A SEMI-GLOBAL MOTION ESTIMATION OF A REPETITION PATTERN REGION FOR FRAME INTERPOLATION

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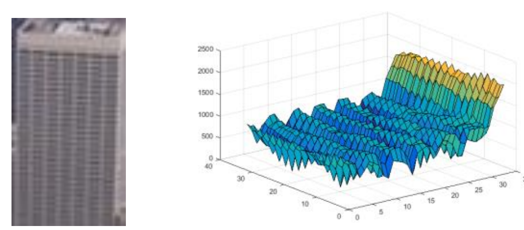
ABSTRACT

In motion compensated frame interpolation, a repetition pattern in an image makes it difficult to derive an accurate motion vector because multiple similar local minima exist in the search space of the matching cost for motion estimation. In order to improve the accuracy of motion estimation in a repetition region, this paper attempts a semi-global approach that exploits both local and global characteristics of a repetition region. Experimental results demonstrate that the proposed method significantly outperforms the previous local approach achieving the PSNR improvement by around 2.59 dB.

***Index Terms*—** Repetition pattern, Frame interpolation, FRUC, MEMC

1. INTRODUCTION

For frame rate up conversion, the derivation of an accurate motion vector is important to ensure the high visual quality of the interpolated frame. However, a repetition pattern in an image makes it difficult to derive an accurate motion vector because multiple similar local minima exist in the search space of the matching cost for motion estimation. A number of previous algorithms have been proposed to reduce the matching errors in the estimation of motion vectors in repetition regions. In [1], an exhaustive full-search motion estimation is used to find solutions for repetition pattern regions. In [2], the motion vectors of repetition pattern blocks are corrected by recursive average operations. In [3], the spectral image is analyzed to estimate the motion vectors for repetition regions. In [4], a new design methodology is explored by using suboptimal measures for two different motion estimation algorithms. In [5-8], a Maximize-A-Posterior (MAP) based method is proposed for motion estimation. The matching cost is regularized by a smoothness constraint in order to improve the accuracies of motion vectors. These previous methods use a local approach that estimates or corrects the motion vector of a repetition pattern block by using only the information from the block itself and its neighbors. These methods sometimes miss the corrected motion vector because multiple similar local minima exist in the search space of the matching cost for motion estimation. Fig. 1 shows an example of the repetition pattern region with multiple similar local minima in the SAD surface of a block in the region.



(a) Repetition pattern region (b) SAD surface

Fig 1. An example of a repetition pattern region and its SAD surface.

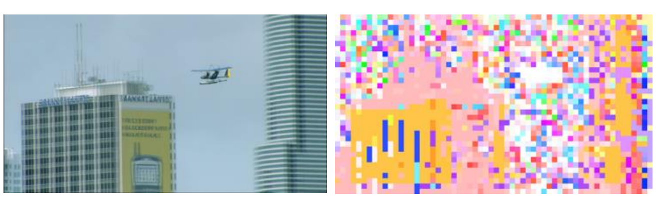
The paper tackles the multiple local minima problem by using a semi-global approach that obtains an accurate motion vector for a repetition pattern region. The idea of the proposed algorithm comes from the following observation. Repetition pattern blocks share the same motion vector that is the motion vector of the whole repetition pattern region. Therefore, the blocks in a repetition region can be merged to form a repetition pattern region and a single motion vector is derived for the merged region. The larger the repetition region is, the more accurate the estimated motion vector is. This merging based method obtains a very accurate motion vector at the cost of the increased memory bandwidth and large memory buffers to store pixels of the region and save the pixel differences. Therefore, the proposed algorithm uses a semi-global approach in order to replace the global approach that estimates the motion vector of the whole region. As a result, the semi-global approach reduces the computational complexity while maintaining the accuracy of motion estimation.

The proposed algorithm is the first attempt to adopt the semi-global approach to estimate the motion vector of the repetition pattern blocks. It efficiently handles multiple local minima problem of repetition pattern blocks. The rest of paper is organized as follows. Section II introduces the idea of the semi-global approach. The proposed method is presented in Section III and experimental results are given in Section IV. Section V concludes this paper.

2. SEMI - GLOBAL APPROACH

Because a local approach cannot handle multiple local minima problem of repetition pattern blocks, the motion vector field obtained by previous correction methods still include many noisy and unreliable motion vectors as shown in Fig. 2(b). Observation of the example image shows that the repetition pattern blocks share the same motion vector that is the motion vector of the whole repetition pattern region. Therefore, the repetition pattern blocks can be merged together and the motion vector is derived for the whole region. Motion estimation for the whole region can obtain an accurate motion vector because it exploits the global property of the movement of the repetition pattern region. However, the motion estimation for a large region requires complex computation. Therefore, it is necessary to find another way to compute the motion vector for a repetition pattern region without additional search operation. In other words, the motion vector of the whole region is derived by exploiting the global property to achieve good accuracy but using local approach to reduce computational complexity.

The most frequent motion vector among estimated motion vectors of repetition pattern blocks may be the representative motion vector for the whole region. However, the motion vectors of repetition pattern blocks are unreliable, and consequently, the derivation of the motion vectors from unreliable ones may also be unreliable. Fig. 2 shows an example of the estimated motion vector field obtained by full search block matching algorithm. Fig 2(b) shows that the motion vector field includes many wrong noisy motion vectors in the repetition pattern regions. The most frequent motion vector is [6, 15] but it is not the correct motion vector of the repetition pattern region. In fact, the ground-truth motion vector is equal to [6, 0]. The derivation of the motion vectors by observing their histogram among the blocks in the repetition region may generate an accurate motion vector without an addition search operation. The proposed algorithm that combines the multiple similar local minima characteristic of the repetition pattern blocks and global property of the movement of the repetition pattern regions together to make the reliable derivation of the correct motion vector.



(a) (b)

Fig 2. Example of motion vector field for repetition pattern estimated by a local approach. (a) Original frame, (b) Estimated motion vector field

3. PROPOSED ALGORITHM

The proposed algorithm assumes that the global minimum of the matching cost of the entire repetition pattern region corresponds to one of the local minima of the blocks in the repetition region. Therefore, the motion vector of the repetition region can be obtained from the motion vector candidates of the blocks in the repetition region. Based on the above assumption, the proposed algorithm consists of two steps. Step 1 makes a histogram of the motion vector candidates that are obtained during the motion estimation for individual blocks in the repetition region. Step 2 selects the most frequent motion vector candidate in the histogram to be the final motion vector of the entire repetition region.

The details of the proposed algorithm are presented in Fig. 3. At the beginning of Step 1, the proposed algorithm estimates multiple smallest local minima, or a Motion Vector (MV) candidate set. In order to avoid a local minimum with a relatively large value, the algorithm limits the maximum number of local minima to 10. If the number of the MV candidates is smaller than 10, the algorithm continues searching a local minimum pushing it to the MV candidate set. If 10 MV candidates are in the set and a new local minimum is found, the proposed algorithm compares the local minimum value to the maximum value among the local minima in the MV candidate set, denoted by MAX_VALUE. If the local minimum value is smaller than MAX_VALUE, then the new local minimum is pushed to the MV candidate set. In this manner, all local minima inside the MV candidate set are guaranteed to be the smallest ones. The next step detects whether the block belongs to a repetition pattern or not, by using the integral projection method presented in [1]. Finally, a motion vector histogram is generated and then the most frequent motion vector is selected as the representative motion vector for the whole repetition region.

Step 1 exploits the property of multiple local minima in a repetition pattern block while Step 2 represents the global property of a repetition region. In other words, Step 1 improves the reliability of the voting process in Step 2, and consequently, increases the accuracy of the most frequent MV candidate obtained by Step 2. For illustration of the proposed algorithm, an example with five blocks (N = 5) is presented next. Suppose that the MV candidate set for five blocks are obtained as follows:

MV Set_1 = {[-2,-4], [-2, 0]}
MV Set_2 = {[-6,-4], [-2, 0]}
MV Set_3 = {[-2,-4], [-2, 0], [2, 0], [8, 0]}
MV Set_4 = {[-6,-4], [-2, 0], [-2, 2], [4, 2]}
MV Set_5 = {[-2,-2], [-2, 0], [8, 0]}

Then, the histogram of MV candidates are as follows:
MV histogram = {[-6,-4], [-2,-4], [-2,-2], [-2, 0], [-2, 2], [2, 0], [4, 2], [8, 0]}
Corresponding counts: {2, 2, 1, **5,** 1, 1, 2}

In this example, the most frequent motion vector is [-2, 0] derived five times in the motion estimations of all the blocks in the repetition region.

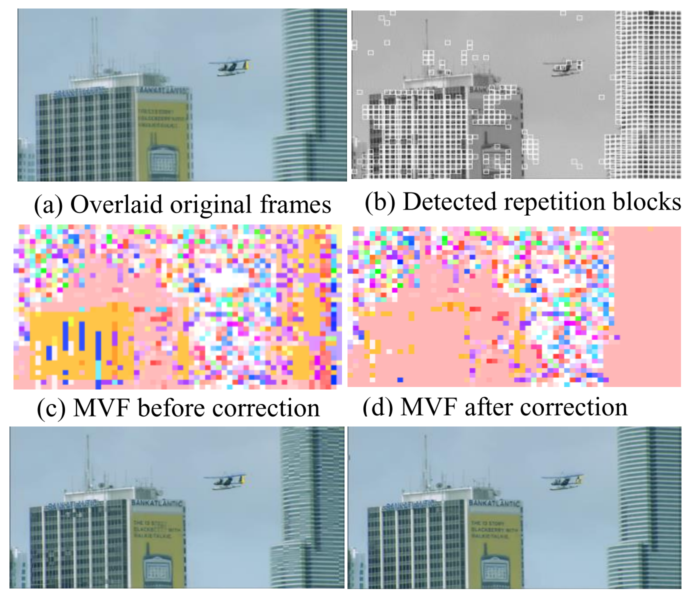
Proposed Algorithm
Step 1: Make MV Histogram of MV candidates
  1.1. Initialization: All bins are the MV histogram are empty
  1.2. Build an MV set for each block
  Core Algorithm
  For (each block k)
    Initialization: MV Set_k = {Empty}
    Loop over search range
      1.2.1. Find a local minimum
      1.2.2. Push the local minimum into the MV Set_k or Not
      if (size_of(MV Set_k) < 10)
        push the local minimum into the MV Set_k
      else {
        find MAX_VALUE = max(local minima in MV Set_k)
        if (the local minimum < MAX_VALUE) {
          remove MAX_VALUE out of MV Set_k
          push the local minimum into the MV Set_k
        }
      }
    Check the block is in a repetition region or not
    If (repetition block k)
      Push the motion vectors in the MV Set_k into corresponding bins
Step 2: Choose the representative of the region
  - The most frequent MV candidate in the MV Histogram

Fig 3. Proposed algorithm

Additional memory buffers for the proposed algorithm
In step 1.2.1, the proposed algorithm saves eight neighboring SAD values to find a local minimum. In addition, maximum ten motion vector candidates are stored for each block. For the motion vector histogram, the maximum of the number of the MVs in the MV histogram is equal to the size of the search range. In other words, the size of the MV histogram is 33x33 = 1089 MVs. Assuming the raster scan search, the proposed algorithm does not need to save MVs. Instead, it just saves the indices (or positions) of the MVs in the search range because the algorithm can derive the MVs from their indices. The only information that needs to be saved is the frequency count values for the MV candidates in the MV histogram. For a full HD frame with the block size of 8x8, the number of the blocks is 32,400. In the worst case when all blocks belong to a repetition region, the frequency count value can take the value of 32,400, and therefore it requires 15 bits to save each frequency count value, or 2 Bytes. Totally, for all MV candidates, the proposed algorithm requires 2 * 1089 ~ 2 KB, which is relatively small when compared with the memory size to store the original image.

4. EXPERIMENTAL RESULTS

The performance of the proposed algorithm is shown in Fig 4. From two original frames in Fig. 4(a), the algorithm estimates the initial motion vectors of the blocks by using exhaustive full search-based block matching, shown in Fig. 4(c) and detects repetition pattern blocks presented in Fig. 4(b). The corrected motion vector field by the proposed algorithm is shown in Fig. 4(d) and the whole repetition region shares the same motion vector that is the representative motion vector of the region. It is accurate and equal to the ground truth-value. Therefore, the interpolated frame generated by the corrected motion vector field is clearer than the interpolated frame generated by the noisy motion vector field before correction (see Fig. 4(e)).



(a) Overlaid original frames (b) Detected repetition blocks
(c) MVF before correction (d) MVF after correction
(e) Interpolated frame generated by (c) (f) Interpolated frame generated by (d)

Fig. 4: An example result of the proposed method

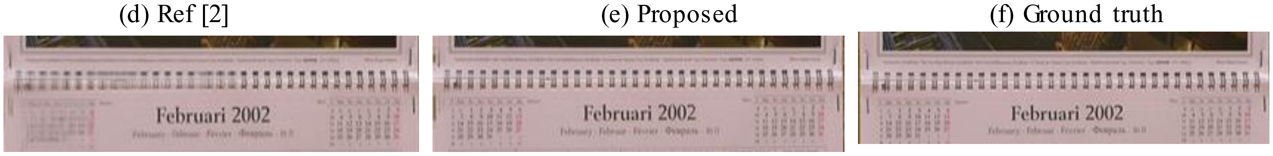
The proposed algorithm is compared with the previous local-based method in [2]. Simulation is conducted with three standard datasets, Bus, Mobile and Calendar sequences which include repetition regions. The PSNR is used as the measurement metric for objective comparison. The simulation result is shown in Table 1 which shows the proposed algorithm outperforms the previous method significantly by around 2.59 dB.

Table 1. PSNR comparison.

Testbeds	Local-based algorithm [2]		Proposed algorithm
	PSNR (dB)	Δ (dB)	PSNR (dB)
Bus	24.72	2.23	26.95
Mobile	26.16	0.67	26.83
Calendar	28.80	4.86	33.66
Average	**26.56**	**2.59**	**29.15**

(a) Ref [2] (b) Proposed (c) Ground truth

(d) Ref [2] (e) Proposed (f) Ground truth



(g) Ref [2] (h) Proposed (i) Ground truth

Fig. 5: Subjective comparison between the previous and the proposed algorithms.

First row: Mobile sequence – frame 11, Second row: Bus sequence - frame 33, Last row: Calendar sequence – frame 301

Subjective comparisons are presented in Fig. 5 in which the left column presents the interpolated frames by the previous method in [2]. The interpolated frames generated by the proposed algorithm are shown in the middle column. The last column corresponds to the ground truth frame. In the previous method in [2], the interpolated frame is blurred and unclear. On the other hand, the proposed algorithm estimates the motion vector of repetition regions accurately, and consequently, generates the output clearer than the previous method does.

5. CONCLUSION

This paper presents a novel algorithm to estimate the motion information in repetition pattern regions. The algorithm is the first to adopt a semi-global approach that exploits both local and global properties of repetition pattern regions. It merges the repetition pattern blocks into a large region and makes the histogram of the smallest local minima of all blocks in the region. The merging represents a large region and makes the histogram of the smallest local minima. It improves the accuracy of the motion vectors in the repetition pattern region. The proposed algorithm is simple but effective in the estimation of the motion vectors for repetition pattern blocks.

6. ACKNOWLEDGEMENT

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