A Novel Approach for Video Frame Interpolation using Cubic Motion Compensation Technique

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Abstract

Increasing frame rates by frame interpolation is one of the main challenges in video processing. Motion estimation and motion compensation are two main keys of video frame interpolation algorithm. Motion estimation algorithms are used to get refine motion vectors while motion compensation algorithm assigns motion vectors accurately. Recent studies on video frame interpolation mainly focused on motion estimation algorithms, but along with that assigning motion vectors accurately is also an important issue. This paper concentrates on motion compensation. In this paper we have proposed a novel method for video frame interpolation using Cubic Motion Compensation technique which assigns motion vectors accurately. Instead of using two consecutive frames for motion estimation as in Conventional method, this paper considers four consecutive frames and calculates three different motion vectors. It is observed that proposed algorithm have relatively outperforms over conventional Motion compensated frame interpolation algorithm. For evaluation, average Peak Signal to Noise Ratio (PSNR) and average Structural Similarity (SSIM) are considered to compare the results. According to simulation results, using test sequences of different frame sizes, it can be observed that the proposed algorithm have effectively improves average PSNR of reconstructed frame by around 3dB and average SSIM have increased upto 5% with reference to the traditional methods.

Keywords: Motion Estimation (ME), Motion Compensated Frame Interpolation (MCFI), Structural Similarity (SSIM), Video Graphic Array (VGA), Common Intermediate Format (CIF).

INTRODUCTION

Temporal frame interpolation upconverts frame rate by inserting new frames between the original frames of video sequences. This process plays significant role in modern video processing applications like frame rate up-conversion, low bit rate video coding, scalable video coding, slow motion playback, distributed video coding etc. To satisfy bandwidth requirement over internet or wireless networks, it is observed that, many a times frame dropping or filtering techniques are used. With emergence of new multimedia and television systems, it is required to convert frame rate between two different display formats with different frame rates for different display devices [2].

Temporal frame interpolation or Frame rate up conversion algorithms can be divided into two different methods. Simplest

method includes repetition of frames or average of two frames and another method is motion compensated frame interpolation. Repetition of frames cause motion judder, while by averaging two frames to reconstruct the new frame leads to motion blur commonly referred as ghost artifacts.

Many motion compensated frame interpolation techniques are widely used for better quality [1-13]. Motion compensated frame interpolation algorithm have two main aspects i.e. motion estimation (ME) and motion compensation (MC). To achieve better performance in temporal frame interpolation, first it requires proper motion estimation to get accurate motion vectors and second priority is to accurately assign motion vectors in new interpolated frame. In this paper we are emphasizing on second issue of accurately assigning motion vectors.

Many efficient motion estimation algorithms have been proposed till date [10-13]. Previous studies adopt motion compensation technique discussed in section III-A. This paper, proposes a new motion compensation frame interpolation algorithm based on cubic interpolation technique. This approach improves quality of reconstructed frame.

The paper is organized as follows: First, the basic algorithm and existing work is described, then proposed cubic motion compensated algorithm is explained followed by performance evaluation of the proposed algorithm compared with existing motion compensated algorithm and conclusion of the work.

THEORETICAL BACKGROUND

Kang and Kim, [1] proposed unidirectional and bidirectional matching blocks in previous and current frames to achieve better visual quality. Wang et al, [2] proposed a technique in which moving objects are detected and segmented into blocks to perform motion compensated frame interpolation and also investigates the quality and complexity trade-off. Choi et al, [3] proposed a motion compensated frame interpolation method using bi-directional motion estimation. By segmentation, frame is divided into stationary background, moving object, covered and uncovered regions. Guo et al, [13] handles occluded region while frame rate up-conversion.

Motion estimation and motion compensation are two important methods in temporal frame interpolation. In this section idea of motion estimation (ME) algorithm is described. Motion estimation is done to reduce temporal redundancy i.e. to evaluate change between original adjacent frames. Motion Estimation (ME) method discussed in this paper is based on block matching algorithm. Process of getting best match block by block is called block based Motion Estimation. Forward motion estimation, backward motion estimation and

bidirectional motion estimation are three different methods of ME. For getting best match in ME, there are some matching criteria [16-17],

- Mean Squared Error (MSE)
- Mean Absolute Difference (MAD)
- Sum of Absolute Difference (SAD)
- Sum of Absolute Transformed Difference (SATD)
- Sum of Bidirectional Absolute Difference (SBAD)

In this paper we are using MAD as matching criteria, after experimental results compared with MSE. There are different search algorithms of Motion Estimation (ME) [17],

- Full Search algorithm (Exhaustive search)
- 2D Logarithmic Search Algorithm
- Cross Search
- Three Step Search (TSS) Algorithm
- One at a time Search Algorithm
- Diamond Search Algorithm
- Hierarchical motion estimation (HME)
- 3D-Recursive Search algorithm (3DRS) [11]
- Hierarchical 3DRS motion estimation [11]

In this paper, TSS algorithm is applied as it is simple and takes less computational time with achieving approximate estimation [16].

In block matching motion estimation, two consecutive frames are considered. Here we are considering forward motion estimation wherein, current frame is divided into non-overlapping blocks of size $N \times N$ and each block is searched in next frame within a search window of size $(N+2P)$ [17]. P is a search window range. Assuming f_{k-1} and f_{k+1} as current frame and next frame respectively, motion vectors $V(MV_x, MV_y)$ are estimated using MAD as given in Eq. 1 and Eq. 2 [17]. MV_x, MV_y are motion vectors.

$$MAD(i, j) = \left(\frac{1}{N \times N} \right) * \left[\sum_{x=0}^{N-1} \sum_{y=0}^{N-1} |f_{k-1}(x, y) - f_{k+1}(x+i, y+j)| \right] \quad (1)$$

$$V(MV_x, MV_y) = \arg \min \{MAD(i, j)\} \quad (2)$$

Where, i and j represents pixel positions of frames. After finding motion vectors, constructing the interpolated frame using motion compensation is very essential part.

Here we introduce the concept of applying cubic interpolation for motion compensation to get better interpolated frame.

PROPOSED WORK

Conventional motion compensation algorithm is discussed in section-A, followed by proposed cubic motion compensated frame interpolation algorithm in section-B.

Conventional Motion Compensation frame interpolation Algorithm

Using motion vectors from Eq. 2, the conventional motion compensation algorithm can be applied as,

$$f_k(x, y) = \frac{1}{2} \left\{ f_{k-1}(x, y) + \left[f_{k+1} \left(x - \frac{MV_x}{2}, y - \frac{MV_y}{2} \right) \right] \right\} \quad (3)$$

$f_k(x, y)$ is an intermediate frame to be interpolated. For comparing proposed algorithm with conventional algorithm,

Eq. 3 [4] is used for motion compensated frame interpolation. Eq. 3 is linear motion compensated interpolation as it is averaging two frames using motion vectors.

It is proven that for spatial interpolation, bicubic interpolation method outperforms over bilinear interpolation method. So this paper uses the cubic motion compensated frame interpolation algorithm to improve the reconstructed quality of intermediate frame.

Cubic Motion Compensated Frame Interpolation Algorithm

Instead of using conventional linear Motion Compensated Frame Interpolation (MCFI), cubic interpolation is introduced in this paper. Instead of two successive frames for frame interpolation, four successive frames are considered in the cubic interpolation technique. Say f_k is an intermediate frame to be interpolated, f_{k-1} is a current frame, f_{k-2} is a previous frame, f_{k+1} is a next frame and f_{k+2} is a next to next frame. The equation for calculating intermediate frame f_k is given by Eq. 4, $f_k(x, y) = [B(t_1) * Z_1] + [B(t_2) * Z_2] + [B(t_3) * Z_3] + [B(t_4) * Z_4]$ (4)

Where,

$$Z_1 = f_{k-2} \left(x - \frac{MV_{x2}}{2}, y - \frac{MV_{y2}}{2} \right) \quad (5a)$$

$$Z_2 = f_{k-1}(x, y) \quad (5b)$$

$$Z_3 = f_{k+1} \left(x - \frac{MV_{x1}}{2}, y - \frac{MV_{y1}}{2} \right) \quad (5c)$$

$$Z_4 = f_{k+2} \left(x - \frac{MV_{x3}}{2}, y - \frac{MV_{y3}}{2} \right) \quad (5d)$$

Where, x and y represents pixel positions of frames and $MV_{x1}, MV_{y1}, MV_{x2}, MV_{y2}, MV_{x3}$ and MV_{y3} represents motion vectors. $V(MV_{x1}, MV_{y1})$ is estimated motion vector between frames f_{k-1} and f_{k+1} by forward ME, $V(MV_{x2}, MV_{y2})$ is estimated motion vectors between frames f_{k-1} and f_{k-2} by forward ME, $V(MV_{x3}, MV_{y3})$ is estimated motion vectors between frames f_{k-1} and f_{k+2} by backward ME, $B(t_i)$ (where, $i=1,2,3,4$) is an interpolation kernel which is known as B-spline function, t_i are data positions.

Equations for interpolation are given from Eq. 6 to Eq. 12 [14]. Let, $B(t_i) = u(s_i)$, where $u(s_i)$ is calculated by Eq. 6-Eq. 12. If f is original function and g is its corresponding interpolation function, then $g(x_k) = f(x_k)$ for x_k as interpolation node. The interpolation function can be written as Eq. 6,

$$g(x) = \sum_k \left(c_k u \left(\frac{x - x_k}{h} \right) \right) \quad (6)$$

Where, $g(x)$ is interpolation function. C_k is control point which is a parameter depend on known data point or k^{th} sample. It can be also written as $C_k = f(x_k)$. u is the interpolation kernel. h is sampling increment. $h = x_{i+1} - x_i$. x_k is interpolation node. x is a point where data is to be interpolated and it is between x_{i+1} and x_i which are consecutive interpolation nodes. Say, x is a point in an interval $[x_0, x_1]$. For this x , $k = -1, 0, 1, 2$. The difference between two interpolation nodes x_i and x_k is given by Eq. 7,

$$x_i - x_k = (i - k) * h \quad (7)$$

Let,

$$s = \frac{x - x_i}{h} \quad (8)$$

$$\frac{x - x_i}{h} = \frac{x - x_i + x_i - x_k}{h} = s + i - k \quad (9)$$

Eq. 6 can be written as Eq. 10,

$$g(x) = \sum_k (c_k u(s + i - k)) \quad (10)$$

For $i=k$, Eq. 10 becomes Eq. 11,

$$g(x) = \sum_k (c_k u(s)) \quad (11)$$

The cubic interpolation kernel is given by Eq. 12,

$$\left. \begin{aligned} u(s) &= \frac{3}{2}|s|^3 - \frac{5}{2}|s|^2 + 1 & 0 < |s| < 1 \\ u(s) &= -\frac{1}{2}|s|^3 + \frac{5}{2}|s|^2 - 4|s| + 2 & 0 < |s| < 1 \\ u(s) &= 0 & 2 < |s| \end{aligned} \right\} \quad (12)$$

Outline of proposed work is shown as a block diagram in Figure 1. Flow chart summarizes all steps in entire process of temporal frame interpolation.

Figure 1: Flow Chart of Proposed Algorithm

PERFORMANCE EVALUATION

All simulations has been done using MATLAB and tests were executed on an Intel(R) Core(TM) i7-4770 CPU @ 3.40GHz clock frequency and 32 GB of RAM. For simulation, video sequences of different frame sizes are taken. These videos are taken from different video databases [21-24]. To compare the cubic motion compensated interpolation method with the conventional motion compensated interpolation, a common

motion estimation method i.e. TSS has been applied. Taking this motion estimation method as a common platform we have compared results obtained. For performance evaluation Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE) and Structural Similarity (SSIM) have been used.

The proposed method has been applied to different video sequences with frame size varying from CIF (Common Intermediate Format) 352*288 to HD1080p (High Definition) 1920*1080 progressive. To verify proposed method, we have dropped all even frames intentionally from original sequence and reconstructed all dropped frames to compare them with the originally dropped frames. The reconstructed frames are mathematically compared with the original frames using the parameters PSNR, MSE and SSIM. Mean Squared Error is given by Eq. 13 [1, 19],

$$MSE = \frac{1}{M * N} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [f_k(x, y) - f'_k(x, y)]^2 \quad (13)$$

Where f_k is original frame and f'_k is reconstructed frame and $M*N$ is size of frame. Peak Signal to Noise Ratio is given by Eq. 14 [1, 19],

$$PSNR = 10 * \left[\log_{10} \left(\frac{255 * 255}{MSE} \right) \right] \quad (14)$$

Where, MSE is mean Square error. Structural Similarity index (SSIM) is given by Eq. 15 & Eq. 16 [1, 15, 20].

$$SSIM(x, y) = L(x, y) * C(x, y) * S(x, y) = \frac{4\mu_x\mu_y\sigma_{xy}}{(\mu_x^2 + \mu_y^2)(\sigma_x^2 + \sigma_y^2)} \quad (15)$$

$$L(x, y) = \frac{2\mu_x\mu_y}{(\mu_x^2 + \mu_y^2)}, C(x, y) = \frac{2\sigma_x\sigma_y}{(\sigma_x^2 + \sigma_y^2)}, S(x, y) = \frac{\sigma_{xy}}{(\sigma_x + \sigma_y)} \quad (16)$$

$L(x, y)$ is luminance comparison, $C(x, y)$ is contrast comparison and $S(x, y)$ is structure comparison. These are three similarity measurement comparisons. Consider I_x and I_y as original and reconstructed frame respectively. μ_x , μ_y , σ_x , σ_y and σ_{xy} denote the mean, the variance and the covariance of I_x and I_y respectively.

For evaluation, initially motion vectors are calculated using TSS method. Table I shows video database used for evaluation of the proposed algorithm. In this work only gray scale videos are considered.

TABLE I. Video Parameters

Type of Video (Resolution)	Video Name	No. of frames	Frame Rates	Source
CIF (352*288)	Foreman.yuv	300	30	VIPS [21]
VGA (640*480)	visor_1.avi	65	16	Visor [22]
HD 720p (1280*720)	agh_src6_hrc0.avi	300	25	VQ [23]
HD 1080p (1920*1080)	Boat.avi	200	29	[24]

TABLE II. Average PSNR & Average SSIM In Tabular Form

Type Of Video	Average PSNR (dB)		Average SSIM	
	<i>Conventional MCFI</i>	<i>Cubic MCFI</i>	<i>Conventional MCFI</i>	<i>Cubic MCFI</i>
CIF	24.2743	26.9561	0.7226	0.7921
VGA	33.2069	36.0185	0.9729	0.9825
HD720p	26.4010	29.3940	0.9429	0.9657
HD1080p	27.3397	29.2548	0.8951	0.9391

Experimental results are shown in Table II. Comparison between two approaches represented graphically in terms of average PSNR and average SSIM in Figure 2-Figure 3. Figure 4-Figure 7 shows graphical representation of PSNR of each skipped frames in a video using conventional MCFI algorithm and cubic MCFI algorithm. Original frame and reconstructed frames of videos using conventional MCFI algorithm and cubic MCFI algorithm are shown in Figure 8-Figure 11.

Figure 2: Graphical representation of average PSNR

Figure 3: Graphical representation of average SSIM

Figure 4: For HD1080p resolution video, graphical representation of PSNR of each skipped frames using; (a) conventional MCFI algorithm, (b) cubic MCFI algorithm.

Figure 5: For HD720p resolution video, graphical representation of PSNR of each skipped frames using; (a) conventional MCFI algorithm, (b) cubic MCFI algorithm.

Figure 6: For VGA 640*480 resolution video, graphical representation of PSNR of each skipped frames using; (a) conventional MCFI algorithm, (b) cubic MCFI algorithm.

Figure 7: For CIF 352*288 resolution video, graphical representation of PSNR of each skipped frames using; (a) conventional MCFI algorithm, (b) cubic MCFI algorithm.

(a)

(b)

(c)

Figure 8: For HD1080p resolution video; (a) Original frame No. #58, (b) Reconstructed frame No. #58 using Conventional MCFI algorithm, (c) Reconstructed frame No. #58 using Cubic MCFI algorithm.

(b)

(c)

Figure 9: For HD720p resolution video; (a) Original frame No. #32, (b) Reconstructed frame No. #32 using Conventional MCFI algorithm, (c) Reconstructed frame No. #32 using Cubic MCFI algorithm.

(a)

(a)

(b)

(c)

Figure 10: For VGA 640*480 resolution video; (a) Original frame No. #38, (b) Reconstructed frame No. #38 using Conventional MCFI algorithm, (c) Reconstructed frame No. #38 using Cubic MCFI algorithm.

(a)

(b)

(c)

Figure 11: For HD1080p resolution video; (a) Original frame No. #42, (b) Reconstructed frame No. #42 using Conventional MCFI algorithm, (c) Reconstructed frame No. #42 using Cubic MCFI algorithm.

CONCLUSION

This paper proposes a new cubic MCFI method for different video sequences with different frame sizes varies from CIF to HD 1080. Experimental results show that cubic MCFI algorithm achieved better performance than conventional algorithm qualitatively. From Table II and Figure 2-Figure 3, it can be concluded that proposed algorithm improves PSNR by approximate 3dB and SSIM by 5% than conventional algorithm. Results can be further improved by using recent motion estimation methods like hierarchical search method or 3D recursive search method or combination of both methods in Motion Estimation block of temporal frame interpolation process.

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