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Employing a novel cross-diamond search in a modified hierarchical search motion estimation algorithm for video compression

Nijad Al-Najdawi [a,*], M. Noor Al-Najdawi [a,1], Sara Tedmori [b,2]

[a] Computer Science Department, Prince Abdullah Bin Ghazi Faculty of Information Technology, Al-Balqa Applied University, Jordan
[b] Computer Science Department, The King Hussein School for Computing Sciences, Princess Sumaya University for Technology, Jordan

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ABSTRACT

The large amount of bandwidth that is required for the transmission or storage of digital videos is the main incentive for researchers to develop algorithms that aim at compressing video data (digital images) whilst keeping their quality as high as possible. Motion estimation algorithms are used for video compression as they reduce the memory requirements of any video file while maintaining its high quality. Block matching has been extensively utilized in compression algorithms for motion estimation. One of the main components of block matching techniques is search methods for block movements between consecutive video frames whose aim is to reduce the number of comparisons. One of the most effective searching methods that yield accurate results but is computationally very expensive is the Full Search algorithm. Researchers try to develop fast search motion estimation algorithms to reduce the computational cost required by full-search algorithms. In this research, the authors present a new fast search algorithm based on the hierarchical search approach, where the number of searched locations is reduced compared to the Full Search. The original image is sub-sampled into additional two levels. The Full Search is performed on the highest level where the complexity is relatively low. The Enhanced Three-Step Search Algorithm and a new proposed searching algorithm are used in the consecutive two levels. The results show that by using the standard accuracy measurements and the standard set of video sequences, the performance of the proposed hierarchal search algorithm is close to the Full Search with 83.4% reduction in complexity and with a matching quality over 98%.

1. Introduction

Video compression is the process of representing the video data using fewer bits than the original representation. The captured video frames consist of redundant data in the spatial and temporal domains. Therefore, researchers have developed inter and intra-frame coding methods to eliminate the temporal and spatial domains redundancy, respectively. In inter-frame coding, motion estimation and compensation algorithms are powerful in eliminating the temporal redundancy, due to the high correlation between consecutive frames. Motion estimation algorithms express the transformation from one frame to another using motion vectors and can be classified into, Pel-recursive algorithms and Block Matching Algorithms (BMA). Pel-recursive algorithms are used to iteratively refine individual pixels using gradient methods. The BMAs assume

* Corresponding author. Tel.: +962 (0)775054992.
E-mail addresses: n.al-najdawi@bau.edu.jo (N. Al-Najdawi), mohednoor@bau.edu.jo (M. Noor Al-Najdawi), s.tedmori@psut.edu.jo (S. Tedmori).
[1] Tel.: +962 (0)53491111.
[2] Tel.: +962 (0)779969654.

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that all the pixels within a block have the same motion activity, and are used to estimate motion on the basis of rectangular blocks, producing one motion vector for each block. BMAs are more applicable due to their lower complexities and simplicity [13]. In BMAs, the current frame of a video sequence is divided into non-overlapping square blocks of $N \times N$ pixels. For each reference block in the current frame, the algorithm searches for the best matched block within a search window in the previous frame of size $(2w + N) \times (2w + N)$, where w is the window size. The relative position between the reference and its best matched block is represented as the motion vector of the reference block [34]. Amongst the available matching criteria, the Sum of Absolute Difference (SAD) given by: $\mathrm{SAD}_{(m,n)} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1}|A - B|$ where $A = f_t(g + x, h + y)$, 83.4%, and $-w \leqslant m,\ n \leqslant w$, $f_t(g,h)$ is the current frame reference block of its upper left pixel at the coordinate (g,h), and $f_{t-1}(g + m, h + n)$ is a candidate block in the previous frame. The total computations of $\mathrm{SAD}_{(m,n)}$ are N^2 absolute values and $2N^2 - 1$ additions. A straight forward method of BMA is the Full-Search Algorithm (FSA), which requires computing the $\mathrm{SAD}_{(m,n)}$ for all $(2w + 1)^2$ positions of candidate blocks in the search window, where w is the maximum displacement within the search window. The FSA requires $(2w + 1)^2 \times N^2$ absolute values, $(2w + 1)^2 \times (2N^2 - 1)$ additions and $(2w + 1)^2$ comparisons for each reference block. Although FSAs yield the best possible results, they require intensive computation processes, hence limiting their practical applications. Therefore, researchers have investigated the use of computationally efficient fast search motion estimation algorithms. Fast search algorithms are classified as sub-optimal to the FSAs as they do not result in a quality that is as good [11]. In this research, the authors present a new fast search algorithm based on the hierarchical search approach, where the number of searched locations is reduced compared to the Full Search.

The rest of the paper is organised as follows: Section 2 presents the related literature. Section 3 introduces the proposed method and Section4 presents the experimental results and evaluation. Finally, Section 5 concludes this work.

2. Related work

BMAs are built depending on search patterns, step sizes, and the total number of required searches, attempting to reduce the complexity of FSA, by mostly reducing the number of required comparisons. Many BMAs have been developed using different search patterns such as cross, and diamond patterns. The former pattern involves searching the diagonal neighboring points, and the latter involves searching the adjacent vertical/horizontal neighboring points. Another criterion that differentiates between BMAs is the step size, which indicates the distance (in pixels) between the searching points and the center of search. Some algorithms are based on fixed distances, while others calculate step sizes based on the searching window size. The total number of required searches (comparisons) is algorithm dependent, and it indicates how many comparisons the algorithm will perform before it concludes with the best match. The total number of required comparisons has a great impact on the algorithm's complexity; therefore researchers have attempted to develop algorithms that require a low number of comparisons. Amongst the available block matching algorithms, the Three-Step-Search (TSS) is the most popular algorithm. While the FSA requires, for a standard window size of (∓ 7) pixels, 225 comparisons to find the best match, the TSS algorithm [18] requires only 25 comparisons. The TSS algorithm however, uses a uniformly allocated checking point pattern, making it inefficient for searching small motion video sequences. The New Three Step Search (NTSS) Algorithm [28] is an altered version of the existing TSS algorithm. Whilst the TSS algorithm requires predefined checking points pattern, the NTSS algorithm uses center-biased checking point pattern, by making the search adaptive to the motion vector distribution. In NTSS, a halfway-stop technique is used to reduce the computation cost. Another approach that enhances the existing TSS algorithm is the Efficient Three Step Search (ETSS) algorithm [16]. This algorithm is used in this research and is described thoroughly in Section 3.3. The Four-Step-Search algorithm [32] uses a center-biased checking point pattern; and the Halfway-stop technique. It utilizes a small initial step compared to the TSS.

The Dynamic Search Window Adjustment and Interlaced Search (DSWA/IS) algorithm [27] improves the performance of the TSS algorithm. The DSWA algorithm adaptively adjusts the size of the search window based on the best match position, whilst in the IS algorithm, only five positions are alternatively tested. The DSWA/IS algorithm presents a more intelligent logarithmic step search with variable patterns.

The Two Dimensional Logarithmic Search (TDLS) algorithm [14] works by dividing a frame into blocks and then finds the minimum distortion for each block. The TDLS employs the cross search pattern in each step. The Binary Search algorithm [43], works by dividing the search window into a number of regions and then performs a Full Search only on one of these regions. The New Diamond Search algorithm (NDSA) [44] uses two search patterns. The first pattern is a large diamond search comprised of nine checking points. The second pattern is a small diamond search pattern consisting of five checking points. The Orthogonal Search Algorithm [33] has three checking points to be searched horizontally. The best match becomes the center of the three point vertical search, where the step size is decreased by half and the same strategy is used.

In the Cross Search Algorithm [12], each step involves 4 locations to be searched. Starting from the center point and forming searching points at the end of cross (X) pattern, the best match is selected to be the new center point, and the step size is decreased by half. The same procedure is repeated until the step size becomes equal to 1. At this step size, a (+) cross search pattern is used, if the best match of the previous step is either the center, upper left or lower right checking point, otherwise, a (X) cross search pattern is used.

The Block-Based Gradient Descent Search algorithm [29] uses the center biased checking block in the initial search step. The search procedure of the algorithm involves evaluating all of the nine points in the block. If the minimum occurs at the center, the algorithm stops and the motion vector points to the center; otherwise the best match is selected to be the center