Efficient Medical Video Streaming by Pre-Processing and Network Traffic Prioritization in Real-Time

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***Abstract*— Developing advanced healthcare applications to cater to the requirements of an ever-growing population has become one of the key areas of research in engineering. One major application in this area is medical video streaming, which is often used for remote monitoring of patients. Medical video streaming helps to overcome geographical barriers and offers medical services at the convenience of the patient. However, as medical videos carry critical and time-sensitive information, retaining the quality and reducing latency during transmission is paramount for accurate medical diagnosis. This paper presents the concept of effective medical video streaming, which incorporates novel methods in video pre-processing, video compression, and transmission of medical data over optical networks.**

Keywords— Medical video streaming, pre-processing of a medical video, video compression, High priority medical traffic, Difference service priorities, Elastic Optical Networks.

I. INTRODUCTION

Transmission of real-time medical data over communication networks (i.e., medical video streaming) has garnered much interest in recent times [1]. Modern applications such as telemedicine and remote surgeries often rely on high-quality medical video streaming services [2-4]. Such services are also used by medical practitioners in developing countries to monitor patients living in rural areas [1,5]. Medical video streaming services can also be used to transmit scanned videos (e.g. ultrasound, endoscopy, etc.) between two geographical locations in real-time, thereby reducing commuting time and cost incurred by both the patient and the practitioner [6,7].

However, when the medical video streams travel through transmission media (e.g. optical fibers, wireless), they will experience physical layer impairments and external noise [8]. As a result, the quality of the received signal will deteriorate and, thus, produce erroneous medical diagnosis [9]. Therefore, ensuring the quality of service (QoS) during transmission is important. Furthermore, medical applications are time-sensitive and, therefore, any delays should also be minimized [10]. In addition, as high-resolution medical videos typically carry a large amount of data, modern compression techniques should be applied to ensure that the capacity of the communication network does not get overwhelmed [1,5].

To tackle the aforementioned issues pertaining to medical video streaming, in this concept paper, we propose a three-stage solution: medical video (1) pre-processing, (2) compression, and (3) transmission. The remainder of the paper is structured as follows. First, we analyze the state-of-the-art techniques that can be used to compress individual frames of a medical video stream while preserving its quality. Specifically, in Section II, we analyze the pre-processing techniques. Second, we investigate how modern video compression technologies can be used effectively to reduce the bit rates of high-quality medical videos. The advantages of such compression techniques are discussed in detail in Section III. Third, we study how to optimize resource allocation to increase the efficiency of the transmission medium and network throughput. Thus, an impairments-aware novel resource allocation scheme is proposed for a network that handles high priority medical data in Section IV. The Flow chart of the proposed work is given in Fig. 1.

II. MEDICAL VIDEO PRE-PROCESSING

In this section, the requirement of video pre-processing for medical video streaming is emphasized. Since the medical videos contain important data that contributes to accurate diagnosis and treatment, maintaining high quality while streaming is required. Medical videos are distorted with various types of noise which results in a reduction of quality that may lead to misdiagnosis. Therefore, it is essential to filter out noise before diagnosis or treatment [11]. In any

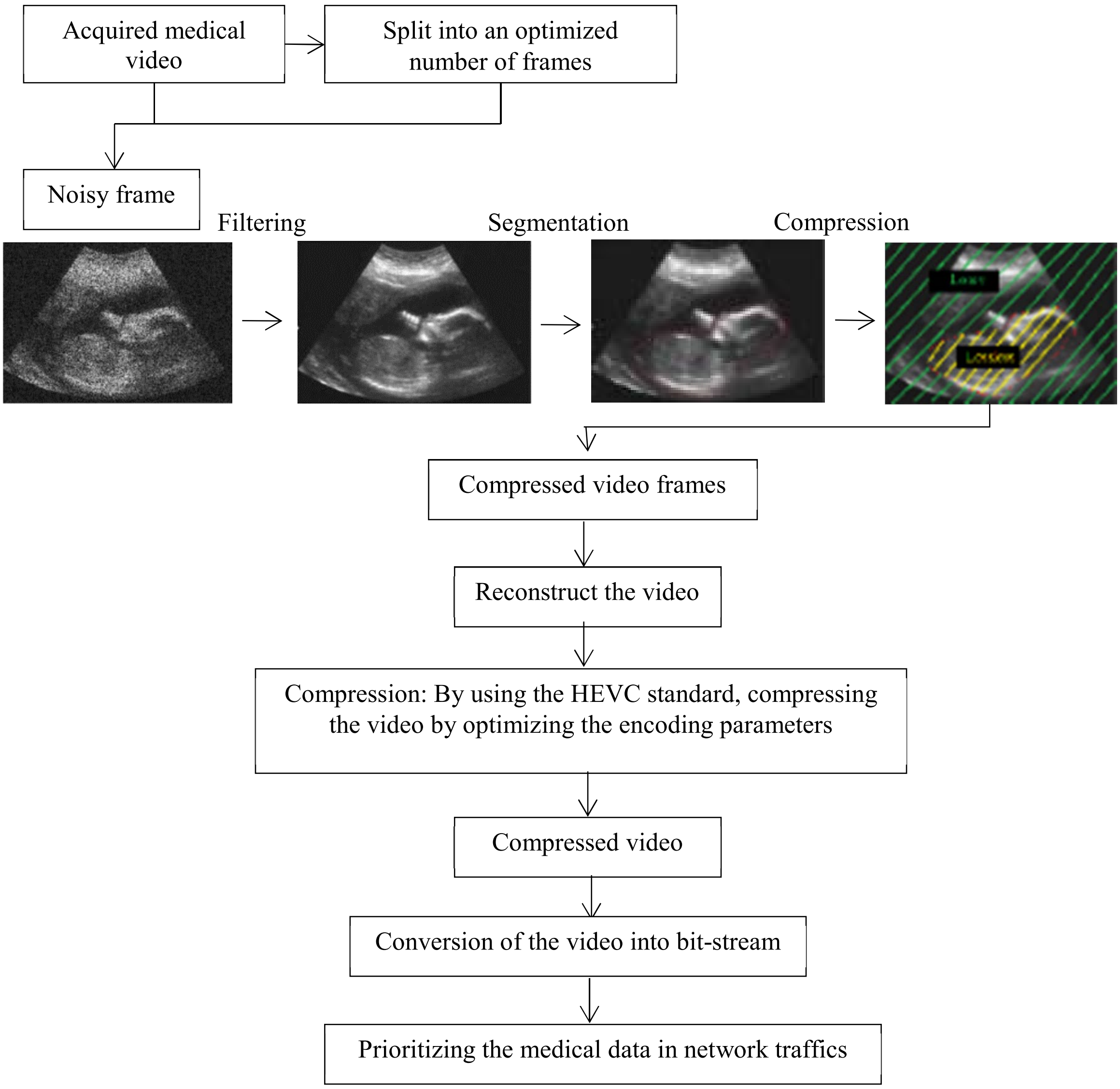


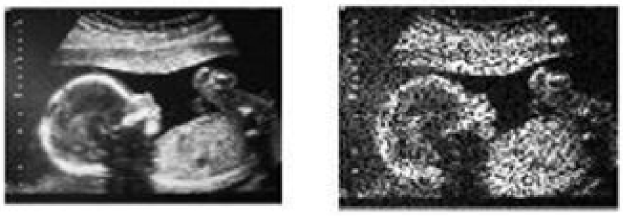
Fig. 1: Flow chart of the proposed work.

medical video, each frame consists of Region-of-interest of-interest (ROI), non-ROI and background. The ROI is the key area in a frame that contains the required medical data for an accurate diagnosis and treatment. Hence, maintaining the quality and preserving data in ROI is necessary [12]. Further, de-noising also aids in the accurate segmentation of each frame in the video. The de-noised video is segmented to extract the ROI for efficient compression while maintaining the quality and preserving the data.

The ROI in a medical video might continuously change its position, orientation, and size. For efficient compression, it is required to detect the ROI accurately. In order to achieve the above requirement, medical video is first split into frames. The number of frames in a video affects the real-time data transmission as the processing time varies accordingly. Hence, the requirement of automatic selection of the optimum number of frames per unit time of the video without affecting the medical application is identified as a key problem to be addressed. Once the video is split into frames, each frame is de-noised, then compression is carried out in the segmented frame. Finally, the pre-processed frame sequence is converted back into a video in order to obtain the pre-processed video to transmit. Ultrasound videos are distorted with speckle noise due to interference of transmitted and reflected signals occurring at transducer aperture [13].

According to the literature, there are different types of techniques that have been introduced to remove speckle noise both in the spatial domain and transform domain. Wavelet transform-based methods are prominent amongst other transform-based techniques such as Fourier transform-based and Hilbert transform-based methods [11,14,15].

Subjective results always play a major role in medical diagnosis and treatment. Therefore, it is important to understand the relationship between subjective and objective results. In order to compare the performance of the filters subjectively and objectively, five spatial domain filters, namely, Lee filter, Kuan filter, Frost filter, Median filter and Weiner filter [11] were implemented. The output of each filter is shown in Table 1. The original image and the noisy image which is distorted by speckle noise with the variance of 0.3 is given in Fig. 2.



A B

Fig. 2: A – Original ultrasound image, B – Noisy ultrasound image distorted with speckle noise variance of 0.3.

Objective analysis is carried out by comparing Peak-signal-to-noise-ratio (PSNR), Mean Square Error (MSE) and Structural similarity Index (SSIM), which depends on the smoothing capabilities and noise reduction of the filter.

Yet, subjective results depend on how good the filtered video in visual interpretation. Subjective results are analyzed by collecting data from the experts in the relevant field. The results show that the Weiner filter has the minimum computational complexity with almost equal objective results.

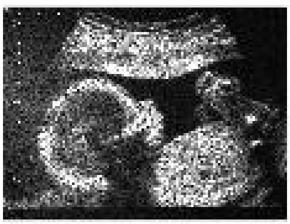
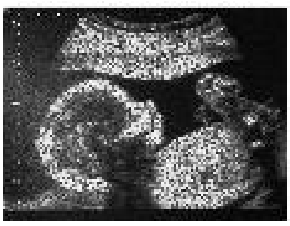
However, the visual quality of the filtered image is poor. Thus, it is worth to mention that analyzing subjective results is essential in selecting a de-noising filter for medical images. The objective and subjective results show that it is essential to develop an advanced filter which provides better results in visual quality as well as in computational time.

The next step is to develop a time-efficient and reliable method to segment medical images/ frames while preserving vital information in the ROI when compressing the image/ frame, hence the video.

TABLE 1 DISCUSSION OF THE OUTPUT OF IMPLEMENTED SPATIAL DOMAIN FILTERS

<table>
<tr><th>Filter</th><th>Filtered output image</th><th>Computational time</th><th>Discussion</th></tr>
<tr><td>Lee</td><td></td><td>1.6 s</td><td rowspan="5">The Computational time of implemented filters, namely, Lee, Kuan, Frost, Median, and Weiner filter is analyzed. The minimum computational time is taken by the Weiner filter which is 0.9 s while the maximum computational time is taken by Frost filter which is 28 s. The Lee, Kuan and Median filters took 1.6s, 27.8s, and 2.2 s respectively.

However, it is noted that there are differences in visual outputs of each filter which might lead to misdiagnosis. Even though, Weiner filter provides better computational time, the visual quality of the filtered image is poor. Therefore, it is essential to analyze subjective results also in selecting a de-noising filter.

By considering both objective and subjective results, we can see that it is essential to develop an advanced filter that provides better results in visual quality as well as in computational time.</td></tr>
<tr><td>Kuan</td><td></td><td>27.8 s</td></tr>
<tr><td>Frost</td><td></td><td>28 s</td></tr>
<tr><td>Median</td><td></td><td>2.2 s</td></tr>
<tr><td>Weiner</td><td></td><td>0.9 s</td></tr>
</table>

III. Medical Video compression

The advances in medical video compression technologies have enabled the delivery of high-quality video over various transmission platforms. Despite these recent advancements [5], several challenges arise in maintaining the quality of the medical video especially in areas that have access to slower data rates. Furthermore, as the available bandwidth in both wireless and wired transmission media is limited, compression of medical video is important to reduce the network load and prevent data losses. Since medical videos carry sensitive data, which needs to be delivered accurately for effective diagnosis [1,5], a reduction in bit-rate (i.e., compression) will lead to degradation in the quality of the video and produce erroneous results [1]. Therefore, an efficient compression technique should be applied to reduce the total bit-rate while preserving the required Quality of

TABLE 2 RESULTS OF THE COMPRESSED VIDEO WITH DIFFERENT QP VALUES

QP Values	20th frame of the Encoded Video with corresponding QP value	MOS given by the medical Experts	Bit-Rate	Result Analysis
8		3.8	41850 Kbps	Though the MOS value is considerable bit-rate is high. (Not desirable)
16		4	13522 Kbps	High MOS value with High bit-rate (Not desirable)
20 (Optimized QP value)		4	6358 Kbps	High MOS value which indicates high video quality with considerable bi-rate. As a result, this QP value is selected.
40		2.5	375 Kbps	Low MOS which indicates low video quality though the bit-rate is very low. (Not-desirable)
50		1.3	90.2 Kbps	Very low MOS value which indicates very poor video quality. (Not-desirable)

Service (QoS). Therefore, this has become the primary focus of several research groups in recent times [1,16]. The results of [1] and [5] indicate that among available video compression techniques High-Efficiency Video Coding (HEVC) provides the best results in terms of both quality and performance.

In our proposed system, we use the HEVC compression technique as it gives 50% of bit-reduction by maintaining the same quality by comparing it with its previous compression standard H.264. The motive behind selecting HEVC for our work is also based on several other factors. HEVC is specially designed for High Definition (HD) video coding. Hence, it is more suitable to encode the acquired ultrasound video without affecting the resolution and frame rate.

Moreover, HEVC is the first standard, which supports parallel processing tools, which can provide real-time encoding for transmitting HD videos. Importantly, HEVC supports ultra-high definition 8k×4k (7680×4320) video resolutions, which makes the quality of the compressed ultrasound video similar to the original clinical resolution. These advanced features in the HEVC makes this standard very suitable for telemedicine-applications [16,17].

As an initial step in our work, a clinically acquired ultrasound video is studied thoroughly with the help of a medical expert. As ultrasound video contains lots of spatial and temporal redundancies, compressing ultrasound video is necessary. Thus, HEVC is used as the compression standard in our work. The primary objective of our work is to optimize the encoding parameters, mainly the Quantization Parameter (QP) values, to achieve a higher compression rate (i.e., reduced bit size) while retaining the quality.

In our initial experiment, a human abdomen ultrasound video sequence that has a resolution of 1920×1080 in yuv format with a frame rate of 25 fps was encoded using HM 16.0 reference software. Following the recommendations of the Joint Collaborative Team on Video Coding (JCT-VC), the QP values were selected from the range of 0-51. One effective QP value can be optimized by comparing the quality and bit-rate of the video.

Finally, the quality of the encoded videos is analyzed using subjective and objective analysis. For the subjective analysis, the encoded videos are scored by six medical experts by comparing them with the original video according to their perception. Based on their perception each video encoded with different QP value is scored as follows,

5- Excellent

4- Good

3- Fair

2- Poor

1- Bad

From the obtained score, Mean Opinion Score (MOS), is calculated. Then, QP which gives the high-quality video (from the MOS value) with considerable bit-rate is selected as the optimized encoding parameter. The resultant encoded video is transmitted across a simulated communication network. The results are depicted in Table 2.

IV. Medical video transmission

A communication network generally handles traffic (i.e., bitstreams) with different service priorities [18]. As traffic that carries medical data (e.g. medical video), which can often be used for remote surgeries, are both time-critical, susceptible to channel noise and losses, it is indeed important to assign them a higher priority and make them travel through the shortest possible routing path from source to destination. In terms of network infrastructure, optical networks are better suited to carry medical data as they offer much higher bandwidth, less processing times, higher transmission speeds, and less channel noise. However, even the most advanced next-generation elastic optical networks (EONs) have a limited capacity and they only can carry a finite number of connections [19]. In such situations (e.g. during peak traffic hours), to provide the space for an incoming high priority connection an existing low priority connection may have to be altered (i.e., disrupt) or dropped. As the existing resource allocation schemes are not optimized for a network with the traffic of different service priorities, we propose a novel resource allocation scheme [20]. To be able to distinguish the traffic of different priorities, in our work, there are two priority levels as low priority (LP) and high priority (HP). Thus, HP traffic that carries medial data is assigned priority value 1 while other traffic streams are given priority value 0.

The objective of our proposed algorithm can be summarized as follows [20]: by taking into account continuity, contiguity, and quality of transmission (QoT) constraints of an EON [19], and minimum latency constraint for HP connections, precisely performs routing, modulation, and spectrum allocation (RMSA) to each incoming HP and LP traffic connection to increase spectrum efficiency. The spectrum efficiency of an EON is defined by the used maximum subcarrier index (i.e., capacity) [10,19,22]. At the beginning of the algorithm, the capacity of an optical fiber is assigned the value of 10 subcarriers and allowed to expand when the need arises. A lower maximum subcarrier relates to higher spectrum efficiency.

To ensure the quality of received medical video streams, the minimum latency constraint is guaranteed by routing each incoming HP connection via the shortest path. If an HP connection cannot be routed via the shortest path due to insufficient spectrum bandwidth in the optical fibers, the proposed algorithm will make alterations (i.e., disruptions) to an existing LP connection(s) and create the relevant space. However, disruptions (i.e., re-tuning, re-modulating) can lead to excessive processing, cost, and energy consumption [21]. Therefore, to minimize the disruptions, the algorithm first attempts to re-route LP using the same modulation format and the spectrum band. If failed, the algorithm attempts to re-route LP using the same modulation format and different spectrum band. If all attempts failed, the algorithm re-modulates and re-tunes the LP and routes it along a different path. If a traffic connection cannot be served by making alterations to existing LP connections, the capacity of the optical fibers is increased and the connection is appended to the edge of the spectrum band in the optical fibers along the desired routing path. In order to compare the results of the proposed algorithm, an already existing spectrum allocation algorithm [19] is taken as the benchmark and modified slightly by applying the shortest path constraint for HP connections. The relevant network parameters were extracted from [19].

TABLE 3 RESULTS FOR 6-NODE NETWORK

Percentage of High priority traffic connections in the network	Percentage of disruptions made to existing low priority traffic connections	Efficiency increased in resource utilization
25 %	6.25%	18.75%
50 %	12.5%	27.31%
75 %	6.09%	17.09%

The experiment is carried out for a 6-node network and the results are presented as a percentage of total traffic in Table 3. For the 6-node network, it was observed that compared to the benchmark algorithm, our method increases spectrum efficiency by 27.3% while causing only 12.5% of LP connections being disrupted. In fact, in this method, the percentage of dropped HP connections are null and the percentage of dropped LP connections is less than 1%. Hence, our proposed algorithm showed excellent results in serving HP medical data while increasing the spectrum and causing minimum disruptions to existing LP connections.

V. Discussion and Conclusion

Medical video streaming carries time-sensitive critical information, and to perform accurate diagnosis, it is important to retain quality and reduce incurred delays during transmission of medical video streams. In this paper, the proposed three-stage solution using novel methods in video pre-processing, video compression, and transmission of medical data over optical networks showed that both objective and subjective results should be accounted for when developing the advanced de-noising filter for video pre-processing. In addition, a higher video compression rate is achieved, while retaining quality, by appropriately optimizing the encoding parameters, mainly the Quantization Parameter (QP) values. Finally, this paper elaborates on a heuristic algorithm that showed a maximum increment of 27.31% in spectrum efficiency in an elastic optical network carrying high-priority medical video streams with minimum latency constraint.

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