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M-Health Medical Video Communication Systems: An Overview of Design Approaches and Recent Advances

A. S. Panayides[1], *Member, IEEE,* M. S. Pattichis[2], *Senior Member, IEEE, A. G. Constantinides[1], Fellow, IEEE* and C. S. Pattichis[3], *Senior Member, IEEE*

***Abstract*— The emergence of the new, High Efficiency Video Coding (HEVC) standard, combined with wide deployment of 4G wireless networks, will provide significant support toward the adoption of mobile-health (m-health) medical video communication systems in standard clinical practice. For the first time since the emergence of m-health systems and services, medical video communication systems can be deployed that can rival the standards of in-hospital examinations. In this paper, we provide a thorough overview of today's advancements in the field, discuss existing approaches, and highlight the future trends and objectives.**

I. INTRODUCTION

M-health systems will significantly benefit from the emergence of the new high efficiency video coding (HEVC) standard [1] and 4G (LTE-Advanced and IEEE 802.16m) wireless networks upload data rates [2] that rival data rates of wired infrastructure. These advances will provide new opportunities and capabilities to current m-health systems and services (see Fig. 1) that were mostly based on the evolution of 3G cellular networks and the H.264/AVC standard [3]-[7]. Yet, despite the significant number of m-health studies, there has been very limited adoption in daily clinical practice [8]. A substantial constraint of 3G studies comes from the limited upload data rates that cannot support low-delay high-resolution and high frame rate medical video communications. In other words, current 3G approaches do not provide for an encoding setting that will rival the experience of in-hospital examinations.

As documented in [6], [7], 3G-based systems imposed bounds on incorporated source encoding parameters. Clinically acquired video resolution was usually down converted to CIF (352x288) resolution, while the frame rate was often restricted to approximately 15 frames per second. As a result, the medical video's diagnostic capacity did not meet the minimum requirement of 30 frames per seconds for effective, clinical motion assessment.

The new HEVC standard promises to deliver a 50% reduction in bitrate requirements over the current H.264/AVC standard [9] for videos of equivalent perceptual quality [10]. Thus, when deployed over network channels with the same bandwidth, the additional bitrate can be used for increasing diagnostic quality or for allocating more redundant bits for error resilience purposes. In addition, 4G wireless systems, incorporating most of the technologies found in 3.5G systems, provide reliable communications in stringent conditions, cater for high mobility video streaming, and accommodate for low delay communications needed for responsive emergency systems [11].

This paper provides an overview of the most recent m-health systems found in the literature. It documents the ever increasing trend for diagnostically relevant encoding, it highlights the connection between wireless transmission and diagnostic capacity, while it also describes how error-resilient and error-concealment techniques can be used to improve diagnostic performance over noisy networks with significant packet losses.

The rest of the paper is structured in the following way. Section II highlights design trends in m-health medical video communication systems. Section III summarizes the most important and most recent studies in the area. Finally, section IV provides the discussion and some concluding remarks.

II. M-HEALTH MEDICAL VIDEO COMMUNICATION SYSTEMS DESIGN APPROACHES

Beyond standard video compression methods, clinical video compression is also, *diagnostically driven*. Previously, in [6], [7], m-health studies were categorized into methods that employed diagnostic regions-of-interest (ROIs), and studies that did not use ROIs. In this paper, we generalize this concept by referring to *diagnostically relevant* encoding.

A. Diagnostically Relevant Encoding

Diagnostically relevant encoding exploits the properties of the incorporated medical video modality and its specific clinical application [12]-[15], [17], [18]. Such approaches can significantly improve coding efficiency [14], [15], [17], [18], using robust transmission mechanisms [12], [14], [18], or sophisticated error-resilience and concealment techniques [13], as described next.

B. Diagnostically Robust Transmission

Diagnostically robust transmission schemes employ adaptive algorithms for maximizing the clinical capacity of the communicated medical video modality. Such algorithms range from adapting to the wireless network's varying state [19], applying unequal error protection (UEP) schemes for protecting more strongly the diagnostically important video regions, such as forward error correction codes (FEC) [12],

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[1] A. S. Panayides and A. G. Constantinides are with the Department of Electrical and Electronic Engineering, Imperial College, London, UK (e-mail: {a.panagidis, a.constantinides}@imperial.ac.uk).

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

[3] C.S. Pattichis is with the Department of Computer Science, University of Cyprus, Nicosia, Cyprus (tel:+357-22892697, e-mail: pattichi@ucy.ac.cy).

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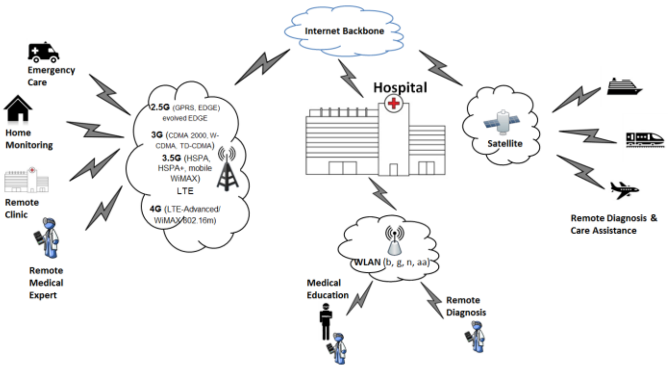

Fig. 1. M-Health Medical Video Communication Systems Applications Scenarios. Scenarios range from remote diagnosis and care in emergency incidents, home monitoring for the elderly and people with mobility problems, mass population screening, medical education, etc [22].

[14], employing selective retransmissions of clinically sensitive regions, using customized, clinically oriented protocols [14], etc.

C. *Diagnostically Resilient Encoding and Decoding*

This approach includes customizing the use of error resilience and concealment tools for enhancing the diagnostic robustness of the communicated medical video [17]-[13]. Intra-updating to match the beginning of each cardiac cycle, selective macroblock intra-refreshes within the diagnostic ROIs, redundant slices (RS) insertion only for slices that describe the diagnostic ROIs, as well as applying sophisticated error-concealment algorithms (as post-processing) for protecting more strongly the clinically important regions are some of the incorporated techniques.

III. RECENT ADVANCES IN M-HEALTH MEDICAL VIDEO COMMUNICATION SYSTEMS

In this section we discuss the latest advances in m-health medical video communications systems since the publication of [7], which reviewed 3G-based studies. The emergence of new 3.5G wireless channels have had considerable impact on the incorporated source encoding parameters, and hence the clinical quality of the communicated medical video. Higher upload data rates accommodate higher resolutions and frame rates that can now rival the clinically acquired setups. Table I depicts the most important and recent studies in the field of wireless medical video communications systems. These studies can be further categorized according to the afore-described diagnostically driven approaches. Here, we differentiate between diagnostically relevant encoding and systems that do not use diagnostic information.

A. *Diagnostically Driven M-Health Systems*

Flexible macroblock ordering (FMO) error resilience technique of H.264/AVC standard was used to define diagnostic ROIs for cardiac ultrasonography [12] and common carotid artery (CCA) ultrasound videos [17], [18]. FMO type 2 mode was modified accordingly to allow for variable quality slice encoding, subject to the slice's diagnostic importance.

In [12], UEP mechanisms based on FEC channel encoding schemes were employed to protect the clinically sensitive regions more strongly. Simulations performed over mobile WiMAX networks verified the error resilience of the proposed scheme.

The authors in [13] proposed the use of a sophisticated post processing error-concealment technique over the diagnostic ROI, for improving the diagnostic performance of the communicated ultrasound video. The method was evaluated over a simulated mobile WiMAX topology, and was found to achieve higher PSNR scores, at the expense of slightly higher computational complexity.

A very interesting study was described in [14] where a new transmission protocol was defined for the transmission of clinical ultrasound video, based on read-solomon (RS) FEC codes and retransmissions, termed real time clinical transmission protocol (RTCTP). Promising results were recorded during the experimental evaluation.

Exploiting the properties of B-Mode and M-Mode echocardiogram ultrasound video, the authors in [15] proposed a diagnostically relevant technique which reduced bitrate requirements for wireless transmission. Source encoding recommendations and associate bitrate demands for diagnostically lossless ultrasound videos were provided using a modified version of the clinical distortion index introduced in [16]. The modified clinical distortion index reduced assessment time while it maintained the efficacy of the clinical criteria's evaluation process.

In [17], [18], diagnostic ROIs were identified using automated segmentation algorithms for atherosclerotic plaque ultrasound video. The proposed diagnostically relevant encoding setup in the aforementioned studies documented significant bitrate demands savings for scalable resolutions. Toward this end, extensive experimentation in [17] showed that error resilient tools such as intra-updating and redundant slices insertion can deliver acceptable diagnostic performance even at high packet loss rates. Moreover, correlation investigation between subjective and objective ratings showed that new, diagnostically driven video quality assessment (VQA) algorithms are needed, since existing methods fail to correlate with clinical quality. Efficient mobile WiMAX network parameter selection for maximizing transmitted videos' clinical capacity was considered in [18]. Different scenarios were simulated for medium access control (MAC) and physical (PHY) layer characteristics, including service prioritization classes, modulation and coding schemes, fading channel's conditions, and mobility. Recommendations of use were based on clinical VQA.

B. *Non-Diagnostically Driven M-Health Systems*

Alinejad *et al.* [19] described a cross-layer approach for real-time adaptation to the wireless channel's varying state based on minimizing a cost function. The cost function was composed of source and channel encoding parameters, as well as objective VQA measurements. The approach was validated over commercially available HSUPA mobile cellular networks in the UK and mobile WiMAX wireless network using own equipment in a controlled environment. The latter wireless network achieved better objective VQA ratings while it provided for higher resolution medical video communication.

TABLE I
M-HEALTH MEDICAL VIDEO COMMUNICATION SYSTEMS USING MOBILE WIMAX AND HSPA 3.5G WIRELESS NETWORKS

	Author	**Year**	**Resolution, Frame Rate, BitRate**	**Encoding Standard**	**Medical Video Modality**	**Description**
Diagnostically Driven Systems	Martini *et al.* [12][1]	10	480x256@15fps 300 Kbps	H.264/AVC	Cardiac Ultrasound	Context –aware FMO encoding using unequal error protection (UEP).
	Debono *et al.* [13][1]	12	640x480 @ 25fps	H.264/AVC	Cardiac Ultrasound	ROI- based error concealment technique (post-processing) for maximizing clinical performance.
	Cavero *et al.* [14] [1,3]	12	720x576 @ 25fps, 200 kbps	SPIHT	Cardiac Ultrasound	Diagnostically resilient transmission scheme based on FEC RS codes and retransmissions using the RCVTP protocol.
	Cavero *et al.* [15] [1,3]	12	720x576 @ 25fps 40 kbps (M-mode), 200 kbps (B-mode)	SPIHT	Cardiac Ultrasound	Diagnostically-relevant SPIHT encoding and clinical evaluation protocol, index, and recommendations.
	Panayides *et al.* [17][1,3]	11	352x288 @ 15fps 10 videos: 197-421kbps	H.264/AVC	Carotid Artery Ultrasound	Diagnostically-relevant and resilient ROI encoding. ROI-driven subjective (clinical) and objective VQA correlation investigation.
	Panayides *et al.* [18] [1,3]	12	704x576@15fps Bitrate: 768 kbps - 1.5 Mbps	H.264/AVC	Carotid Artery Ultrasound	Diagnostically relevant encoding. Clinical evaluation of different network parameter settings over mobile WiMAX networks.
Non-Diagnostically Driven Systems	Alinejad *et al.* [19][2]	12	{176x144, 352x288} @ 10/20fps 220 kbps, 430 kbps, 1.3 Mbps	WMV	Cardiac Ultrasound	Cross-layer real-time adaptive technique over mobile WiMAX and HSUPA wireless networks.
	Hewage *et al.* [20][1,3]	11	NA, 50fps, NA	Multi-View H.264/AVC	Endoscopy Procedures	3D encoding investigating optimum packet sizes for LTE communications based on objective and subjective VQA.
	Khire *et al.* [21] [1,3]	12	720x480 @ 30fps, 125 kbps – 200 kbps	H.264/AVC	Maxillofacial Surgery Clips	Head-mounted camera for real-time surgical video streaming from disaster relief fields for tele-mentoring purposes. ROI-based functionality.
	Panayides et al. **Error! Reference source not found.**[1,3]	13	{176x144, 352x288, 560x416} @ 15fps, 64 kbps – 768 kbps	H.264/AVC	Carotid Artery Ultrasound	Open-source software for real-time communications. VFD calibration before objective evaluation.
	Panayides *et al.* [23] [1,3]	12	176x144, 352x288, 704x576 @15fps 64 kbps - 1.5 Mbps	HEVC	Carotid Artery Ultrasound	HEVC vs H.264/AVC and HEVC vs H.264/AVC variable quality slice encoding used in [17] comparison
	Panayides *et al.* [24][1,3]	13	560x416 @ 40fps, up to 2 Mbps	HEVC	Carotid Artery Ultrasound	Ultrasound video denoising as a pre-processing step. HEVC vs H.264/AVC comparison.

3D medical video encoding using H.264/MVC (multi-view coding) and transmission over LTE wireless networks was attempted in [20]. Preliminary results suggested that 3D medical video communication is viable using current compression and wireless transmission advances.

Based on x264 codec, the most efficient and open-source H.264/AVC implementation, the authors in [21] proposed an ROI-based video encoding system. The system targeted low-bitrate communications for surgical tele-mentoring in disaster relief and military combat fields. While the concept of this study would normally be classified under diagnostically driven design, we decided to include this particular study in non-diagnostically driven systems. The reasoning is that the particular setting can be used for a plethora of emergency surgical interventions taking place at remote ends. An interesting feature of the proposed system is that the video camera transmitting the surgical video was mounted on the surgeon's head. An open-source platform for reliable medical video communications was developed in **Error! Reference source not found.**. The platform was based on widely used open-source software tools and was evaluated over commercial HSPA wireless networks in Cyprus. Rigorous testing involving a plethora of source encoding parameters concluded that diagnostically acceptable medical video communications can be realized using open-source software. The clinical evaluation showed that while clinical motion was affected by temporal freezes introduced by real-time communications, error-free cardiac cycles allowed confident diagnosis. Toward this end, variable frame delay (VFD) algorithm which removes temporal mismatch between compared frames was used as a pre-processing step for objective VQA measurements.

Significant bitrate demands reductions achieved by the new, HEVC standard were depicted in [23], [24]. HEVC performed better that the proposed variable quality slice technique described in [17], which used H.264/AVC. Moreover, preliminary results in [24], showed that using despeckle filtering in ultrasound video as a pre-processing step, attained additional bitrate gains, while it enhanced the diagnostic capacity of the communicated ultrasound video.

IV. DISCUSSION AND CONCLUDING REMARKS

This paper reviews the major advances in m-health medical video communication systems. The leading trend is the use of diagnostically driven methods. Diagnostically driven systems exploit the properties of the underlying medical video modality to provide for increased coding efficiency, while maximizing error robustness. In most cases, the H.264/AVC video coding standard was used.

The new HEVC standard is expected to replace the current use of the H.264/AVC. Similarly, 3.5G wireless networks were used in the majority of the reviewed studies as mobile WiMAX, and especially HSPA cellular networks are the current best available wireless channels.

With 4G systems already deploying, m-health medical video communication systems are likely to enter a decisive new era in the near future, utilizing HEVC encoding over 4G networks. The latter is expected to aid the adoption of such systems and services in daily clinical practice. Already, currently reviewed studies materialize medical video transmission at the clinically acquired resolution and frame rates. More specifically, reviewed studies documented high resolution, high frame rate, and high bitrate communications. This is attributed to the considerably increased 3.5G upload data rates compared to the 3G upload data transfer rates. With HEVC targeting beyond high definition (HD) medical video streaming and 4G rates more than doubling the available bandwidth, m-health systems that can approximate the in-hospital experience are foreseen in standard clinical practice.

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