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Robust and Efficient Ultrasound Video Coding in Noisy Channels Using H.264

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Abstract—**In this paper we define diagnostic Regions of Interest (ROIs) for carotid ultrasound medical video, which we then use as input for Flexible Macroblock Ordering (FMO) slice encoding. We extend the FMO concept 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 evaluate our scheme on a series of five (5) carotid ultrasound videos at QCIF and CIF resolutions, for packet loss rates up to 30%. Quality assessment based on a clinical rating system that provides for independent evaluations of the different parts of the video (subjective), as well as PSNR ratings (objective), shows that encoded videos attain enhanced diagnostic performance under noisy environments, while at the same time achieving significant bandwidth demands reductions.**

Index Terms— **error resilience, FMO, H.264, redundant slices, ROI segmentation, ultrasound video.**

I. Introduction

Higher compression ratios and error resilience features provided by H.264/AVC [1] linked with continually increasing bandwidth availability through new wireless technologies have enabled new, diagnostic approaches in mobile health (m-Health) systems and services [2]. A thorough overview of the current status while also highlighting future directions is given in [3]. Ultrasound video aided stroke diagnosis is discussed in [4].

A limited number of studies though have been focused on medical video transmission over wireless environments making use of error resilience features defined in current state of the art H.264/AVC. In [5], scalable coding is used for adaptive transmission of medical images and video snapshots over simulated wireless networks, while in [6], a saliency-based visual attention ROI for low bit-rate medical video transmission is proposed. Efficient encoding scheme selection for wireless medical video transmission is highlighted in [7].

Medical experts evaluating carotid ultrasound video are mainly interested in identifying possible stenosis of the carotid artery. Having diagnosed a stenosis, they aim at extracting atherosclerotic plaque (causing the stenosis) features, tracking of which in time can aid in the prediction of the severity of this abnormality. Intima media thickness (IMT) of the near and far walls also aid in this direction. The remaining regions of the video carry little diagnostic importance.

Bearing in mind the abovementioned implications, in [8], 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, FMO type 2 was employed which enables the definition of foregrounds (diagnostic ROIs) and leftover (non-diagnostic regions) for each frame. Diagnostic regions of interest bounds describing atherosclerotic plaque, IMT and ECG (when available) were defined based on the method described in [9].

In [8], experiments showed considerable bandwidth reductions while at the same time not compromising diagnostic performance. In fact, for the same bitrate the proposed approach significantly outperformed the conventional rate control encoding scheme of the reference software.

In this paper, we want to explore robust video encoding schemas that can provide high diagnostic quality video reconstructions at any given data rate, while transmitting through very noisy channels. Urgent clinical practice is directly related with the recovered amount of clinical data, hence medical video needs to be shielded against such scenarios. FMO slice encoding (incorporated by the proposed approach) yields better resilience to the presence of errors rather than conventional frame encoding, however video degradation is rapid under heavy loss rates (above 8-10%).

The basic idea here is to achieve better quality image reconstructions by increasing the video transmission time, at a fixed transmission rate. To achieve this, we enhance our approach by inserting Redundant Slices (RS) within the transmitted sequence. RS are identical representations of encoded frames and aim to substitute corrupted/lost packets

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during decoding. Bandwidth demands increases slightly, whereas transmission time proportional to the percentage of the inserted slices. In this manner, we aim to constitute our transmitted sequence resilient to presence of errors and attain a graceful degradation of video diagnostic quality under heavy loss rates. Extensive simulations by dropping RTP packets carrying video data up to 30% are performed in order to evaluate our proposed scheme, including a clinical evaluation rating system as well as PSNR ratings.

The rest of the paper is organized as follows. Section II introduces the fundamental concepts of FMO, redundant slices and segmentation procedure. Section III describes the methodology, while Section IV presents an analysis of the conducted experiments. Finally Section V provides some concluding remarks.

II. Flexible Macroblock ordering, Redundant Slices and Segmentation Procedure

A. Flexible Macroblock Ordering and Redundant Slices

Flexible macroblock ordering (FMO) has been introduced in H.264/AVC for error-resilient applications [10]. FMO is essentially a slice structuring approach, where a frame is partitioned into independently transmitted and decoded slices. Prediction between slices is not allowed and consequently corrupted packets do not propagate error to subsequent packets. It is the case however that a packet carrying a whole slice is dropped. To enhance robustness in such cases, H.264/AVC allows the transmission of redundant slices (RS). RS can be coded in a different manner with respect to the primary slices (i.e. different coding parameters) and are utilized in the absence of a clear primary slice. FMO defines seven different types for macroblock to slice allocation. FMO type 2 is depicted in Figure 1b) (see [8] for details).

B. Segmentation Procedure

The region of interest (ROI) specification procedure followed during encoding is identical to the one defined within the context of the JM 15.1 Reference Software [11] for FMO type 2 slice encoding. By defining upper left and lower right corner points (on a MacroBlock (MB) basis) we select the rectangular diagnostic ROIs as illustrated in Figure 1b). These bounds are defined at the beginning of each encoded sequence and were extracted from the method described in [9]. Taking plaque movement into account we select a slightly broader area as ROI, thus avoiding redefinition of the rectangular area further in the sequence (incorporating additional bits for picture parameter sets).

III. Methodology

A. Material

Ultrasound video is widely used in vascular imaging to visualize the arterial lumen and wall. Monitoring of the

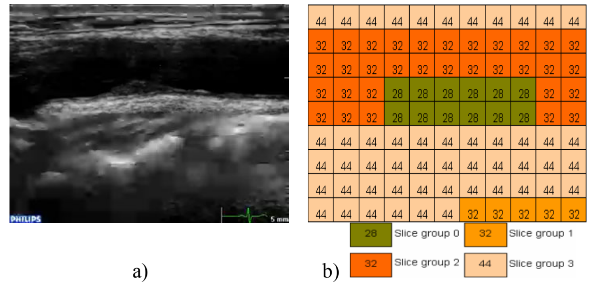

Fig. 1. a) Frame 1 of compressed carotid ultrasound video using variable QP FMO. b) The corresponding Quantization Parameter Allocation map (QPAmap). Slice groups: 0: atherosclerotic plaque, 1: ECG, 2: Upper and lower intima media complex, including the lumen diameter, 3: other components.

arterial characteristics like the vessel lumen diameter, the intima media thickness (IMT) of the near and far walls and the morphology of atherosclerotic plaque are important in order to assess the severity of atherosclerosis and evaluate its progression [4]. Bearing in mind the aforementioned, ROI encoding identifying these regions of diagnostic interest was employed. The key concept is that once diagnostic ROIs have been defined, the remaining part of the video can be safely compressed without affecting diagnosis.

B. Encoding/Decoding Procedure

By using a modified version of the JM 15.1 Reference Software we enable FMO type 2 variable quality slice encoding. Following a similar concept with MB Allocation Map (MBAmap) used to keep track of macroblocks assigned to slices, we define a QP Allocation Map (QPAmap), which stores the QP of each macroblock (see Figure 1b). 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.

To evaluate our proposed approach a series of five videos at QCIF and CIF resolutions were encoded using:

1) FMO type 2 with constant QP throughout a frame, which is the default encoding scheme. Here, we are interested in showing that incorporated bitrate is a preventing factor, while at the same time not achieving better diagnostic performance than any of the proposed approaches.
2) FMO type 2 with variable QP according to the ROIs diagnostic importance (following a low, medium and medium to high QP allocation pattern for non-important regions, IMT (and ECG when available) and atherosclerotic plaque slices respectively, see Table I). The QPs of FMO constant QP encoding and slice 0 (describing the atherosclerotic plaque) are equal so as to be able to deduct conclusions regarding diagnostic quality. Our aim is to depict that similar diagnostic performance is attained at a significantly reduced bitrate.
3) Similar to 2) but with the insertion of one redundant slice for every encoded slice. In this manner we aim to achieve robust diagnostic performance in noisy channels rates at a fixed transmission rate, by increasing transmission time.

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 by adding an implementation of the random number generator described in [12]. JM 15.1 supports encoding but not decoding of redundant slices, so we moved this functionality to the packet loss simulator. In this fashion only clear primary slices are fed to the decoder. The simulator was also enhanced with a number of loss distributions. The Bernoulli distribution was used throughout the experiments and all results were obtained by averaging 10 consecutive runs. 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 16 frames, 25 fps and a total of 100 frames per video were used. Simple frame copy error concealment method is applied at the decoder to reconstruct corrupted packets. Here, the use of this simple error-concealment scheme is allowed due to the fact that plaque motion is not of diagnostic interest (for urgent care applications). On the other hand, stenosis characteristics are only slightly affected by frame copying.

IV. RESULTS

A. Technical Evaluation

Diagnostic quality for carotid ultrasound video evaluation can be defined as the PSNR over the (atherosclerotic) plaque, being the primary focus point of the clinical evaluation. In Figure 2 we provide rate-distortion curves of both quality (taking video as a whole, Figure 2a)) and diagnostic quality (Figure 2b)) and the impact that can have on bitrate. For simplicity reasons 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.

In Figure 2a) constant QP FMO encoding attains the highest PSNR ratings since it employs equal QP throughout a frame. When it comes to diagnostic quality however (Figure 2b)), variable QP FMO schemes attain similar PSNR ratings with constant QP FMO, the key observation being the drastically lower sequence bitrate they involve. RS encoding bandwidth demands, as evident by the graph, are slightly higher than non-RS encoding. Figure 3 demonstrates the performance of the three tested encoding schemes when extracting the atherosclerotic plaque (diagnostic ROI) of the decoded video under losses of 10% of transmitted RTP packets. We have significant bandwidth requirement reductions without sacrificing diagnostic quality.

Furthermore, variable QP FMO with RS provides increased error resilience outperforming both compared approaches which attain similar PSNR ratings. The latter is illustrated in Figure 4 where all three approaches are tested under heavy loss rates. Variable QP FMO with redundant slices achieves a graceful degradation of video quality (diagnostic performance), as the presence of redundant slice representations in a transmitted stream over noisy channels aids in smoothly concealing extensive packet losses. Variable and constant QP FMO follow the same trend as expected, again the key observation being that variable QP FMO requires significantly less bandwidth to achieve the same results. Figures 2-4 show the results of CIF resolution video with ECG lead (see Figure 1a)) while Tables I and II record an indicative sample of the clinical evaluation for a CIF resolution video with no ECG lead. Results are video specific but the trend is the same for all investigated videos.

B. Clinical Evaluation

The tested encoding schemes performance was also evaluated by a medical expert. The videos were played back on a laptop at their original pixel size dimensions.

The evaluation verified the results obtained by the technical evaluation. Table I records the medical expert's rating on the compressed videos for a representative sample of the investigated QPs while Table II for a number of loss rates for videos encoded with ROI QP of 28. Rating values are between 1 and 5, 1 for lowest quality and 5 for highest. Plaque type classification is only considered between echogenic and echolucent. For this particular video, for ROI QP of 28, the medical expert could identify almost as much information in the compressed video as in the original. Thus, a selection of ROI QPs of 28 and lower were found to qualify for clinical practice. Higher QPs may be selected for urgent clinical practice with respect to bandwidth availability, however an ulcer on the plaque visible for ROI QP of 32 was not visible for ROI QP of 36. Table II can be interpreted in the same way as Figures 3 and 4 and demonstrates the resilience of the scheme incorporating redundant slices, even if channel conditions introduce 15% error on the transmitted stream. Furthermore, it depicts the similar behavior as to video degradation of the compared approaches that don't utilize RS.

For QCIF resolution, the medical expert underlined that plaque classification could not be derived for all videos, primarily constrained by video dimensions and to a considerably less extend by quality levels. This of course is video specific; but we do note that for the same video at CIF resolution, classification could be obtained. Another important aspect pointed out by the medical expert is that variable QP encoding helped as a better visualization tool leading in faster diagnosis as opposed to constant QP encoding where equal quality levels caused him to loose focus of what is relevant.

V. CONCLUDING REMARKS

This paper deals with medical ultrasound video streaming for urgent care. Using ROI encoding, diagnostic regions of interest are identified for carotid ultrasound videos. These ROIs are mapped to slices and encoded utilizing FMO type 2. The FMO type 2 concept is extended to support variable quality slice encoding according to the slices' diagnostic importance. By inserting redundant representations within the transmitted sequence the encoded video becomes resilient to

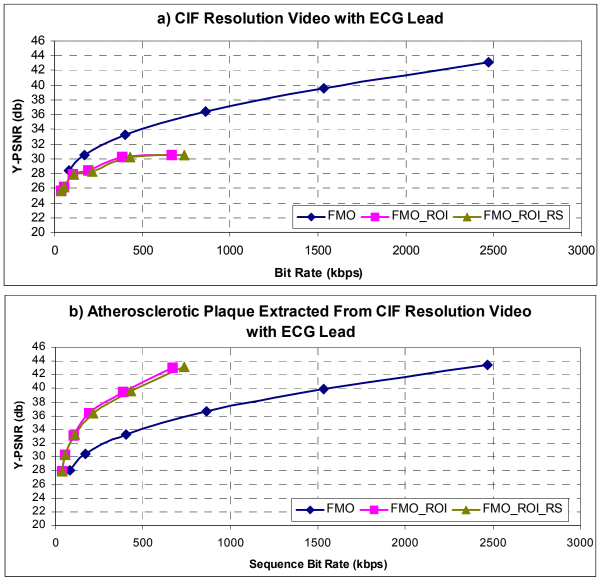

Fig. 2. a) Rate-distortion curves for entire video. b) Rate-distortion curves for diagnostic ROI (atherosclerotic plaque) extracted from a). Variable QP FMO (FMO_ROI and FMO_ROI_RS) achieve similar PSNR with constant QP FMO at a significantly reduced bitrate.

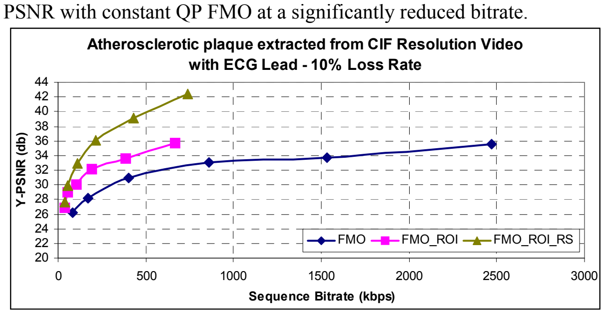

Fig. 3. Rate-distortion curves for diagnostic ROI (atherosclerotic plaque) extracted from decoded video in the presence of 10% packet loss rate. FMO ROI RS achieves the best diagnostic performance while FMO ROI and FMO perform similarly. Variable QP FMO achieves significant bandwidth requirement reductions.

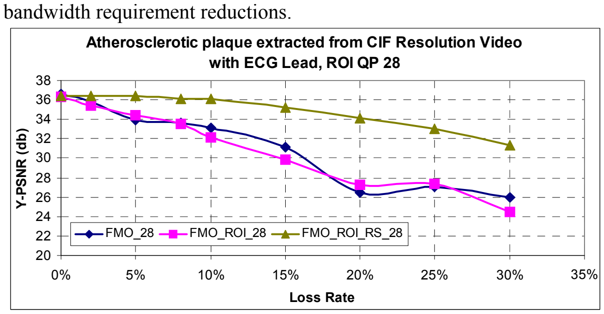

Fig. 4. PSNR vs Loss Rate curve for diagnostic ROI (atherosclerotic plaque) with QP 28. FMO_ROI_RS achieves graceful degradation of video quality, even in the presence of heavy loss rates. FMO_ROI and FMO attain similar ratings, the former requiring significantly less bandwidth demands than the latter as illustrated in Figs. 2-3 above.

the presence of heavy loss rates. Comprehensive experiments indicate that enhanced diagnostic quality is attained in noisy environments at a significantly reduced bitrate.

Future work includes the investigation of a diagnostically relevant optimum number of inserted RS, while also pairing with an Unequal Error Protection (UEP) scheme to further enhance robustness of diagnostically important regions.

TABLE I

CLINICAL EVALUATION, CIF RESOLUTION VIDEO, NO ECG LEAD

FMO ***QP:***	36/36/**36**	32/32/**32**	28/28/**28**	24/24/**24**
plaque	5	5	5	5
Stenosis	4	4	5	5
plaque type	4	4	4	5
FMO ROI ***QP:***	48/40/**36**	44/36/**32**	44/32/**28**	40/28/**24**
plaque	5	5	5	5
Stenosis	4	4	5	5
plaque type	4	4	5	5
FMO ROI RS ***QP:***	48/40/**36**	44/36/**32**	44/32/**28**	40/28/**24**
plaque	5	5	5	5
stenosis	4	4	5	5
plaque type	4	4	5	5

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

TABLE II

CLINICAL EVALUATION, CIF RESOLUTION VIDEO, NO ECG LEAD - ROI QP 28

	FMO	**FMO ROI**	**FMO ROI RS**
Loss Rates %	**5/ 8/ 15**	**5/ 8/ 15**	**5/ 8/ 15**
Plaque	4/ 4/ 3	4/ 4/ 3	4/ 4/ 4
stenosis	4/ 4/ 3	4/ 4/ 3	4/ 4/ 4
plaque type	4/ 3/ 3	4/ 3/ 3	4/ 4/ 4

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

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