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Multi-Level Optimization in Encoding to Balance Video Compression and Retention of 8K Resolution☆

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Summary This paper presents a technique that aimed to accomplish an efficient balance between video compression using H.265 protocol and retention of 8K resolution. The study implements multi-level of optimization in the encoding process using H.265 where JPEG2000 standards play a crucial role. The study also applies a novel concept of orthogonal projection that manages pixels metadata required in every frame transition followed by motion compensation. By using multiple file formats of 30 video datasets, the outcome of the study is found to be accomplishing approximately 49% of enhancement in data quality and around 59% of improvement in video compression in comparison to the existing techniques of HEVC-based video compression.

Introduction

From the viewpoint of a video file, compression is performed to minimize the overall size of the file for optimizing the storage requirements. However, with the increasing modernization in the area of digital entertainment, the emphasized has been focused more on the availability of data and ensuring superior data quality. Similarly, in the domain of multimedia compression, H.265 is one of the latest compression standards. It is also known as High-Efficiency Video Coding (HEVC) and is coined by ISO/IEC Moving Picture Experts Group (Sze et al., 2014; Wien, 2014). Better than its legacy version (i.e. H.263/4), H.265 is capable of retaining better data quality with just half of the bit rate. The prime good factor of H.265 is a reduction in multimedia delivery cost with the enhanced visual quality for the user. Usage of H.265 has also opened the arena of high-resolution visual display, i.e. 8K Ultra High Definition (UHD) as it can offer an efficient compression performance as well as minimized utilization of the channel capacity. The usage of H.265 has slowly gained pace and is used by the

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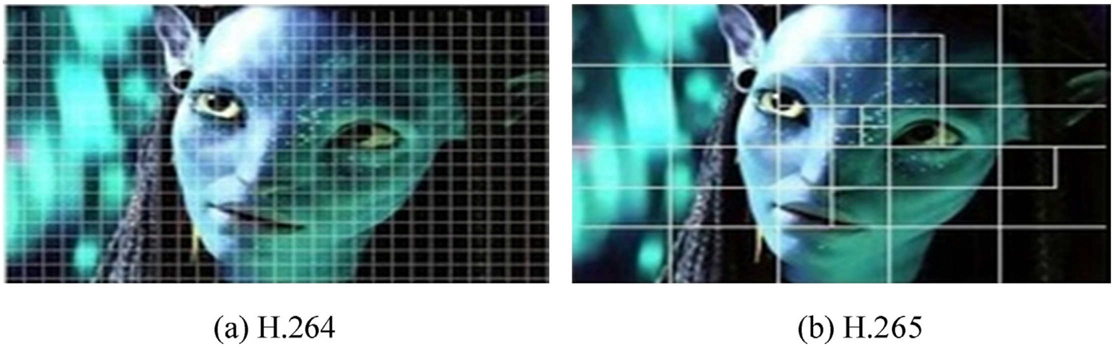

Figure 1 Difference between H.264 and H.265.

commercial product design as well as various types of service providers targeting to the 4K broadcasting of television channels. However, no such services have ever started for mobile devices or communication system. However, with the presence of various mobile apps for supporting streaming of SD channels, there is an increasing attention on broadcasting UHD resolution over mobile communication by encouraging research works towards H265 or HEVC. The technique of H.265 is quite capable of managing 64×64 pixels resolution for variable blocks of still frames. The block size of H.265 is larger as compared to its legacy version, i.e. H.264 as shown in Fig. 1. The biggest problem in this is that developing a video encoding protocol for upcoming mobile devices is fair new and is associated with various challenges about the hardware supportability. The present era also witnesses ongoing investigation and experiments for the possibility of graphical processing unit that supports a significant level of mobile transcoding using H.265. These are the feasible solution in this preliminary stage where hardware has not made a significant improvement. For example, at present, the user can watch Blu-ray video or any HD video even in standard display. However, problem shoots up when such video files are being transmitted over wireless media.

The prime purpose of the proposed study is to develop a technique that can perform video compression using H.265 and retain a robust resolution for 8K UHD video over mobile communication. The paper will discuss the problems being identified by reviewing the existing studies towards HEVC-based compression and presents an elaborated methodology with algorithm description and result discussion.

Background

This section discusses the existing research work being carried out using H.265 video compression standard. Most recently, Chen and Sze (2015) have introduced a decoder by H.265 using the hardware-based architecture with supportability of the parallel processing. The outcome of the study evaluated concerning decoding speed shows that presented technique can support decoding of 8K UHD. Dias et al. (2015) have presented a study by incorporating H.265 protocol for enhancing the quantization with an aid of rate distortion theory. The presented study has used spatial-based solution to enhance the visual perception of the signal. The study has been testified with mean opinion score and multimedia quality. A similar direction of work by adopting rate-distortion theory has been implemented by Nguyen and Marpe (2015). The authors have used the image as data to be compressed using H.265 protocol. The study outcome found that mean of bit rate saving using JPEG is quite high compared to other compression technique along with H.265. Panayides et al. (2015) have presented a study recently that studied comparative analysis of various existing signalling protocols for H.265 taking the case study of medical video dataset. Trzcianowski (2015) have also presented a study that has focussed on video coding for legacy protocol, e.g. AVC. A fascinating study was put forward by Ye et al. (2015) have elaborated about the usage of UHD files and its management over the networks. The author discussed that usage of H.265 can save around 64% of the bit rate as compared to high definition and standard definition video. He et al. (2015) have presented a new approximation technique for ensuring processing of UHD files with a primary focus on minimizing computational complexity about search techniques for optimal coefficients of resolutions. The method was implemented on hardware-based approach over VLSI architecture. Ahn et al. (2014) have discussed various optimization techniques using H.265 with an aid of parallel processing. Besides, the authors have also presented a task scheduling method along with slicing process in parallelization over multicores using H.265. Blasi et al. (2014) have shown a technique for minimizing the complexity related to motion compensation. Dias et al. (2014) have presented an FPGA-based study for performing compression using H.265 protocol using an integrated scheme of the efficient computational process along with 2D transforms. Mul et al. (2014) have presented a cascaded technique for legacy protocols, e.g. H.264/AVC and was subjected to H.265 encoding process to extract the encoding coefficients. The focus was laid on enhancing the speed of coding tree unit. Hence, various studies have focused on using video compression algorithm. The techniques are associated with advantages as well as the limitation. However, it has acted as better guidelines for designing a novel protocol of video compression. The next section discusses the problems associated with the existing literature.

The problem

This section discusses the issues explored after reviewing the literature in the existing system. The problems which are identified in the current systems are as follows:

- A trade-off in 8K resolution and compression: As a majority of the present studies were more focused on performing compression using H.265, the retention of the 8K resolution was not much emphasized in the current system particularly in mobile communication. Although usage of H.265 ensures the potential performance of rate-distortion compared to its legacy version, it doesn't guarantee 8K resolutions over the wireless communication system. Moreover, resource requirement (buffer, channel capacity) of 8K resolution is quite high, which lacks in prior studies.
- Less Scope of Multi-Level Optimization: There are various forms of the compression techniques and algorithms presented by different authors. Unfortunately, the entire compression algorithm designed till- date seriously lacks multi-level optimization, which will mean that the existing algorithm can offer one round of better solution and cannot go beyond that. Usage of conventional optimization techniques are also highly resource bound and is expensive in nature.
- Insufficient Benchmarking: Majority of the manuscripts highlighting the usage of existing techniques for video compression, are not compared with the benchmark. Hence, it is quite uncertain if the video compression techniques can be used again in case of change of implementation scenario or dataset.
- Less Efficient Performance Parameters: One of the best performance parameter to frequently observed is compressed data. Although PSNR is found in literature, its values are less emphasized on 8K or UHD data quality.

Moreover, it was also noticed that there are few studies towards retention of 8K resolution in mobile communication where the degree of complexity is higher concerning maintaining superior data compression and ensuring highest signal quality. Therefore, the problem statement of the study can be stated as ''It is a challenging task to develop a multi-level optimization technique to maintain well balance between video compression and utmost retention of 8K UHD in mobile communication.'' The next section briefly discusses the proposed solution and its contribution.

The proposed solution

The prime aim of the proposed study is to develop a technique that can maintain an efficient balance between compression and data quality for video files using the recent H.265 standard. The prime contributions of the presented study are:

- To perform processing of the video frames suitable for retaining 8K resolution exclusively for the mobile communication system.
- To develop a novel encoding algorithm that can perform extensive compression of the video file using H.265 standard.
- To develop a condition that can perform optimization of video encoding and enhancing the pixel density cost effectively.
- To present a technique that can achieve an effective management of metadata of the unit frame ensuring no loss of data during video streaming.
- To assess the performance concerning size of the compressed bits, data quality, and algorithm processing time.

The next section discusses the research methodology adopted for the proposed study.

Research methodology

The proposed study has considered analytical research methodology and is a continuation of our prior studies (Murthy and Sujatha, 2014; Murthy and Sujatha, 2015a, Murthy and Sujatha, 2015b). The study involves performing compression of the video file using H.265 using the novel logic of retaining the 8K resolution of the video. This section discusses the methodology adopted for developing the proposed compression technique.

- Design of processing video frames: Different from conventional video processing techniques, the proposed system applies processing the video based on NTSC standard (National Television, 2015). This consideration is by NTSC standards are still prevalent in many countries with 16:9 scale of broadcasting for a regular channel. Another reason for this concern is supportability of various mobile apps for streaming live channels.
- Design of Primary Encoding system: This stage primarily performs enhancing the resolution by 16 times of the existing pixels for retaining 8K picture quality. Although the 8K resolution is focused more on horizontal direction, we extend the resolution quality equally to a vertical direction of maintaining a proper balance between height and width of the frame complying with NTSC standard. This design stage also included incorporation of JPEG2000 standards as it is the best encoders for existing 4K and 8K Ultra High Definition resolution. Multiple conditions were formulated by ensuring if the system requires an optimization. (in the event of any difference in height and width from standard 8K format).
- Design of Secondary Encoding System: This design stage typically performs a second layer of encoding to achieve further compression. The system initially computes Lagrangian multiplier based on a quality parameter. To maintain meta-data of the pixel resolution during compression, it performs blocking of various sizes followed by generation of different macro blocks of the frames. This technique drastically minimizes the size and also maintains a proper amount of image Metadata in the form of a header, and is retained in a loop at every level of compression in a separate matrix. Finally, we calculate the minimum cost of a Lagrangian factor to get better-optimized values of compressed bits.
- Design of Tertiary Encoding System: The entire concept of tertiary encoding scheme initiates with the novel concept known as an Orthographic projection that deals with both current and neighbouring pixels. The system maintains the projection of the pixels based on orthonormal angles to ensure that streaming becomes extremely smooth during frame transition. Orthographic projection is one of

the novel alternative techniques that we have used in replacement of temporary memory for maintaining bit streams. Another unique part of this phase of the study is it can efficiently manage two memories (one for image quality and other for the highly reduced size of compressed bits). At every stage of H.265-based encoding, we add a header that ensures no pixels related information is lost by the compression. Finally, the system computes the computational complexity by extracting the minimum Lagrangian cost. Another significant incorporation is a dependency of primary and secondary encoding scheme on performing tertiary encoding scheme. Finally, the outcome is subjected to integer-based transforms followed by quantization to accomplish the compressed bits. The result of the study was eventually assessed using the size of compressed bits, Peak-Signal-to-Noise-Ratio, and processing time.

Algorithm implementation

The design and development of the proposed technique are carried out in Matlab. To implement the proposed method, develop four different connecting algorithms that are responsible for performing compression of the video to maintain the highest perceptual quality of the video regarding resolution using H.265 encoder. The discussions of the algorithms are as follows:

Algorithm for processing video frames

Although the primary purpose of this algorithm is to take video as input and convert it into frames, we add a bit of flexibility in the process by complying with the NTSC standard (National Television, 2015). The input to the algorithm can be any forms of video file v of frequently used formats. We use the Matlab method mmreader() to read the video and performs the selection of start and end frames. Although, we carry out the preliminary experiments on a range of frames, but later we conducted the experiment for the complete video frames. A matrix of frame f is created that can read the input video (line-3). Applying NTSC standards will allow the implication of three different multimedia coefficients α, β, γ whose values are considered as 2989, 5870, 1140 as standard (line-4). Finally, the count for reading the consecutive frames increases (line-5) until it reaches the last frame.

Algorithm for Processing Video Frames
Input: *v* (Sample video), f_1 (first frame), f_2 (last frame)
Output: *I* (video frames)
Start
1. input v
For $i = f_1{:}f_2$
3. $f = \text{read}(v, i)$
4. $I = f.\ (\alpha+\beta+\gamma)$
5. $I = I + 1$
5. End
End

Algorithm for primary encoding with H.265 standard

This algorithm is responsible for performing primary encoding scheme for compression video using H.265 standard. The algorithm extracts the height *h* and width *w* information from the frame *f*. In order, to enhance the resolution to 8K signal quality, the proposed system will perform encoding to increase 16 times in every iteration of *h* and *w*. We select another parameter *i* and *j* in Line-5 which represents further four bits of increment in pixel resolution for both *h* and *w*, respectively. We also apply three different conditions for further optimizing the outcomes considering both the values of *i* and *j*. If both are found to be similar to unity than it doesn't represent a case of even HD (1080p), hence, we reject such cases to be subjected to optimization. If the value of *i* is found to be unity, it represents a case where horizontal directionalities of the pixels are required to be extended. The vertical extension of the pixels is done by checking the value of *j* to be unity. Finally, the system performs integer-based transform and some conventional steps of quantization and entropy encoding mechanism to leverage further primary encoding in video compression using H.265 standard.

Algorithm for Primary Encoding with H.265 standard
Input: *h* (height), *w* (Width), *f* (frame sequence)
Output: Encoding of frame
Start:
1. define $(h, w) \rightarrow \text{size}(f)$
2. for $m = 1{:}16{:}h$
3. for $n = 1{:}16{:}w$
4. bits_frame→encode(binary)
If ($i == 1$ && $j == 1$)
6. No Optimization
7. elseif ($i == 1$)
8. Horizontal optimization
9. elseif($j == 1$)
10. Vertical optimization.
12.Perform integer-based transform, quantization, and entropy
13. Perform encoding.
End

Algorithm for secondary encoding with H.265 standard

Algorithm for secondary encoding is carried out for further generating a balance between H.265 based video compression and retention of 8K resolution. The algorithm takes the input of frame *f* and quantized parameter ρ and applies the principle of Lagrangian multiplier considering the quality parameter QP (line-1). The prior motion vectors are stored in the matrix mat (line-2). The algorithm further generates reconstructed macro blocks of the frames of size 16×16 for any sizes of blocks (bi, where suffix *i* was taken as 4, 8, and 16). The algorithm further adds header for retaining more pixel information making the size lowered down to an extremely large extent. The compression technique was furthermore optimized by evaluating the minimum Lagrangian cost that is calculated by the multiplying absolute difference between the old and new block position, Lagrangian multiplier, and encoded bits using JPEG2000 standards. Finally, the algorithm extracts the value of mean squared error (mse), compressed present frame (Sr), and bitrate (R).

Algorithm for Secondary Encoding with H.265 standard
Input: f (frame sequence), ρ (quantization).
Output: S_r (compressed present frame), mse (Mean Squared Error of frame), R (bitrate)
Start
1. Apply Lagrangian multiplier (λ_{me})
$\lambda_{me} = ((0.85) * 2^{\frac{Q_p-12}{13}})^5$
2. mat→prior motion vectors
3. for i = 1:b_i:h
4. for j = 1:b_i:w
5.   Write the reconstructed 16 × 16 macro block to the output
6.   Add header for a quadruplet split
7.   Extract minimum Lagrangian cost
8.   Get value of S_r, mse, R w.r.t b_i.
9. End
10. End
End

Algorithm for tertiary encoding with H.265 standard

The algorithm for tertiary encoding mechanism highly depends on the primary and secondary encoding mechanism applicable on different sizes of the block. This algorithm also considers performing orthographic projections considering multiple orthonormal rotation angles of the projected pixels. The prime purpose is to maintain high-end compression using H.265 with maximum remnant pixel information on defined image plane. The algorithm computes the row and column of the block using line-3. It then extracts the header information and forward it to the bitstreams thereby maintains a superior quality of frame transition without much loss of motion vectors.

Algorithm for Enhanced H.265-based compression
Input: b (size of blocks), O_P (Orthographic Projection), f (frame), Q_P (Quality parameter)
Output: Compressed bits ($Comp_{bits}$)
Start
1. init $b = [b_i]$ where i = 4, 8, 16
2. init O_P, Q_P,
3. Define row & col multiple of block size
$$n_r = \text{round}\left(\frac{n_r}{b_i/4}\right) * b_i * 4,\ n_c = \text{round}\left(\frac{n_c}{b_i/4}\right) * b_i * 4$$
3. nr, nc, k←size(f)
4. Extract header→bit streams
5. Encode I-Frame
6. Append I-Frame header '1111'
7. Extract I-Frame
8. Convert to unsigned integer
9. Apply Algorithm-2 for encoding.
10. Store Received frame
11. Appending I-Frame bit stream
12. For K = 2:Frame_end
13. $k = K$-1;
13. Appending P-Frame header ('0000') & extract
14. Apply Algorithm-3 for encoding
15. Store Received Frame
16. Appending P-Frame bit stream ('1100...')
17. Calculate $Comp_{bits}$ = length of bit stream
End

The algorithm then performs encoding of the I-Frame (line-5/6/7) and append it to the frame header followed by extraction of the I frame. The size is further reduced to an unsigned integer (line-8) followed by applying the primary encoding algorithm in line-9. The received frame is stored in a temporary matrix for the purpose of appending I-frame along with the bit stream. The process is repeated for all the frames in a given video clip which is followed by appending of P-frame in the header. Finally, the secondary encoding technique is applied and entered bit stream is encoded. This method ensures maintaining all the metadata information of the pixels along with superior reduction of sizes of video packets while streaming.

Result and discussion

This section discusses the outcomes being accomplished from the presented study. We present the result in two ways, i.e. individual as well as comparative analysis results. For the discussion of the individual result, we use the performance parameter, e.g. compressed bits, PSNR, and algorithm processing time to assess the outcomes. The evaluation was carried out over 30 samples of video files of few seconds in multiple video formats to evaluate the quality of the outcomes. Table 1 illustrates data for five samples.

The above outcomes show that the proposed is not only able to compress the video files exponentially, but it also maintains exactly the PSNR value approximately in the range of 47—49 dB, which is highly essential to keep the 8K UHD resolution. Hence, we can state the optimal data quality can be maintained by proposed system with a faster processing time that can support the majority of the streaming applications over large and overhaul network in the present scenario. For the purpose of the comparative analysis, we compare the recent work being done by Dehkordi et al. (2014) as well as Weerakkody et al. (2014).

Figs. 2 and 3 show that proposed system highlights the superior data quality in comparison to existing approach using 10 sample videos. The technique implemented by Dehkordi et al. (2014) uses a complex mechanism of encoding process that results in more storage of buffer in frame transition that finally results in not more than 44 dB of PSNR. Moreover, the study didn't attempt to enhance the resolution of the signal. Weerakkody et al. (2014) on the other hand have focused on data quality using basic test cell. However, due to lack of optimization, the trend of the curve is found to be maximum 46 dB. The prime reason for superior outcomes of proposed system was due to multi-level optimization technique and efficient management of meta-data that retains 8K resolution.

Fig. 4 shows the outcome of compression regarding percentage, which shows that proposed system is capable of performing compression of the data to a larger extent as compared to the existing approaches. The approach of

Table 1 Numerical outcomes.

Formats	Samples	Compressed bits (bits)	PSNR (dB)	Processing time (s)
AVI	Sample-1	1536077	48.36	0.0016418
	Sample-2	79461	47.98	23.4292
	Sample-3	70287	45.66	21.2266
	Sample-4	65792	48.88	19.8522
	Sample-5	193911	49.09	23.9622
MPEG	Sample-1	154260	49.12	0.0091136
	Sample-2	111341	41.76	23.7641
	Sample-3	82797	43.98	21.5206
	Sample-4	74744	48.59	20.9059
	Sample-5	27862	47.07	19.1752
WMV	Sample-1	151830	48.71	0.0015863
	Sample-2	69693	47.75	22.034
	Sample-3	70442	48.98	20.0588
	Sample-4	72763	49.57	20.6276
	Sample-5	186708	49.96	23.1699

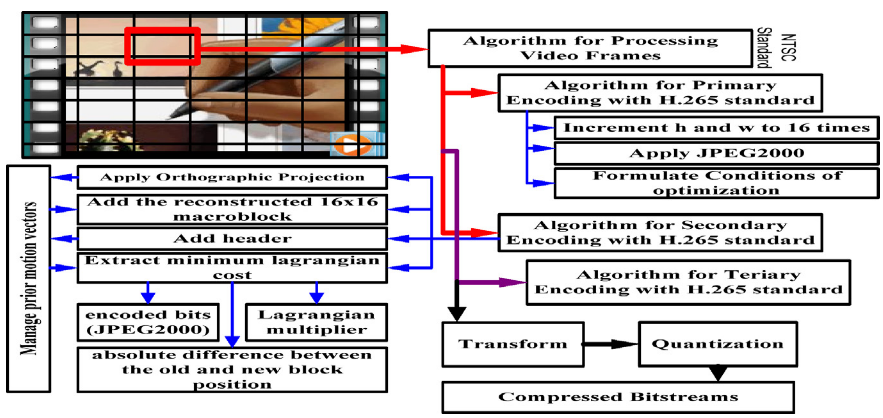

Figure 2 Adopted research methodology of proposed system.

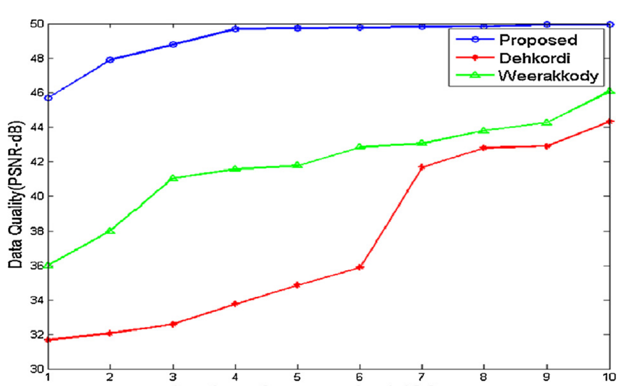

Figure 3 Comparative analysis of data quality.

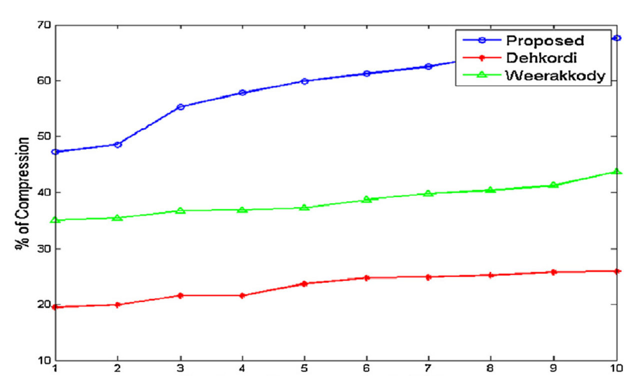

Figure 4 Comparative analysis of compression.

Dehkordi et al. (2014) maintains almost a stable and quite predictable performance of compression even with increasing number of processing frames. The trend of the curve is more or less same even if the frames are raised. Although this compression performance is good for static video and dataset, it cannot be used for streaming massive bit streams. Weerakkody et al. (2014) have just implemented HEVC on multiple subjects; however, there is no algorithm to enhance the computational performance. However, the proposed system has four different algorithms apart from implementing HEVC followed by reduction of storage complexity and effective management of pixel metadata. The scheme introduced by proposed system performs three level of optimization of the video frames to ensure that 8K resolution.

Conclusion

The paper has emphasized on the usage of the recent video compression standard called as H.265 or HEVC. Our theoretical study findings on this protocol show that it has superior compression performance and can offer better resolution standards too. However, we have found that there is a trade-off in hardware supportability with compression cum 8K resolution for mobile devices as well as mobile communications. Hence, we reviewed some of the existing techniques for the usage of H.265 and found that majority of the research implements it for compression with less focus on visual quality. Although, there are many research work found to discuss connection of H.265 with 8K resolution, but till date, there is no technical implementation to prove it. Hence, we propose a novel approach where we use multiple video samples to be compressed using H.265. However, we have not only perform HEVC encoding, but we have redefined the encoding pattern by incorporating primary, secondary, and tertiary encoding scheme with multi-level optimization. The outcome of the study was found to possess a well balance between the video compression and retention of superior data quality. Our result shows that we have achieved 49% enhancement in data quality and 59% enhancement in compression.

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