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Title **pVAR: An ultra-low complexity IQA via spatial error variance**
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Abstract

This informative document presents a full-reference objective quality metric **pVAR** based on error variance and psychophysical saturation. Experiments on four VQA and IQA databases show that while preserving computational complexity of PSNR, it outperforms it significantly, reaching efficiency of more complex SSIM and MS-SSIM.

1 The metric

1.1 PSNR basis

The metric is based on PSNR, which by default is calculated as:

$$\mathrm{PSNR} = 10 \cdot \log_{10} \frac{\left(2^b - 1\right)^2}{\mathrm{MSE}},$$

where:

$$\mathrm{MSE} = \frac{1}{H \cdot W} \sum_{y=1}^{H} \sum_{x=1}^{W} \left(R(x,y) - T(x,y)\right)^2,$$

where R and T are compared images. Considering $N = H \cdot W$ and $i = y \cdot H + x$, it can be shown as:

$$\mathrm{MSE} = \frac{1}{N} \sum_{i=1}^{N} e_i^2,$$

where $e_i = R(i) - T(i)$.

1.2 Variance in error calculation

Variance of the error signal e is calculated as:

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (e_i - \mu)^2,$$

where μ is the mean error. After simple conversions, it can be defined as:

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} \left(e_i^2 - 2 \cdot e_i \cdot \mu + \mu^2\right),$$

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} e_i^2 - \frac{1}{N}\sum_{i=1}^{N} 2 \cdot e_i \cdot \mu + \frac{1}{N}\sum_{i=1}^{N} \mu^2,$$

and

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} e_i^2 - 2 \cdot \mu \cdot \underbrace{\frac{1}{N}\sum_{i=1}^{N} e_i}_{\mu} + \mu^2 \cdot \underbrace{\frac{1}{N}\sum_{i=1}^{N} 1}_{1}.$$

Therefore:

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} e_i^2 - 2 \cdot \mu^2 + \mu^2,$$

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} e_i^2 - \mu^2.$$

1.3 MSE vs. variance

Considering two equations given above:

$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{N} e_i^2, \qquad \sigma^2 = \frac{1}{N}\sum_{i=1}^{N} e_i^2 - \mu^2,$$

MSE can be calculated as:

$$\mathrm{MSE} = \sigma^2 + \mu^2.$$

The first component, variance σ^2 penalizes the spatial error inconsistency.

The second component, squared mean error μ^2 penalizes changes of luminance/brightness:

- HVS adapts to illumination changes by pupil dilation and contrast masking,
- HVS does not consider this change evenly important as the inconsistencies.

Therefore, the metric entirely skips the mean part, and is based solely on the variance.

1.4 Variance in color images/video

For a single color component c variance is calculated as:

$$\sigma_c^2 = \frac{1}{N}\sum_{i=1}^{N} e_{c,i}^2 - \mu_c^2.$$

This calculation, however, requires two passes. One for mean calculation and the other for variance itself. A single pass calculation is defined as:

$$\sigma_c^2 = \frac{1}{N}\sum_{i=1}^{N} e_{c,i}^2 - \left(\frac{1}{N}\sum_{i=1}^{N} e_{c,i}\right)^2.$$

Such a definition requires floating-point implementation, which could be fragile and sensitive on rounding errors. SIMD-friendly, integer-based implementation requires calculation of scaled variance $S_c = N^2 \cdot \sigma_c^2$:

$$S_c = N \sum_{i=1}^{N} e_{c,i}^2 - \left(\sum_{i=1}^{N} e_{c,i} \right)^2.$$

For three component YUV image, the total, global variance is calculated as a weighted average with the same weights (4:1:1) as for IV-PSNR [1] and derivatives:

$$\sigma_{\text{global}}^2 = \frac{4 \cdot S_Y + S_{Cb} + S_{Cr}}{6 \cdot N^2}.$$

1.5 Psychophysical mapping function

The raw global variance σ_{global}^2 scales linearly with signal energy but correlates non-linearly with perceived quality. Moreover, it is counterintuitive – higher values indicate lower quality.

In order to resolve both problems, a mapping function has been proposed:

$$\text{pVAR} = \frac{C}{\sigma_{\text{global}}^2 + C},$$

where C is a stabilizing constant equal to a half of the video/image dynamic range, i.e., $C = 2^{b-1}$.

This function maps the unbounded variance into the range $(0, 1]$.

The proposed mapping function preserves the absolute value of rank-order correlation metrics (SROCC, KROCC), additionally inverting their sign (making them positive), and significantly increases the linearity of correlation (PLCC).

2 The experiment

2.1 Experimental setup

The metric was compared with several SOTA metrics within a single framework – QMIV [2].

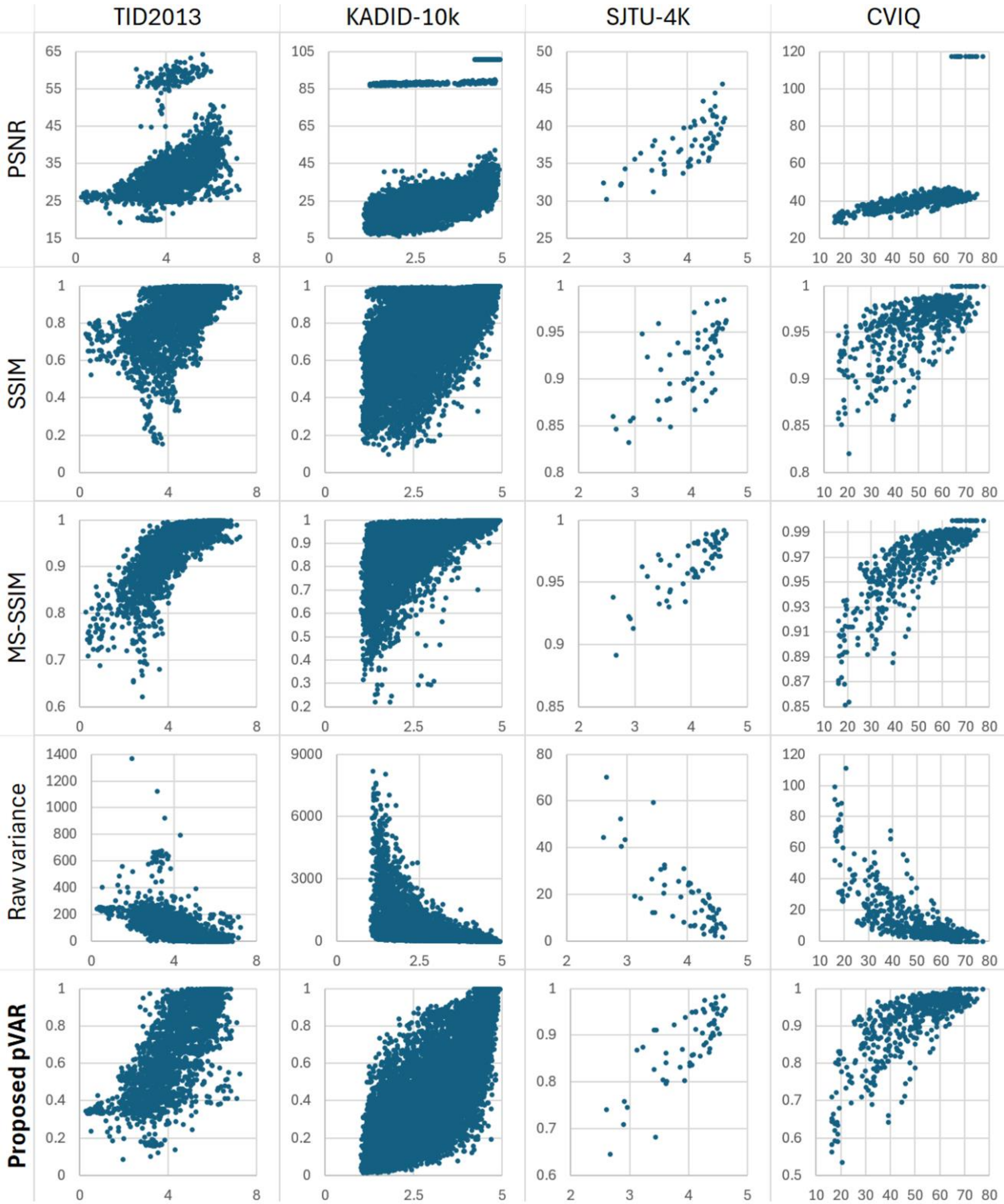
Comparison was performed against four VQA and IQA databases:

- TID2013 – 3000 static images with 24 distortion types, SD resolution,
- KADID-10k – 10000 static images with 25 distortion types, SD resolution,
- SJTU-4K – 60 videos with video compression, 4K resolution,
- CVIQ – 500 static 360° images with image compression, 4K resolution.

Computational time was measured on a 12-core Ryzen 9 7900X processor, on a 4K×4K sequence.

2.2 Correlation with MOS

Metric	TID2013			KADID-10k			SJTU-4K			CVIQ		
	PLCC	KROCC	SROCC	PLCC	KROCC	SROCC	PLCC	KROCC	SROCC	PLCC	KROCC	SROCC
PSNR_Y	0.343	0.470	0.639	0.280	0.430	0.591	0.699	0.560	0.746	0.448	0.570	0.774
PSNR_{YUV}	0.466	0.481	0.665	0.320	0.442	0.607	0.718	0.545	0.732	0.450	0.589	0.788
IV-PSNR	0.672	0.507	0.699	0.541	0.477	0.661	0.770	0.571	0.768	0.528	0.655	0.848
SSIM_Y	0.652	0.462	0.636	0.569	0.418	0.572	0.624	0.475	0.628	0.671	0.495	0.690
SSIM_{YUV}	0.538	0.398	0.569	0.593	0.444	0.614	0.652	0.483	0.641	0.649	0.472	0.663
MS-SSIM_Y	0.779	0.605	0.785	0.603	0.542	0.707	0.750	0.557	0.746	**0.845**	**0.688**	**0.878**
MS-SSIM_{YUV}	**0.790**	**0.624**	**0.824**	0.650	**0.587**	**0.775**	**0.816**	**0.596**	**0.786**	0.831	0.665	0.858
IV-SSIM	0.471	0.353	0.521	0.511	0.399	0.567	0.704	0.501	0.674	0.754	0.604	0.802
IV-MS-SSIM	0.711	0.554	0.756	0.546	0.502	0.691	0.809	0.614	0.802	0.836	0.686	0.874
σ^2_{global} (Raw variance)	-0.599	-0.549	-0.743	-0.502	-0.565	-0.757	-0.789	-0.563	-0.742	-0.723	-0.580	-0.782
pVAR (Proposed)	0.742	0.549	0.743	**0.790**	0.565	0.757	0.789	0.563	0.742	0.768	0.580	0.782



2.3 Average performance

Metric	PLCC	KROCC	SROCC
PSNR_Y	0.443	0.507	0.688
PSNR_{YUV}	0.489	0.514	0.698
IV-PSNR	0.628	0.553	0.744
SSIM_Y	0.629	0.462	0.632
SSIM_{YUV}	0.608	0.449	0.622
MS-SSIM_Y	0.744	0.598	0.779
MS-SSIM_{YUV}	**0.772**	**0.618**	**0.811**
IV-SSIM	0.610	0.464	0.641
IV-MS-SSIM	0.725	0.589	0.781
σ^2_{global} (Raw variance)	-0.653	-0.564	-0.756
pVAR (Proposed)	**0.772**	0.564	0.756

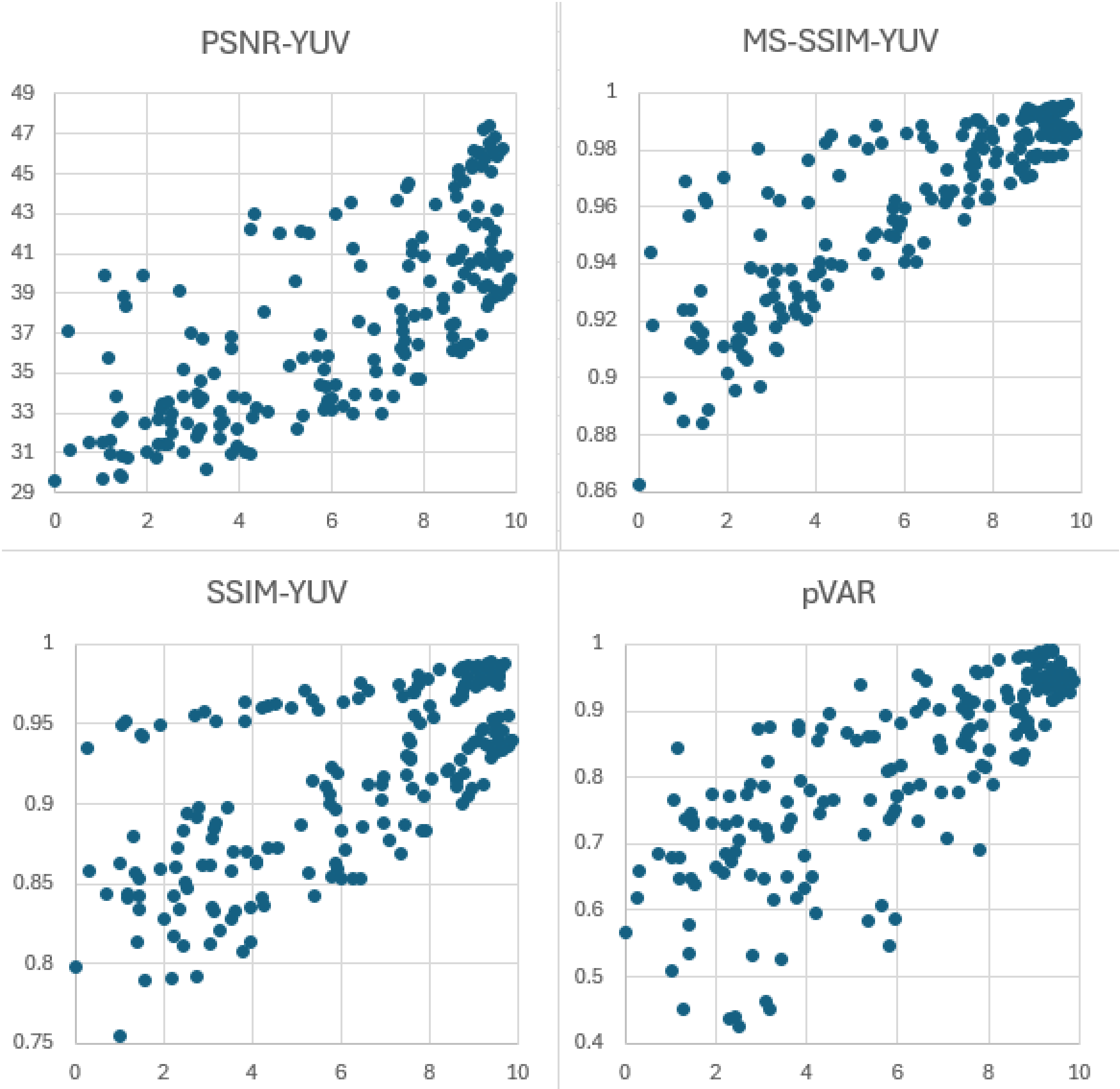
2.4 Computational time (per single 4K×4K frame)

Metric	Single-Thread		Multi-Thread	
	Time (ms)	Relative	Time (ms)	Relative
PSNR_{YUV}	3.80	1.0×	3.45	1.0×
pVAR (Proposed)	**4.20**	≈ 1.1×	**3.71**	≈ 1.1×
SSIM_{YUV}	7082.08	1864×	621.02	180×
MS-SSIM_{YUV}	9385.19	2470×	835.73	242×

3 CVQM database

3.1 HD content

Metric	SROCC	KROCC	PLCC_{raw}	$\text{PLCC}_{\text{mapped}}$	RMSE
PSNR-Y	0.7635	0.5589	0.7443	0.7653	1.8794
PSNR-YUV	0.7512	0.5559	0.7263	0.7601	1.8973
IV-PSNR	0.7869	0.5867	0.7732	0.8043	1.7351
SSIM-Y	0.6957	0.5045	0.7113	0.7131	2.0469
SSIM-YUV	0.6656	0.4877	0.6833	0.6934	2.1041
IV-SSIM	0.7019	0.5052	0.7189	0.7249	2.0115
MS-SSIM-Y	0.8923	0.7102	0.8769	0.8997	1.2747
MS-SSIM-YUV	0.8514	0.6648	0.851	0.8598	1.491
IV-MS-SSIM	0.8392	0.6449	0.8387	0.8589	1.4953
pVAR	0.8283	0.6107	0.7846	0.829	1.633



4 Acknowledgment

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5 No recommendations

This is an informative contribution.

6 References

[1] A. Dziembowski, D. Mieloch, J. Stankowski, A. Grzelka, "IV-PSNR – the objective quality metric for immersive video applications", IEEE Transactions on Circuits and Systems for Video Technology 32, June 2022, pp. 7575 – 7591.

[2] J. Stankowski, A. Dziembowski, "Software manual of QMIV 2", ISO/IEC JTC1/SC29/WG4 MPEG 148, N0580, November 2024.