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Compression of Patient's Video for Transmission Over Low Bandwidth Network

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ABSTRACT In this paper, we propose a solution for video transmission over a low-bandwidth network that enables a physician to take in charge of remote trauma patient. We propose and analyze a method based on an H.264 compression scheme that relies on transmitting high-quality video of a moving and dynamic region of interest while scarifying quality in the background. Our method is motivated by the problem of limited bandwidth usually encountered in air-to-ground communication channels. We propose to use a region of interest with smoothed edges to increase the video quality of the transition between the regions of various qualities. The moving region of interest, covering the torso and the head, is segmented and tracked by using the skeleton information provided by a Kinect camera. Our proposed compression scheme respects the real-time, low-complexity, and interoperability constraints. We have analyzed the results of our method obtained with various bit rate targets and have shown that a visual assessment of a patient is achievable over very low bandwidth.

INDEX TERMS Video compression, telemedicine, region of interest, body skeleton, H.264, emergency medical services.

I. INTRODUCTION

Telemedicine is defined by "the remote delivery of healthcare services and clinical information using telecommunications technology. This includes a wide array of clinical services using internet, wireless, satellite and telephone media" [1]. Telemedicine encompasses many applications such as teleconsultation when a patient or a primary care physician consults a specialist, remote medical training, and remote patient monitoring and assistance [2]. It is based on exchanging medical information using electronic means such as audio conversation or video conferencing.

Video transmission of a remote patient is needed in various telemedicine scenarios; it enables a physician to assess the patient's state and to take in charge the medical situation. Video transmission of a patient is needed to take in charge a remote medical situation where there is no specialist on site; it is also needed to take in charge a trauma patient during an emergency evacuation by ground or air transportation. We are motivated by emergency medical services and more specifically by the air-to-ground communication [3]. Emergency medical services are important while transporting a trauma patient; they are also being considered for onboard deployment of commercial civilian flights as an attempt to avoid their costly deviation in the case of a medical emergency. The incidence of in-flight emergencies on commercial flights is around one per 753 inbound flights, or one per 39600 inbound passengers, according to [4]. This observation demonstrates the importance of having an efficient video acquisition, compression and transmission system, to allow early recognition of critically ill or injured passengers, as well as to follow the situation, to stabilize it, and mitigate the risks. To achieve this goal, the system must allow the ground station to assess the general mobility of the patient, the capacity to open his/her eyes, the movement of the body members as well as the chest. Nowadays, the hospital's team has no choice but to rely on a proxy for voice-transmission of clinical information. This condition limits the ability of the medical specialists on the ground and the onboard paramedical crew in their capacity to act.

Air to ground communication channels have bandwidths that are limited and cannot be controlled [3]. Since the

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video size is too significant to be transmitted, video codecs are required to compress the transmitted images. H.264 is a compression standard defined by ITU/ISO/IEC [5]. Also known as Advanced Video Coding (AVC), it is a block-oriented motion-compensation and one of the most popular video compression standard. Several aspects of the H.264 make its usage very interesting. It is based on the principle of profiles and provides a better video compression than the older MPEG-2 standard. Besides requiring low resources, H.264 allows defining precise compression parameters, depending on the application requirements regarding quality and reactivity. It is also possible to control, in a non-exhaustive manner, color information, intra, and inter-frame prediction, the number of frames used for prediction, the block size and the quantization measure. Although it is not the latest codec released by the FFMPEG [6] group (H.265 being the latest [7]), it is embedded in almost every video decoding device, which ensures a very large interoperability.

To transmit diagnostically relevant videos, with no loss in quality, over channels of limited and uncontrolled bandwidths, we are considering compressing the video with different qualities: a high quality in a Region of Interest (ROI) to preserve its clinical value while at the same time, scarifying the quality in the background. Consequently, we are interested in a method for achieving ROI compression with H.264, where the ROI would be compressed with high quality combined with a lower quality background.

To segment the ROI, we propose to use the skeleton information, obtained with the Kinect camera [8]. Despite being a gamepad originally, the Kinect camera has rapidly emerged as a reference device for video data acquisition, in various fields, such as the medical one. Its vast recording capabilities mostly explain this popularity (video, depth, infrared, sound, etc.), all integrated into a compact device, which use is made easy by the Microsoft Software Development Kit (SDK) and by its affordable price. The main component of the Kinect is its video camera which offers a full High Definition (HD) (1920 × 1080 pixels) resolution in a progressive and Red Green Blue (RGB) format, with a frequency of 30 Hz. Kinect also includes an infrared sensor for depth measurement, with a resolution of 512 × 424 pixels, at 30 Hz. We have chosen to use the Kinect camera in this emergency setting primarily for its capability of providing depth information that can be used to measure other clinically relevant information [9]. The depth information can be used to evaluate the patient's respiratory function for example.

In our case, we need a simple stream with high interoperability and low delay. Therefore, we will analyze the H.264 profiles and parameters to choose and justify how to use it to achieve our compression objectives. The additional power brought by H.265 is not justified for our low complexity and real-time implementation.

In this paper, we analyze and propose a compression method using the H.264 standard to enable a physician take in charge a remote trauma patient, over a limited bandwidth communication channel. Our proposed compression method is based on transmitting high-quality video of a moving and dynamic ROI while scarifying quality in other regions, to meet the limited bandwidth constraint usually encountered in air-to-ground communication channels. We also propose to use a ROI with smoothed edges, to increase the video quality of the transition between the regions of various qualities. Moreover, we propose to segment and track the moving ROI by using the skeleton information provided by the Kinect camera.

The paper is organized as follows: in Section II we present a literature review of methods for ROI video compression; in Section III we present our methodology; in Subsection III-A, we present and analyze the H.264 compression standard in order to choose a compression profile and justify this choice; in Subsection III-B, we present our ROI implementation with H.264; in Subsection III-C we describe our rate control algorithm; in Section IV we present the results obtained with our proposed method and discuss the minimum bandwidth requirements needed to achieve a good quality ROI suitable for emergency medical video communication; in Section V we summarize the method and discuss the results.

II. LITERATURE REVIEW

In the recent literature, we can identify different contributions to the ROI video coding.

Leiva [10] proposes the use of salient points for automatic ROIs extraction. This method is too computationally intensive and cannot be used in real time without a hardware implementation. In our case, the skeleton information provided by the Kinect camera is fast enough to be used for the ROI segmentation.

The work of [11] and [12] deal with improving the rate control algorithm of the encoder. Chen *et al.* [11] use a weighting coefficient to define the significance of the ROI with respect to the background, and then use it to calculate the Mean Absolute Difference (MAD) of the ROI and the background. The authors did not provide any specific method to define the weighing parameter. The method developed in [12] uses a Rate Distortion Optimization (RDO), to determine the Quantization Parameter (QP). Their methods require high computational resources; drawbacks have been noted, such as an overall decreased quality in the presence of complex motion and faulty predictions.

Debono *et al.* [13] and Panyavaraporn and Cajote [14] use resilience tools to encode the ROI. The method developed in [13] applies resilience tools only on the ROI zone defined by a physician, without directly modifying the quantizers, to keep low computational requirements while enhancing the visual quality. It is specific to worldwide interoperability for microwave access (WiMAX), and its limitation lies in the quality difference between the ROI and non-ROI that cannot be large. Panyavaraporn and Cajote [14] use the error resilience tool at the encoder known as Flexible Macroblock Ordering (FMO) to define an explicit map representing the ROI. This method has the same limitations as the previous one, in addition to requiring additional bits to transmit the explicit map.

The methods developed in [15] and [16] are based on the wavelet transform. Selvi and Nadarajan [15] use the movements in the images to define the ROI, considering they represent arteries in angiograms images. It is based on removing the low-level contourlet coefficients for the region that is considered diagnostically insignificant. According to the authors, the proposed technique is not suitable for encoding texture information. They also noted the limited compression ratio, in comparison to other methods based on Discrete Cosine Transform (DCT). The method developed in [16] segments the ROI that is manually defined by the user by identifying its wavelet coefficients in all sub-bands; it uses a Set Portioning in Hierarchical Trees (SPIHT) compression known for its low power consumption while maintaining good quality performance. These methods are not suited for our application as we are interested in low bandwidth networks where a high compression ratio is needed.

Wu *et al.* [17] propose to use three characteristics to define the ROI, forming a vector. These characteristics are only adapted to black and white medical images, and not to textured information, which makes it not suitable for us.

The methods developed in [18] and [19] deal with the implementation of ROI using classic DCT, one applied to H.265 and the other to H.264. Chen *et al.* [18] chose to transmit two H.265 streams, including an enhancement layer. It is highly complex, not suitable for real-time applications and targets very high quality and high-bandwidth applications. Finally, the method proposed in [19] introduces a low-complexity, H.264-compliant, and Diagnostically Lossless (DL) solution to enable mentoring of surgical procedures in a very-low-bandwidth scenario. Although they target an application close to ours, they choose to use fixed ROI, which limits the flexibility of the solution. They also noted a ''weird depth effect'' reported by physicians, when the edge between the ROI and non-ROI is too sharp.

Our proposed method uses the skeleton information provided by the Kinect camera to define the ROI. The ROI is dynamic and its segmentation is simple and fast. Moreover, we use the standard H.264 compression along with one single parameter to dictate the difference in quantization between the ROI and the background. This difference depends on the available bit rate and is automatically estimated from the overall quantization returned by the encoder on the complete previous frame. This estimation is easy to implement with existing encoders and does not require complex calculations which makes it suitable for real-time implementations. Furthermore, we propose a smooth transition between the ROI and non-ROI by gradually changing the quantizers of the blocs in the transition region.

III. METHODOLOGY

Our goal is to record the video sequence of a person, to track the torso ROI, and to encode the video sequence with an ROI of higher quality than the background. This section is divided in three subsections: in Subsection III-A we review the H.264 video encoding and discuss the various encoding profiles in order to choose the one that best suits our application; in Subsection III-B we present how a ROI can be implemented in accordance with H.264; in Subsection III-C, we describe our rate control algorithm that preserves the quality of the ROI while scarifying the quality of the surrounding region.

FIGURE 1. Video encoding steps.

A. VIDEO ENCODING

A video codec aims to compress video data by eliminating spatial and temporal redundancies. A codec does motion compensation, transformation, quantization and entropy coding (Fig. 1). The first step is a prediction that can be either temporal (inter prediction) or spatial (intra prediction). Temporal prediction is made using one or more reference frames. It aims to compensate changes due to motion between two frames, by producing a field of pixel trajectories, and a residual, per block. In H.264, blocks, also called macroblocks, are constituted of 16x16 pixels. Sometimes, large motion makes the temporal prediction useless, and a spatial prediction is created instead. Spatial predictions are made using previous samples from the same frame. The second step is a transformation that converts the image or motion compensated residual data into the transformed domain. The transform can be either the DCT or Discrete Wavelet Transform (DWT). The third step is a quantization controlled by a scalar that sets the QP where larger QP results in a lower quality compressed result. The subsequent step consists in reordering the stream and zero encoding it; that is grouping together the non-zero coefficients, in a specific scan order, to compact the data and efficiently encode the zeros. The last compression step is a binary encoding. The most efficient binary encoding techniques are Context-Adaptive Variable-Length Coding (CAVLC) [20] and Context-Adaptive Binary Arithmetic Coding (CABAC) [21]. The latter is the most efficient, but it is more computationally intense; it is only available in the more advanced profiles of the codec and is not available in basic implementations.

Using the ×264 encoder requires choosing a compression profile. A profile defines a set of features that can be tuned to suit specific classes of applications. It specifies conformance points to enable interoperability between the encoder and the decoder; it allows a decoder to recognize the requirements needed to decode the encoded stream. A discussion about profiles is presented in [20] for conversational services, entertainment video applications, and streaming services by considering bit rate and latency requirements. We present and discuss hereafter the available profiles to choose and justify the one that we will use.

TABLE 1. Capability of each profile to handle the list of constraints.

	CBP	BP	Ext.	Main	High
Low latency	✓✓✓	✓✓✓	✓	✓	✓
High compatibility	✓✓✓	✓✓✓	✓	✓	✓
Low hardware	✓✓✓	✓✓✓	✓✓	✓	✓
High data loss	✓	✓✓✓	✓✓✓	✓	✓
High compression	✓	✓	✓✓	✓✓✓	✓✓✓

Legend: ✓ = low; ✓✓ = medium; ✓✓✓ = high

In terms of color depth, we have chosen the standard one that uses 8 bits and not 10 nor 14 bits, because we considered that higher color resolution was not needed. Regarding the chroma format choice, we have chosen the standard one, which is 4:2:0. These two choices, being the most basic ones, do not affect the profile choice.

The high profiles (High, High 4:2:2 and High 4:4:4) achieve a compression ratio that is undoubtedly useful for low-bandwidth applications like ours; however, they require extensive computational resources and lack compatibility.

The Main Profile is a candidate profile for our application. To achieve an efficient compression, it allows the use of a powerful entropy encoding scheme (CABAC), and bi-prediction (B slices). CABAC requires additional computational resources. The use of B slices induces delay, which may not be tolerated by the physician. Moreover, the Main Profile has a drawback that is its incompatibility with the resilience tools. In our case, we are targeting wireless data transmission that exhibits an important risk of errors.

Extended Profile, on the other hand, offers the resilience features in addition to B prediction. However, it does not support CABAC. It is the most scalable solution and a good trade-off between efficiency, robustness and computational cost. However, the lack of implementation of the extended profile in decoders limits its compatibility.

Baseline Profile offers the three resilience features (FMO, Arbitrary Slice Ordering, and Redundant Slices) but does not support B slices. It is a valuable choice if we want to prioritize compatibility and make use of the resilience features.

Constrained Baseline Profile (CBP) does not offer the resilience features, but it is the most compatible profile with most decoders.

Table 1 lists the discussed profiles. Their capabilities to handle the list of constraints are categorized by low, high or medium.

To ensure large compatibility, low computational requirements as well as low delays, we choose the Constrained Baseline Profile. Resilient features for future improvements can be added and the stream would become a Baseline Profile (BP) one. If the delay induced by the B frames is acceptable and the decoder is compatible, the Extended Profile could be used. If, moreover, resilience features are not needed, the Main Profile could be used to profit from the CABAC feature.

Considering the constraints discussed above, we choose to use and test the CBP.

FIGURE 2. An acquired image with the person standing in the centered position.

B. ROI IMPLEMENTATION

We use ×264, a standard compliant, free software library developed by VideoLAN. It is the most popular open source software for encoding streams into H.264. We propose to modify the implementation of the ×264 codec in order to compress an ROI with higher quality.

We use the Kinect camera and SDK from Microsoft, to generate a lossless video as an input for our encoder. We also use the skeleton information provided by the Kinect to define and track an ROI that comprises the torso region. To achieve the torso tracking, we retrieve the joints coordinates of: the head, the left and right shoulders, and the left and right hips. Each joint is defined by two coordinates (X, Y) in the pixels frame of reference. The ROI in each frame is defined as a rectangular region as shown in Fig. 2. Our method does not change the encoder rate control algorithm. It can be used with any encoder as it consists in imposing a differential quantization on blocs within or outside the ROI.

The quality of a given macroblock is affected by the QP that is applied during the quantization step. If QP increases, the visual quality decreases. Quality is usually measured by assessing the peak signal to noise ratio (PSNR). Other measurements exist. To reflect the subjectivity in quality assessment, the human visual systems (HVS) is taken into account by using the Structural SIMilarity index (SSIM). If QP increases quality decreases, however a more precise relationship between quality and quantization depends on the video frames content. Models expressing the relationship between quality and QP can be developed [22] in order to achieve specific quality-based compression. Each encoder has its algorithm to determine the QP to apply in order to achieve either a particular bit rate or a specific quality [23], [24].

QP can take 52 values, from 0 to 51 [20]. A QP of 51 yields to high compression and usually results in a terrible visual quality. Roughly, it is commonly accepted that a QP of 17 results in a quality very close to visually lossless (or near-lossless); a QP of 20 results in a very good quality; a QP of 23 results in a good quality; a QP of 26 results in an average quality and a QP of 29 results in an acceptable quality.

We are interested in achieving relative qualities: a higher quality compression in the ROI relative to the background. Therefore, let ΔQP be defined by:

$$\Delta QP = QP_{\text{non-ROI}} - QP_{\text{ROI}} \tag{1}$$

where ΔQP is a QP offset, and it represents the difference between the QP applied to the ROI (QP_{ROI}), and the QP applied to the background ($QP_{non-ROI}$).

We propose to control the compression by setting the ΔQP of each macroblock depending on its location, whether it is part of the ROI, part of the background, or part of the transition region between the ROI and the background. To illustrate how we have used ΔQP to control the compression quality, let us consider some specific examples:

- In the case of narrow bandwidth, the QP of the background would be 51 (the lowest quality possible). If we consider a ΔQP of 24, then the QP of the ROI macroblocks would be 27, if the available bandwidth allows it. The visual quality of a macroblock quantized with a QP of 27 would be considered acceptable.
- If the bandwidth is narrower, the quality of the background cannot be decreased further; therefore, the quality of the ROI would be decreased, by the encoder, by increasing its QP. The QP of the ROI could be increased until reaching 51. A QP of 51 results in an unrecognizable video of a much-degraded quality that would look like a degraded still image.

Our ROI implementation consists of the following steps:
1 - For each frame, allocating a memory space to hold an array of quantizer offsets for all the blocks in the frame;
2 - retrieving the ROI joints coordinates from the skeleton;
3 - expressing the coordinates in the macroblock reference;
4 - identifying the macroblocks that belong to the ROI;
5 - setting the offset value of the ROI macroblocks;
6 - setting the offset value of the macroblocks that define the transition region between the ROI and the background according to a smoothing Gaussian function.

The use of the Gaussian function results in a smooth decrease of quality between the ROI and the background. It is introduced to meet our goal of smoothing the edges of the ROI, and to avoid therefore the "weird depth effect" reported and discussed in [19]. The Gaussian is a function of a macroblock distance to the ROI.

We use the code submitted on videolan.org [25] to implement our ROI compression based on the use of quantizer offset per macroblock of 16x16 pixels. We set the offset to a default value of 24; this results in a quantization step sixteen times smaller in the ROI, as compared to the background. The relationship between QP and the quantization step is logarithmic; an increase of 6 in QP results in an increase of quantization step size by a factor of 2 [26]. The relationship between QP and the quantization step (Q_{step}) is:

$$Q_{\text{step}} = 2^{(QP/6)} \tag{2}$$

An increase of the quantization step results in a reduction of bit rate as well as a reduction in quality.

C. DIFFERENTIAL RATE CONTROL IMPLEMENTATION

In a narrow bandwidth situation, our compression algorithm will try to preserve the quality of the ROI while scarifying the quality of the surrounding region. In the case of extremely limited bandwidth, the codec will reach the maximum compression of the surrounding region. It will then start diminishing the quality of the ROI, regardless of the quantizer offset setting.

When the bandwidth is high enough to allow a maximum visual quality in the ROI, it becomes interesting to explore the possibility of increasing the quality of the surrounding region, or in other words the quality of the overall image. Allocating additional bits to the ROI would not enhance the overall quality of the image. However, increasing the quality of the surrounding region would be interesting.

We propose to allow ΔQP to be less than 24, so the quality of the non-ROI could increase. Therefore, we vary ΔQP with respect to the quality of the ROI. Ideally, we would need to measure the ROI visual quality. A possible solution would imply to decode the result and to calculate the error between the original image and the decoded image inside the ROI. This solution would have required the use of a decoding step that is external to the encoder implementation.

We propose a different solution that, we believe, is more straightforward. Our proposed solution does not require any external step and does not interfere with the encoder algorithm. It can be used with any encoder. It is based on using an available measurement from the encoder: the global mean QP of the previous frame ($QP_{meanf-1}$).

We define a linear ΔQP as a function of $QP_{meanf-1}$. To define a line, we need to define two points for that line. To choose the first point, we apply the following reasoning:

$$\Delta QP = 0 \tag{3}$$

$$QP_{\text{meanf-1}} = 20 \tag{4}$$

In fact, we set $\Delta QP = 0$ when the visual quality of the overall image is very good. By setting $\Delta QP = 0$, there is no ROI, and the mean visual quality of the image applies to the ROI as well.

The second point is defined as follow:

$$\Delta QP = 24 \tag{5}$$

$$QP_{\text{meanf-1}} = 26 \tag{6}$$

To explain the rationale behind the choice of this second point, let X be the size of the ROI with respect to the size of the whole image. Based on the empirical linear rate-distortion model, the number of bits needed for encoding is inversely proportional to the quantization step. The number of bits needed to encode the whole frame is the sum of bits needed to encode the ROI and the non-ROI. Therefore:

$$X/Q_{\text{step\_ROI}} + (1 - X)/Q_{\text{step\_nonROI}} = 1/Q_{\text{stepf-1}} \tag{7}$$

where Q_{step_ROI} is the quantization step of the ROI, Q_{step_nonROI} is the quantization step of the non-ROI, and $Q_{stepf-1}$ is the quantization step of the whole frame, estimated

TABLE 2. QP distribution by available bandwidth.

Case	$QP_{meanf\text{-}1}$	ΔQP	Description
1a	≥ 27	≤ 24	Extreme low bandwidth
1b	[26;27]	24	Low bandwidth
2	[20;26]	[0;24]	Medium bandwidth
3	≤ 20	0	High bandwidth

from the previous one. With the objective of ensuring a good quality inside the ROI, $QP_{ROI} = 20$; this results in $X = 47\%$, from the equations described previously and by setting $QP_{non-ROI} = \Delta QP + QP_{ROI} = 44$. In other words, the choice of this second point ensures a good quality ROI for a region whose area is almost half the image size when $QP_{meanf-1} = 26$. If the ROI size is smaller than half the image size, its quality would be better.

By varying ΔQP, we ensure that, when high bandwidth is available, the bandwidth is not wasted on a visually imperceptible quality improvement inside the ROI zone, but is rather used to enhance the non-ROI zone.

In summary, we consider four cases depending on the evaluation of $QP_{meanf-1}$. Table 2 shows the different cases in terms of available bandwidth. These are:

1. Extreme low bandwidth

When $QP_{meanf-1}$ is higher than 27, this indicates a low bandwidth situation with a saturation of the codec. It is depicted in the first line of Table 2. We set $\Delta QP = 24$. However, the real ΔQP is less than 24 because the codec can reach its limits (extreme low bandwidth).

2. Low bandwidth

When $QP_{meanf-1}$ is equal to 26 or 27, this indicates a low bandwidth situation. It is depicted in the second line of Table 2. We set $\Delta QP = 24$.

3. Medium bandwidth

When $QP_{meanf-1}$ is between 20 and 26, we set ΔQP linearly between 0 and 24.

4. High bandwidth

When $QP_{meanf-1}$ is less than 20, we set ΔQP to 0.

IV. RESULTS AND DISCUSSION

We have evaluated our method for different bandwidths and have compared the results obtained with the Main and the Baseline profiles.

First, we tested our solution with a very restrictive bandwidth of 64 Kbit/s corresponding to a narrow bandwidth connection. These results are presented and discussed in Subsection IV-A. Then, we tested our solution with a bit rate that varied between 128 and 2048 Kbit/s by doubling the bit rate at each test, in order to cover low to high available bandwidth situations. These results are presented and discussed in Subsections IV-B.1 – IV-B.5 for target bit rates of 128, 256, 512, 1024 and 2048 Kbit /s respectively. Each target bit rate was tested and results compared for the Main and the Baseline profiles. Each test was conducted as follows: 1- a target bit rate and a specific profile are set; 2- $QP_{meanf-1}$ as measured by the encoder is reported to determine the case as per Table 2; 3- the encoding speed as calculated by the encoder is reported; it is analyzed with respect to the frame rate to determine whether real-time encoding is achieved; 4- the achieved bit rate as obtained by the encoder is reported and compared to the specified target; 5- the actual ΔQP as obtained by the encoder is presented. The actual ΔQP varies as it depends on the complexity on the video. In the presence of motion, the video is more complex and ΔQP would be higher. Therefore, we have reported the range of ΔQP obtained. Furthermore, to quantitatively evaluate the results obtained with our method, we measure, present and compare the PSNR in Subsection IV-C.

Acquisitions were realized on Windows using the acquisition software used in [26]. Fig. 2 shows one acquired frame.

We are interested in testing our method by tracking and compressing the ROI in various bit rate situations, mainly low bandwidths. Therefore, we have acquired one video in our laboratory. Our goal being to test our method in a controlled experimental environment before testing it on real patients. The same video was used to report the results obtained with various bit rates. It consists of one person whose torso and arms move. The ROI is delimited by the shoulders, hips and head joints as depicted in Fig 2. The arms motion is part of the background. In the video a person starts in a centered position and then: 1 – moves to the left; 2 – moves to the right; 3 – knees down; 4 – stands up; 5 – leans left; 6 – and leans right. We generated a video from the recorded series of images. The images had a resolution of 960x540 (quarter HD). The first encoded frame corresponded to the first skeleton joint encoded.

In addition to reporting and comparing various measures achieved by the encoding step, the visual quality of the encoded videos is assessed by comparing ROI and non-ROI. We have also measured the PSNR inside the ROI and have compared it with the non-ROI compression method. This comparison is reported for a very low bandwidth situation for all frames. The mean PSNR was also compared and is reported for all bandwidth situations (Subsection IV-C).

A. VIDEO ENCODING AT EXTREMELY LOW BANDWIDTH

We tested our solution for a target bandwidth of 64 Kbit/s. A barely acceptable quality in this environment would be a very encouraging result. We compressed the video using ×264 by: 1 – setting the target bit rate to 64 Kbit/s; 2 – using the baseline profile, which automatically turned into Constrained Baseline Profile because of the resilience features being disabled by default; and 3 – using the slower preset, which ensured that all the options offered by the profile would be reasonably used.

Table 3 shows the results obtained for a target bit rate of 64 Kbit/s with the Baseline and the Main profiles. The results obtained using the Baseline and Main profile are

TABLE 3. Encoding results for Baseline and Main profiles at 64 Kbit/s.

Profile	Target bit rate	$QP_{meanf-1}$	Enc. Speed (f/s)	Output bitrate (Kbit/s)	ΔQP
Baseline	64	32.69	100.53	54.95	24
Main	64	30.38	70.24	55.44	24

FIGURE 3. A moving (left) and a motionless (right) patient, using Baseline Profile at 64 Kbit/s.

FIGURE 4. A moving (left) and a motionless (right) patient, using Main Profile at 64 Kbit/s.

presented in Fig. 3 and 4 respectively. In each of these figures, the left picture shows a moving scene, and the right picture shows a static scene.

As we can see in Fig. 3, the ROI is not acceptable in terms of details but allows limited visual feedback that could be usable by a physician in extreme conditions.

We tried to improve this result by using the Main Profile instead of the Baseline Profile, because of its higher compression ratio thanks to the use of B frames and a more efficient entropy coding technique – CABAC. We obtained a better visual quality for the same bandwidth. However, this was achieved at the expense of a 20% higher encoding time and additional delays. The delays are the result of the bi-prediction scheme of B frames, which takes previous frames as references, and future ones as well. Indeed, the decoder must wait for all frames used as references by the current frame before being able to decode it. If the reference frame is a future one, this induces a delay. If the computational power is not a constraint and the receiver is compatible, using the Main Profile with disabled B frames to avoid more delays but enjoying the better entropy coding, can be an appropriate choice. If, also, we want to prioritize compression over the delay, we can use the Main Profile with B frames option enabled.

Delay is indeed, a non-negligible transmission characteristic. In conversational applications we usually use the very restrictive "zero latency" tuning, which disables a lot of features that induce delays; this has a very bad impact on the visual quality achieved for the same bandwidth. In our case, it made the ROI zone entirely visually unacceptable below 150 Kbit/s. Considering that for our medical use case the quality is much more important than a delay of few seconds (while the audio channel can be real time), zero latency is not optimum for our application. However, a tradeoff must be made between quality, computational requirements, and delay, by setting the choice of the profile, the use of B frames and the preset parameter.

FIGURE 5. A moving (L) and a motionless (R) patient, using Baseline Profile at 128 Kbit/s.

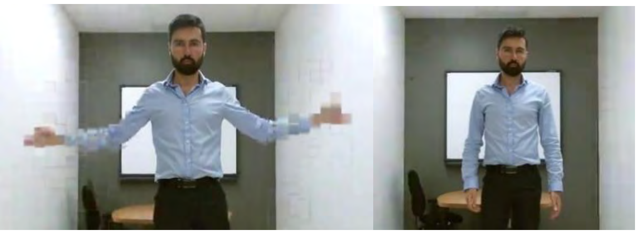

FIGURE 6. A moving (L) and a motionless (R) patient, using Main Profile at 128 Kbit/s.

Fig. 4 shows the results obtained with the Main Profile. The results are visually acceptable, even at a bit rate as low as 64 Kbit/s. The motionless scene is very sharp and allows an assessment of the whole patient's body, including his/her eyes. In case of motion, a good visual assessment can also be made, for example, to track the movement of the lips and the eyes.

B. VIDEO ENCODING AT HIGHER BANDWIDTHS

We evaluated the results at different bit rates. We have compared the visual quality obtained in four situations: 1 – moving patient compressed with the Baseline profile; 2 – motionless patient compressed with the Baseline profile; 3 – moving patient compressed with the Main profile; 4 – and motionless patient compressed with the Main profile.

1) TARGET BIT RATE OF 128 Kbit/s

Table 4 shows the results obtained for a target bit rate of 128 Kbit/s with the Baseline and the Main profiles. $QP_{meanf-1}$ is just at the limit of the linear zone of our algorithm ($QP_{meanf-1}$ is around 26). For the Baseline test, ΔQP stays at 24 because the $QP_{meanf-1}$ remains over 26. For the Main profile (with a better compression efficiency),

TABLE 4. Encoding results for Baseline and Main profiles at 128 Kbit/s.

Profile	Target bit rate	$QP_{meanf-1}$	Enc. Speed (f/s)	Output bit rate (Kbit/s)	ΔQP
Baseline	128	26.61	86.83	114.5	24
Main	128	25.39	53.86	114.0	17-24

TABLE 5. Encoding results for Baseline and Main profiles at 256 Kbit/s.

Profile	Target bit rate	$QP_{meanf-1}$	Enc. speed (f/s)	Output bit rate (Kbit/s)	ΔQP
Baseline	256	23.53	64.57	238.3	12-18
Main	256	22.59	35.77	239.1	7-15

TABLE 6. Encoding results for Baseline and Main profiles at 512 Kbit/s.

Profile	Target bit rate	$QP_{meanf-1}$	Enc. speed (f/s)	Output bit rate (Kbit/s)	ΔQP
Baseline	512	21.79	40.23	495.3	5-13
Main	512	21.20	20.81	510.8	0-18

the differential rate control algorithm is in the linear zone, allowing ΔQP to vary between 17 and 24. This means that with an effective bandwidth of only 114 Kbit/s, we reach a good quality for the ROI zone, which is very impressive with regards to the encoding speed. It is fast enough for real-time communication. The visual quality shown in Fig 5 and 6 confirms this assessment.

2) TARGET BIT RATE OF 256 Kbit/s

Table 5 shows the results obtained for a target bit rate of 256 Kbit/s with the Baseline and the Main profiles. In this scenario, the algorithm is in its linear zone ($20 < QP_{meanf-1} < 26$), causing ΔQP to vary, depending on the amount of motion in the scene. ΔQP varies between 12 and 18 for the Baseline profile and between 7 and 15 for the Main profile. The ΔQP value is lower for the Main Profile than for the Baseline Profile, because of better compression. The encoding speed is fast enough for real-time communication. The output bit rate is very close to the target bit rate. Fig. 7 and Fig. 8 illustrate the results.

3) TARGET BIT RATE OF 512 Kbit/s

Table 6 shows the results obtained for a target bit rate of 512 Kbit/s with the Baseline and the Main profiles. For a bit rate of 512 Kbit/s, the visual quality of the non-ROI increases. $QP_{meanf-1}$ is between 20 and 26, therefore, we are in case 2, the linear zone. In this case, ΔQP is linear; however, for some non-complex scenes, we are in case 3, and $\Delta QP = 0$. These scenes are less complex to compress.

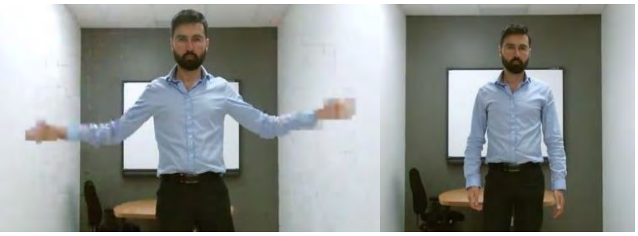

FIGURE 7. A moving (L) and a motionless (R) patient, using Baseline Profile at 256 Kbit/s.

FIGURE 8. A moving (L) and a motionless (R) patient, using Main Profile at 256 Kbit/s.

A target bit rate of 512 Kbit/s is relatively a very constraining bandwidth. In the linear algorithm zone, the quality of the non-ROI macroblocks increases and for some non-complex images $\Delta QP = 0$ meaning that the complete image is quantized at the same level. This result is a direct consequence of our linear differential quantization. To better illustrate this, let's consider the case of a constant ΔQP; in that case, the increase in the available bit rate would have been spent on the ROI instead of the non-ROI, increasing the ROI quality beyond necessary and encoding the non-ROI blocs with bad quality. Our algorithm allowed the quality of the non-ROI to increase when the ROI quality was judged good enough, improving thus the quality of the whole image instead of continuing to invest the bits on the ROI.

The encoding speed is fast enough for real-time communication. Fig 9 and 10 show good quality ROI as compared to the background.

4) TARGET BIT RATE OF 1024 Kbit/s

Table 7 shows the results obtained for a target bit rate of 1024 Kbit/s with the Baseline and the Main profiles. ΔQP is out of the linear zone, and the image has a perfect visual quality most of the time.

The algorithm is always in case 2 with $QP_{meanf-1}$ being between 20 and 26. Only 14.40 frames per second can be encoded with our hardware using the Main Profile: this is lower than our objective of 15 frames per second, meaning that encoding is no longer real time. This can be explained by the presence of a higher number of non-zero coefficients at this bitrate, implying more complex computations. This limitation can be overcome by lowering the preset from "slower" to slow or below, in order to force the codec to reasonably use its parameters, like using fewer prediction frames. Moreover,

FIGURE 9. A moving (L) and a motionless (R) patient, using Baseline Profile at 512 Kbit/s.

FIGURE 10. A Moving (L) and a motionless (R) patient, using Main Profile at 512 Kbit/s.

TABLE 7. Encoding results for Baseline and Main profiles at 1024 Kbit/s.

Profile	Target bit rate	$QP_{meanf-1}$	Enc. speed (f/s)	Output bitrate (Kbit/s)	ΔQP
Baseline	1024	21.10	23.69	989.9	0-9
Main	1024	20.95	14.40	1013.7	0-5

TABLE 8. Encoding results for Baseline and Main profiles at 2048 Kbit/s.

Profile	Target bit rate	$QP_{meanf-1}$	Enc. speed (f/s)	Output bitrate (Kbit/s)	ΔQP
Baseline	2048	19.70	13.58	2053.2	0
Main	2048	18.64	10.18	2040.1	0

regarding the available bandwidth, lowering the preset will not have a direct consequence on the resulting quality. This is to be considered for future implementation. Fig. 11 and 12 validate the excellent visual quality achieved.

5) TARGET BIT RATE OF 2048 Kbit/s

Table 8 shows the results obtained for a target bit rate of 2048 Kbit/s with the Baseline and the Main profiles. With a very comfortable available bandwidth of 2 Mbit/s, the algorithm is not in the linear zone anymore, and the frames are now of perfect quality, whatever the region, as we can observe in Fig. 13.

This is a consequence of using a reasonable resolution of 960x540 and a frame rate of 15 images per second. If we had chosen to handle Full HD at 30 Hz, this point would have likely been reached for a four to eight times higher bandwidth, without any visual gain in terms of sharpness or smoothness. Indeed, the human brain can process a maximum of 12 images a second to be able to recognize them as independent pictures. Over this number, including 15, the brain sees it as a video sequence. In the case where we are encoding the video of a patient with few movements, the gain in terms of smoothness from 15 Hz to 30 Hz would have been hardly noticeable.

FIGURE 11. A moving (L) and a motionless (R) patient, using Baseline Profile at 1024 Kbit/s.

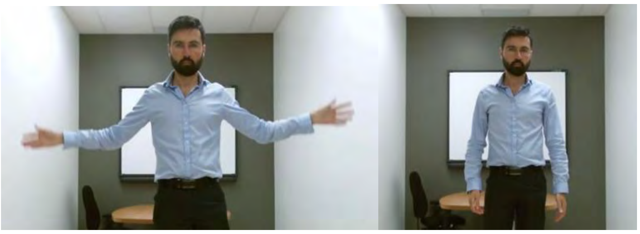

FIGURE 12. A moving (L) and a motionless (R) patient, using Main Profile at 1024 Kbit/s.

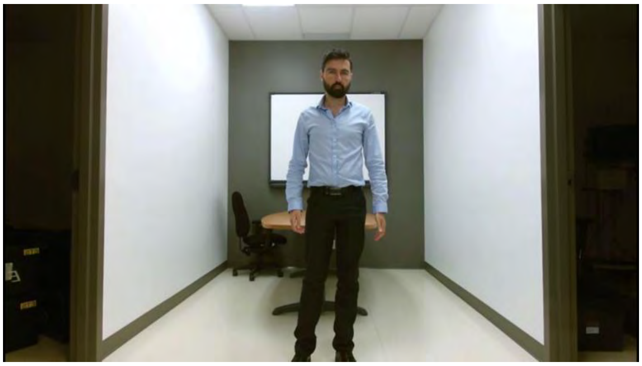

FIGURE 13. A motionless patient, using Baseline Profile at 2048 Kbit/s.

C. QUANTITATIVE EVALUATION

To quantitatively evaluate our results, we have calculated the PSNR obtained for the encoded video with a target bit rate of 96 Kbit /s. The PSNR is calculated inside the ROI for each frame of the video. The PSNR obtained with our method (Fig. 14 green line) is compared to the one obtained with no ROI (Fig. 14 red line). From Fig. 14, the PSNR obtained with our method is always better than the one without ROI. Moreover, the PSNR mean value obtained with our approach is 52.7 dB compared to 48.1 dB obtained with no ROI. Our method greatly improves the quality inside the ROI; the PSNR with our method is 3 times higher. Table 9 shows the PSNR mean values obtained with our method and without ROI, for various bit rates. It can be seen that the PSNR mean value obtained with our method is always higher. Using our method, the gain in PSNR is low at high bitrate, is maximum around 128 kbps and decreases below 96 kbps while always

TABLE 9. PSNR mean values with and without ROI for various bit rates.

Bit rate **(Kbit/s)**	**64**	**96**	**128**	**256**	**512**	**1024**	**2048**
PSNR with ROI	48.7	52.7	54.6	57.4	58.5	59.6	60.4
PSNR without ROI	45.3	48.1	49.7	53.1	55.7	58.0	60.2

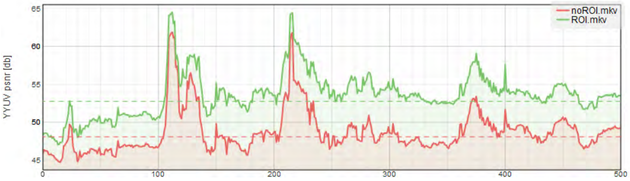

FIGURE 14. The PSNR (vertical axis in dB) plotted against the frame number (horizontal axis). The green line is the PSNR obtained with our method; the red line is the PSNR obtained with no ROI.

maintaining an important improvement with respect to the non-ROI method.

V. CONCLUSION

In this work, we addressed the challenges of video compression for telemedicine applications in a very low bandwidth environment, such as air-to-ground transmission channels. The system had to be able to record a video of the patient in addition to tracking his/her movements, acquiring this data and processing it in real time during the encoding. The primary goal is to prioritize a diagnostically visual quality in the significant zones of the video at the cost of lesser quality in the other regions.

Our method compresses the ROI with higher quality by using, for a specific available bit rate, different quantizers for blocs inside and outside the ROI. Our approach presents several innovations. It uses one single parameter to dictate the difference in quantization between the two regions. This difference depends on the available bit rate.

Moreover, our method does not choose to always prioritize the quality of the ROI by scarifying the quality of the non–ROI. We had proposed and implemented a novel differential rate control algorithm that increases the quality of non-ROI when it was estimated that the quality inside the ROI was acceptable and it was more interesting to increase the quality of the overall image instead.

To avoid measuring the quality inside the ROI that would have required implementing a feedback loop of a quality measurement calculated inside the ROI, we have proposed to estimate this quality from the overall quantization returned by the encoder and calculated on the complete previous frame. This estimation, rather than a precise calculation, results in a more straightforward implementation as it requires a limited change to the existing standard codec. The results obtained are very encouraging and confirm that the estimation is a good alternative to a precise calculation that would have required a feedback loop and a complex calculation to evaluate the quality inside the ROI blocs.

We proposed a linear differential rate control algorithm to control the difference in quantization between two situations: 1- the available bit rate is high enough to allow both ROI and non-ROI to be equally quantized; 2- and the available bit rate is low so the ROI needs to be prioritized. The parameters of the linear function were chosen to account for the worst-case scenario by assuming that the ROI is not bigger than half the image size. Otherwise, this would not be an ROI. This assumption ensures the quality of a worst-case scenario as the ROI is usually less than half the image size. Therefore, our method is simple and does not require complex additional calculations which makes it suitable for real-time implementations. It can be implemented with any encoder as it does not require any modification to the encoding algorithm. It is also standard and works with any decoder.

Furthermore, we proposed a soft transition between the ROI and non-ROI by gradually changing the quantizers of the blocs in the transition region.

The proposed method uses a dynamic ROI obtained from tracking the patient's skeleton. To implement our method, we used a Kinect acquisition software that records images of the patient and retrieves five coordinates from the skeleton to delimit a ROI bounding the torso and the head.

We have analyzed, discussed and justified the choice of the parameters needed, in terms of compression profiles using the H.264 compression standard. We choose a 960 × 540 15 Hz progressive video stream that ensured broad compatibility, clear images and a smooth video. We also prefered to use the Constrained Baseline Profile with the slower preset, to keep large compatibility, while reducing delays and maintaining a high priority on quality. Finally, we integrated the ×264 source code to read the skeleton coordinates and use them to implement a differential quantization for achieving a better quality of the ROI while encoding.

The obtained results were highly encouraging. We have found that even in low bandwidth conditions, the system gives exploitable results that would enable the physician to assess a patient's state. The obtained ROI quality is very good for bandwidth as low as 114 Kbit/s, especially for the resolution and frame rate used. Moreover, the smooth ROI edges enhance the overall quality. The results obtained have exceeded our expectations by allowing a visual assessment of the patient, even with very low bandwidth.

Although we were motivated by cases of remote emergencies requiring immediate intensive monitoring, our proposed method is not limited to these cases. Our method enables the transmission of patient's video with high quality ROI when the bandwidth is limited.

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