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A Novel Based Approach for Finding Motion Estimation in Video Compression

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ABSTRACT: **This paper mainly focuses on the two main classification of motion estimation algorithms used for video compression. Motion Estimation (ME) algorithms vary with respect to the a priori information and constraints they employ, as well as the method of computation they use to obtain the estimate. The classifications for ME algorithms are based on feature/region matching, gradient based methods, spatiotemporal energy methods, deterministic model based methods and stochastic model based methods. This paper focuses more on block matching algorithms which comes under feature/region matching and gradient based methods. This paper compares 2 important ME algorithms. They are Full Search (FS) and a newly found adaptive algorithm called AMEA. In FS every candidate points will be evaluated and more time will be taken for predicting the suitable motion vectors. Based on the above noted drawback, the above said adaptive algorithm called AMEA is proposed. These algorithms are used for implementing various standards, which ranges from MPEG1 / H.261 to MPEG4 / H.263 and H.264/AVC. A very brief introduction to the entire flow of video compression is also presented in this paper.**

Keywords: **AMEA, block matching, gradient based method, motion estimation, MPEG, H.261, H.263, H.264/AVC, video compression.**

I. INTRODUCTION

With the onset of the multimedia age and the wide use of Internet, video storage on CD or DVD and streaming video has become highly popular. The digital video application has gained wide appeal in mobile terminals. Examples relating to this are personal digital assistance and cellular phones. The rate of communications with moving video applications are increasing day by day. Now a days video is required in many remote video conferencing systems and for many real time applications, (space application is one of the real time application) also it is expected that in the near future itself the cellular telephone systems will start sending and receiving real time videos. But a major problem still remains in a video is the high requirement for bandwidth. Yet, due to digital video's inherent data intensity of video sequences, storing and transmitting raw video data becomes impractical. For example a typical system have to send large number of individual frames per second to create an effect or illusion of a moving picture . With the limited storage and bandwidth capacity, this data (raw video data) must be compressed to a transportable size. For this reason, several standards for compression of the video have been developed. Many video compression standards were already in vogue. Digital video coding has gradually become very popular since the 1990s when MPEG-1 first emerged. The video coding achieves higher data compression rates and also it eliminates the need of high bandwidth requirements. The important aspect in the video coding is that without any significant loss of subjective picture quality, the video coding achieves higher data compression rates. The ISO Moving Picture Experts Group (MPEG) video coding standards has relevance in compressed video storage on physical media (like CD/DVD). Compared to the ISO MPEG, the International Telecommunications Union (ITU) addresses real-time point-to-point communications or multi-point communications over a network. The MPEG standards has the advantage of having lesser bandwidth for data transmission. In recent years, several video compression standards had been proposed for different applications such as CCITT H.261 [5], MPEG-1 [6] and MPEG-2 [9]. One common feature of these standards is that they use Discrete Cosine Transform (DCT), transform coding to reduce spatial redundancy and block motion estimation or compensation modules to reduce the temporal redundancy. In addition, the encoders complexity of these video standards are dominated by the motion estimation. Currently MPEG-4 has become the dominant video codec algorithm for streaming and distribution of video contents across wireless media at low bandwidth. The latest approved video compression standard, known as MPEG-4 Part 10 AVC or H.264 AVC (AVC - Advance Video Coding), has shown a 50% compression improvement when compared to the previous standards. The H.264 or MPEG-4 Part-10 AVC is a block-oriented motion compensation standard. This motion compensated based codec standard and was developed by the combined effort of both ITU-T VCEG and the ISO/IEC MPEG group. The huge improvement over the compression rate, makes MPEG-4 Part 10 AVC the best choice of video compression for the next 5-15 years. By analyzing we can understand that, this improvement comes at the cost of increase in computational complexity, which results in higher computation power dissipation. This will be a major drawback for many mobile devices with limited battery lifetime. Several sources of major computation power dissipation have been identified. One such important cause for this computation power dissipation is Motion Estimation (ME). Motion estimation techniques form the core of video compression and video processing applications. It is the most computationally expensive step in the entire video compression process. Majority of the time

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is used for ME in video compression process. There are so many algorithms used for ME based on different classifications (the classifications are already quoted in the abstract). The algorithms that are most commonly used in video image processing belong to either the feature/region matching or the gradient based methods classes. This paper will discuss more on the block matching algorithm called FS coming in feature/region matching class. The entire flow for video compression is explained in section II with a block diagram. Motion Estimation and a brief classification of ME algorithms will be present in section III and IV. Then the coming section, section V will briefly discuss on block matching algorithm and the most important FS bma. The newly found AMEA algorithm will be provided in section VI. Simulation results will be provided in section VII. Summary and references will be provided in the last sections.

II. VIDEO COMPRESSION PROCESS

An image sequence (or video) is a series of 2-D images that are sequentially ordered in time. Image sequences can be acquired by video or motion picture cameras, or generated by sequentially ordering 2-D still images as in computer graphics and animation. Video compression means to reduce data redundancy and irrelevancy. The sources of data redundancy are of spatial, temporal and color space (statistical correlation between frames). In spatial redundancy the nearby pixels are often correlated (as in still images). The temporal redundancy deals with the adjacent frames. There the adjacent frames are highly correlated. In color space, RGB components are correlated among themselves. The second aspect in video compression is to reduce irrelevancy. The irrelevancy deals with perceptually unimportant information. The main addition over image compression, in video compression is to exploit the temporal redundancy. In video compression process we can predict the current frame based on previously coded frames (that is reference frame). The Motion estimation (section III) process extracts the entire motion information from the video sequence. Motion information is used in video compression process to find best matching block in reference frame to calculate low energy residue, also it is used in scan rate conversion to generate temporally interpolated frames. The motion information is used in applications like motion compensated de-interlacing and motion tracking. Three types of coded frames are included in video compression (I-frame, P-frame and B-frame). For both MPEG and International Telecommunication Union (ITU) standard the basic flow of the entire compression –decompression process is largely the same and is shown in Fig. 1. The encoding side calculates the motion in the current frame and compares it with a previous frame. A motion compensated image for the current frame is then created (motion compensated image is built of blocks of image from the previous frame).The motion vectors for blocks used for motion estimation are transmitted. In addition to that the difference of the compensated image with the current frame is also JPEG encoded and sent.

After that the encoded image that is sent is then decoded by the encoder .This image is then used as a reference frame for the subsequent or coming frames. In the decoder side the decoder will reverse the entire process and then creates a full frame. The entire idea behind ME based video compression process is to save on bits. By sending JPEG encoded difference images which inherently have less energy we can save bits. We can achieve high compression with the JPEG encoded difference. Basically compressions are of two types. They are lossy compression and lossless compression. In lossless compression the original data can be reconstructed exactly as it was before compression. Loss of data is less in this type of compression technique. So this type of compression will not give high degree of compression. From the above aspects it is clear that in digital world when we decompress a lossless compression data definitely it should match the original data bit by bit. From computer programmers point of view these kind of compression are generally good and used for computer files or programs where importance is given to each bit. So for audio/visual data lossless compression technique will not give a high compression rate. The second classification of compression is lossy type. It demands high degree of compression. Usually it is used in compressing audio/visual data. But the problem is that the reconstructed data is not the same as that of the original data. In JPEG the compression used is lossy type. In Motion JPEG, where all frames are JPEG encoded, the compression ratio achieved is anything between 10:1 to 15:1. By comparing this ratio with the MPEG it can achieve a compression ratio of 30:1 and is also useful at ratio of 100:1 [13] [15] [18]. One important thing to be noted is that the first frame will be always sent fully. And also for some other frames that might occur at some regular interval (like every 5th frame). The standards do not specify this criteria exactly. This requirement might change with every video being sent based on the dynamics of the video. Generally speaking, video compression can be defined as a technology for transforming video signals. The constraints can be of different types. For example, storage constraint, time delay constraint or computation power constraint. In addition to the above, by applying computational resources the video compression takes advantage of data redundancy between successive frames to reduce the storage requirement. Usually for designing a data compression systems there will be tradeoff between quality of the image, speed, utilization of resources and power consumption.

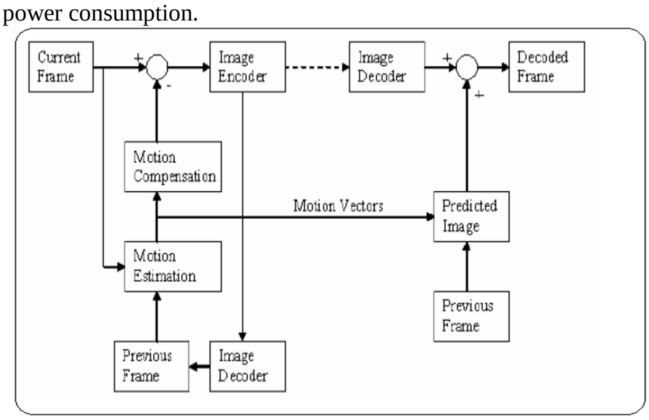

Fig. 1. MPEG / H.26x video compression process flow.

The next section, section III will focus on Motion Estimation (ME). Before dealing with ME or to understand what is 'Motion Estimation', it is essential that we have to know about what "MPEG" is, of which motion estimation is a part. Moving Pictures Expert Group (MPEG) is actually a body used for developing a

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suitable encoding scheme or what are called standards. It is used for transmitting moving pictures and sound over various broadcast links. Accordingly here recording the datas in standard digital storage media such as DVD, CD, Flash Memory etc. The term is used synonymously to the whole family of digital video or audio compression standards and also for the file formats developed by the MPEG group. Hybrid video coding[21] architectures have been developed and used from the first generation of video coding standards, that is MPEG Standard. The MPEG encoding scheme consists of three main modules to reduce the data redundancy from the three sources described earlier (spatial, temporal and statistical correlation between frames). Both Motion Estimation and Motion Compensation (MC) techniques are used to reduce the temporal redundancy between successive frames, which is in the time domain. The second module which is Transform coding is used to reduce the spatial dependency within a frame. As stated earlier both ME and MC will consider the time domain, whereas transform coding will be in the spatial domain. The transform coding is one of the module which is commonly used in image compression. Finally the Entropy coding is used to reduce the statistical type of redundancy over the residue and the compression data. MPEG is a lossless compression technique which is commonly used for file compression. Here the idea employed is that each individual frame is coded inorder to remove the redundancy. A great amount of redundancy is removed with the help of a motion compensation system, from between the consecutive frames. The various standards of MPEG released so far are: MPEG-1 ,MPEG- 2 and MPEG-4.Under MPEG-4 itself there came many parts, of which the latest international video coding standard is H.264 Advanced Video Coding AVC or MPEG-4 part 10 AVC.

III. MOTION ESTIMATION

As said you earlier the most computationally expensive and difficult operation in the entire compression process is Motion Estimation. Therefore for the above reason this field has seen the highest research activity and advanced research interest in the past two decades. Motion Estimation is one of the most critical modules in a typical digital video encoder. Many implementation tradeoffs should be considered while designing such a module. We can define ME as a part of 'inter coding' technique. Inter coding refers to a mechanism of finding 'co-relation' between two frames (still images), which are not far away from each other as far as the order of occurrence is concerned, one frame is called the reference frame and the other frame called the current frame, and then encoding the information which is a function of this 'co-relation' instead of the frame itself. As stated earlier ME is the basis of inter coding, which exploits temporal redundancy between the video frames, to scope massive visual information compression. In ME each block in a frame is represented by a motion vector that represents the displacement of the block with respect to another "highly correlated" block in a previously encoded frame [18][14][19].

In short by motion estimation, we mean the estimation of the displacement (or velocity) of image structures from one frame to another in a time sequence of 2-D images. Simply ME can be illustrated as shown in Fig. 2. The figure explains the 2D displacement of the pixel (pel) located at point p in frame at time t to frame at time t + Dt. In short we can summarize the concept of ME as, normally a video can be considered as the discretized 3 dimensional projection of the real four dimensional continuous space-time objects. As we know that the objects in the real world has got the ability to move, rotate, or deform. But the problem is that some of the minute movements cannot be observed directly.

Changes between adjacent frames are mainly due to the movement of the above said objects. So by using a model for estimating the motion of the objects between frames, it is easier for the encoder to estimate the motion that occurred between the reference frame and the current frame. This process is called motion estimation (ME). The ME block diagram is shown in Fig. 2a. The concept of Motion Compensation (MC) technique is that to provide a better prediction of the current frame, the encoder uses the motion model and informations to move the contents of the reference frame. This process is known as motion compensation (MC) [1] - [4], and the prediction produced for this purpose is called the motioncompensated prediction (MCP) or the displaced-frame (DF). The difference of ME from motion compensation is that, the ME detect the movement of objects in an image sequence and it will try to obtain the motion vectors representing the estimated motion. Apart from ME the motion compensation techniques uses the knowledge of object motion so obtained in order to achieve data compression. So we can say that ME techniques form the core part of video compression aswell as video processing applications.

There are different search algorithms developed for finding the motion estimation. The algorithms are used to estimate the accurate motion between frames. When ME is performed by an MPEG-2 encoder it groups the pixels into 16×16 macro blocks. The MPEG-4 AVC encoders can further divide these macro blocks into small partitions (as small as 4 × 4). It is also possible to divide, even for variable size within the same macro block. Partitions are allowed for ensuring more accuracy in ME process. The reason is that areas with high motion can be isolated from those with less movement.

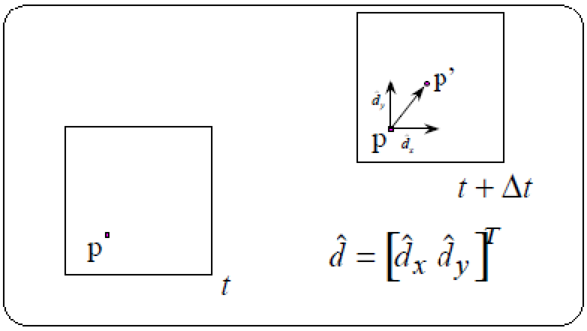

Fig. 2. Simple concept of Motion Estimation

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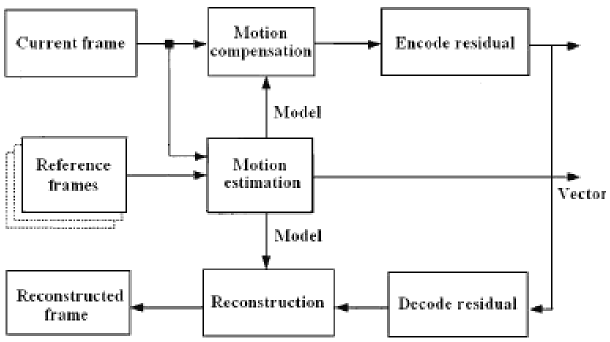

Fig. 2a. ME Block Diagram

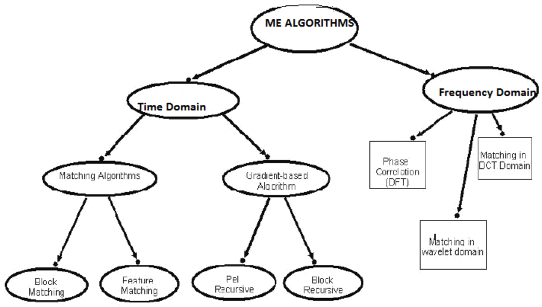

Fig. 2b. Classification Diagram for ME

IV. CLASSIFICATION OF ME ALGORITHMS

The ME algorithms are classified into feature/region matching, gradient based methods,spatiotemporal energy methods,deterministic model based methods and stochastic model based methods. In feature/region matching the motion is estimated by correlating/matching features (e.g., edges) or regional intensities (e.g., block of pixels) from one frame to another. The block matching algorithms and phase correlation methods will come under this class. The phase correlation technique, which generates motion vectors via correlation between current frame and reference frame. However the most popular technique is Block Matching Algorithm. The Gradient-Based Methods estimate the motion by using spatial and temporal changes (gradients) of the image intensity distribution as well as the displacement vector field. The methods coming under this class are Pel-Recursive methods (which derive motion vector for each pixel) , Netravali-Robbins, Walker-Rao, Wienerestimation based and the Horn Schunck algorithm. Both the matching algorithms and the gradient based methods comes under time-domain algorithms. Spatiotemporal Energy methods make use of the energy concentration, in the 3-D spatiotemporal frequency domain, of a 2-D image distribution undergoing a constant-speed translational motion. Next classification called Deterministic-Model Based methods are based on deterministic models of motion (e.g., affine models and planar surface models). Finally Stochastic-Model Based methods are based on Markov random field models of both the image distribution and the displacement vector field, where the estimation problem takes the form of MAP estimation. This paper concentrates more on FS, the fundamental block matching algorithm and the recent adaptive algorithm called AMEA. The above said algorithms are implemented for interframe coding in moving video sequences. The classifications for ME is shown in Fig. 2b.

The major goals of the ME techniques are:
1) A good ME technique will try to reduce the computational complexity involved in the process.
2) It will work in a good manner to produce an effective visual quality
3) A well accepted ME algorithm will result in a high compression ratio.
The first goal for ME techniques can be achieved by determining three factors. They are
1) The search algorithm, decides the overall computational complexity of a ME
2) The search area, the region of search window to find the suitable match and
3) Cost function, the different cost metrics used to find the suitable match. Some of the cost functions are MSE, SAD etc

V. BLOCK MATCHING ALGORITHMS

In recent years, many fast block Motion Estimation (ME) algorithms have been proposed to alleviate the computation burden involved in a video encoder [23]. The research has led to so many fast algorithms. ME is highly scene dependent and no one technique can be fully relied to generate good visual quality for all kinds of video scenes. Therefore most ME algorithms exhibit tradeoffs between quality and speed. The most common ME method is the block matching algorithm (BMA). It is adopted in many compression standards. Block Matching Algorithm (BMA) is the most popular and famous ME algorithm. Instead of individual pixels, BMA calculates the motion vector for an entire block of pixels. The same motion vector is applicable to all the pixels in the block. This reduces computational requirements and also results in a more accurate motion vector since the objects are typically a cluster of pixels. The BMA algorithm is explained in Fig. 3.

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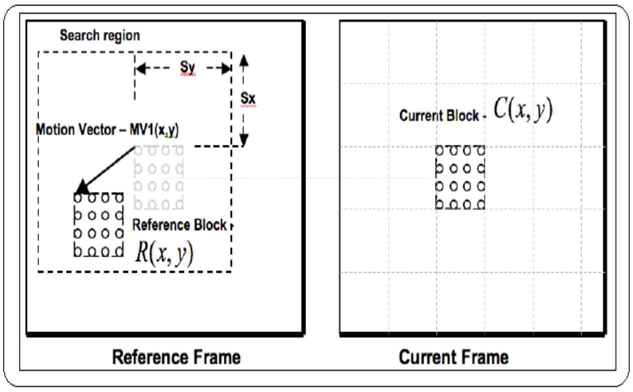

Fig. 3. Block Matching Algorithm (BMA)

In BMA, the current frame is divided into a number of pixel blocks (matrix of 'macro blocks') each of which consists of luminance and chrominance blocks. For coding efficiency, ME is performed only on the luminance block. The motion estimation is performed independently for each pixel block (that is for luminance block). For doing ME identify a pixel block from the reference frame that best matches with the current block, and whose motion is being estimated. For comparing each blocks in the current frame with the block in the reference frame some cost functions are used. The reference pixel block is generated by displacement from the current block's location in the reference frame. The displacement is provided by the Motion Vector (MV). MV consists of a pair (x, y) of horizontal and vertical displacement values. The reference pixel blocks will be generated only from a region known as the search area. Search region defines the boundary for the MV and limits the number of blocks to evaluate. The height and width of the search region is dependant on the motion in video sequence. The search range can also be determined from the available computing power. The search area for a good macro block match is constrained up to *p* pixels on all fours sides of the corresponding macro block in previous frame. This '*p*' is called as the search parameter. Larger motions require a larger search parameter *p*. If larger the search parameter the more computationally expensive the process of motion estimation becomes. That is bigger search region requires more computations because of the increase in number of evaluated candidates. Normally the macro block is taken as a square of side 16 pixels, and the search parameter *p* is 7 pixels. The idea is represented in Fig. 4. The matching of one macro block with another block is based on the output of a cost function (error criteria's). Which macro block matches closest to the current block is computed by finding the macro block that results in the least cost. Typically the search region is kept wider (i.e. width is more than height) because many video sequences often exhibit panning motion. The search region can also be changed adaptively depending upon the detected motion. The horizontal search range and vertical search range, Sx & Sy, define the search area (+/-Sx and +/- Sy) as illustrated in figure 3. The basic principles of ME by block matching are the following.

1) To calculate the displacement or movement of a particular pixel p in frame at time t, a block of pixels centered at p is considered.
2) The frame at time t + Dt (that is small difference in time) is searched for the best matching block of the same size.
3) In the matching process, it is important to assume that the pixels belonging to one block are displaced with the same amount.
4) Matching is performed by either maximizing the cross correlation function (that is a cost function) or by minimizing an error criterion function.
5) The most commonly used error criteria are the mean square error (MSE) or the sum of square error (SSE) and the minimum absolute difference (MAD) or the sum of absolute difference (SAD).

There are various criterias available for calculating the block matching. The above said were the two popular criterias. (SSE and SAD). There are various other criterias also available such as cross correlation, maximum matching pixel count etc.
The SSE can be calculated using the following formula

$$\sum_{x=1}^{x=N}\sum_{y=1}^{y=N}(C(x,y)-R(x,y))^2 \quad \text{------(1)}$$

Also the SAD can be calculated using the formula

$$\sum_{x=1}^{x=N}\sum_{y=1}^{y=N}|C(x,y)-R(x,y)| \quad \text{--------(2)}$$

In both (1) and (2) equations,
N = is the side of the macro block.
C and R are the pixels being compared in current macro block and the reference macro block, respectively.
The SSE gives a more accurate block matching, however it requires more computations. The SAD provides fairly good match at lower computational requirement and because of this SAD is widely used for block matching.
Some of the issues coming in block matching is
1) Matching criterion
2) Search procedure
3) Block size
4) Spatial resolution of the displacement field (Do we obtain an estimate for every pixel location?, every other pixel location?, etc.,)
5) Amplitude resolution of the displacement field (integer versus real-valued displacement vectors)

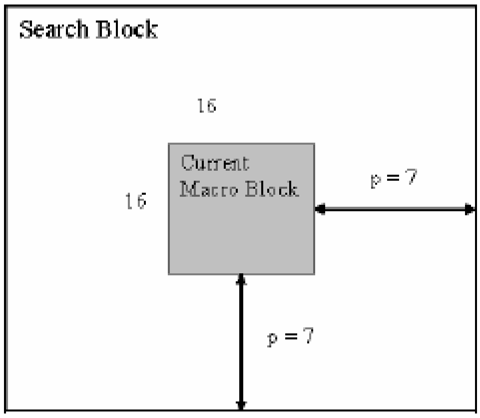

Fig. 4. Block Matching a macro block of side 16 pixels and a search parameter *p* (of size 7 pixels).

Peak-Signal-to-Noise-Ratio (PSNR) characterizes the motion compensated image. This image is created by using MV's and macro blocks from the reference frame.

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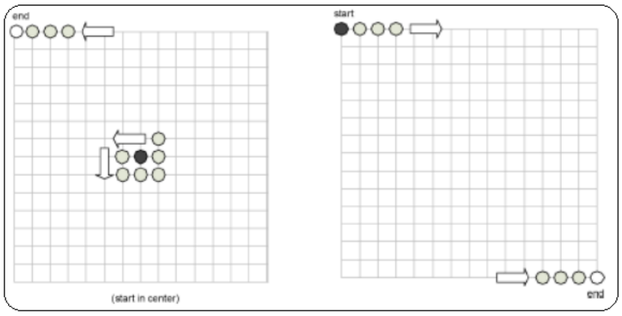
A. *Exhaustive Search (ES)*

This algorithm is also known as Full Search (FS) Motion Estimation algorithm. It is the most computationally expensive block matching algorithm of all the existing algorithms. Full Search Block Matching algorithm evaluates every possible pixel blocks in the search region (search area). By evaluating each and every possible pixel blocks in the search area this algorithm can generate the best block matching motion vector (MV). As a result of which it finds the best possible match. Also it returns the highest PSNR amongst any block matching algorithm. The FS calculates the SAD value at each possible pixel location in the search region. For analyzing each block in the current frame, each and every candidate block that resides within the search window (or search region) in the referenced frame is searched. The motion vector (MV) is then calculated and it points to the block with the lowest distortion (minimum distortion value) in the reference frame. This type of BMA can give least possible residue for video compression. But, the required computations are exceedingly very high due to the large amount of candidates present in each blocks to get evaluated. The number of candidates to evaluate are (2Sx+1)*(2Sy+1) (where Sx and Sy are horizontal and vertical search range). Because of the above said problems full search block matching algorithm is typically not used. Also, it does not guarantee consistent motion vectors required for video processing applications. There are several other fast Block-Matching Algorithms which reduce the number of evaluated candidates still try to keep a good block matching accuracy. Other fast block matching algorithms try to achieve the same PSNR value produced by FS, by doing little computation as possible. These algorithms test only the limited candidates. Also results in selecting a candidate corresponding to local minima. But the Full Search results in global minima [16]. The full search technique is very systematic. But on the other hand the limitation found out is that it is impractical or less efficient in terms of computational complexity or runtime. When the search window increases, the computations it requires also increases. In short the FS method is a simple routine that searches all the blocks in the search area so it finds the best matched block. But its complexity is prohibitively high for software implementation. The two-dimensional logarithmic search algorithm [15], three-step search (TSS) [18], new three-step search (NTSS) [14], four-step search (4SS) [19], block-based gradient descent search (BBGDS) [6], diamond search (DS) [5] and hexagon-based search (HEXBS) [6] algorithms are amongst the class of fast search methods used. They reduce the NSPs *(*number of search points) in the process of block motion estimation. ME can consume up to 75% to 80% of the computational power of the encoder, if we use the full search (FS) algorithm. Because FS is used by exhaustively evaluating each and every possible candidate blocks within the search region. Therefore, other fast algorithms are highly desired to significantly speed up the computation process. These faster algorithms will not sacrifice the distortions seriously. The two different approaches used in the full search procedure are shown in Fig. 5. The full search technique is also called the brute force technique. Here in this type of search all the pixel values will be compared with the block in the reference frame and the diagram is shown in Fig. 5a. From the fig. 5a it is clear that T is the current frame and T-1 is the previous (reference) frame.



(a) (b)
Fig. 5. Full Search algorithms (a) – Spiral and (b) – Raster.

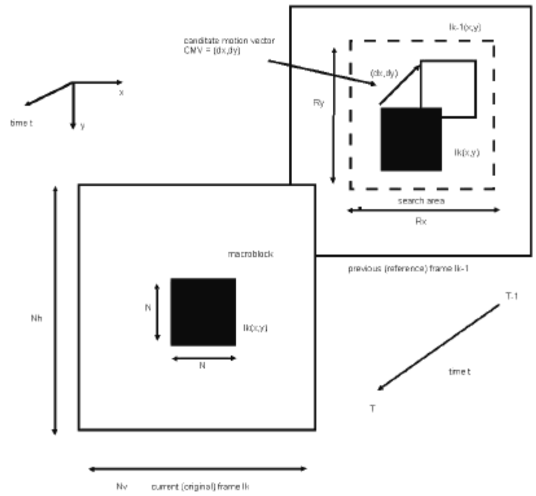


Fig. 5a. Full Search (Brute force technique)

GRADIENT BASED METHOD

We already discussed that ME can be classified into many groups. In this paper focus is given to both block matching techniques and the gradient based methods. In the last section we already presented a study on FS block matching algorithm. In the block based techniques the MV can be determined based on the variations in the pixel intensities. The best matching MV is considered as the pixel with less intensity difference between the current frame and the reference frame. But in the gradient based techniques, the spatiotemporal derivatives of pixel intensities is calculated to determine the MV values. The total derivative of the I function should be zero for each position in the image. It should be made as zero every time and the I function is the image intensity function.

$$\frac{\partial I}{\partial x}\frac{dx}{dt}+\frac{\partial I}{\partial y}\frac{dy}{dt}+\frac{\partial I}{\partial t}=0$$

During the search process, there comes a problem. That is we have to find the MV for the current block B□ (y,x) for time instance □ .Therefore the SAD value between the current block and the matching block at □ is minimized.

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VI. ADAPTIVE MOTION ESTIMATION ALGORITHM (AMEA)

AMEA algorithm makes use of the fact that the general motion in a frame is usually coherent, i.e. if the macro blocks around the current macro block moved in a particular direction then there is a high probability that the current macro block will also have a similar motion vector. This algorithm uses the motion vector of the macro block to its immediate left to predict its own motion vector. In addition to checking the location pointed by the predicted motion vector, it also checks at a rood pattern distributed points, where they are at a step size of S = Min (|X|, |Y|). X and Y are the x-coordinate and y-coordinate of the predicted motion vector. This rood pattern search is always the first step. It directly puts the search in an area where there is a high probability of finding a good matching block. The point that has the least weight becomes the origin for subsequent search steps, and the search pattern is changed to SDSP. The procedure keeps on doing SDSP until least weighted point is found to be at the center of the SDSP. The main advantage of this algorithm over DS is if the predicted motion vector is (0, 0), it does not waste computational time in doing LDSP, it rather directly starts using SDSP.

VII. SIMULATION RESULTS

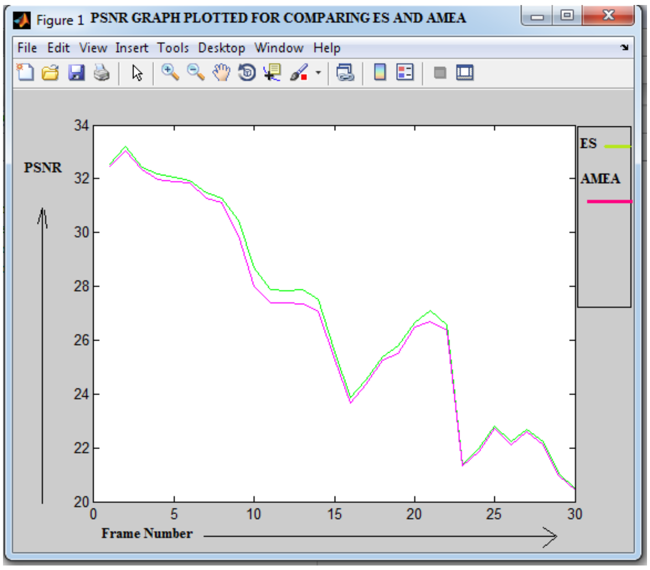

Fig 6: Graph showing the comparison view for ES and AMEA

VIII. CONCLUSION

In this paper we presented an overview of what a video compression process is and how we can implement the ME techniques. Furthermore we briefly introduced BMA in video coding. Based on the BMA techniques, we discussed 2 important block matching algorithms (they are FS and AMEA). Usually the ME is the quite computationally intensive and expensive step in the video compression process. It can consume up to 75-80% of the computational power of the encoder if the FS is used by exhaustively evaluating all the possible candidate blocks within the search window. As a consequence, the computation of video coding is greatly reduced with pattern based block motion estimation. We also stated the difference between the block based ME techniques and the gradient based methods. Finally an adaptive ME algorithm is found and its performance is compared against FS. The results showed that the PSNR values obtained for AMEA is some way closer to FS while it shown a reduction in the number of computations taken to obtain the best matching block.

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