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Robust Video Compression System for Onboard Space Application

Sabin S Sabu, Sandhya L, Subha Varier G

Abstract— To efficiently transmit the huge volume of data captured during the stage separation of a spacecraft system, it is very necessary and important to find out efficient and advanced video compression techniques. In space missions, the available bandwidth for video transmission and power are critical parameters under consideration. Commercially available video compression techniques generally fail to meet the constrained power and bandwidth requirement of the space missions. This anticipates the need for better compression tools which suits the demands of onboard systems in terms of higher compression efficiency and lesser computational time. In this paper, we propose to develop an entropy based video compression approach based on H.264 standard which tends to exploit the pertinent temporal and spatial redundancy in video frames. The most time consuming part of H.264 encoder is the inter prediction stage. Here we compared four types of search algorithm for inter prediction in terms of PSNR time and chooses the best search algorithm for our proposed system.

Index Terms— H.264, compression efficiency, inter prediction, PSNR, temporal redundancy

I. INTRODUCTION

In space missions, an image sensor available in the onboard launch vehicle system captures a series of images during the stage separation phase. Generally high definition cameras are used for acquiring high quality images. The outputs of these cameras are fed to the image processing system consisting of a CODEC to compress the captured images before transmitting to the ground station. The compressed images are sent to the ground station along with the telemetry data within the available bandwidth of 2 Mbps.

This compressed images received at the ground stations are analyzed using various image processing algorithms to study the impact of stage separation on satellite. Images are received at the ground station with a frame rate of 5 frames per second. This series of images will give the illusion of a video. Disadvantage of this type of video transmission systems are poor resolution and loss of data. This leads to development of H.264/AVC standard capable of providing good video quality at substantially lower bit rates than previous standards without increasing the complexity of design. Presently the CODEC at the onboard uses JPEG 2000 [1], as compared to JPEG [2] which was used earlier.

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***** Correspondence Author (s)
Sabin S Sabu, M.Tech Scholar, Department of Electronics and Communication Engineering, Sree Chitra Thirunal College of Engineering, Kerala, India.
Sandhya L, Assistant Professor, Department of Electronics and Communication Engineering, Sree Chitra Thirunal College of Engineering, Kerala, India.
Subha Varier G, Scientist/Engineer, Vikram Sarabhai Space Center/ ISRO, Trivandrum. Kerala, India.

Compared to the standard JPEG, JPEG 2000 offers higher compression performance with a varying compression rates from very low to very high value. The digital video industry always emphasizes on the development of video processing systems with better processing performance keeping an eye on the available bandwidth and power constraints. Such system lack in computational time owing to increased complexity and makes it unsuitable for real time applications. This anticipates the need for the development of a better compression tool with lesser computational time which suites the demands of real time environment.

H.264 or MPEG-4 Part 10 [3], Advanced Video Coding (MPEG-4 AVC) is a video coding format that is currently one of the most commonly used formats for the recording, compression, and distribution of video content. H.264/MPEG-4 AVC is a block oriented motion compensation based [4] video compression standard developed by the ITU-T Video Coding Experts Group (VCEG) together with the ISO/IEC JTC1 Moving Picture Experts Group (MPEG). The H.264/AVC has been designed with the goal of high compression performance relative to all existing video coding standards. Such a standard uses advanced compression techniques that in turn, require high computational time.

In this paper we propose to develop an entropy based H.264 compression system with reduced complexity to meet the real time system constraints. Proposed video compression system incorporates fast algorithms for motion estimation and optimized transform and quantization steps to speed up the processing time without much reduction in compression efficiency. The most time consuming part of H.264 encoder are the motion estimation phase [5]. As part of this work, here we have implemented various motion estimation algorithms and performance is evaluated in terms of PSNR. Out of the evaluated algorithms, the one which gives high PSNR performance is selected for our final system in order to reduce the processing complexity.

II. AN OVERVIEW OF H.264 ENCODER

H.264 encoder mainly consists of prediction, transform, quantization and entropy encoding. Prediction is performed to remove redundancy in video frame pixels. Two types of redundancy occurring in video frames are spatial and temporal redundancies. Redundancy between pixels in two adjacent frames is known as temporal redundancy and redundancy within a frame is known as spatial redundancy. Inter prediction and intra prediction is employed in H.264 encoder to remove temporal and spatial redundancy respectively.

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Inter prediction is achieved through motion estimation (ME) and motion compensation. Motion estimation is the method of determining how much relative motion has occurred in an object from one frame to another. Amount of measured motion is generally expressed using motion vectors (MV). By using this motion vectors, motion of objects in the current frame relative to the reference frame is predicted and compensated to achieve motion compensated frames. Then the residual frame is computed by taking the difference between motion compensated frame and current frame. Residual frames are then transformed, quantized and entropy encoded prior to the transmission in H.264 encoder.

Motion estimation algorithms are mainly categorized into pixel based and block based approaches. Pixel based motion estimation approach seeks to determine motion vectors for every pixel in an image. This is also referred to as the optical flow method. But the practical disadvantage of this method is hectic computational complexity. Therefore for real time applications, block based ME is preferred over optical flow method as it takes lesser computational time with acceptable performance measures. In block based approach, single MV is computed for a block of pixel after dividing the image into non-overlapping blocks.

III. BLOCK BASED MOTION ESTIMATION

Block based motion estimation algorithms starts with splitting the input video frames into blocks. Each block in the current frame is then matched against a candidate blocks of same size within the search window of reference frame. The most suitable candidate block in reference frame corresponding to the block in the current frame is chosen based on a matching criterion. The commonly used matching criteria used for block based motion estimation includes Mean of squared error (MSE), Sum of absolute difference (SAD) and Matching pixel count (MPC). The displacement (motion vector) between the block in the current frame and chosen block in the reference frame is then computed. Various algorithms have been developed by the researchers in the field of video processing to efficiently compute the motion vectors based on block matching concept. Among all algorithms proposed, only full search gives optimal result within the search range. Other algorithms will give near to optimal results but significant lower complexity by reducing the number of search points. Usually a search window is defined in the reference frame and search is carried out within this search window. Search parameter p will define the search window length. Usually p=7 is taken because the motion is assumed to be not so fast. A larger search window will make the search method a time consuming one. There are two types of search methods which are exhaustive search and fast search algorithms.

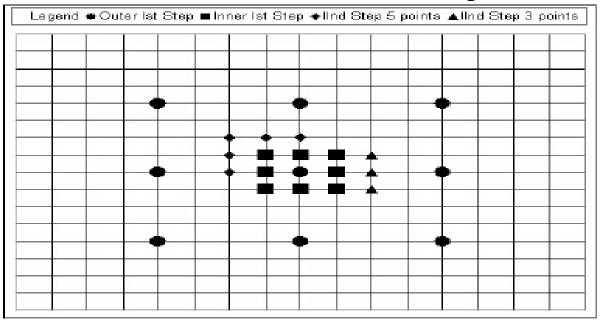

Fig 1. Three step search method

A. Exhaustive Search or Full Search

In exhaustive search [5] method, a block in the candidate frame is searched in all position within the search window of the reference frame. Exhaustive search (ES) is an optimum method of searching, which gives the highest PSNR among all the search algorithms. The obvious disadvantage of this method is the large computation time since all the block in the search window are searched for determining the best MV. Because of this disadvantage ES is not used for real time application.

B. Fast Search Algorithms

In this method not all the points within the search window are searched instead some specific points are searched based on the assumption that the object motion is unimodal. An unimodal approach means a minimum is obtained at a single point and if move from this minimum point, the cost function value will increase. Out of the various fast search methods, we compared three step, four step and diamond search algorithms in this paper.

C. Three Step Search

In three step search [6] method, some specific points are searched within the search window instead of searching all the points. The one with minimum cost function will be taken as the best MV. The search location in this method starts with the center of the search window. It also searches at other eight locations with a step size of S=4 around the center point as shown in Figure 1. Among these nine search points the one which gives the least cost function will be taken as the new search center. In the next step the step size is reduced to S=2 and search for other points around the new center. The iteration will go on until the step size becomes S=1 and the MB with least cost will be considered as the best match and the MV is calculated with respect to this best matched macro block (MB). Obviously the search will terminate with three steps hence the name Three step Search (3SS).

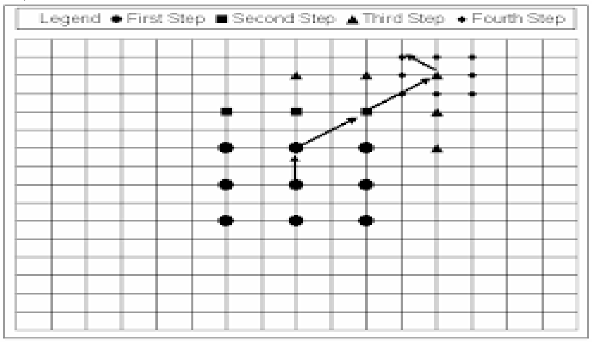

Fig 2. Four Step Search method

D. Four Step Search

Four step search (4SS) has a step size of S=2 which is fixed irrespective of the search parameter p. This method [7] has the advantage of having halfway stopping provision. The search pattern of four step search algorithm is depicted in Figure 2. It also starts with the searching at the center of search window and other eight points are searched similar to 3SS but the step size is reduced from S=4 to S=2.

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If the minimum cost function is found at the center of search window then the algorithm jumps to final stage where the step size is reduced to S=1 and the MB with minimum cost function is the best matched MB. On the other hand if the minimum cost function is other than the center point then the search will go to next step with step size as same as the first step that is S=2. Again if the least function is found at the center, algorithm will go to final step else it will go to third step. The search pattern of third step is similar to that of second step. In the final stage the step size is reduced to S=1 and the MB with least cost function is declared as the best match and MV is calculated with respect to this MB. Thus the algorithm terminates at the fourth step.

D. Diamond Search

Performance of the fast prediction algorithms mainly depends on the shape of the search pattern. Fast block matching algorithm such as 3SS, 4SS are having a square shape search pattern and provides reasonable performance. The distribution of global minimum points is centered at the center of search window. The diamond search (DS) provides a better performance than the 3SS, 4SS algorithms. Search pattern for diamond search algorithm is given in Figure 3. The diamond search [8] algorithm uses a diamond shape pattern with nine search points, four points located at the corners and another four points located at the midpoint of the edges of the diamond shape. This algorithm uses an unrestricted center biased searching process. The diamond search employs a large diamond search pattern (LDSP) and small diamond search pattern (SDSP).

DS starts with finding cost function on LDSP pattern. If the minimum cost function is at the center of LDSP then it switches to SDSP pattern otherwise form a new diamond shaped pattern around the minimum cost point. In SDSP if the minimum cost is at the center point then the search will stop declaring the center point as the best matched MB otherwise search will continue till the center point become best matched MB. As some of the search points in the newly formed LDSP are overlapping, only the non over lapping points need to be evaluated. This greatly reduces the number of search points compared to other existing fast search algorithms. Therefore the search pattern uses five search points in the new LDSP if the minimum cost point is the corner point and the three search points if the minimum cost point is at the edge of the pattern. Thus the diamond search algorithm gives a faster processing and similar distortion performance compared with the other fast searching algorithms. The increase in number of steps leads to more number of search points which has an effect on the speed of the algorithms. This algorithm gives the less complexity when compared to the previous algorithms.

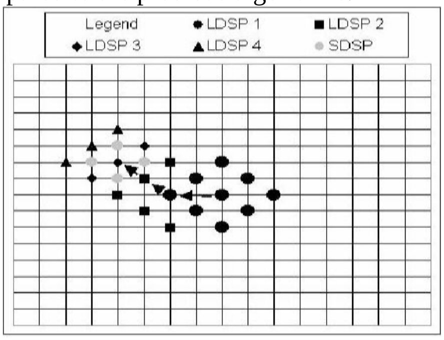

Fig 3. Diamond Search method

IV. SIMULATION RESULTS

To develop a robust video compression system which suits the demand of real time space application, various motion estimation algorithms are implemented in MATLAB and compared. ES, 3SS, 4SS and DS inter prediction algorithms are evaluated on a series of consecutive video frames obtained after reading a video in QCIF format. For each frame, reference frame is chosen as the previous frame and search parameter p is chosen as 7. Performances of various inter prediction algorithms are evaluated by measuring the PSNR. Average Peak Signal to Noise Ratio (PSNR) is computed over a series of 30 video frames and results are tabulated in Table 1. PSNR value is plotted against consecutive frames and given in Figure 4. It is evident from Table 1 and Figure 4 that the PSNR value of diamond search come very close to exhaustive search algorithm which is the optimum search algorithm. In terms of computational speed 3SS, 4SS and DS are close to each other and takes very less time compared to the exhaustive search algorithm. Based on the obtained results, we select DS algorithm in our H.264 encoder as it gives an optimum PSNR value with less computation time compared to other fast search algorithms.

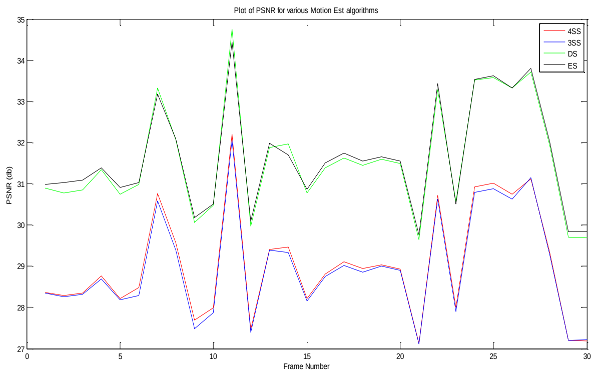

Fig 4. PSNR Plot

V. CONCLUSION AND FUTURE WORK

In this paper MATLAB codes have been developed for various H.264 inter prediction algorithms. The simulation results of various prediction algorithms showed that diamond search algorithm takes lesser computational time without sacrificing much on the quality of reconstructed picture and it is well suited for real time applications where processing time is a critical factor.

Presently the work is under progress for the implementation of fast algorithms for intra prediction and optimization of integer transform and quantization in H.264. This future work will focus on the reduction on H.264 complexity and maintaining the coding efficiency by meeting the real time constraints.

Table 1: Simulation Results of inter prediction algorithms

Algorithm	Average PSNR (db)
Exhaustive Search	31.63
Three step search	28.96
Four step search	29.04
Diamond Search	31.57

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