32nd Annual International Conference of the IEEE EMBS
Buenos Aires, Argentina, August 31 - September 4, 2010

An overview of Recent End-to-End Wireless Medical Video Telemedicine Systems using 3G

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Abstract—**Advances in video compression, network technologies, and computer technologies have contributed to the rapid growth of mobile health (m-health) systems and services. Wide deployment of such systems and services is expected in the near future, and it's foreseen that they will soon be incorporated in daily clinical practice. This study focuses in describing the basic components of an end-to-end wireless medical video telemedicine system, providing a brief overview of the recent advances in the field, while it also highlights future trends in the design of telemedicine systems that are diagnostically driven.**

I. Introduction

The history of telemedicine systems [1] is tightly coupled with the continuous growth of computing technologies and systems in general. Computer technology is rapidly advancing according to Moore's law [2]. The most relevant advances include increases in processing speed and memory capacity, at lower costs. As anticipated, this has also resulted in significant advances in mobile health systems and services [3], leading to the design of a broad spectrum of new applications [4]. Such applications range from remote diagnosis and care, ambient assisted applications and computer aided diagnosis, to medical data analysis and electronic health records, wearable devices and clothing, implantable sensors and robotics for healthcare.

Telemedicine systems depend on data compression technology for transmission over the wireless network infrastructure. Current state of the art video coding standards such as H.264/AVC [5], provide for efficient (size wise) and timely (real time) encoding. On the other hand, increasingly available bitrate through revolutionary wireless transmission channels [6], realize communications previously only available to wired infrastructures. Coverage is extended practically across the globe with the latest 3G and satellite systems.

Despite this rapid growth of telemedicine systems, wireless channels remain error prone, while the continuous bitrate and compression efficiency increase is soon met by demands on data bandwidth. Absence of efficient video quality assessment (VQA) metrics for the evaluation of the transmitted medical video contribute to the challenges associated with streaming adequate diagnostic quality video at a required bitrate.

The objective of this paper is to summarize current wireless medical video telemedicine systems and highlight the trends and challenges associated with implementation of diagnostically-based systems.

The rest of the paper is organized as follows: Section II describes the essential components of telemedicine system architecture along with incorporated software and hardware tools for research purposes. Section III provides a synopsis of the recent advances in end-to-end wireless medical video telemedicine systems using 3G, while section IV highlights the importance of diagnostically driven developed systems. Finally, section V gives some concluding remarks.

II. A Telemedicine System Architecture

Figure 1 depicts the essential components involved in the real time transmission of medical ultrasound (or trauma) video. The basic setup supports the wireless transmission from paramedics to the physicians on call. The video is also transmitted to the hospital premises for the necessary preparations to take place for the patient's admission (in case of emergency).

We next provide a summary of all the steps that are involved. Following the acquisition, raw medical video is pre-processed so that it's suitable for encoding. This step typically involves resolution and frame rate adjustments as well as format conversion. Then, the video is compressed by the video coding layer (VCL) of H.264/AVC. This is followed by adaptation of the encoding bitstream to the underlying transmission medium (H.264 to RTP/UDP/IP), handled by the network abstraction layer (NAL) of H.264/AVC. Following wireless transmission through the best medium, the reverse

This work was funded via the project Real-Time Wireless Transmission of Medical Ultrasound Video ΠΕΝΕΚ/ΕΝΙΣΧ/0308/90 of the Research and Technological Development 2008-2010, of the RPF Cyprus.

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procedure is followed for decoding, post-processing and error recovery. The presence of a back channel provides for network adaptation and for the medical expert to convey feedback to the paramedic staff.

For emergency cases, the goal is to provide an appropriate response within the first hour (golden hour). Here, the use of wireless video transmission is expected to help speed up the process. This can have significant implications for the patient's recovery and/or survival.

A. *Hardware and Software tools*

Acquisition of the medical video is done via a portable ultrasound device and/or a high quality camera. Source encoding can be performed using the JM H.264/AVC reference software [7], the most popular open source Codec for H.264/AVC. It incorporates most parameters and profiles defined in the standard, is well documented and frequently updated. It is mostly recommended for research and on-demand streaming as it's not optimized for real time encoding. For real-time encoding, FFMPEG [8] is a widely used open source platform. It includes previous coding standards (MPEG and H.26x series) and can also be used for a plethora of pre-processing tasks, facilitating a large number of multimedia conversion algorithms. Video streaming can be achieved using the cross platform VLC media player (which acts as a streaming server), hosted by videolan [9]. Here, pre-processing, source encoding, and broadcasting are to be carried out by a single laptop in the ambulance.

For research purposes, it is often sought a controlled environment (compared to actual streaming), where parameters involved in video streaming (such as loss rate, delay, jitter, available bitrate, mobility, end-user devices, etc.) can be easily modified in order to measure different possible aspects that can affect the design of a developed application. This kind of environment can be found in network simulators like OPNET [10] or NS-2 [11] (open-source). To import video traffic in network simulators, video traces are employed. Video traces [12] aim to map the encoded video bitstream realistically, in order to simulate video transmission in a way that does not diverge from the actual transmission, enabling the researchers to investigate the performance of their experimental setup.

III. End-to-End Wireless Medical Video Telemedicine Systems Using 3G

We classify research in mobile health (m-health) systems into:

1) Systems focusing on the encoding aspect,
2) Systems exploiting transmission aspects and network infrastructures,
3) A combination of the aforementioned approaches where both source encoding and transmission are taken into consideration for the design of the system, and finally
4) Application oriented developed systems.

For the purposes of this paper, we are interested in exploiting systems designed for the efficient encoding and transmission of medical video over wireless channels (summarized in Table I), and more precisely over the 3rd generation (3G) of mobile communication networks. These systems are further categorized as diagnostic region-of-interest (ROI) and non-diagnostic ROI based systems. Section IV summarizes this trend and provides future directions. We believe that the need for diagnostic quality validation will drive growth in end-to-end telemedicine systems.

A. *Diagnostic Region of Interest (ROI) based Systems*

The basic idea here is to allocate more bandwidth to regions of interest (ROIs). At the same time, far less bandwidth is allocated to the rest of the video. The most basic challenge is to identify and allocate appropriate bandwidth to the ROIs.

In [13], ROI coding was based on a visual attention saliency map. In [14], scalable ROI coding is used for adaptive transmission of medical images and video snapshots over simulated wireless networks. Context awareness is introduced based on patient's status monitoring and resource availability of the underlying transmission medium.

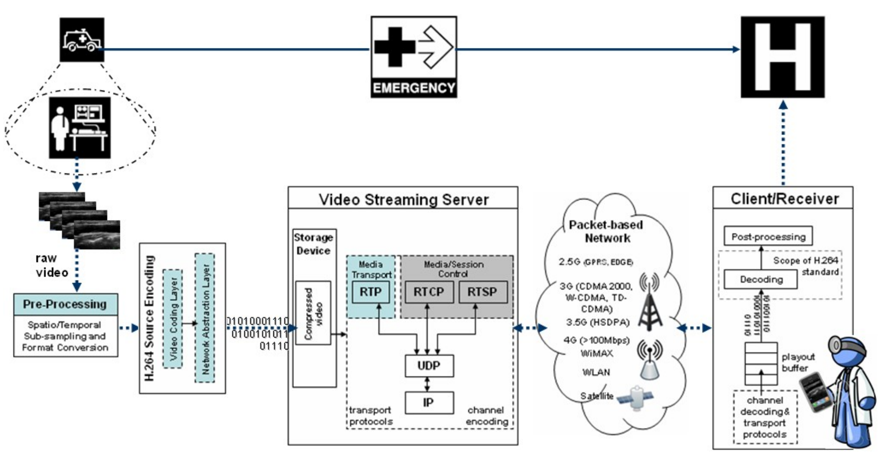

Fig. 1. An H.264 based wireless medical video telemedicine system.

A spatially-varying encoding scheme where quantization levels are spatially varying as a function of the diagnostic significance of the common carotid artery (CCA) ultrasound video is proposed in [15]. Diagnostic ROIs for carotid ultrasound medical video are derived using segmentation algorithms, which are then used as input for Flexible Macroblock Ordering (FMO) slice encoding. Redundant Slices (RS) utilization increase compressed video's resilience over error prone transmission mediums.

The design of an elastic ROI coding which incorporates different quantization levels for ROI and non-ROI, targeting Diagnostically Lossless (DL) encoding over bitrate limited wireless channels utilizing physician expert feedback is presented in [16]. An encoder states diagram for different quality levels is designed and a state transition is considered every Group of Pictures (GOP). A number of medical video modalities are used to demonstrate the proposed technique.

B. Non-Diagnostic Region of Interest based Systems

Identifying suitable regions of interest can be difficult. In this section we summarize systems that provide diagnostic quality without using ROIs.

A portable tele-trauma system that provides for simultaneous transmission of trauma video, medical images, and ECG signals is presented in [17]. Media transformation, data prioritization, and application-level congestion control allow adaptation to network conditions.

Scalable video coding employing spatiotemporal scalability for ultrasound videos over different wireless networks is found in [18]. Wireless transmission medium parameters are examined (data rate, packet loss, delay, jitter and latency) and their correlation with diagnostic quality is depicted.

In [19], the authors develop an QoS Ultrasound Streaming Rate Control (Q-USR) algorithm. Based on the concept of reinforcement learning, the frame rate is varied as a function of the state of the network, while at the same time conforming to a pre-defined medical Quality of Service (QoS) criterion. The proposed mechanism is validated utilizing the robotic tele-ultrasonography system OTELO [19].

The OTELO system is also used in [20], where multilayer control is employed to optimally tune source and channel encoding parameters. Frame rate, quantization step, intra-refreshing period and average code-rate channel protection are the key parameters that are varied in these experiments which, however, are initially performed over WLANs.

IV. Diagnostic Validation

Diagnostic validation is a required step in the development of wireless telemedicine systems. The primary goal of such systems is to provide for adequate diagnostic information for the medical expert to reach a confident diagnosis, irrespective of channel conditions.

Thus far, quality assessment, both objective and subjective [22], was solely based on conventional VQA metrics (such as

TABLE I
END-TO-END WIRELESS MEDICAL VIDEO TRANSMISSION SYSTEMS USING 3G

	Author	Year	Real-Time / Simulation	Encoding Standard	Medical Video Modality	Comments
Diagnostic ROI-based Systems	Tsapatsoullis *et al.* [13]	07	Simulation	MPEG-2/ MPEG-4	Common Carotid Artery (CCA) Ultrasound video	A saliency-based visual attention ROI coding for low bit-rate medical video transmission.
	Doukas *et al.* [14]	08	Simulation	H.264/ AVC	Skin Legion and MRI images, Trauma video snapshots	Scalable ROI encoding. Adaptive transmission based in context awareness (patient status and network state).
	Panayides *et al.* [15]*	09	Simulation	H.264/ AVC	Common Carotid Artery (CCA) Ultrasound video	FMO variable quality slice encoding, tightly coupled by each region's diagnostic importance. Diagnostic ROIs derived using segmentation algorithms. Clinical rating system that provides for independent evaluations of the different parts of the video.
	Rao *et al.* [16]*	09	Simulation	MPEG-2	Pediatric respiratory distress related videos	Elastic ROI coding which incorporates different quantization levels for ROI and non-ROI, targeting diagnostically Lossless (DL) encoding over bitrate limited wireless channels utilizing physician expert feedback.
Non-diagnostic ROI-based Systems	Chu *et al.* [17]	04	Real-Time	M-JPEG	Trauma video	Real time trauma video transmission. Network adaptation enabled through media transformation, data prioritization, and application-level congestion control.
	Pedersen *et al.* [18]*	09	Real-Time	H.264/ AVC	Echocardiogram	Spatiotemporal scalability over different wireless networks. Diagnostic quality and how it's affected by network parameters.
	Istepanian *et al.* [19]*	09	Real-Time	H.264/ AVC	Echocardiogram (OTELO system)	QoS Ultrasound Steaming Rate Control (Q-USR) algorithm based on reinforcement learning that satisfies a medical QoS criterion.

*Diagnostic validation criteria

PSNR and MSE, recently SSIM, etc. [22]). Most of today's well established objective VQA algorithms cannot efficiently assess high motion videos [24] and –most importantly- diagnostic information. Consequently, there is a growing demand for new, diagnostically relevant quality assessment techniques that will fulfill certain -common- diagnostic quality criteria, while at the same time being able to efficiently adapt to individual requirements of different medical modalities.

In [15], [16], [18], [19] we observe this shift towards the establishment of diagnostic validation criteria in the evaluation of the transmitted medical video.

We expect to see a growth in clinical evaluation rating systems. Basic guidelines of subjective quality evaluation of conventional videos [25] may be of particular interest. We next want to see the establishment of new quality assessment algorithms that correlate with clinical ratings. If this happens, we can use the new quality assessment algorithms to estimate diagnostic quality. To guarantee a minimum diagnostic quality we will then have a minimum bandwidth requirement.

V. Conclusion

Telemedicine applications contribute to patient's quality of life, while emergency telemedicine systems are likely to aid in the critical battle against time for a patient's treatment and recovery. It is foreseen, that different medical modalities will be exploited in the near future, utilizing the already gained knowledge by on-going research activities, leading to new telemedicine applications.

In the design of an efficient video based telemedicine system, many different aspects need to be considered. Efficient encoding, adaptation to varying network conditions, and resiliency to data losses introduced by error prone transmission channels are key factors for a successful setup. In conjunction with medical experts, minimum clinical evaluation criteria must be determined, which the system must be able to provide, for a confident diagnosis to be reached.

This paper tries to give an overview as to the aforementioned design considerations, highlighting current trends and future challenges. Wireless medical video telemedicine system architecture is described, case studies incorporating most of the discussed features are presented (see Table I), while the need for setting diagnostic validation criteria is emphasized. Given the rapid growth of such systems and services, incorporation in daily clinical practice is anticipated in the near future.

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