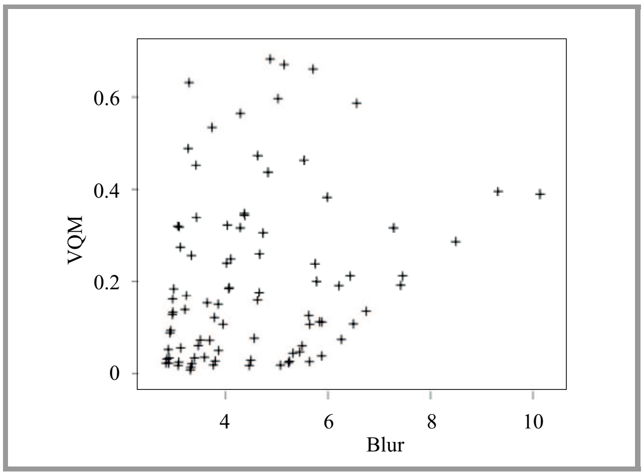

Fig. 2. Correlation with VQM for blur.

proach. The temporal and spatial inconsistency could be incorporated to overcome such problems.

6. Conclusion and Further Work

In case of pixel-based NR methods, an accurate model which combines different kind of artifacts would generate an estimation of the perceptual quality using weighting factors. The strength of weights, which could be determined by a regression analysis, is computed with respect to a particular single metric. This latter is combined to another distortion measure, based on a linear or non-linear model. Furthermore, even the VQM measurement combines several features and represents with a certain precision perceptual characteristics, implicating subjective scores in the assessment process still more effective. For instance, correctness functions such as sigmoid model, can be applied on the predicted measures according to the subjective evaluation as it requires parameters' estimation.

The HEVC specificities as the highly flexible quad-tree structure and effective prediction tools allow an accurate exploitation of the video content in addition to the high compression performance. Assessing quality of HEVC processed videos for different types of distortions require sophisticated techniques for a successful NR approach. In this work, the proposed metrics as a basic step to establish a completing framework of quality assessment are analyzed, taking into consideration particular aspects introduced in this new codec.

Acknowledgments

The work was co-financed by The Polish National Centre for Research and Development (NCBR), as a part of the EUREKA Project no. C 2012/1-5 MITSU and contract number 11.11.230.018. This research was further supported by the Bureau For Academic Recognition and International Exchange.

References

[1] M. Leszczuk, M. Hanusiak, M. Farias, E. Wyckens, and G. Heston, "Recent developments in visual quality monitoring by key performance indicators", *Multimed. Tools & Appl.*, pp. 1–23, 2014 [Online]. Available: http://dx.doi.org/10.1007/s11042-014-2229-2

[2] G. Sullivan, J. Ohm, W. J. Han, and T. Wiegand, "Overview of the high efficiency video coding (HEVC) standard", *IEEE Trans. Circ. Syst. Video Technol.*, vol. 22, no. 12, pp. 1649–1668, 2012.

[3] ITU-T Recommendation H.265, "High efficiency video coding", 2015 [Online]. Available: http://www.itu.int/rec/T-REC-H.265

[4] M. Leszczuk, M. Hanusiak, I. Blanco, A. Dziech, J. Derkacz, E. Wyckens, and S. Borer, "Key indicators for monitoring of audiovisual quality", in *Proc. 22nd Sig. Process. Commun. Appl. Conf. SIU 2014*, Trabzon, Turkey, 2014, pp. 2301–2305.

[5] ITU-T Recommendation P.930, "Principles of a reference impairment system for video", 1996 [Online]. Available: http://www.itu.int/rec/T-REC-P.930-199608-I

[6] ITU-T Recommendation J.144, "Objective perceptual video quality measurement techniques for digital cable television in the presence of a full reference", 2004 [Online]. Available: http://www.itu.int/rec/T-REC-J.144-200403-I

[7] ITU-T Recommendation J.247, "Objective perceptual multimedia video quality measurement in the presence of a full reference", 2008 [Online]. Available: http://www.itu.int/rec/T-REC-J.247-200808-I

[8] ITU-T Recommendation J.246, "Perceptual visual quality measurement techniques for multimedia services over digital cable television networks in the presence of a reduced bandwidth reference", 2008 [Online]. Available: http://www.itu.int/rec/T-REC-J.246-200808-I

[9] ITU-T Recommendation J.249, "Perceptual video quality measurement techniques for digital cable television in the presence of a reduced reference", 2010 [Online]. Available: http://www.itu.int/rec/T-REC-J.249-201001-I

[10] ITU-T Recommendation J.341, "Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a full reference", 2011 [Online]. Available: http://www.itu.int/rec/T-REC-J.341-201101-I

[11] ITU-T Recommendation J.342, "Objective multimedia video quality measurement of HDTV for digital cable television in the presence of a reduced reference signal", 2011 [Online]. Available: http://www.itu.int/rec/T-REC-J.342-201104-I

[12] ITU-T Recommendation P.1202, "Parametric non-intrusive bitstream assessment of video media streaming quality", 2013 [Online]. Available: http://www.itu.int/rec/T-REC-P.1202

[13] ITU-T Recommendation J.343, "Hybrid perceptual bitstream models for objective video quality measurements", 2014 [Online]. Available: http://www.itu.int/rec/T-REC-J.343

[14] J. Gustafsson, G. Heikkila, and M. Pettersson, "Measuring multimedia quality in mobile networks with an objective parametric model" in *Proc. 15th IEEE Int. Conf. Image Process. ICIP 2008*, San Diego, CA, USA, 2008, pp. 405–408.

[15] A. Takahashi, K. Yamagishi, and G. Kawaguti, "Global standardization activities recent activities of QoS/QoE standardization in ITU-T SG12", *NTT Tech. Rev.*, vol. 6, no. 9, pp. 1—5, 2008.

[16] M. Aabed *et al.*, "No-reference quality assessment of hevc videos in loss-prone networks", in *Proc. IEEE Int. Conf. Acoust., Speech Sig. Process. ICASSP 2014*, Florence, Italy, 2014, pp. 2015–2019.

[17] M. Shahid, J. Panasiuk, G. Van Wallendael, M. Barkowsky, and B. Lövström, "Predicting full-reference video quality measures using hevc bitstream-based no-reference features", in *Proc. 7th Int. Worksh. Quality of Multimed. Exper. QoMEX 2015*, Costa Navarino, Messinia, Greece, 2015.

[18] N. Staelens, S. Moens, W. Van den Broeck, I. Marien, B. Vermeulen, P. Lambert, R. Van de Walle, and P. Demeester, "Assessing quality of experience of IPTV and video on demand services in real-life environments", *IEEE Trans. Broadcast.*, vol. 56, no. 4, pp. 458–466, 2010.

[19] B. Lee and M. G. Kim, "No-reference psnr estimation for hevc encoded video", *IEEE Trans. Broadcast.*, vol. 59, no. 1, pp. 20–27, 2013.

[20] L. Janowski, P. Kozłowski, R. Baran, P. Romaniak, A. Głowacz, and T. Rusc, "Quality assessment for a visual and automatic license plate recognition", *Multimed. Tools & Appl.*, vol. 68, no. 1, pp. 23–40, 2014.

[21] G. Van Wallendael, N. Staelens, E. Masala, and M. Barkowsky, Full-HD HEVC-encoded video quality assessment database", in *Proc. 9th Int. Worksh. Video Process. Quality Metrics VPQM 2015*, Chandler, AZ, USA, 2015.

[22] M. Mu, P. Romaniak, A. Mauthe, M. Leszczuk, L. Janowski, and E. Cerqueira, "Framework for the integrated video quality assessment", *Multimed. Tools & Appl.*, vol. 61, no. 3, pp. 787–817, 2012.

[23] E. Cerqueira, L. Janowski, M. Leszczuk, Z. Papir, and P. Romaniak, "Video artifacts assessment for live mobile streaming applications", in *Future Multimedia Networking*, A. Mauthe, S. Zeadally, E. Cerqueira, M. Curado, Eds. *LNCS* 5630, pp. 242–247. Springer, 2009.

[24] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: from error visibility to structural similarity", *IEEE Trans. Image Process.*, vol. 13, no. 4, pp. 600–612, 2004.

[25] M. H. Pinson and S. Wolf, "A new standardized method for objectively measuring video quality", *IEEE Trans. Broadcast.*, vol. 50, no. 3, pp. 312–322, 2004.

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