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Real-Time, Near-Lossless, Energy-Constrained Compression Method for High Frame Rate Videos

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***Abstract* — High frame rate video and energy consumption are the two important and most demanding constraints in today's video compression technique. Among lossy, lossless and near-lossless method of video compression, near-lossless method has been found to be good for high frame rate video. The method has three major conventional parts i.e. prediction, quantization and entropy coding. Also it has been observed that most of the energy is consumed during prediction stage, as encoder spends more time on doing prediction. Thus this paper tried to adopt already implemented energy constraint solution in near lossless compression method of high frame rate videos. Here Rate-Distortion optimization technique is used. Earlier implementation results of energy-constrained compression shows that one can save as much as 35% of the energy with small impact on RD performance. Thus when implemented with near-lossless high frame rate video compression will surely give the same results.**

***Key Words* — Energy constraints, near-lossless, Rate, distortion, video compression.**

I. INTRODUCTION

Nowadays, video is a popular media for everyday usage. In different research areas, there is a need for recording events in high frame rates. In recent years, high speed digital video cameras have been used to record fast action and play back in slow motion. A high speed digital video camera records a sequential series of images at hundreds or thousands of frames per second. The volume of produced data which is recorded by high speed digital video cameras is very massive. Therefore storing the produced data for processing and transmitting on limited bandwidths become a bottleneck. It is both valuable and efficient to compress these sequences. There are different lossless, lossy and near-lossless methods for compressing video sequences. As the name suggests, in lossless compression methods, the reconstructed video is the same as the original video. This is not the case for lossy compression where some video information is lost. In near-lossless compression some metrics control the upper limit of the amount of tolerable loss that could exist in the compression process. Therefore near-lossless method is considered to be good for compressing high frame rate videos.

Also Over the past years, digital video communication technologies have demanded higher computing power availability and, therefore, higher energy expenditure. But energy usage and carbon emissions are a major concern today. Thus, saving energy has become a leading design constraint for computing devices through new energy-efficient architectures and algorithms.

Thus in this paper real-time, near-lossless energy-constrained, compression method for high frame rate videos is proposed.

II. BACKGROUND

As high frame rate videos has sequential series of images at thousands of frames per second. Thus out of the three types of video compression method i.e., among lossy, lossless and near-lossless, near-lossless method is considered good for high frame rate video compression. The method for near-lossless compression of high frame rate videos proposed in [1] has three major conventional parts i.e. prediction, quantization and entropy coding. Also nowadays energy saving is being most important. It has been observed that encoder spends much of its time during prediction. So work regarding near-lossless compression method of high frame rate video to satisfy the energy constraints i.e. to work within estimated energy budget is done. For this method proposed in [2] is adopted here.

III. PREVIOUS WORK DONE

In [1] paper, author Najmeh Nazari proposes a near-lossless method that is comparable with successful existing methods of video compression and yet is simple enough for real-time applications. It includes the major conventional parts for this goal which are prediction, quantization and entropy coding. A simple rate control is embedded by different approaches in quantization. The experimental results demonstrate good compression ratios while considering reliability due to control of the maximum pixel error. As compression performance achieved is not upto 100%, so there is need to develop some new more efficient near-lossless compression techniques for high frame rate video. Also relatively not too many works has been done on lossless video compression, so there is need to do more work in this area.

In [2] paper, author Tiago A. da Fonseca suggests new strategies in the direction of saving energy in real-time computation. Author presents a fidelity-energy (ΦE) optimization strategy to constrain the energy demanded by an application in a real-time scenario; particularly for a software video encoder, the fidelity Φ can be evaluated in terms of the rate-distortion (RD) performance. Then, the optimized parameters are used to implement an RDE-optimized real-time encoding framework.

Author chose an open-source high-performance encoder, x264, as the H.264/AVC software implementation due to its excellent encoding speed and good rate distortion (RD) performance. The proposed approach suits, for example, mobile communication systems where energy efficiency is still a major bottleneck. Further work can be done on making an encoder aware of environmental and communications conditions, capable of adjusting itself to meet channel, quality and energy constraints.

In [3] paper, author Stamos Katsigiannis presents a scalable video coding algorithm based on the contourlet transform that incorporates both lossy and lossless methods, as well as variable bitrate encoding schemes in order to achieve compression. Furthermore, due to the transform utilized, it does not suffer from blocking artifacts that occur with many widely adopted compression algorithms. The proposed algorithm is designed to achieve real-time performance by utilizing the vast computational capabilities of modern GPUs, providing satisfactory encoding and decoding times at relatively low cost. Future work could include an improvement on the handling of the chrominance channels in order to reduce the difference in the PSNR values between the full video sequence and its luminance channel.

In [4] paper, author Yu Sun proposed a direct non-buffer real-time rate control algorithm for video encoding, which has two unique features. First, unlike traditional algorithms which adopt buffers in rate control, the proposed algorithm does not use a buffer in rate regulation which can reduce the delay and improve real-time response. Second, we propose a new Proportional-Integral-Derivative (PID) bit controller to directly control encoding bitrates. In addition, author also developed a simple but effective method for real-time target bit allocation. This is the first work that conducts video rate control without using a buffer. Extensive experimental results have demonstrated that the proposed algorithm outperforms the MPEG-4 rate control algorithm by achieving more accurate rate regulation and improving overall coding quality. Regarding future work directions, work should be done for further enhancing the overall performance of video rate controller. Extend this research to H.264/AVC and the new compression standard H.265. In addition, also continue research on investigating impact of our non-buffer algorithm, developing more advanced rate control structure, and exploring better real-time target bit allocation method which considers the frame complexity, etc.

In [5], paper demonstrates that DAVIS sensors inherently perform high-speed, video compression in each pixel by describing the first decompression algorithm for this data. The algorithm performs an online optimization of the event decoding in real time. This paper presents the first publication on an algorithm for the decompression of asynchronous temporal contrast events. The algorithm is applied on the output of a dynamic and active pixel vision sensor (DAVIS) which performs in-pixel video compression in the form of temporal contrast events. The system allows real-time decompression of video information with sub-ms resolution and a dynamic, activity-dependent compressive ratio. By reducing the output data, the system allows reducing power consumption for data processing and communication so that it can be applied in surveillance tasks or distributed sensor networks, where most of the time nothing is happening and power consumption is of importance. Also the system allows a simple inspection of fast processes without the necessity of a strong light source.

IV. Existing Methodology

In paper [1], a simple near-lossless method of high frame rate video compression is proposed which has major conventional parts as prediction, quantization and entropy coding. The general block diagram of system is depicted in Fig 1.

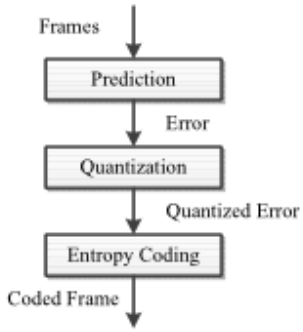

Fig 1. General block diagram of a video coder [1].

A. Predictor

As mentioned above, high levels of correlation between consecutive frames in high frame rate video sequences can be used for compression using some prediction methods. Due to importance of real time processing and speed, a simple predictor is considered in the proposed method. The predictor that we have used is DPCM.

Assume u (x, y, n) be the video sequence to be compressed, and û (x, y, n) the predicted sequence. A simple temporal predictor is used in our case, such that:

$\hat{u}(x_o, y_0, n) = u(x_o, y_0, n-1)$.

B. Quantizer

Three methods are proposed for quantization, which express different qualities and compression ratios. The idea of using different amount of quantization to control the amount of compression has been used by MPEG. In near-lossless compressions, usually a uniform quantizer is used. Three types of quantizers were considered. All approaches use Histogram Bin Grouping (HBG). The first grouping scheme is a Fixed HBG (HBG-F), the second is based on which bin has the Maximum Probability (HBG-MP), and the last one uses the Expected value of Error (HBG-EE) to determine the representative of each group.

HBG-F

In this case, a uniform quantization method is used. Equation (1) shows the quantization rule.

$$\bar{e} = \frac{e + d.sgn(e)}{2d + 1} \quad (1)$$

Where ē is the difference between predicted value of a pixel's intensity and the real value, d is the maximum error, and ē is the quantized value.

HBG-MP

In this method, our goal is to reduce loss for errors that are more probable to occur. Therefore, the error with maximum probability is chosen to represent the range. In order to achieve higher PSNRs, especially for small maximum errors, and lower amounts of compression ratio, this quantizer is designed such that:

- The maximum error is less than some certain value, d.
- The bin with the most probability represents each interval.
- Lengths of the intervals is maximum.

HBG-EE

This method is proposed in order to achieve higher PSNRs compared to previous methods. Therefore qualities of the reconstructed videos compressed with this method are better than other methods. It is noteworthy that in many different cases of maximum errors, compression ratios achieved by this method are higher than those of the first method.

C. Entropy coding

Entropy coding is used to encode the quantized data. Different coding methods could be used, such as Golomb-Rice coding, arithmetic coding, Huffman coding, etc. In the proposed approach a Huffman encoder is used to reduce the statistical redundancy of the data. The grouping process reduces the symbols which are inputs for Huffman coder. It should be emphasized that our proposals concentrate on the quantization part of compression and hence any other entropy coding could have been used.

V. Analysis And Discussion

Although presented near lossless compression method is reliable, which is simple enough for real time compression of high frame rate video. But as digital video communication technologies have demanded higher computing power availability and, therefore higher energy expenditure. Thus saving energy has become a leading design constraints for computing devices.

Now it has been observed that encoder take most of time doing prediction, so in order to scale the amount of energy used to encode a particular video sequence, the most computational intensive steps when encoding digital video i.e., the predictions stage is chosen to modify.

VI. Proposed Methodology

The work presented in [2] which suggests new strategies in the direction of saving energy in real-time computation is used here, where author presents a fidelity-energy (ΦE) optimization strategy to constrain the energy demanded by an application in a real-time scenario; particularly for a software video encoder, the fidelity Φ can be evaluated in terms of the rate-distortion (RD) performance. Then, the optimized parameters are used to implement an RDE-optimized real-time encoding framework.

Let a software encoder execute its job for which we can somehow measure its cost. For signal compression, the cost measure can be a measure of quality, like distortion (D) or the bitrate (R) or a combination of both. The compression is assumed parameterized, i.e parameters {Pi}i=1,...,N. Let P be the vector with all Pi. The encoder runs on a given set of data Z that may be different at every instantiation. For every choice of P and Z, we can have a measure C of the encoder cost. In essence we can have a mapping

C = f(P,Z).

Another attribute we can derive from each instantiation is the effort taken to execute the encoding task, which can be measured as demanded energy E = g(P,Z). It is expected that some parameters like number of iterations, data sizes, etc. would influence the demanded energy while some others would not. The central idea in this paper derives from the fact that the correlation of E and C is differently affected by different parameters. We will use this to find points that minimize the energy consumption. Specifically, we would like to operate in the lower convex hull (LCH, represented in Fig. 2 by green points), which is the set composed by instantiations that yield the lowest energy for a given cost. Departing from a simple explanation using a scalar cost, in video coding, the mapping is conveniently addressed by a multidimensional variable as

C = [R,D].Hence, C = f(P,Z).

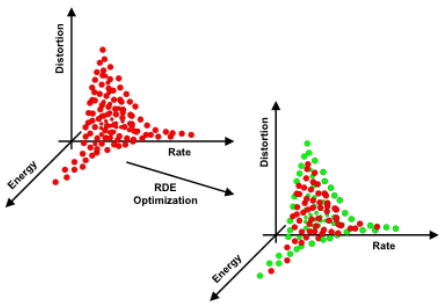

Fig.2. Illustration the set of RDE points that compose the Pareto front. The visible green points belong to the lower convex hull; some points are hidden due to the viewpoint [2].

P and Z are mapped to R, D and E, adding the energy dimension to the usual rate-distortion optimization problem. We want to find the parameters that allow us to operate on the LCH in RDE space. In this manner, we can be assured that no configuration would yield lower energy consumption for a given

cost value. Conversely, we can assure that, for a given energy consumption level, no other configuration would achieve better RD performance. Figure 1 illustrates the LCH in RDE space.

One approach is to use training data sets. Let {Pk} be the set of all parameter choices, ordered in some fashion. Let also Pk have elements Pkn. If we use a representative data set $\hat{Z}$, we can span {Pk} computing E, R and D for each choice and identifying the points that belong to the LCH of E×R×D. If the n-th point belongs to the LCH, we record Qn = [En, Rn, Dn, Pn], which contains the optimal points for the set $\hat{Z}$, but which are also assumed good enough for other data. The **off-line training algorithm** is:

1. Input a representative data set $\hat{Z}$ and create an empty list Q.
2. For all k, compute Ek = g(Pk, $\hat{Z}$) and [Rk, Dk] = f(Pk, $\hat{Z}$). If point belongs to LCH, record Qk= [Ek, Rk, Dk, Pk] into Q.
3. Output a list Q of points in the LCH.

After finding the Nq points which belong to LCH, we sort Q in an ascending order of energy, i.e. {Ei} in Q in non-decreasing. When running on-line, the parameter finding algorithm is as follows. Initially, consider a bit-rate R^r (channel constraint) and a desired energy target E^r. Then:

1. Input a list Q of points in the LCH, the energy target E^r and the rate target R^r. Create an empty list L.
2. Span Q, for k = 1,...,Nq. If $|Rk - R^r| < \varrho$ insert Qk into L.
3. Count Nl, the number of items in L. Note that the items in L are still in ascending order of energy and all parameters are supposed to achieve similar bit-rate.
4. Span L, for k = 1,...,Nl, until $Ek \le E^r \le Ek+1$, then stop.
5. Find P′ as a proportional interpolation of Pk and Pk+1in L.
6. Output parameter vector P′.

Parameter set P′ is then used to compress data set Z. We used energy targets E^r constrained to a bitrate R^r, but it is trivial to replace it with a distortion target D^r. Of course, many parameters do not assume continuous values and some action has to be taken to properly assign them. For example, being that the case for the m-th parameter, one can use the value from Pkm if $E^r - Ek < Ek+1 - E^r$, otherwise use the value from Pk+1, m.

If a feedback control is allowed, one can monitor the system energy consumption and continuously adjust the parameters. If the energy consumption is not as predicted, it is because of discrepancies between Z and $\hat{Z}$, so that $\hat{Z}$ is not as representative as one would assume. Such a mismatch may also depend upon the non-linear mapping g. One solution is to start with a target E^r and to periodically measure the energy E(n). We then adapt the parameters in order to control the energy expenditure (or cost). Assume that at any given instant n, P′ is taken somewhere as an interpolation of Pj and Pj+1. If $E(n) < E^r$ one should move P′ towards Pj+1 or even Pj+2. Conversely, if $E(n) > E^r$ one should move in the opposite direction, i.e. towards Pj or even Pj−1.

Using the proposed methodology, extending an RD-optimization strategy, adding the E dimension (which stands for energy) to the regular 2-D problem of optimizing a particular codec to spend the smallest bitrate (R) necessary to represent a encoded video signal at a particular distortion (D). Measure E by integrating on time the power reading provided by wattmeter. Find out the aggregation of computational-effort related parameters. The cost C is taken as the duple rate-distortion RD, where rate is taken as bit per seconds while the distortion is evaluated as the MSE (Mean Squared Error) between the original and the coded signal.

Evaluate an empirical approximation to the energy function E = g(P,Z) through energy measurements. So, for each particular encoder setup compute the total bitrate (R), the MSE (D) and the energy spent to encode a training sequence (E). Use the RDE points to populate an initial search space from whose points that lie on its lower convex hull are derived by RDE optimization. After finding the setups that belong to the LCH, build a lookup table from the performance numbers in order to provide optimal starting RDE points. Any intermediate demanded energy point not found in the table can be easily achieved by interpolation in such a way that the global demanded energy is very close to the energy "budget".

VII. Possible Outcomes And Results

Earlier implementation results of energy-constrained compression shows that one can save as much as 35% of the energy with small impact on RD performance. Thus when implemented with near-lossless high frame rate video compression will surely give the same results.

Conclusion

Presented RDE-optimized framework which allows for software-based real-time video compression, meets the desired targets of electrical consumption. Hence controls carbon emissions. Proposed framework moderately affects the Rate-Distortion performance. Also the proposed approach suits, for example, mobile communication systems where energy efficiency is still a major bottleneck.

Future Scope

Further work can be done on making an encoder aware of environmental and communications conditions, capable of adjusting itself to meet channel, quality and energy constraints. Also relatively not too many works has been done on lossless video compression, so there is need to do more work in this area.

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