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Evaluation of MPEG Motion Compensation Algorithms

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Abstract

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Abstract

This paper describes on-going research about the development of an evaluation scheme which allows an objective comparison of different motion detection algorithms used while compressing image sequences: "real world" sequences as well as generated sequences containing special textures or objects. Its focus is on block motion detection algorithms used by MPEG video encoding and the goal is to develop an objective motion compensation quality metric.

Keywords: *digital video, motion compensation, MPEG, quality metrics.*

1. Introduction

The majority of video compression algorithm designers favour the assessment of compressed image data by human observers because traditional signal processing methods like the mean square error (MSE) or the signal-to-noise ratio (SNR) for evaluating the whole encoding process does not correlate highly with the perceived image quality. The development of quality assessment techniques using assumptions about the human visual system (HVS) needs not only a model for the HVS. They are also expensive, time-consuming and depend on the judgments of the testing person. This paper focuses on the motion compensation (MC) employed in encoding digital video sequences, especially in the MPEG video compression standard, and attempts to give an objective metric to describe the errors generated by fast block-based MC algorithms. The later stages of MPEG encoding as the Discrete Cosine Transformation (DCT) is well understood, so the improvement of MC is a very active research area now and an evaluation method of MC will help in this field of the development of motion compensation algorithms.

2. MPEG video compression

MPEG digital video compression [1] allows effective video sequence compression by utilising the high spatio-temporal redundancy data normally found in a sequence of frames. During the encoding process, first a motion compensation prediction between two frames is performed on 16x16 pels. Such a "macroblock" contains blocks of data from the luminance and chrominance components with a sampling rate between Y U V as 4:2:2 or 4:1:1. Finding a nearly similar window in the previous frame means that only the motion vector and the remaining (error) difference between these two frames has to be transmitted. In the second step this data is encoded by a DCT to get the transform coefficients (usually by blocks of 8x8 pels) to code the spatial correlations in the frame. Normally quantization is performed to cut off high image frequencies to achieve the desired data rate. A sequence of original frames (I-frames), predicted frames (P-frames) and bi-directional prediction/interpolation frames between I-frames (B-frames) forms the compressed video data stream. This general scheme of block motion compensation and block coding is employed by all types of MPEG video coding standards so the testing will be done with a common MPEG2 software encoder/decoder.

3. MPEG motion compensation

The motion compensation is the most time-consuming part of the video encoder. It uses a search window (usually four times of the size of the macroblock) to find a motion vector pointing to a macroblock in the previous video frame with the best matching to the current block. To get a fast result, search strategies are used which test only a few positions inside the search window [2], [3]. An evaluation of different block matching algorithms concludes the difference of the estimated motion vector to the "real" vector, the number of search steps and a description of the ability of an algorithm to avoid getting trapped into local minima on the search path.
This project is directed on comparing different motion compensation algorithms as:

- full search,
- 2-D logarithmic search (e.g. 3-step search),
- increasing accuracy search, and
- center biased search with variable stepsize

within MPEG software encoders as [4], [5] to evaluate these algorithms on different classes of video sequences.

4. Block motion estimation errors

Typical block motion estimation errors are periodic patterns on block boundaries due to frequency skips and smoothed edges. Quantization errors occur if adjacent macroblocks in frame I are generated from very different macroblocks in frame $I-1$ due to limitations in the search algorithms and search window. All these effects are generally highly structured in digital video as opposed to errors in analog video where most of the errors are caused by analog filters and signal transmission. It will be studied which statistical methods provide reasonable measurements to these distortion artifacts. Employing these error metrics regarding the whole process of encoding and decoding will give an assessment if these search algorithms have a wider meaning for the quality measurement of the entire compression/decompression process.
A first example metric can be defined by comparing compression and decompression of the same video sequence using two different motion compensation algorithms. Let F, G be the two video sequences with the same number n of frames and the same frame resolution $N \times M$. Let f_i, g_i with $i \in [0 \dots n-1]$ be corresponding frames of F and G, so the metric

$$d(f_i, g_i) = \frac{1}{N \times M} \sum_{x=1}^{N} \sum_{y=1}^{M} |f_i(x,y) - g_i(x,y)|^2$$

gives the mean square error for a frame i. Note that here $f_i(x,y)$ and $g_i(x,y)$ are RGB colour values and therefore $|f_i(x,y) - g_i(x,y)|$ is the normal distance between two vectors in 3D space as: $\frac{1}{3}\|a-b\|^2$ with $a = (a_R, a_B, a_G), b = (b_R, b_B, b_G)$.
Let F be the original sequence and $G^{\mathcal{A}}, G^{\mathcal{B}}$ two compressed/uncompressed sequences of F employing different MC algorithms $\mathcal{A}$ and $\mathcal{B}$, then an error metric $d^{(F)}$ evaluating the algorithms at frame i can be written as:

$$d^{(F)}(g_i^{\mathcal{A}}, g_i^{\mathcal{B}}) = \left| d(f_i, g_i^{\mathcal{A}}) - d(f_i, g_i^{\mathcal{B}}) \right| .$$

Figure 1 shows a measure of the fast and full search algorithms of the MPEG2Tool [4] compressing a lab sequences of 338 frames with a moving person and peaks of motion in the frames 127-164 and 275-300, showing an encoding without any I-frames in between.

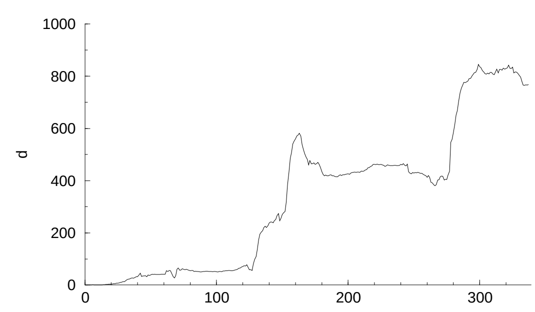

Figure 1: MC error $\mathbf{d^{(F)}}$ between fast and full MC

The metric $D_0^{(F)}$ with

$$D_0^{(F)}(G^{\mathcal{A}}, G^{\mathcal{B}}) = \frac{1}{n} \sum_{i=0}^{n-1} d^{(F)}(g_i^{\mathcal{A}}, g_i^{\mathcal{B}})$$

gives an assessment for the MC quality over the whole image sequence.
The next step will be to find a set of metrics $D_1 \ldots D_n$ which matches the different MC related errors. An other error to measure is the dependency of the MC from the quality of the MC of preceding frames in the frame window $f_n \cdots f_m$ as

$$D(F_{n,m}, G_{n,m}) = \frac{1}{c_{nm}} \sum_{i=n}^{m} a_{i-n} * d(f_i, g_i)$$

$$\text{with } \; m - n \geq 0 \; , \; c_{nm} = \sum_{i=0}^{m-n} a_i \; ,$$

$$a_i = \frac{1}{(m-n)i + 1} \; , \; i = 0, \ldots, m-n$$

for windows containing high motion or abrupt changes.

5. Testing

For the MPEG encoding and motion compression algorithm development, we are using two software packages, the MPEG2Tool from the University of Pennsylvania [4] and the MPEG-2 Video Codec of the MPEG Software Simulation Group [5].
The development of a set of synthetic testing video sequences has been started. For an exact measurement these video sequences contain sets of

- bars
- polygons
- circles
- line patterns

including variations of different colours and textures which allow a comparison of the images after the compression/decompression with the "ground truth". These patterns are rotating and moving at variable speed. Abrupt speed and scene changes are required to explore the search algorithms. These sequences will reveal the typical errors introduced by the motions compensation. Also the addition of uniform and Gaussian noise at different levels and time frames to the test sequences gives a measurement to the limitations of the search strategies of the different implementations. A set of "real world" test sequences will be used as control of the purposed error metrics.

6. Goals

The development of a set of error metrics for the assessment of block motion compensation and of a series of test sequences will lead to the question of how video compression before motion tracking (e.g. with hardware compression in the camera or on a frame grabber hardware) influences the speed and accuracy of motion tracking applications. Another field of interest is how the preprocessing of video in respect to typical MC errors has an influence on the quality of the compressed video sequence. The results can also support the development of an improved fast motion compensation algorithm.

7. References

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