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High Efficiency Video Coding for Ultrasound Video Communication in M-Health Systems

A. Panayides[1], Z. Antoniou[1], M.S. Pattichis[2], C. S. Pattichis[1], and A. G. Constantinides[3]

Abstract— Emerging high efficiency video compression methods and wider availability of wireless network infrastructure will significantly advance existing m-health applications. For medical video communications, the emerging video compression and network standards support low-delay and high-resolution video transmission, at the clinically acquired resolution and frame rates. Such advances are expected to further promote the adoption of m-health systems for remote diagnosis and emergency incidents in daily clinical practice. This paper compares the performance of the emerging high efficiency video coding (HEVC) standard to the current state-of-the-art H.264/AVC standard. The experimental evaluation, based on five atherosclerotic plaque ultrasound videos encoded at QCIF, CIF, and 4CIF resolutions demonstrates that 50% reductions in bitrate requirements is possible for equivalent clinical quality.

I. INTRODUCTION

Recent advances in areas associated with m-health medical video communication systems are expected to further advance the adoption of such systems in daily clinical practice [1], [2]. More specifically, the new high efficiency video coding (HEVC) standardization initiative [3] aims to reduce bitrate requirements up to 50% for equivalent perceptual quality, compared to the highly successful current state-of-the-art H.264/AVC video coding standard. At the same time, current and emerging wireless channels [4], such as mobile WiMAX and Long Term Evolution (LTE) systems, and especially WirelessMan-Advanced and LTE-Advanced 4G wireless networks, facilitate data transfer rates and cutting edge technologies, which will significantly advance existing m-health applications (mostly based on 3G-sytems [5] and beyond). Moreover, clinical video quality assessment, targeted for each medical video modality, is quickly gaining the attention of the research community, and validates the system's objective of providing medical video of adequate diagnostic quality to the remote medical expert [1], [6].

The significant number of m-health systems developed over the past decade depict the broad spectrum of usage while also highlight the necessity of such systems and services [7], [8]. For medical video communications systems, successful systems utilize context-aware (i.e. medical video modality specific) implementations, diagnostically-driven encoding, and adaptation to the wireless network's characteristics and varying state. A more detailed description of current trends appears in [1].

On the other hand, wider adoption of m-health systems in routine clinical practice is limited by the inability of current technologies to support medical video transmission at the acquired resolution and frame rates. The reduction in video resolution, frame rates and the need to critically assess compression-induced artifacts provides further obstacles to wider adoption.

The emergence of the HEVC video standard and new 3.5G and 4G wireless networks will provide additional coding efficiency and network reliability that will facilitate stronger support for m-health video communications systems. Ultimately, the goal is to deliver sufficiently high resolutions and video frame rates with low-delay responsive systems that can rival the experience of in-hospital examinations. Clearly, success in meeting this goal will lead to widespread use of m-health video communication technologies in standard clinical practice.

In this study we investigate the compression efficiency of the anticipated HEVC video standard for atherosclerotic plaque ultrasound video transmission. For this purpose we investigate the use of three different video resolutions: (i) high-resolution 4CIF (704x576), (ii) medium-resolution CIF (352x288), and (iii) low-resolution QCIF (176x144) sequences. We compare our findings to the use of the standard flexible macroblock ordering (FMO) H.264/AVC encoding, as well as the recently introduced diagnostically driven approach presented in [6]. In [6], we applied a spatially varying encoding scheme where quality levels were varied as functions of the diagnostic significance of each video region. The approach provided for significant bitrate reductions at equivalent clinical quality. We demonstrate the HEVC associated benefits both in terms of bitrate demands reduction (objectively) as well as enhanced diagnostic capacity of the resulting medical video (subjectively).

This paper is focused on the study of high-efficiency video encoding of clinical ultrasound at different resolutions. In particular, we measure HEVC performance for the current use of lower (QCIF) and medium (CIF) video resolutions. Our experiments in higher-resolution (4CIF) reflect transmission at the in-hospital, original video acquisition resolution. For each case, we measure improvement in terms of the reduction in bitrate which can be used for increasing the reconstructed video PSNR as compared to standard H.264/AVC encoding and the variable quality diagnostic-ROI encoding introduced in [6].

The rest of the paper is organized as follows: Section II provides a brief overview of HEVC standardization initiative, coding tools, and current version of HEVC reference

[1]A.Panayides, Z. Antoniou, and C.S. Pattichis are with the Dept. of Computer Science, University of Cyprus, Nicosia, Cyprus (tel:+357-22892697, e-mail: {panayides, antoniou.zinonas, pattichi }@ucy.ac.cy).

[2]M.S. Pattichis is with the Dept. of Electrical and Computer Engineering, University of New Mexico, Albuquerque, USA (e-mail: pattichis@ece.unm.edu).

[3]A.G. Constantinides is with the Dept. of Electrical and Electronic Engineering, Imperial College, London, UK (e-mail: a.constantinides@imperial.ac.uk).

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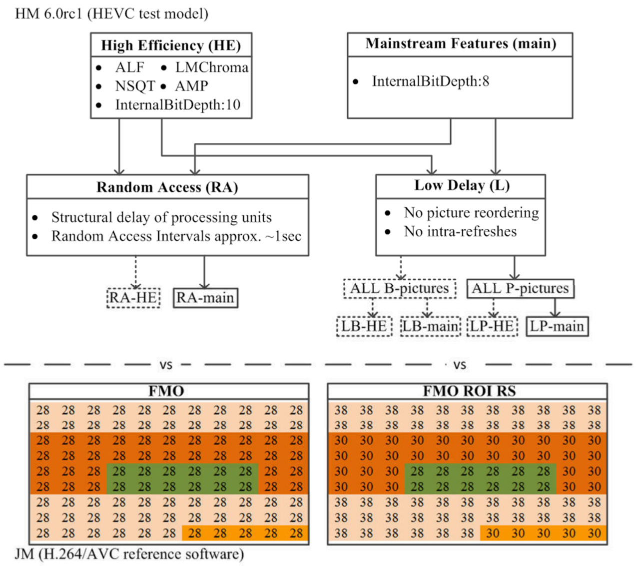

Fig. 1. Summary of emerging HEVC test model (HM 6.0rc1) encoding schemes and H.264/AVC FMO and FMO ROI RS settings for comparison.
ALF: Adaptive Loop Filtering, LMChroma: Chroma from Luma intra prediction mode, NSQT: Non-Square Transforms, AMP: Asymmetric motion (see [10]-[14] for details).
FMO: Flexible Macroblock Ordering, FMO ROI RS: variable quality slice encoding and Redundant Slices (RS) (see also [6]).

software. In Section III we present the methodology, while Section IV discusses the achieved results. Finally, we give some concluding remarks and future work in Section V.

II. Emerging High Efficiency Video Coding Standard

The ITU-T VCEG and the ISO/IEC MPEG groups issued a joint call for proposals (cfp) in 2010 [9] to initiate the process of the new video coding standard. The new standard initiative, termed high efficiency video coding (HEVC), is expected to be finalized in 2013, and was undertaken by the Joint Collaborative Team on Video Coding (JCT-VC) established by the afore-mentioned organizations.

The emerging high efficiency video coding standard is based on extended modes of within-frame (intra) and inter-frame (inter) prediction, followed by residual transform, quantization and encoding. Key to the success of the new standard is the introduction of a new block structure which allows partitioning of a picture to larger sub-blocks of variable size, which replaces the macroblock structure found in previous standards. The new coding units (CU) may contain one or more prediction units (PU) and transform units (TU). High efficiency video coding is achieved primarily through the use of Context-Adaptive Binary Arithmetic Coding (CABAC) borrowed from H.264/AVC and the introduction of a new, Adaptive Loop Filter (ALF). Adaptive loop filtering uses a Wiener filter to reduce blocking artifacts among different block types [10]. ALF is not included in the main mode. The main mode uses structured variable-length coding tables, context adaptation, and a modified coding of transform coefficients to reduce computational complexity while achieving comparable coding accuracy (see [11], [12]).

The current standardization considerations are reflected via the HM test model [13] -the HEVC reference software-, which was originally created combining the best performing proposals of [9], documented in [14]. As the standard has not been finalized yet, the HM software is frequently updated to incorporate new design implementations and algorithmic elements. Currently, the HM 6.0rc1 test model defines two primary common test conditions, namely (a) *high efficiency* (HE) and (b) *main* (*low complexity* (LC) in former versions). These configurations, which aim at evaluating the performance of individual coding tools for different applications, are further categorized to *random access* and *low delay* schemes. For the low delay scenarios, in addition to the *B-frames* used, which is the current default in all schemes, only *P-frames* configuration also exists. Furthermore *all intra frames* scenarios for HE and main test conditions serve for benchmark purposes and intra coding tools evaluation. The total common test conditions found in HM 6.0rc1 is therefore eight and are summarized in Fig 1 (besides all-intra configuration). Here, we should remark that profiles and levels have not been yet defined for HEVC [15].

III. Methodology

We investigate the compression efficiency gains of the HEVC video standard from a medical video communication perspective. For this purpose, we compare a subset of the HM 6.0rc1 common test condition settings, namely the random access main (RA-main) and low delay all P-frames (LP-main) configurations, against standard FMO H.264/AVC encoding as well as the method we introduced in [6] for atherosclerotic plaque ultrasound videos (see Fig. 1). A total of five (5) ultrasound videos comprise our data set.

In [6], a diagnostically driven (context-aware) system was proposed, where clinically important video regions (diagnostic regions of interest (ROIs)) are encoded using quality levels proportional to the diagnostic significance of each region. The latter method which uses flexible macroblock ordering (FMO) coding tool (termed FMO ROI RS), achieved significant reductions in bitrate requirements for equivalent clinical quality. Moreover, using redundant slices (RS), an H.264/AVC error resilience feature, the method provided for clinical quality that was superior to the default FMO H.264/AVC (which applies uniform picture encoding) in noisy environments.

Here, we incorporate the same data set described in [6], but we extend our experiments to include lower QCIF (176x144), as well as higher 4CIF (704x576) resolutions, in addition to the CIF (352x288) resolution used in [6], at fifteen (15) frames per second (fps). We use four different quantization parameters (QP): 24, 28, 32, and 36, and estimate the bitrate requirements gains using the BD-PSNR algorithm [16]. For FMO ROI RS, the quantization levels are set as 42/38/36, 40/34/32, 38/30/28 (see Fig. 1), and 36/26/24. The 1st QP is used for encoding the non-clinically important background, the 2nd QP for encoding the area around the atherosclerotic plaque including the near and far artery walls, as well as the electrocardiogram region when available, while the lower QP (higher quality) is used for encoding the plaque region (see Fig. 1 and Fig. 2(f)). More details on the selection of the afore-mentioned quality levels are given in [6].

For HEVC, we exclude the high efficiency and low delay all B-frames configurations. This is due to the fact that

TABLE I – AVERAGE BITRATE REQUIREMENTS REDUCTIONS (%) FOR LOW DELAY HEVC ENCODING WHEN COMPARED TO STANDARD FMO AND TO VARIABLE QUALITY FMO H.264/AVC ENCODINGS FOR EQUIVALENT VIDEO QUALITY LEVELS

Low Delay						
Video No.	**HEVC vs H.264 FMO (%)**			**HEVC vs FMO ROI RS (%)**		
	QCIF	**CIF**	**4CIF**	**QCIF**	**CIF**	**4CIF**
#1	45	58	61	38	49	48
#2	67	57	59	56	35	20
#3	63	52	57	44	10	13
#4	61	62	67	45	40	45
#5	66	60	64	58	40	46
Average	60	58	62	48	35	36

TABLE II – AVERAGE BITRATE REQUIREMENTS REDUCTIONS (%) FOR RANDOM ACCESS HEVC ENCODING WHEN COMPARED TO STANDARD FMO AND TO VARIABLE QUALITY FMO H.264/AVC ENCODINGS FOR EQUIVALENT VIDEO QUALITY LEVELS

Random Access						
Video No.	**HEVC vs H.264 FMO (%)**			**HEVC vs FMO ROI RS (%)**		
	QCIF	**CIF**	**4CIF**	**QCIF**	**CIF**	**4CIF**
#1	52	59	66	45	50	54
#2	61	59	65	47	39	39
#3	57	55	61	34	14	22
#4	55	62	69	36	40	49
#5	58	59	67	48	40	50
Average	57	59	66	42	36	43

H.264/AVC videos are encoded using the baseline profile, which uses as IPPP coding structure, and is specifically designed for streaming video to mobile devices. However, as the HEVC LP-main configuration does not incorporate intra-refreshes (as in the case of the H.264/AVC encodings), we also evaluate the performance of the RA-main configuration (which uses B-frames).

IV. RESULTS AND DISCUSSION

In this section we discuss the experimental evaluation of the proposed HEVC standard for low, medium, and high resolution medical video communications. The results indicate that HEVC provided significant bitrate reductions while also improving video quality.

A. *Objective Evaluation*

Table I depicts the bitrate gains of the low delay scheme of the currently developed HEVC standard, compared to the standard FMO H.264/AVC and the variable quality slice [6] encodings, while Table II illustrates the bitrate demands reductions of the HEVC random access configuration compared to the afore-mentioned H.264/AVC encodings.

We observe that low delay HEVC configuration achieves approximately 60% bitrate savings for QCIF resolution, 58% for CIF resolution, and 62% for 4CIF resolution compared to standard FMO H.264/AVC encoding. For the random access scenario, the bit rate demands requirements are reduced by as much as 57% for QCIF, 59% for CIF, and 66% for 4CIF resolutions. It is evident that the new coding tools found in the currently developed HEVC video standard will likely meet the goal set for 50% bitrate reductions for equivalent perceptual quality. Here, we would like to remark that the highest bitrate gains are observed for the highest 4CIF resolution, as the HEVC standard is optimized for high-resolution encodings (video resolutions ranged from 416x240 (WVGA) to 2560x1600 in [9], [14]). On the other hand, it is worth noting that bitrate savings are comparable for QCIF and CIF resolutions.

TABLE III – AVERAGE BITRATE DEMANDS AND OBJECTIVE MEASUREMENTS OF THE INVESTIGATED ENCODING SCHEMES FOR 4CIF RESOLUTION

	Bitrate (kbps)				**PSNR (dB)**			
QP	**36**	**32**	**28**	**24**	**36**	**32**	**28**	**24**
RA	108	193	362	673	34.7	36.8	39.4	42.2
LD	101	206	418	793	34.2	36.6	39.5	42.5
FMO	298	613	1203	2051	34.0	36.9	40.2	42.9
FMO ROI RS	197	381	684	1146	34.0	36.9	40.1	42.8

See Fig. 1 for acronyms.

When compared to the variable quality slice encoding scheme, HEVC also documents significant bitrate demands reductions. More specifically, it requires 48% and 42% less bitrates for QCIF resolution, for low delay and random access schemes respectively, 35% and 36% for CIF resolution, and finally 36% and 43% for 4CIF resolution. Clearly, the additional bitrate can be used for increasing medical video's diagnostic capacity, while it alleviates the requirement of defining diagnostic-ROIs prior to transmission. The latter can prove particularly useful in the absence of a back-channel when the clinically important regions are defined by the medical expert at the remote end, or by reducing complexity associated with executing algorithms for automated segmentation (see Fig. 2(f)).

Table III records the PSNR ratings and the associated bitrate demands for 4CIF resolution atherosclerotic plaque ultrasound videos. The key observation is that 4CIF resolution ultrasound videos encoded using HEVC, require significantly less bitrate than 1Mbps for all cases, providing for transmission over today's 3.5G wireless channels (typical upload data rates 500 kbps - 4 Mbps [4]) and beyond. It is expected that the HEVC video standard, linked with current advances in wireless networks (4G) will aid in the transmission of high-resolution medical ultrasound video for remote diagnosis and emergency incidents, at the acquired resolution and frame rates, which will rival the experience of in-hospital examinations.

B. *Clinical Evaluation*

A representative sample of 15 HEVC encodings for a QP of 28 (which is the diagnostically acceptable threshold defined in [6]) was evaluated by a medical expert. The medical expert was only asked to evaluate whether the HEVC encoded videos were of at least the same clinical quality as the H.264/AVC encoded videos. The objective was to verify the HEVC goal for reducing bitrate demands while not compromising perceptual (diagnostic) quality. In all cases, the medical expert noted that the HEVC encoded videos were of the same diagnostic quality, if not superior, to the H.264/AVC encoded videos.

V. CONCLUSION

This paper presents an initial evaluation of the high efficiency video coding (HEVC) standardization initiative for medical video communications. Experimental results show that the new video standard is likely to meet the set

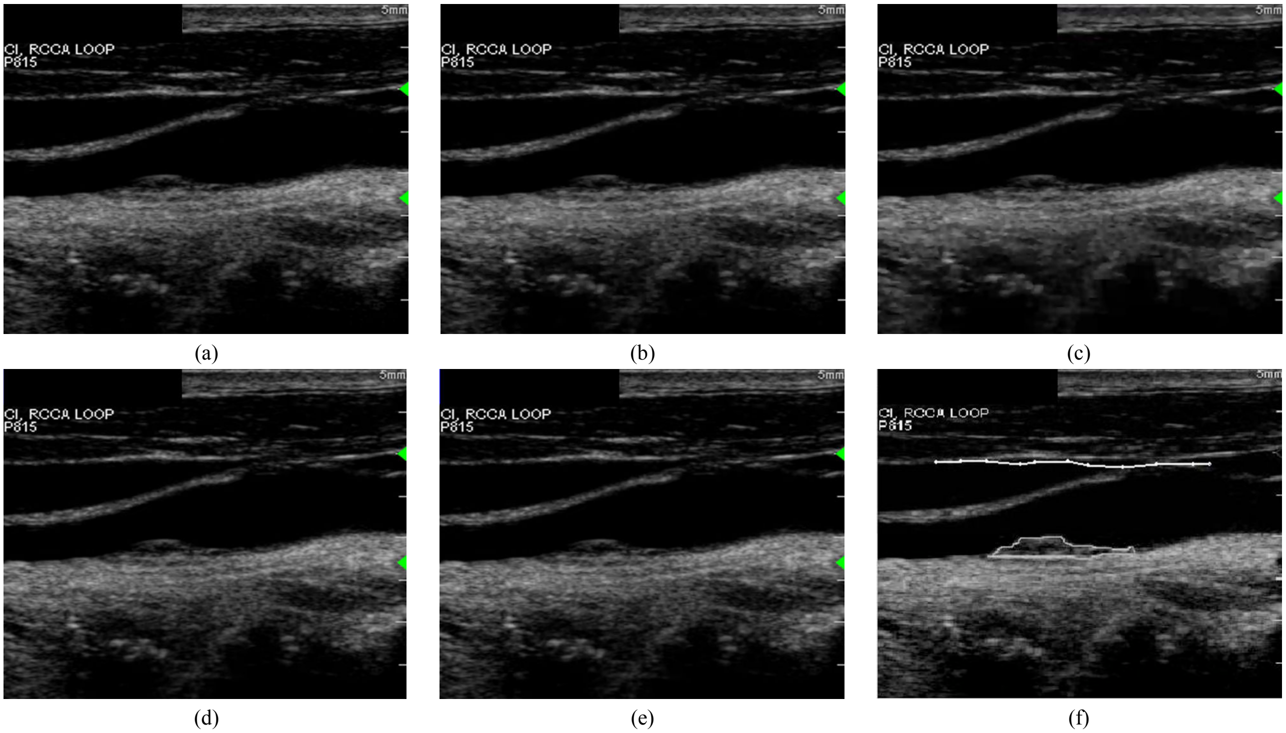

Fig. 2. Video image examples of HEVC and H.264/AVC encodings (4CIF@15fps, QP: 28). All videos are reconstructed at PSNR levels that exceed the clinically acceptable levels of [6]. (a) Original video image, (b) standard FMO H.264/AVC, PSNR: 39.8 dB, Bit Rate: 1,21 Mbps, (c) variable quality slice encoding, FMO ROI RS H.264/AVC, PSNR: 39.6 dB, Bit Rate: 701 kbps, (d) HEVC-Random Access main, PSNR: 39.4 dB, Bit Rate: 375 kbps, (e) HEVC-Low delay all-P main, PSNR: 39.6 dB, Bit Rate: 423 kbps, (f) automated plaque and artery wall pixel-level segmentation (CIF resolution).
[1]The black area on the upper left corner of each image has been manually inserted to hide the exam date (no personal information is displayed)

goal of 50% bitrate requirements reductions for equivalent perceptual quality. A series of five atherosclerotic plaque videos encoded at QCIF, CIF, and 4CIF video resolutions used in this study, document bitrate demands reductions over 50%, while the clinical evaluation verified that medical video's diagnostic capacity is not compromised. When used with modern wireless networks (4G), the HEVC standard is expected to provide for medical video communication at the acquired resolution and frame rate.

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