

Proceedings



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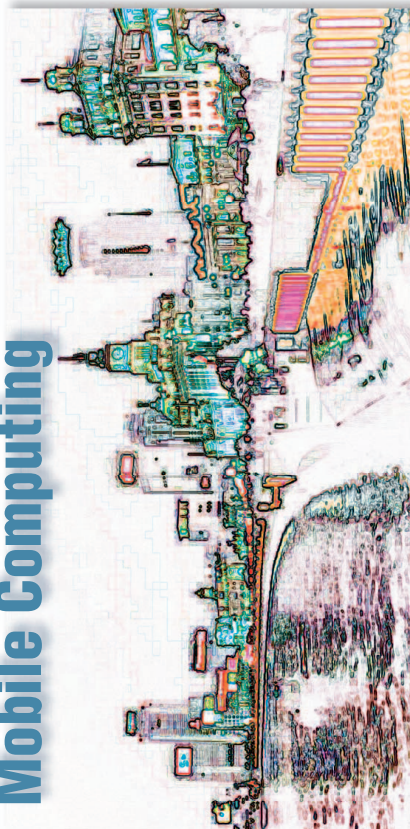
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A Novel Method of Keyframe Setting in Video Coding: Fast Adaptive Dynamic Keyframe Selecting

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Abstract

In this paper, we describe a novel method of keyframe setting in video coding: Fast Adaptive Dynamic Keyframe Selecting. The method analyzes video contents and decides keyframe setting dynamically and adaptively. Utilizing information generated by motion-estimation, our method involves only a little additional computing cost. Our method can improve both objective and subjective quality compared with traditional keyframe setting. It can be applied to any motion-estimation based video compression. We tested the method on not only standard test sequences but also real movie sequences proving that it gives valuable results.

1. Introduction

As a mature video technology, motion-estimation has existed for many years. Keyframes, also known as reference frames, are bases of prediction in motion-estimation. However, if one frame contains a lot of things or a large part of the picture that cannot be found in the keyframes, the prediction efficiency will turn very low. In traditional video coding, the intervals between keyframes are static and fixed, so that the problem above is inevitable. JVT (MPEG-4 AVC) involves multi-reference-frame prediction, but this technique can only slightly reduce the problem.

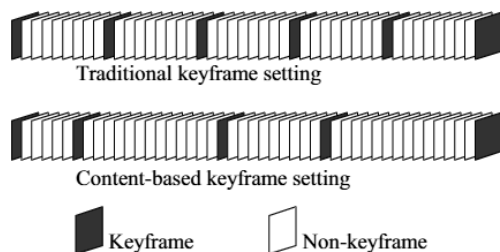


Figure 1

If we do content-based keyframe setting, as shown in Figure 1, we can find out those shot-edge or big-change frames and set them as keyframes, so the prediction will be more efficient. A.Y. Lan [3] proposed a Scene Context Dependent Reference Frame Placement method. But his motion-analysis preprocessing involved lots of additional computing costs. His results were also not very good. Actually, there are many existing video-analysis techniques. They can extract as many features as you want. But they are too sophisticated to be integrated into video coding. Till now, we are still using fixed keyframe intervals.

In adjacent research area, D.T. Hoang [4] proposed a real-time VBR rate-control algorithm. He utilized VBV-buffer information generated by existing encoder as rate-control guide. So his algorithm didn't require heavy preprocessing and became single-pass actually. This inspired us to design such a single-pass dynamic keyframe selecting method.

In this paper, we describe a novel method of keyframe setting: Fast Adaptive Dynamic Keyframe Selecting, as follows: in section 2, we present a detailed analysis of the relationship between keyframe intervals and compression efficiency. In section 3, we present our method. In section 4, we describe our experiments and results. Finally, in section 5, we describe the usability of our method, and forecast its application foreground.

2. The relationship between keyframe intervals and compression efficiency

Let us discuss how keyframe intervals influence compression efficiency. To make our discussion easier, we take a simplification that there are only I-frames and B-frames in our sequence. Since P-frame's behavior, such as its compression ratio and prediction mode, is between I-frame and B-frame, this simplification will not make any significant differences. Now, keyframe means I-frame only, so keyframe interval is the interval between two adjacent I-frames – that is, the number of B-frames between them.

First, let's look at what will happen when keyframe intervals turn too small. Consider an extreme case that the keyframe intervals are all zeros, so the sequence will be all I-frames like "IIIIIIIIIIIIII...IIIIIIIIIIII". Actually it is Motion-JPEG coding. No temporal correlation is utilized. All temporal redundancies are kept. The compression efficiency will be extremely low.

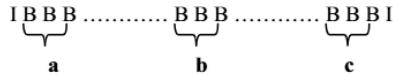


Figure 2

However, bigger keyframe intervals do not always bring higher compression efficiency. Figure 2 shows such a special case. There are too many B-frames between the two I-frames. So, only B-frames in segment **a** and segment **c** can benefit from motion compensation. B-frames in segment **b** have to be all intra-coded, and become de facto I-frames, since they cannot find matching macroblocks in so faraway I-frames. In fact, these B-frames are even worse than true I-frames. If there was a true I-frame within segment **b**, all other B-frames in segment **b** could get motion compensation from it. But now, B-frames in segment **b** are all intra-coded as Motion-JPEG.

Therefore, our goal is to find out the most appropriate keyframe intervals.

There's one more question: if we increase the interval between two I-frames, B-frames between them will necessarily take larger residual errors after motion compensation, so the compression ratio of B-frames will decrease. Where is the advantage by doing so? In fact, this case is not inevitable and is no more than a possible case. Increasing I-frame interval will not necessarily cause larger residual errors of motion compensation. For example, as depicted in Figure 3, it is an "alternate" sequence. All "black" frames are similar, so do the "white" ones. Thus, there's no difference whether the second I-frame is set at location 4 or 8.

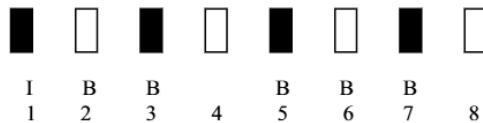


Figure 3

In fact, our method will try to find out those segments in which increasing keyframe intervals will not cause unacceptable prediction errors but benefit from decreasing one or more keyframe.

3. Fast adaptive dynamic keyframe selecting

The basic idea of our method is: make the prediction more effective by adjusting keyframe intervals, so we can save more bits from unnecessary keyframes and over-intra-coded B-frames without any quality degradation. We

needn't worry about how to utilize added bandwidth. Simply save more storage space is good enough. Or let the encoder run at same bitrate to achieve higher quality, especially higher subjective quality.

We cannot expect that one fixed interval, even selected according to the sequence to be encoded, could give any valuable results. Videos in the real world are as complicated as possible. Figure 4 shows three typical cases, each block represents a shot.

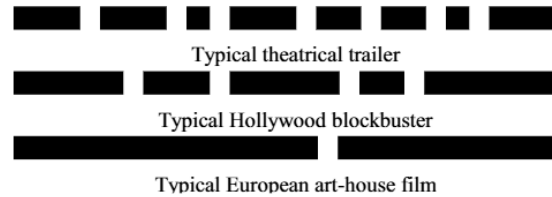


Figure 4

3.1. From two-pass to quasi single-pass

We expect adaptive and dynamic keyframe setting to be usable and valuable. It is very straight to design such a two-pass process: in first pass, the whole video sequence is analyzed, useful features are extracted, then which frames should be keyframes are determined; In second pass, do actual encoding according to those selected keyframes. Undoubtedly this two-pass process can get nearly optimal keyframe intervals. But it has three fatal disadvantages as follows:

1. The encoding process cannot be finished in single-pass. Two or more passes are required. This will restrict its application area severely. Single-pass coding has much more application areas than multi-pass coding. Many applications, such as videoconference and video monitoring, require real-time coding. Multi-pass coding is supposed to be non real-time.
2. For video analysis, it will involve too heavy computing costs to be practical in today's computing environments.
3. It is not worthy to add such a big video-analysis preprocessing module into existing video codecs for utilizing only one tool. We can expect its rapid disappearing.

To avoid the disadvantages as above, we propose an eclectic solution, which doesn't require pre-analysis on video sequence. Existing video codecs will generate much information during their encoding process. Our method simply utilizes this information as guide for keyframe selecting, so that the modified encoding process becomes quasi single-pass. Additional computing costs are heavily reduced. This method is easy to implement. Although it is not optimal, it gives pretty decent results.

3.2. The algorithm description

The kernel algorithm of our method is as follows:

Let $\text{diff}(f_1, f_2)$ represent the difference between frame f_1 and frame f_2 (The definition of the function diff will be described later). Let R_k represent the no. k reference frame in the whole video sequence (I-frames and P-frames are all considered as reference frames).

Step 1: The first frame of the whole sequence is always an I-frame. Mark it as the first reference frame, represented by R_1 (that is, R_k when $k=1$);

Step 2: Calculate $\text{Avg}(\text{diff}(R_1, R_2), \text{diff}(R_2, R_3), \dots, \text{diff}(R_{k-1}, R_k))$ – the average of differences (The definition of the function Avg will be described later);

Step 3: Suppose that the original codec's keyframe interval is m . Find next "reference frame candidate" with m . Mark it as R_{k+1} ;

Step 4: Calculate $\text{diff}(R_k, R_{k+1})$. Let λ represent $\text{diff}(R_k, R_{k+1}) / \text{Avg}(\text{diff}(R_1, R_2), \text{diff}(R_2, R_3), \dots, \text{diff}(R_{k-1}, R_k))$:

if $\lambda \leq \alpha$

Make the no. σ frame following the frame R_{k+1} be new "reference frame candidate" R_{k+1} , as shown in Figure 5. Repeat step 4;

else if $\lambda \geq \beta$

Make the frame R_{k+1} be I-frame, as shown in Figure 5. $k++$. Go to step 2;

else if $\lambda \in (\alpha, \beta)$

Make the frame R_{k+1} be P-frame, as shown in Figure 5. $k++$. Go to step 2.

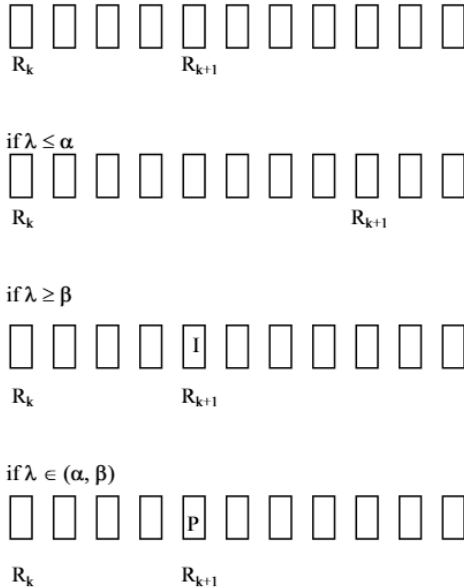


Figure 5

The description of the function diff : Generally, there are many calculating methods that can be used to measure the difference between two frames. For example, the sum of absolute differences between corresponding pixels of two frames, the mean arithmetical value of the modules of every macroblock's motion vectors from last frame to next frame, the mean square of the modules of every macroblock's motion vectors from last frame to next frame, and so on. We use the mean square of the modules of every macroblock's motion vectors from last frame to next frame. The original encoder generates the motion vectors when it encodes our "candidates" as P-frames. A reason to choose the mean square is that spatial local motions are very important to human's subjective vision.

The description of the function Avg : There are also many average calculating methods, such as, mean arithmetical, mean square, median, and so on. In order to emphasize the importance of temporal local motion to human's subjective vision, we choose mean square again.

3.3. The parameters in the algorithm

There are three parameters in our algorithm: α , β , σ . What values should they take? It's a key problem. The parameters will affect the final results deeply.

In theory, we think that adjusting the parameters dynamically during encoding process will generate best results. But it seems a little too complex till now. There are two ways to choose three static and fixed values for them as follows:

First, create a mathematical model; get the optimal values from lots of formulas.

Second, do lots of experiments; get the average best values from various real video sequences.

My experiences make me choose the second way. As I believe, videos in the real world are as chaotic as the world. Their shot distributions are very random. I don't think it is feasible to design such a mathematical model.

On the other hand, almost all the existing video codecs and methods have Achilles' heel. It is not very difficult to "design" a tragic sequence against a given codec. So, if one codec does well in many familiar-type sequences, it is successful.

Finally, we use up to 100 sequences to train our method and get three usable values: 0.4, 0.7, and 4.

4. Experiments

We implemented our Fast Adaptive Dynamic Keyframe Selecting method on both MPEG-2 codec and JVT (MPEG-4 AVC) JM codec.

The common standard test sequences are too short to test our method. There are usually only 1 or 2 shot

conversions in each of them, such as Foreman, Coastguard, and so on. So we must prepare test sequences by ourselves.

Our test sequences consist of four kinds as follows:

1. Patchworks from standard test sequences, as shown in Figure 6.



Figure 6

2. Movie trailers. They have most frequent rapid shot conversions and will be difficult to any codec.
3. Segments from movies. Every genre, such as Drama, Action, Sci-Fi, Horror, Animation, has several spokesmen in our test sequences.
4. Segments from TV. News, sports, ads, cosmic, and so on.

4.1. Tests on MPEG-2 codec

The resolutions of all the sequences tested on MPEG-2 codec are all 720x480. Original codec and our modified codec were set to generate the same average bitrates. The frame type pattern of the original codec was set as "IBBBBPBBBBPBBBB".

Our modified codec's average PNSR is about 0.2~0.3dB higher than the original codec. In some scenarios our method tied with the original but most of these sequences are slow-motion clips. In some other scenarios, especially movie trailers, our method notched up to 0.6dB higher than the original.

The average coding speed of our method is about 10~15 percent slower than the original.

Not only objective quality but also subjective quality was improved by our method. Especially at those shot conversion and rapid motion scenes, we noticed that images turned more stable and had fewer noticeable compression artifacts than the original.

The results proved that our method is valuable on MPEG-2.

4.2. Tests on JVT codec

The resolutions of all the sequences tested on JVT codec are CIF and QCIF. Original codec and our modified codec were set to generate the same average bitrates. The frame type pattern of the original codec was set as "IBBBBPBBBBPBBBB". No "multi-reference-frames" was enabled.

Our modified codec's average PNSR is about 0.1dB higher than the original codec. In some scenarios our method tied with the original but most of these sequences are slow-motion clips. In some other scenarios, especially

movie trailers, our method notched up to 0.8dB higher than the original.

The average coding speed of our method is about 5~11 percent slower than the original.

There was also noticeable subjective quality improvement by our method.

The results also proved that our method is valuable on JVT.

5. Conclusions and outlook

Traditional static and fixed keyframe setting doesn't exert all the potentials of prediction coding. We present a method to do fast adaptive dynamic keyframe selecting to make the prediction more effective. This method adopts a quasi single-pass strategy to avoid unacceptable additional computing costs. Experiments proved that our method is valuable.

This method doesn't change any bitstream grammar and syntax of existing video coding standards. It outputs standard bitstreams, which can be decoded by any compatible decoders. Actually, it can easily be implemented in any prediction-coding based video codecs, such as MPEG-1, MPEG-2, MPEG-4, and JVT.

Since our method mainly utilizes information generated by existing encoders as its guide, it doesn't involve any very special processes. So, it can also benefit from available hardware accelerating.

Our future work is to research better functions *Avg* and *Diff*, as well as better parameters.

In some particular applications, such as video database and transcoding, there are already many extracted features and existing information. Utilizing these features and information to improve the efficiency of our method is also an interesting problem.

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