Wireless Ultrasound Video Transmission for Stroke Risk Assessment: Quality Metrics and System Design

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***Abstract*—In this paper we discuss the use of clinical quality criteria in the assessment and design of ultrasound video compression systems. Our goal is to design efficient systems that can be used to transmit quality ultrasound videos at the lowest possible bitrates. This led us to the development of a spatially-varying encoding scheme, where quantization levels are spatially varying as a function of the diagnostic significance of the video. Diagnostic Regions of Interest (ROIs) for carotid ultrasound medical video are defined, which are then used as input for Flexible Macroblock Ordering (FMO) slice encoding. Diagnostically relevant FMO slice encoding is attained by enabling variable quality slice encoding, tightly coupled by each region's diagnostic importance. Redundant Slices (RS) utilization increases compressed video's resilience over error prone transmission mediums.**

We present preliminary findings on three carotid ultrasound videos at CIF resolution, for packet loss rates up to 30%. Subjective quality evaluation incorporates a clinical rating system that provides for independent evaluations of the different parts of the video. Experimental results show that encoded videos attain enhanced diagnostic performance under noisy environments, while at the same time achieving significant bandwidth requirements reductions.

1. INTRODUCTION

Mobile health (M-Health) systems and services are part of a rapidly growing research and application sector driven by advances in computing technologies [1], [2]. Incorporating state of the art technologies, remote diagnosis and care is quickly becoming one of the most valuable tools in daily clinical practice. Pre-hospital emergency treatment, monitoring of the elderly and patients with chronic diseases, remote diagnosis provision for patients residing at distant locations with limited access and resources, are paradigms of noteworthy contributions made to patient's quality of life and/or even survival.

Increasingly available bitrate, coverage and capacity of wireless transmission technologies (2.5 G, 3G, 3G and beyond (4G), WiMAX) and compression advances (H.26x and MPEG series) facilitated the revolution from medical image transmission of the common carotid artery (CCA) to medical ultrasound video streaming. Despite bitrate availability, wireless channels remain error prone, while the absence of objective (motion) quality metrics limits the ability of providing video of adequate diagnostic quality at a required bitrate. Recent, large-scale studies [3], [4], attempt to shed light as to objective quality assessment algorithms performance, and to what degree the subjective experience is indeed described by these algorithms. Medical video streaming and assessment is even more complicated. Loss tolerance is subject to the amount of clinical data recovered and whether this amount is suitable for providing diagnosis, while failure to do so may result in imprecise diagnosis.

In this paper, we want to discuss the use of new image and video quality criteria that can be used for designing stroke ultrasound transmission systems (see Tables I and II). We have three diagnostic quality criteria that are given in Tables I and II. First, for "plaque detection", we are interested in the visualization of the plaque boundary. For "plaque type", the components of the plaque need to be sufficiently visible so as to determine the plaque type. For stenosis, we need to visualize the geometry around the plaque.

There are interesting still image and video image quality issues associated with the three clinical criteria. Overall though, the video repeats over the cardiac cycle. Thus, if we can visualize the three clinical criteria over a small number

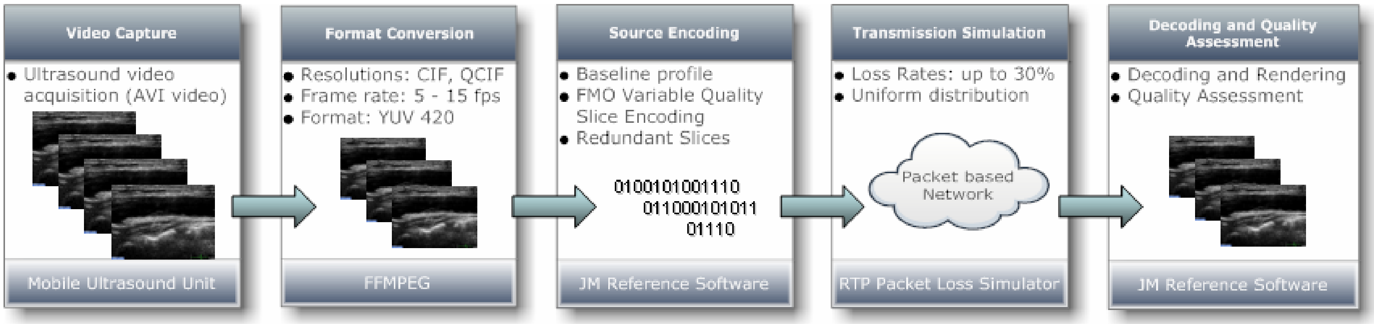

Fig. 1. Wireless Ultrasound Video Transmission System Diagram. First, the ultrasound video is acquired. Format conversion is then performed (resolution, frame rate, avi to yuv 420). This is followed by source encoding employing variable quality slice encoding with Redundant Slices. RTP packet loss simulator is used to simulate transmission errors. At the receiver end, the bitstream is decoded, and the CCA ultrasound video is rendered and assessed.

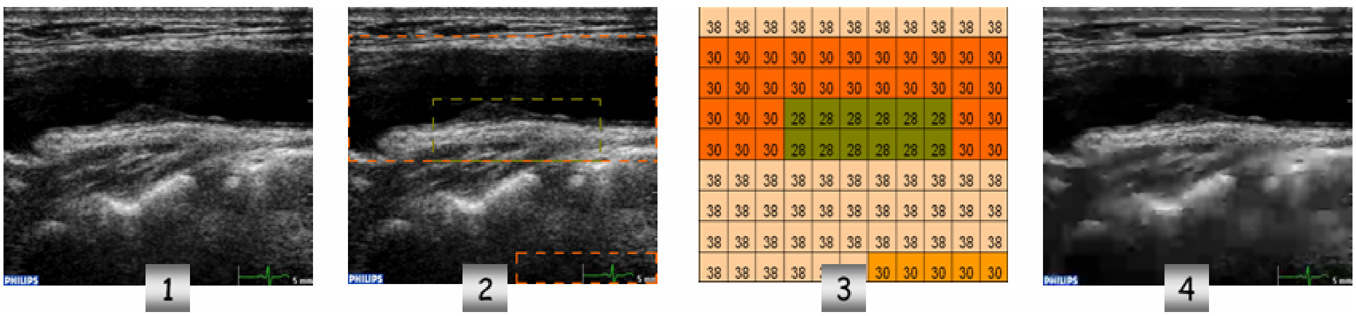

Fig. 2. Variable Quality Slice Encoding Example. In this example, we show: (1) the capture video frame, (2) the segmented frame, (3) the corresponding QP Allocation Map (QPAMap), and (4) the resulting decoded video after variable quality slice encoding. Here with QPs 38/30/28.

TABLE I
CLINICAL EVALUATION RATING SYSTEM

	Plaque Detection	Stenosis	Plaque Type
5	plaque(s) presence in transmitted video identifiable as in original	degree of stenosis in transmitted video determined as in original	plaque type classification in transmitted video as in original
4	plaque(s) presence easily diagnosed	enough clinical data to determine degree of stenosis	enough clinical data for plaque type classification
3	plaque(s) presence diagnosed, careful attention needed	clinical data only allow approximation of degree of stenosis	plaque type classification is case dependant
2	plaque(s) presence may be diagnosed after freeze of a clean frame	very limited ability to estimate degree of stenosis	not classified
1	not detectable	not determinable	not classified

TABLE II
CLINICAL EVALUATION RATING SYSTEM LECTIC AND OTHER ENCODING FACTORS THAT IMPACT ON DIAGNOSTIC QUALITY

	Clinical Significance	Clinical Differentiation for:	
		Display Resolution	Frame Rate
Plaque Detection	Diagnose plaque(s) presence, plaque boundary	QCIF (176x144), CIF (352x288)	15,10,5 fps
Stenosis	Estimate the degree of stenosis	QCIF (176x144), CIF (352x288)	15, 10, 5 fps Recommended ≥10 fps
Plaque Type	Visibility of plaque components that can be used to classify Plaque Type	CIF (352x288)	15,10 fps

(up to 5) cardiac cycles, there is no need to transmit the entire video. Furthermore, it is interesting to observe the motion of plaque components and the variation of the stenosis throughout the cardiac cycle. This is especially true for systole and diastole. We are thus led to consider important spatial and temporal resolution issues. In this preliminary investigation, we will not address physical resolution requirements. Instead, we state that we are targeting up to 15 frames per second, at CIF pixel resolution.

In related work [5], we introduced a new approach which allocates encoding resources (i.e. quantization parameters accountable for video quality) according to video region's diagnostic importance. Diagnostically important regions were assigned lower QPs (i.e. better quality, more bits), whereas none diagnostically important regions higher ones (lower quality, less bits). To achieve that, Flexible Macroblock Ordering (FMO) error-resilient technique of current state of the art H.264 [6] video compression standard was employed. More specifically, FMO type 2 which enables the definition of foregrounds (diagnostic ROIs) and leftover (non-diagnostic regions) for each frame. Diagnostic regions of interest bounds describing atherosclerotic plaque, Intima Media Thickness (IMT) and electrocardiogram (ECG) (when available) were defined based on the method described in [7].

To constitute the transmitted bitstream diagnostically resilient to the presence of severe loss rates likely to occur when transmitting over error prone wireless mediums, we enhanced our approach with Redundant Slices (RS) utilization [8]. In this fashion, we aim high quality video reconstructions (providing the medical expert with adequate amount of clinical data) at any given data rate while transmitting through noisy channels.

In [5], [8], experiments showed considerable bandwidth reductions while at the same time not compromising diagnostic performance, even under heavy loss rates. RS utilization increases transmission time proportional to the amount of inserted slices, however this can be addressed by inserting only representations of the diagnostically important regions.

Video quality assessment measurements based on both objective [9] and subjective criteria are presented. Well known quality metrics such as PSNR, SSIM, and VIF comprise the objective quality evaluation part. Subjective quality evaluation is based on a clinical rating system that provides for independent evaluation of the different parts of the video.

2. METHODOLOGY

A block diagram of the system's architecture is depicted in Figure 1. Firstly, the ultrasound video of the CCA is captured (avi format) using a portable ultrasound device. Spatio/Temporal sub-sampling is then performed to create videos at the desired resolutions (CIF, QCIF) and frame rate (5, 10, and 15), as well as format conversion (avi to yuv 420). FFMPEG software [10] is used for this purpose. This is followed by source encoding by the JM reference software [11], employing variable quality slice encoding with Redundant Slices. RTP packet loss simulator is used to simulate the transmission errors likely to occur when transmitting over error prone wireless mediums. Up to 30% of the transmitted packets are dropped following a uniform distribution. At the receiver end, the JM reference software is used to decode the received bitstream, conceal missing parts and render the transmitted ultrasound video. Quality assessment is based on the metrix_mux software [12].

2.1. Diagnostically driven source encoding

A schematic representation of the clinically relevant regions is depicted in Figure 2. The segmentation algorithm described in [7] is used to identify diagnostic regions at a pixel level and then this is transformed to a macroblock level to comply with FMO type 2 variable quality slice encoding. The corresponding quantization parameter allocation map is used by the encoder to vary quality factors. The resulting ultrasound video of the CCA aims at providing the medical expert with all the existing clinical data on the original video at a reduced bitrate.

2.2. Technical and experimental setup

By using a modified version of the JM 15.1 Reference Software we enable FMO type 2 variable quality slice encoding. Here, our basic idea is to keep track of macroblocks assigned to slices by defining a QP Allocation Map (QPAmap) which stores the QP of each macroblock (see Figure 2). Here, the videos are automatically segmented using a snakes segmentation algorithm [7].

We use a low QP parameter value that allocates the majority of the bandwidth over the plaque region, so as to preserve the plaque boundary and allow the identification of the plaque type. The QP of each ROI slice is defined via the same configuration file used to define the boundaries of the rectangular ROIs. Employing these minor adjustments achieves variable quality FMO slice encoding.

We present preliminary findings in five videos using:

1) FMO type 2 with constant QP throughout a frame.
2) FMO type 2 with variable QP according to the ROIs diagnostic importance (see Table III).
3) Similar to 2) but with the insertion of one redundant slice every four encoded slices. In this manner we aim to achieve robust diagnostic performance in noisy channels rates at a fixed transmission rate, by increasing transmission time.

The assigned QPs depicted in Table III were derived through previous studies [5], [8]. To evaluate the performance of the aforementioned encoding schemes in error prone wireless environments, the pseudo-random RTP packet loss simulator included in JM was modified to provide significantly improved random performance. More specifically, an implementation of the random number generator described in [13] was added. The Uniform distribution was used throughout the experiments and all results were obtained by averaging 10 consecutive runs of each simulated video transmission for every loss rate (3 videos x 3 frame rates x 1 resolution x 9 H.264 different encodings x 7 different loss rates x 10 runs each, equals a total of 5670 processed videos). Baseline profile suitable for wireless transmission (FMO is only supported by the baseline and extended profiles), IPPP… coding structure with an I-frame inserted every 15/10/5 frames, 15/10/5 fps and a total of 100/(80-100)/(40-60) frames per video were used (processed videos not long enough to complete 100 frames at 5fps and in some cases 10fps). Simple frame copy error concealment method (implemented by the JM reference software) is applied at the decoder to reconstruct corrupted packets.

3. RESULTS

3.1. Technical Evaluation

Given the fact that variable quality slice encoding is employed, and as explained above, not all video regions are of equal clinical significance, in order to assess the processed videos more objectively, the term diagnostic quality is introduced. Diagnostic quality records the objective quality metric value over the atherosclerotic plaque region, which is the primary focus point of the medical expert. For evaluation purposes, quantization levels over the atherosclerotic plaque are equal. For simplicity on figures and tables, FMO, FMO_ROI and FMO_ROI_RS stand for constant QP FMO encoding, variable QP FMO encoding and variable QP FMO with RS respectively.

Rate-distortion curves in Figure 3 depict the difference between quality (taking video as a whole, Figure 3a)) and diagnostic quality (Figure 3b)), and the impact that can have on bitrate. In conjunction with clinical evaluation we observe that variable quality slice encoding achieves significant bandwidth requirements reduction without sacrificing diagnostic quality. Figure 4 demonstrates that lowering frame rate may be beneficial for encoding time but the opposite stands for quality (see also Tables II and IV). Finally, Figure 5, records the error resiliency gained by the insertion of RS at the expense of a slightly increased bitrate and transmission time. RS utilization achieves graceful video degradation enabling diagnosis even at losses of 15%.

3.2. Clinical Evaluation

Our goal is to identify the minimum possible bitrates that can still be used to deliver the video at a sufficient video quality. We present preliminary results in Tables II - VI. Table II presents global knowledge gained by current study and [5], [8] in clinical evaluation of CCA ultrasound videos. Table III records the medical expert's rating on the investigated QPs and corresponding compressed videos. For noisy channels and different frame rates, we present the achieved bitrates in Tables IV and V. We refer to Tables I and II for details on the clinical evaluation.

Table IV a) demonstrates the resilience of the scheme incorporating redundant slices, even if channel conditions introduce 15% error on the transmitted stream. Tables IV b) and c) clearly indicate that clinical quality is affected by lowering the bitrate and error resiliency is constrained to 10% loss rate. It is noteworthy, that videos with lower objective quality ratings than others (especially true for approaches that don't utilize RS), attained similar clinical ratings. This is due to the fact that the medical expert was able to provide diagnosis by evaluating consecutive error free cardiac cycles in the video, disregarding erroneous ones. Table V shows that better quality encoding provides for better results (and increased bitrate), while Table VI incorporates a list of quality metrics used for this study. We present the related rate-distortion plots in Figures 3-5.

4. CONCLUSION

We present a summary of our preliminary findings on the use of clinical criteria to evaluate the transmission of ultrasound video for clinical diagnosis of stroke. Clearly, variable quality slice encoding provides for an efficient encoding and transmission preserving valuable bandwidth resources. Incorporated RS enhanced transmitted videos resilience under severe loss rates, while the clinical evaluation revealed that consecutive error free cardiac cycles may be adequate for providing accurate diagnosis even in cases where objective quality evaluation shows the opposite. A recommended setting would incorporate CIF resolution video at 15fps, QP less or equal to 28 and utilization of RS.

Future work includes experiments based on a broader data set incorporating a plethora of different case ultrasound videos of the CCA. Variation of ultrasound cases clinically assessed by medical experts will enable the deduction of minimum threshold values for providing diagnosis for a list of the most common objective quality algorithms. Nevertheless, the minimum number of consecutive error free cardiac cycles which enable accurate diagnosis will be sought. Similarly to [3], [4], a study investigating the best matching objective quality metric to the medical expert's diagnosis is planned.

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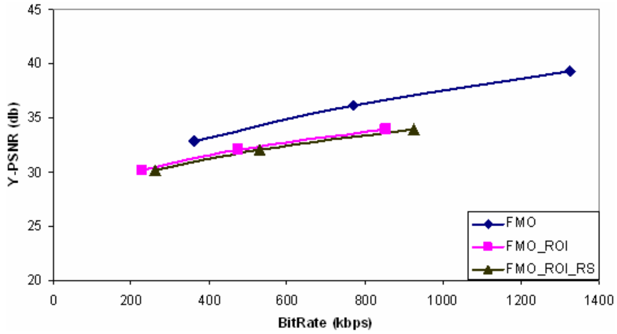
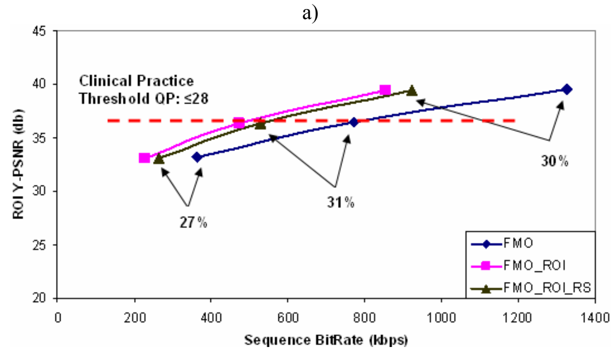
TABLE III
CIF RESOLUTION VIDEO, NO ECG LEAD. THIS EXAMPLE PRESENTS THE ACHIEVED BITRATES FOR EACH CLINICAL SCENARIO

FMO	***QP***	32/32/**32**	28/28/**28**	24/24/**24**
	BitRate (kbps)	**416**	**788**	**1295**
Plaque Detection		5	5	5
Stenosis		4	5	5
Plaque Type		4	5	5
FMO ROI	***QP***	40/34/**32**	38/30/**28**	36/26/**24**
	BitRate (kbps)	**191**	**355**	**625**
Plaque Detection.		5	5	5
Stenosis		4	5	5
Plaque Type		4	5	5
FMO ROI RS	***QP***	40/34/**32**	38/30/**28**	36/26/**24**
	BitRate (kbps)	**225**	**412**	**700**
Plaque Detection.		5	5	5
Stenosis		4	5	5
Plaque Type		4	5	5

1: Lowest Quality, **5:** Highest Quality



a)



b)

Fig. 3. a) Rate-distortion curve for the entire video. b) Rate-distortion curve for diagnostic quality (extracted from a), see Figure 3). Variable QP FMO (FMO ROI and FMO ROI RS) and constant QP FMO achieve similar PSNR ratings as expected (since atherosclerotic plaque region is encoded with equal QP for all cases). The key point is the significantly reduced bitrate without compromising clinical quality. Indicatively, for this particular video, FMO ROI RS requires 27%, 31% and 30%% less bitrate than conventional FMO for QPs of 32, 28, and 24 respectively.

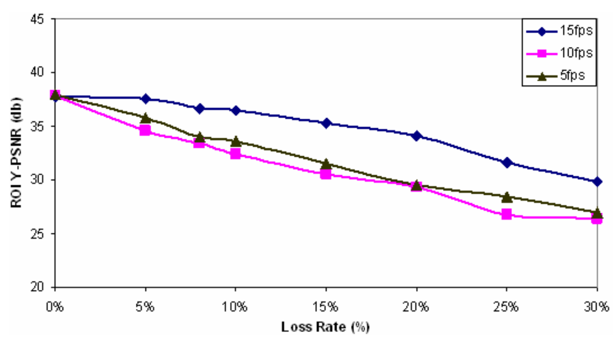


Fig. 4. Diagnostic Quality Evaluation for Different Frame Rates. Here, we evaluate the PSNR vs Loss Rate curve for FMO ROI RS and diagnostic ROI (atherosclerotic plaque) QP of 28. At 15 fps video achieves graceful degradation compared to 10fps and 5fps.

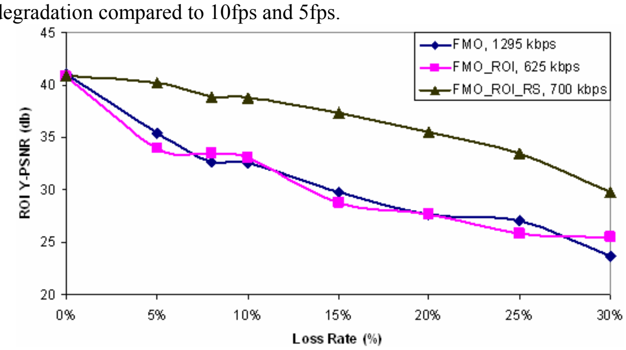


Fig. 5. Diagnostic Quality Evaluation for Error-prone channels. Here, we evaluate the PSNR vs Loss Rate curve for diagnostic ROI (atherosclerotic plaque) QP of 28. FMO ROI RS achieves graceful degradation of video quality in the presence of severe loss rates, qualifying for clinical practice even at 15% loss rate. FMO ROI and FMO attain similar ratings. Bandwidth requirements reductions as above.

TABLE IV A

CIF RESOLUTION VIDEO, NO ECG LEAD - ROI QP 28 – 15 FPS

	FMO	**FMO ROI**	**FMO ROI RS**
BitRate (kbps)	**788**	**355**	**411**
Loss Rates %	**5/ 8/ 10/ 15**	**5/ 8/ 10/ 15**	**5/ 8/ 10/ 15**
plaque	5/ 5/ 5/ 5	5/ 5/ 5/ 4	5/ 5/ 5/ 5
stenosis	5/ 5/ 5/ 4	5/ 5/ 5/ 4	5/ 5/ 5/ 5
Plaque type	4/ 4/ 4/ 4	4/ 4/ 4/ 4	4/ 4/ 4/ 5

1: Lowest Score, **5:** Highest Score

TABLE IV B

CIF RESOLUTION VIDEO, NO ECG LEAD - ROI QP 28 – 10 FPS

	FMO	**FMO ROI**	**FMO ROI RS**
BitRate (kbps)	**610**	**289**	**323**
Loss Rates %	**5/ 8/ 10**	**5/ 8/ 10**	**5/ 8/ 10**
plaque	5/ 5/ 4	5/ 5/ 4	5/ 5/ 5
stenosis	5/ 5/ 4	5/ 5/ 4	5/ 5/ 4
Plaque type	4/ 4/ 4	4/ 4/ 4	5/ 5/ 4

1: Lowest Score, **5:** Highest Score

TABLE IV C

CIF RESOLUTION VIDEO, NO ECG LEAD - ROI QP 28 – 5 FPS

	FMO	**FMO ROI**	**FMO ROI RS**
BitRate (kbps)	**381**	**202**	**212**
Loss Rates %	**5/ 8/ 10**	**5/ 8/ 10**	**5/ 8/ 10**
plaque	5/ 4/ 4	5/ 4/ 4	5/ 4/ 4
stenosis	4/ 4/ 4	4/ 4/ 4	4/ 4/ 4
Plaque type	4/ 4/ 4	4/ 4/ 4	4/ 4/ 4

1: Lowest Score, **5:** Highest Score

TABLE V

CIF RESOLUTION VIDEO, WITH ECG LEAD - ROI QP 24 – 15 FPS

	FMO	**FMO ROI**	**FMO ROI RS**
BitRate (kbps)	**1326**	**854**	**924**
Loss Rates %	**5/ 8/ 10/ 15**	**5/ 8/ 10/ 15**	**5/ 8/ 10/ 15**
plaque	5/ 5/ 5/ 5	5/ 5/ 5/ 5	5/ 5/ 5/ 5
stenosis	5/ 5/ 4/ 4	5/ 5/ 4/ 4	5/ 5/ 5/ 5
plaque type	5/ 4/ 4/ 4	5/ 4/ 4/ 4	5/ 5/ 5/ 5

1: Lowest Score, **5:** Highest Score

TABLE VI
QUALITY METRICS VS LOSS RATE – CIF RESOLUTION VIDEO WITH ECG LEAD - FMO ROI RS, ROI QP 28, 15 FPS

	0%	**5%**	**8%**	**10%**	**15%**	**20%**	**25%**	**30%**
PSNR	36.3762	35.8313	35.5275	35.7696	34.2613	32.705	31.5726	30.0158
MSE	14.9979	19.1307	22.6579	19.4445	41.5341	77.6763	80.3611	128.719
SSIM	0.94095	0.93528	0.93096	0.93502	0.91768	0.89723	0.87540	0.84744
VSNR	35.1645	34.0975	33.6908	34.012	31.5409	29.5745	27.0611	25.0454
VIF	0.65321	0.63696	0.62853	0.63271	0.59242	0.55254	0.49792	0.45503
VIFP	0.63869	0.62747	0.62057	0.62737	0.59708	0.55802	0.52294	0.48195
UQI	0.89367	0.88692	0.88155	0.88645	0.86477	0.84004	0.81489	0.78148
IFC	4.03875	3.92584	3.86957	3.89472	3.62546	3.35831	3.00376	2.73007
NQM	20.3672	19.6967	19.327	19.602	17.8518	16.1171	14.6496	12.9629
WSNR	37.3658	35.7234	35.043	35.496	31.9385	28.8232	26.5788	23.8645
SNR	23.8449	23.3	22.9962	23.2383	21.73	20.1738	19.0414	17.4846

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