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Lossless video compression based on backward adaptive pixel-based fast motion estimation

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ABSTRACT

This paper presents a lossless video compression system based on a novel Backward Adaptive pixel-based fast Predictive Motion Estimation (BAPME). Unlike the widely used block-matching motion estimation techniques, this scheme predicts the motion on a pixel-by-pixel basis by comparing a group of past observed pixels between two adjacent frames, eliminating the need of transmitting side information. Combined with prediction and a fast search technique, the proposed algorithm achieves better entropy results and significant reduction in computation than pixel-based full search for a set of standard test sequences. Experimental results also show that BAPME outperforms block-based full search in terms of speed and entropy. We also provide the sub-pixel version of BAPME as well as integrate BAPME in a complete lossless video compression system. The experimental results are superior to the selected state-of-the-art schemes.

1. Introduction

Recently, lossless video compression has become more and more important, especially for emerging applications such as video archiving, digital cinema, remote sensing, and medical imaging [1]. Similar with the lossy counterpart, lossless video compression has been studied in both transform and spatial domains. In transform domain, Oami and Ohta [2] proposed to approximate the Discrete Cosine Transform (DCT) with an integer-matrix transform and performed a mapping-based quantisation process, to achieve lossless capability. Also, various forms of 2-D [3,4] and 3-D [5] wavelet transforms were investigated in the context of lossless video compression. In spatial domain, motion estimation is usually applied to remove the temporal redundancy. Due to the shift-variant property [3,6] and the added complexity of operating in the transform domain, we are in favour of performing motion estimation in the spatial domain.

There are generally two kinds of motion estimation: block-matching algorithm (BMA) and pixel-based algorithm (PBA). BMA is simple and efficient. A large number of researchers employed and improved BMA in their lossless video compression schemes [7–11]. Memon and Sayood were among the pioneers looking into the problem of lossless compression of video [7]. They presented a hybrid compression scheme that adaptively switches between the temporal predictor based on BMA and the spectral predictor which takes the best predictor among spectral planes. Brunello et al. [8] introduced a temporal prediction scheme based on motion estimation and optimal 3-D linear prediction. Carotti and Martin [11] combined the CALIC [12] framework with a temporal predictor which uses multi-frame motion estimation and least square method to weigh predicted values from multiple frames. The advanced video compression standard H.264/MPEG-4 AVC [13], featuring multi-frame variable block-size block-base motion estimation, has the

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advantage of being flexible and efficient. It has a 4×4 and a 16×16 block-based intra-frame prediction, each of which supports nine and four prediction modes, respectively. Its "High Profile" includes a simple predictive method to encode the marcoblocks losslessly. These BMA based methods need to transmit the motion vectors (MV) to the decoder. When high accuracy of motion estimation is required, the size of MV often increases and thus becomes a large burden. Pixel-based algorithm (PBA), on the other hand, makes use of the past information so as to avoid sending large amount of MV as side information. Yang and Faryar [14] proposed a simple pixel-based scheme which adaptively chooses either intra-frame or inter-frame predictor by comparing the variance of the intra-frame and inter-frame neighbourhoods. Its inter-frame predictor directly takes the pixel in the previous frame with the same position of the current pixel as predicted value. Carotti et al. [1,15] used the previous two frames to predict the pixel in the current frame. It is based on the assumption that the motion registered between the previous two frames continues at the present time. Li and Sayood [16] designed a temporal predictor which used a local neighbourhood to do full search (FS) within the search area and finds the one that minimises the mean of absolute difference (MAD). It also includes wavelet transform and spatial prediction in the video compression system. These pixel-based motion estimation schemes need to perform at least a certain amount of motion estimation on the decoder side as well as the encoder.

However, much as it is efficient in temporal decorrelation, motion estimation is computationally intensive and can consume up to 80% of the total computational requirement in the H.264/AVC encoder (JM software) [17–19]. Therefore, many *fast search* techniques have been invented to alleviate the heavy computation of full search, which exhaustively evaluates all possible positions within the search area in the reference frame. In the popular block-matching algorithm, full search is assumed to be able to achieve the best motion estimation accuracy, regardless of the bitrate, due to its exhaustiveness which, however, leads to very heavy computation load. The idea of fast search is to examine only a few positions instead of all positions in the search area. This would often result in less accurate estimation of the motion than using full search. The goal of fast search is to reduce the computation as much as possible while maintaining the motion estimation accuracy. Classical representative fast search examples are three step search [20], diamond search [21,22] and hexagonal search [23].

While full search and fast search have been widely used in block-matching motion estimation [13,8], only full search is adopted by pixel-based schemes [16]. Fig. 1 shows the main trend of algorithms in the literature (solid line). One of our contributions, as the dash line shown in Fig. 1, is to bridge pixel-based algorithms and fast search, on which we are not aware of any research work in the literature. This well serves our goal to develop a lossless video compression system that is able to achieve high compression ratio with reduced complexity. Our previous letter [24] has introduced the concept of a backward

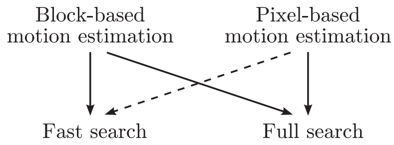

Fig. 1. Main trend of algorithms in the literature vs. our approach (dash line).

adaptive pixel-based fast predictive motion estimation (BAPME) for this purpose. In this paper, we will provide the first complete description of BAPME and discuss more details of it in depth. We also provide the sub-pixel version of BAPME, as well as a complete lossless video compression system using BAPME. We have to emphasise that the techniques proposed here mainly aim for lossless video compression and hence we are not considering the rate–distortion problem.

This paper is organised as follows. In Section 2, we propose a pixel-based fast predictive motion estimation and discuss its performance and complexity. The sub-pixel version of the motion estimation and its empirical performance are presented in Section 3, followed by the complete system and its performance in Section 4. Conclusions are drawn in Section 5.

2. Pixel-based fast predictive motion estimation

In this section, we describe the Backward Adaptive pixel-based fast Predictive Motion Estimation (BAPME) scheme and discuss various issues of it. The goal of BAPME is, without transmitting any overheads, to obtain smaller residual after motion estimation and to reduce the computational complexity. Because no motion vector is transmitted, BAPME is a symmetric coding scheme, where the whole procedure has to be performed at both the coder and the decoder. In brief, the main novelties of BAPME are: (1) it is pixel-based; (2) it includes a new prediction scheme for initial motion vector; and (3) it performs fast search on our designed routine. We explain these features in detail below.

1. The proposed motion estimation scheme is conducted on a pixel-by-pixel basis, due to the natural difficulties of block-matching: first, objects in video usually have irregular shapes. Some schemes introduced variable block size (from 16×16 to 4×4) to adapt to the video contents [13,18], but this still has limitation in shapes and increases the complexity and the amount of side information; second, the rigid motion (e.g. rotation and zoom) and non-rigid motion (e.g. elastic or deformable motion) are hard to model by rigid blocks; third, the transmission of side information is undesirable. To this end, we seek an alternative pixel-based approach which cares for each individual pixel and possibly achieves better motion estimation accuracy without sending any side information. In contrast with BMA, our pixel-based scheme is more "prediction-based" rather than "matching-based", because the pixel to be coded is not included in any matching